Dual offspring size strategies in fish

Theoretical and realised offspring size strategies

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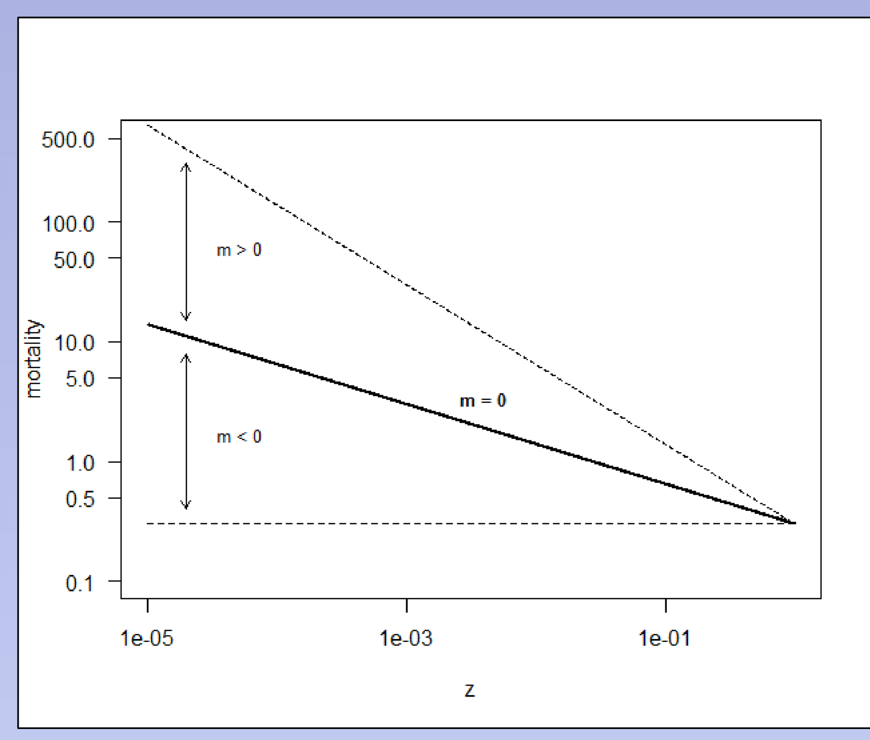
Offspring size represents the trade-off between number of offspring and investment in individual offspring. Assuming that mortality depends on size, the optimal offspring size should be the size which yields the greatest number of surviving offspring in a lifetime. Size spectrum models link decreasing offspring size to increasing lifetime fitness [1], but if juvenile and adult mortality rates differ, optimum offspring size is influenced by the scaling difference [2]. We identify realised offspring size strategies in fish and use life history data to parameterise the offspring model.

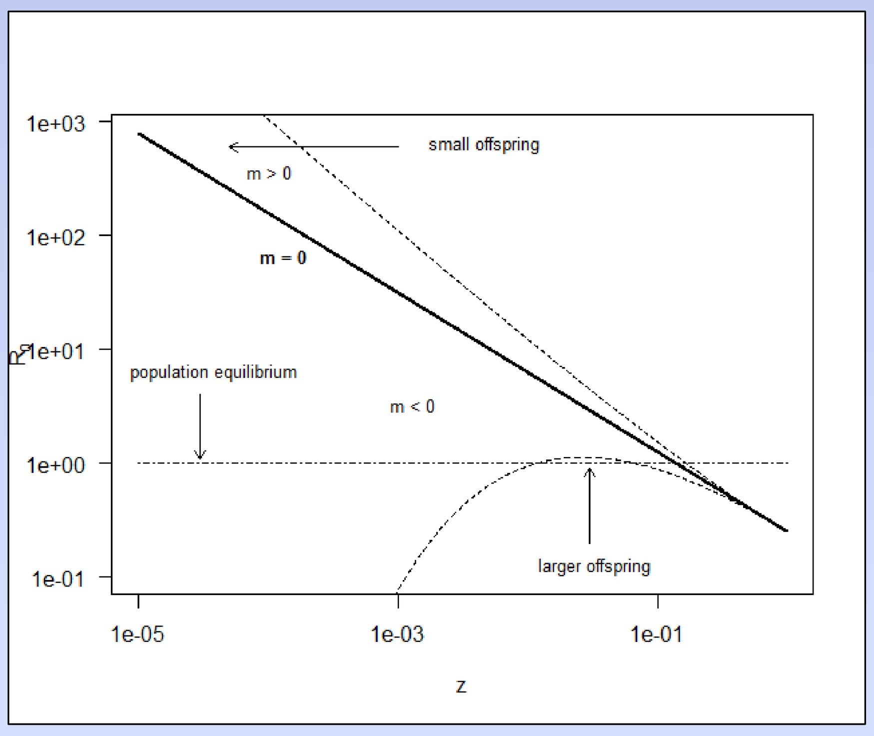
Model assumptions

1. Energy acquisition scales positively with size
   $$E(w) = Aw^n$$
2. Mortality scales negatively with size and possibly differently for juveniles (w) and adults (W)
   $$\mu(w) = aAW^{n-1}\left[\frac{w}{W}\right]^{n-1+m}$$
3. The optimal strategy maximises lifetime expected number of offspring
   $$R_0 = \frac{\in}{2}\exp\left[-\int_{w_0}^{W}\frac{\mu(w)}{E(w)}dw\right]^{\frac{E(W)}{\mu(W)}}\Big/ w_0$$
   Solving shows that R_0 only depends on the fraction $\frac{w_0}{W}$, defined as z
   $$\text{for } m = 0, R_0 = \frac{\in}{2a}z^{a-1}$$
   $$\text{for } m \neq 0, R_0 = \frac{\in}{2az}\exp\left[\frac{a}{m}(z^m - 1)\right]$$
4. An evolutionary viable strategy requires non-shrinking populations, $R_0 \geq 1$

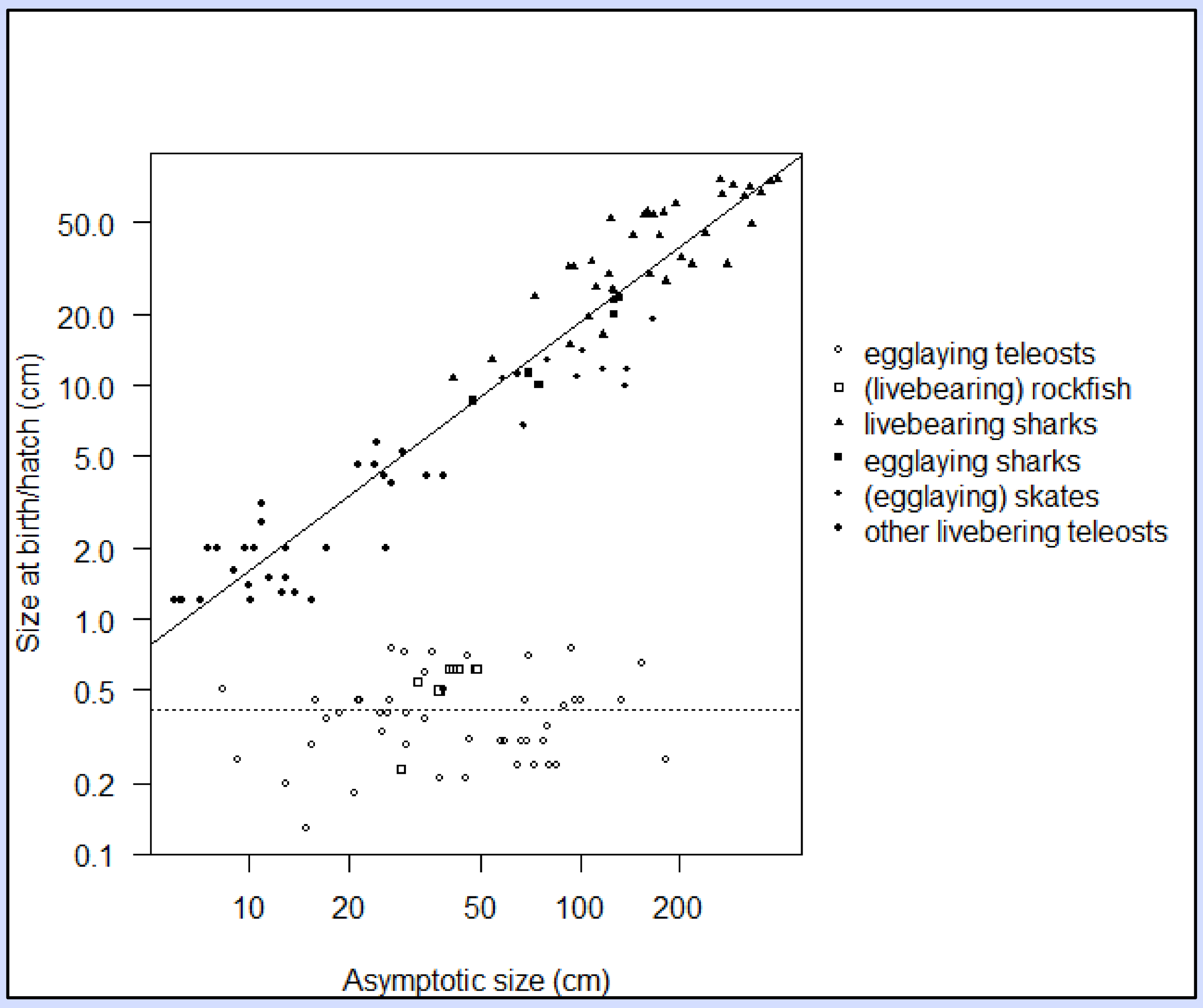
If mortality scales identically across all life stages ($m = 0$, solid line), life history theory predicts increasing mortality but also increasing net reproductive rate with decreasing offspring size.



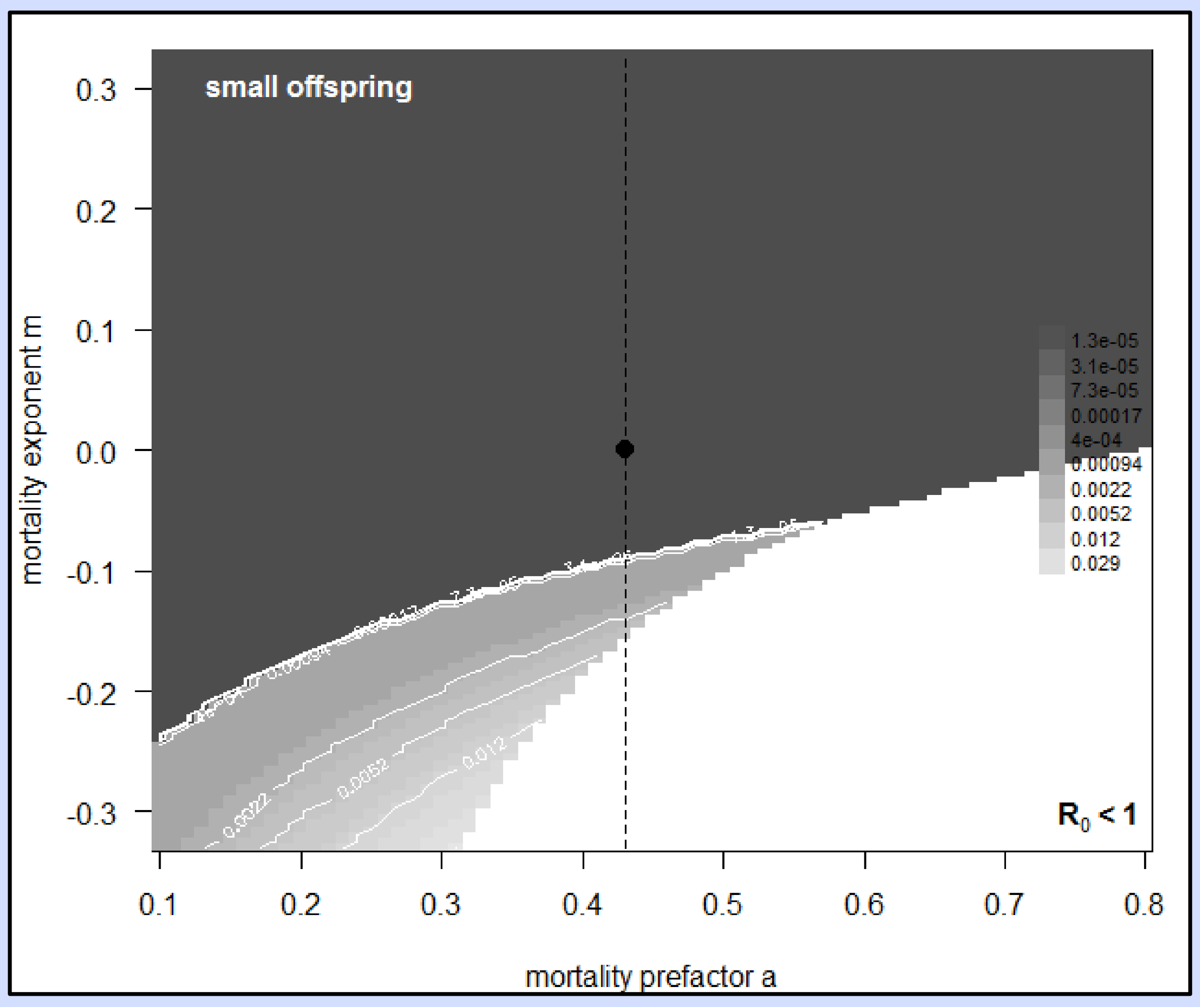
If mortality scaling differs between juveniles and adults ($m \neq 0$), optimal offspring size depends on the value of m. If $m > 0$, the advantage of small offspring is reinforced but if $m < 0$ optimal offspring size may be larger with a lower $\max(R_0)$.



The actual viability of the strategy ($\max(R_0) \geq 1$) also depends on the values of $\in$ and a.



There are two identifiable offspring size strategies among fish: the dominant strategy with small offspring (~ 3 mm) irrespective of adult size, and the less common with offspring size at a fixed proportion to adult size ($\sim 0.15 L_\infty$). The majority of bony fish species produce small offspring with the exception of some small viviparous species (e.g. guppies and splitfins). All elasmobranch species have fixed proportion offspring.



From life history data, we estimated $a \sim 0.43$ and $\in \sim 0.15$, which favours small offspring for $m > -0.1$ and larger offspring for $-0.1 > m > -0.16$. Lower values of m are not sustainable. Lower values of a (reduced mortality level) would open up for viable proportional offspring strategies for a wider range of values of m.

Conclusion

Two offspring size strategies are found among fish: a dominant strategy with very small offspring and offspring of a size that is a fixed proportion of the adult size.

Estimates of mortality and reproductive efficiancy suggest that juvenile and adult mortality rates scale differently to allow for proportional offspring size.

Conditions which favour small offspring predict a higher fitness than solutions which favour proportional offspring.

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[1] Uffe Høgsbro Thygesen, Keith D Farnsworth, Ken Haste Andersen and Jan E Beyer. 2005. How optimal life history changes with the community size-spectrum. Proc. R. Soc. B 272

[2] Christian Jørgensen, Sonya K. Auer, David N. Reznick. 2011. A model for optimal offspring size in fish, including live-bearing and parental effects. The American Naturalist Vol. 177, No. 5

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