

## **A1 - The challenge of measuring energy expenditure: current field and laboratory methods**

### **A1.1**

#### **The past, present and future of real-time metabolic measurement using flow-through respirometry**

John Lighton (University of Nevada at Las Vegas)

Flow-through respirometry is a common tool in biological and clinical research, and can measure the metabolic rates of individual animals ranging in body mass from *Drosophila* to *Orcinus* and beyond. It can be used to address many fundamental biological questions, and may also hold the key to understanding the origins and mechanisms of major public health concerns such as the obesity epidemic. Though an important technique, it can be tricky to implement correctly. My talk ranges from the history of the field, through its fundamental principles, to the identification and correction of common sources of error (stressing the importance of maintaining an audit trail from raw to processed data), and finally to some recently developed, novel flow-through respirometry techniques such as "background baselining".

Email Address for correspondence: [lighton@sablesys.com](mailto:lighton@sablesys.com)

09:00 Saturday 3rd July 2010

### **A1.2**

#### **Feeder-mask based respirometry in hummingbirds**

Kenneth Welch (University of Toronto Scarborough)

Many birds spend a significant portion of their time and energy flying. For this reason, quantification of metabolic rates during flight is of crucial importance to understanding avian energy balance. The measurement of rates of organismal gas exchange using a mask enclosing respiratory orifices or the whole head has long served as an important tool for the study of animal energetics because it frees the rest of the body, permitting movement. Application of so-called "mask respirometry" to the study of avian flight energetics presents unique challenges because birds must be tethered to gas analysis equipment thus typically necessitating use of a wind tunnel. In some studies, consequent alterations to a study organism's behavior, physiology, and aerodynamics have

made interpretation of the data obtained contentious. In contrast, the study of hovering flight energetics in hummingbirds using a specialized form of mask respirometry is comparatively easy. Small size, hovering flight, and a nectarivorous diet are characteristics shared by all hummingbird species that make these birds ideally suited for this approach. Specifically, nectar feeders are modified to function as respirometry masks, which hummingbirds voluntarily 'wear' when hover-feeding. Such respirometry has revealed some of the highest vertebrate metabolic rates in hovering hummingbirds. In this talk I discuss techniques for the measurement of metabolic rate using feeder-mask respirometry. I also emphasize how this technique has been used to address fundamental questions regarding avian flight energetics such as fuel use capacities and mechanisms linking ecology, behavior and energy balance.

Email Address for correspondence: [kwelch@utsc.utoronto.ca](mailto:kwelch@utsc.utoronto.ca)

09:40 Saturday 3rd July 2010

### **A1.3**

#### **Linking the mechanical and metabolic power requirements of flight in the cockatiel**

Charlotte R Morris (University of Leeds), Frank E Nelson (University of Washington), Graham N Askew (University of Leeds)

Little is known about how in vivo muscle efficiency is affected by changes in locomotory tasks. One of the main problems with determining in vivo muscle efficiency is the large number of muscles generally used to produce mechanical power. Animal flight provides a unique model for determining muscle efficiency because only one muscle, the pectoralis muscle, produces all of the mechanical power required for flight. To estimate in vivo flight muscle efficiency, we measured the metabolic cost of flight across a range of flight speeds using respirometry in the cockatiel and compared it with measurements of mechanical power determined in the same wind tunnel. The calculated pectoralis muscle efficiency increased with flight speed and ranged from 6.9-11.2%. However, actual pectoralis muscle efficiency is likely to be higher as previous estimates of the postural costs of flight have probably been too low.

Email Address for correspondence: g.n.askew@leeds.ac.uk  
10:10 Saturday 3rd July 2010

---

#### A1.4

##### **Acceleration as a proxy for energy expenditure: what it is, what it is not and what we still need to know**

Emily L Shepard (Swansea University), Lewis G Halsey (University of Roehampton), Adrian C Gleiss (Swansea University), Rory P Wilson (Swansea University)

Activity is a key determinant of the metabolism of free-living animals. Neither of the two most popular methods for estimating rate of energy expenditure, the doubly-labelled water or the heart-rate techniques, can determine activity-specific energy expenditure alone. A new method, overall dynamic body acceleration (ODBA), is a single integrated measure of body motion that has recently been shown to correlate well with energy expenditure in a range of animals during locomotion (typical R<sup>2</sup> values of > 0.8 between V'O<sub>2</sub> and ODBA for a group of animals) as well as provide information on behaviour. Initial trials also suggest that it can be used to estimate changes in energy expenditure within individuals. Limitations of this technique include the extent to which movement correlates with energy expenditure which varies with, for example, force generation, the contribution of elastic tendons, specific dynamic action, and input of kinetic energy from the environment such as wave action. Nonetheless, acceleration data are relatively easy and cheap to obtain and provide unparalleled resolution of patterns of wild animal behaviour. This, coupled with results from laboratory tests to date, suggest that ODBA is likely to compliment existing techniques and be an important tool for ecologists measuring the costs of behaviourally-mediated energy expenditure in many free-living animals.

Email Address for correspondence: 381601@swansea.ac.uk  
11:00 Saturday 3rd July 2010

---

#### A1.5

##### **Movement patterns, swimming speed and metabolic rate of a vulnerable temperate rocky-reef fish, *Cheilodactylus spectabilis* during the spawning season**

Jayson M Semmens (University of Tasmania), Dale M Webber (Vemco), Peter B Frappell (University of Tasmania), Jonas Haag (University of Tasmania), Jeremy M Lyle (University of Tasmania), Colin D Buxton (University of Tasmania)

In Tasmania, Australia, detailed movement and activity information is urgently required for *Cheilodactylus spectabilis* (Hutton 1872), given its vulnerability to fishing. Acoustic telemetry was used to examine the temporal/spatial movement and activity patterns of *C. spectabilis* on rocky reefs around the Tasman Peninsula, Tasmania during the 4 month spawning season. *Cheilodactylus spectabilis* fitted with accelerometer/depth tags showed a repeatable pattern of fish moving to > 20m and up to 45m in the morning to spawn and returning to < 20m in the afternoon during the spawning period. Acceleration was calibrated with swimming speed and metabolic rate (MO<sub>2</sub>) in the laboratory, allowing for swimming activity and MO<sub>2</sub> of individual fish during spawning to be examined. This study has provided important data on the temporal and spatial movement, and activity patterns, of *C. spectabilis*, including providing crucial information for implementing appropriate management strategies for this vulnerable species.

Email Address for correspondence: jayson.semmens@utas.edu.au  
11:30 Saturday 3rd July 2010

---

#### A1.6

##### **Measuring body mass loss to estimate daily energy expenditure**

Steven J Portugal (University of Birmingham), Magella Guillemette (Université du Québec, Rimouski)

During starvation, energy production occurs at the expense of body reserve utilisation which results in body mass loss. Knowing the role of the fuels involved in this mass loss, along with their energy equivalent, allows an energy equivalent of body mass loss to be calculated. Mass loss during a prolonged fast is best described as an exponential function of time,  $W_t = W_0 e^{-kt}$ , where  $W_0$  is mass at the start,  $W_t$  is mass  $t$  days later, and  $k$  is a constant which is the proportion of mass loss per day. Therefore, it is possible to determine daily energy expenditure (DEE) if two body mass loss measurements at an interval of a few days are obtained. The technique can be cheap, is not stressful for the animals involved, and the data relatively simple to gather. Here we will review the use of body mass loss to estimate DEE through demonstrating the technique's strengths and weaknesses, and detail the methodology that must be adhered to in order to garner accurate measures of DEE from daily body mass loss. Owing to the biology of Antarctic seabirds, the use of the technique has been used predominantly in these species, particularly penguins and albatrosses. We will demonstrate how reliable the technique can be in predicting DEE in a non-Antarctic species which fasts, but also how inaccurate the technique can be if the assumptions are not met or the methodological considerations are not attended to.

Email Address for correspondence: S.Portugal.1@bham.ac.uk  
11:50 Saturday 3rd July 2010

---

## A1.7

### Allometric estimation of metabolic rates in animals

Craig R White (University of Queensland)

The relationship between body mass ( $M$ ) and metabolic rate (MR) typically accounts for most (>90%) of the inter-specific variation in MR. As such, when measurement of a species of interest is not possible, its MR can often be predicted using  $M$ . However, choosing an appropriate relationship to make such predictions is critical, and the choice is complicated by ongoing debate about the structure of the relationship between  $M$  and MR. The present study examines a range of methods including ordinary least squares (OLS), reduced major axis (RMA), and phylogenetically-informed (PI) approaches for estimating  $\log(\text{MR})$  from  $\log(M)$ , as well as non-linear approaches for estimating the relationship between MR and  $M$  without the need for log-transformation. Using data for the basal metabolic rates of mammals, it is shown that RMA regression overestimates the scaling exponent of MR ( $b$ , where  $\text{MR} = a M^b$ ), suggesting that OLS regression is appropriate for these data. PI approaches are preferred over non-PI ones, and the best estimates of  $\log(\text{MR})$  are obtained by including information on body temperature, climate, habitat, island endemism, and use of torpor in addition to  $\log(M)$ . However, the use of log-transformed data introduces bias into estimates of MR. The use of non-linear regression on untransformed data eliminates this bias, but underestimates MR for small mammals. This suggests that no single relationship is appropriate for describing the relationship between MR and  $M$  for all mammals, and that relationships for more narrow taxonomic groups or body mass ranges should be used when predicting MR from  $M$ .

Email Address for correspondence: craig.white@uq.edu.au  
13:20 Saturday 3rd July 2010

---

## A1.8

### Using the doubly labelled water method to measure energy expenditure in free-ranging birds: some concerns and recent progress

Jorg Welcker (Norwegian Polar Institute), Scott A Shaffer (Department of Biological Sciences San Jose State University)

The doubly labelled water (DLW) method is the most commonly used method to estimate energy expenditure

(or field metabolic rate, FMR) of animals in their natural environment. It is based on introducing heavy isotopes of hydrogen and oxygen into the body of study animals, and estimating  $\text{CO}_2$ -production rate by comparing the elimination rates of both isotopes. Several advantages of the method include its easy application in the field, moderate costs, and close correspondence of derived estimates with indirect calorimetry, which have led to its widespread use among ecophysiologicalists. However, several assumptions are required to estimate  $\text{CO}_2$ -production from water turnover, and several equations exist reflecting these assumptions. A recent review of studies using DLW to estimate FMR in albatrosses indicates that FMR can vary up to 45% depending on the equation used, emphasizing the need for careful selection of the appropriate equation. Furthermore, the validity of FMR estimates depends on the assumption that study animals behave naturally during the experiment. Surprisingly, this assumption has rarely been tested. A current study suggests that altered behaviour may occur even in relatively stress-tolerant species leading to biased estimates of FMR. Despite apparent limitations, the DLW method is one of our best tools for evaluating field energetics. When combined with bio-logging methods, the DLW method can improve our understanding of individual variation in FMR. Finally, the DLW method is a vital tool to monitoring inter-annual variation in FMR, providing new insights into factors that limit energy expenditure of wild animals.

Email Address for correspondence: welcker@npolar.no  
13:45 Saturday 3rd July 2010

---

## A1.9

### The heart rate method: review and recommendations

Jonathan A Green (University of Liverpool)

To anyone who has ever run for a bus, climbed a flight of stairs or used exercise equipment, it is evident that heart rate is related to rate of energy expenditure (i.e. metabolic rate; MR). In this presentation I will review the principles and history of the application of the heart rate method to studies of MR in animals. Heart rate can be used to make both qualitative and quantitative estimates of MR, and I will review studies of animal ecology, behaviour and physiology where each of these approaches has been used. In doing so, I will emphasise the importance of using the correct analytical and statistical approaches. To make quantitative predictions it is necessary to derive a calibration relationship between heart rate and MR. I will review various methods and techniques used to derive these relationships, and highlight several important points to be considered in their derivation such as body mass and activity state. Ultimately, when deriving calibration relationships it may be more important to obtain a relationship which is usable in the field rather than one which considers every potential influence.

Email Address for correspondence: jonathan.green@liverpool.ac.uk  
14:15 Saturday 3rd July 2010

## A1.10

### Regional patterns of muscle blood flow during steady swimming in trout

Shannon P Gerry (Wellesley College), David J Ellerby (Wellesley College)

Sustained undulatory swimming in fishes is powered by slow myotomal muscle. Rainbow trout, *Oncorhynchus mykiss*, are sub-carangiform swimmers with undulations confined to the posterior two-thirds of the body axis. Skeletal muscle performs a number of roles during swimming in addition to mechanical power production, e.g. maintaining stability by controlling fin shape and orientation and powering respiratory movements. The relative energetic costs of these functions are not known. The rate of blood flow to muscle tissue is proportional to its aerobic energy expenditure. Therefore, regional blood flow to specific categories of muscle can be used to indicate their relative functional costs. We hypothesized that during steady swimming blood flow would be concentrated at the myotomal muscles, with less flow to the respiratory, pelvic and pectoral girdle and fin ray muscles. Fluorescent microspheres were injected into the trout systemic circulation via a dorsal aortic cannula at rest and swimming at speeds of 50%, 75% and 100%  $U_{crit}$ . Following dissection, body tissues were digested to recover the microspheres and quantify their distribution. Approximately 40% of the relative total muscle blood flow was to the slow myotomal muscles at all swimming speeds. Similarly, the fin ray, pelvic and pectoral girdle muscles also receive 40% of total muscle blood flow. The respiratory muscles receive about ten percent of total blood flow, which may indicate a transition from branchial pumping to low-cost ram ventilation during swimming. Future studies will integrate muscle activation and mechanical performance data.

Email Address for correspondence: sgerry@wellesley.edu  
15:30 Saturday 3rd July 2010

## A1.11

### Thermal imaging and heat transfer analysis in birds: estimating energy costs in emperor penguins

Dominic J McCafferty (University of Glasgow Scotland UK), John C Currie (Scottish Energy Centre Edinburgh Napier University Scotland UK), Anne-Mathilde Thierry (IPHC-DEPE UMR7178 CNRS-UdS Strasbourg

France), Yvon LeMaho (IPHC-DEPE UMR7178 CNRS-UdS Strasbourg France), Caroline Gilbert (Nancy-Université Université Henri Poincaré IPHC-DEPE UMR7178 CNRS-UdS Strasbourg France), André Ancel (IPHC-DEPE UMR7178 CNRS-UdS Strasbourg France)

Infrared thermography is a technique that accurately records surface temperature and therefore it can be used to estimate metabolic heat loss of captive and free ranging animals. The advantage of this technology is that it provides thermal images with high spatial temperature resolution and allows the non-invasive measurement of animals exhibiting natural behaviours. We review the influence of environmental, physical and physiological factors on thermal imaging of animals and examine how these factors can be taken into account in experimental design and data analysis. The value of combining infrared thermography with heat transfer analysis is demonstrated using a heat transfer model of an emperor penguin (*Aptenodytes forsteri*), that is based on thermal images recorded at the breeding colony at Point Géologie, Dumont d'Urville, in Adélie Land, Antarctica during June 2008. The relationship between heat loss and environmental conditions for this species are examined. This approach will lead to new insights into the ways in which emperor penguins and other species cope with the metabolic demands of different climates. Furthermore, recent advances in thermal imaging technology will allow novel applications in a wide range of animal studies.

Email Address for correspondence: d.mccafferty@educ.gla.ac.uk  
15:50 Saturday 3rd July 2010

## A1.12

### Estimating metabolic rate by direct calorimetry and infrared thermography

Roger Seymour (University of Adelaide), Ingolf Lamprecht (Free University of Berlin), Philip Matthews (University of Queensland), Craig White (University of Queensland)

Direct calorimetry involves measurement of the rate of heat loss from an organism, while indirect calorimetry usually involves measurement of respiration rate as  $O_2$  consumption or  $CO_2$  production. Coupling both methods can provide insights that neither method can achieve alone. Direct calorimetry is usually limited to laboratory environments under very restrictive conditions, but one example from thermoregulating lotus flowers shows its use in the field. Here the balance between the rate of heat production (measured by  $O_2$  consumption), heat loss (measured by direct calorimetry and hydrometry) and heat storage (measured by floral temperature) reveal a complete picture of changing energy balance. Coupling direct calorimetry with respiration in resting beetles demonstrates coupling of bursts of  $CO_2$  loss with

simultaneous heat absorption due to water evaporation. Coupling of infra-red thermal imaging with respiration in beetles reveals superimposable patterns of thoracic temperature elevation and rate of CO<sub>2</sub> production during bouts of endothermy. Heat generated in the thorax by oscillatory waves of respiration are coupled with thoracic temperature increases, which provides the exciting new possibility of measuring metabolic rate indirectly, without contact or enclosure. The advantages and restrictions of the techniques are presented.

Email Address for correspondence: roger.seymour@adelaide.edu.au  
16:20 Saturday 3rd July 2010

### A1.13

#### **The accelerometry technique for amphibian ecophysiology: Describing energy expenditure in an important invasive species, the cane toad**

Lewis G Halsey (Roehampton University), Craig R White (University of Queensland)

Introduced species that flourish in new environmental conditions can be environmentally and economically costly. Cane toads are an exemplar; a species introduced to Australia as a control agent that now has a rapidly progressing invasion front and damages new habitats it enters. Evidence is emerging that those individuals at the invasion front are morphologically different to the established populations, aiding in the rate of species spread. Information on their energy expenditure is necessary to accurately predict their future distribution but to date there has not been a suitable method for measuring field metabolic rate in an amphibian. Thus researchers have been limited in assessing both the morpho-physiological adaptations of cane toads in Australia and the future ecological consequences of their presence. The accelerometry technique is a relatively new method for estimating energy expenditure, which we applied in the present study to obtain the first measurements of energetics in free ranging cane toads. Furthermore, acceleration data were used to generate behavioural time budgets for cane toads which, combined with the energetics data, can provide fundamental information on the ecology of this species. The present research demonstrates an advance in our ability to both measure metabolic rate and quantify behaviour in free-ranging anurans. Eco-physiologists should consider the accelerometry technique as a veritable approach for their comparative studies exploring intra- and inter-specific variation in field energetics, in both amphibians and other medium and large animals.

Email Address for correspondence: l.halsey@roehampton.ac.uk  
Poster Session 17:00-19:00 Friday 2nd July 2010

### A1.14

#### **Time matters: post-surgical recovery of gastric evacuation rate in Atlantic cod**

Jane W Behrens (Technical University of Denmark National Institute of Aquatic Resources), Albin Gräns (University of Gothenburg Department of Zoology), Niels G Andersen (Technical University of Denmark National Institute of Aquatic Resources), Stefan Neuenfeldt (Technical University of Denmark National Institute of Aquatic Resources), Michael Axelsson (University of Gothenburg Department of Zoology)

During the last decades, new technology has allowed collection of physiological and behavioral data from free-ranging specimen, minimizing stress and providing more reliable data than traditional methods. However, such biotelemetry methods demands surgical introduction of a foreign object into the fish, which may affect the animal, and studies dealing with the affect of surgery and implants are still scarce. A variable known to be sensitive to postsurgical and other stressors is the gastric evacuation rate (GER). GER is tightly linked to gut blood flow and in the present study we analysed how GER was affected after surgically introducing dummies of a blood-flow biotelemetry system into the abdominal cavity of Atlantic cod. Two days post surgery the cod with implants were, together with a control group, force-fed a standardized meal and the stomach contents recovered 24h later. This procedure was repeated for both groups of fish after one additional week of recovery. After two days GER was significantly lower in the group of fish with surgical implants compared to the control group, but the difference was not maintained after one additional week of recovery. We conclude that 10 days of postsurgical recovery will stabilize GER in cod. The results indicate that the presence of the implant *per se* did not affect GER but that the effects observed came from surgery and/or postsurgical stress. 10 days should consequently be a starting point for future studies even if longer recovery periods will probably be beneficial to the animal.

Email Address for correspondence: jabeh@aqua.dtu.dk  
Poster Session 17:00-19:00 Friday 2nd July 2010

### A1.15

#### **Accelerometry reveals diel patterns in field metabolic rate of giant Australian cuttlefish *Sepia apama* during breeding**

Nicholas Payne (Southern Seas Ecology Laboratories University of Adelaide), J M Semmens (Tasmanian Aquaculture Fisheries Institute University of Tasmania), B M Gillanders (Southern Seas Ecology Laboratories University of Adelaide), R S Seymour (Southern Seas Ecology Laboratories University of Adelaide), D M Web-

ber (Vemco Amirix Systems Inc. Halifax Nova Scotia), EJ Snelling (Southern Seas Ecology Laboratories University of Adelaide)

Estimating the metabolic rate of animals in nature is central to understanding the physiological, behavioural and evolutionary ecology of animals. Doubly labelled water and heart-rate methods are the most commonly used approaches, but both have limitations that preclude their application to some systems. We combined two-dimensional accelerometry and swim-tunnel respirometry to estimate patterns of energy expenditure in giant Australian cuttlefish *Sepia apama* during breeding. Both oxygen consumption rate  $V.O_2$  and swimming speed showed strong positive associations with body acceleration, with coefficients of determination comparable to those using similar accelerometers on terrestrial vertebrates. Despite being significantly higher during the day, field metabolic rate rarely approached  $V.O_2$  max and night-time  $V.O_2$  was similar to that at rest. These results are consistent with the life-history strategy of this species, which has a poor capacity to exercise anaerobically, and a mating strategy that is visually-based.

Email Address for correspondence: nicholas.payne@adelaide.edu.au  
Poster Session 17:00-19:00 Friday 2nd July 2010

### **A1.16** **Energy turnover in muscles from mice over-expressing Uncoupling Protein-3**

Prof Nancy Curtin (Imperial College London), Dale C Bickham (Imperial College London), Roger C Woledge (Imperial College London), Willem J Van der Laarse (VU University Amsterdam)

Uncoupling protein 3 (UCP-3) is a member of the mitochondrial transporter super-family and is expressed almost exclusively in skeletal muscle. Its localization in the inner mitochondrial membrane, a key site of ATP production, suggests a role in energy supply. UCP-3 may act as a proton leak channel that uncouples respiration from ATP synthesis. Transgenic mice (TG) over-expressing UCP-3 are lean despite being hyperphagic (eating more than wild type (WT) mice). We investigated the cellular mechanism of this phenotype by testing the hypothesis that TG muscle has higher oxygen consumption and heat production than WT muscle. The basal rate oxygen consumption by resting soleus fibres from male TG mice was significantly higher than that of female TG mice and both male and female WT mice. There were similar significant differences in the resting heat production. Thus higher basal metabolism was a feature of muscle from TG mice. However, when performing a series of working contractions, the TG muscles were more efficient than the WT muscles; the supra-basal oxygen consumption by TG muscles was

17% less per unit of work done than that of WT muscles. This finding is surprising: the opposite of that expected for the hyperphagic, lean phenotype of TG mice. It raises the question: does the supra-basal oxygen consumption underestimate the real cost of working contractions in TG muscle? This would occur if low [ADP] promotes uncoupling.

Email Address for correspondence: n.curtin@imperial.ac.uk

### **A1.17**

#### **Using body acceleration to estimate energy expenditure during diving in adult green turtles (*Chelonia mydas*)**

Dr Manfred Enstipp (IPHC-DEPE CNRS Strasbourg), Katia Balorain (IPHC-DEPE CNRS Strasbourg), Stephane Ciccione (Kelonion - l'observatoire des tortues marines), Akiko Kato (IPHC-DEPE CNRS Strasbourg), Yan Ropert-Coudert (IPHC-DEPE CNRS Strasbourg), Jean-Yves Georges (IPHC-DEPE CNRS Strasbourg)

Knowledge of an animal's energy expenditure is fundamental for our understanding of its physiology, ecology, and ultimately population dynamics. However, measuring energy expenditure in free-ranging aquatic animals remains a challenge to date. In recent years two promising methods have been advanced to achieve such measurements: recording heart rate or ODBA/PDBA (overall/partial dynamic body acceleration) as a proxy of energy expenditure. Marine turtles are large aquatic ectotherms that spend their life at sea, returning to land only to deposit their eggs. Today, apart from one doubly-labelled water study in leatherback turtles (*Dermochelys coriacea*), no measurements of energy expenditure in freely swimming adult marine turtles exist. We used open flow-through respirometry to measure oxygen consumption rates in adult green turtles resting and swimming within a 13 m long swim canal (max depth: 2 m). Mean ( $\pm$ S.D.) oxygen consumption rate of six turtles (mean mass: 142.1 $\pm$ 26.9 kg) when resting at a water temperature of 25.8 $\pm$ 1.0 °C was 30.1 $\pm$ 6.2 ml min<sup>-1</sup>. During activity, when turtles swam freely within the canal, oxygen consumption rate increased on average by 86.4 $\pm$ 50.6 % (range: 38.1-179.3 %). Deploying two-axis accelerometers in conjunction with respirometry, we investigated if PDBA could be used as a reliable proxy of energy expenditure. GLMM analysis revealed a significant relationship between oxygen consumption rate and PDBA, which was modified by water temperature and body mass. This suggests it is possible to estimate energy expenditure in wild turtles, of known mass and at known temperature, through the deployment of accelerometers.

Email Address for correspondence: manfred.enstipp@c-strasbourg.fr