Evolution in the Age of Us: Mechanisms of adaptation to a human-modified world

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Evolution in the Anthropocene

- Nuclear Disaster
- Pollution
- Human-Wildlife Conflict
- Climate Adaptation
- Extreme Weather Events
- Border Politics
- Urbanization
- Extreme Weather Events
Evolution REVEALS THE LASTING BIOLOGICAL IMPACTS OF Anthropogenic Change PROVIDES UNIQUE INSIGHTS ABOUT THE PROCESS OF
Evolution in the Anthropocene

**PART I**
Thermal Stress and Adaptation of Complex Traits

**PART II**
Ecological Impacts of Human-Mediated Selection

**PART III**
Human-Mediated Selection and Evolutionary Medicine

Urbanization
Human-Wildlife Conflict
Contamination/Pollution
URBANIZATION
THERMAL STRESS AND ADAPTATION OF COMPLEX TRAITS

PUERTO RICO
Ecological Homogenization of Urban Environments

Gould Revisited:

DO POPULATIONS THAT COLONIZE HUMAN-MODIFIED ENVIRONMENTS FIND SIMILAR EVOLUTIONARY PATHS TO ADAPTATION?

Urbanization: Global Environmental Homogenization
Urban Heat Island Effect

Imperious Surfaces in dense urban areas create locally elevated temperatures.

Modified from Oke 1978, Atmos. Environ.
Provides a framework for testing the repeatability of urban adaptation.
**MAJOR FINDINGS**

**Divergence thermal profiles across habitats**

Lizards in urban environments endure higher temperatures than their forest counterparts throughout the day.

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**CAMPBELL-STATON ET AL. 2020, NAT. ECO. EVO.**
Temperature-dependent functional divergence between habitats

**Parallel increases in heat tolerance across multiple city colonizations**

CAMPBELL-STATON ET AL. 2020, NAT. ECO. EVO.
Parallel signatures of selection at a single locus

A SINGLE NON SYNONYMOUS POLYMORPHISM WITHIN THE RARS LOCUS SEGREGATES AT DIFFERENT FREQUENCIES IN URBAN AND FOREST HABITATS

Arginyl tRNA Synthetase (RARS)

Forest Urban
C C
G T
575 Iso/Thr

Forest Urban
A A
G G
796 Val/Iso

Forest* Urban
C G
575 Iso/Thr

Forest Urban
A A
G G
1673 Thr/Ser

Forest Urban
G G
1853 Ser/Asp

24.86Kb

Municipality
- Arecibo
- San Juan
- Mayaguez
- Aguadilla

Genetic Differentiation ($F_{ST}$ Forest vs Urban)

CAMPBELL-STATON ET AL. 2020, NAT. ECO. EVO.
Parallel signatures of selection at a single locus

Genotype at the non-synonymous position is associated with differences in heat tolerance within urban habitats.

Campbell-Staton et al. 2020, Nat. Eco. Evo.
Take Home Points:

• Human-built environments can present extreme selection pressures that require rapid adaptation of complex traits in wildlife

• Even with complex traits, these evolutionary changes can be highly repeatable (i.e. predictable)
HUMAN-ANIMAL CONFLICT
ECOLOGICAL IMPACTS OF ANTHROPOGENIC SELECTION

Campbell-Staton et al. 2021, Science
SIGNIFICANT CHANGES IN POPULATION SIZE AND FREQUENCY OF TUSKLESSNESS ASSOCIATED WITH 15 YEARS OF CIVIL WAR

Campbell-Staton et al. 2021, Science
Tusklessness in the African elephant

A low frequency (2-10%) female-specific trait

Campbell-Staton et al. 2021, Science
SIGNIFICANT CHANGES IN POPULATION SIZE AND FREQUENCY OF TUSKLESSNESS ASSOCIATED WITH 15 YEARS OF CIVIL WAR

**Mozambican Civil War (1977-1992)**

- Population Size
- Year
- Frequency of Tuskless Females

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Campbell-Staton et al. 2021, *Science*
TUSKLESS SURVIVAL 5.13 TIMES GREATER THAN TUSKED COUNTERPARTS DURING 15 YEAR PERIOD OF WAR (95% CI: 3.98 - 6.6)

Mozambican Civil War (1977-1992)

(a) Population Size

(b) Proportion of Tuskless Females

(c) Tuskless Survival Bias

Campbell-Staton et al. 2021, Science
Evidence for tusk loss as an X-linked dominant trait with male lethality

Prediction 1: Two-tusked mothers have exclusively two-tusked daughters

Campbell-Staton et al. 2021, Science
TWO-TUSKED MOTHERS DISPLAY SIGNIFICANT SKEW TOWARDS TWO-TUSKED DAUGHTERS

Campbell-Staton et al. 2021, Science
Evidence for tusk loss as an X-linked dominant trait with male lethality

**Prediction 2:** Tuskless mothers show a significant female offspring bias (66.67%)
TUSKLESS MOTHERS DISPLAY SIGNIFICANT FEMALE OFFSPRING BIAS

Campbell-Staton et al. 2021, Science
**SINGLE LOCUS MODEL EXPLAINS 87.15% OF ALL TUSK INHERITANCE PATTERNS IN GORONGOSA**

**FEMALE SEX-BIAS AMONG OFFSPRING MEET 98.9% OF MODEL EXPECTATIONS**

**RESULTS CONSISTENT WITH SINGLE SEX-LINKED LOCUS OF LARGE EFFECT WITH ONE OR MORE MODIFIER LOCI OF SMALLER EFFECT**

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**Campbell-Staton et al. 2021, Science**
METHODS
Genetic sampling of African elephants

Blood samples taken from sedated female elephants in Gorongosa National Park, Mozambique
**Single Locus Model** explains 87.15% of all tusk inheritance patterns in Gorongosa.

Female sex-bias among offspring meet 98.9% of model expectations.

Results consistent with single sex-linked locus of large effect with one or more modifier loci of smaller effect.

Campbell-Staton et al. 2021, Science
GENOME-WIDE SCANS IDENTIFY SECOND CANDIDATE LOCUS FOR TUSKLESSNESS IN GORONGOSA

Campbell-Staton et al. 2021, Science
Known Functional Effects of Candidate Loci on Mammalian Tooth Development

- a) Enamel
- b) Cementum
- c) Dentin (Ivory)
- d) Periodontium
- e) Root

Campbell-Staton et al. 2021, *Science*
Candidate locus is associated with amelogenesis imperfecta in humans

A RARE AND SPORADIC X-LINKED CONDITION IN HUMANS THAT IS USUALLY LEthal IN MALES

MALIK ET AL. 2012, BRIT. DENT. J.
Candidate locus is associated with ameliogenesis imperfecta in humans

A RARE AND SPORADIC X-LINKED CONDITION IN HUMANS THAT IS USUALLY LETHAL IN MALES


MICRODONT UPPER

MALIK ET AL. 2012, BRIT. DENT. J.
Behavioral and Ecological Consequences of Selection Against Key Innovation in Keystone Species

**Downstream Impacts of Human-Mediated Selection on Ecosystem Health**

Dietary shifts associated with tusk morphology

Tuskless individuals consume less woody vegetation and more grasses

Data: Pringle Lab, Princeton University
FUTURE DIRECTIONS: HIERARCHICAL MULTIGENERATIONAL IMPACTS OF ANTHROPOGENIC SELECTION

HABITAT MODIFICATION  NUTRIENT DISTRIBUTION  NICHE CREATION AND RESOURCE AVAILABILITY

SPECIES DIVERSITY AND ABUNDANCE  ECOSYSTEM HEALTH AND SUSTAINABILITY
• Human action can have rapid evolutionary impacts on long-lived species, via demographic and adaptive evolutionary change.

• Selection targeting one or a few genes in a single species may have cascading impacts for broader regional biodiversity that impact ecosystem quality.

Take Home Points:
Krogh’s Principle

"for some large number of [medical] problems there will be some animal of choice, or a few such animals, on which it can be most conveniently studied."
Estimated number of new global cancer cases

2040

19.3 Million

World Health Organization
International Agency for Research on Cancer
Estimated number of new global cancer cases

2040

= 1 Million

World Health Organization
International Agency for Research on Cancer
Chernobyl wolf population: ~7 generations of chronic low-dose radiation exposure

Grey Wolf (Canis lupus)
Chernobyl wolf population:
~7 generations of chronic low-dose radiation exposure
Lineage-specific genetic divergence within the CEZ

Genomic Position

Extreme genetic divergence among cancer-related loci

- **CMTM6** - anti-tumor immunity
- **EMC6** - tumor proliferation
- **TRPV4** - invasion/migration
- **APBB1IP** - prognostic marker
CMTM6 POSITIVELY REGULATES PDL1 BY PROMOTING ENDOSONAL RECYCLING OF THE SURFACE PROTEIN

Burr et al. 2017 Nature
CMTM6 KO RESULTS IN LYSOSOMAL DEGRADATION OF PDL1 AND INCREASED IMMUNE RECOGNITION

BURR ET AL 2017 NATURE
PDL1 Expression Correlates with Cancer Survival Outcomes

A

Palivela et al. 2019

Overall Survival

N = 11

N = 7

N = 25

Time (Months)

P = 7x10^{-6}

No/Low (<55%) High (55-100%)

PDL1 Gene Expression (cpm)

Yellowstone

NP

Belarus

Chernobyl

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Take Home Points:

- Wildlife exposed to anthropogenic pressures are sentinels for environmental quality and potential physiological threats.

- Adaptive response to anthropogenic stressors may reveal biological solutions for human health in a modern world.
Evolution REVEALS THE LASTING BIOLOGICAL IMPACTS OF Anthropogenic Change PROVIDES UNIQUE INSIGHTS ABOUT THE PROCESS OF
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**MAJOR TAKEAWAYS**

- A powerful tool for understanding adaptive innovation of complex traits and the repeatability of evolution
- Unique insights into the ecological consequences of human-driven evolution
- Means for identifying candidate genes associated with human disease states
Coming in 2023…

Exploring the global impact of Earth’s most ingenious, destructive, and adaptable species: us.

By Day’s Edge Productions for PBS
Evolution in the Anthropocene

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- Border Politics
- Urbanization
Thank you

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