Little Black-and-White Lies:
The True Story of the Peppered Moth

Matt Young
Department of Physics
Colorado School of Mines
Golden, Colorado  80304

www.mines.edu/~mmyoung

[The latest version of my presentation on the peppered moth.]
The peppered moth (*Biston betularia*)

Britain, mid-1800’s
- Air pollution, soot kill lichens, blacken trees
- Moths evolve black (*melanic*) form for camouflage

1950’s: Clean air acts
- Moths evolve back to light-colored (*typica*) form
- Hard to see on birch or lichen-covered trees
Bernard Kettlewell’s studies, mid-50’s

1. *Release—recapture experiments in woods*

Compared *Industrial* with *rural*, or

*Polluted* with *unpolluted* habitats

(Bruce Grant)
Procedure

Marked and released both melanic, typica moths
Recaptured some in wee hours of next morning
Used both optical and pheromone traps

Results

Polluted woods — more melanic (+ insularia)
Unpolluted woods — more typica
2. Direct observation and filming

Observed, filmed birds eating moths directly off tree trunks

Enlisted (future) Nobelist Niko Tinbergen for photography

Controversial result at time
3. Camouflage

Visually rated camouflage of moths on different backgrounds

Compared effectiveness of camouflage with predation rates
  - In aviary
  - In field

*Good correlation* between camouflage and predation

Despite birds having ultraviolet vision

Moths may be camouflaged in the ultraviolet as well
4. Geographic distribution
Distribution of melanic moths matched areas of industrialization

- Typica
- Melanic + insularia
- Industrial area

(Kettlewell, 1959)
Compare with rudimentary map of Wells

(a) Proportion of melanics less than predicted
(b) Melanism high despite lichens
(c) Melanism increased after pollution control
(d) Melanism decreases before lichens
(?) Best discrepancy is actually Ireland, not shown
And before and after maps by Bruce Grant
"Melanism: Evolution in Action"

Book by Michael Majerus, University of Cambridge
- Pointed out flaws in Kettlewell’s work
- Nevertheless defended Kettlewell, supported conclusions

Review by Jerry Coyne, University of Chicago:
- "For the time being we must discard Biston as a well-understood example of natural selection in action."

Creationists pounced!
Wells’s *Icons of Evolution*

Moths do not “normally” rest on trunks

25% of the time they do, and anyway

Birds hunt at all levels in canopy

Photos of moths staged (but so are portraits), and anyway

Majerus provides unstaged photos

Typica reappeared *before* lichens reappeared, but anyway

Trees *lightened* as soot *decreased*,

Typica moths better camouflaged on *clean* trunks,

branches, leaves than on *sooty* (lichens or no)

Bird predation not only factor

So, nu?
Charges of fraud

*Of Moths and Men*, 2002

Judith Hooper charges fraud:

> Sudden increase in recapture rate directly follows “threatening” letter from mentor

But

Moths released *as they hatched* from cocoons

No control over hatching
Letter to Kettlewell from E.B. Ford

Received after increase in recapture rate

“It is disappointing that the recoveries are not better ... However, I do not doubt that the results will be very well worth while ....”

Hooper’s interpretation:

“Now I do hope you will get hold of yourself and deliver up some decent numbers.”
7-year field study by Majerus

Countered all of Hooper’s objections

- Released moths at dusk, into natural resting positions
- Used low density of moths
- Used only local moths
- Compared wild moths with lab-bred moths

Confirmed Kettlewell’s results
Can you see it?

(Michael Majerus)
Blind as a bat

Hooper suggests differential bat – bat! – predation

Yes, it would still be natural selection

Majerus released moths into areas where bats feed

Bats ate 208 typica, 211 melanic
Coyne recants

"I thought I was drawing attention to some problems and was doing the scientific community a service. I wasn't very clear. The key was well-understood."

Review of Hooper's book in Nature

“... industrial melanism still represents a splendid example of evolution in action. ... No force other than selection could have caused such striking and directional change.”
I get into the act

What do physicists do?

- Devise *models*
- Perform *uncertainty analyses*

*Young’s law*

- A number without a statement of uncertainty is worthless

*Young’s other law*

- Some numbers are inherently worthless

Soooo ...
Physical model (Young and Musgrave, 2005)

Estimated average 1- and 2-day recapture rates from data

\[ y = 0.25 \times r^2 = 0.80 \]
Included effect of *moonlight*

Recapture rate falls with increasing exposure to moonlight (optical traps)

\[ y = -0.22x + 0.30 \]

\[ r^2 = 0.75 \]

(Exposure = brightness \times time)
For experts: Calculated *standard uncertainty* of data points

Binomial distribution: Variance, $\sigma^2 = N \rho (1 - \rho)$

$N =$ number of moths released on given night

$\rho =$ probability of recapture (recapture rate)

$u = \sigma =$ standard uncertainty

Graph 95 % *confidence interval*, or $\pm 2 \ u$

*Chi-squared test* compared model with data

$\rho = 0.17$, no moonlight; $\rho = 0.75$, with moonlight

$\rho < 0.05$ if model were statistically different from data
Error bars overlap both curves

Data, model *indistinguishable within standard uncertainty*

—— simple model, – – – model with moonlight
Skeptical Inquirer
THE MAGAZINE FOR SCIENCE AND REASON
Volume 29, No. 2 • March / April 2005

EVOLUTION AND EVIDENCE

One Longsome Argument
Defending The Peppered Moth Studies

MEDIA AND MISINFORMATION
• Asteroid and Meteor Impact Hype
• Ringing False Alarms

Published by the Committee for the Scientific Investigation of Claims of the Paranormal

Fast
No page charges
What Hooper believes

Everything her informant Ted Sargent says

   Competing theory (induction) not accepted by experts

Nothing Kettlewell says

What Hooper does not understand

Science

Biology

Vagaries of experimental science

More erratic vagaries of field measurements
Confirming evidence

Kettlewell was first — a pioneer

Made mistakes

Work has been replicated

In moths
In other species
In other locales

_Industrial melanism understood beyond reasonable doubt_

_And is result of natural selection in peppered moths_
Conclusion

All scientific experiments in some way flawed

(All unscientific experiments too)

Black-and-white thinkers (read: creationists) wrongly think

*Any mistake* or discrepancy ≡ *wholly wrong*

Cf. attacks by creationists on “Darwinism”

Countless other studies support Kettlewell’s pioneering work

*Peppered moth properly remains icon of evolution*
Shameless self-promotion by author

Coming soon: *Why Evolution Works (and Creationism Fails)*

Matt Young and Paul Strode, Rutgers, 2009