



# Evolutionary dynamics of broadcast spawners

By David McAvity\* and Geneva Mottet\*\*

## Introduction

Broadcast spawners such as sea urchins and abalone reproduce by releasing gametes. Successful fertilization depends on variables such as binding efficiency, sperm and egg concentration, and physical characteristics of gametes. The binding proteins on the surface of gametes are known to evolve rapidly and show diversity of type within species (Levitan). One theory explains this diversity through selection pressure to reduce binding efficiency under high sperm concentration. We developed an agent based model to study the evolutionary dynamics of binding proteins under various environmental conditions.

## Gamete Kinetics

Sperm move within the environment with a random walk at a particular speed (Vogel, Styan). Only monospermic eggs are successfully fertilized, as opposed to polyspermic which have two or more sperm. The percent of monospermic, polyspermic, and unfertilized eggs is dependent on the concentration of sperm. Figure 1 illustrates the distribution of eggs after a fixed spawning period for our purely kinetic agent based model of sperm dynamics.

### Distribution of eggs after spawning

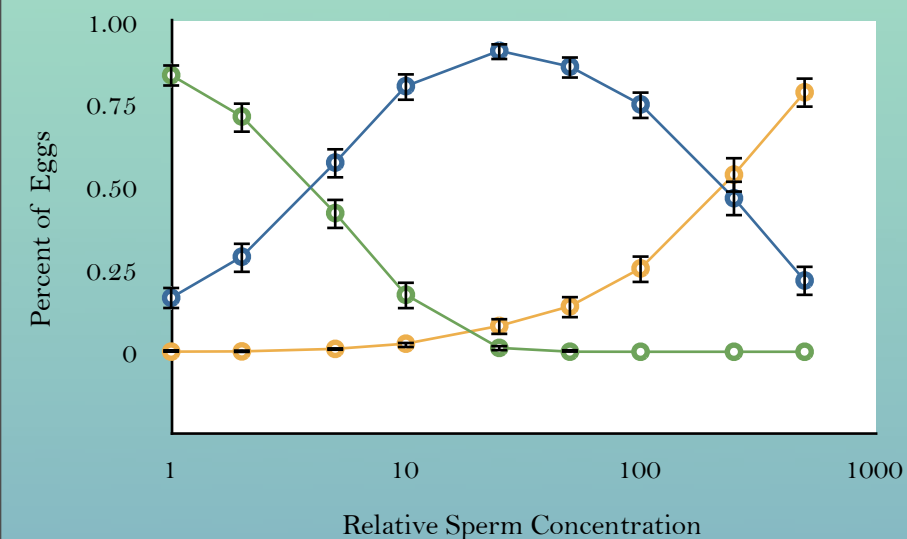


Fig. 1.

## Binding Efficiency

The eggs and sperm have different surface proteins that control the efficiency with which they bind. Each gamete carries a receptor and ligand gene. The receptor gene is expressed in eggs and the ligand gene is expressed in sperm, as illustrated in figure 2. Matching expressed proteins result in more efficient binding. Under low sperm concentration, high binding efficiency would be favored. Under high sperm concentration, eggs with rare receptor proteins that bind less efficiently are favored.

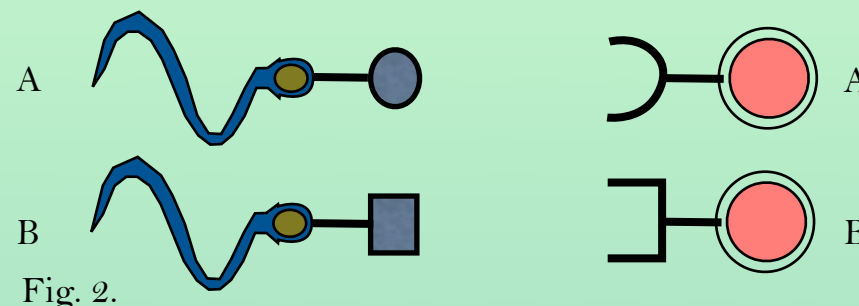


Fig. 2.

## Evolution of bindin proteins

We created an agent based model with realistic parameters for sea urchin gametes in Netlogo. We ran the model with an initial population of gametes with A receptor and A ligand genes denoted AA. Ligand mutations to genotype AB are not selected for. Receptor mutation to genotype BA are selected for when sperm concentration is above a critical value  $Q$  as shown in figure 3.

### Relative abundance of bindin genotype

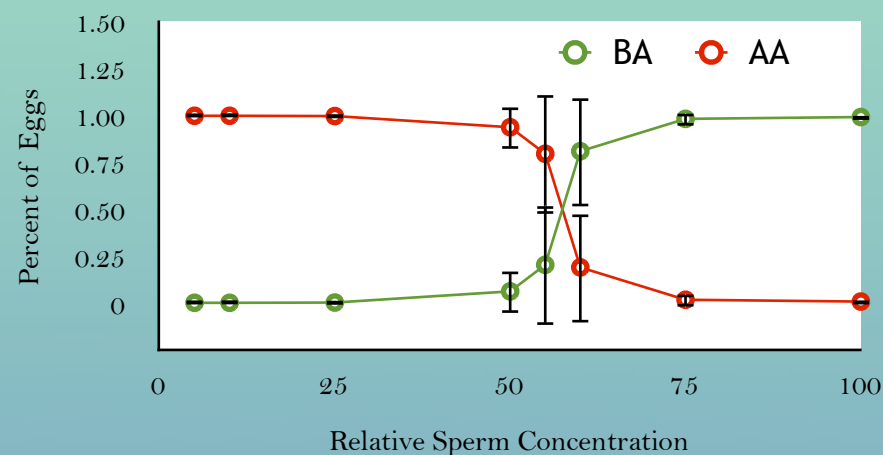


Fig. 3.

## Blocking Time

In a series of experiments run with different block times, critical values of sperm concentration were plotted against the amount of time that an egg takes to erect a chemical barrier against polyspermy, shown fig 4. When the block time is very short the critical value is high, as expected. As block time increases, it approaches a constant non-zero value.

### Stability diagram bindin genotypes

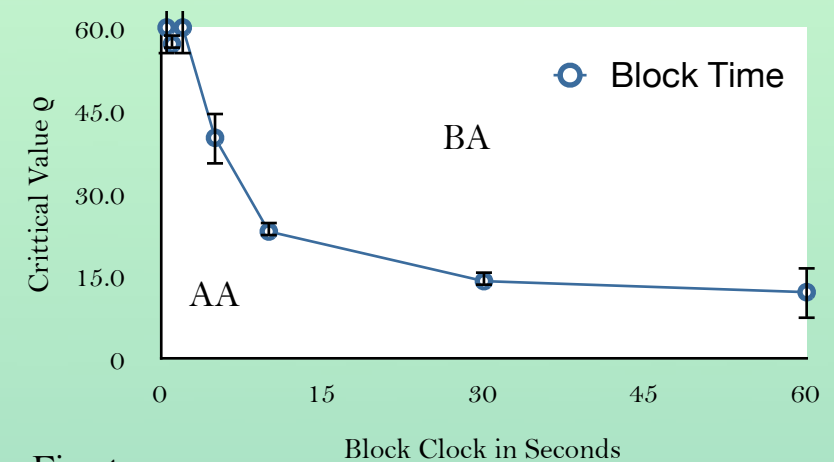


Fig. 4.

## Conclusion

Sperm and eggs use bindin proteins to reduce fertilization efficiency. Using agent based models, we showed the environmental conditions that favor selection for rare alleles in high relative sperm concentrations.

## Sources Cited

- Levitan, Don R., Ferrell David L. 2006. Selection on gamete recognition protein depends on sex, density, and genotype frequency. *Science*. Vol. 312.
- Styan, Craig A. 1998. Notes and comments polyspermy, egg size, and the fertilization kinetics of free-spawning marine invertebrates. *The American Naturalist*. Vol. 152: 290-297.
- Vogel, Helmut., Czihak, Gerhard., Chang, Patrick., Wolf, Wieland. 1982. Fertilization kinetics of sea urchin eggs. *Mathematical Biosciences*. Vol. 58, Issue 2: 189-216.

## Contact Details

\* [mcavityd@evergreen.edu](mailto:mcavityd@evergreen.edu)

\*\* [gjmottet@gmail.com](mailto:gjmottet@gmail.com) (supported by Evergreen SURF Grant)