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

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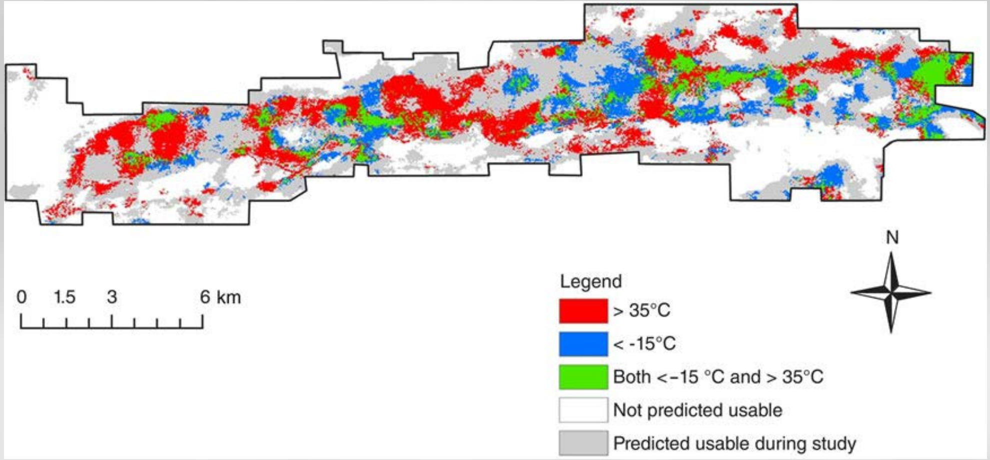
Year-round
Birds of North America

Winter Challenges

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

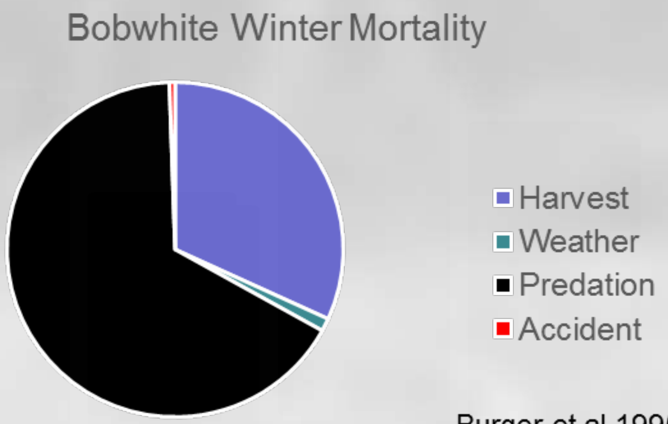
Northern Bobwhite Conservation Initiative



Tanner et al. 2016 , Global Change Biology (2016), doi: 10.1111/gcb.13505

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



Burger et al 1995

Missouri Department Conservation

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^{o} – 34^{o} C
- Case and Robel (1974) relationships between T_a and existence energy for M and F from 5^{o} – 34^{o} C.
- Spiers et al. (1983) – indirect respirometry, E, VO_2, CO_2, T_b from 10^{o} – 35^{o} C
- Swanson and Weinacht (1997) – indirect respirometry BMP (VO_2), and SMR from -10^{o} – 30^{o} 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 T_a, open-air covered pens
- Winter acclimated
- Ambient photoperiod
- Ad-lib gamebird feed and water
- Jan – March 1992.

Indirect Respirometry

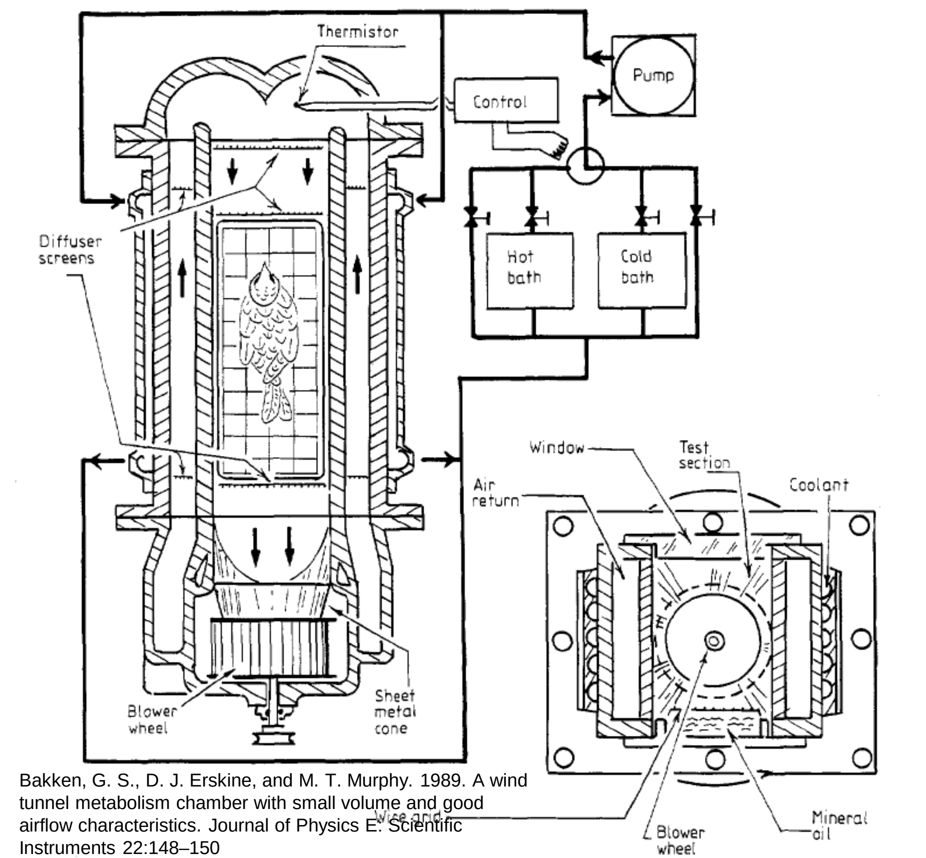
- Metabolic heat production (VO_2, mL O_2/min)
- Open circuit respirometry, closed circuit wind tunnel.
- Oxygen concentration measured using Applied Electrochemistry S-3A/1 and R-1 flow controller

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
- Modelled after Bakken et al (1989)
- 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^o C (SD = 0.9)
- Wall temp differed from T_a by < 0.5^o C, so $T_a \approx T_e$



Bakken, G. S., D. J. Erskine, and M. T. Murphy. 1989. A wind tunnel metabolism chamber with small volume and good airflow characteristics. Journal of Physics E: Scientific Instruments 22:148–150

Roosting Metabolism

- Metabolic Heat Production (VO_2, mL O_2/min)
- Free Convection
  - Each of 8 birds, at 8 temperatures
  - -15^{o}, -10^{o}, -5^{o}, 0^{o}, 5^{o}, 10^{o}, 20^{o}, 30^{o} C
- Forced Convection
  - Each of 8 birds, at 3 wind speeds and 2 temperatures
  - -15^{o} and 0^{o} C
  - 0, 1, 2 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

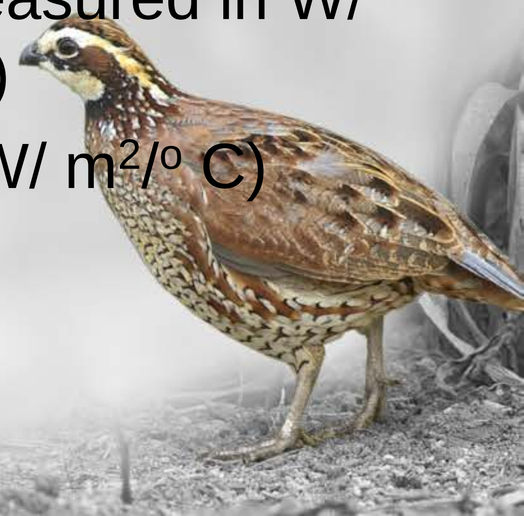
- Food restricted 7 hrs prior to trial
- Post-adsorbtive state
- Body mass measured to 0.1 g
- Birds unrestrained in chamber on wire mesh grate
- Fecal droppings captured in tray of mineral oil
- 60 min adjustment period prior to measurement of VO_2
- Equilibration period adequate to allow VO_2 to achieve steady state

Respirometry

- Dry, CO_2-free room air drawn through the chamber at 1,000–2,500 mL/minute
- Sample of dry, CO_2-free outflow chamber air was drawn through the S-3A O_2 analyzer at 100 mL/minute and pO_2 continuously analyzed.
- Fractional concentration of O_2 recorded at 5-minute intervals and averaged over a 40-minute trial
- Calculated O_2 consumption using Whithers (1977) equation 4a

Respirometry

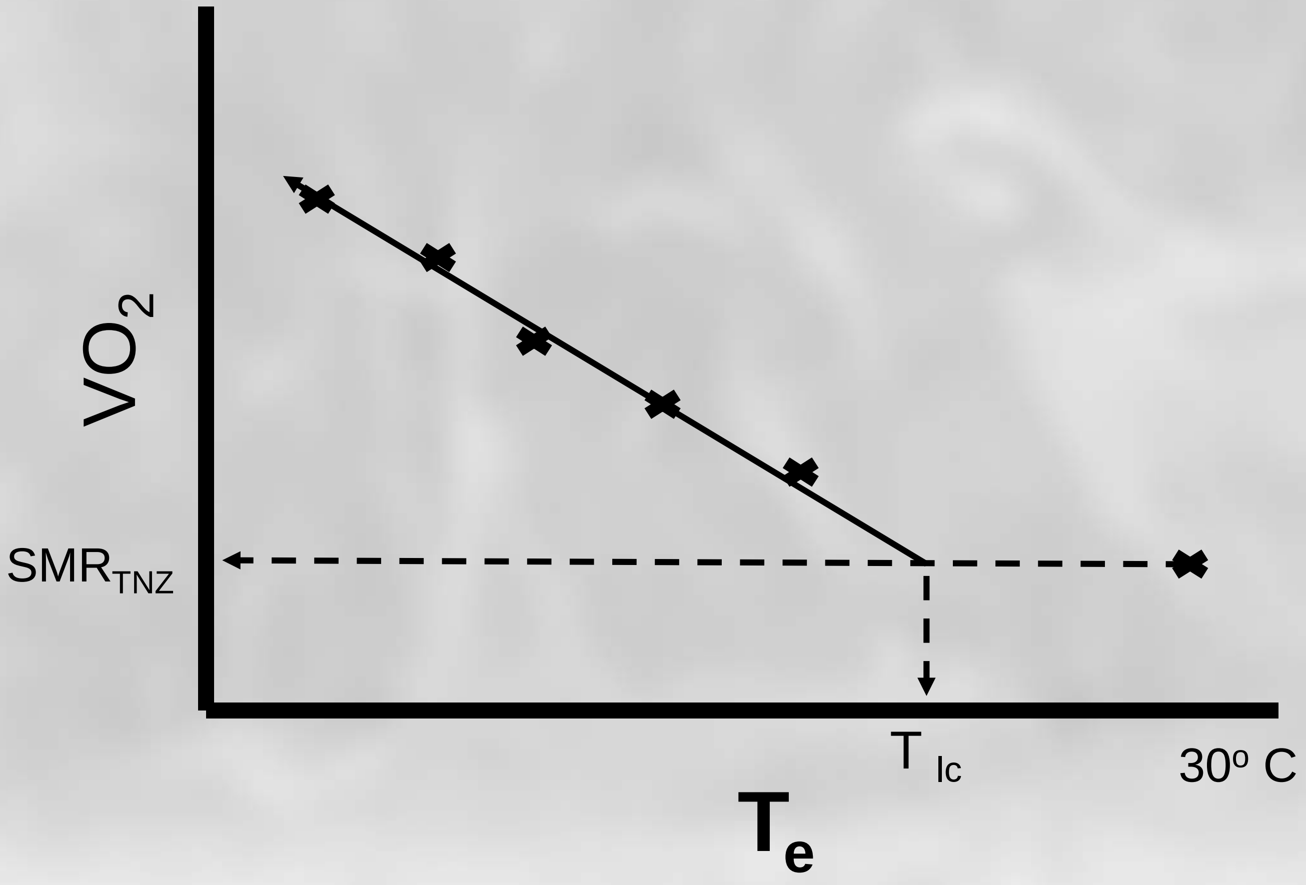
- Assumed respiratory quotient of 0.8 (Spiers et al 1983)
- Assumed 4.8 cal generated for each mL O_2 consumed
- Expressed thermoregulatory responses in units of O_2 consumption (VO_2/min/bird, VO_2/min/g) and watts (W/bird, W/m2)
- Estimated surface area from body mass using equation for galliforms from Leighton et al. (1966)
- Calculated total thermal conductance (C measured in W/ $m^2/^o$ C) according to Calder and King (1974)
- Dry thermal conductance (C_d measured in W/ $m^2/^o$ 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
  - In PROC MIXED, SAS 9.4 (SAS 2002).
- 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



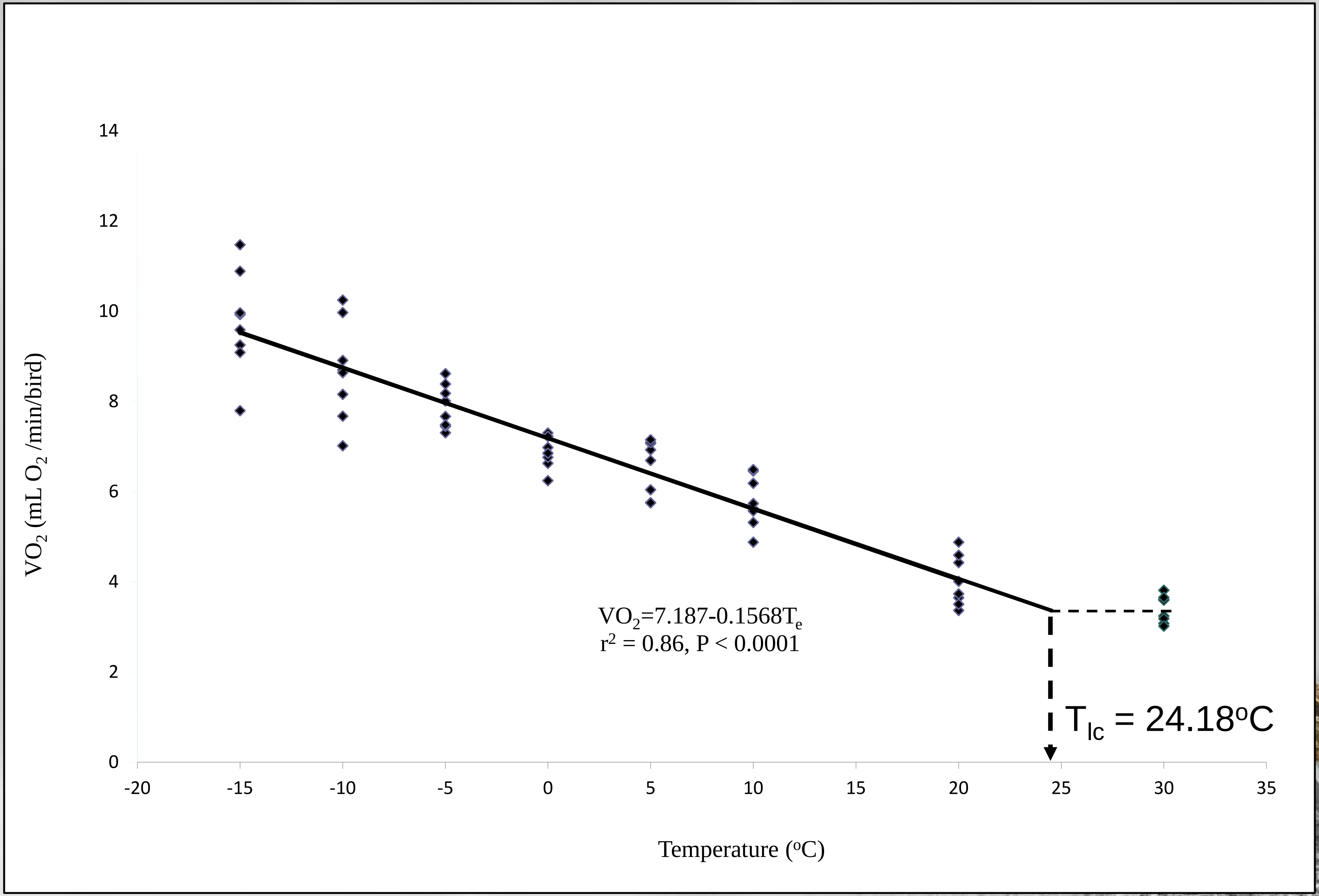
Analysis

- Modeled effects of wind on VO_2 at -15º and 0º 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:
  - VO_2 as response;
  - wind speed as a continuous variable (0, 1, 2 m/sec);
  - T_e (0º and15º C) as a dummy variable coded 0 and 1;
  - and the interaction WIND x T_e
- Wind x T_e not significant ($t_1 = 1.05$, $P = 0.40$), indicating $\beta_{Te=0}$ not different from $\beta_{Te= -15}$
- Modeled common slopes, different intercepts using a reduced model with VO_2 as response, wind speed as a continuous variable, and T_e as a dummy variable

Results

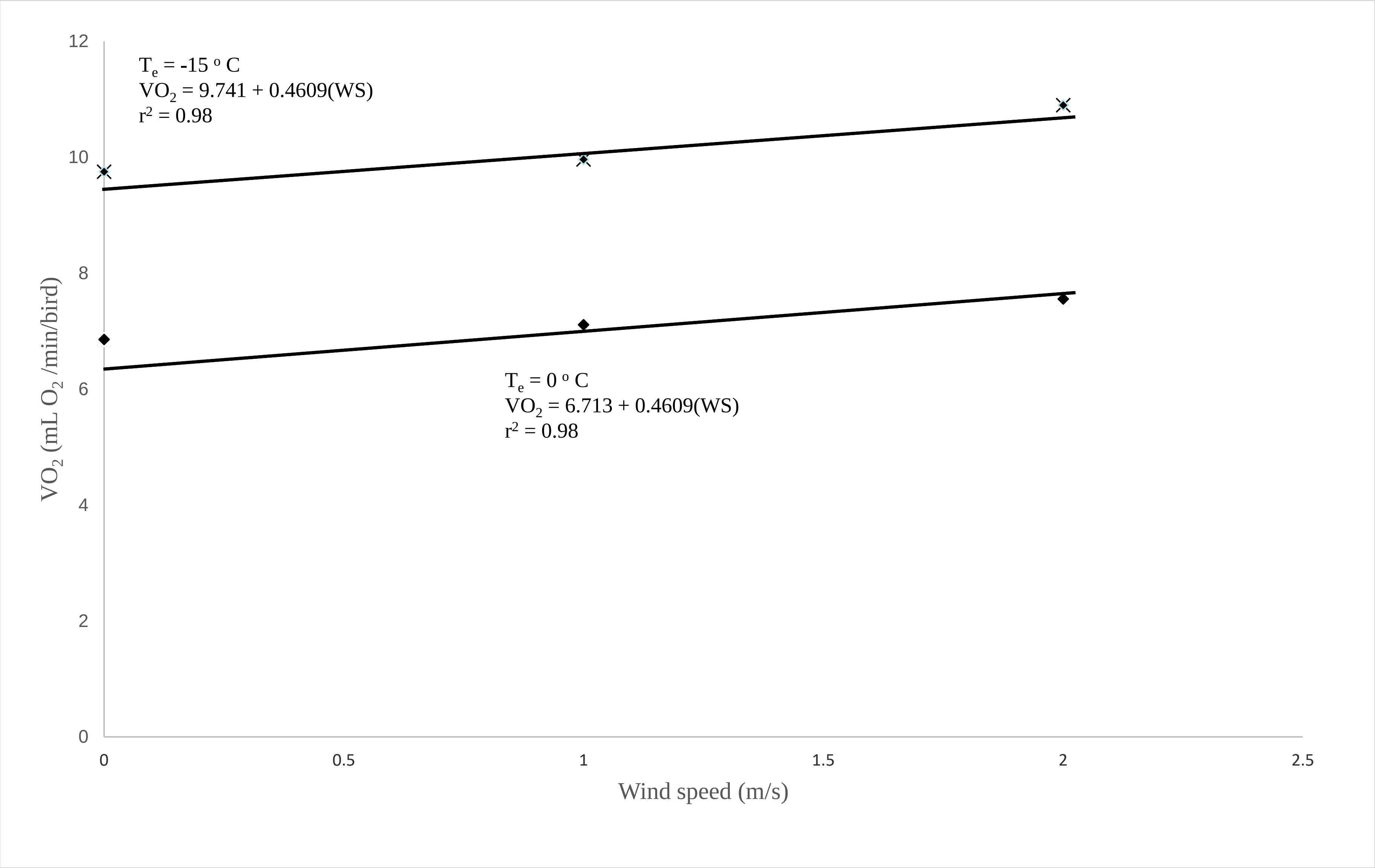
- SMR at $T_e = 30^o$ C for a bird of mean weight 198.7 g
  - 3.4 $\pm$ 0.11 mL O_2/minute/bird
  - 1.14 $\pm$ 0.04 W/bird.
- Mass-specific SMR at $T_e = 30^o$ C
  - 0.0171 $\pm$ 0.0004 mL O_2/minute/g.
- Surface-area–specific SMR
  - 41.9 $\pm$ 1.1 W/m^2.
- Across all T_e ,
  - VO_2 was influenced by body mass
    - ($F_{1,48}$ = 25.85, P , 0.001)
    - VO_2 increased by 0.024 mL O_2/minute/bird for each 1-g increase in body mass.
  - VO_2 did not differ between sexes
    - Males - 6.68 $\pm$ 0.104 mL O_2/min/bird)
    - Females - 6.54 $\pm$ 0.104 mL O_2/min/bird).

Results



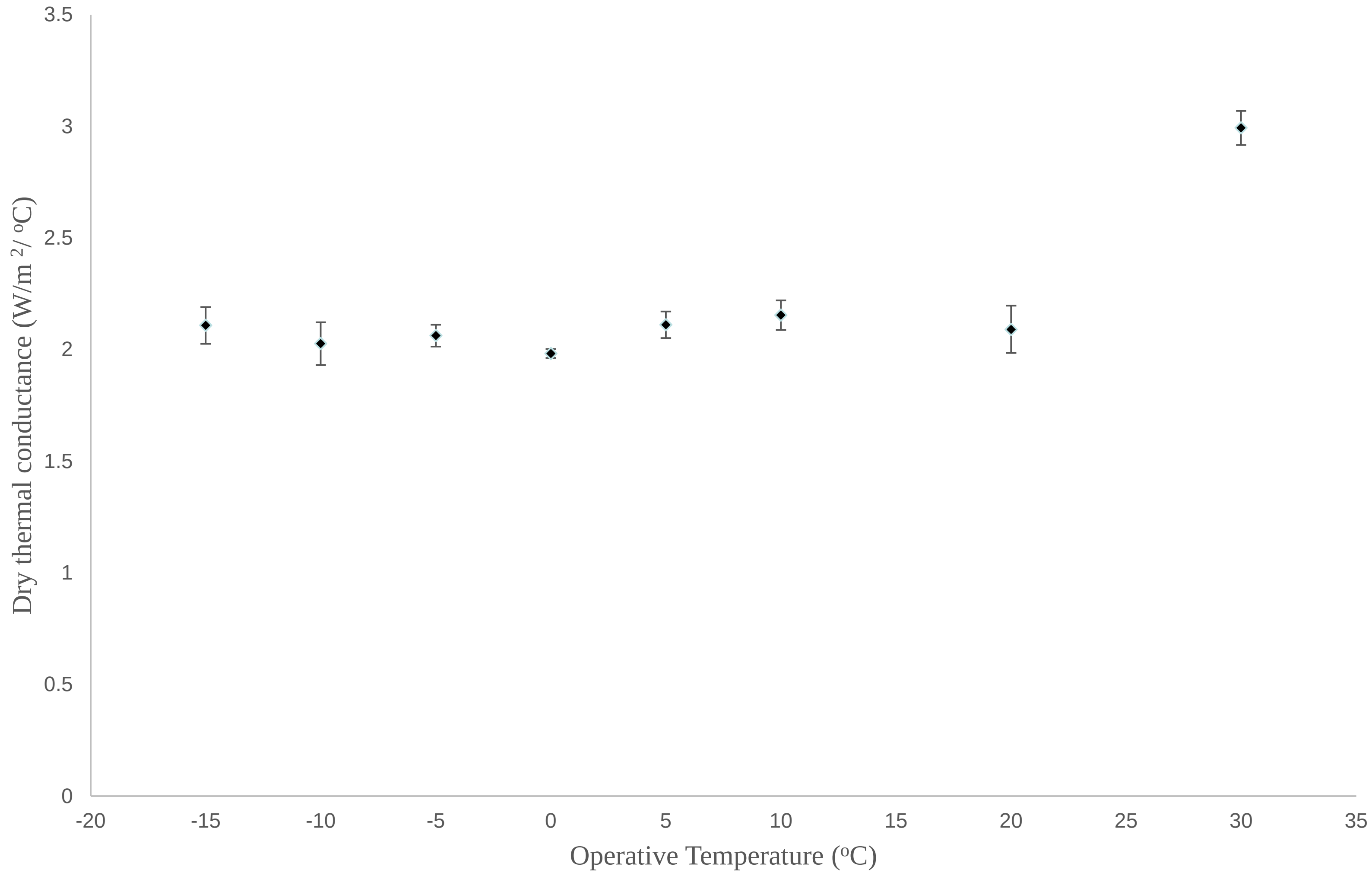
14
12
10
8
6
4
2
0
-20
-15
-10
-5
0
5
10
15
20
25
30
35
VO2 (mL O2 /min/bird)
Temperature (oC)
VO2=7.187-0.1568Te
r2 = 0.86, P < 0.0001
Tlc = 24.18oC

Results



12
10
8
6
4
2
0
0
0.5
1
1.5
2
2.5
T_e = -15 ° C
VO_2 = 9.741 + 0.4609(WS)
r^2 = 0.98
T_e = 0 ° C
VO_2 = 6.713 + 0.4609(WS)
r^2 = 0.98
VO_2 (mL O_2 /min/bird)
Wind speed (m/s)

Results



Dry thermal conductance (W/m 2/ oC)
3.5
3
2.5
2
1.5
1
0.5
0
-20
-15
-10
-5
0
5
10
15
20
25
30
35
Operative Temperature (oC)

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/m^2 (↓ 16%)
- Spiers et al. (1983) – 1.06 vs. 1.03 mL O_2/g/hr (↓ 3%)
- Swanson and Weinacht (1997) – 3.76 vs. 3.4 mL O_2/min/bird (↓ 9.6%)
- Swanson and Weinacht (1997) – 1.03 vs. 1.01 mL O_2/g/hr (↓ 2%)

Lower Critical Temperature

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

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