EFFECT OF TEMPERATURE AND WIND ON METABOLISM OF NORTHERN BOBWHITE IN WINTER

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Birds of North America

Year-round

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Winter Challenges

- Winter survival critical vital rate
- Low ambient temperatures
- Higher thermoregulatory costs
- Declining food resources
- Limited access to energetic resources
- Constrained space use

Winter Weather

- Direct mortality from weather minor component of total mortality
- Combination of low $T_a$, snow cover, and wind can cause mortality
- Indirect effects

Bobwhite Winter Mortality

- Harvest
- Weather
- Predation
- Accident

Missouri Department Conservation

Burger et al 1995
Response to Thermal Stress

- Selection of favorable microclimates
- Increased foraging activity
- Huddling
- Increased metabolic heat production
- Metabolizing lipid stores
- Catabolizing muscle
Response to Thermal Stress

- Little seasonal adjustment in:
  - Basal metabolic rate (BMR)
  - Insulation

- Core temperature invariant across wide range of $T_a$

- Respond to cold stress through increased metabolic heat production

- Thermoregulation = 60 – 70% of winter energy expenditures
Bobwhite Energetics

- Case (1973) – energy intake, excretory energy, existence energy 5° – 34° C
- Case and Robel (1974) relationships between $T_a$ and existence energy for M and F from 5° – 34° C.
- Spiers et al. (1983) – indirect respirometry, E, $VO_2$, $CO_2$, $T_b$ from 10° – 35° C
- Swanson and Weinacht (1997) – indirect respirometry BMP ($VO_2$), and SMR from -10° – 30° C.
- No studies of metabolic response under forced convection
Objectives

• Effects of temperature and forced convection on metabolic heat production of roosting bobwhite
• Determine $T_{lc}$ of bobwhite
Methods

- 8 bobwhite (4 F, 4 M)
- Commercial quail farm
- 8 – 10 months of age
- Mean mass = 201.5g (SE = 1.3, range = 173 - 222g)
- Housed colonially at Ta, open-air covered pens
- Winter acclimated
- Ambient photoperiod
- Ad-lib gamebird feed and water
Indirect Respirometry

- Metabolic heat production ($\text{VO}_2$, mL O$_2$/min)
- Open circuit respirometry, closed circuit wind tunnel.
- Oxygen concentration measured using Applied Electrochemistry S-3A/1 and R-1 flow controller
Metabolic Chamber

- Free convection – 7.3 L rectangular chamber
- Forced convection – 93.5 L dual-return, recirculating wind tunnel
- Temperature regulated by nesting chambers within a 651 chest freezer
Metabolic Chamber

- 93.5 L dual return wind tunnel
- Wind generated by a 25.4 cm blower wheel powered by a ¼ HP motor
- Wind speed regulated with a proportional controller
- Wind speed (m/sec) measured at bird level with a hot-wire anemometer
- Mean deviation of $T_a$ from set temperature -0.1°C (SD = 0.9)
- Wall temp differed from $T_a$ by < 0.5°C, so $T_a \approx T_e$
Roosting Metabolism

- Metabolic Heat Production ($\text{VO}_2$, mL $\text{O}_2$/min)
- Free Convection
  - Each of 8 birds, at 8 temperatures
  - $-15^\circ, -10^\circ, -5^\circ, 0^\circ, 5^\circ, 10^\circ, 20^\circ, 30^\circ \text{ C}$
- Forced Convection
  - Each of 8 birds, at 3 wind speeds and 2 temperatures
  - $-15^\circ$ and $0^\circ \text{ C}$
  - $0, 1, 2 \text{ m/sec wind speed}$
Roosting Metabolism

- Jan 6 – March 9, 1992
- Random order for individual bird, wind speed, and temperature
- 1-3 trials/night
- Individual birds experienced only 1 wind temperature combination per night
- Nocturnal trials between 1900 – 0600 hrs
Roosting Metabolism

- Food restricted 7 hrs prior to trial
- Post-adsorbtive state
- Body mass measured to 0.1 g
- Birds unrestrained in chamber on wire mesh grate
- Fecal droppings captured in tray of mineral oil
- 60 min adjustment period prior to measurement of VO$_2$
- Equilibration period adequate to allow VO$_2$ to achieve steady state
Respirometry

• Dry, CO₂-free room air drawn through the chamber at 1,000–2,500 mL/minute

• Sample of dry, CO₂-free outflow chamber air was drawn through the S-3A O₂ analyzer at 100 mL/minute and \( pO_2 \) continuously analyzed.

• Fractional concentration of O₂ recorded at 5-minute intervals and averaged over a 40-minute trial

• Calculated O₂ consumption using Whithers (1977) equation 4a
Respirometry

- Assumed respiratory quotient of 0.8 (Spiers et al 1983)
- Assumed 4.8 cal generated for each mL O₂ consumed
- Expressed thermoregulatory responses in units of O₂ consumption (VO₂/min/bird, VO₂/min/g) and watts (W/bird, W/m²)
- Estimated surface area from body mass using equation for galliforms from Leighton et al. (1966)
- Calculated total thermal conductance (C measured in W/m²/°C) according to Calder and King (1974)
- Dry thermal conductance (Cₚ measured in W/m²/°C) following Spiers et al (1983)
Analysis

• Tested effects of sex and body mass on $VO_2$ and $C_d$ under free convection across the range of $T_e$ using:
  – a repeated-measures, mixed-model analysis of covariance
  – $VO_2$ as response,
  – sex and $T_e$ as categorical fixed effects, and
  – body mass as a continuous covariate

• Repeated measures
  – included BIRD ID as a random effect using SUBJECT = BIRD ID and REPEATED = $T_e$ options.
  – 4 alternative covariance structures
    • variance components
    • first-order autoregressive
    • Compound symmetry
    • Heterogeneous compound symmetry
Analysis

VO₂

SMRₜₙₙₙ

Tₑ

Tₑc

30° C
Analysis

- Modeled effects of wind on VO₂ at -15° and 0° C with linear regression using PROC REG in SAS 9.4
- Tested for differences in slope and intercept for the 2 temperatures using a dummy regression model with:
  - VO₂ as response;
  - wind speed as a continuous variable (0, 1, 2 m/sec);
  - Tₑ (0° and 15° C) as a dummy variable coded 0 and 1;
  - and the interaction WIND x Tₑ
- Wind x Tₑ not significant (t₁ = 1.05, P = 0.40), indicating βₑ=0 not different from βₑ=-15
- Modeled common slopes, different intercepts using a reduced model with VO₂ as response, wind speed as a continuous variable, and Tₑ as a dummy variable
Results

• SMR at $T_e = 30^\circ$ C for a bird of mean weight 198.7 g
  – $3.4 \pm 0.11 \text{ mL O}_2/\text{minute/bird}$
  – $1.14 \pm 0.04 \text{ W/bird}$.

• Mass-specific SMR at $T_e = 30^\circ$ C
  – $0.0171 \pm 0.0004 \text{ mL O}_2/\text{minute/g}$.

• Surface-area–specific SMR
  – $41.9 \pm 1.1 \text{ W/m}^2$.

• Across all $T_e$,
  – VO$_2$ was influenced by body mass
    • $(F_{1,48} = 25.85, P < 0.001)$
    • VO$_2$ increased by $0.024 \text{ mL O}_2/\text{minute/bird}$ for each 1-g increase in body mass.
  – VO$_2$ did not differ between sexes
    • Males - $6.68 \pm 0.104 \text{ mL O}_2/\text{min/bird}$
    • Females - $6.54 \pm 0.104 \text{ mL O}_2/\text{min/bird}$.
Results

\[
VO_2 = 7.187 - 0.1568 T_e
\]

\[ r^2 = 0.86, \, P < 0.0001 \]

\[ T_{lc} = 24.18^\circ C \]
Results

\[ T_e = -15 \, ^\circ C \]
\[ \text{VO}_2 = 9.741 + 0.4609(\text{WS}) \]
\[ r^2 = 0.98 \]

\[ T_e = 0 \, ^\circ C \]
\[ \text{VO}_2 = 6.713 + 0.4609(\text{WS}) \]
\[ r^2 = 0.98 \]
Results
Literature SMR Values

- Allometric (Zar 1969) – 28.06 vs 23.5 kcal/bird/day (↓ 16%)
- Case & Robel (1974) – 25.56 vs. 23.5 kcal/bird/day (↓ 8%)
- Guthery (2002) – 117.1 vs. 98.37 kJ/day (↓ 16%)
- Spiers et al (1983) – 47.76 vs. 41.9 W/m² (↓ 16%)
- Spiers et al. (1983) – 1.06 vs. 1.03 mL O₂/g/hr (↓ 3%)
- Swanson and Weinacht (1997) – 3.76 vs. 3.4 mL O₂/min/bird (↓ 9.6%)
- Swanson and Weinacht (1997) – 1.03 vs. 1.01 mL O₂/g/hr (↓ 2%)
Lower Critical Temperature

- This study – $T_{lc} = 24.18^\circ C$
- Hiller and Guthery (2005) bobwhite exhibited heat-seeking behavior at $T_e < 26.7^\circ C$
- Case (1973) – speculated that $10^\circ C < T_{lc} < 20^\circ C$
- Swanson and Weinacht (1997)
  - Winter acclimated – $22.4^\circ C$
  - Summer acclimated – $25.5^\circ C$
Below the TNZ

- Slope of mass specific metabolic rate and $T_e$
  - This study - -0.0470 mL O$_2$/g/hr
  - Swanson and Weinacht - -0.05 mL O$_2$/g/hr
  - Spiers (1983) - -0.0717 mL O$_2$/g/hr
Ecological Implications

- At $T_e$ of $-15\,^\circ C$ SMR was 2.9 times > BMR in TNZ
- Wind speed of 2 m/s increased metabolic expenditures by additional 9.5%
- Behaviors and selection of microhabitats that reduced wind speed, convective heat loss, or radiative heat loss would lead to energy conservation
Management Implications

• Managers should consider factors that provide positive energy balance
  – Increasing energy intake
    • High energy feed
  – Reducing energy loss
    • Reducing movements
    • Microhabitats that increase $T_{ES}$

• Body mass/Energy requirements and translocation