Hanta-bearing mice: is their movement diffusive?

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The diffusion paradigm

\[ \frac{\partial u(x, t)}{\partial t} = r u (1 - u) + D \nabla^2 u \quad (Fisher, 1937) \]

Epidemics of Hantavirus in *P. maniculatus*

Abramson, Kenkre, Parmenter, Yates (2001-2002)

\[ \frac{\partial M_S(x, t)}{\partial t} = bM - cM_S - \frac{M_SM}{K(x)} - aM_SM_I + D_S \nabla^2 M_S, \]

\[ \frac{\partial M_I(x, t)}{\partial t} = -cM_I - \frac{M_IM}{K(x)} + aM_SM_I + D_I \nabla^2 M_I, \]
Three categories of wrongfulness

Okubo & Levin, Diffusion and Ecological Problems

**Wrong but useful**: the simplest diffusion models cannot possibly be exactly right for any organism in the real world (because of behavior, environment, etc). But they provide a standardized framework for estimating one of ecology most neglected parameters: the diffusion coefficient.

**Not necessarily so wrong**: diffusion models are approximations of much more complicated mechanisms, the net displacements being often described by Gaussians.

**Woefully wrong**: for animals interacting socially, or navigating according to some external cue, or moving towards a particular place.
The source of the data

Gerardo Suzán & Erika Marcé, UNM

Six months of field work in Panamá (2003)

Zygodontomys brevicauda
Host of Hantavirus Calabazo
Recapture and age

*Zygodontomys brevicauda*, 846 captures:

411 total mice, 188 captured more than once (2-10 times)

<table>
<thead>
<tr>
<th></th>
<th>J</th>
<th>SA</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>0.22</td>
<td>0.13</td>
<td>0.42</td>
</tr>
<tr>
<td>M</td>
<td>0.00</td>
<td>0.47</td>
<td>0.55</td>
</tr>
<tr>
<td>Total</td>
<td>0.13</td>
<td>0.37</td>
<td>0.49</td>
</tr>
</tbody>
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Recapture probability:

One mouse (SA, F) recaptured off-site, 200 m away

- J: juvenile
- SA: sub-adult
- A: adult
- F: female
- M: male
**Recapture and weight**

*Z. brevicauda*

Weight is weight at first capture

- 75 females recaptured
- 113 males recaptured
- 193 females total
- 218 males total

Distribution of weight ⇒

![Graph showing recapture probability and weight distribution for Z. brevicauda](image)
Different types of movement

Adult mice $\Rightarrow$ diffusion within a **home range**

Sub-adult mice $\Rightarrow$ run away to establish a home range

Juvenile mice $\Rightarrow$ excursions from nest

Males and females…
The recaptures

\[ \Delta x (m) \]

\[ \Delta t \text{ (days)} \]
Individual mouse walks

Z. brevicauda captured ~10 times

\[ x(t) \] (m) vs. \( t \) (days)
"Mean" square displacement?

Z. brevicauda captured ~10 times

\[ \langle \chi^2 \rangle \]

\( t \) (days)
PDF of individual displacements

The population as an ensemble of walkers

\[ P(dx), P(dy) \]

\[ dx, dy \]

Gaussian fit

Lorentzian fit

Z. brevicauda, all sites, 434 recaptures

\[ <dx> = -0.88 \text{ m} \]

\[ \sigma_x^2 = 18.7 \text{ m}^2 \]

\[ <dy> = 1.2 \text{ m} \]

\[ \sigma_y^2 = 20.5 \text{ m}^2 \]

\[ P(dx), P(dy) \]

\[ dx, dy \] (m)
PDF of individual displacements

As three ensembles, at three time scales

Z. brevicauda

247 steps
170 steps
17 steps

$P(dx)$

$dt \sim 1\text{day}$

$dt \sim 1\text{month}$

$dt \sim 2\text{months}$
An ensemble of displacements
An ensemble of displacements

...representing the walk of an “ideal mouse”
Ideal mouse walks

Z. brevicauda - 1-day steps

- Average
- Linear fit
  - slope = 686 m²/d
  - $D_1 = 342$ m²/d

\[ t \]
Mean square displacement

\[
\langle \Delta x^2 \rangle, \langle \Delta y^2 \rangle (m^2)
\]

\[
\langle \Delta x^2 \rangle, \langle \Delta y^2 \rangle \quad (t \text{ (days)})
\]
Confinements to diffusive motion

- Home ranges
- Capture grid
- Combination of both
Confinements to diffusive motion

- Home ranges
  \[ \langle x^2 \rangle = \frac{L^2}{12} \left\{ 1 - \frac{L}{\alpha \pi^3} \sum_{n=1}^{\infty} \frac{(-1)^{n+1} \sin(n \pi \alpha / L)}{n^3} e^{-\frac{(2n\pi)^2 D_t}{L^2}} \right\} \]

- Capture grid
  \[ \langle x^2 \rangle = 2D_t \left\{ 1 - \frac{Ge^{-G^2/16D_t}}{\sqrt{4\pi D_t} \text{ erf} \left( \frac{G}{4\sqrt{D_t}} \right)} \right\} \]

- Combination of both
Mean square displacement

\[ \frac{\langle x^2 \rangle}{(G^2/12)} = \frac{L}{G} \]

- \( L = G \)
- \( L > G \)
- \( L = \infty \)
- \( L < G \)
In summary

- Mouse “transport” is more complex than diffusion
- Different subpopulations with different mechanisms
  - Existence of home ranges
  - Existence of “transient” mice
- Limited data sets can be used to derive some statistically sensible parameters
- Possibility of analytical models
- Analysis of other systems (New Mexico… )
REFERENCES

These were the initial papers:


The present analysis has been submitted as:

*Diffusion and home range parameters from rodent population measurements in Panama*, Giuggioli, Abramson, Kenkre, Suzán, Marcé and Yates, (2004).