Modeling Natural Mortality (*M*)

Basic Population Dynamics

- By Numbers

$$\mathbf{N_{t+1} = N_t + Births_t - Deaths_t}$$

- By Biomass

$$\mathbf{Biomass_{t+1} = Biomass_t + Births_t + Growth_t - Deaths_t}$$

- Fishing impact

$$\mathbf{Biom_{t+1} = Biom_t + Births_t + Growth_t - NatMort_t - Catch_t}$$

- Continuous Case by numbers

$$\frac{dN}{dt} = b(t) - (M(t) + F(t))N(t)$$

Basic Population Dynamics

- By Numbers, age-structured

$$\mathbf{N_{a,t+1} = N_{a,t} + Births_{a,t} - Deaths_{a,t}}$$

Noting that Births is zero except when a is zero

- Continuous Case

$$\frac{d\boldsymbol{N}}{dt} = r(\boldsymbol{N}, \boldsymbol{t}) - (M + F)\boldsymbol{N}$$

- Noting, within a year, particularly for a>0:

$$\frac{d\boldsymbol{N_a}}{dt} = -(M + F)\boldsymbol{N_a}$$

  - *Noting also that this means M and F can be confounded in modeling and estimation*

Natural Mortality (*M*)

- Key parameter in population dynamics
- M is continuous/instantaneous rate of mortality from causes other than fishing (F is rate of fishing mortality)
- We often model M as constant not only within year and age, but across ages.
  - This is a simplification – M is typically higher for younger and smaller fish, as well as for the oldest fish.

Natural Mortality (*M*)

- In fact, Natural Mortality varies by:
  - Age
  - Sex
  - Time
  - Density
  - Environmental drivers
    - Predation
    - Prey availability
    - Disease/parasites
    - Competition
    - Temperature
    - Etc...

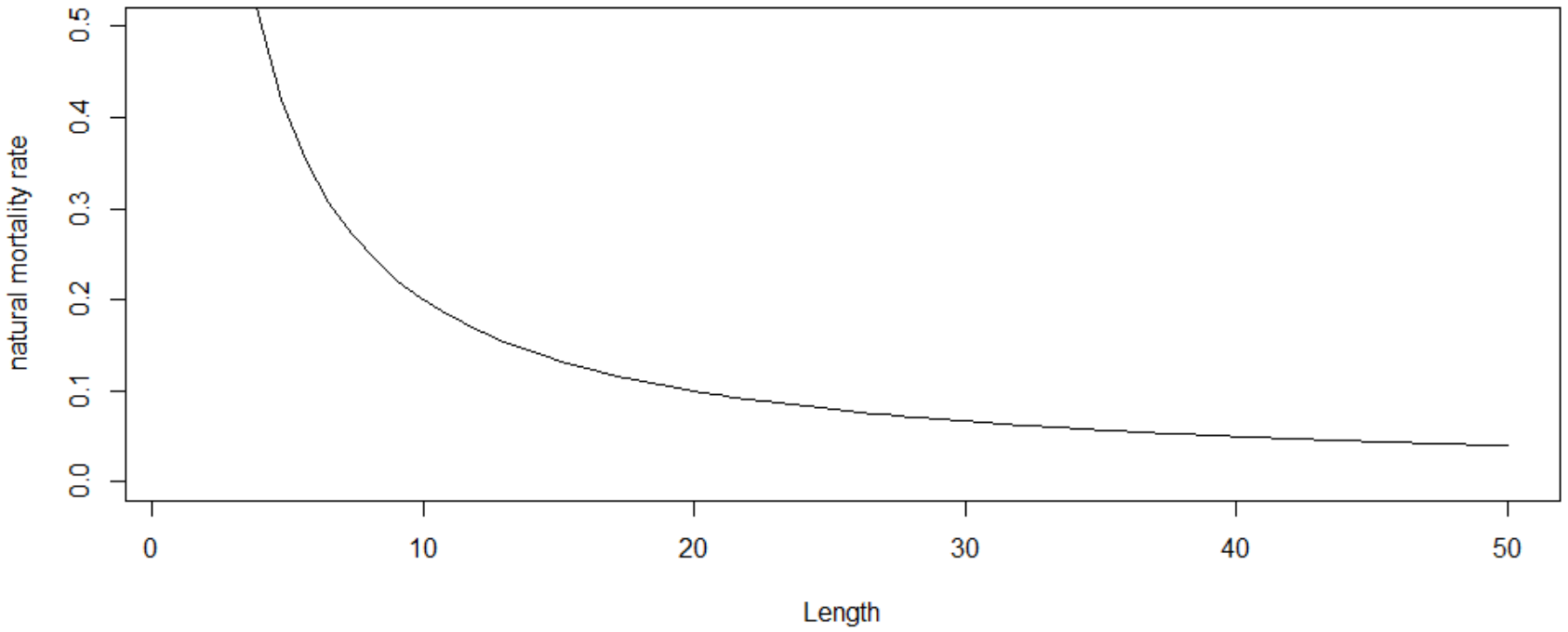
Natural Mortality (*M*)

- However, we often model M in our assessments as:
  - M = constant,
  - or
  - $M_{female} = C_1$; $M_{male} = C_2$

- For species that mature and show up in fisheries closer to maximum size, this can be reasonable

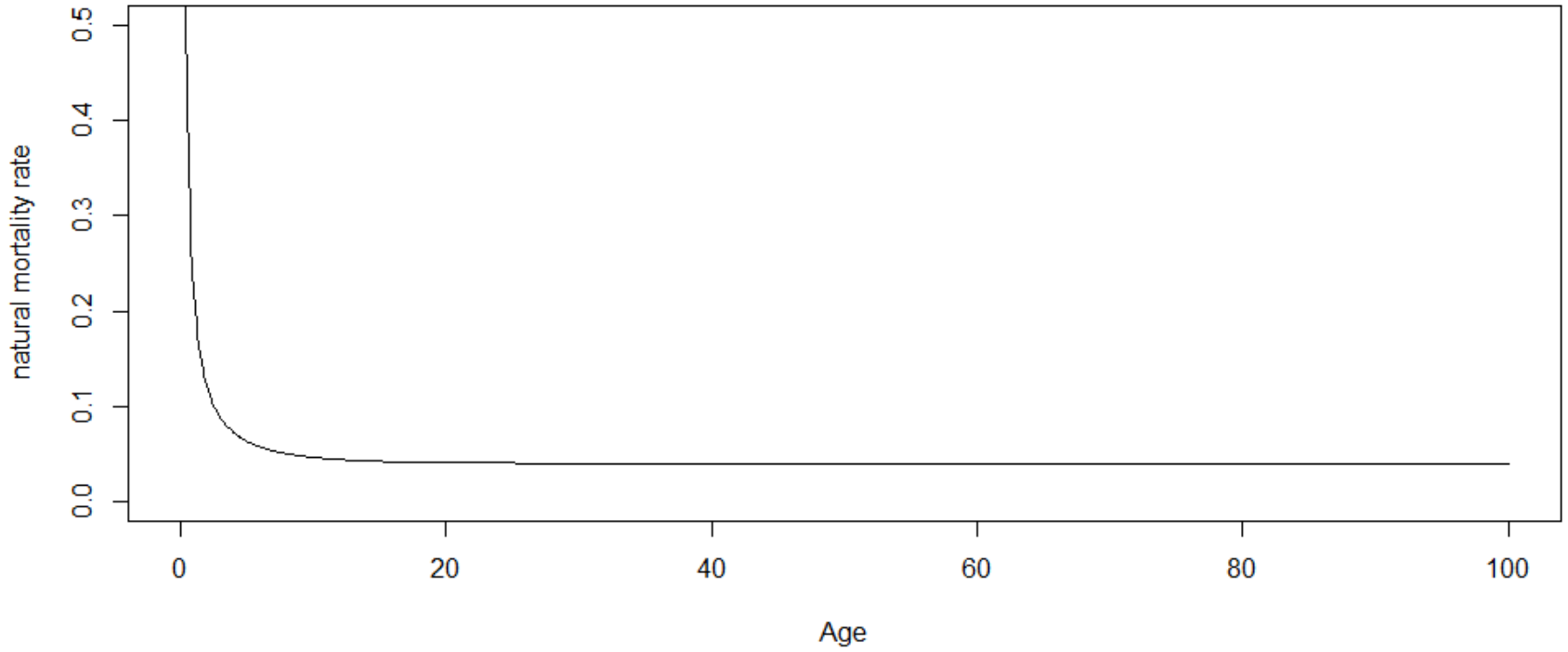
Natural Mortality (*M*)

- To restate, We often model M as:
  - M = constant, even though there is evidence for M being inversely related to length (on average) (e.g. Lorenzen 2022; Lorenzen et al. 2022)



Natural Mortality (*M*)

- However, we often model M as:
  - M = constant: looks more reasonable with M at age



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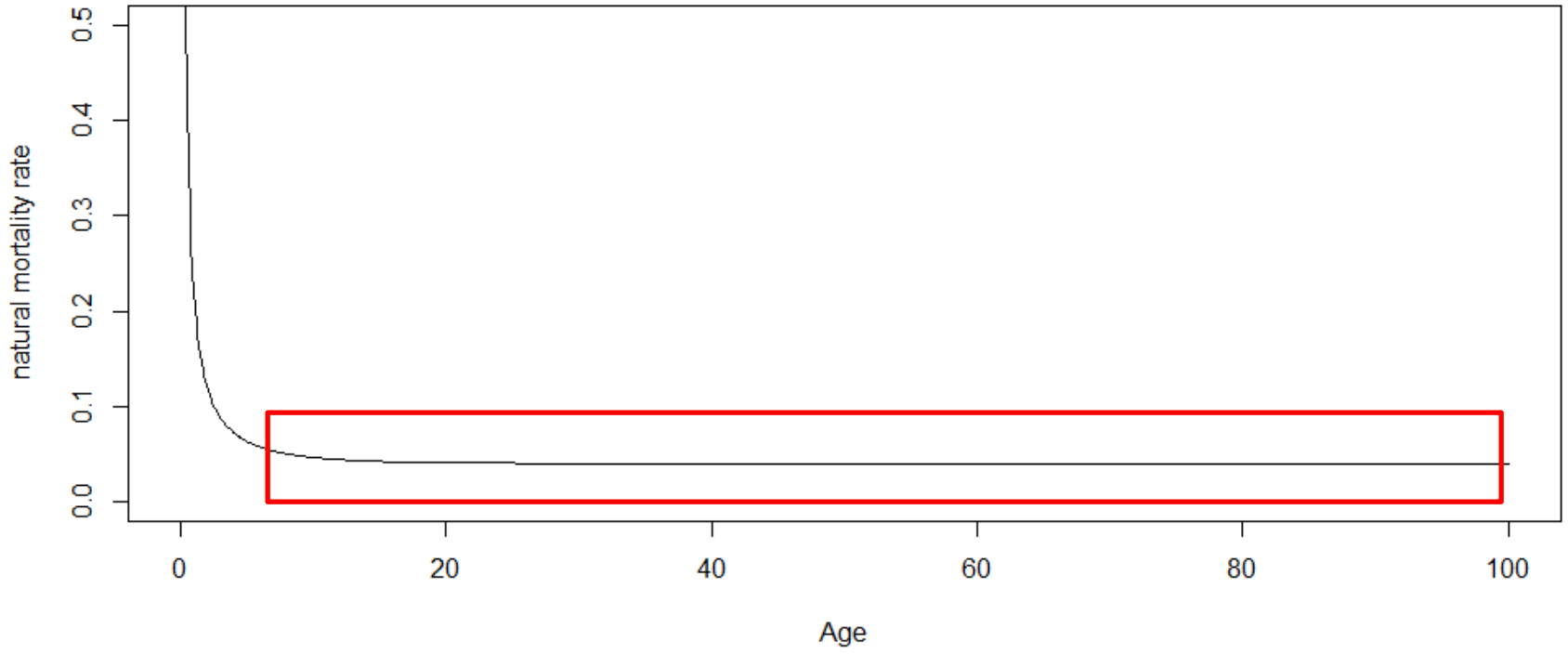

Natural Mortality (*M*)

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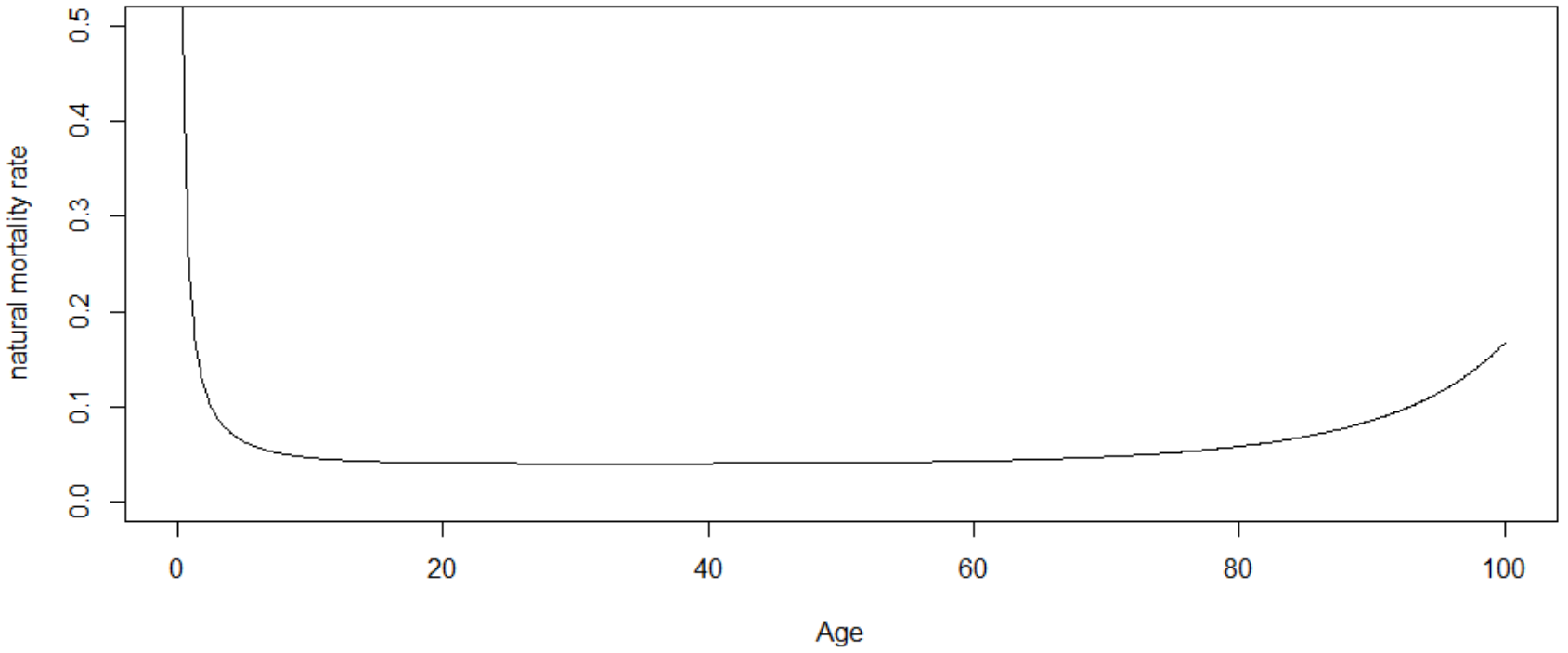
  - (even with senescence)



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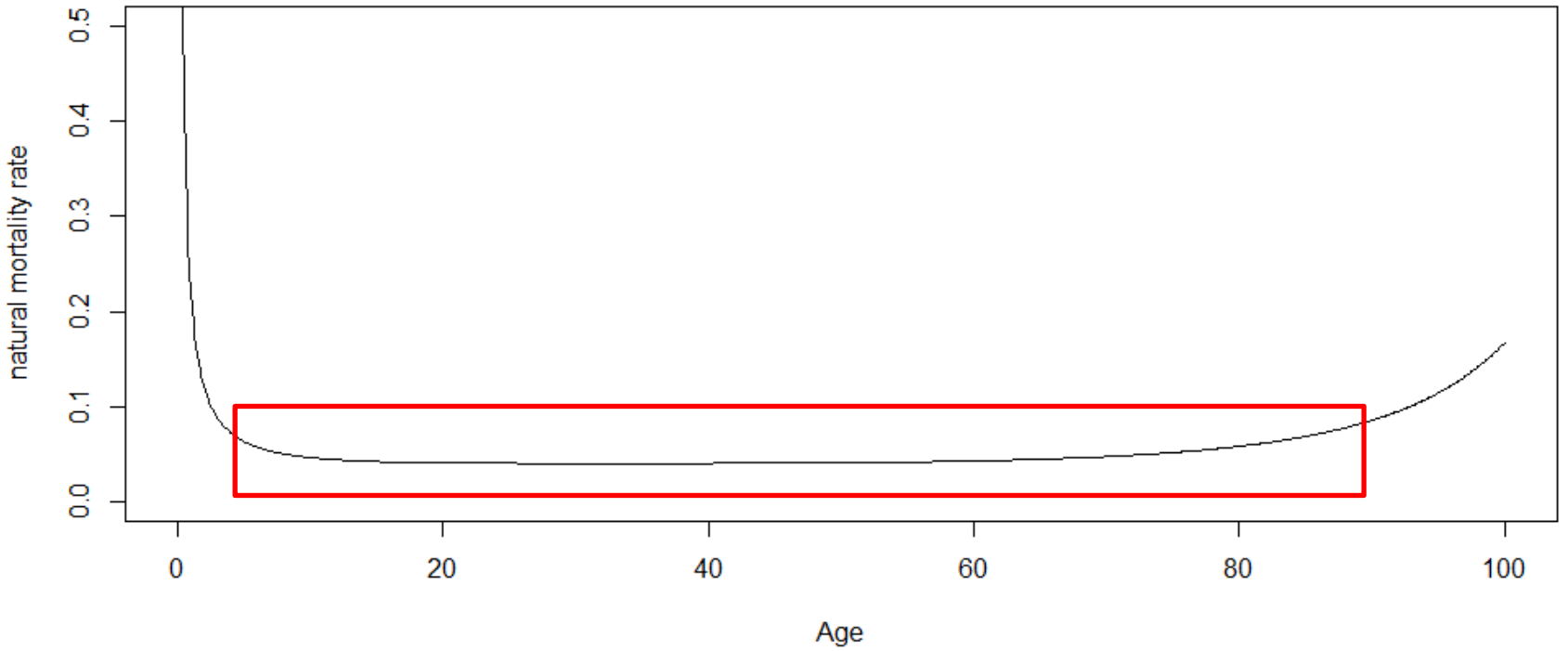
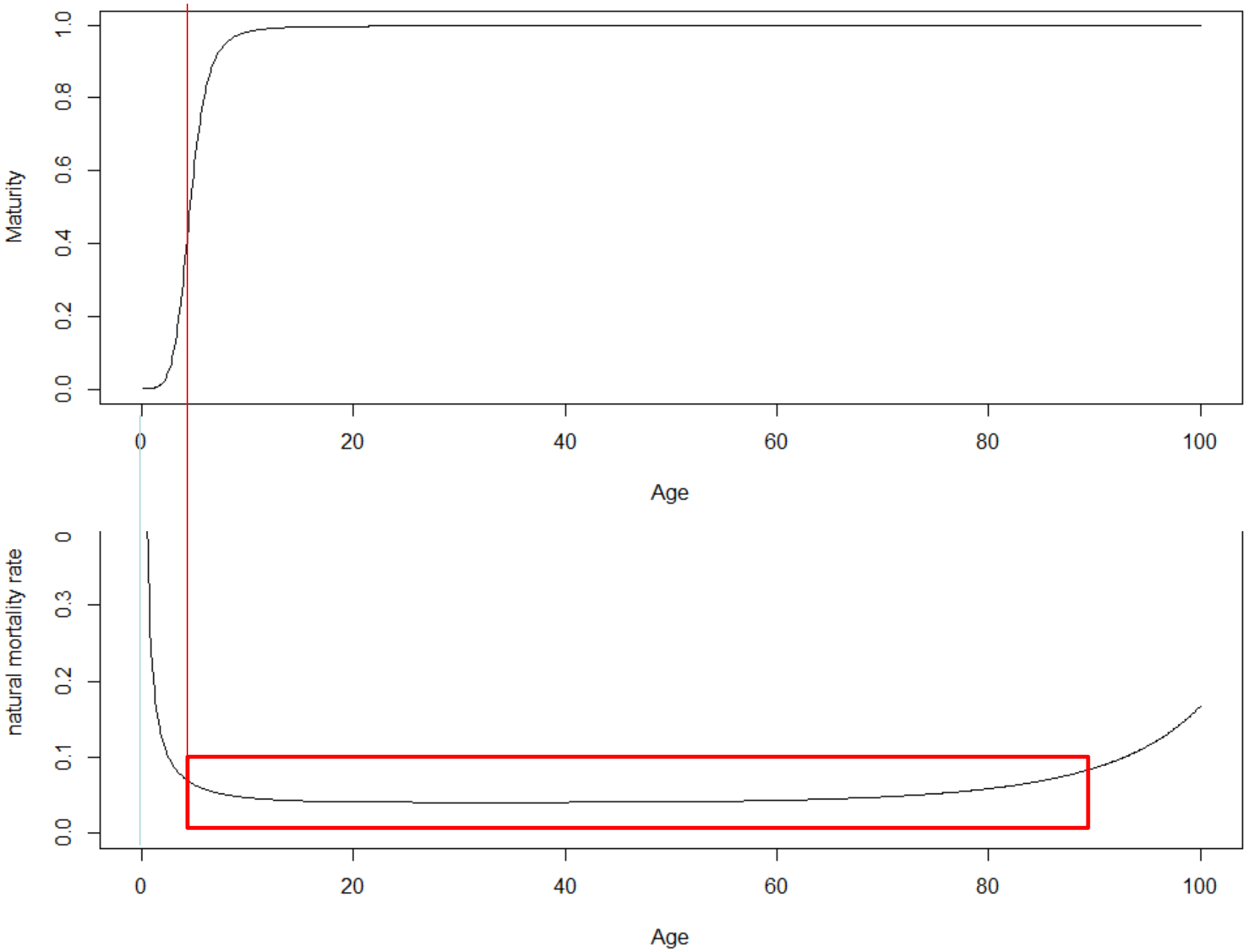



Maturity
0.0
0.2
0.4
0.6
0.8
1.0
0
20
40
60
80
100
Age
natural mortality rate
0.0
0.1
0.2
0.3
0
0
20
40
60
80
100
Age

Natural mortality

- Constant M at age OK
  - We won't accurately model numbers at age for youngest fish, but we aren't catching them either, so all wrapped up in recruitment values
    - Maybe we are overestimating the impact of fishing on the youngest fish – but for long-lived fish, F is small, so not a large error
  - Sensitivity analyses could include a Lorenzen relationship between length and M

Natural mortality

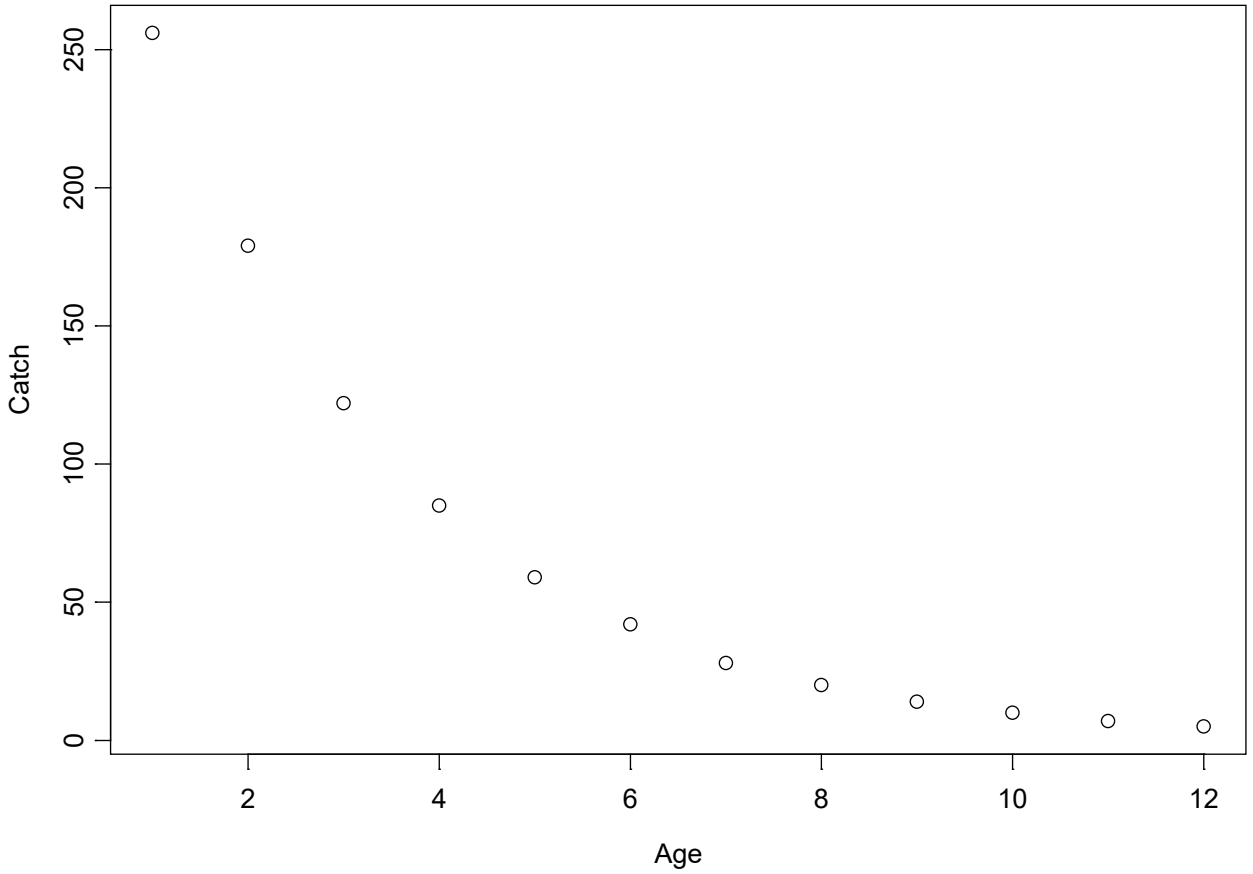
- How do we estimate *M*?
  - Directly from data or in assessment (rare)
  - From meta-analyses with other life history parameters (e.g.:
    - maximum age (longevity),
    - growth rate,
    - size,
    - environmental temperature,
    - etc.)

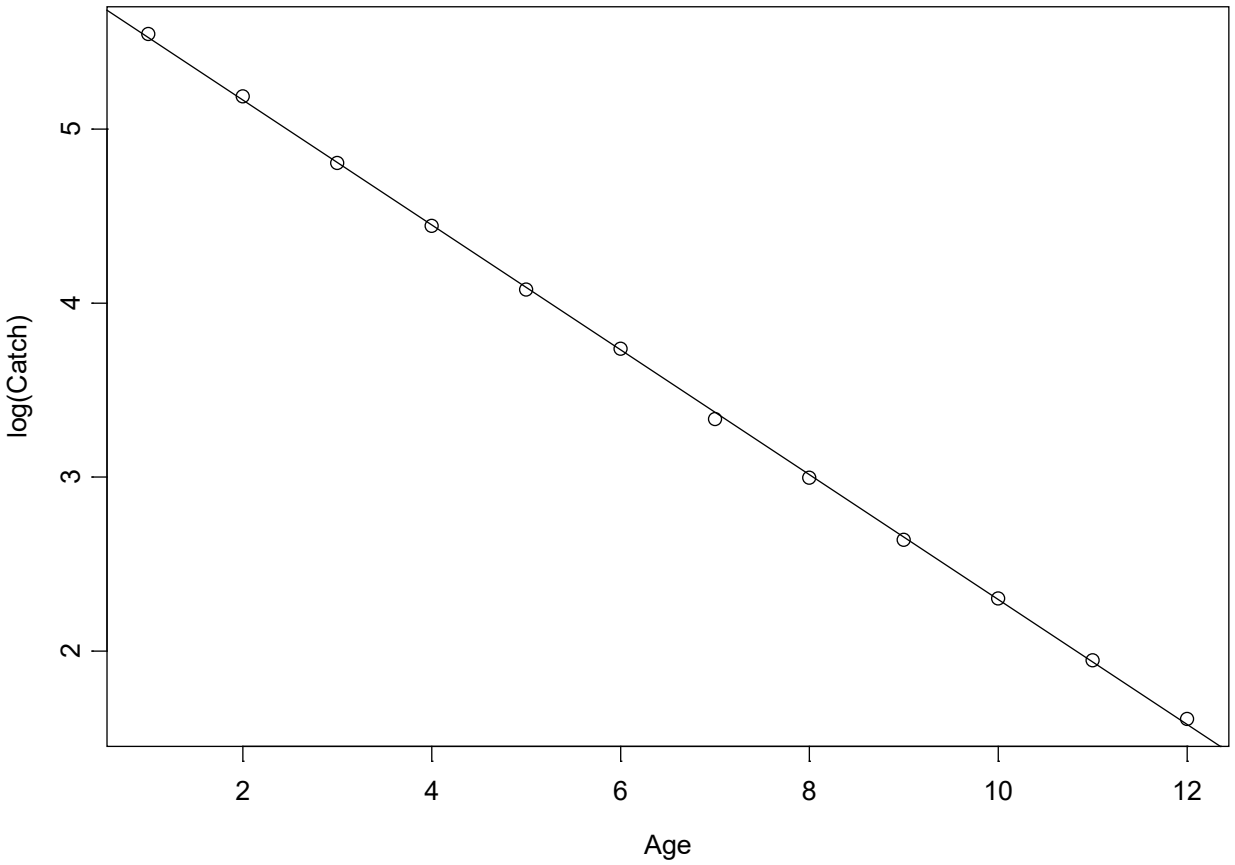
How to estimate M?

- Beverton and Holt (1957):
  - Catch curve analysis
    - Ratio of abundance or catch of a single year class in successive years (with very low F)
    - Ratio abundance or catch of adjacent age groups in a sample
  - Mark-Recapture
    - Great, if can get adequate (lots) and reliable data
    - Biases due to change in fish behavior/survival/capture due to marking, incomplete reporting by fishermen, migration.

How do we estimate M?

- Ideally, one has a nice catch curve…





M = 0.359

But…

- This never happens
- There are issues with:

 - Ageing error
 - Selectivity
 - recruitment variability
 - age and time varying parameters
 - etc.

Natural mortality

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  - Directly from data or in assessment (rare)
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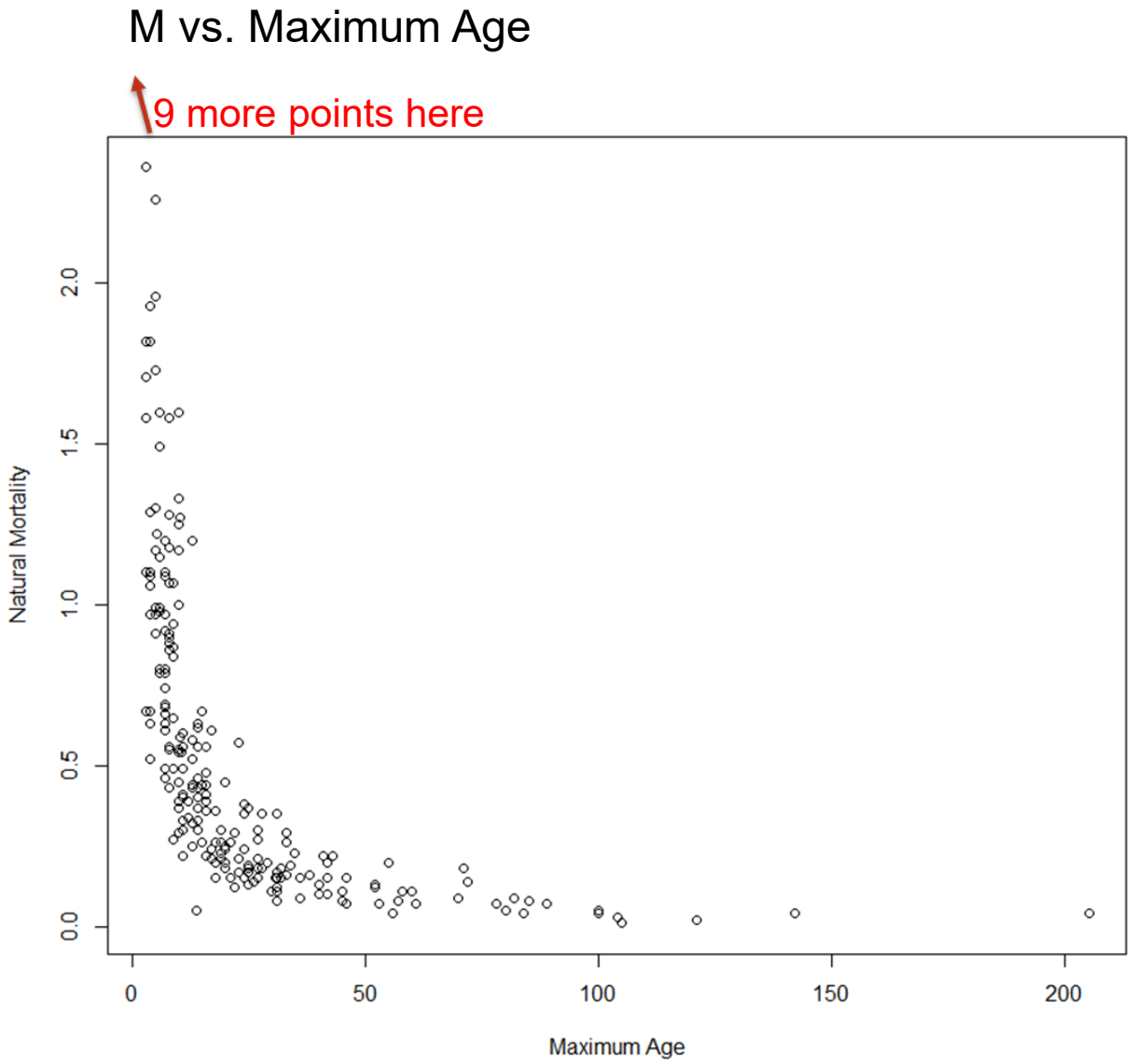
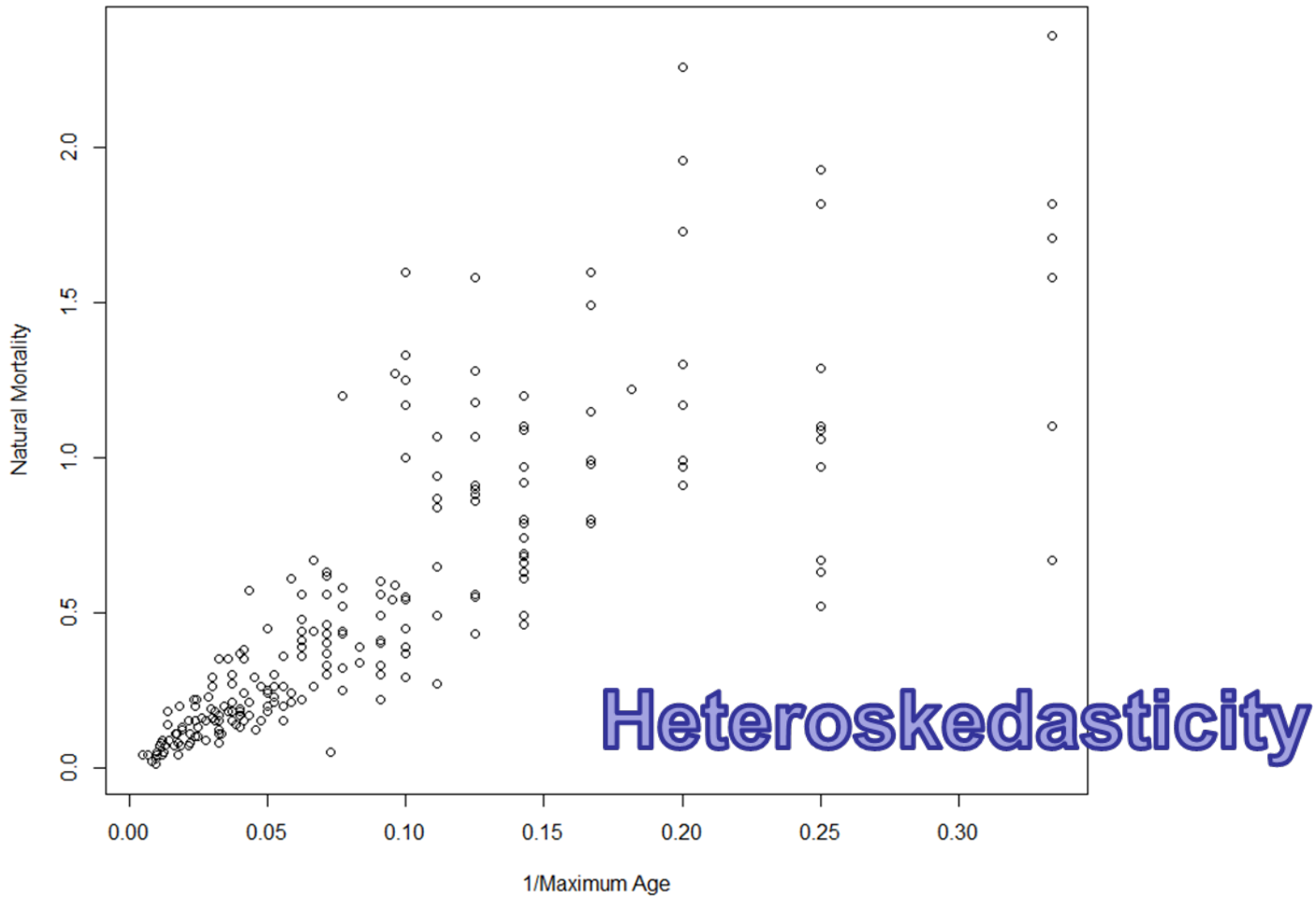
Then et al. 2015 Data Set

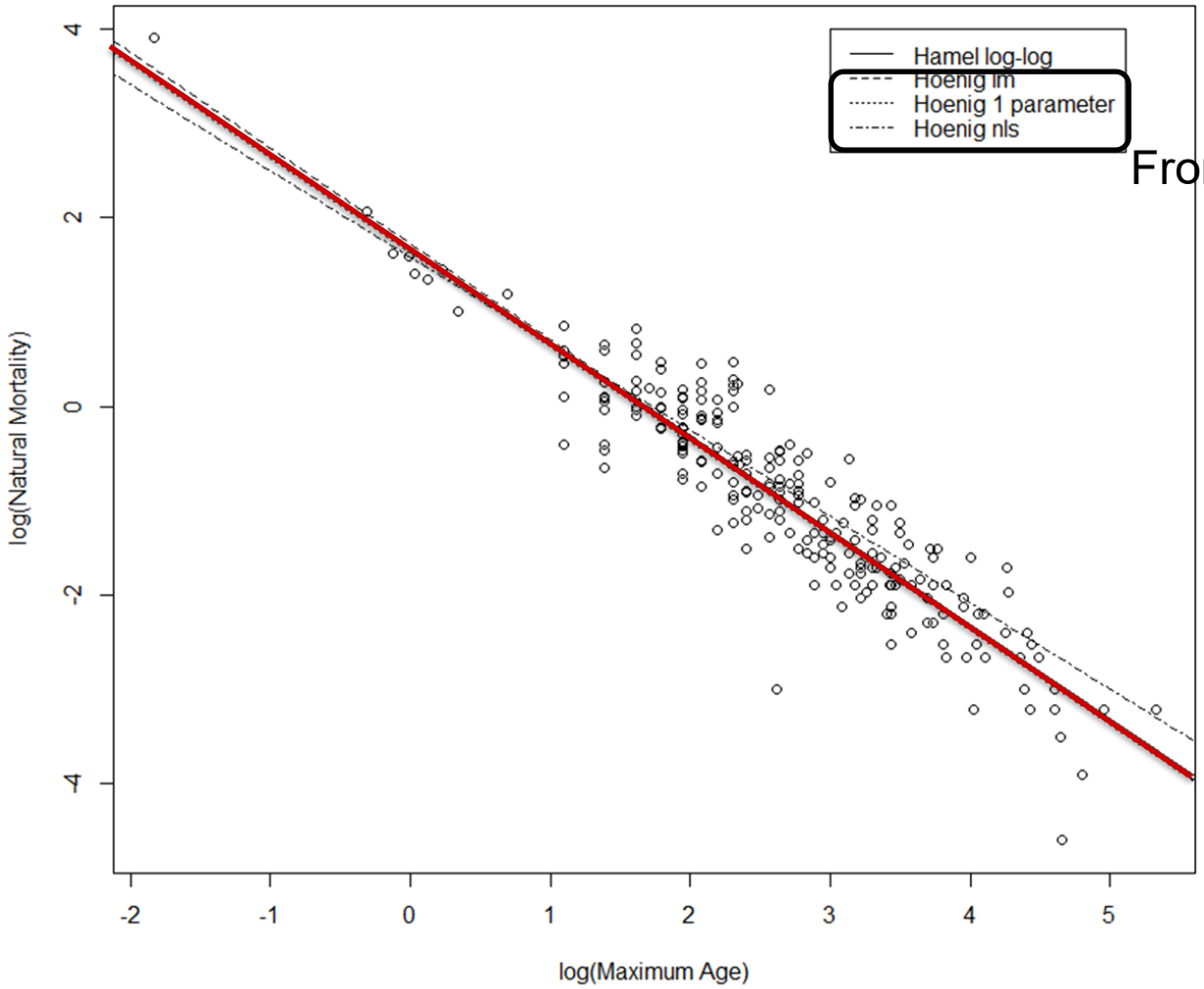


Then et al. 2015 Data Set

M vs. 1/Maximum Age



Hamel and Cope 2022

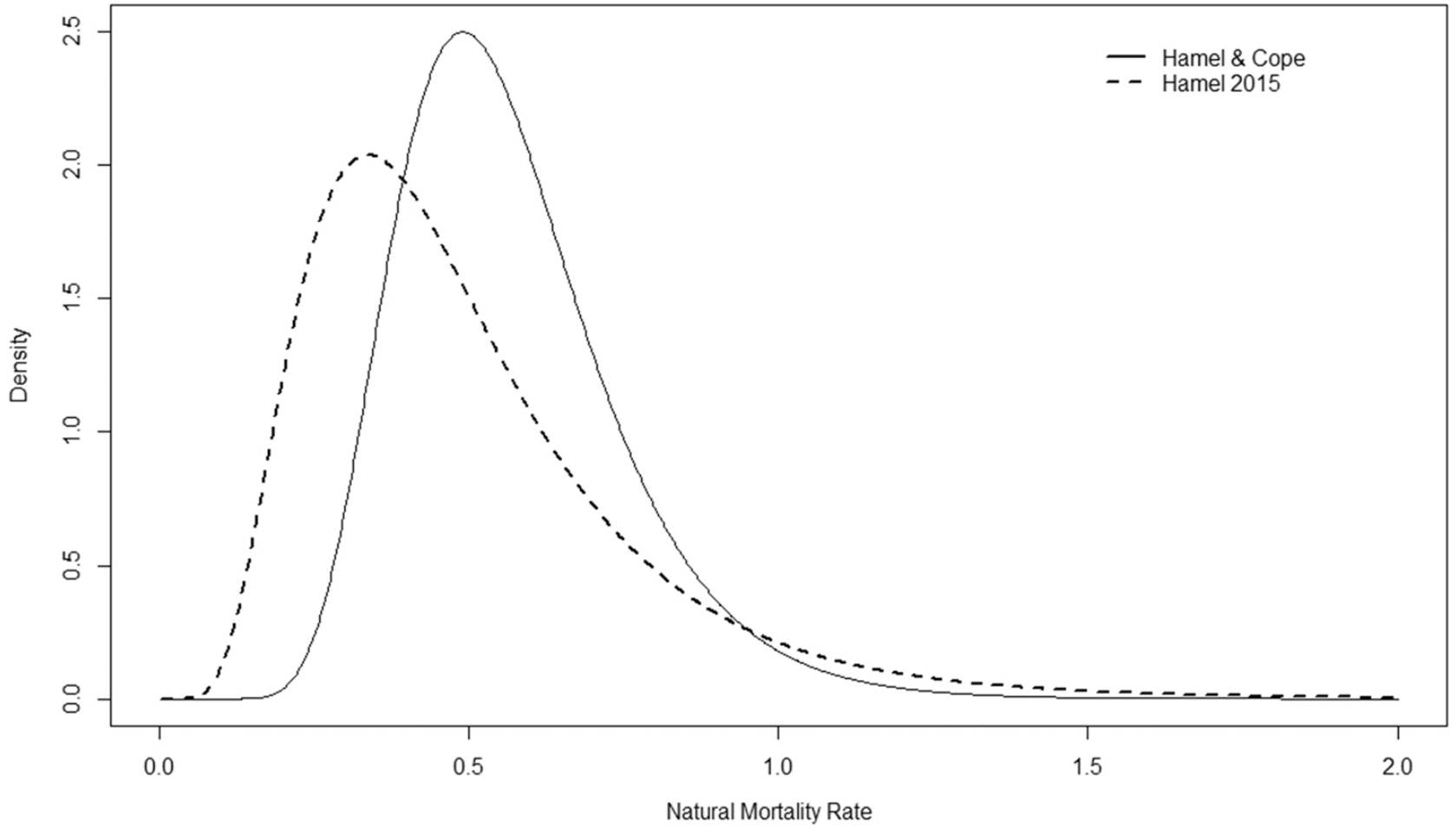


From Then et al. 2015

Prior/point estimate

- $M = \frac{5.40}{A_{max}}$ (we usually fix this in assessment)
  - Value above is median (= log space mean)
    - Risk neutral (half of probability density above, half below)
    - In contrast to using mean for e.g. weight at length
- For Prior:
  - log-space sd =0.31
  - This is an improvement over previous work (e.g. Hamel 2015, Then et al. 2015)

Prior on M (for max age = 10)



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