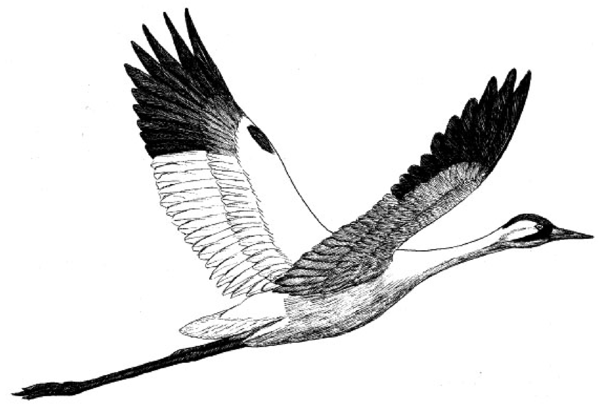
Optimal Net Energy and Foraging Behavior of the Grus americana

Kristen Lawler and Christian Schmidt
Advisors: Dr. John Alford and Dr. Edward Swim
Sam Houston State University, Marist College

Biological Motivation



- Overhunting→16 wild birds
- Migrate to ANWR, a rapidly changing wetland

Energy accumulated while wintering in Texas plays a crucial role in the future survival of the whooping cranes both on an individual and reproductive basis.

Goals: develop a predictive model for net energy intake of a whooping crane based upon resource availability in a crane's territory, and find its maximum

Prey Consumed to Net Energy

Let $i \in I = \{b, c, ...\}$, the set containing all prey types that make up the crane's diet.

$$J = \sum_i T_i \lambda_i p_i \ ,$$

T_i	Total time in patch type i
λ_i	$\overline{sd_i}$, the average encounter rate in patch
p_i	Probability of successful capture of prey type i

Since 95-97% of a crane's diet consists of blue crabs and Carolina wolfberries, we describe total number of prey consumed in the following way:

$$T_c\lambda_c p_c + T_b \lambda_b p_b \ .$$

Let α and β be the energy gained by the crane per crab and berry, respectively. Observe that

$$[\alpha(T_c\lambda_c p_c) + \beta(T_b\lambda_b p_b)] - \phi,$$

is then a net energy intake equation where ϕ describes energy loss.

Adding Dynamics

1. Model berry and crab availability in response to crane foraging
2. Use time dependent prey availabilities to make encounter rates dynamic
3. Incorporate integration to account for total time spent in ANWR

Final Model: Net Energy Intake

$$\int_0^{T_b} (\beta p_b \lambda_b - m_b)\ dt + \int_0^{T_c} (\alpha p_c \lambda_c - m_c)\ dt - \int_0^{T_r} \ell\ dt$$

Maximum and Sufficient

Let W be the weight of the crane in grams. Then

$$0.18 \cdot 39 \frac{KJ}{gram} \cdot W$$

is the net energy needed to give the crane a better chance at reproductive success.

1: Find a global maximum net energy intake
2: Compare this energy to the energy deemed necessary

Maximum:

$$(T_b, T_c) = \left(\frac{ln\left(\frac{(m_b-\ell)h_b}{\beta s n_{b0} p_b}\right)}{-f}, \frac{ln\left(\frac{(m_c-\ell)h_c}{\alpha s n_{c0} p_c}\right)}{-c} \right)$$

Let our model for net energy intake be called, A. When

$$A \geq 0.18 \cdot 39 \frac{KJ}{gram} \cdot W,$$

we anticipate:

- Sufficient energy resources in a crane's territory
- A higher probability of reproductive success for the whooping crane.

Conditions for Global Maximum

Energy intake associated with all time being spent in each patch type must be greater than the energy loss associated with spending all time outside of a patch.

A Switch in Prey Preference

Compare the energy efficiency ratios of prey:

$$\frac{E_b}{I_b} \quad , \quad \frac{E_c}{I_c}$$

- E_i is the energy gain per prey type i
- I_i is the time involved with prey type i which we would expect to be inversely related to the encounter rate:
  1. Accounts for search and capture within patch
  2. Accounts for learning curve.

So we have that

- $I_b = \frac{k_b}{\lambda_b}$ and $E_b = 1.3$ KJ
- $I_c = \frac{k_c}{\lambda_c}$ and $E_c = 139.4$ KJ

Switching Point

Equality of energy efficiency ratios:

$$t = \ln\left(\frac{k_c h_c \beta s n_{b0}}{k_b h_b \alpha s n_{c0}}\right) \frac{1}{f-c}$$

Conditions and Significance

This time must be non-negative. Therefore

- if $0 < k_b h_b \alpha s n_{c0} < k_c h_c \beta s n_{b0}$, then $f > c$
- if $k_b h_b \alpha s n_{c0} > k_c h_c \beta s n_{b0}$, then $f < c$.

Why is this point important? This gives us incite into the foraging behavior of the crane. The switching point aids in the determination of how time spent hunting and foraging is broken up over the winter.

Parameter Estimates for ANWR

α	kJ/crab	139.4
β	kJ/berry	1.3
c	-	0.065
f	-	0.87
h_b	m^2	878,800
h_c	m^2	310,900
ℓ	kJ/day	2,016
m_b	kJ/day	3,001.6
m_c	kJ/day	3,225.6
n_{b0}	berries	6,837,064
n_{c0}	crabs	739,182
p_b	-	0.36
p_c	-	0.01
s	m^2/day	9,197.928
k_b	-	0.2
k_c	-	20
T	days	151

Energy and Switching Point

Maximum: $(T_b, T_c) = (4.05, 49.6) \rightarrow 119, 288.1KJ$
This satisfies our inequality and suggests 80% of daylight hours are spent hunting and foraging.

Switching Point: 3.79 days
The initial switch in prey preference from berries to crabs occurs after about 91 hours of foraging.

Future Analysis

- Consider different search rates of the crane based upon different patch types
- Consider the effect of tidal fluctuations on crab availability

Acknowledgements

Dr. Brian Loft, Dr. John Alford, Dr. Edward Swim, Christian Schmidt, and Dr. Matthew Glomski. Funding for this project was provided by the NSF (DMS-1262897) and Sam Houston State University.