Can Ranavirus Alter Host Extinction Probabilities? Use of Stage-Structured Population Models

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References

- Chapt. 8 in the Ranavirus Book, section on Models
  - Supplemental information has the Matlab code for the wood frog model
- Earl and Gray. 2014. Introduction of *Ranavirus* to isolated Wood Frog populations could cause local extinction. *EcoHealth* 11: 581-592.
- Unpublished work: Earl, Chaney, Sutton, Lillard, Kouba, Langhorne, Krebs, Wilkes, Hill, Miller, and Gray. In revision. Ranavirus could facilitate local extinction of rare amphibian species. (Dusky gopher frog and boreal toad)

Die-offs and Declines

- Amphibian die-offs quite dramatic
  - adults in Europe
  - tadpoles in North America (Wheelwright et al. 2014)
- Declines
  - common frog (*Rana temporaria*) (Teacher et al. 2010)
  - whole communities in Spain (Price et al. 2014)
- **Could ranavirus cause extinction?**

Population Models

- Great tool to examine how changes in survival might affect populations
- Apply estimates of survival and fecundity to starting population sizes
  - estimate what may happen in the future by simulating mortality and reproduction for some number of years
- Years with ranavirus: if p is the probability of survival

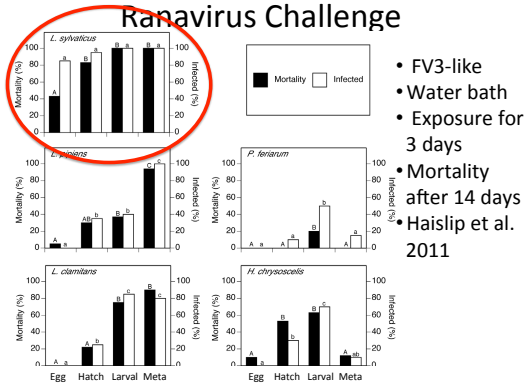
$p = p_{typical} \times p_{ranavirus}$

$$\begin{pmatrix} N_{pm}(t) \\ N_1(t) \\ N_{2+}(t) \end{pmatrix} = \begin{pmatrix} 0 & 0 & F \\ p_1 & p_2 & 0 \\ 0 & p_3 & p_4 \end{pmatrix} \times \begin{pmatrix} N_{pm}(t-1) \\ N_1(t-1) \\ N_{2+}(t-1) \end{pmatrix}$$

Effects of Ranavirus

- Start with the most likely scenario where extinction of a single population could occur
  - closed populations
  - very susceptible species
- Looked at experimental challenge trial data to choose species

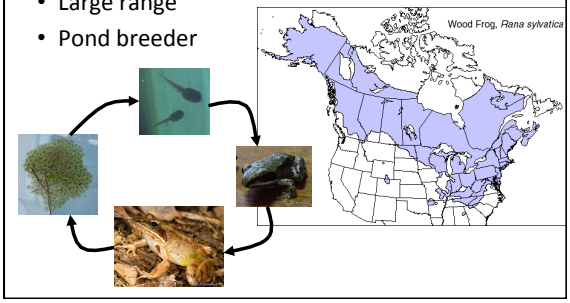
Ranavirus Challenge



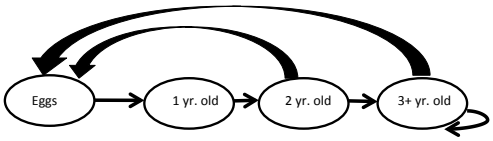
- FV3-like
- Water bath
- Exposure for 3 days
- Mortality after 14 days
- Haislip et al. 2011

Wood Frogs

- Lots of great population data (Keith Berven)
- Large range
- Pond breeder



Model



$$\begin{pmatrix} N_{\mathrm{pm}}(t) \\ N_1(t) \\ N_2(t) \\ N_{3+}(t) \end{pmatrix} = \begin{pmatrix} 0 & F_1 & F_2 & F_3 \\ p_1 & 0 & 0 & 0 \\ 0 & p_2 & 0 & 0 \\ 0 & 0 & p_3 & p_4 \end{pmatrix} \times \begin{pmatrix} N_{\mathrm{pm}}(t-1) \\ N_1(t-1) \\ N_2(t-1) \\ N_{3+}(t-1) \end{pmatrix}$$

- Very simple stage-structured matrix model of females
- N = population size, p= probability of survival, F= fecundity, t= time (years)

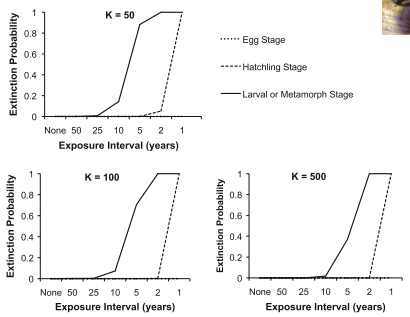
Model Implementation

- Used published parameters that represent a very robust population (Harper et al. 2008)
- Built in stochasticity in the model- drew random values for parameters from a normal distribution each year
- Sensitivity analysis- which parameter values change the model the most?
  - Survival from eggs to juvenile has most influence

Simulations

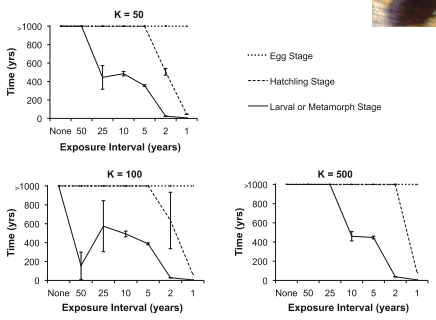
- Ranavirus- challenge trial data for each life stage
  - Die-off concentrations of virus (10^3 pfu/mL)
  - Only one life stage is exposed at a time in the pond
  - Examined different exposure intervals
  - Examined different carrying capacities (# of adult females)
- Ran each scenario 1000 times- calculated probability of extinction and time to extinction

Extinction Probability over 1000 Years Wood Frogs



Earl and Gray (2014) EcoHealth 11: 581-592.

Time to Extinction Wood Frogs



Wood Frog Results

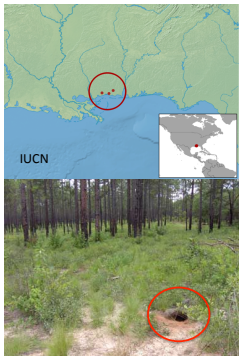
- Increase in extinction probability, time to extinction, and population declines with increasing frequency of ranavirus exposure
- Most effects occur with ranavirus in the larval or metamorph stage
  - highest mortality with exposure
  - life stage with highest sensitivity
- Concerning, but
  - most wood frog populations have metapopulation structure allowing immigration to mitigate declines
  - widespread distribution indicates low conservation concern

Next Step

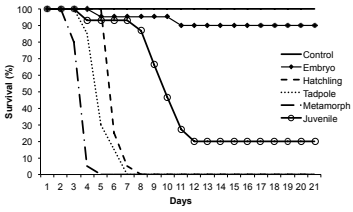
- Examine species of actual conservation concern
  - Dusky gopher frog (*Lithobates sevosus*)
  - Boreal toad (*Anaxyrus boreas boreas*)
- Examine effects of immigration where appropriate- Boreal toad

Dusky Gopher Frog- *Lithobates sevosus*

- One of the most endangered frogs in the USA- listed in 2001
- Only one regular, viable population- Glen's Pond (MS)
- Pond breeder- eggs in Dec.
- Metamorphs emerge in June when the pond dries
- Adults in long leaf pine often associated with Gopher Tortoise Burrows

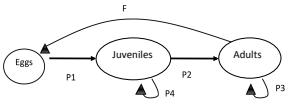


Dusky Gopher Frog: Ranavirus Susceptibility



Sutton et al. 2014- Examined adults: 100% mortality in 18 days

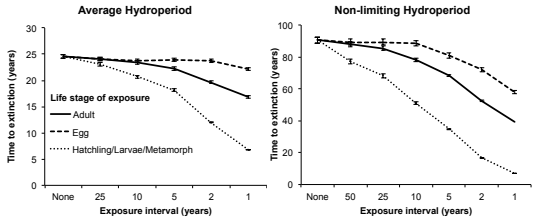
Model



- 3 stage model
- Parameterized using data from 1995-2001 monitoring Glen's pond (Richter et al. 2002, 2003)
- Hydroperiod threshold for metamorph production- 190 days
  - examined the Glen's pond avg. hydroperiod and a nonlimiting hydroperiod

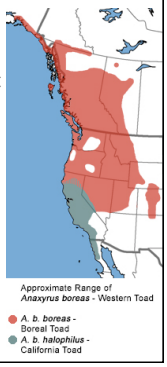
$$\begin{pmatrix} N_{pm}(t) \\ N_1(t) \\ N_{2+}(t) \end{pmatrix} = \begin{pmatrix} 0 & 0 & F \\ p_1 & p_2 & 0 \\ 0 & p_3 & p_4 \end{pmatrix} \times \begin{pmatrix} N_{pm}(t-1) \\ N_1(t-1) \\ N_{2+}(t-1) \end{pmatrix}$$

Time to Extinction Dusky Gopher Frog

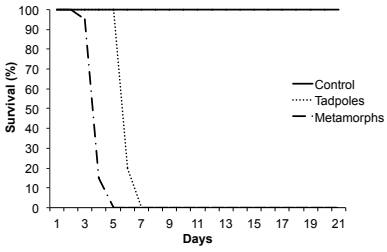


Boreal Toads

- *Anaxyrus boreas boreas* populations in Colorado under review for listing under the Endangered Species Act as a distinct population segment
- Major declines due to Bd
- Pond breeder, eggs spring/summer
- Metamorphs in August
- Long-lived, up to 10 years



Boreal Toad Ranavirus Susceptibility



Boreal Toad Model

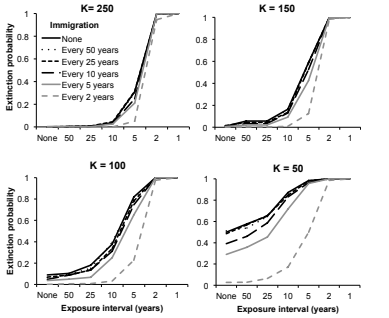
- 7 stage model: years 1-5, breeders, nonbreeders
- Females skip breeding at least every other year

$$\begin{pmatrix} N_1(t) \\ N_2(t) \\ N_3(t) \\ N_4(t) \\ N_5(t) \\ N_b(t) \\ N_{nb}(t) \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & F*p_a & 0 \\ p_1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & p_j & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & p_j & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & p_j & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & p_j & 0 & p_a*\Psi_b \\ 0 & 0 & 0 & 0 & 0 & p_a & p_a*\Psi_{nb} \end{pmatrix} \times \begin{pmatrix} N_1(t-1) \\ N_2(t-1) \\ N_3(t-1) \\ N_4(t-1) \\ N_5(t-1) \\ N_b(t-1) \\ N_{nb}(t-1) \end{pmatrix}$$

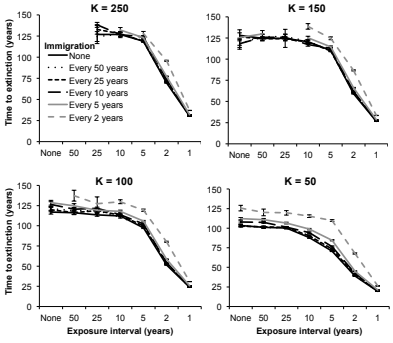
Other Features

- Different Carrying Capacities: 50-250 adult females
- Key question: Will immigration "rescue" populations from ranavirus?
  - Low levels of immigration
    - Muths et al. 2006 found only 17 males and 3 females switched breeding sites out of >1900 captures over 15 years
  - Model: immigration of 1 adult female over different intervals- every 2-50 years

Boreal Toads: Extinction Probability (150 years)



Boreal Toads: Time to Extinction



Conclusions

- Ranavirus has the potential to cause extinction in highly susceptible species
  - in common species with no immigration
  - in endangered species
  - in species of conservation concern even with low levels of immigration
- Extinction risk varies with the interval of exposure and carrying capacity
- Immigration may not "rescue" populations unless very frequent

References

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