Robustness of sexual partnerships and its impact on the spread of sexually transmitted infections

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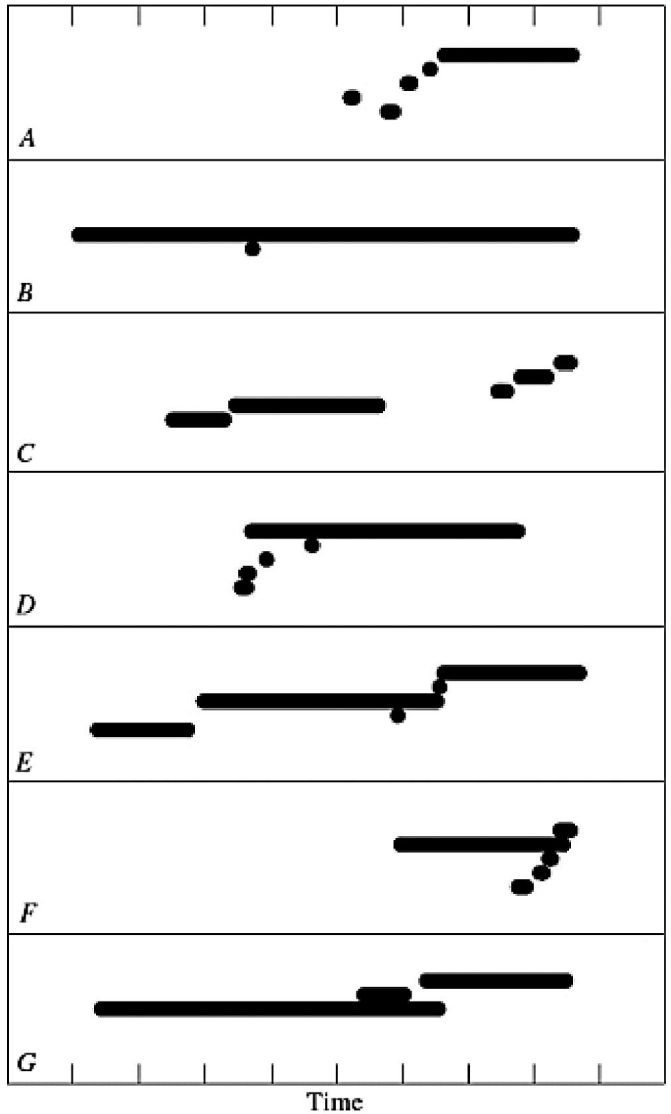
Sexual partnerships

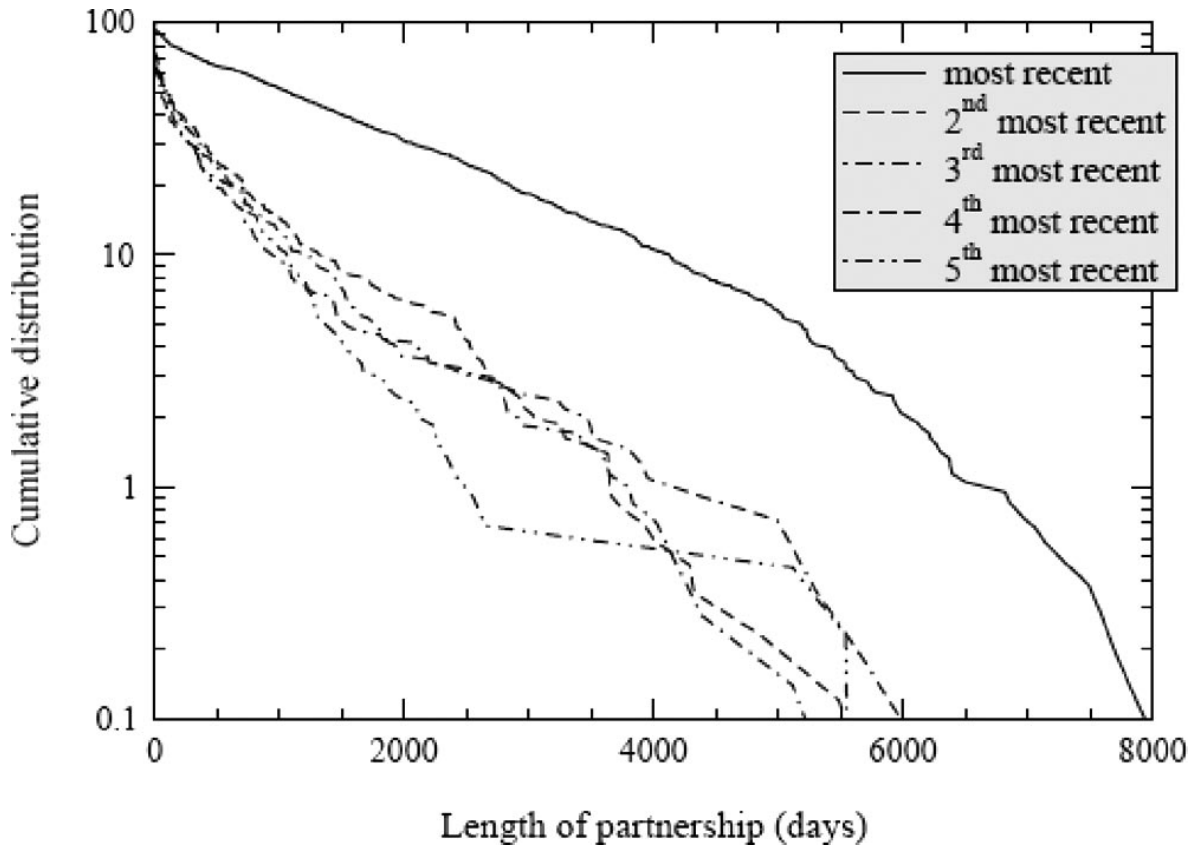
- Sexual partnerships are the key unit where sexually transmitted infections (STIs) are passed on
- Mathematical models of STI transmission often assume static sexual networks or that sexual partnerships happen instantaneously
- Sexual partnerships last for a certain duration which can be inferred from population-based probability sample surveys of sexual behavior
- How do STIs spread in dynamic sexual networks with realistic sexual partnership durations?

Sexual partnership histories



Foxman et al. (2006) Sex Transm Dis

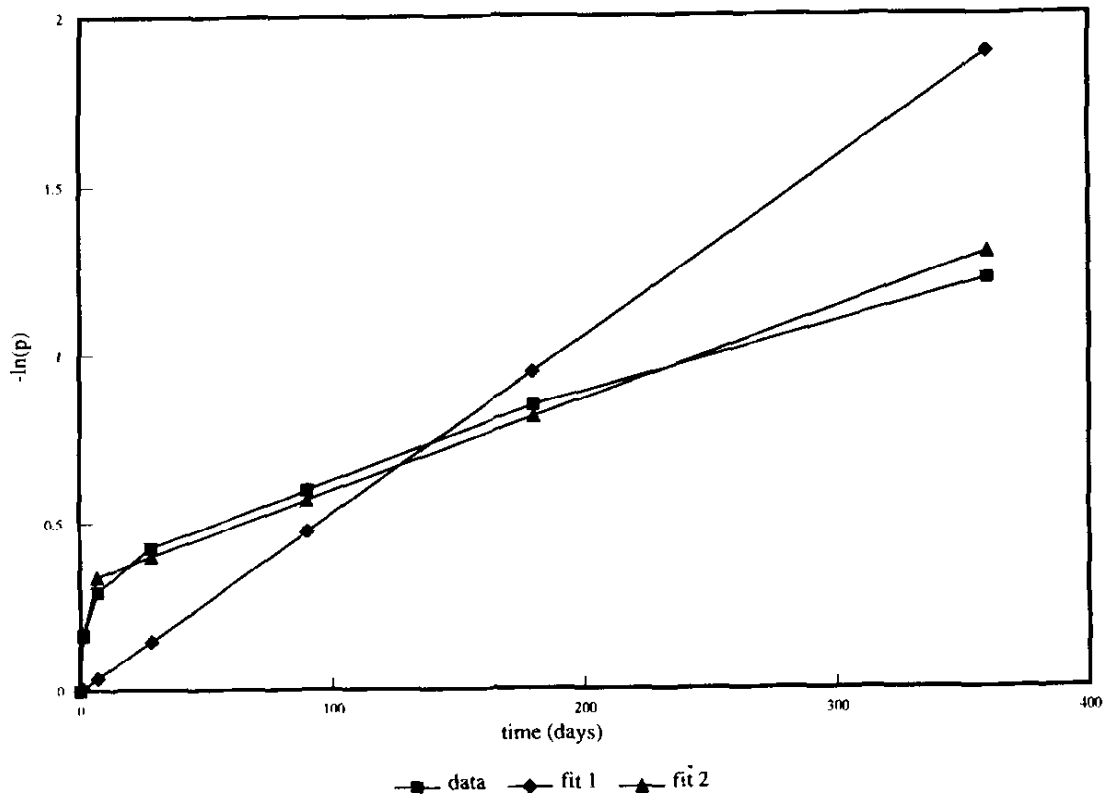
Distribution of sexual partnerships durations



"Each of the distribution appears to be roughly linear on the semilogarithmic scales used in the figure, indicating an exponential distribution."

Foxman et al. (2006) Sex Transm Dis

Distribution of sexual partnerships durations



"A hypothesis that could explain this form of the survival curves is that there are two types of partnerships, both with exponentially distributed survival times (...): casual partnerships with a short average duration and steady partnerships with a long average duration."

Kretzschmar et al. (1994) Math Biosci

Moving away from exponential distributions

- Exponentially distributed sexual partnership durations imply that partnerships break up with a constant hazard rate

- **Hypothesis:**
  Sexual partnerships become more stable with ongoing duration

- Weibull distributions can take this property into account

Weibull distribution

The probability density function of a Weibull random variable *x* is:

$$f(x;\lambda,k) = \begin{cases} \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-(x/\lambda)^k} & x \geq 0, \\ 0 & x < 0, \end{cases}$$

where $k > 0$ is the **shape parameter** and $\lambda > 0$ is the **scale parameter** of the distribution.

A value of $\boldsymbol{k < 1}$ indicates that the **failure rate decreases** over time.

For $\boldsymbol{k = 1}$, the Weibull distribution corresponds to an **exponential distribution** with a mean of λ.

from: http://en.wikipedia.org/wiki/Weibull_distribution

Analyzing sexual partnership durations

- Data from **Natsal 2000**[1], a population-based (16-44 year olds) probability sample survey of sexual attitudes and lifestyles in Britain (n = 11,161)

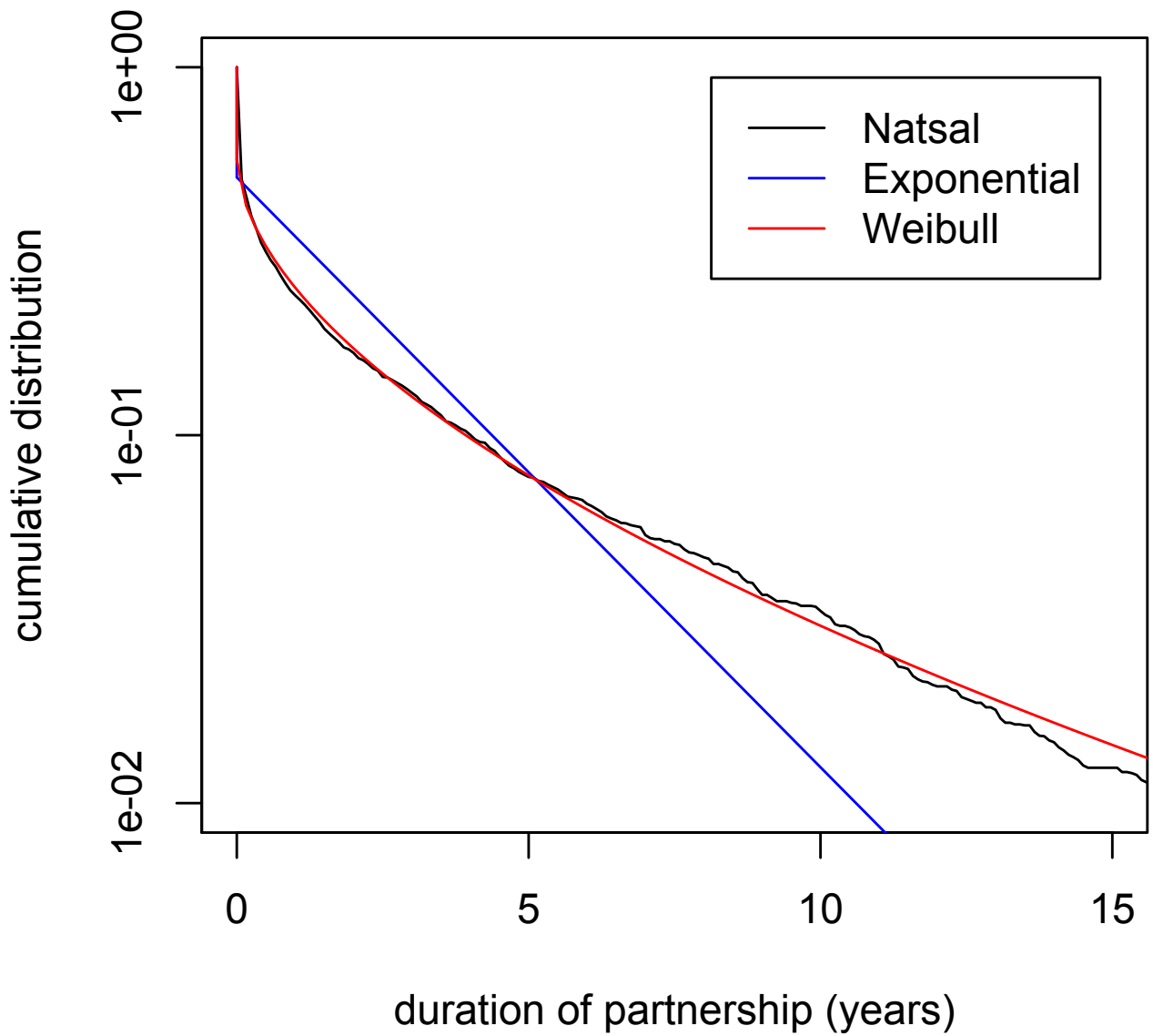
- Duration of second most recent partnerships are used to limit potential biases such as left-truncation (oversampling of long partnerships)

- Correction for rounding effect since time of first and last sexual intercourse with a partner are given in months

- **Maximum likelihood estimation** of sexual partnership durations using models that include one-night stands and either exponentially or Weibull distributed partnership durations

[1] *Johnson, AM et al. (2001) Lancet*

Fitting sexual partnership durations

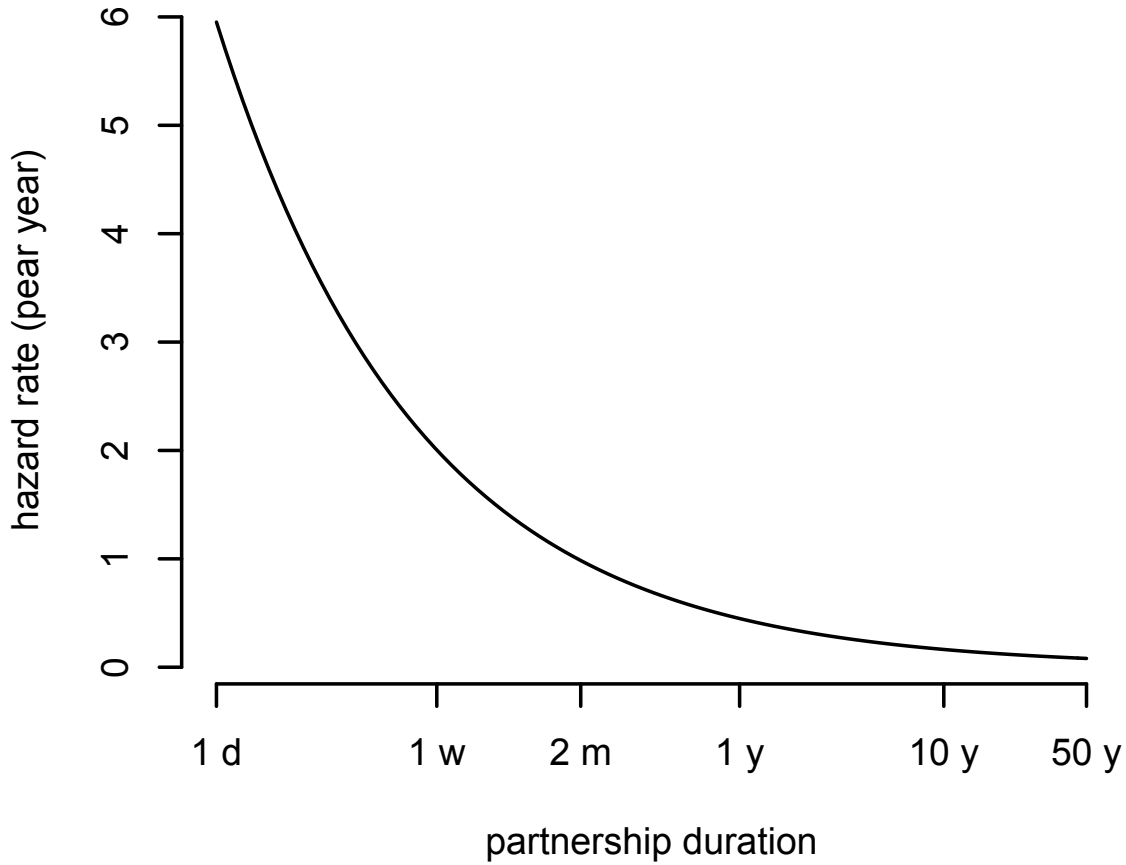


Fitting sexual partnership durations: Model comparison and estimates

Model	Properties					Proportion of one-night stands	Mean duration of partnerships
	Number of parameters	Degrees of freedom	- 2*LL	AIC	BIC	%	Years
One-night stand and one exponential	2	3898	22678.4	22682.4	22694.9	49.8 %	1.360 years
Two exponentials	3	3897	22460.4	22466.4	22485.2	-	1.358 years
One-night stand and Weibull	**3**	**3897**	**21861.1**	**21867.1**	**21885.9**	**44.0 %**	**1.375 years**
One-night stand and two exponentials	4	3896	21855.7	21863.7	21888.8	48.2 %	1.362 years

Robustness in sexual partnerships

The best fit model (44% one-night stands and a Weibull distribution with shape parameter k = 0.56) supports the hypothesis that sexual partnerships become more stable with ongoing duration.



Simulating sexual partnership networks

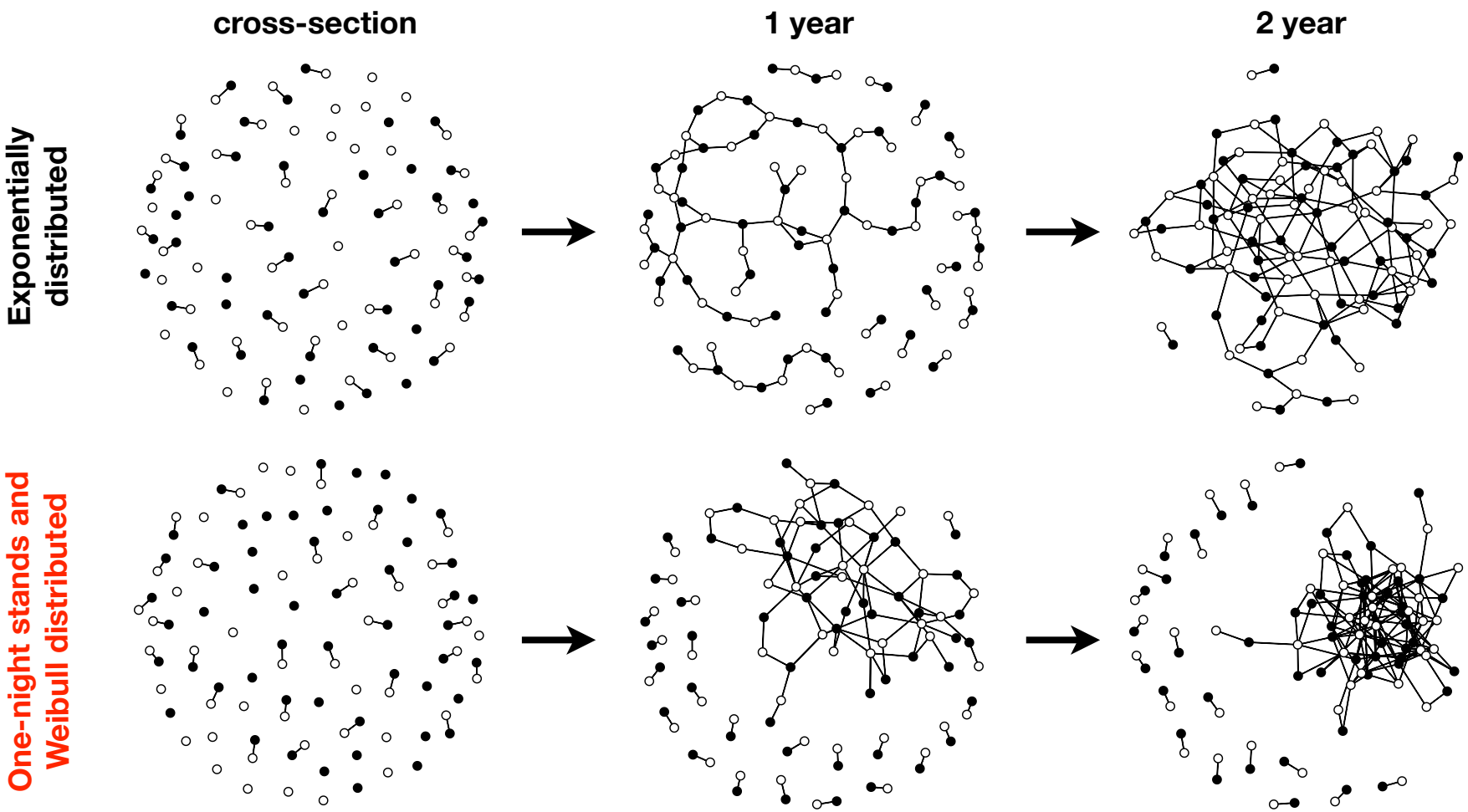
- With an individual-based modeling framework called *Rstisim*[1], we can simulate the dynamic sexual partnership network

- We compare the emerging sexual networks from three different models of sexual partnership duration:
  - Exponentially distributed partnership durations (standard scenario)
  - One-night stands and exponentially distributed partnerships
  - One-night stands and Weibull distributed partnerships

- The average duration of sexual partnerships and the total number of contacts remain the same in the different models

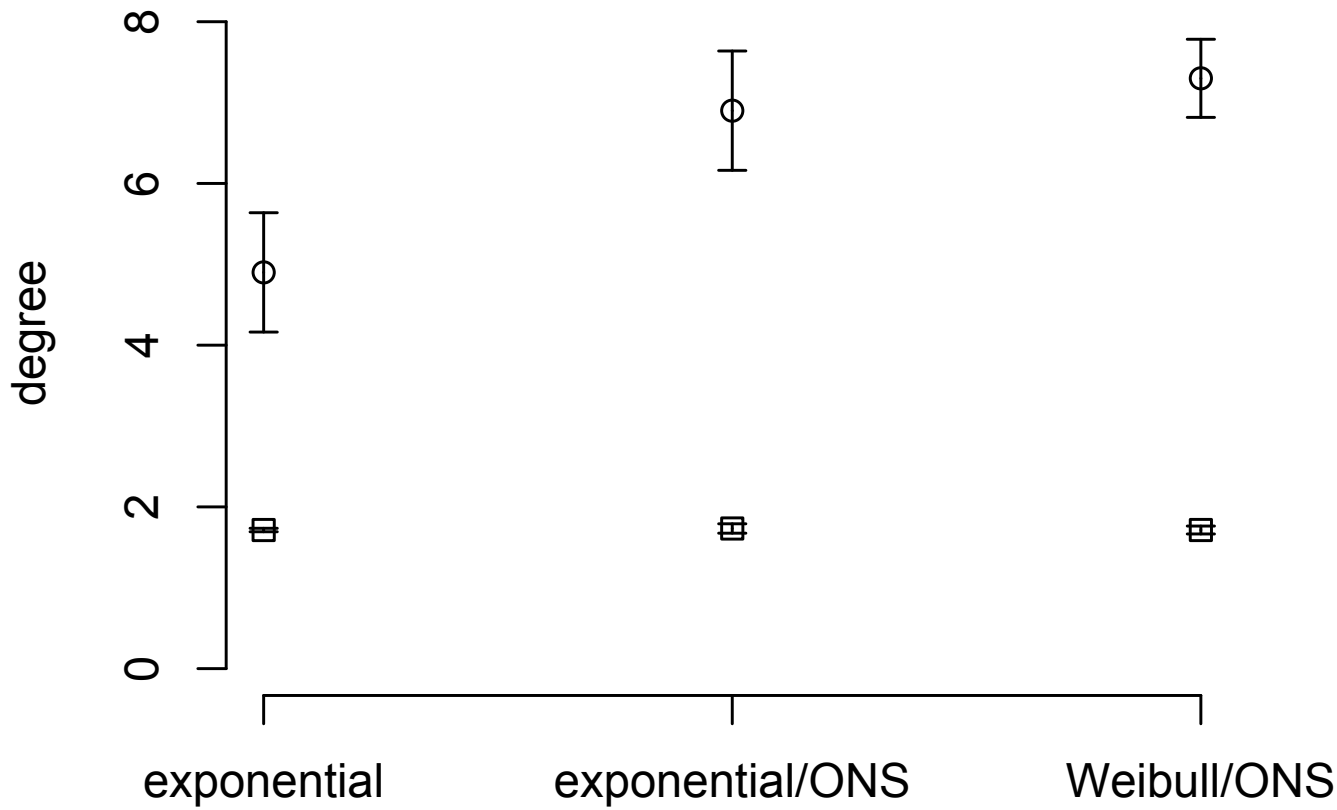
[1] *Althaus et al., manuscript in preparation*

Sexual partnership networks



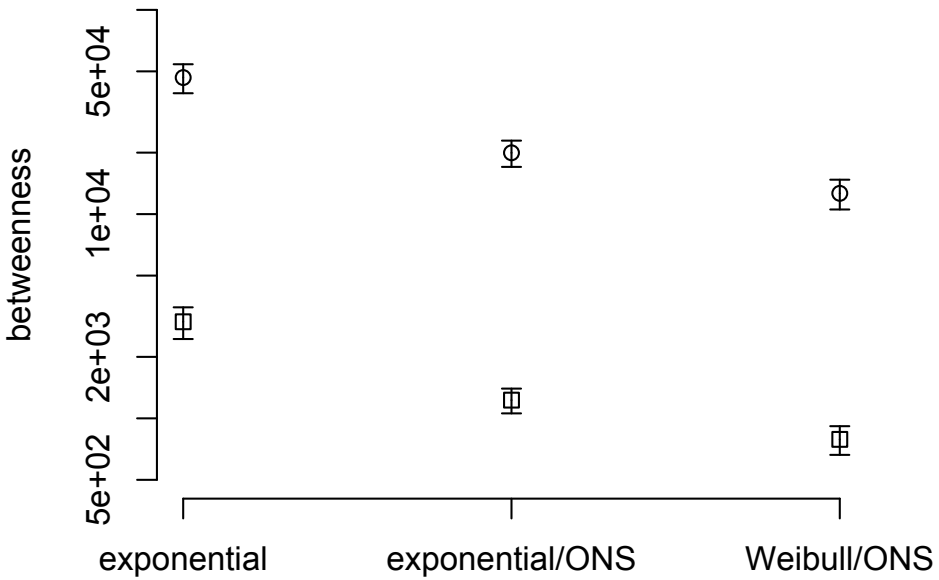
Realistic sexual partnership durations result in **small and highly connected components**.

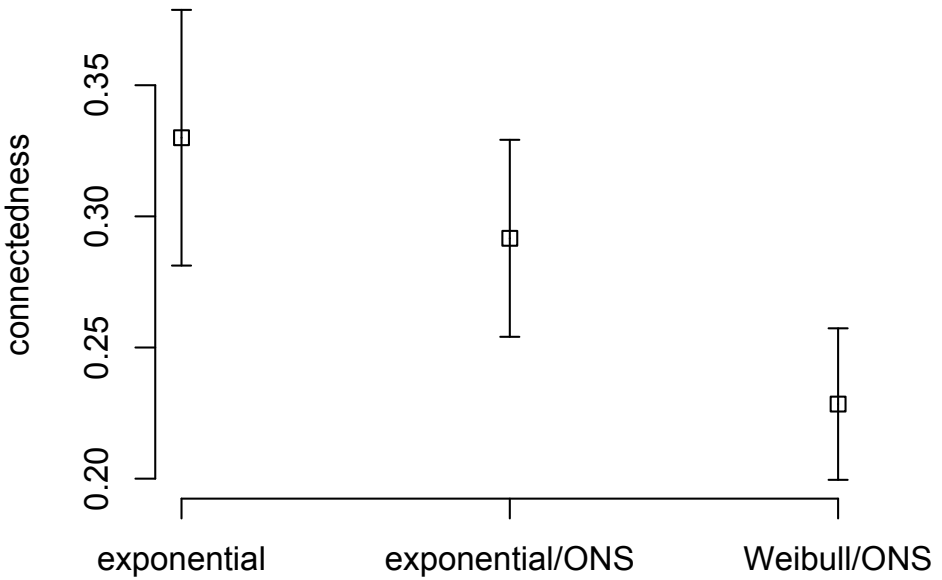
Sexual partnership networks: Degree distribution



Weibull distributed sexual partnership durations result in a **higher variance in the degree distribution**.

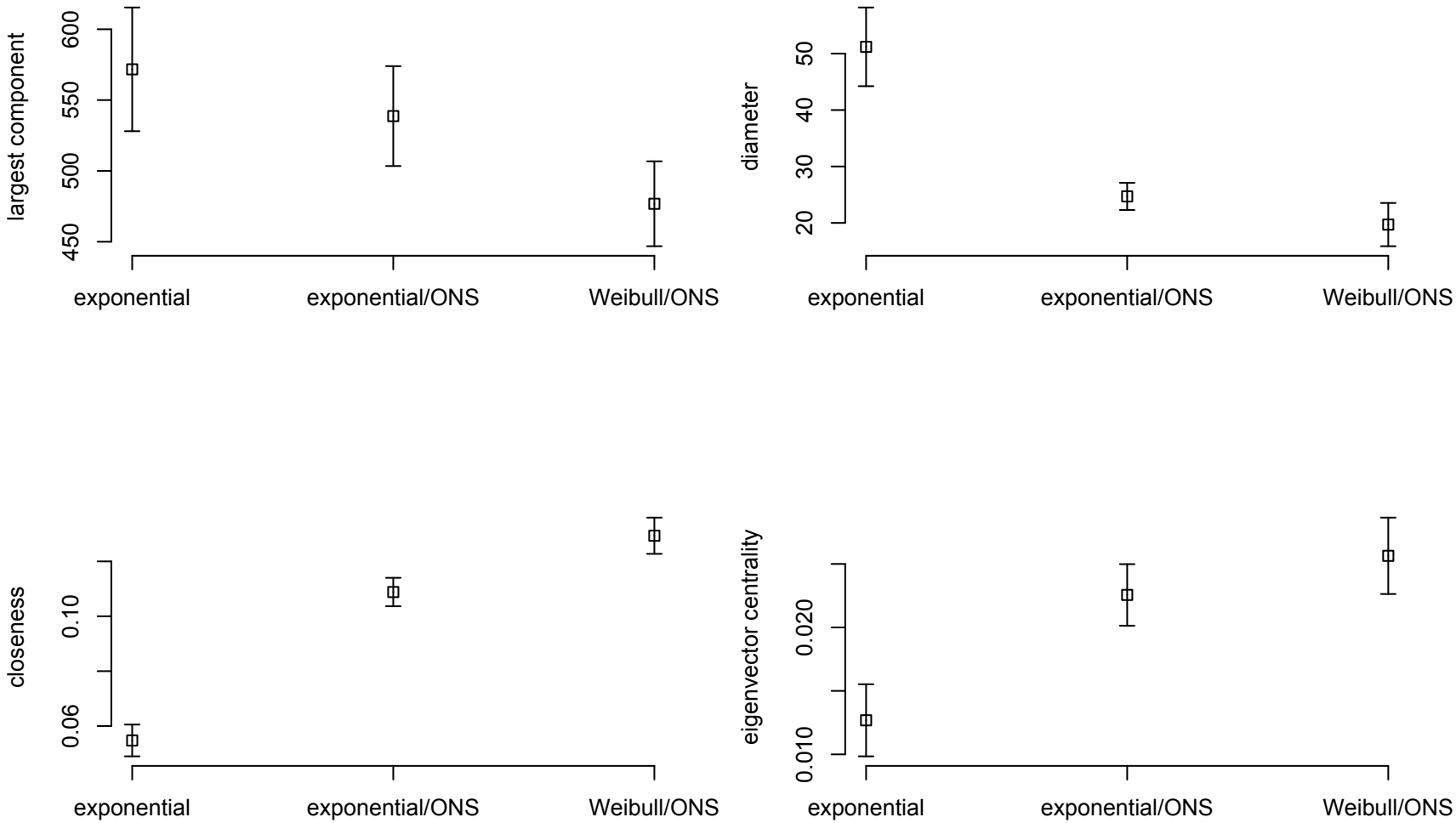
Sexual partnership networks: Betweenness and connectedness





Weibull distributed sexual partnership durations result in **sexual networks that are less strongly connected**.

Sexual partnership networks: Largest component

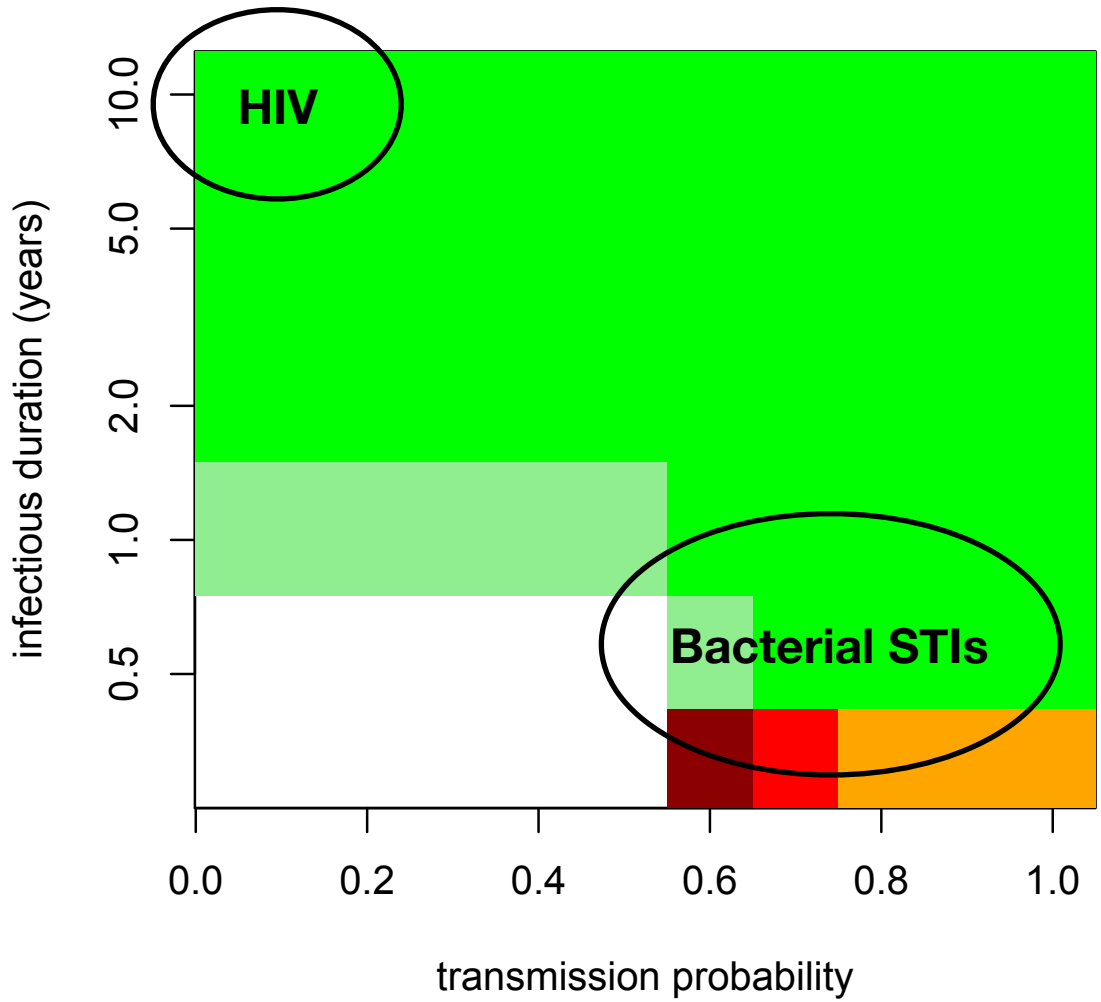


The size of the largest component decreases but is more highly connected if partnerships are Weibull distributed.

Transmission of STIs through sexual partnership networks

- How do realistic distributions of sexual partnership durations affect the transmission of STIs?
- Comparing the standard scenario (partnerships follow a single exponential distribution) with the more realistic scenario that also includes one-night stands
- In both scenarios, the total number of partners, the average duration of sexual partnerships and the realized number of sex acts are equal

Transmission of STIs through sexual partnership networks



Green: Transmission is reduced for realistic sexual partnerships

Red/orange: Transmission is increased for realistic sexual partnerships

Conclusions

- Sexual partnership durations are best described by a Weibull distribution, indicating **increased robustness** with ongoing duration
- Realistic sexual partnership durations result in **heterogeneous sexual networks** with small but highly connected components
- Transmission of most STIs is constrained if realistic distributions of sexual partnership duration are taken into account
- Sexual partnership durations are a critical component of STI transmission and should be considered when modeling the impact of preventive interventions against STIs

Acknowledgements

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