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A9 — PHYSIOLOGICAL ENERGETICS

A9.1

09:00 Wednesday 1st July 2009

Perturbation as method for research on metabolic organisation of individuals

Bas Kooijman (Vrije Universiteit Amsterdam)

The Dynamic Energy Budget (DEB) theory offers a general framework to evaluate effects of perturbations in the form of toxic compounds or changes in temperature and food abundance from a life cycle perspective. I will illustrate its application with three examples:

– caloric restriction increases mean life span sometimes; the aging module of the standard DEB model has just two aging parameters with the well-known Weibull and Gompertz models as special cases, and an important role for the mobilisation rate of reserve as quantifier for metabolic activity.

– an increase in the cost of structure on the reproduction rate (e.g. by a chemical) reduces growth; food uptake is linked to size, so the long term effect is reduction of food uptake, and so of allocation to reproduction. An increase of the cost of structure also has the effect of a decrease in amount of structure at hatching, which reduces the cost of an egg to the extent that the reproduction rate can show hormesis: an increase in the reproduction at small effects, but a decrease at larger effect levels.

– temperature affects nutrient uptake by phototrophs, but hardly light-limited carbon fixation. The consequence is that carbohydrate reserve builds up at low temperatures, and changes the nutritional value of e.g. algae for bivalves as function of their geographic distribution.

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A9.2

09:40 Wednesday 1st July 2009

Dynamic energy budgets of syntrophic symbiotic relationships between heterotrophic hosts and photoautotrophic symbionts

Erik B. Muller (University of California Santa Barbara), Francis J. Doyle (University of California Santa Barbara), Roger M. Nisbet (University of California Santa Barbara), Peter Edmunds (California State University Northridge), Sebastiaan Kooijman (Vrije Universiteit Amsterdam)

We develop and investigate a Dynamic Energy Budget (DEB) model describing the syntrophic symbiotic relationship between a heterotrophic host and an internal photoautotrophic symbiont. The model specifies the flows of matter and energy among host, symbiont and environment with minimal complexity and uses the concept of synthesizing units to describe smoothly the assimilation of multiple limiting factors, in particular inorganic carbon and nitrogen, and irradiance. The model has two passive regulation mechanisms: the symbiont shares only photosynthate that it cannot use itself, and the host delivers only excess nutrients to the symbiont. With parameter values plausible for scleractinian corals, we show that these two regulation mechanisms are suffice to obtain a stable symbiotic relationship under constant ambient conditions, provided those conditions support sustenance of host and symbiont. Furthermore, the symbiont density in the host varies relatively little as a function of ambient food density, inorganic nitrogen and irradiance. This symbiont density tends to increase with light deprivation or nitrogen enrichment, either directly or via food. We also investigate the relative benefit each partner derives from the relationship and conclude that this relationship may shift from mutualism to parasitism as environmental conditions change.

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A9.3

10:30 Wednesday 1st July 2009

Intraspecific variation in metabolic rate: How is it maintained, and what are the consequences?

Neil B. Metcalfe (University of Glasgow)

While there have been many attempts to explain the variation that exists between species in their standard or resting metabolic rate, variation within a species has until recently been largely ignored. However, this variation can be considerable, and its existence is puzzling. Why should some individuals consistently have two or three

times the 'maintenance costs' of others of the same size and sex? Given the forces of natural selection, such variation in metabolic rate can only persist if it is non-genetic in origin and/or the costs are offset by benefits. In this talk I will use examples from a range of species to discuss the evidence that intraspecific variation in resting or standard metabolic rate has a non-genetic origin, and can be influenced by early nutrition, and to show that metabolic rate is associated with other fitness-related traits. For instance, in salmonid fish a high SMR is linked to greater aggression and dominance, which is likely to confer advantages in some (but not all) environments. Moreover, our recent experiments show that SMR in fish covaries with digestive strategy, so that individuals with a higher SMR pay a greater energetic cost (SDA) but can digest food (and so resume feeding) faster. These results suggest that the fitness consequences of a given metabolic rate will depend on the local circumstances (i.e. different microhabitats may select for different metabolic rates), so leading to the persistence of significant intraspecific variation in this key physiological trait.

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A9.4
11:00 Wednesday 1st July 2009
Field metabolic rate in seabirds — Influences, limits and consequences

Jonathan A. Green (University of Liverpool)

Seabirds make excellent models for studies of field metabolic rate (FMR). FMR has been evaluated using a variety of methods, in a number of populations and species around the world. However, few studies have looked in depth at what factors might be responsible for the variability we observe between species, populations and individuals. In this presentation I will investigate some of these factors by delving deeper into the behaviour and energetics of seabirds. At the species level, I will discuss how time allocation and the energetic costs of specific activities can explain differences observed between species. Careful allocation of time to energetically costly activities is necessary as animals face limits to the intake and expenditure of energy. Using an example from penguins I will show that in seabirds at least, limits appear to apply to demands on energy expenditure rather than supply. At the population level, differences in the success of populations of gannets can be explained by examining time allocation and calculating the proximities of different populations to energetic limits. Finally, new techniques and methods of analysis can for the first time show how even at the individual level, metabolic performance and reproductive performance are linked. Preliminary analyses from both penguins and gannets suggest that higher performing individuals have lower energetic costs.

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A9.5
11:30 Wednesday 1st July 2009
Laboratory model of adaptive radiation: Activity and metabolic rates in bank voles from a multidirectional artificial selection experiment

Pawel Koteja (Institute of Environmental Sciences Jagiellonian University Kraków, Poland), Katarzyna Baliga-Klimczyk (Institute of Environmental Sciences Jagiellonian University Kraków, Poland), Katarzyna M. Chrzascik (Institute of Environmental Sciences Jagiellonian University Kraków, Poland), Milena Damulewicz (Institute of Environmental Sciences Jagiellonian University Kraków, Poland), Dominika Dragosz-Kluska (Institute of Environmental Sciences Jagiellonian University Kraków, Poland), Justyna Morawska-Ploskonka (Institute of Environmental Sciences Jagiellonian University Kraków, Poland)

Explaining interspecific variation of metabolic rates is a topical subject in comparative physiology. We asked how the level of metabolism of a wild rodent, the bank vole (*Myodes glareolus*), would change in response to selection acting in distinct directions: the ability to maintain body mass on a low-quality herbivorous diet (H), high swim-induced aerobic metabolism (A), and intensity of predatory behavior towards crickets (P). Four replicate lines are maintained for each of the directions and an unselected control (C). In generation 7, voles from H lines fed a low-quality diet gained body mass (mean ± SD, 0.35 ± 0.99 g) whereas those from C lines lost mass (−0.65 ± 1.10 g; $p<0.0001$). The swim-induced metabolic rate was higher in A than in C lines (A: 297 ± 37; C: 222 ± 31 ml O_2/h; $p<0.0001$). The proportion of "predatory" individuals was higher in P (82%) than in C lines (29%; $p<0.001$). Continuous records from infra-red motion sensors and visual observations of behaviour (ethograms) showed that voles from A and P lines were more active than those from H and C lines; the pattern of activity differed also between A and P lines. The maximum forced-exercise and cold-induced metabolic rates were higher in A compared to C lines (ml O_2/h, exercise A: 381 ± 54, C: 312 ± 46; cold A: 311 ± 42, C: 282 ± 39; both $p<0.0001$). The basal metabolic rate (BMR) was higher in A lines (51.7 ± 9.1 ml O_2/h) compared to C (47.5 ± 6.7 ml O_2/h) or H (48.4 ± 6.4 ml O_2/h; $p=0.03$) and was intermediate in P lines (50.3 ± 7.4 ml O_2/h). The results are consistent with a hypothesis linking the evolution of endothermy with a selection for active-predator lifestyle.

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A9.6
11:50 Wednesday 1st July 2009
Swim more, weigh less: Linking physiological energetic and behavioural ecology in individual European seabass

Shaun S. Killen (Université Montpellier II), Stefano Marras (Université Montpellier II), David J. McKenzie (Université Montpellier II)

Individual fish exhibit consistent intrinsic differences in standard metabolic rate (SMR), but it is not clear how these differences in physiology may be relevant to their ecology. We investigated relationships between SMR, routine metabolic rate (RMR), maximum metabolic rate (MMR), aerobic scope (AS), starvation tolerance as weight loss, and risk-taking behaviour, in 39 juvenile seabass *Dicentrarchus labrax*. All of these traits showed large inter-individual variation. Standard metabolic rate correlated positively with weight loss during a seven-day period of fasting, although RMR showed a higher correlation, suggesting that individual differences in activity contribute to relative tolerance of starvation. Both MMR and absolute AS showed positive correlations with SMR, indicating that high SMR was associated with increased aerobic capacity. As a consequence, however, MMR also showed a positive correlation with rate of weight loss, suggesting a trade-off between aerobic capacity and starvation tolerance. Behavioural analyses are ongoing, but it appears that individuals show consistent differences in measures of riskiness such as time until first emergence from cover to obtain food after a startling stimulus. The expectation is that these measures of risk-taking tendencies will correlate positively with SMR,

RMR and aerobic capacity. The large degree of individual variation in traits such as metabolic rate, aerobic capacity, starvation tolerance and risk-taking behaviour suggests that there are trade-offs between these traits which – depending on environmental factors such as food availability and predator abundance – could have an important influence on which individuals survive in wild populations.

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A9.7

12:10 Wednesday 1st July 2009

Effects of density on the optimal metabolic rate for stream-living juvenile salmon

Donald Reid (University of Glasgow), John D. Armstrong (Fisheries Research Services), Neil B. Metcalfe (University of Glasgow)

Physiological traits can vary greatly within a species and consequently have great impact on other aspects of performance. Atlantic salmon (*Salmo salar*) exhibit striking variation in standard metabolic rate (SMR) which has been seen to influence their life-histories. The effect of individual variation in SMR under different natural population densities on the feeding and growth rate of 1+ Atlantic salmon was examined using an artificial stream at FRS Almondbank. SMR was strongly correlated with dominance rank, but no overall relationship existed between SMR and growth. While high SMR individuals tended to occupy the best feeding territories, growth rate within holders of good territories was negatively correlated with SMR, presumably due to high costs of metabolism. Of the subordinate individuals who attained a poorer feeding territory, lower SMR individuals exhibited highest growth. Higher densities led to increased aggression and competition, and decreased food capture and growth. Therefore there is a context-dependent energy budget trade-off where the minimal SMR to achieve dominance over conspecifics (and hence acquisition of a good territory) is favoured. This minimal required SMR increases with population density.

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A9.8

13:30 Wednesday 1st July 2009

Limits to sustained energy intake

John R. Speakman (University of Aberdeen)

During late lactation maternal food intake reaches a plateau, indicating that the female is limited in her sustained energy intake. We recently suggested that this limit is mediated by the capacity to dissipate heat. This is consistent with the fact intake at peak lactation and pup growth increase in cold (8 °C) and decrease in hot (30 °C) conditions. Moreover shaving mice at peak lactation allows them to increase their food intake and raise larger pups. A potential mechanism causing these effects is that suckling pups reduce the female's capacity to dissipate heat, causing her body temperature to rise. We have instrumented mice with temperature transmitters and followed their body temperatures in relation to their suckling behaviour during peak lactation. These studies reveal that lactating females are under chronic hyperthermia. The patterns of body temperature change during suckling bouts do not support an interpretation that overheating is caused by the suckling pups preventing heat loss. Heat dissipation problems therefore occur because of the continuous heat production resulting from milk synthesis and the specific dynamic action (SDA) of the diet. The heat dissipation limits hypothesis predicts that when given a choice lactating females should avoid diets with a high SDA. Moreover, when not given a choice intake, milk production and offspring growth should all depend on SDA. I will present some unpublished data testing these predictions in cats and mice. Generally the predictions hold up in a qualitative fashion, but the quantitative details reveal some additional complexity.

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A9.9

14:10 Wednesday 1st July 2009

Resveratrol activates energy metabolism by influencing body temperature, locomotor activity and resting metabolic rate in a non-human primate

Alexandre Dal-Pan (CNRS MNHN), Stéphane Blanc (CNRS), Fabienne Aujard (CNRS MNHN)

Resveratrol is a natural polyphenolic compound that activates proteins implicated in energy metabolism homeostasis. These activations can mimic metabolic aspects of calorie restriction in various species. This pathway targets selective nutrient utilization and mitochondrial oxidative function to regulate energy balance. This work is the first to study the effects of resveratrol on energy metabolism in a non-human primate, the grey mouse lemur (*Microcebus murinus*).

We have followed six mouse lemurs during four weeks by telemetric monitoring in order to evaluate the impact of a resveratrol supplementation (200 mg/kg) on body temperature and locomotor activity. Body mass and resting metabolic rate variations were analysed too. We also measured the rates of gut hormones influencing energy homeostasis (pancreatic polypeptide, peptide YY, glucagon-like peptide-1, insulin and glucose-dependant insulinotropic polypeptide).

Resveratrol had progressive effects on energy metabolism during the four weeks of treatment. Indeed, resveratrol induced an increase of resting metabolic rate and diurnal locomotor activity of the mouse lemurs with a decrease in body mass and in food intake. The animals seem to burn their energy reserves very quickly. We observed a rise of their body temperature and a decrease of daily hypothermia duration. From the fourth week, pancreatic polypeptide, peptide YY and insulin are negatively associated with body temperature and only peptide YY is positively associated with daily hypothermia duration.

These results highlight a quick and important stimulation of energy metabolism with an increase of body temperature, locomotor activity and resting metabolic rate in a non-human primate supplemented with resveratrol.

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A9.10

14:30 Wednesday 1st July 2009 (SEB Education and Public Affairs Section President's Medallist 2009)

Physiological limits to energy turnover: The case of the European hare (*Lepus europaeus*)

Teresa G. Valencak (Veterinary University Vienna), Thomas Ruf (Veterinary University Vienna)

European hares raising young can achieve more than six times their basal metabolic during the four week lactation period. These high energetic costs of lactation peak around the third week and then reach

a plateau which is not further exceeded. With increasing litter size of up to three young, however, milk-intake per juvenile decreases. These and further observations led us to hypothesize that female hares encounter physiological limits during lactation. What is the nature of these physiological ceilings, and which factors influence maximum energy turnover? To answer these questions, we performed a study in laboratory-housed female European hares raising three young.

We found that females in spring covered the high costs of lactation by mobilising fat reserves which were built-up previously (in the preceding autumn). During summer, milk fat content decreased continuously. When raising litters in autumn, however, after body fat deposits have been depleted, females increased energy turnover significantly above those levels reached before. Only when their pups were maintained at cooler temperatures, females kept separately from their offspring boosted milk output even further. These unexpected results demonstrate that energy turnover in lactating hares is normally not constrained by physiological limits and secondly that heat dissipation is not limiting for hares. Instead, females regulate their energy expenditure according to the availability of own fat reserves and pup demand, but avoid exceeding levels of energy expenditure which could bring along potential costs of extremely high metabolic rates.

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A9.11

14:50 Wednesday 1st July 2009

Food availability as a cue for mechanisms of winter energy conservation in red deer

Christopher Turbill (Research Institute of Wildlife Ecology University of Veterinary Medicine Vienna), Thomas Mang (Research Institute of Wildlife Ecology University of Veterinary Medicine Vienna), Thomas Ruf (Research Institute of Wildlife Ecology University of Veterinary Medicine Vienna), Walter Arnold (Research Institute of Wildlife Ecology University of Veterinary Medicine Vienna)

Red deer (*Cervus elaphus*) show large seasonal fluctuations in energy expenditure, with average daily metabolic rates in winter up to 60% lower than in summer. In addition to an underlying endogenous rhythm, seasonal changes in environmental conditions, primarily food availability and air temperature, are considered important cues in the expression of energy-saving adaptations during winter. We tested the effects of food availability and quality on the metabolic rate of red deer under semi-natural conditions. Sixteen female deer received an alternate monthly ration of food ad libitum or restriction (20%) over two years. In addition, deer were switched in each year between high or low protein diets. We recorded heart rate and core body temperature using newly designed transmitters residing in the deer's reticulum. These data were transmitted via a collar repeater unit, which also measured activity, to an automated data logging station. We will use mixed effects models with individual as a random factor to distinguish the effects of food restriction and protein content, independent of season, on variation in heart rate, as a proxy for energy expenditure. Moreover, these data allow us to quantify the importance of a reduction in thermoregulatory heat production to explaining the unusually low heart rates observed in winter, especially during food restriction. Our study provides clear evidence of a strong effect of food availability in triggering mechanisms that reduce the winter energy expenditure of red deer.

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A9.12

15:40 Wednesday 1st July 2009

From Static Energy Budgets (SEB) to Dynamic Energy Budgets (DEB), linking physiology and ecology, illustrated for plaice *Pleuronectes platessa* (L.)

Henk W. van der Veer (Royal Netherlands Institute for Sea Research), Joana F.M.F. Cardoso (Royal Netherlands Institute for Sea Research/CIMAR/CIIMAR – Centro Interdisciplinar de Investigação Marinha e Ambiental – Universidade do Porto), Sebastiaan A.L.M. Kooijman (Free University, Amsterdam),

Although static energy budgets can be determined under laboratory conditions, the various allometric relationships are a purely statistical description of measurements and not physiologically-based on first principles. In addition, these budgets are species-specific and difficult to use for extrapolations beyond the range of data on which they were calculated. Moreover, the dimensions of the various parameters are often not length (L^1)-, surface (L^2)- or volume (L^3)-related but expressed as a fractional number and therefore meaningless and incorrect. Another weakness of static energy budgets is that they are unable to describe the energetics of an organism in a dynamically varying environment. This requires a framework describing the quantitative aspects of energy flows through an organism in a systematic and dynamic way. Dynamic energy budgets (DEB) fulfil these requirements. Moreover, they are based on first principles and they can capture the life history and energetics of species in a single model whereby differences between species are reflected in differences in parameter values only. The main difference between DEB and SEB is the incorporation of reserves in the DEB model, thereby allowing the physiological history of the fish (e.g., previous rates of feeding, growth, etc.) to influence its current physiological performance.

In this presentation, the combined application of SEB and DEB information will be illustrated for juvenile plaice *Pleuronectes platessa* (L.), a flatfish species that is using coastal areas as nursery grounds. Various body size scaling relationships describing the physiological performance of plaice *Pleuronectes platessa* (L.) were derived using the dynamic energy budget (DEB) model and compared with allometric relationships derived from a static energy budget (SEB) model. Results indicated that DEB models can more correctly predict the physiological performance of plaice within variable environments. Moreover, SEB data on observed growth in length or weight in the field in relation to prevailing temperature and fish size can be interpreted by means of the DEB model in terms of whether growth conditions are optimal or food limited. In addition, as a check, the DEB model can be applied for reconstructing experienced food conditions.

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A9.13

16:00 Wednesday 1st July 2009

Understanding the energetic costs of protein synthesis in crustaceans

Nia M. Whiteley (Bangor University)

Protein synthesis is a vital biological process that is an important determinant of protein turnover and growth. It is energetically expensive accounting for 11–42% of resting metabolic rate which is reflected in the general inhibition of protein synthesis rates when energy supplies are limited. Three different methods are used to determine energetic costs of protein synthesis: use of minimal theoretical costs; correlation between whole-animal rates of oxygen uptake and absolute synthesis; and direct measurements after blocking protein synthesis with an inhibitor. All 3 methods have their drawbacks which could account for the wide range of

energetic costs reported in the literature. Our current understanding of the cost of synthesising proteins in crustaceans typifies the range of values reported in other animal taxa. For example, direct measurements on the giant Antarctic isopod, *Glyptonotus antarcticus*, indicated much higher energetic costs than temperate species. In contrast, comparisons between a polar and a boreal population of *Gammarus oceanicus*, a low intertidal amphipod species, revealed similar energetic costs. Reduced protein turnover is consistently associated with lower energy expenditure and reduced metabolic sensitivities to environmental change. In contrast, higher rates of protein turnover imply increased rates of adaptation. If costs of protein synthesis do indeed vary, elevated costs could limit the ability of animals to adapt to environmental change. To get a clearer understanding of the energetics of adaptability it is necessary to optimise and standardise methodologies and determine costs in species with differing thermal histories.

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A9.14

16:20 Wednesday 1st July 2009

Simultaneous flight feather moult in barnacle geese — An alternate moulting strategy

Steven J. Portugal (University of Birmingham), Jon A. Green (University of Liverpool), Patrick J. Butler (University of Birmingham)

Flight feather moult is a major event in the annual cycle of birds that imposes nutritional and energetic demands above those of general maintenance. Eleven groups of birds, including waterfowl, exhibit an unusual kind of flight feather moult, where flight feathers are replaced simultaneously, rendering the birds flightless for approximately 25–40 days. This period of flightlessness can present a number of problems, as it restricts the normal capacity to forage and escape predation, and the energetic cost of synthesising all flight feathers is high. Studies on wild waterfowl have demonstrated that during moult, birds demonstrate a loss of body mass, changes in locomotor musculature, altered behaviour and increases in metabolic rate. We tested the hypothesis that these physiological and behavioural changes are endogenous, by studying a captive population of barnacle geese, *Branta leucopsis*. At the onset of moult, the flight muscles atrophied by 35% despite the captive geese never having flown, and body mass decreased by 25% over the moult period. Resting metabolism was 80% higher during moult when compared to non-moult periods, and average daily metabolic rate increased by 50%. Despite constant access to food and the absence of predators, the geese spent 70% of their time resting during moult in comparison to 42% of their time when not moulting. Our data suggest that the physiological changes associated with wing feather moult in barnacle geese are initiated endogenously and have important selective advantages for wild moulting birds, while also demonstrating the phenotypic plasticity of the avian body.

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A9.15

16:40 Wednesday 1st July 2009 (SEB Animal Section President's Medallist Lecture 2009)

Biochemical adaptations to hypoxia: Glycolytic capacity correlates with hypoxia tolerance in marine sculpins

Jeffrey G. Richards (University of British Columbia), Ben Speers-Roesch (University of British Columbia), Milica Mandic (University of British Columbia)

There is a long-standing hypothesis in the literature that hypoxia tolerant fish have enhanced glycolytic capacity compared with hypoxia intolerant fishes. We tested this hypothesis by comparing the metabolic capacity for oxygen-independent ATP production among 12 species of near-shore marine sculpins, which are known to differ in hypoxia tolerance. Metabolites including glycogen, glucose, and phosphocreatine as well as that activity of enzymes involved in their oxygen-independent catabolism, such as pyruvate kinase, lactate dehydrogenase and creatine kinase, were determined for all the species of sculpins and correlated to two independent measures of hypoxia tolerance, critical oxygen tensions (P_{crit}) and loss of equilibrium response (LT_{50}). In the brain there is a significant positive correlation between hypoxia tolerance and the activity of pyruvate kinase and lactate dehydrogenase with hypoxia tolerant sculpins having higher enzyme activities than the more sensitive species. Currently we are determining if similar patterns in metabolic capacity exist in liver and muscle. We also exposed three different species of sculpins, chosen to represent three different levels of hypoxia tolerance, to a level of hypoxia that was equivalent to 40% of their respective P_{crit}s. During this relative hypoxia exposure, mortality rates varied significantly among these sculpins and differences in survival time were primarily attributed to variation in hepatic glycogen content.

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A9.16

Poster Session — Tuesday 30th June 2009

Shaved mice have improved performance during lactation

Elzbieta Krol (Institute of Biological and Environmental Sciences University of Aberdeen), John R. Speakman (Institute of Biological and Environmental Sciences University of Aberdeen)

The sustained maximum rate of energy intake (SusEI) is an important variable that imposes an upper constraint on animal and human performance. Consequently, there has been intense interest in the factors that may limit it. Early hypotheses that SusEI is limited by the capacity of the alimentary tract or the activity of tissues where energy is utilised have been shown to be inadequate. A popular model for the study of SusEI has been peak lactation. We have recently suggested that the maximum SusEI at peak lactation is limited by the capacity to dissipate heat generated as a by-product of processing food and producing milk. In the current study, we performed an experimental test of this hypothesis by shaving mice during lactation to reduce their external insulation, thereby elevating their heat dissipation capacity. The heat dissipation limit theory suggests that shaved mice should have elevated performance, while alternative theories predict either no effect or reduced performance. Consistent with limits imposed by heat dissipation capacity, female mice that had been shaved ate more food, generated more milk and raised heavier offspring than unshaved individuals. These data show that ambient temperature may have direct effects on lactation, coupling mammalian reproduction much more closely to climate change than indirect effects on food supply alone. More generally, we see many situations where heat dissipation may be a previously unrecognised factor constraining the evolution of endothermic animals — for example the latitudinal and altitudinal trends in clutch and litter sizes and the migration patterns of birds.

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A9.17

Poster Session — Tuesday 30th June 2009

Pressure and temperature interactions on aerobic metabolism of migrating silver eels

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During their Atlantic migration for reproduction, European eels must cope with marked changes in a number of environmental factors such as hydrostatic pressure and temperature. It is well known that pressure and temperature are potent determinants of fish energetics, particularly at muscle level. As migration locomotory activity mainly relies upon aerobically-fuelled red muscle, the question arises of the impact of swimming at depth upon red muscle metabolic performance. Male ($N = 30$, weight $= 92 \pm 2$ g) and female ($N = 30$, weight $= 342 \pm 20$ g) adult eels acclimated to 15 °C were individually exposed to 9 or 15 or 22 °C and immediately compressed to 12.1 MPa by steps of 1 MPa. At each step (30 min duration) oxygen consumption was measured using a confinement method. Whatever the temperature and atmospheric pressure, males display higher oxygen consumption than females when standardized to body mass. At atmospheric pressure, increased temperature enhances the oxygen consumption (Q_{10}: males = 2.5; females = 2.4). Pressure exposure always increases oxygen consumption in both sex but the pressure–temperature interactions are different in males and females. Increased temperature augments the pressure effects in males whereas the reverse effect is observed in females. These results suggest that males and females probably follow different migration strategies to reach the breeding area. Males would tend to privilege cold deep waters while females would opt for warmer shallow waters.

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A9.18

Poster Session - Tuesday 30th June

Physiological energetics may contribute to competitive exclusion in African killifish (*Aphyosemion spp.*).

David J. McKenzie (CNRS Montpellier), Jon C. Svendsen (MBL Helsingør), John F. Steffensen (MBL Helsingør), Jean-François Agnèse (IRD Montpellier)

In the equatorial watersheds of Cameroon, two monophyletic groups of killifish species (genus *Aphyosemion*) have a parapatric distribution based on altitude, one occupying altitudes to 400m (low altitude, LA) and the other altitudes above this (high altitude, HA). These groups are mutually exclusive although LA species occupy high altitudes in watersheds where HA species are absent. The basis for this apparent altitude-related competitive exclusion is unknown. This study investigated the hypothesis that LA and HA groups differ for the effects of temperature on their physiological energetics. Two species from each group (mass ~ 400 mg) were acclimated to 19°, 25° and 31 °C, and their appetite, metabolic rate (MR) and specific dynamic action response (SDA) compared. Appetite was assessed by feeding ad-libitum with live *Artemia*, MR and SDA by measuring patterns of instantaneous oxygen uptake. At 19 °C, there were no significant differences in appetite (~ 20% body mass after 72 h fast), or in routine MR (3.36 ± 0.47 vs 3.05 ± 0.38 μmol O_2 g^{-1} h^{-1} in HA vs LA, respectively, $n = 12$). When fed 5% of their body mass as *Artemia*, however, the HA species completed the SDA response faster than the LA (7.4 ± 1.1 vs 13.8 ± 0.8 h, respectively), with lower overall metabolic cost of the SDA (9.15 ± 1.88 vs 14.31 ± 1.92 kJ g^{-1}, respectively). This is consistent with an energetic advantage to HA fish at 19°C. We are currently investigating effects at the other temperatures.

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