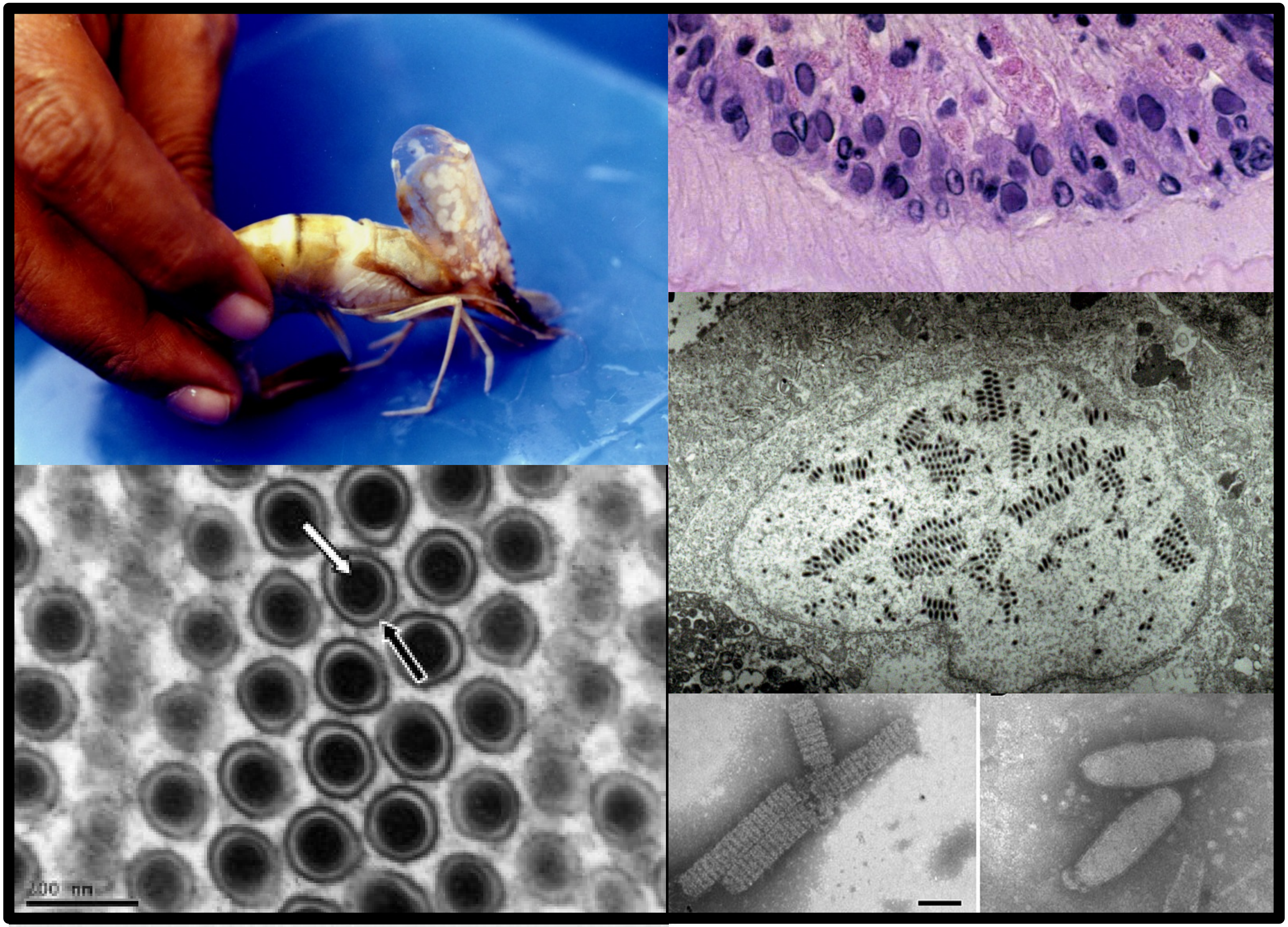
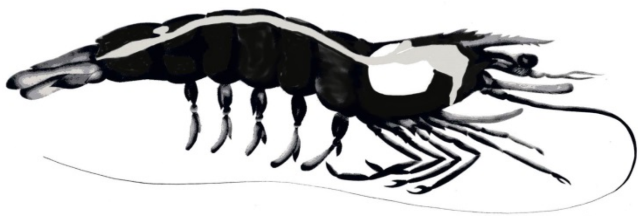
WSSV - White spot syndrome virus

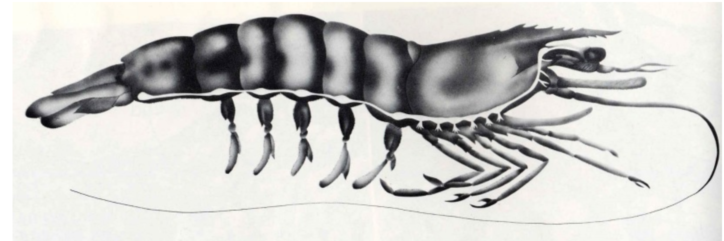


Decapod anatomy

Digestive tract

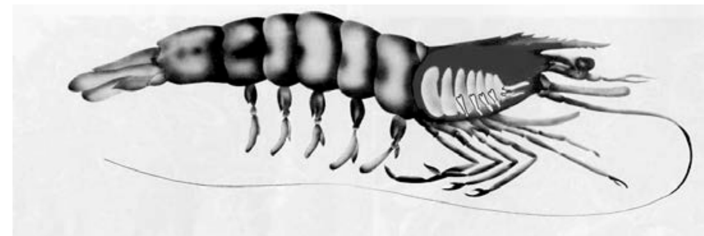


Ventral Nerve chord

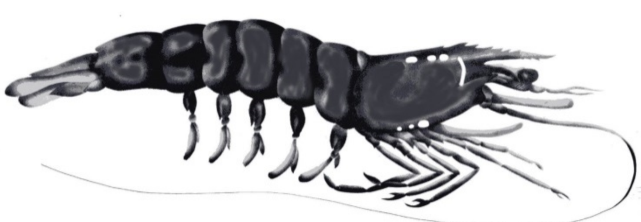


Circulatory system

Respiratory system

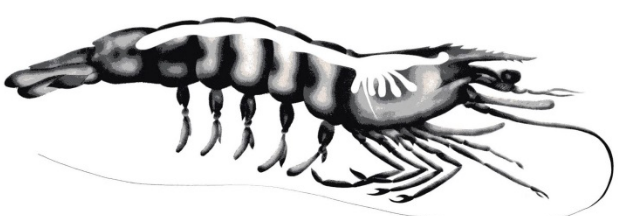


Hematopoietic tissue



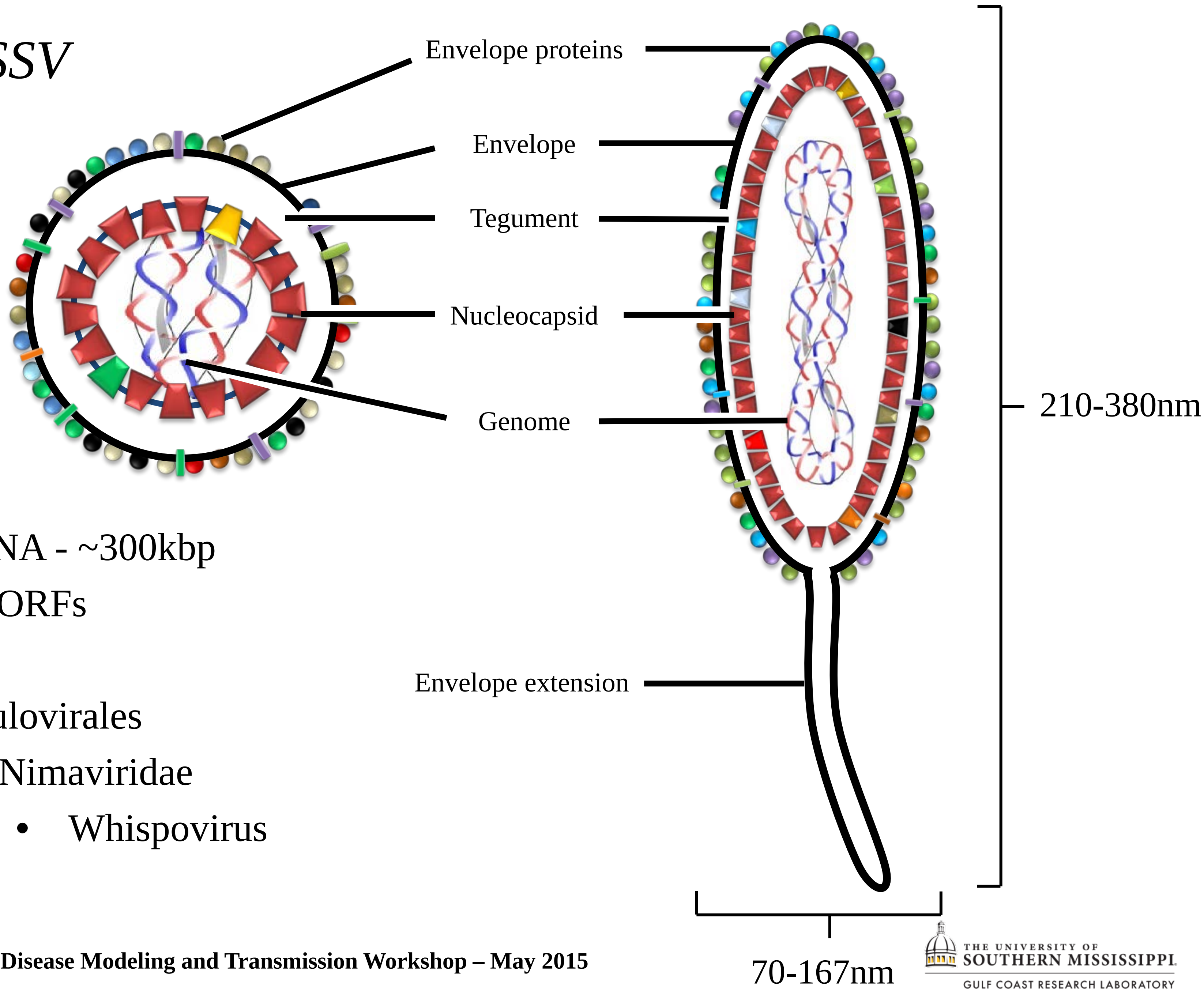
Lymphoid organ

Female reproductive tract



Male reproductive tract

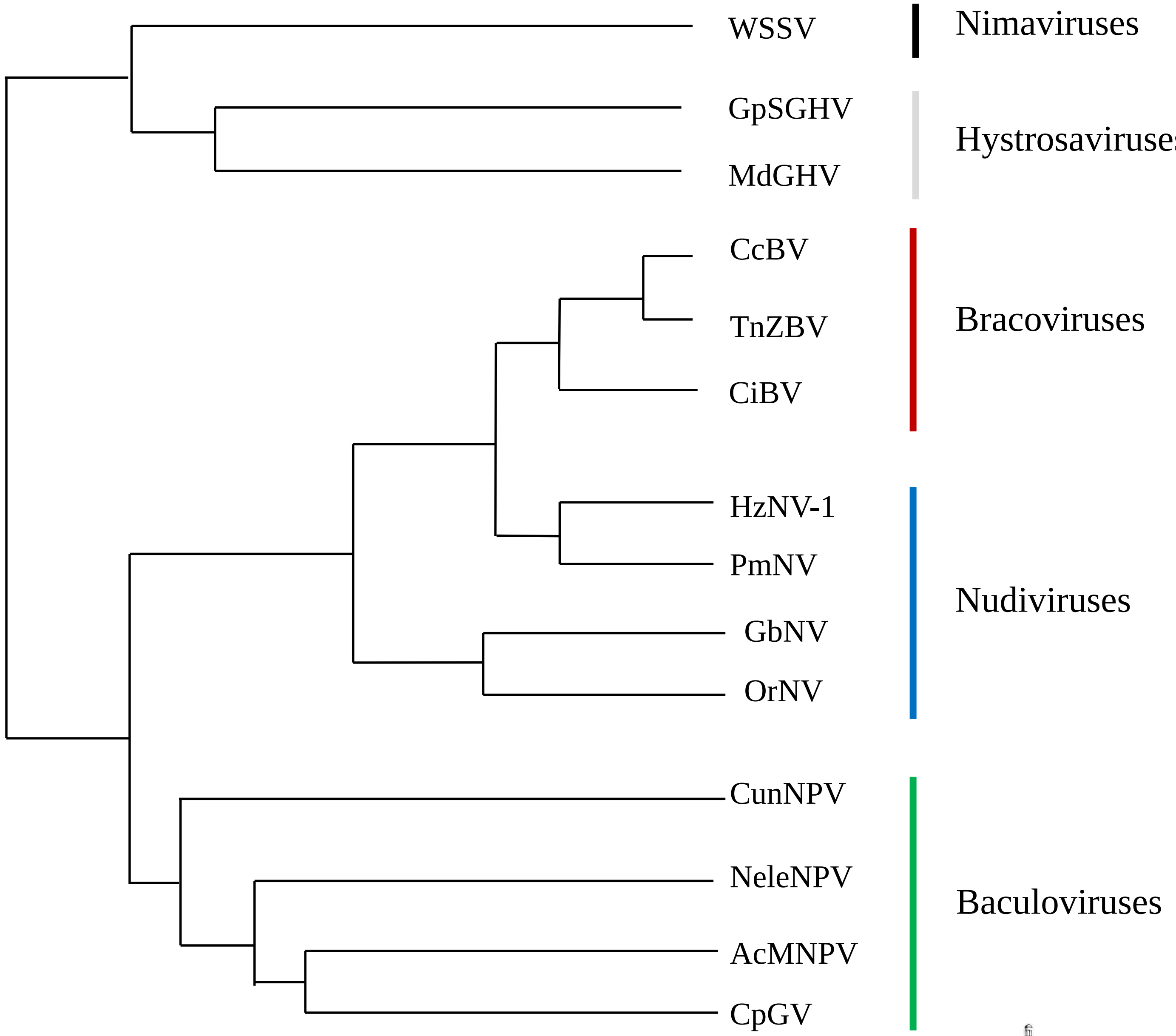
WSSV



- dsDNA - ~300kbp
- 185 ORFs

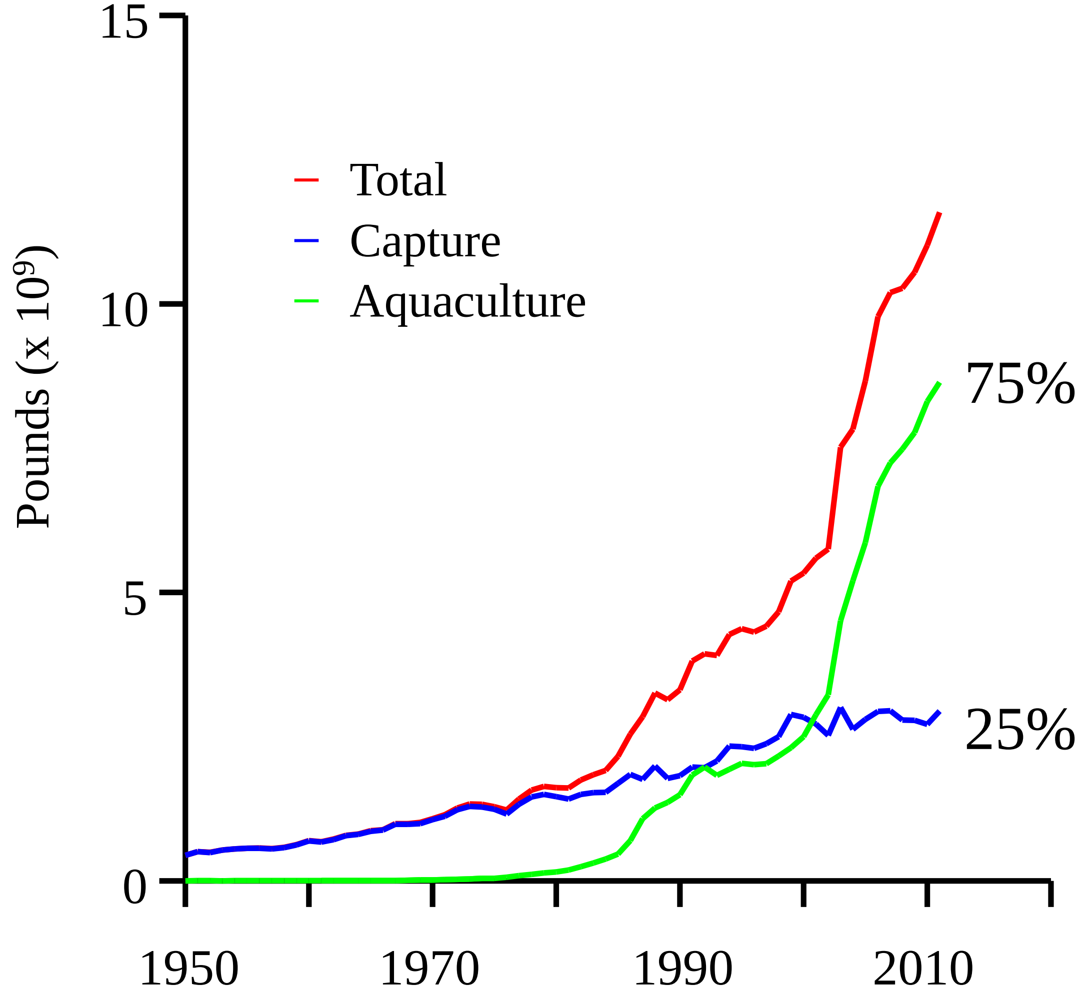
- Baculovirales
  - Nimaviridae
    - Whispovirus

“Baculovirales”



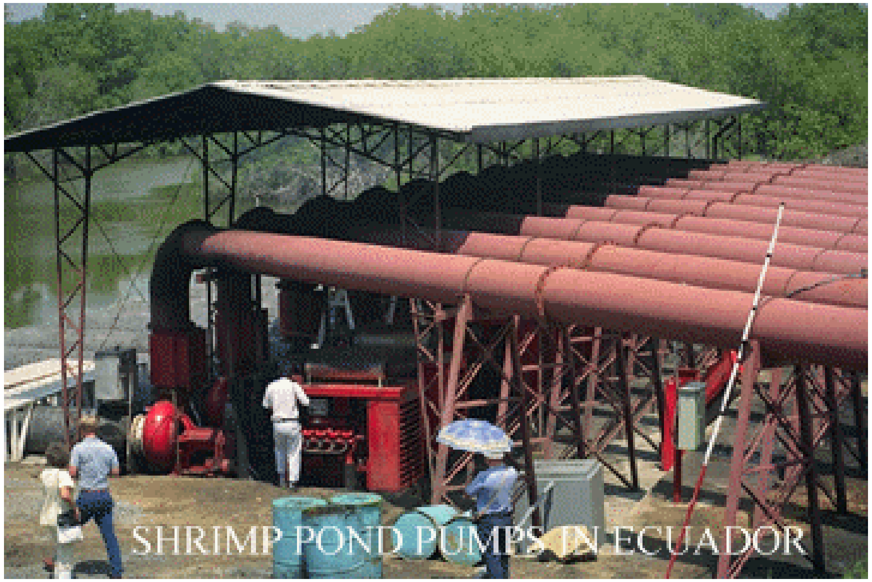
Wang Y, Jehle JA 2009. *JIP* 101: 187-193; Wang Y et al 2011. Vir Gen 42:444 – 456; Thézé J et al. 2011. PNAS ;108:15931-35

World's Production of Penaeid Shrimp



Source: FAO

Shrimp commodity production



Shrimp Aquaculture Species

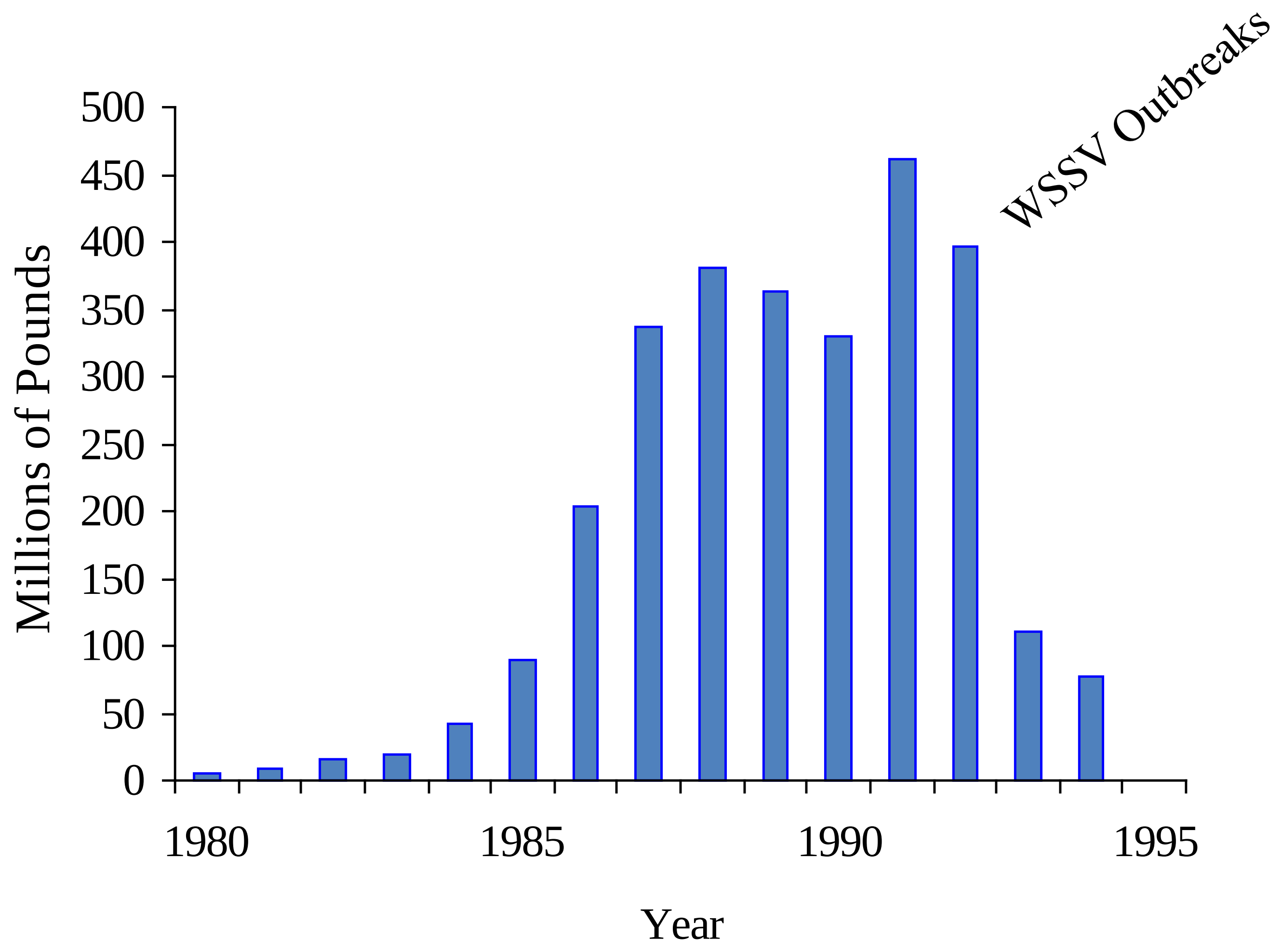
Litopenaeus vannamei

Penaeus monodon

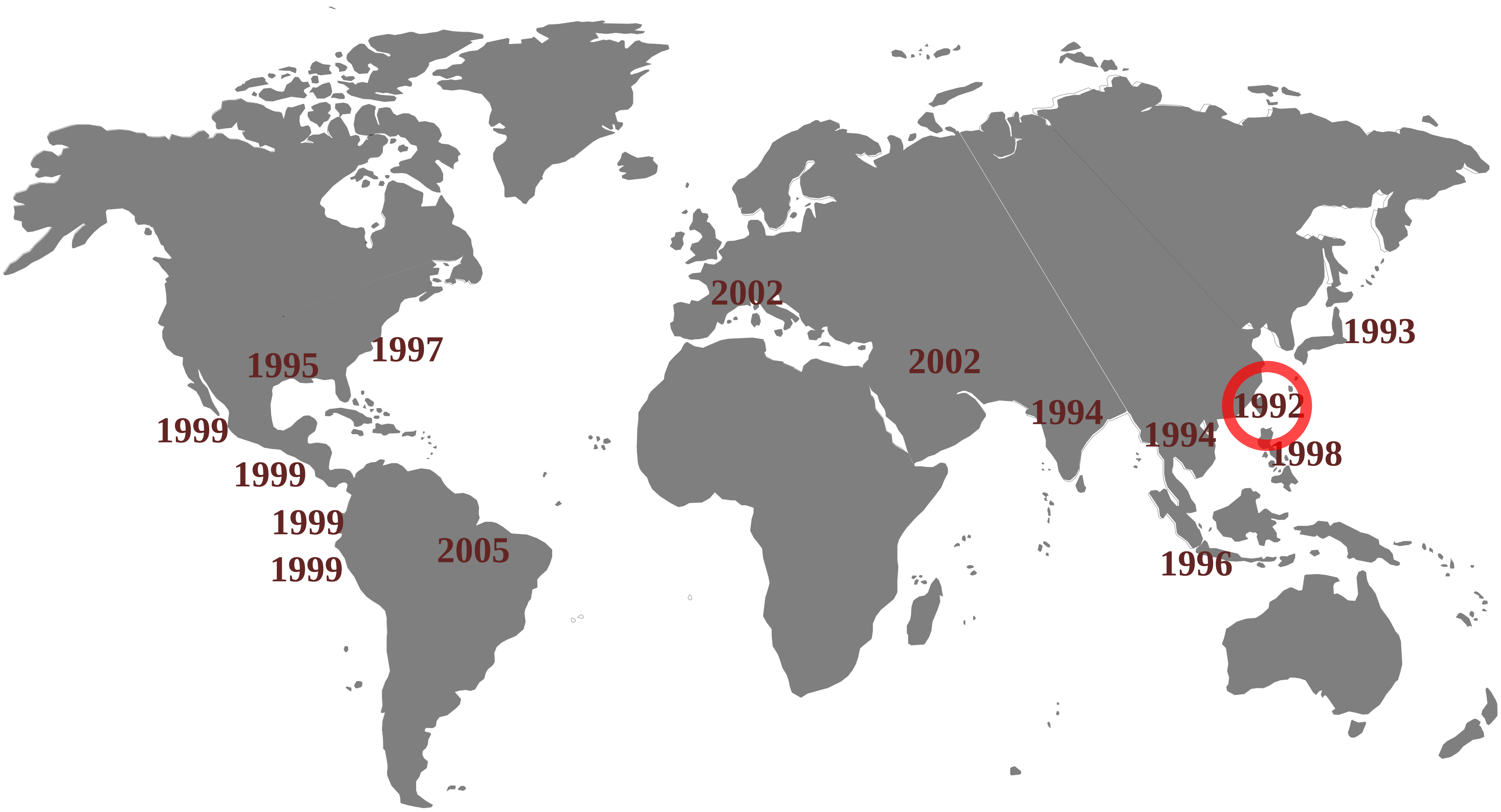
Fenneropenaeus chinensis

Marsupenaeus japonicus

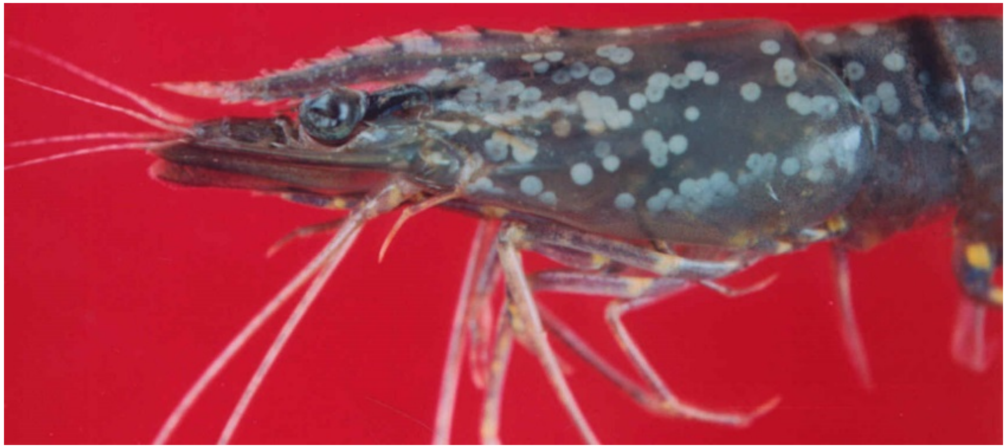
Production of Farmed Shrimp - China



Spread of WSSV



Emergence of White spot syndrome virus



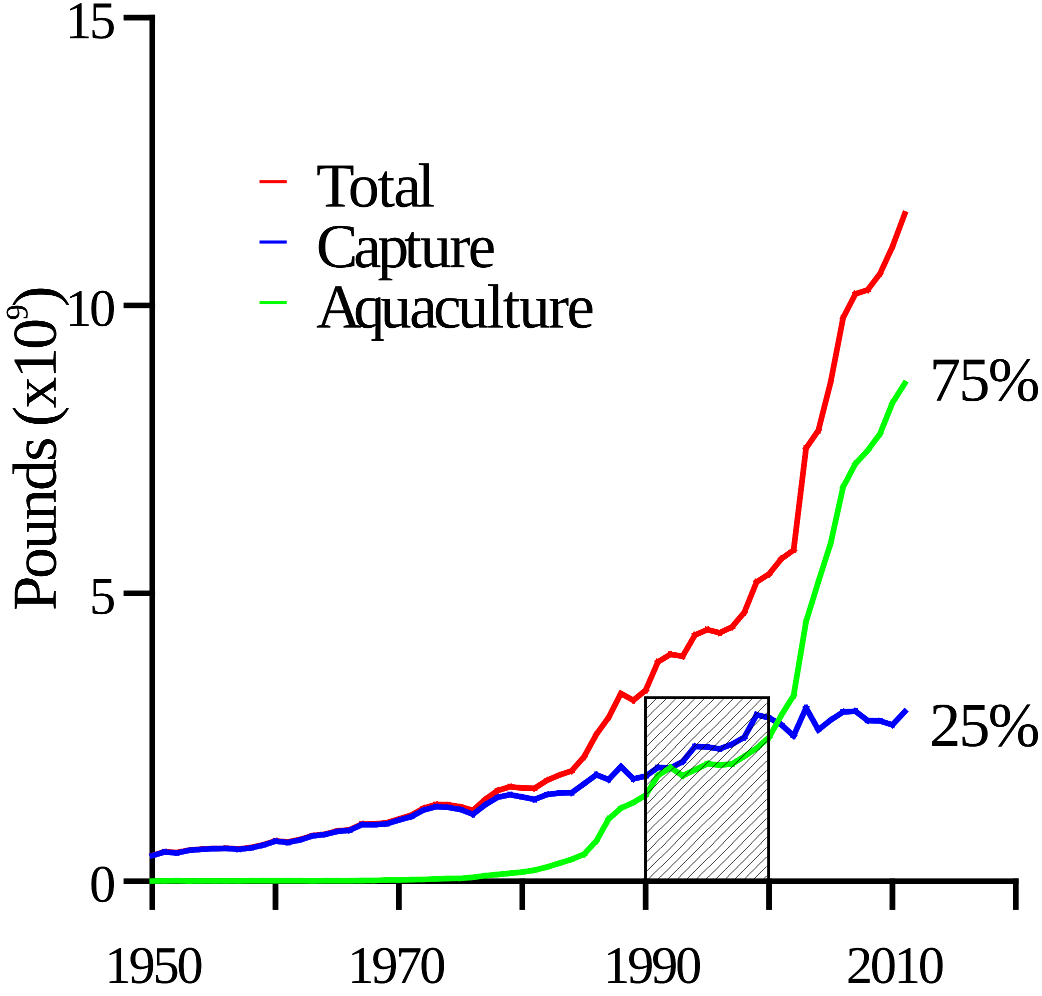
Emergence of White spot syndrome virus

1. Environment changes bringing new contacts
   More shrimp
   Ponds built in new areas – where shrimp never were or in low numbers
   More contact between other (terrestrial) arthropods and shrimp

2. Change in pathogen virulence

3. Introduced from elsewhere

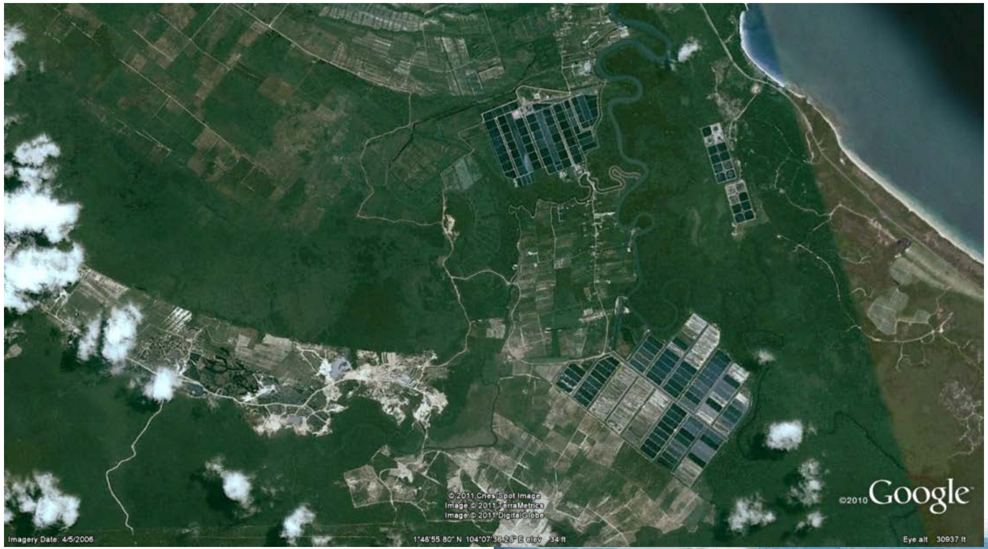
World's Production of Penaeid Shrimp



Source: FAO

More shrimp – more places

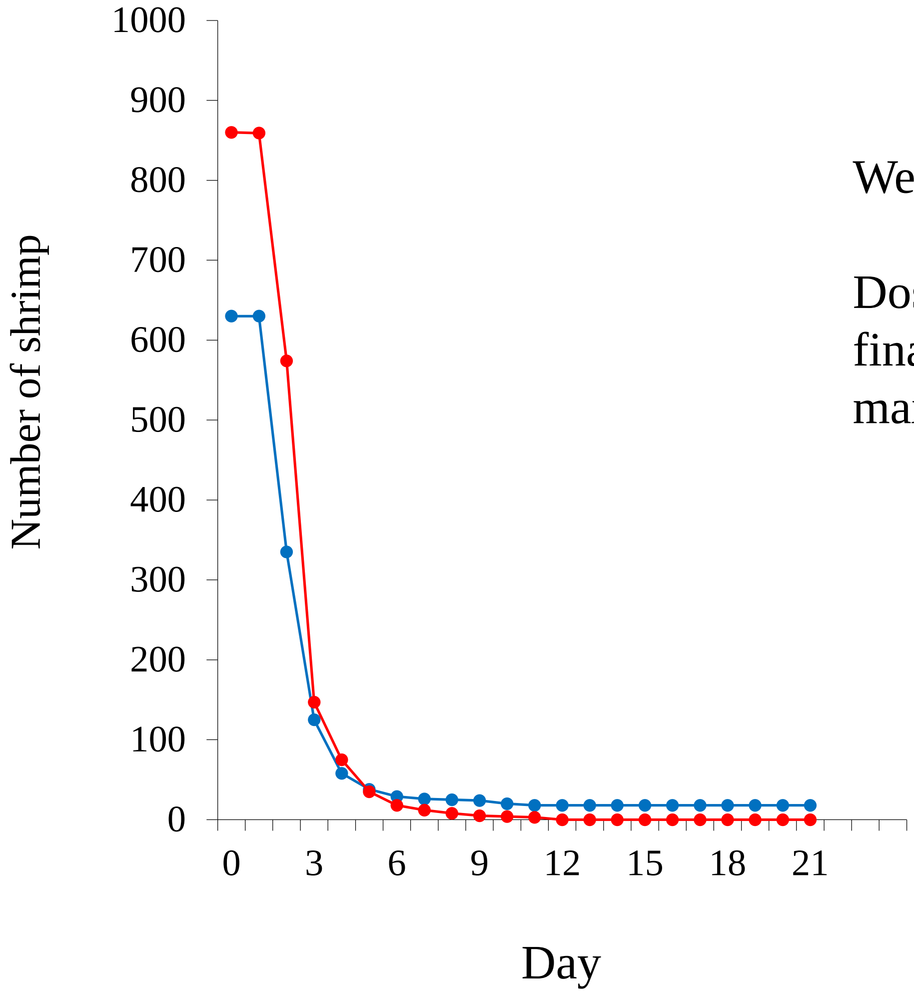
Greater opportunity for contact between shrimp and other arthropods



Hosts of WSSV

- **Shrimp**
  - ***Penaeus***
    - ***monodon***
    - ***semisulcatus***
  - ***Farfantepenaeus***
    - ***aztecus***
    - ***duorarum***
  - ***Fenneropenaeus***
    - ***chinensis***
    - ***indicus***
    - ***merguensis***
    - ***penicillatus***
  - ***Marsupenaeus***
    - ***japonicus***
  - ***Litopenaeus***
    - ***vannamei***
    - ***stylirostris***
    - ***setiferus***
  - ***Metapenaeus ensis***
  - ***Exopalaemon***
    - ***orientalis***
  - ***Macrobrachium spp.***
  - ***Palaemon styliferuus***
  - ***Palaemonetes pugio***
- **Crab**
  - ***Calappa lophos***
  - ***Charybdis***
    - ***feriata***
    - ***natotor***
  - ***Helice sp.***
  - ***Portunus***
    - ***pelagicus***
    - ***Sanguineolentus***
  - ***Callinectes sapidus***
  - ***Armasus cinereum***
  - ***Scylla serrata***
  - ***Sesarma spp.***
  - ***Sommanniathelpusa sp.***
  - ***Thalamita sp.***
  - ***Uca spp.***
  - ***Menippe adina***
- **Lobster**
  - ***Panuluris***
    - ***longipes***
    - ***ornatus***
    - ***argus***
- **Crayfish**
  - ***Procambarus clarkii***
  - ***Cherax quadricarinatus***

WSSV Litopenaeus vannamei



Weight 3 g

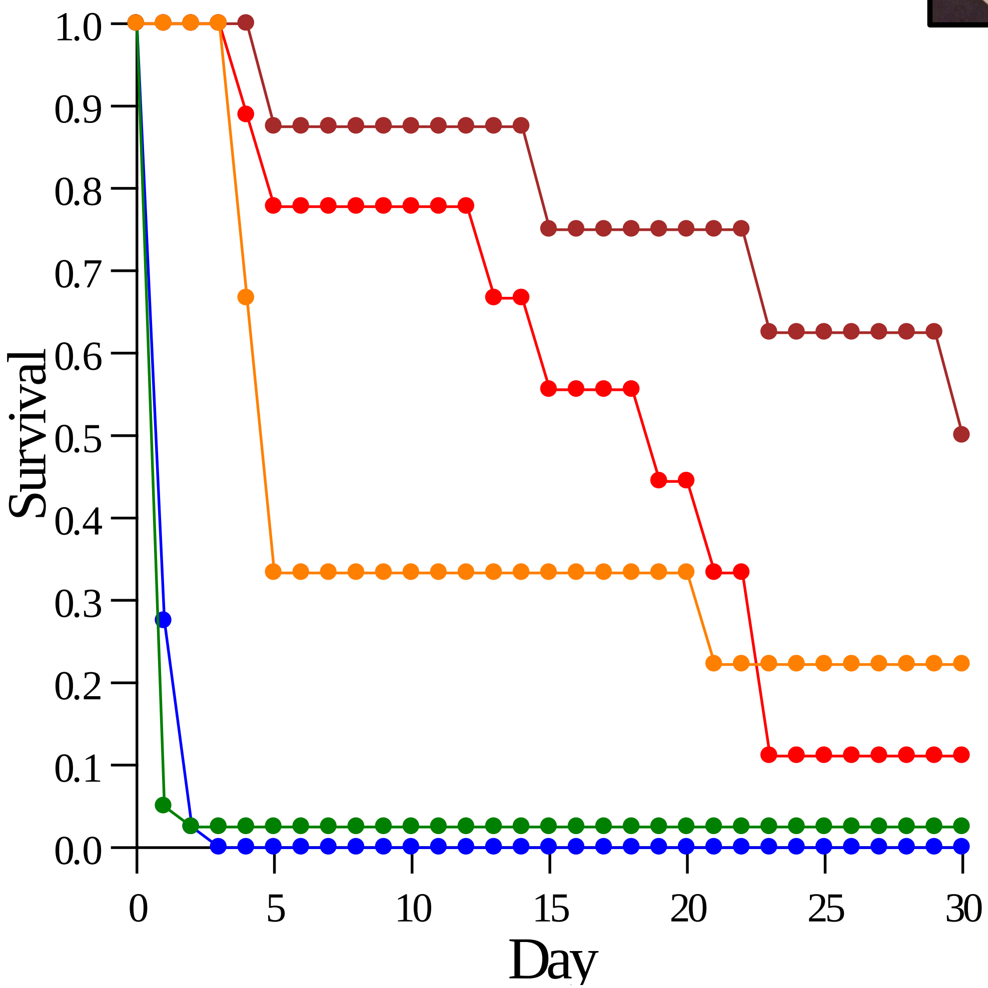
Density 550/m^3

Dose 0.03 bw

final survival 0.00, 0.03

max daily mortality 1.0 ,0.6

Local decapods exposed to WSSV (China)



Uca panacea

Armasus cinereum

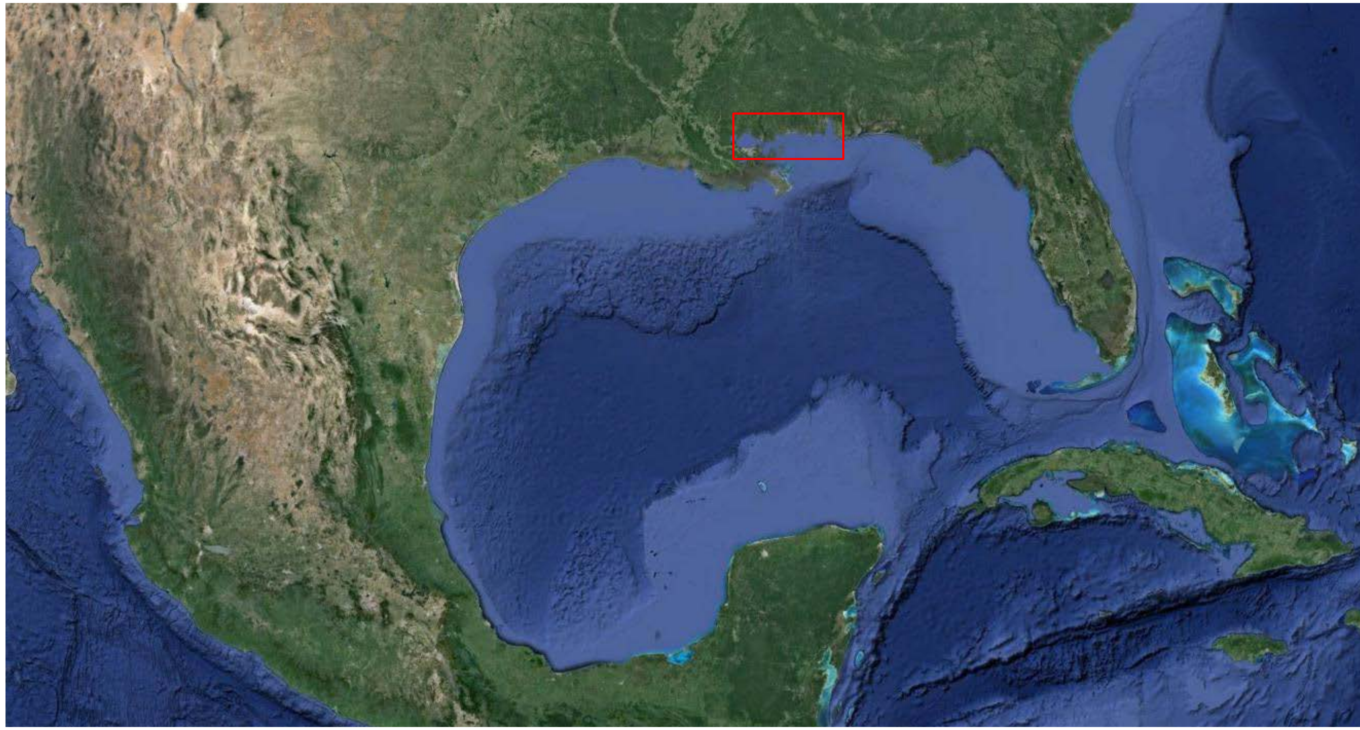
Uca speciosa

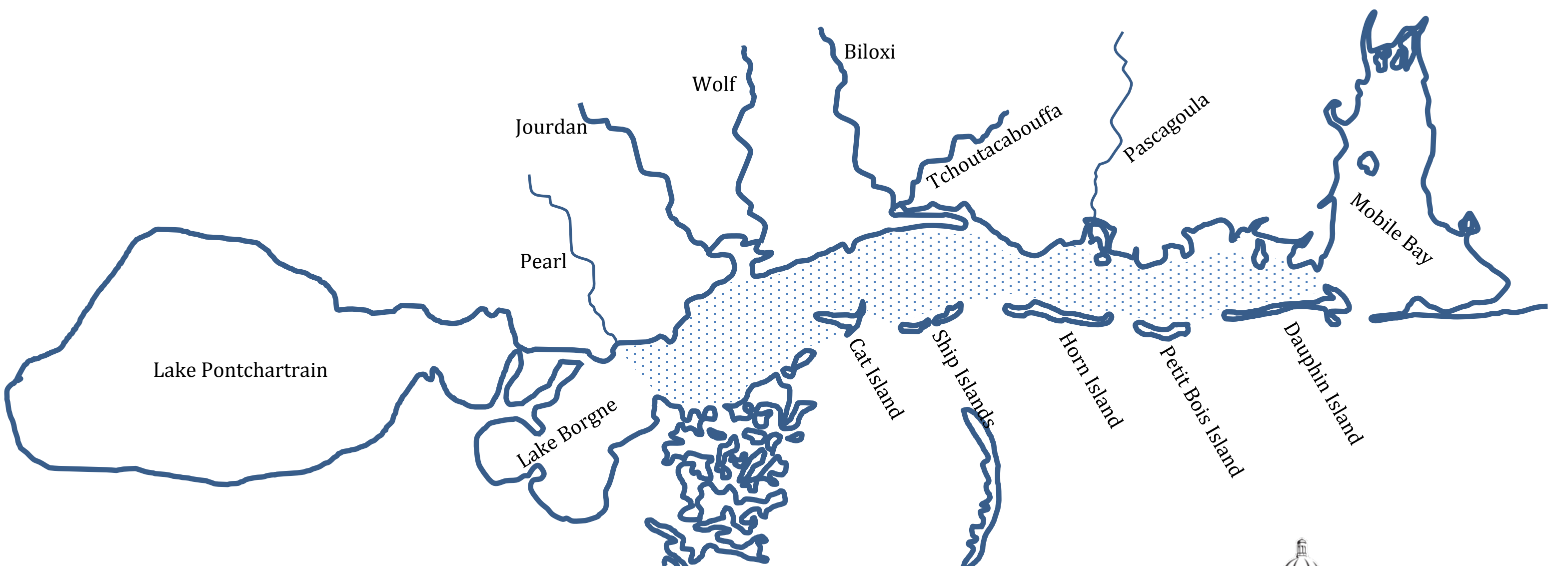
Litopenaeus setiferus

Callinectes sapidus

Salt marshes

Mississippi sound





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GULF COAST RESEARCH LABORATORY

Prevalence of WSSV in decapods of Ms Sound

Blue crab (*Callinectes sapidus*) (8.3%, n=12)

Purple marsh crab (*Sesarma reticulatum*) (10.0%, n=20)

Gulf mud fiddler crab (*Uca longisignalis*) (50.0%, n=72)

Panacea sand fiddler crab (*U. panacea*) (10.8%, n=1404)

Mudflat fiddler crab (*U. rapax*) (23.0%, n=88)

Spined fiddler crab (*U. spinicarpa*) (35.7%, n=98)

Red-jointed fiddler crab (*U. minax*) (22.7%, n=22)

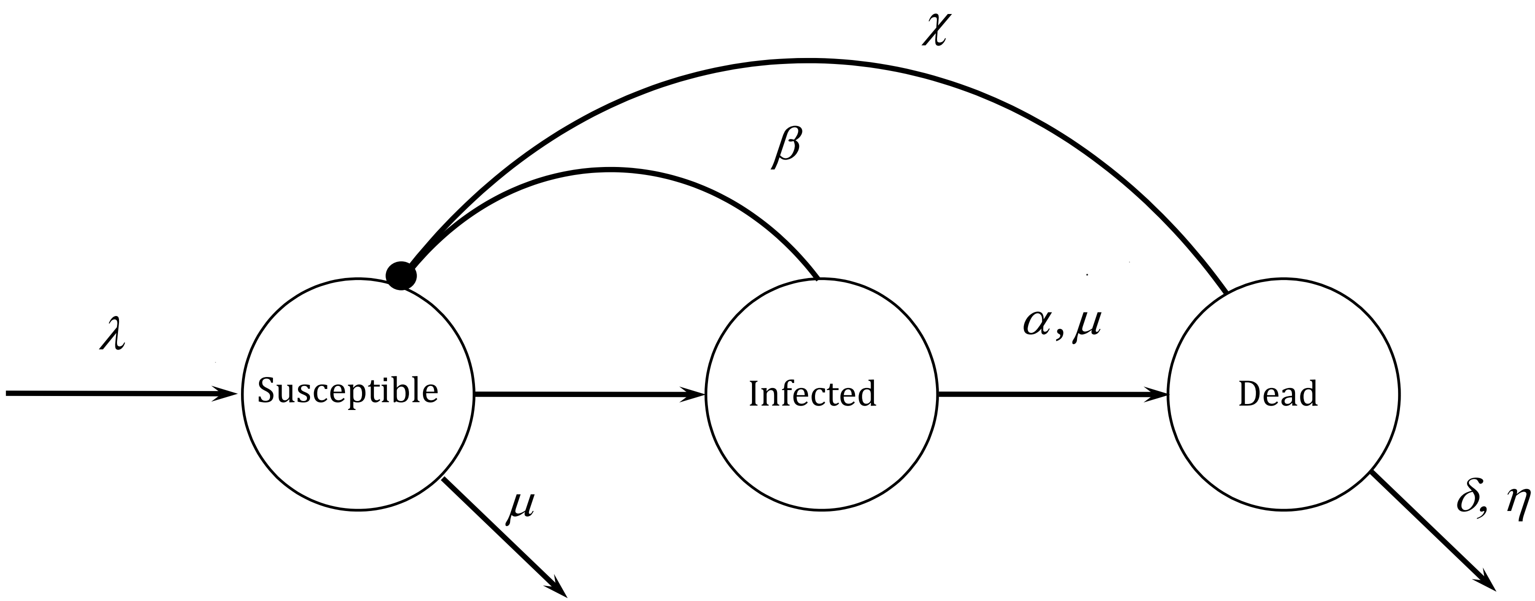
Squareback marsh crab (*Armasus cinereum*) (26.7%, n=30)

Daggerblade grass shrimp (*Palaemonetes pugio*) (9.4%, n=1244)

White shrimp (*Litopenaeus setiferus*) (20.0%, n=40)

Modeling WSSV in communities of decapods

WSSV life cycle diagram



- λ Host recruitment
- β $\text{Transmission}_{\text{Live}}$
- χ $\text{Transmission}_{\text{Dead}}$
- α $\text{Mortality}_{\text{WSSV}}$
- μ $\text{Mortality}_{\text{Natural}}$
- δ $\text{Decay}_{\text{Carcass}}$
- η $\text{Consumption}_{\text{Carcass}}$

$$S_{t+1} = S_t - S_t \cdot \left(1 - (1-\beta)^{I_t} (1-\chi)^{D_t}\right) + \lambda - \mu$$

$$I_{t+1} = I_t + S_t \cdot \left(1 - (1-\beta)^{I_t} (1-\chi)^{D_t}\right) - \left(1 - (1-\alpha)\cdot(1-\mu)\right) \cdot I_t$$

$$D_{t+1} = D_t + \left(1 - (1-\alpha)\cdot(1-\mu)\right) \cdot I_t - \left(1 - (1-\eta)\cdot(1-\delta)\right) \cdot D_t$$

Transmission terms - Force of infection, λ, probability of infection after contact

$$S_{t+1} = S_t - S_t \cdot \left(\beta \cdot I_t\right)$$

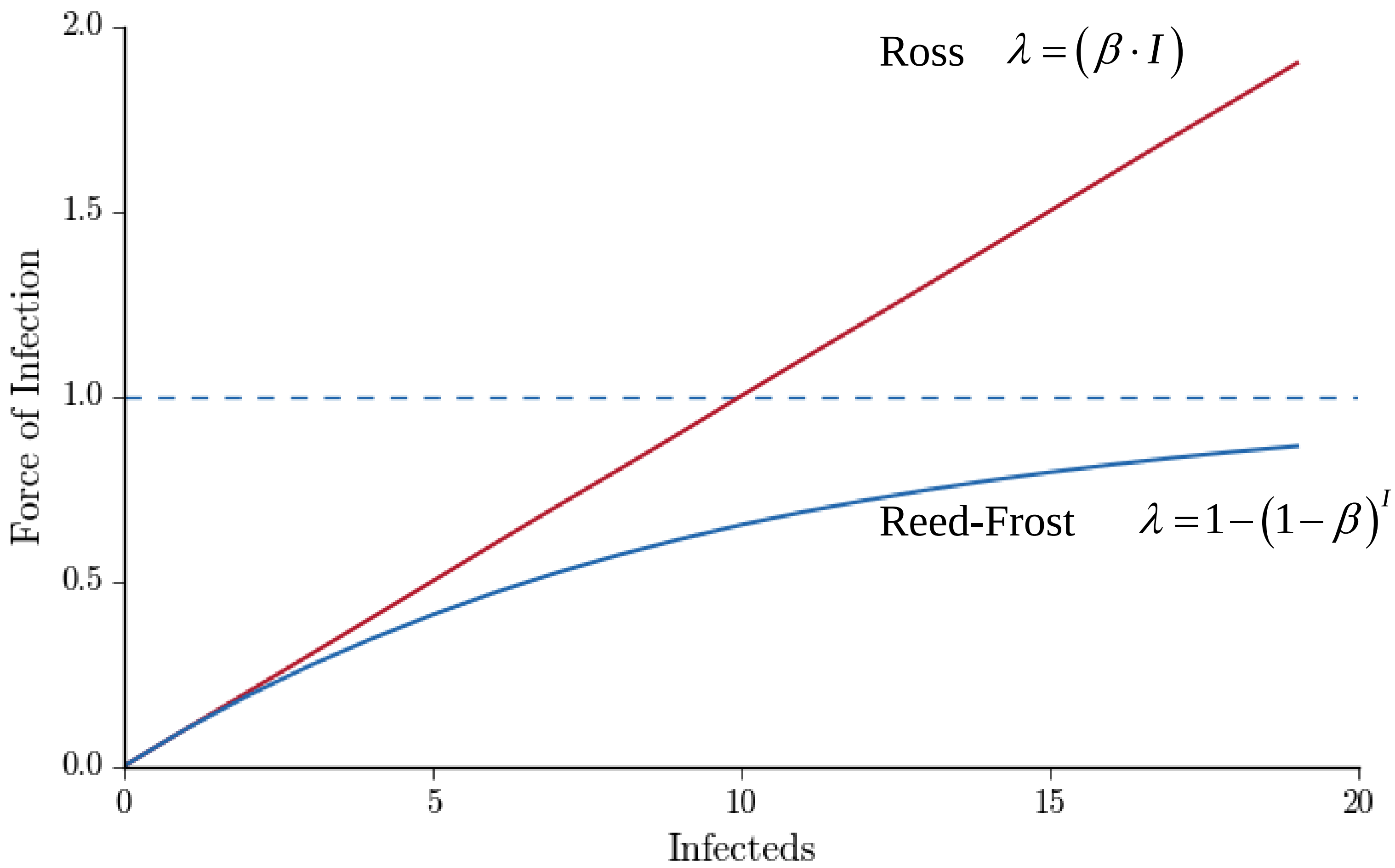
Ross
Kermack-McKendrick

$$S_{t+1} = S_t - S_t \cdot \left(1-(1-\beta)^{I_t}\right)$$

Reed-Frost
Black-Singer

Force of Infection

Probability of infection after contact with all infecteds



$$S_{t+1} = S_t - \left(\beta \cdot \boxed{S_t \cdot I_t}\right)$$

Ross
Kermack-McKendrick

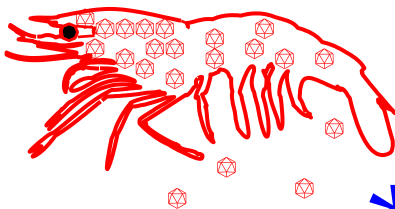
If β is probability of transmission after one S contacts one I
Then S·I is number of contacts between every S and every I

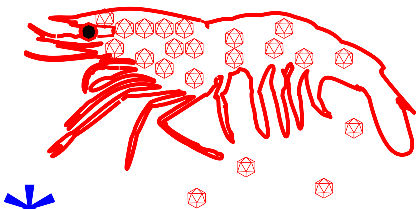
May have more infects than susceptibles
Some transmissions are to the same susceptible

$$\left(\begin{array}{c|ccccccc} & S_1 & S_2 & S_3 & S_4 & S_5 & S_6 & S_7 \\ \hline I_1 & SI_{11} & SI_{12} & SI_{13} & SI_{14} & SI_{15} & SI_{16} & SI_{17} \\ I_2 & SI_{21} & SI_{22} & SI_{23} & SI_{24} & SI_{25} & SI_{26} & SI_{27} \\ I_3 & SI_{31} & SI_{32} & SI_{33} & SI_{34} & SI_{35} & SI_{36} & SI_{37} \end{array}\right)$$

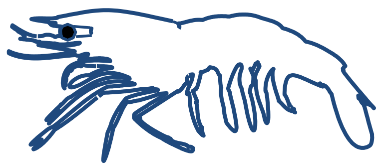
$$S_{t+1} = S_t - S_t \cdot \left(1-(1-\beta)^{I_t}\right)$$

Reed-Frost
Black-Singer





β $\quad 1-\beta$ * $\quad$ * β $\quad 1-\beta$



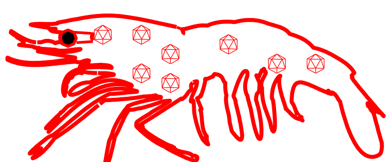
3 Ways to become infected
1 & not 2 β∗(1–β)
or
not 1 & 2 (1–β)∗β
or
1 & 2 β∗β

Only 1 way to remain uninfected
1 & 2 (1- β)∗(1–β)

$$(1-\beta)^2$$

β∗(1–β) + (1–β)∗β + β∗β

$$1-(1-\beta)^2$$



Epidemic models – parameter estimates

$$S_{t+1} = S_t - S_t \cdot \left(1 - (1-\beta)^{I_t} (1-\chi)^{D_t}\right)$$

$$I_{t+1} = I_t + S_t \cdot \left(1 - (1-\beta)^{I_t} (1-\chi)^{D_t}\right) - \alpha \cdot I_t$$

$$D_{t+1} = D_t + \alpha \cdot I_t - \left(1 - (1-\eta) \cdot (1-\delta)\right) \cdot D_t$$

Parameter estimates – transmission (β, χ)

$$S_{t+1} = S_t - S_t \cdot (1 - (1 - \beta)^{I_t})$$

Solve for β

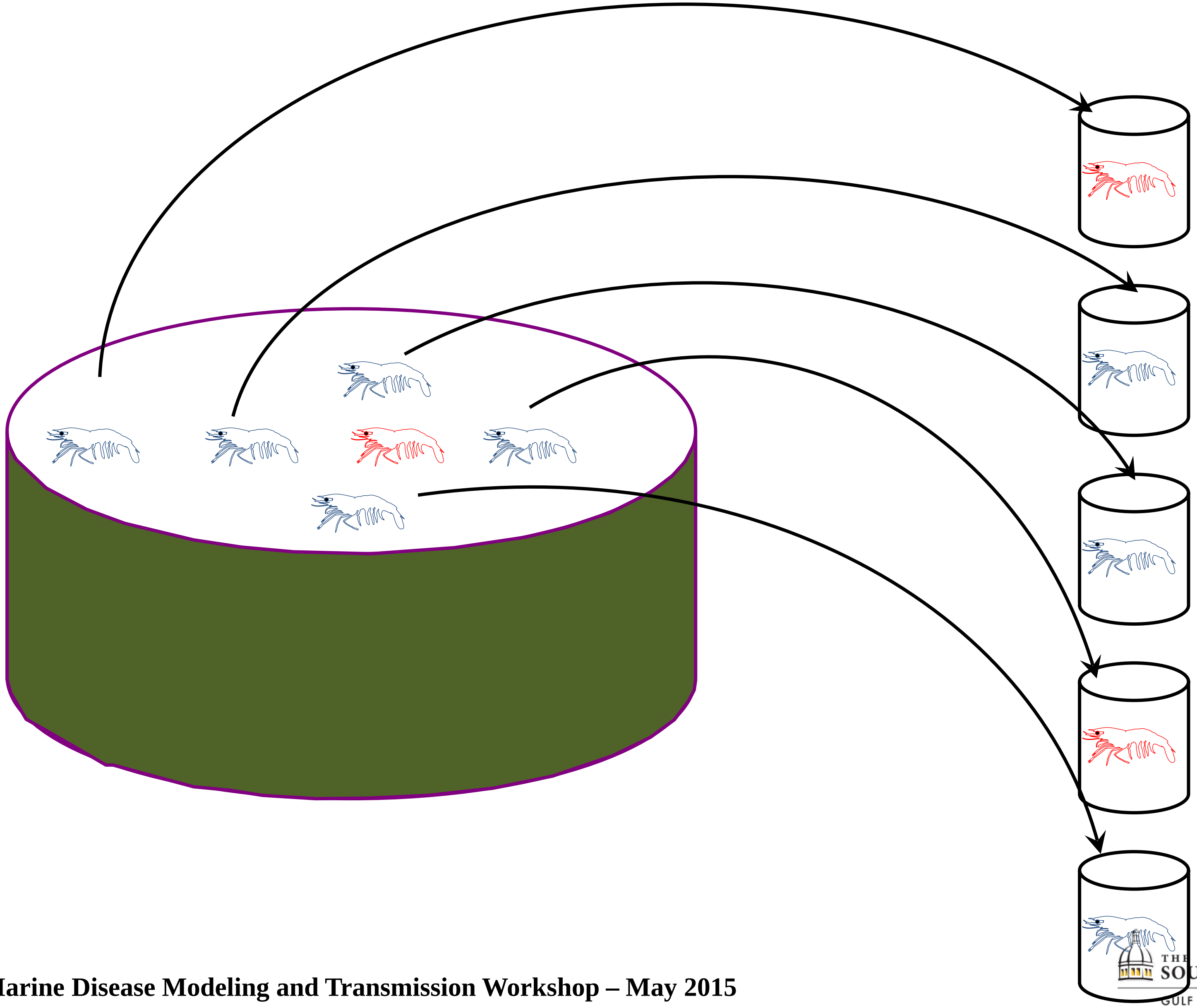
$$\beta(1) = 1 - \exp\left(\frac{\ln\left(\frac{S_1}{S_0}\right)}{I_0}\right)^{\frac{1}{t}}$$

If t = 1 and I_0 = 1:

$$\beta = 1 - \left(\frac{s_1}{s_0}\right)$$

The proportion infected after exposure to one infected shrimp

Parameter estimates – transmission (β, χ)



Parameter estimates – transmission (β, χ)

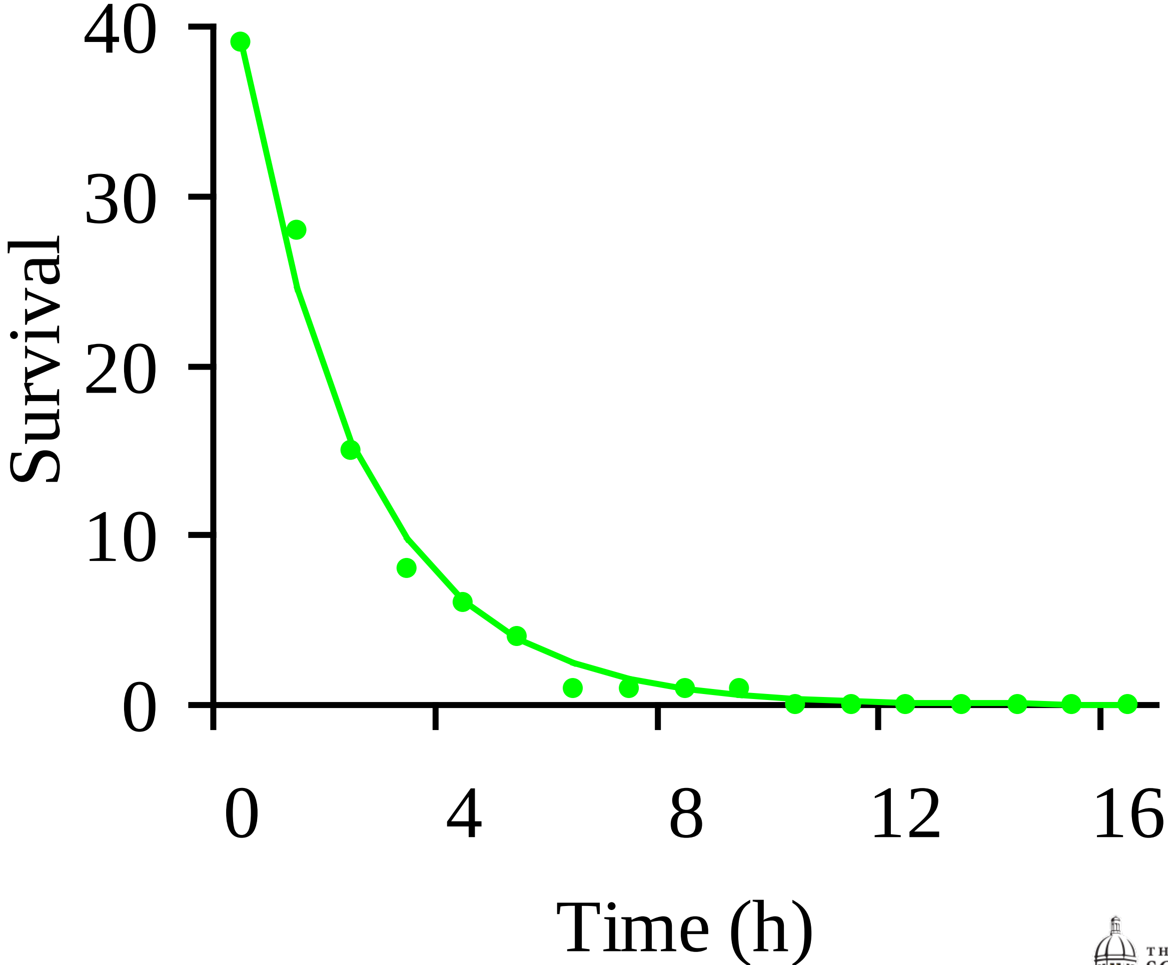
Parameter estimates – transmission (β, χ)

Parameter estimates – transmission (β, χ) and virulence (α)

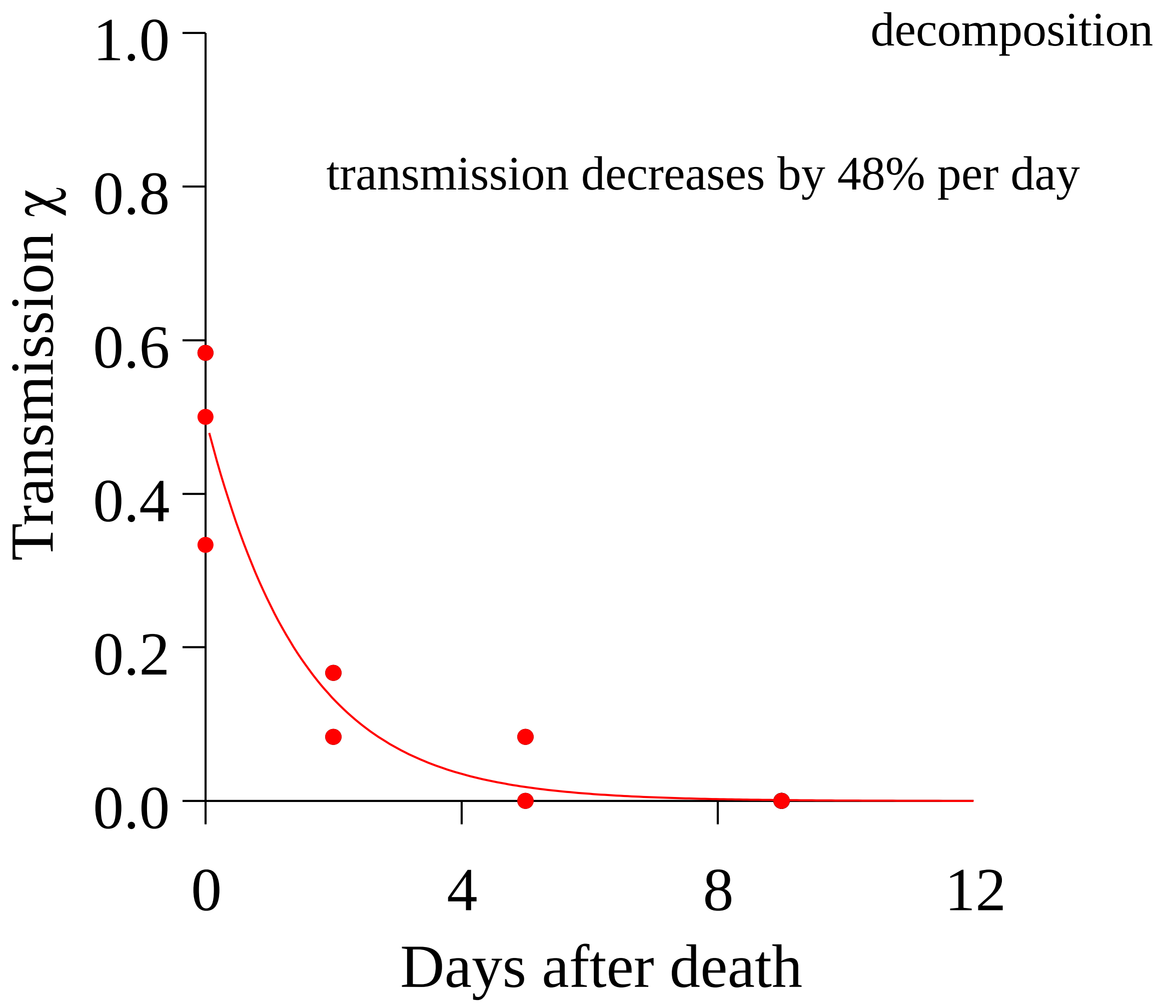
- 1-L jars
- 1 shrimp per jar
- 5d incubation
- Collect mortalities (α)
- Collect survivors

Parameter estimates – virulence (α)

$$I_{t+1} = I_t - I_t \cdot \alpha$$



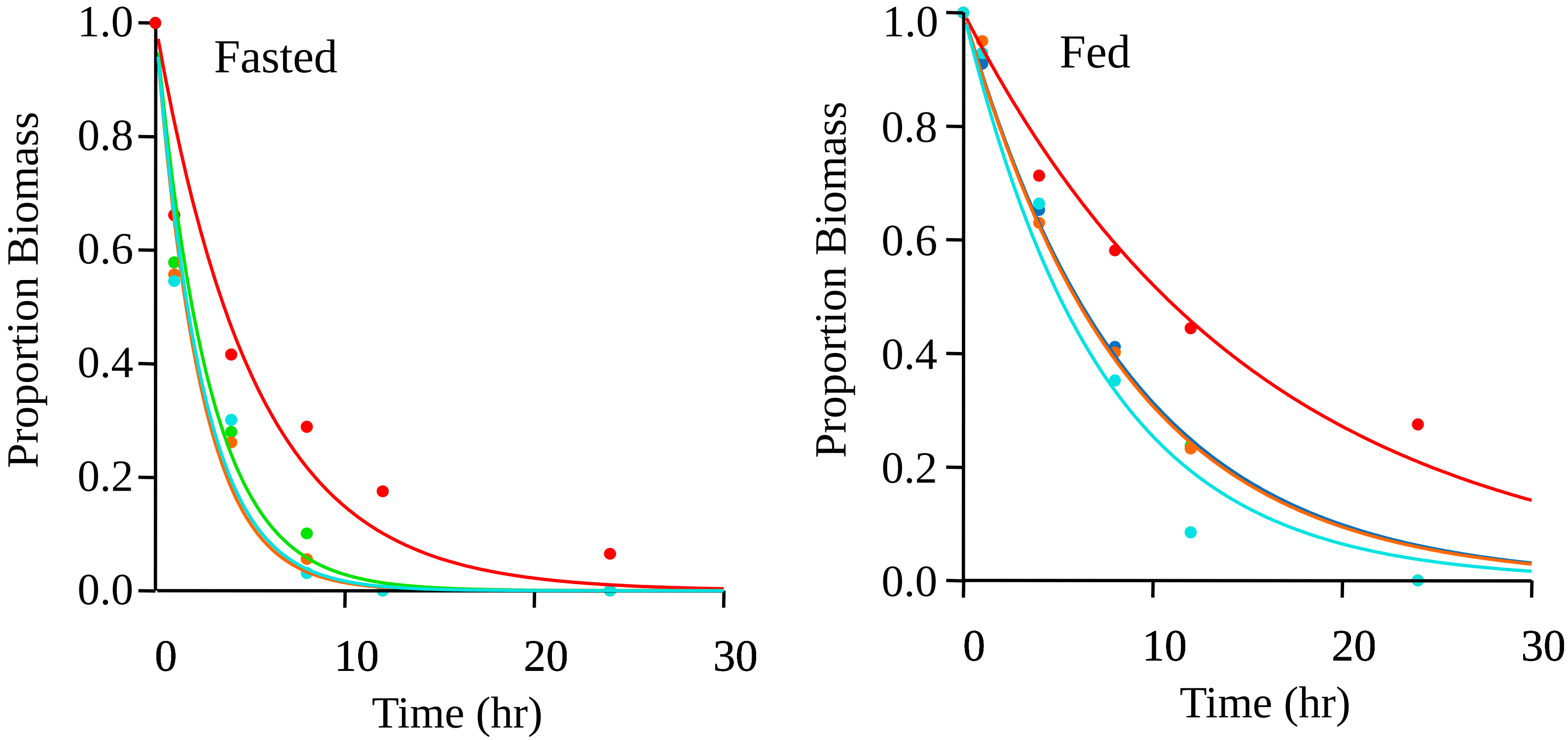
Parameter estimates – decay of transmission (δ)



y-intercept = 0.499

Parameter estimates η: consumption of shrimp

	decrease per hr (day)		decrease per hr (day)
1 shrimp	17% (99)	1 shrimp	6% (79)
6 shrimp	30% (100)	6 shrimp	11% (94)
12 shrimp	34% (100)	12 shrimp	11% (94)
24 shrimp	33% (100)	24 shrimp	12% (96)



Parameter estimates : consumption (η) & decomposition (δ) combined

$$0.48 + 1.00 - 1.0 * 0.48 = 1.00$$

$$0.48 + .79 - .79 * .48 = 0.89$$

An infected dead shrimp retains about 0 – 10% of its infectivity per day

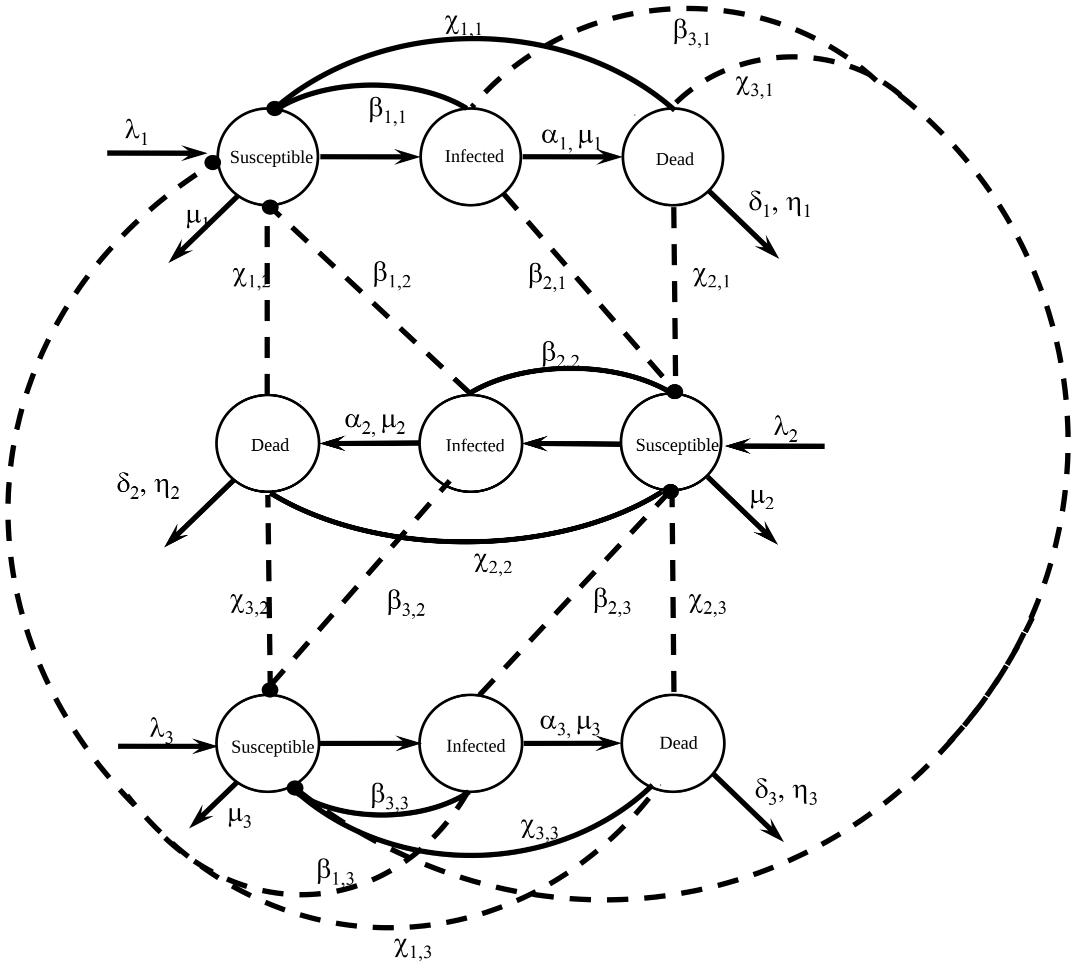
Life table of infection

State	Duration	Transmission	Product
Live Infected	$\frac{1}{\alpha}$	β	$\frac{\beta}{\alpha}$
Dead Infected	$\frac{1}{1-(1-\delta)(1-\eta)}$	χ	$\frac{\chi}{1-(1-\delta)(1-\eta)}$

$$R_0 = \frac{\beta}{\alpha} + \frac{\chi}{\delta + \eta - \delta \cdot \eta}$$

$$R_0 = \frac{0.1}{0.4} + \frac{0.6}{0.5 + 0.9 - 0.5 \cdot 0.9} = 0.9$$

WSSV life cycle diagram
3-host community



WSSV 3-host community matrix model

$$
\begin{pmatrix}
\left(\prod_{i=1}^{3}(1-\beta_{1,i})^{I_i}\cdot(1-\chi_{1,i})^{D_i}\right) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1-\left(\prod_{i=1}^{3}(1-\beta_{1,i})^{I_i}\cdot(1-\chi_{1,i})^{D_i}\right) & 1-\alpha_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \alpha_1 & 1-(1-\delta)\cdot(1-\eta) & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \left(\prod_{i=1}^{3}(1-\beta_{2,i})^{I_i}\cdot(1-\chi_{2,i})^{D_i}\right) & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1-\left(\prod_{i=1}^{3}(1-\beta_{2,i})^{I_i}\cdot(1-\chi_{2,i})^{D_i}\right) & 1-\alpha_2 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \alpha_2 & 1-(1-\delta)\cdot(1-\eta) & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \left(\prod_{i=1}^{3}(1-\beta_{3,i})^{I_i}\cdot(1-\chi_{3,i})^{D_i}\right) & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1-\left(\prod_{i=1}^{3}(1-\beta_{3,i})^{I_i}\cdot(1-\chi_{3,i})^{D_i}\right) & 1-\alpha_3 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \alpha_3 & 1-(1-\delta)\cdot(1-\eta)
\end{pmatrix}
\cdot
\begin{pmatrix} S_1 \\ I_1 \\ D_1 \\ S_2 \\ I_2 \\ D_2 \\ S_3 \\ I_3 \\ D_3 \end{pmatrix}
$$