# Evaluation of Modeling Approaches to Estimate Viable Recovery Criteria for Atlantic Sturgeon

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# General Background

Atlantic sturgeon proposed for listing under the ESA; primary threats identified include

- Bycatch
- Water quality/quantity
- Vessel strikes

Development of appropriate recovery criteria hindered by lack of knowledge

- Demography
- Life history
- Relative effects of different negative factors
    - By-catch
    - Water quality
    - Vessel strikes
    - Habitat loss

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# General Background

- ESA requires that recovery plans incorporate objective and measurable recovery criteria.
- NMFS Protected Resources Division efforts are directed to identify adequate biological recovery criteria for restoration goals and in the event that the proposed listing is finalized
- Possible metrics to determine recovery criteria
  - Minimum Viable Population Size
  - Recruitment rates
  - Heterozygocity
  - Effective Population Size
  - Population growth rates
  - Spawner/recruit ratios

# Minimum Viable Population (MPV)

- Smallest number of individuals required for an isolated population to persist
- Estimated population size necessary to ensure 90-95 % probability of survival between 100 to 1,000 years into the future.
- MVP = 500/50 rule (Franklin, 1980)
  - 500 = approximate effective population size necessary to retain sufficient genetic variation and long term persistence of a population
  - 50 = approximate effective population size necessary to prevent inbreeding

# Minimum Viable Population (MPV)

## Examples 500/50 Rule

- **Pacific Salmon**
  - *Prioritizing Pacific salmon stocks for conservation (Allendorf et al. 1997)*
  - *Viability Criteria for Application to Interior Columbia Basin Salmonid ESUs (Cooney et al. 2007)*
- **Atlantic Salmon**
  - *Biological valuation of Atlantic salmon habitat within the Gulf of Maine Distinct Population Segment (NMFS 2009)*
- **Bull Trout**
  - *Effective Population Size and Genetic Conservation Criteria for Bull Trout (Rieman and Allendorf, 2001)*
- **Cutthroat Trout**
  - *Conserving inland cutthroat trout in small streams: how much stream is enough? (Hilderbrand, R. H., and J. L. Kershner. 2000)*

# Goals

- To evaluate several quantitative approaches to estimate MVP
- We propose that in order for a population to be considered recovered
  - The adult spawner population of each river system most be ≥500
  - The population must demonstrate self-sustaining persistence
    - each population has less than a 50% probability of falling below 500 adult spawners in the next 100 years based on population viability analysis (PVA) projections

# Challenges on considering modeling efforts in implementation of MVP for Atlantic sturgeon populations

- Unknown population growth rates (*r*)
- Unknown natural mortalities across ages
- Estimates of long term total adult and juvenile abundance are almost non-existent (only Hudson, Kahlne 2007 )
- Scarce data on reproduction and ageing across spatial scales
  - Fecundity (data from Hudson river (Van Eenennaam 1996,1998), and South Carolina (Smith 1982 ))
  - Age at first offspring (data from Hudson river (Van Eenennaam 1996,1998 ) and South Carolina( Smith 1982 ))
- Sturgeon PVAs have mostly lacked considerations of demographic and environmental stochasticity and genetics

# Population Viability Analysis (PVA) Methods

- Method of risk assessment frequently used in conservation biology estimate population persistance
- Scalar models
  - Based on time-series data of population sizes
  - Do not include details of population age or stage structure
- Matrix and individual based models
  - Incorporate population structure
  - Account for differences in demographic parameters of the various age or stage classes in a population

# Count PVA Methods

- Stochastic exponential growth model of population size (Dennis, 1991)
- Equivalent to a stochastic Leslie-matrix projection with no density dependence
- Parameters used:
  - estimated population growth rate
  - variance
  - initial abundance level
  - user defined number of years for a user defined number of projections
- Widely used to evaluate the conservation status of many Pacific salmon populations (Matthews and Waples 1991)

# Count PVA

$$\mu = \text{mean}[\ln(N_{t+1}/N_t)]$$

$$\sigma^2 = \text{var}[\ln(N_{t+1}/N_t)]$$

μ= rate of population increase or decrease through time
σ2= is the population variability

$$\pi = (n_e/n_q)^{2\mu/\sigma 2}$$

The probability of declining from the most recent population size nq to a lower threshold population size ne

$$\lambda = \exp(\mu + (\sigma^2/2))$$

mean rate of population growth

$$\theta = \ln(n_e/n_q)/\mu$$

Time to extinction

# Count PVA Methods

- We have developed a simple PVA model
  - Simulates the Hudson River Atlantic Sturgeon future performance
  - Based on previous data from Kahlne 2007 spawner abundance estimates for the Hudson River
  - Time period 1980-1995
  - All Montecarlo simulations consisted of 10,000 iterations projecting forward 100 years
  - The abundance threshold was set at 500 individuals

# Matrix and Individual Population Models

- VORTEX
  - Individual-based Monte Carlo simulation model
  - Uses the action of deterministic factors and environmental, demographic, and genetic stochasticity (Lacy 1993)
  - Loss of genetic variation in populations, by simulating the transmission of alleles from parents to offspring at a hypothetical genetic locus.
- RAMAS GIS
  - Cohort-based program
  - Uses age or size structured projection matrices
  - Tracks the fate of the metapopulation as a whole
  - GIS integrated feature linked to the population model designations of habitat suitability indices or critical habitat can be designated with this software

# Matrix and Individual Population Models

- Applications of Vortex and RAMAS-GIS on sturgeon populations
  - VORTEX:
    - **Jarić, I.**, Ebenhard, T. and Lenhardt, M. 2010. Population Viability Analysis of the Danube sturgeon populations in a VORTEX simulation model. *Reviews in Fish Biology and Fisheries* **20**(2), 219-237
    - Gao, X., S. Brosse, Y. Chen, S. Lek, and J. Chang. 2009. Effects of damming on population sustainability of Chinese sturgeon, *Acipenser sinensis*: evaluation of optimal conservation measures. *Environ. Biol. Fish.* 86:325–336
  - RAMAS
    - Root, K. V. 2002. Evaluating risks for threatened aquatic species: The shortnose sturgeon in the Connecticut River. In W. Van Winkle, P.J. Anders, D. H. Secor, and D.A. Dixon(eds.), *Biology, Management and Protection of North American Sturgeon*, American Fisheries Society
    - Vélez-Espino, L.A., and M.A. Koops. 2009. Recovery potential assessment for lake sturgeon in Canadian designatable units. *North American Journal of Fisheries Management* 29:1065-1090

# Matrix and Individual Population Models

- Model parameterization
  - POPULATION GROWTH RATES
    - Population growth rates (*r*) is one of the key demographic parameters
    - Availability data on *r* values is scarce .
    - Sturgeon population growth rates are low
      - 0.05(Bruch et al. 2008),
      - 0.10 (Secor and Niklischeck 2002)
      - 0.05 and 0.15 (Balnath et al. 2008)
- Based on this information, we have applied three different population growth rates for each population 0.05, 0.10 and 0.15
- In order to acquire such growth rates, age specific natural mortality was fitted so that each of these *r* values was met in different scenarios

# Matrix and Individual Population Models

- Model parameterization
  - NATURAL MORTALITY
    - No empirical data on natural mortality
    - PVA studies have used simple natural mortality distribution across age classes, the same values were used for juveniles after first year and for adults ( Heppel 2007, Beamesderfer et al. 2007, Kennedy and Sutton 2007)
    - This approach is biologically unrealistic
    - Uniform distribution of age specific mortality
      - allows for an existence of only small number of adults in a population
      - prevents them for reaching the old ages that have been reported for this species
    - We placed a larger mortality on younger age classes and lower mortality on adults so that a certain number of older individuals can be present in the population with the normal age distribution.

# Matrix and Individual Population Models

- Model parameterization
  - MAXIMUM AGE AT REPRODUCTION
    - Significant uncertainty regarding maximum age at reproduction
    - Maximum age at reproduction to be the same as the maximum longevity of Hudson River 43 years
  - SEX RATIO
    - Set to be equal
    - Effects of unequal sex ratio were tested in the sensitivity analysis
  - AGE AT FIRST OFFSPRING
    - Only data on age at first offspring comes from the Hudson River (Vanderman 1996, 1998)
    - Set up age at first offspring from females at 16 years and 13 for males
    - Effects of varying age at first offspring were tested in the sensitivity analysis.

# Matrix and Individual Population Models

- Model parameterization
- In order to simulate environmental variation in natural mortality
    - Assumed younger age groups have much higher annual variability in natural mortality and declines for the adult age groups
    - (Jaric' et al. 2010)
        - Standard deviation of the natural mortality for ages 1 to 3 was equal to 40% of the natural mortality of those age groups.
        - Ages groups 4 to adulthood was equal to 25% and for adults it was 10% of the age specific natural mortality
        - Variation in natural mortality of the age 0 to 1 was incorporated though the standard deviation of the mean number of offspring

# Matrix Population and Individual Population Models

- ***Scenario development:***
- Each basic scenario was simulated with three different fittings of age specific natural mortality which were producing three deterministic population growth rates 0.05 0.10 0.15
- simulated at nine different population sizes 50,100 500 1000, 3000, 6000, 10000, 20000, 30000.
- Carrying capacity was set to 60,000 individuals
- pseudo extinction threshold= 500 individuals
- The number of iterations = 1000
- Most scenarios were set to last 100 years.

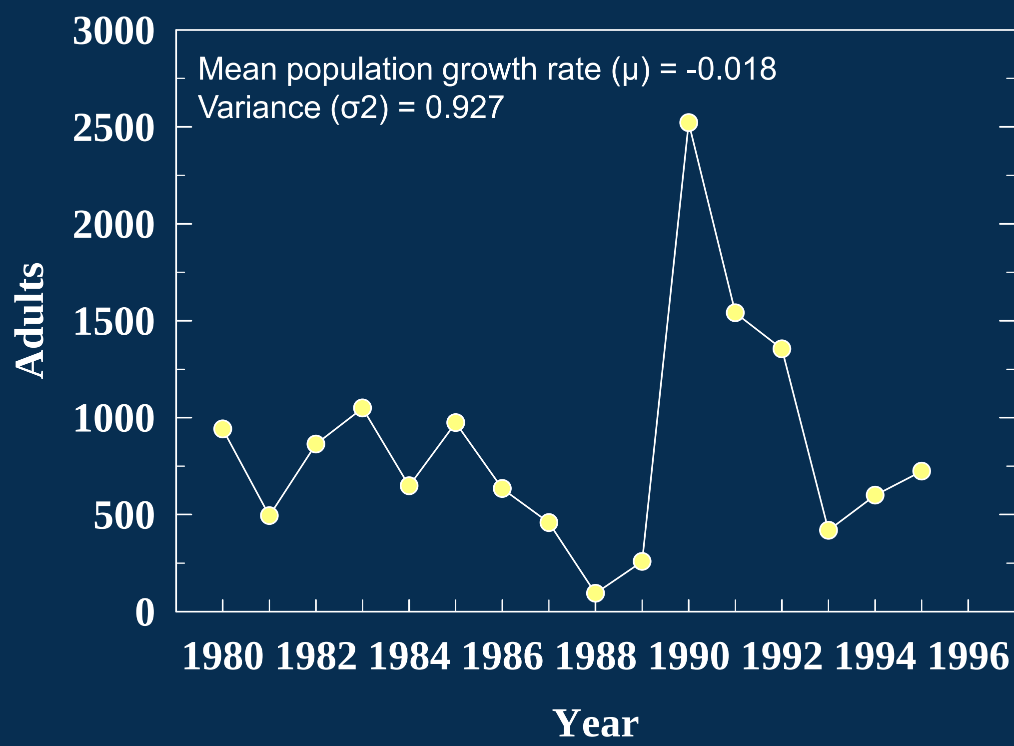
# Matrix and Individual Population Models

- Model parameterization
  - Output values
    - Main output values that were tracked in different scenarios
    - Probability of pseudo extinction
    - Mean population size of extant population
    - Expected heterozygocity
    - Number of extant alleles
    - Mean time to extinction

# Matrix and Individual Population Models

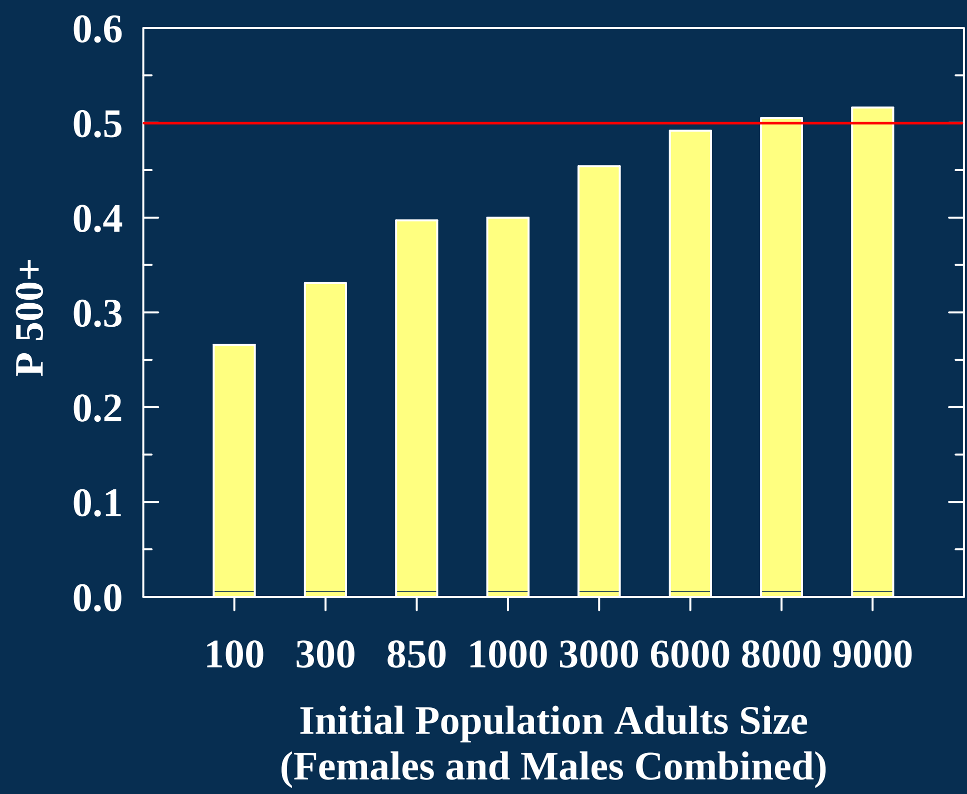
- Model parameterization
  - SCENARIO DEVELOPMENT
    - Modeling potential threats for recovering goals
      - By-catch
      - Vessel strike probability
  - SENSITIVITY ANALYSIS
    - All simulations that were part of the sensitivity analysis were run at population size of 500 and current carrying capacity of 2000
    - Tested change in each parameter was provided either reflecting the ranges provided for that parameter by different authors, or some general amount of change was applied (e.g. ±50%)

# Count PVA Methods




The trend is for negative population growth over the 1980-1995 Hudson River Populations.

# Count PVA Methods




Results from the PVA suggest that an initial population abundance level of 9000 adults would be needed to have a likely chance (>50%) of remaining above 500 adults for the foreseeable future (100 years) for that particular time period 1980-1995

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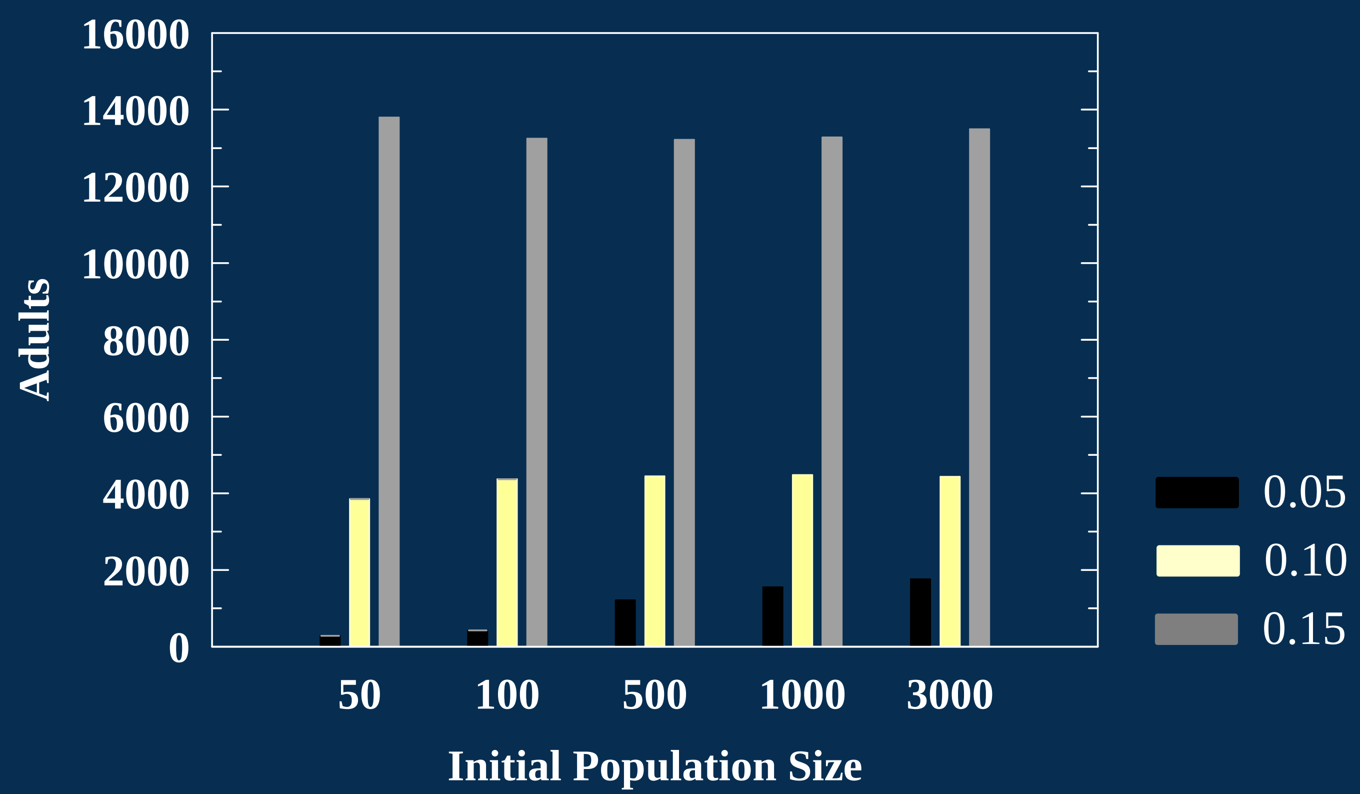
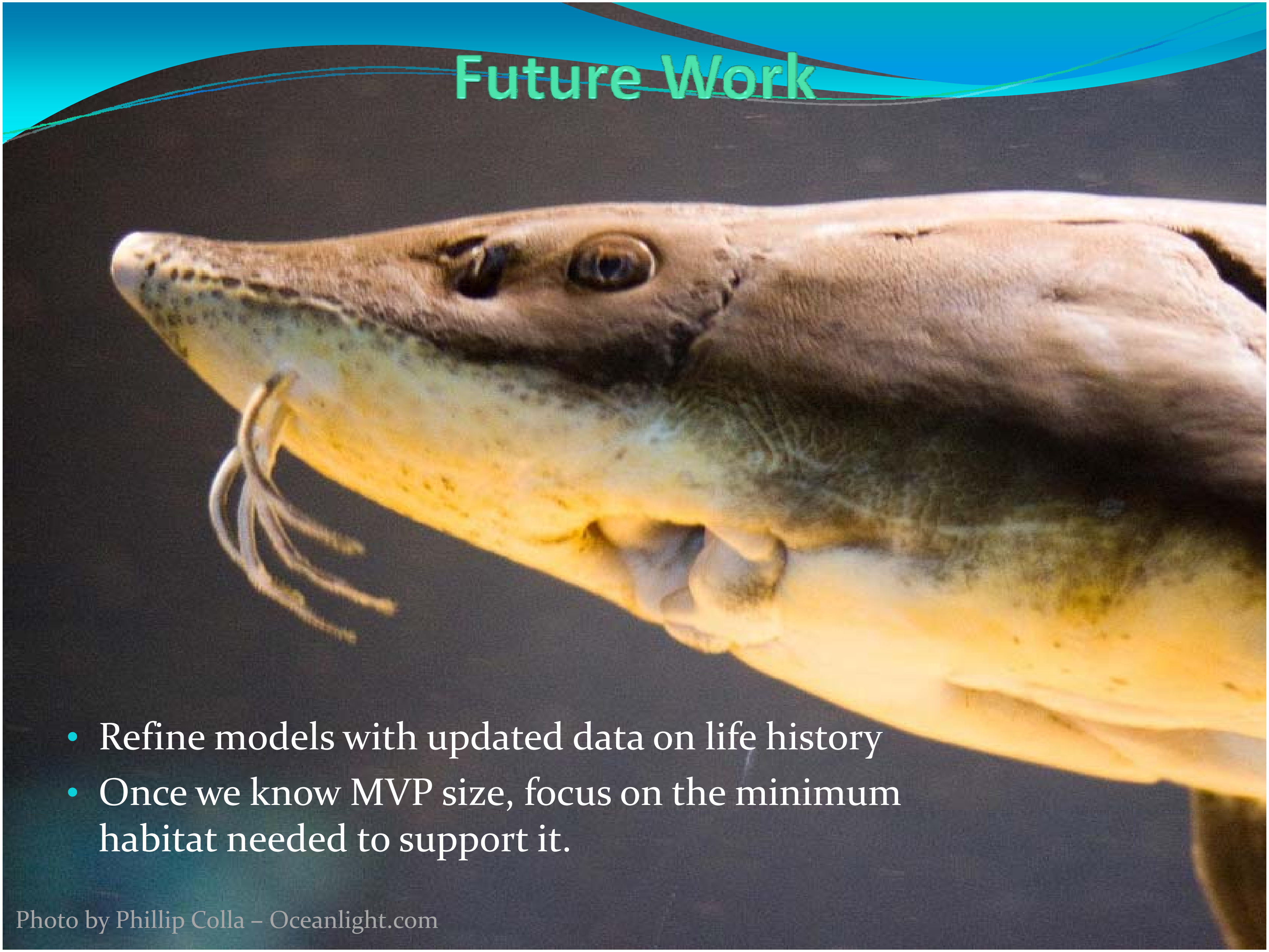
**k1** How does this statement conclude?
krandall, 2/7/2011

# Problems Establishing MPV




MVPs are significantly and substantially affected by the population growth rate, being larger with smaller growth rates.

# Future Work



- Refine models with updated data on life history
- Once we know MVP size, focus on the minimum habitat needed to support it.

Photo by Phillip Colla – Oceanlight.com

# Count PVA

- The forward projection involves taking the natural log of spawners for the year prior and adding to it the mean population growth rate and a random selection from the normal distribution of the population growth rate (This value is then exponentiated to bring it back to normal scale (i.e. adult abundance).
- This process is then repeated until the user defined time frame is completed and the user defined number of projections has been accomplished. The proportion of trajectories where the estimated abundance level falls below a user defined threshold abundance level is then recorded

- we applied these criteria to assess the number of
- adult spawners that would be needed to weather a downturn in abundance as experienced between the years of 1980 and 1995; a period of exceptionally low survival.

The 50% assurance threshold
satisfies the criterion that the population is
“not likely” to become an endangered
species;

- VORTEX is a Monte Carlo simulation model that follows
- each individual in a population in an independent manner.
- The probability of an individual either dying or reproducing
- is randomly drawn from a binomial distribution with a mean
- set by the inputted life history data, while variation in the carryingn capacity K is modelled as a normal distribution (Miller
- & Lacy, 1999). The model was originally designed for vertebrate
- populations of low fecundity and long life span so it is
- highly suitable for modelling big cat populations. Even