Potential for Population-Level Impacts of Endocrine Disrupting Compounds: Implications for Oyster Reef Restoration in Chesapeake Bay

M. Lisa Kellogg, Mark W. Luckenbach and Kennedy T. Paynter

Outline:

1) Background info on *Crassostrea virginica* and oyster restoration in MD
2) Study of sex ratios in "restored" field populations in MD
3) Estimates of potential for sperm limitation based on field sampling and lab experiments
4) Likely impacts of low population densities on fertilization success
5) Potential impacts of endocrine disruptors on field populations and restoration efforts

Sex ratios in *Crassostrea virginica*

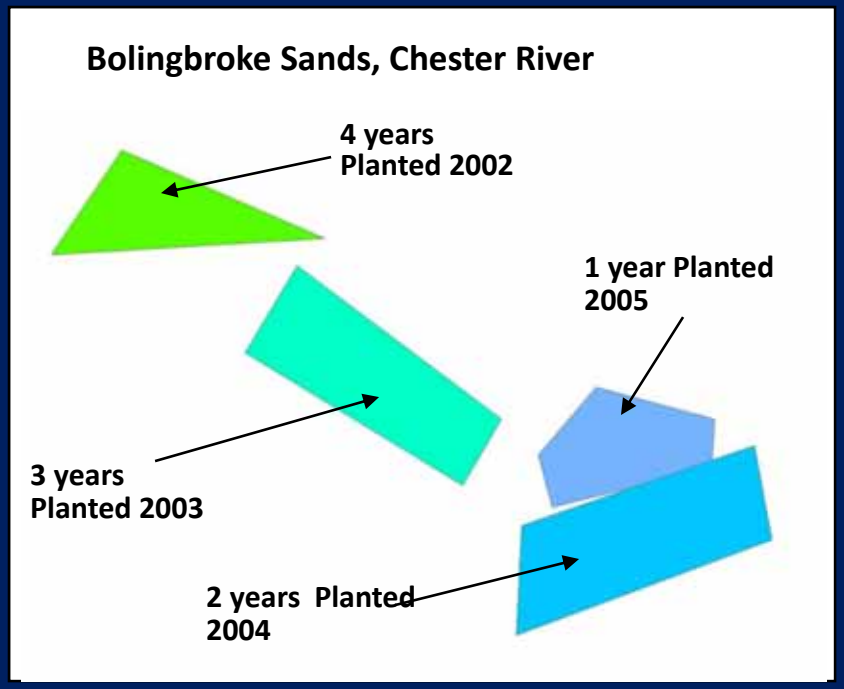
- Oysters are sequential hermaphrodites
  - Sexually maturity ≤ 1 year
  - Generally male first
  - Proportion of females increases with increasing size/age
  - At least some individuals retain the ability to switch back and forth between sexes
  - Populations may contain some true males
    - Study of *Crassostrea gigas* (Guo et al. 1998)
      - Single locus with dominant male (M) and protrandric female (F) allele
- Field populations
  - High variation but most populations have sex ratio of ~1:1
  - Two possible explanations:
    - Passive: Sex ratios are balanced because successive generations recruit
      - Younger generations predominantly male and older ones being predominantly female
      - Difficult to assess population age structure under field conditions
    - Active: Oysters have some ability to determine their sex to optimize their reproductive success
      - In single-sex experimental populations, > 30% of the population changed sex within 1 year (Kennedy 1983)

Oyster Reef Restoration in Maryland

- Population decline ≤ 1 oyster m^{-2}
  - Low natural recruitment in many areas
- Current approach to restoration
  - Native species (*Crassostrea virginica)*
  - Plant juvenile oysters set on oyster shell
  - Historically productive oyster bars
  - Low salinity areas to avoid disease
  - Very low natural recruitment rates
- Goals of restoration
  - Ecosystem services
  - Fishery enhancement
    - Planted annually in discrete year classes
- Opportunity to assess sex ratios in populations of known age

Planted Oyster Reefs Included in Field Study

- Juvenile oysters all from same hatchery (UMCES HPL)
  - Known broodstocks, spawning dates, and planting dates
- Large scale (~0.5-10 hectares)
- Extremely low recruitment rates (≤ 1 m^{-2} y^{-1})
- Age/size distributions
  - Restricted
- Age = 1 to 5 years
- Oysters can change sex ≤ 1 year
  - Population sex ratios have had opportunity to shift through time



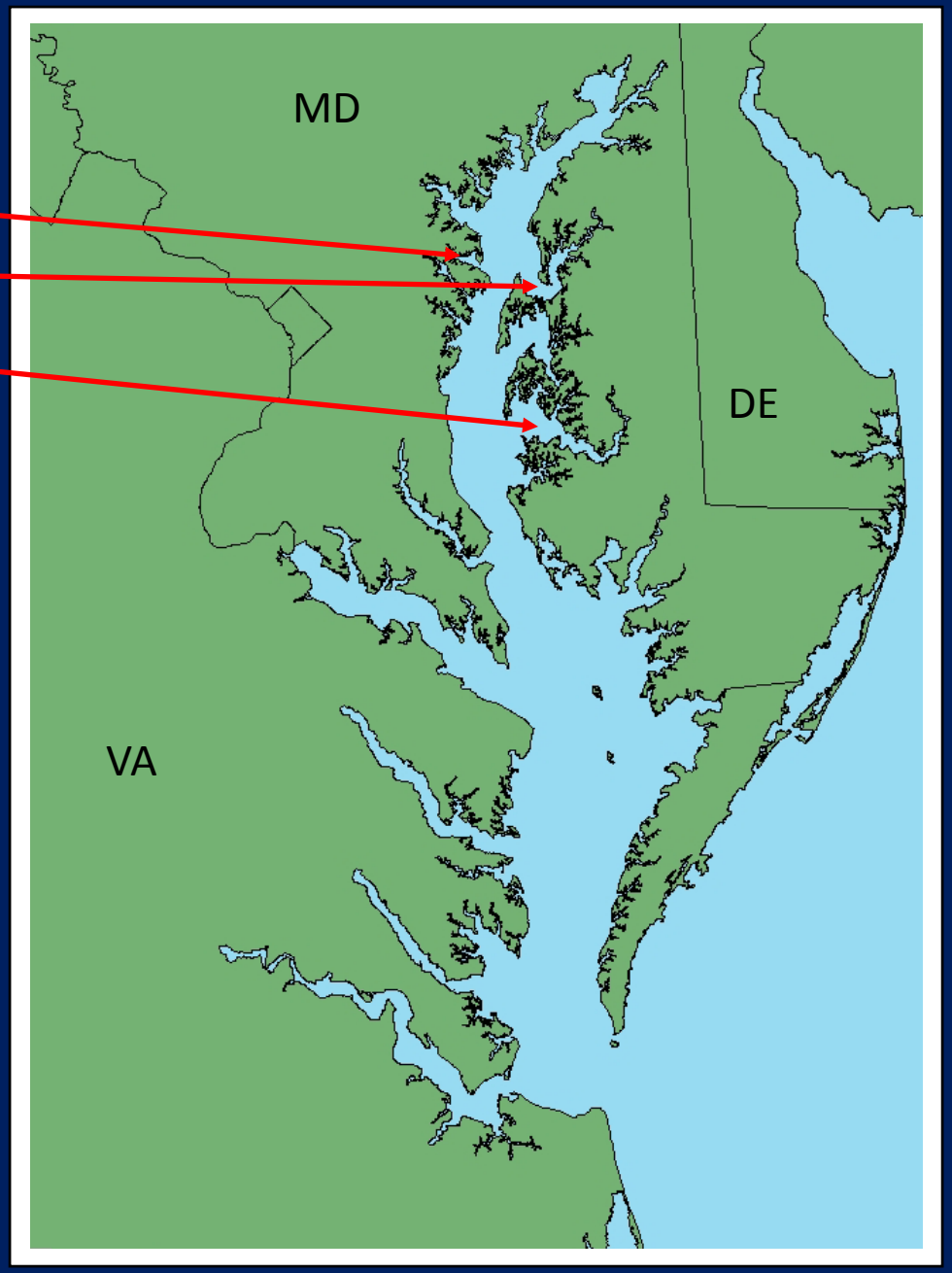
Sampling Locations:

23 sites:

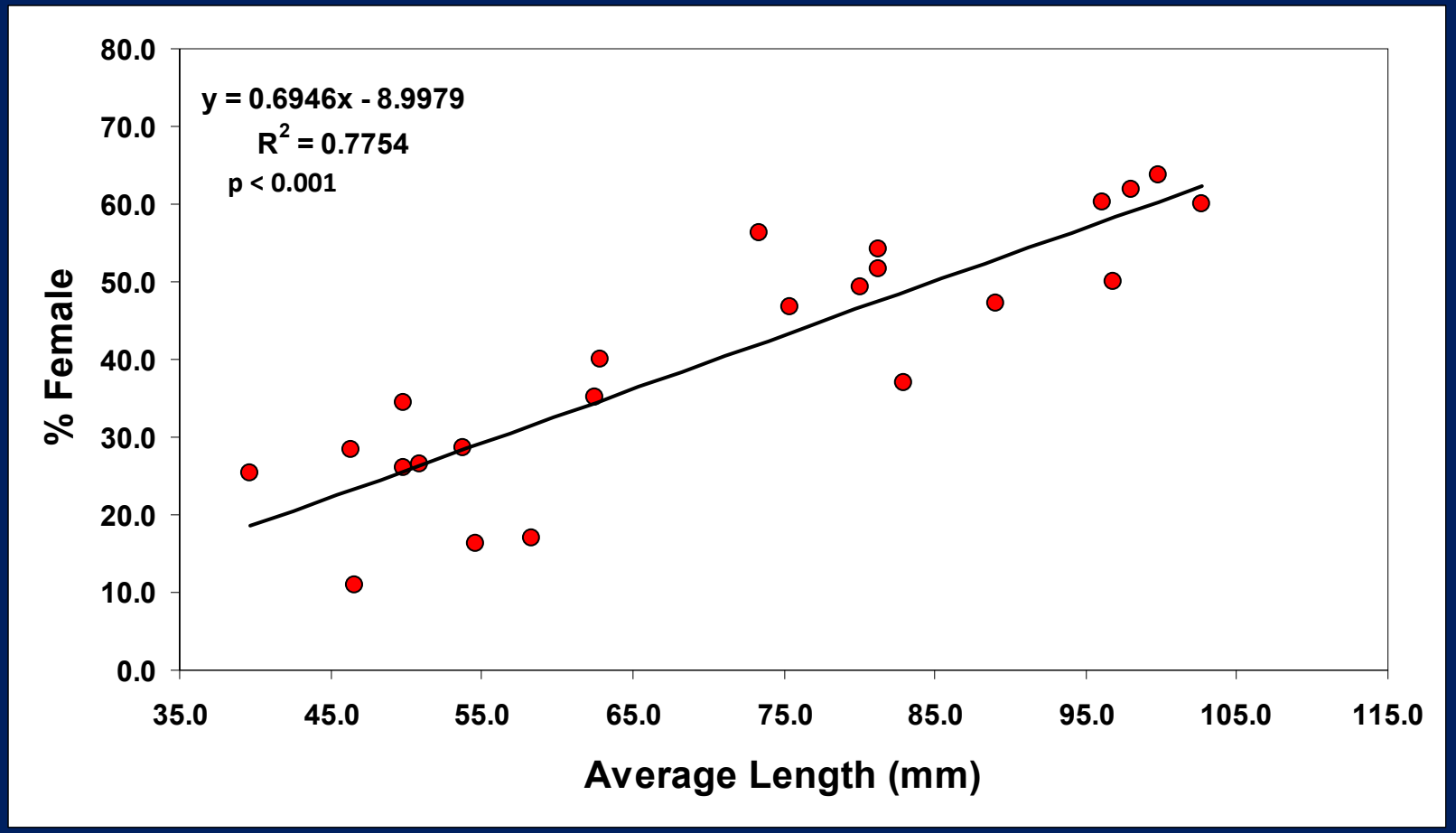
- **Magothy River (n = 1)**
- **Chester River (n = 11)**
- **Choptank River (n = 11)**

Sampling Methods:

- **Divers with quadrats (0.11 m^2)**
  - **Non-random sampling**
- **Minimum = 40 oysters/site**
- **Size and sex of each oyster**
- **Total # oysters = 2129**



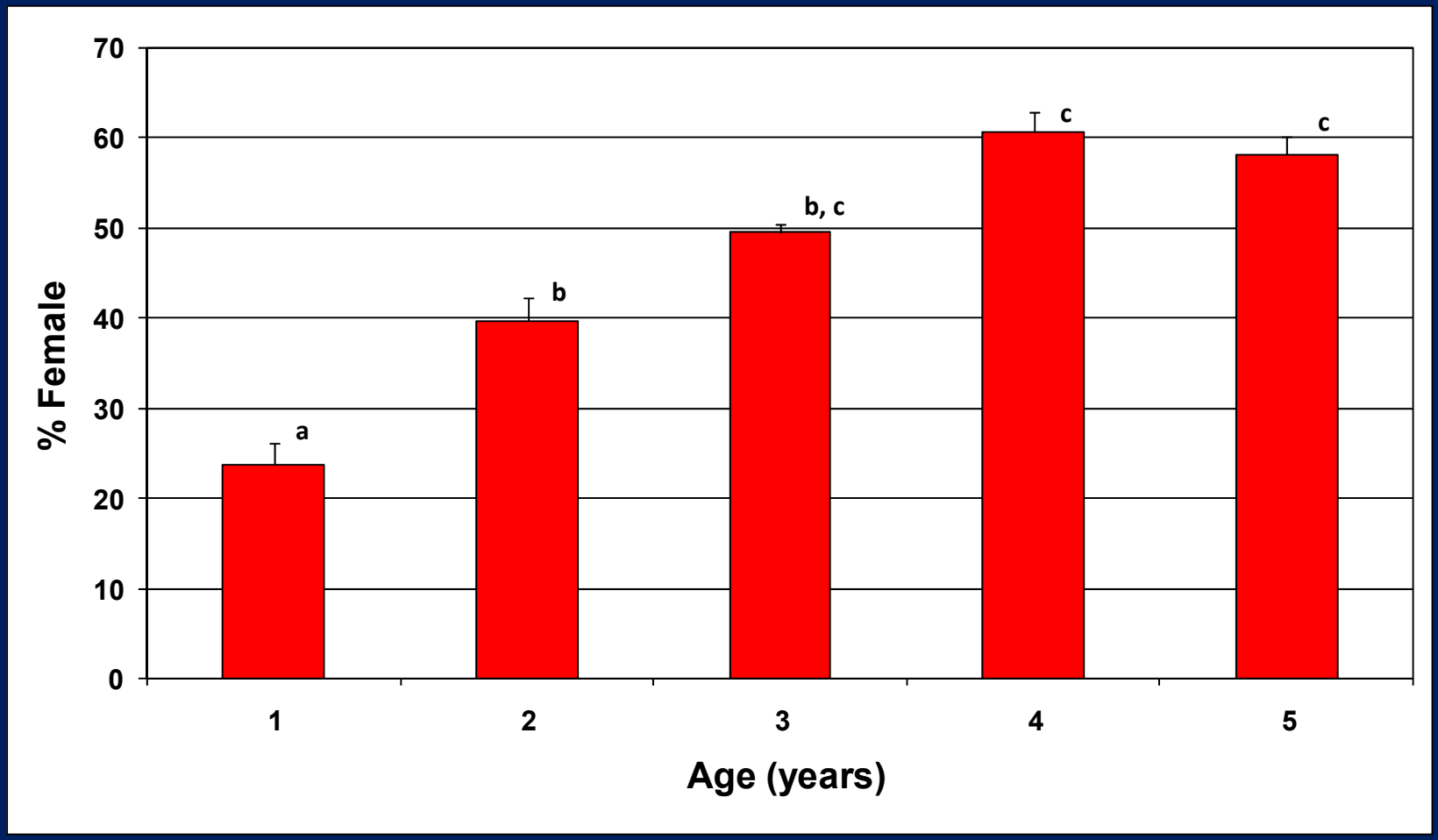
All Sites



Pattern similar to previous studies:

- **Increasing percent female with increasing average size**

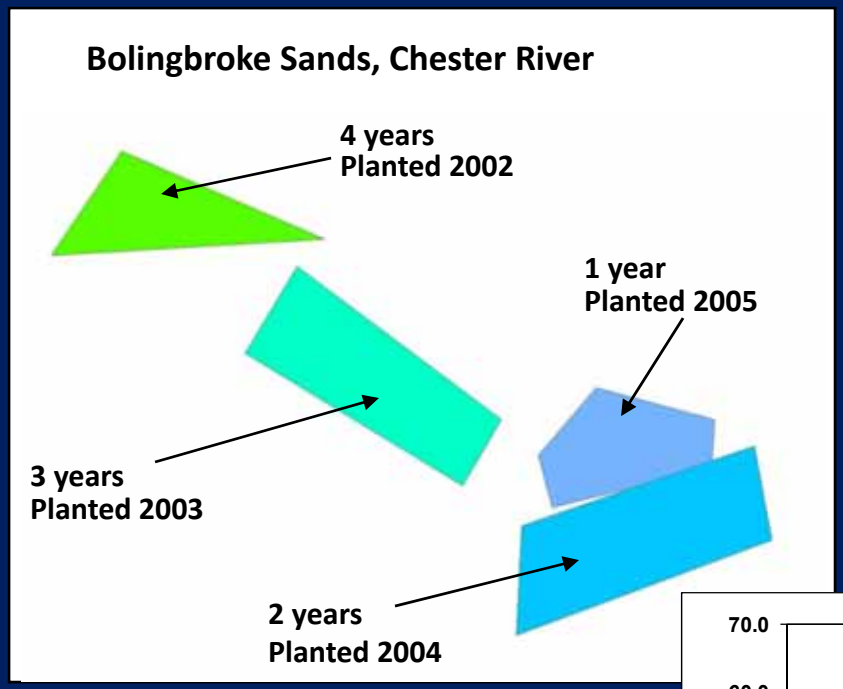
All Sites



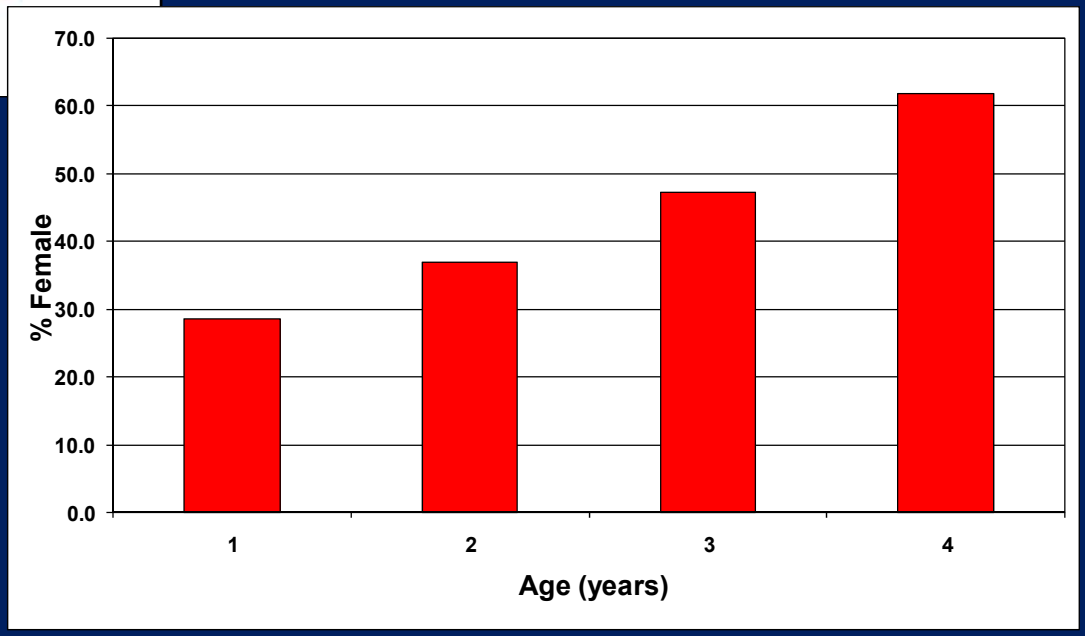
Pattern similar to previous studies:

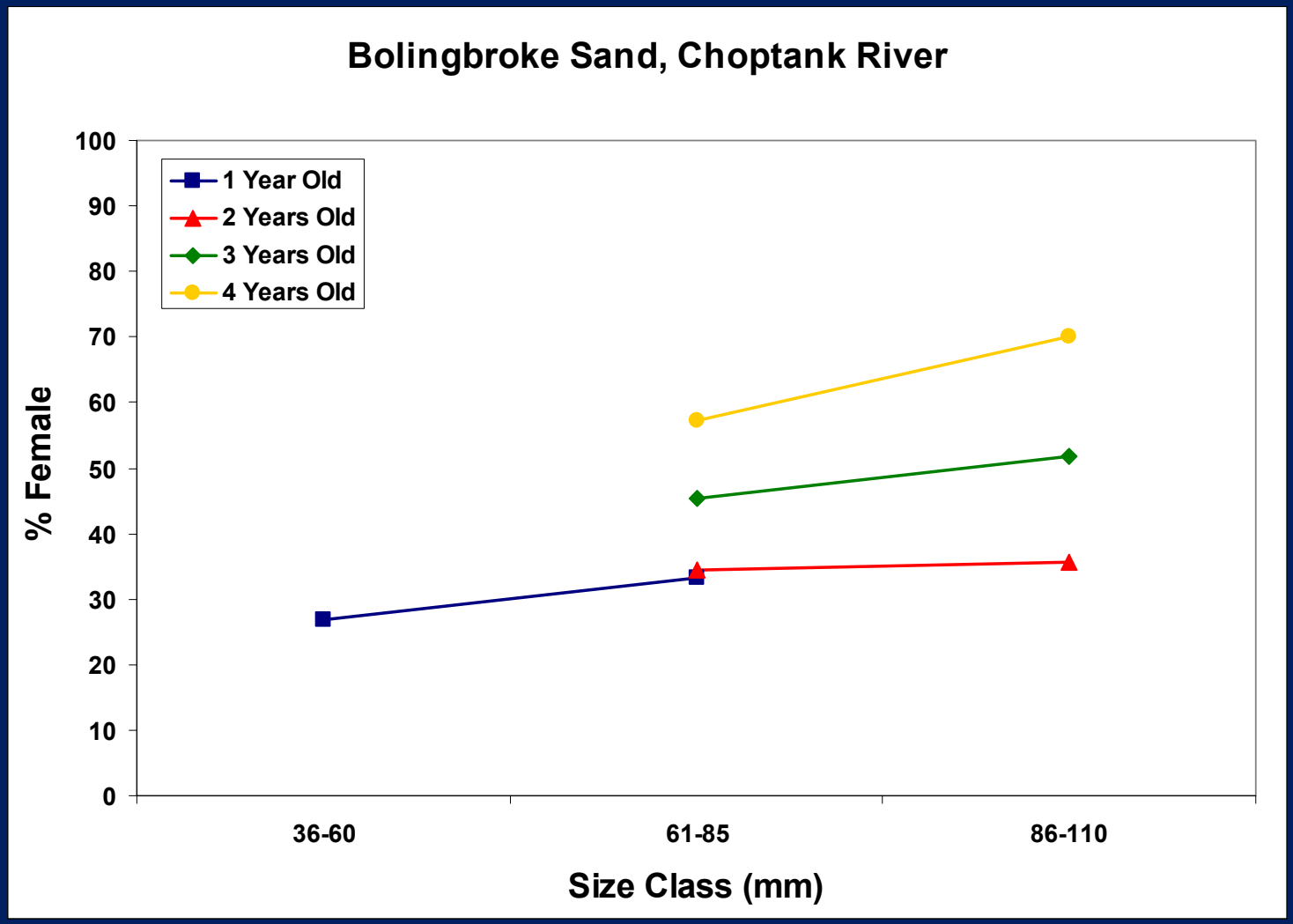
- **Significant effect of age on percent female ($p < 0.001$)**

Example: Bolingbroke Sand, Chester River, MD



Similar patterns within and across areas sampled





Control for influence of size

- **Increasing percent female within most size classes with increasing oyster age**

Field Study Results

Sex ratios of oyster populations on restored reefs in Maryland:

- **11-64 % female**

Patterns of sex ratio:

- **% female often increases with age within a size class**
- **In larger size classes, age may be more important than size in determining sex**

But, at similar shell heights, males are expected to produce many more gametes than females….

Question

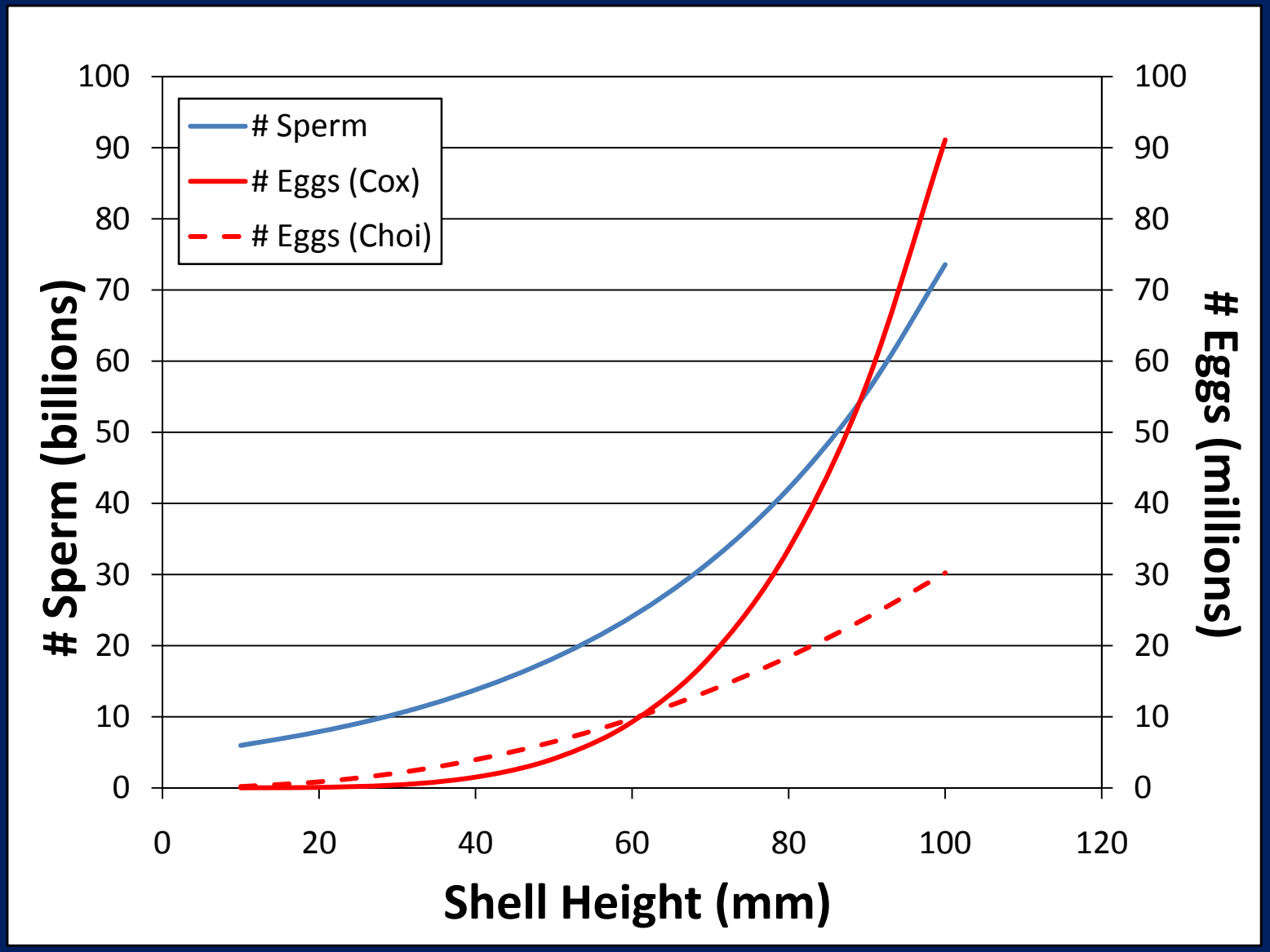
Is sperm limitation likely to occur under present field conditions?

- **Restored reefs with single year class**
- **Natural populations with limited recruitment dominated by one or a few year classes**

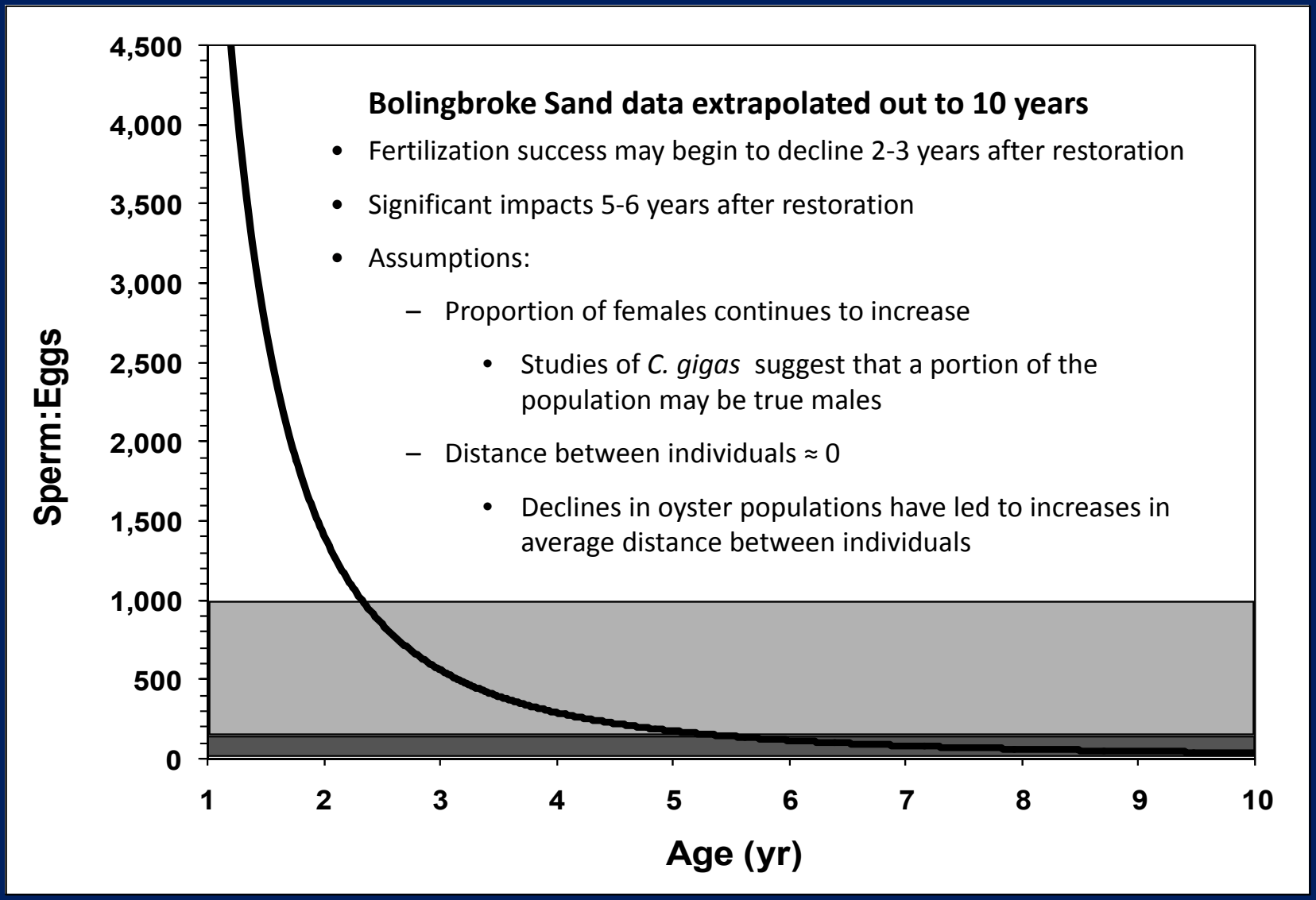
Calculations based on:

- Size-specific male fecundity
  - Luckenbach et al.
- Size-specific female fecundity
  - Fecundity vs. dry weight
    - Cox 1988 (as reanalyzed by Thompson et al. 1996); Choi et al 1993
  - Regression of shell height vs. dry weight
    - Paynter monitoring of restored oyster reefs
- Sperm:egg ratio and fertilization success
  - Luckenbach et al.
- Influence of distances between individuals on fertilization success
  - Spatial density of oysters
    - Estimates of natural populations
    - Data from sampling of “restored” oyster reefs
      - Overestimate actual densities
  - Decreasing fertilization success with increasing distance
    - Mann and Evans 1998 based on Levitan 1991

Size-specific Fecundity

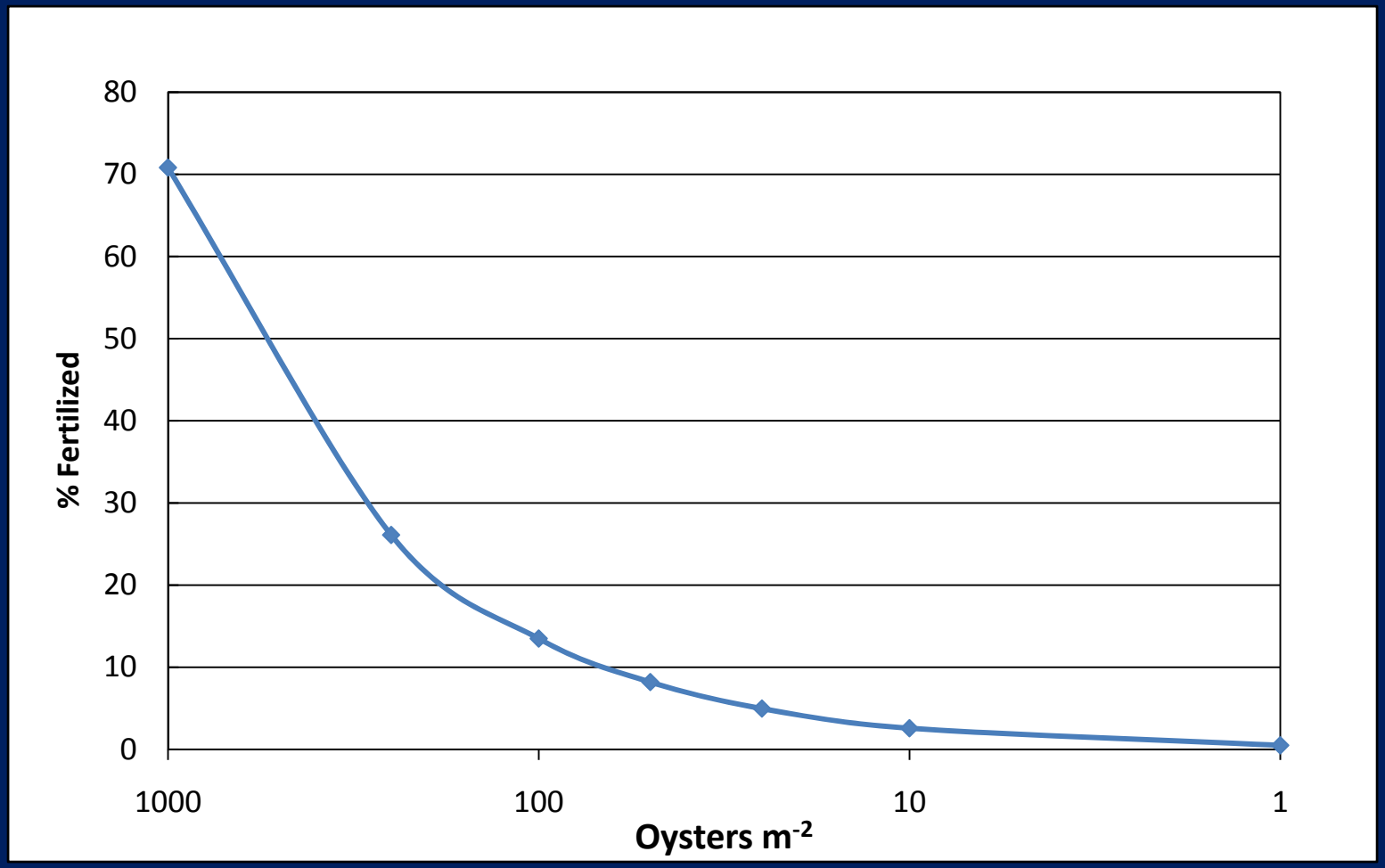


Change in Sperm:Egg Ratio with Age



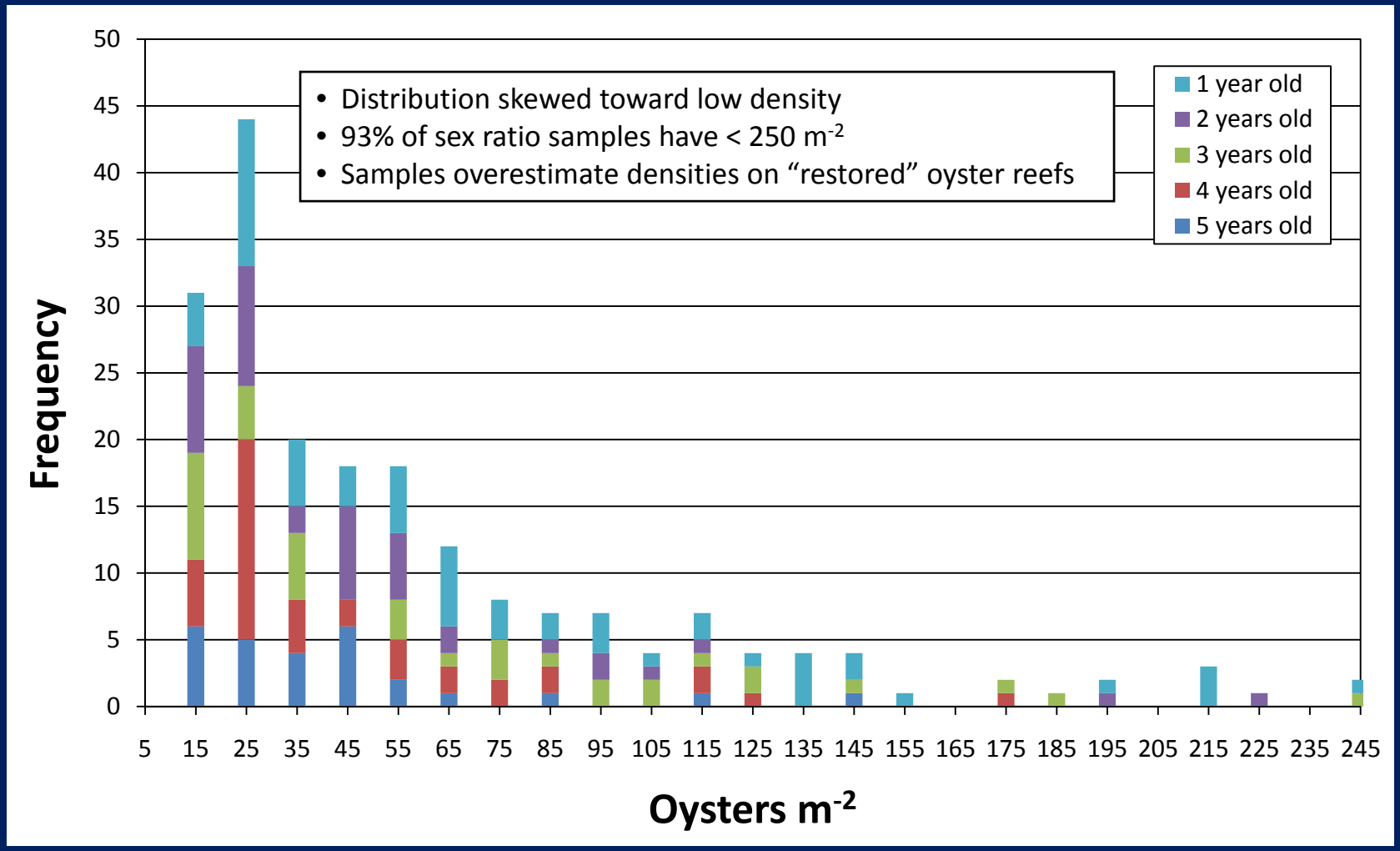
Distance vs. Fertilization Success

- Unknown for oysters
  - Mann and Evans (1998)
    - Calculations based work with sea urchins by Levitan (1991)



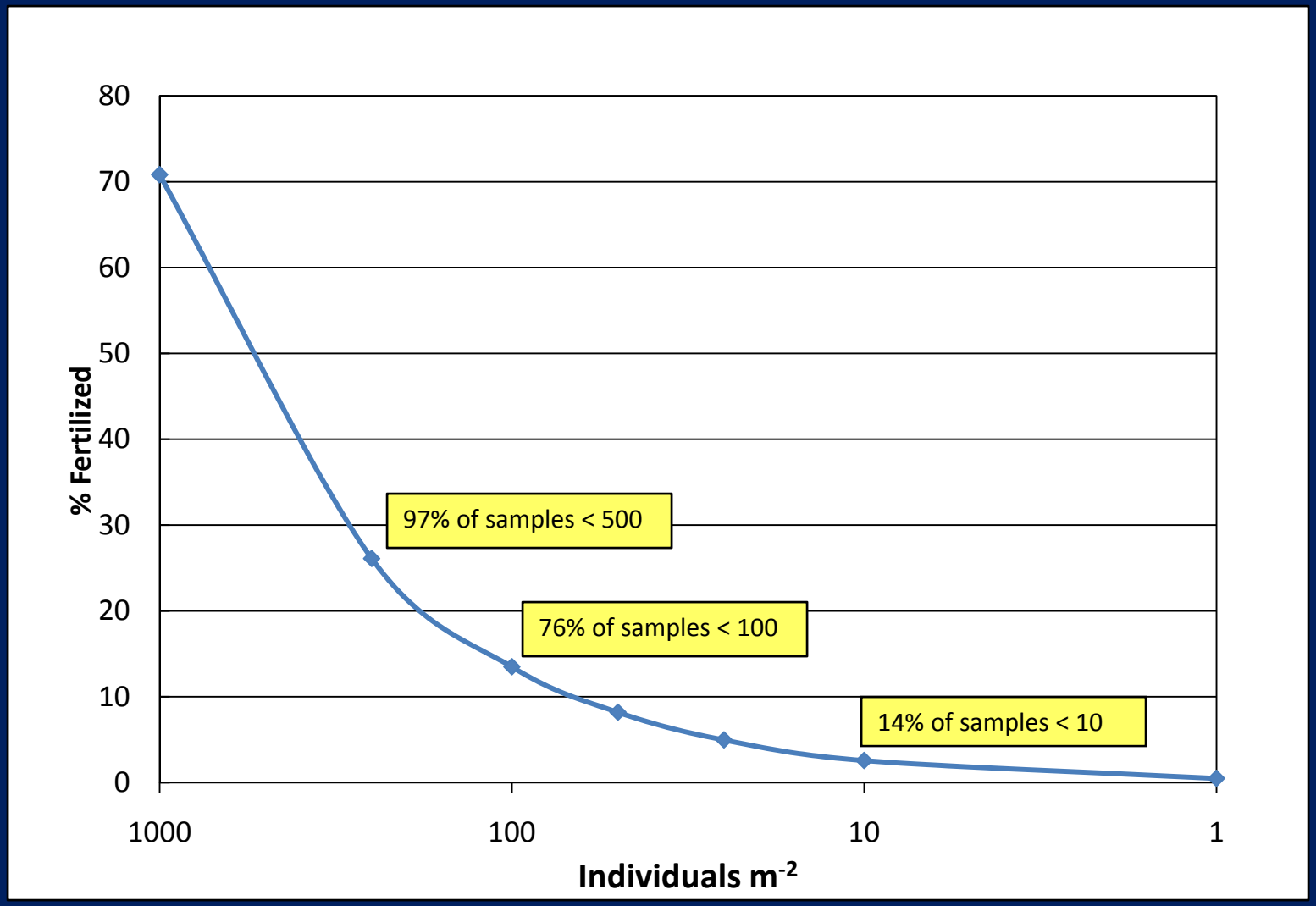
Oyster Densities

- Oyster densities on natural bars ≤ 1 m^{-2}
- Even “restored” reefs have relatively low densities of oysters



Density and Fertilization Success

- Based on densities from sex ratio samples



Conclusions

- Field populations of *C. virginica* may be sperm-limited in some cases
  - Greater proportion of females as oyster age
  - Oyster reefs restored using a single year class in areas with very low levels of recruitment
  - Natural oyster populations in areas with very low levels of recruitment
- Rates of fertilization success in the field are likely to be low
  - Sperm to egg ratio of ≥ 1000:1 need for optimal fertilization success in lab experiments
    - Likely represent “best case” scenario
  - Relatively low densities of oysters even on restored reefs
    - Increasing distance between individuals with decreasing oyster populations
    - Has likely resulted in decreasing larval production

Potential for Population-Level Impacts of EDs

- Rates of larval production may be sensitive to *anything* that shifts absolute or relative gamete concentrations
  - Must consider impact of sperm concentrations
- Impacts on true males may be of particular interest
  - Could be important for preventing sperm-limitation
- Populations in low salinity areas may be particularly susceptible
  - Infrequent recruitment
  - Often closest to significant potential sources of EDs

Implications for Oyster Reef Restoration

- Restoration will depend heavily upon natural larval production and successful recruitment
- EDs have the potential to limit success of restoration efforts
  - Fecundity
  - Gamete viability
  - Sex ratios
- Additional information is needed to determine whether ED levels should be incorporated into restoration planning
  - Are EDs likely to have significant impacts at concentrations observed in the field? Are some EDs of greater concern than others?
  - Which parts of the oyster life cycle are most sensitive to EDs?
  - Which EDs are most common in areas targeted for restoration?

Acknowledgements:

- Sex ratio studies
  - Marcy E. Chen
  - Victor S. Kennedy
  - C. Paul Miller
  - Sara E. Rowland
  - Richard T. Paynter
  - Kennedy C. Paynter
  - Nancy J. Ward
  - Dawn Goldsmith
  - Mark W. Sherman
  - Jacob D. Goodwin
  - Christopher P. McIntyre
  - Steven Allen