Poaching and the Dynamics of a Protected Species

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Motivation

- Traditionally ecologists have studied predator-prey interactions and the underlying qualitative behavior of populations:
  - Oscillatory and chaotic dynamics are common in food web systems for reasonable biological parameters (Hastings and Powell, 1991)
- We consider a household (*predator*) poaching a protected species (*prey*):
  - How is the qualitative behavior of a protected population affected by *economic* parameters?

Theoretical setting

- Household living on the edge of a preserve which houses a protected species.
- Myopic allocation of time to wage employment, poaching and leisure:
  - No value placed on resource in future.
- Poaching is subject to *risky* open access:
  - Fine incurred if caught poaching.
- Study the effects of economic parameters on protected species' dynamics and household welfare.

Economic model of the household

- Maximize $U_t = U(C_t, I_t, T_t^L)$ subject to:
  - time constraint: $T = T_t^H + T_t^W + T_t^L$
  - given prey population : X_t
- $C_t \geq 0$: own consumption of prey
- $I_t \geq 0$: income (= wages + black market sales – fines)
- $T_t^L \geq 0$: leisure time

Protected species dynamics

- Logistic growth function for protected species:
  $F(X_t) = rX_t\left(1-(X_t/K)^z\right)$, K is the carrying capacity.

- Schaefer production (poaching) function:
  $H\left(T_t^H, X_t\right) = qT_t^H X_t$, q is the catchability coefficient.

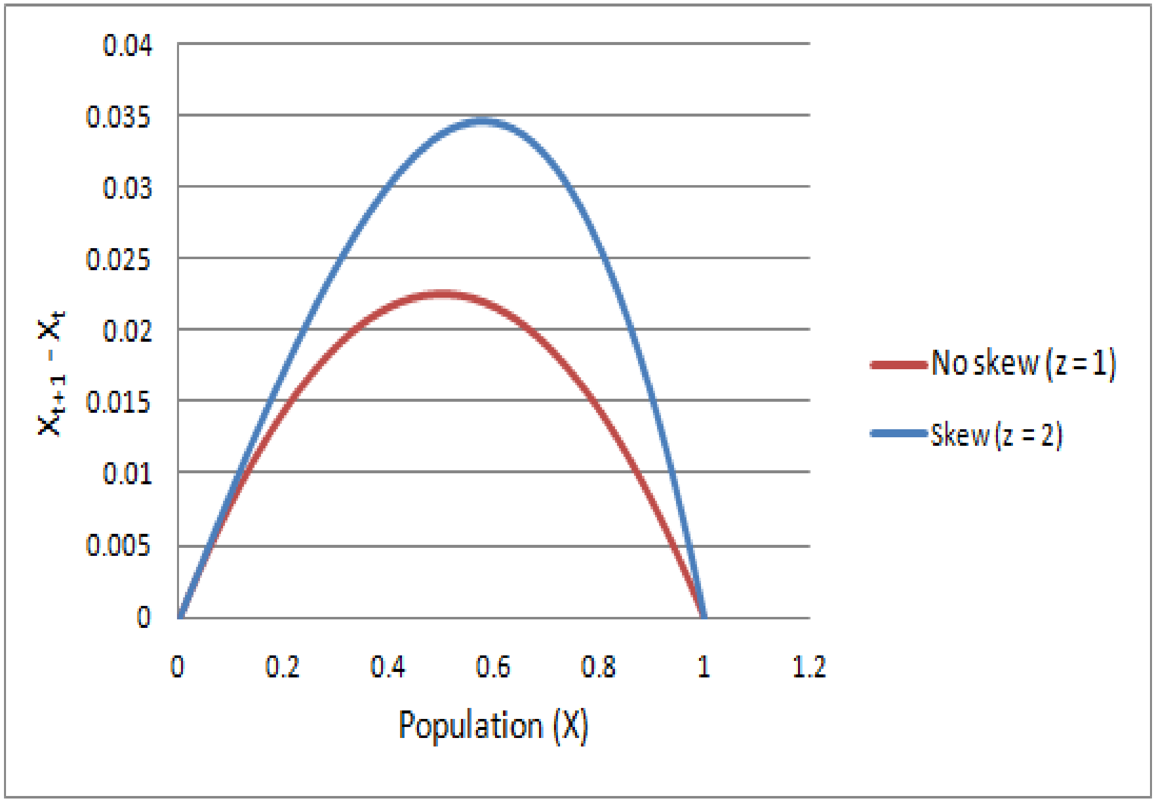
- Protected species' population dynamics:
  $X_{t+1} = X_t + F(X_t) - H\left(T_t^H, X_t\right)$

Logistic growth with a skew parameter (z > 1)

Fowler (1981) suggested that relationship between X_t and $(1-X_t/K)$ may be non-linear:

$$X_{t+1} = X_t + rX_t\left(1-(X_t/K)^z\right)$$

- For large animals, density-dependence is greater when X is closer to K.
- Restricts growth rate at low densities.
- Important for modeling different prey species.



Economic (policy) parameters

- Anti-poaching policy parameter: $\kappa > 0$
- Probability of detecting poaching: $\phi(T_t^H) = (T_t^H / T)e^{-\kappa(T - T_t^H)}$
- Black market price of harvest: $P > 0$
- Protected Area wage rate: $W > 0$
- Fine for poaching: $F > 0$
- Expected household income: $E[I_t] = P(H_t - C_t) + WT_t^W - \phi(T_t^H)F$

Utility functions and solution algorithm

- Household utility:

  $$E[U_t] = \alpha(E[I_t])^{\beta}(T_t^L)^{\gamma}(1+\eta C_t^{\omega}) \quad \text{; Cobb-Douglas utility}$$

  $$E[U_t] = \alpha(E[I_t])^{\beta} + \gamma(T_t^L)^{\varepsilon} + \eta C_t^{\omega} \quad \text{; additive-separable utility}$$

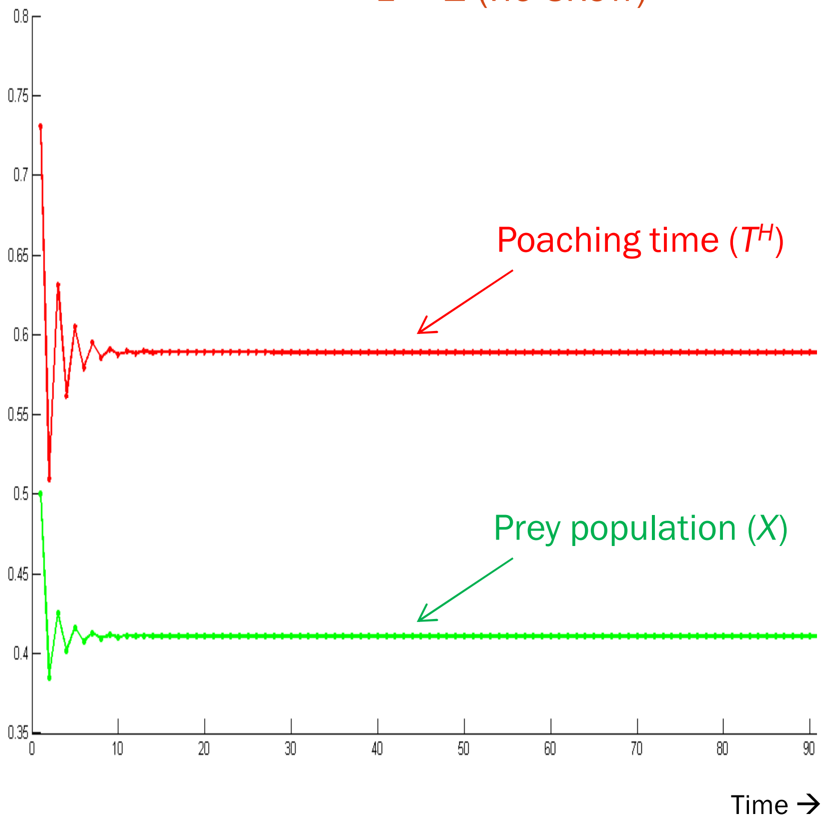
- Initial prey population: X_0
- Solve numerically for poaching time (T_t^H) and wage time (T_t^W) in each period (i.e. household myopic)
- Population evolves according to: $X_{t+1} = X_t + F(X_t) - H(T_t^H, X_t)$
- Repeat for 100 time steps: check for convergence to steady-state value.

Base case parameters

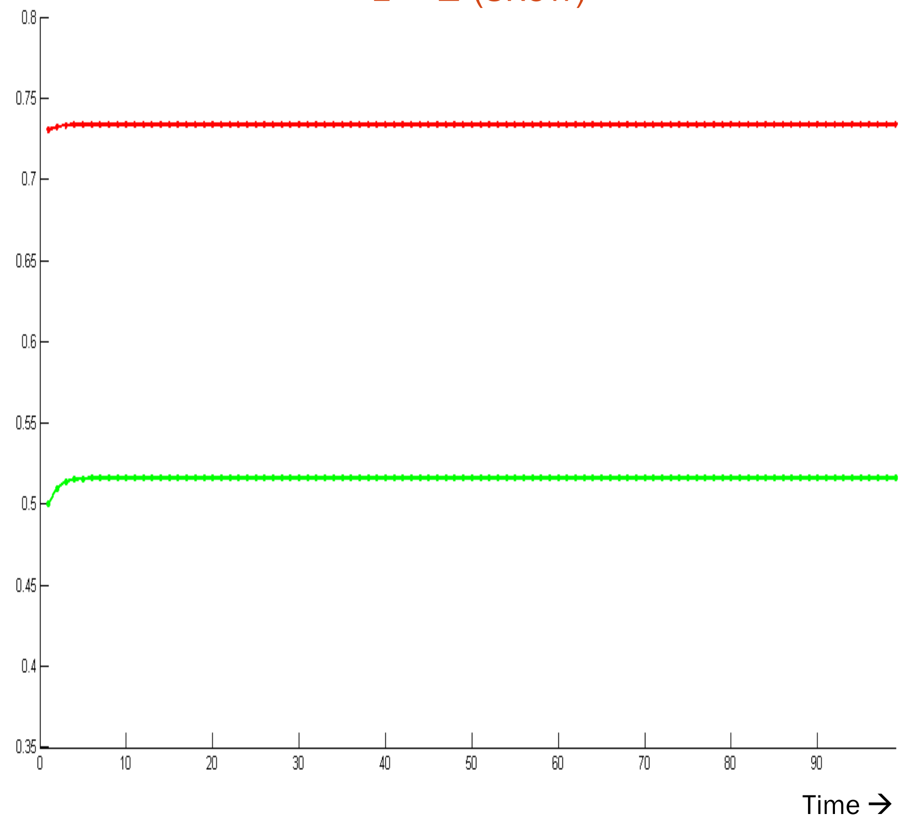
Parameter	Value
Initial population (X_0)	0.5
Carrying capacity (K)	1.0
Intrinsic growth rate (r)	1.0
Catchability coefficient (q)	1.0
Utility parameter (α)	1.0
Utility parameter (β)	1.0
Utility parameter (γ)	0.3
Utility parameter (ω)	0.3
Utility parameter (η)	5.0
Black-market price (P)	5.0
Wage rate (W)	1.0
Fine (F)	1.0
Anti-poaching policy (κ)	1.0
Time constraint (T)	1.0

Base case simulations (Cobb-Douglas utility)

z = 1 (no skew)



z = 2 (skew)



$$X_\infty = K(1 - qT_\infty^H / r)$$

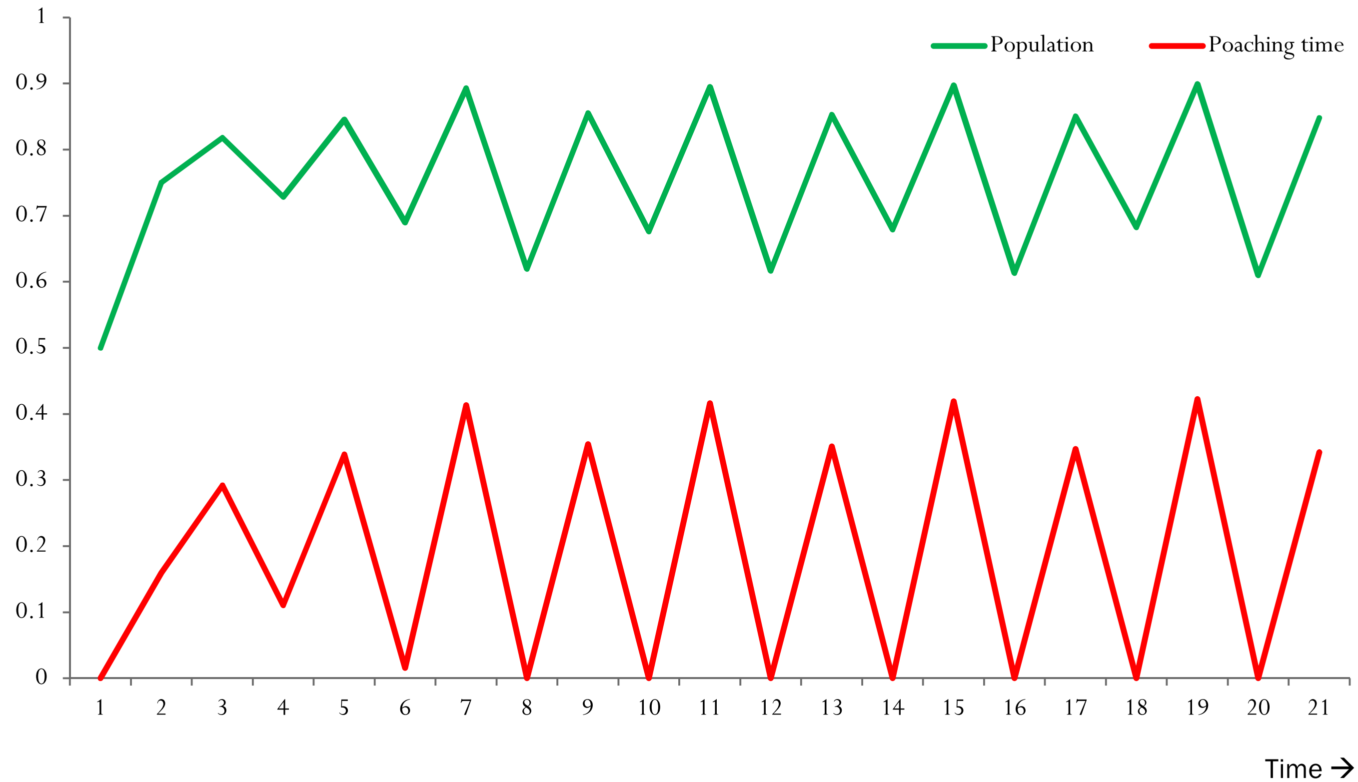
$$X_\infty = 0.4107 \ , \ T_\infty^H = 0.5893$$

$$X_\infty = K(1 - qT_\infty^H / r)^{1/z}$$

$$X_\infty = 0.5159 \ , \ T_\infty^H = 0.7338$$

→ Convergence to analytical steady state

Base case simulations (additive-separable utility)



$$X_\infty = K(1 - qT_\infty^H / r)$$

$$X_\infty = 0.7797 \,,\; T_\infty^H = 0.2202$$

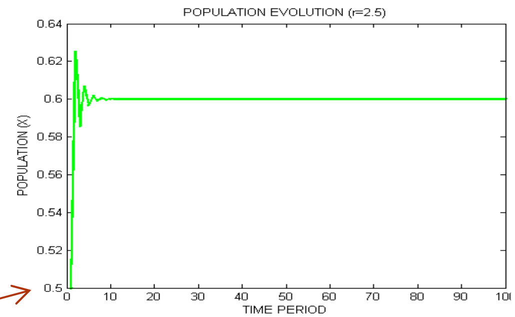
→ No convergence to steady state; 4-point cycle observed

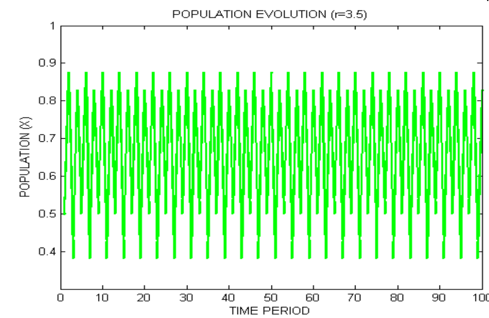
How stable is a solution?

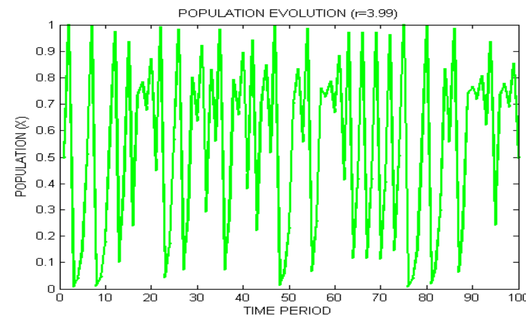
- Robert May (1971) studied the simple logistic equation:

$$X_{t+1} = rX_t(1 - X_t)$$

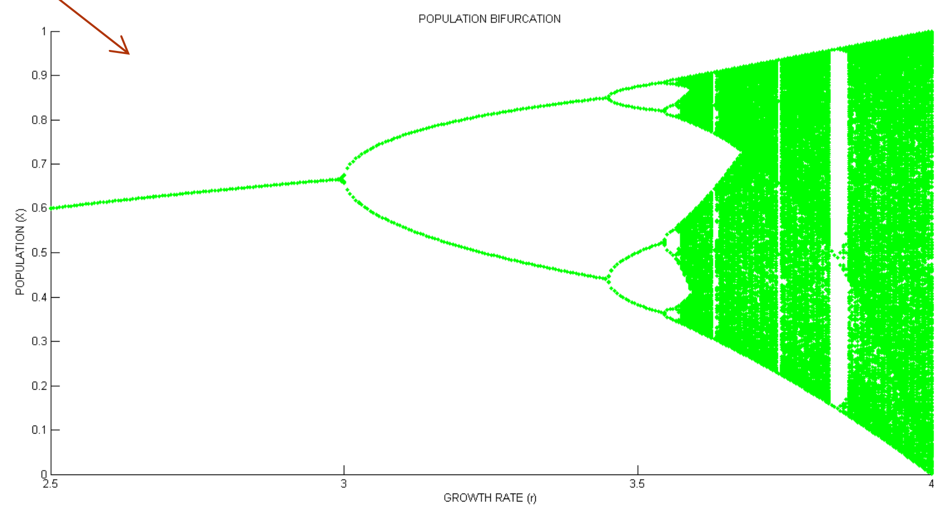
- For small changes in r, one observes complicated dynamics in X:
  - Period-doubling bifurcation
  - Deterministic chaos





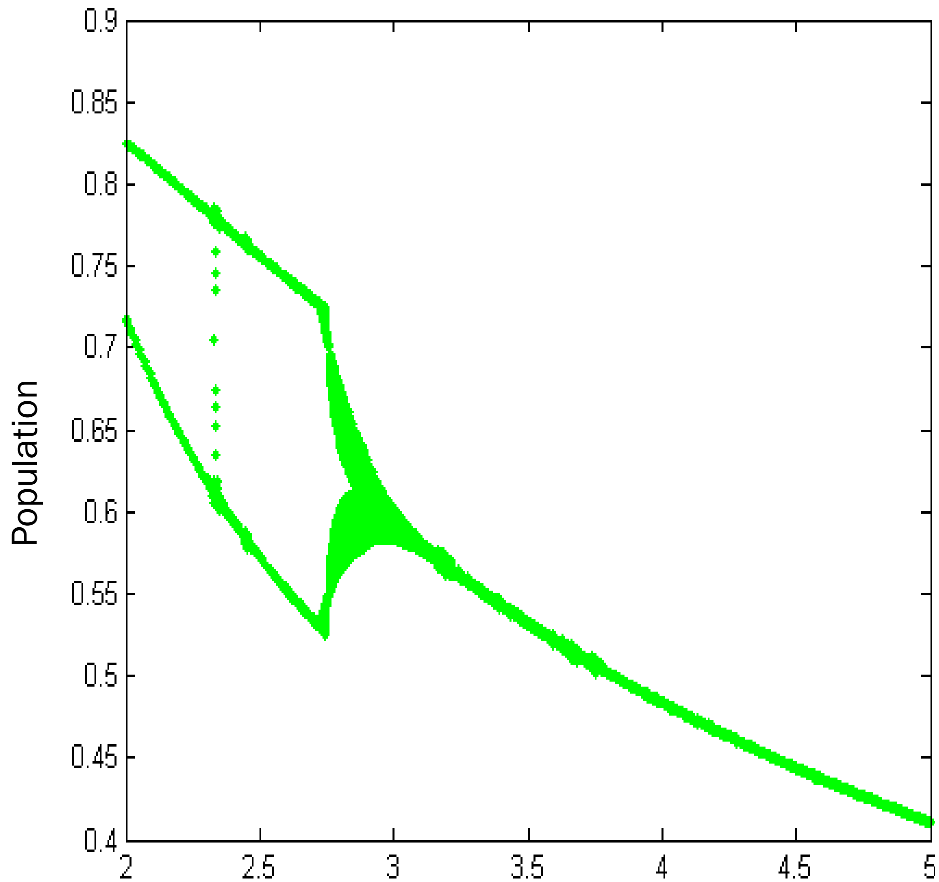


- Bifurcation observed lynx populations
  - Increased trapping effort led to high-amplitude chaotic dynamics (Schaffer (1985), Gamarra and Sole (2000))
- Let us vary our policy parameters one at a time…



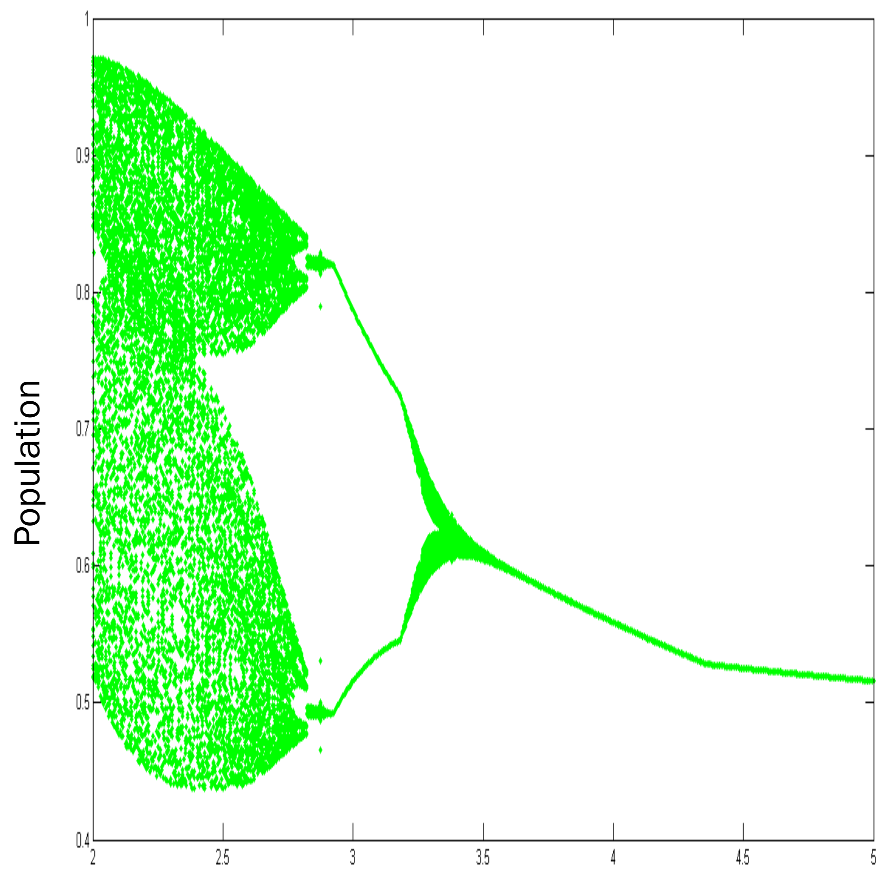
Bifurcation points: black-market price ($2 \leq P \leq 5$)

z = 1 (no skew)



Black-market Price (P)

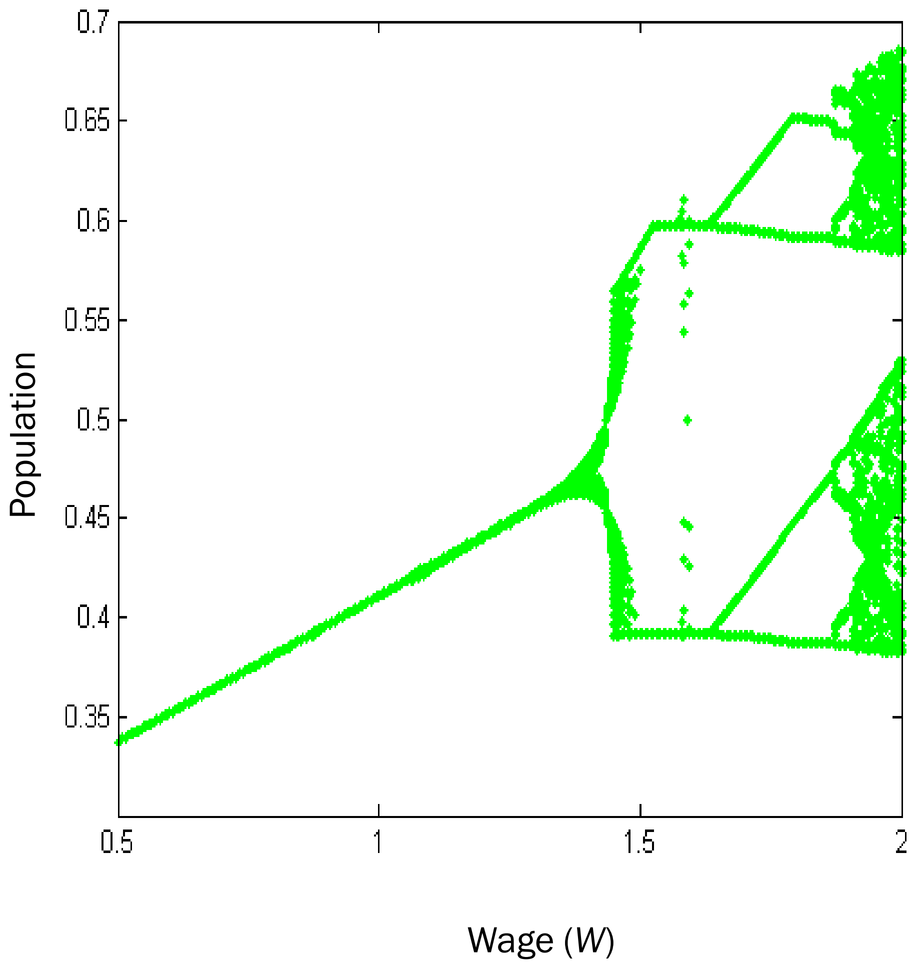
z = 2 (skew)



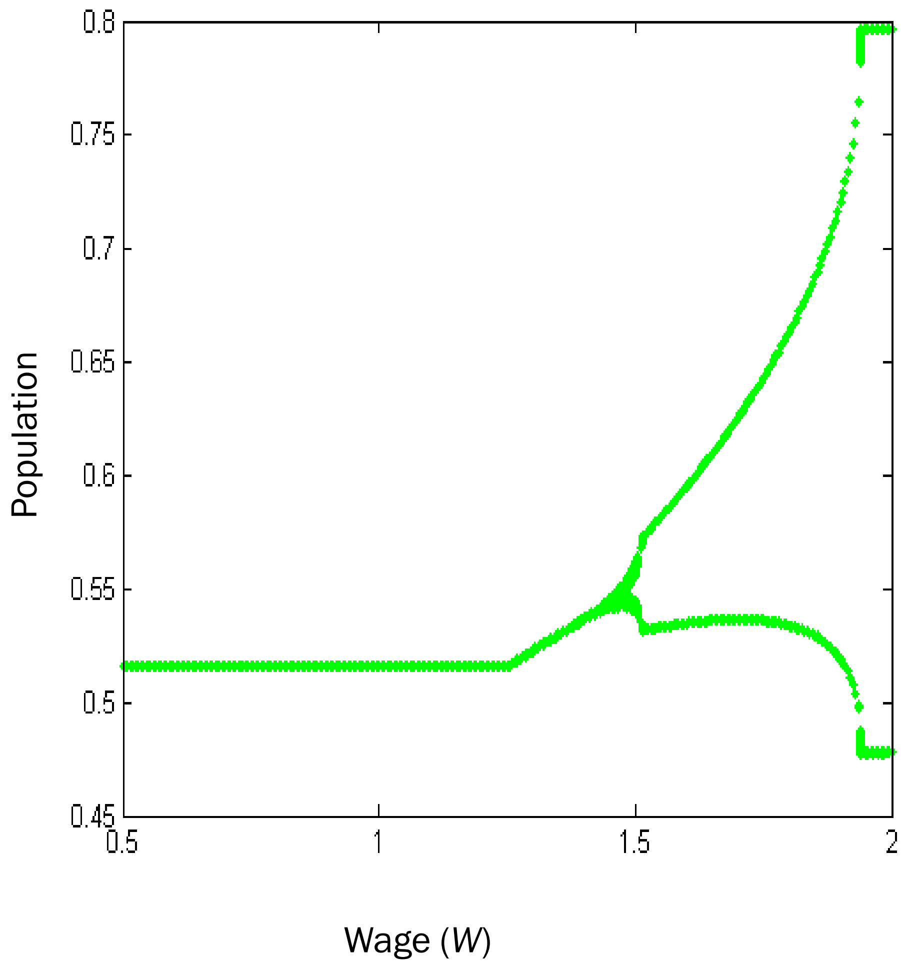
Black-market Price (P)

Bifurcation points: wage rate ($0.5 \leq W \leq 2$)

z = 1 (no skew)

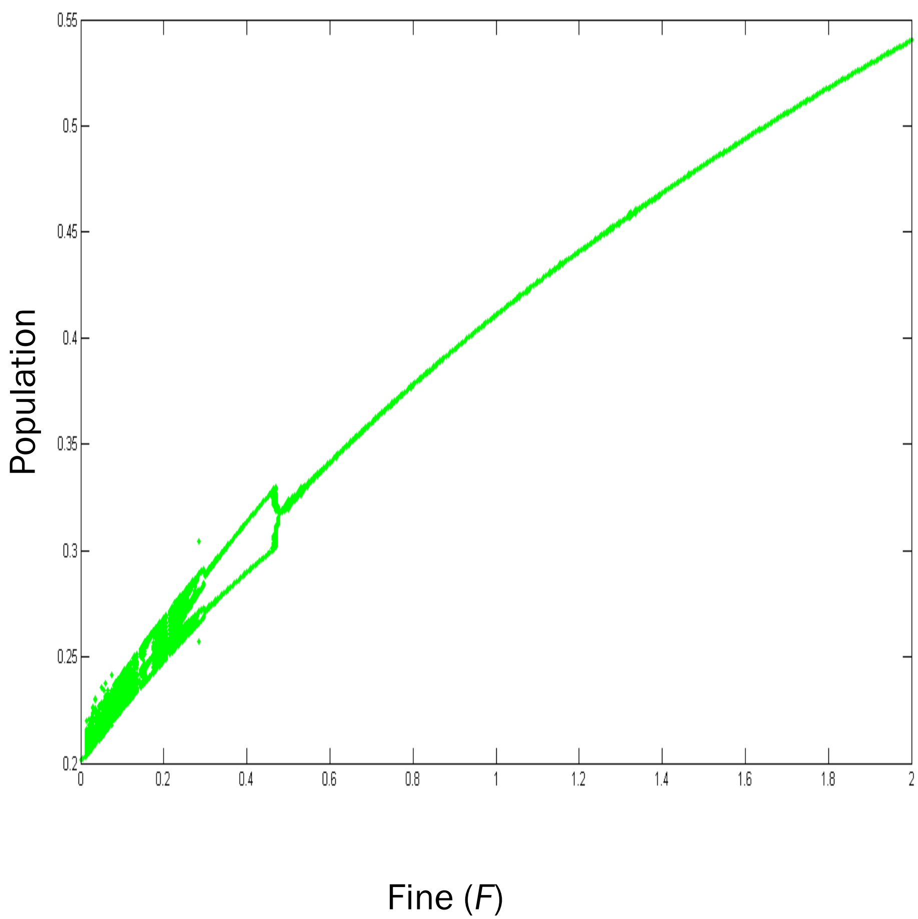


z = 2 (skew)

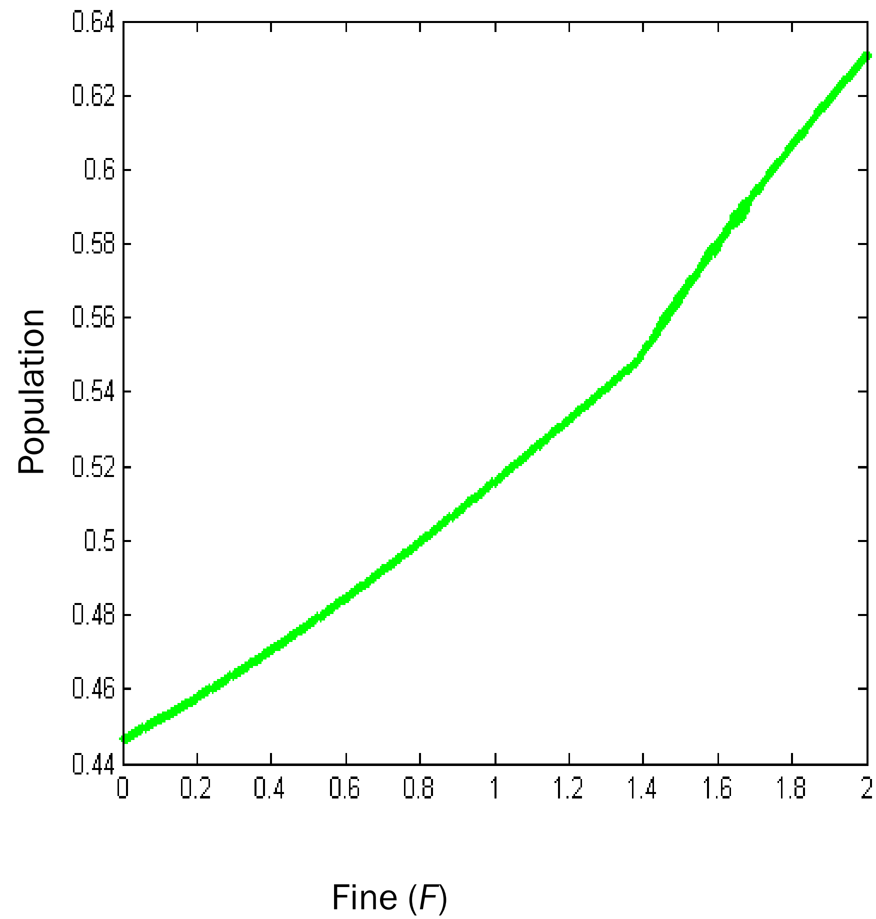


Bifurcation points: fine level ($0 \leq F \leq 2$)

z = 1 (no skew)



z = 2 (skew)

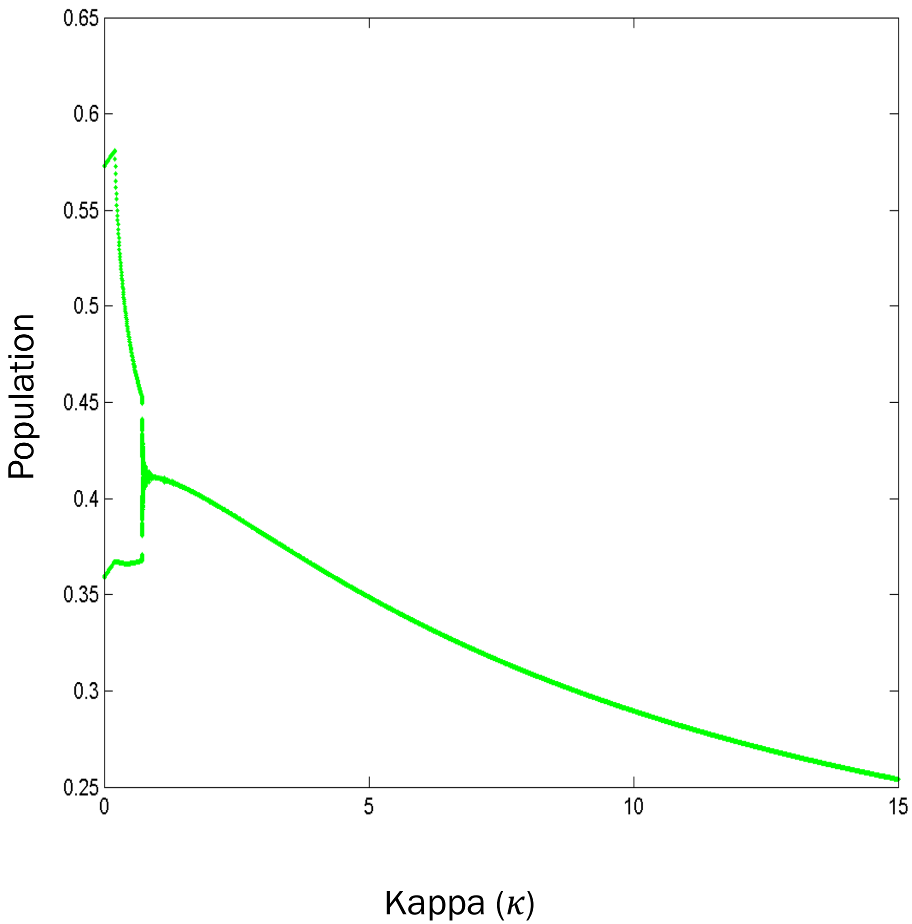


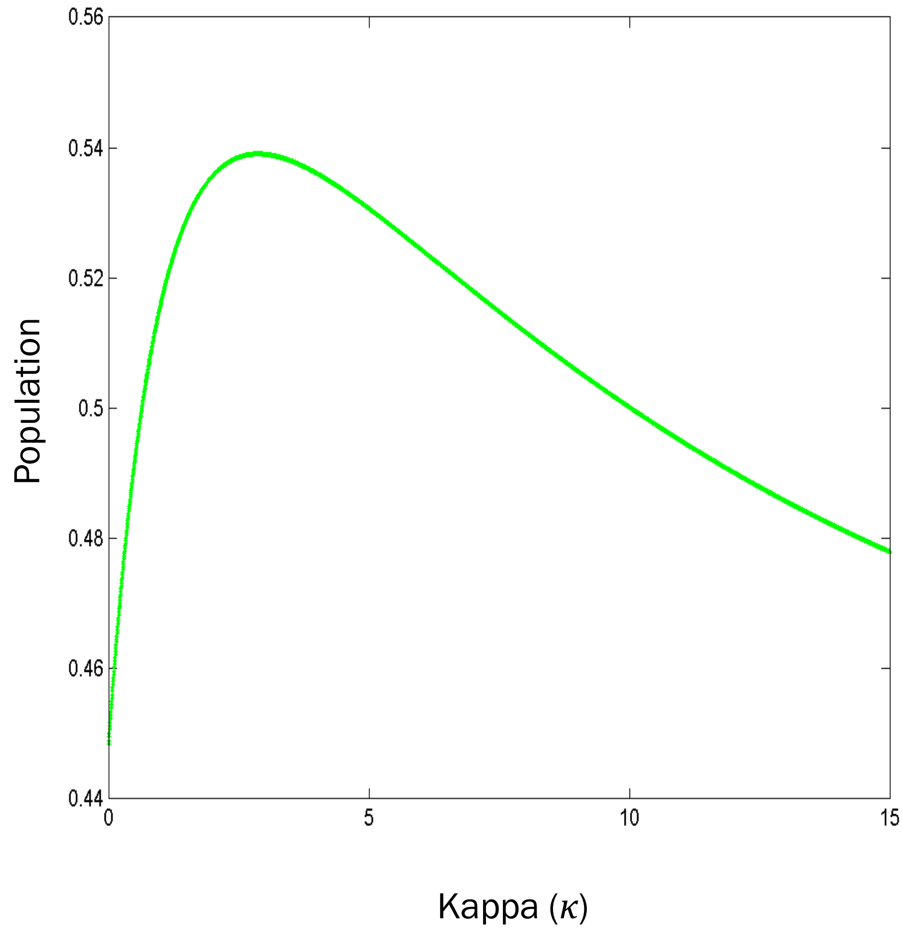
Bifurcation points: probability of getting caught ($0 \le \kappa \le 15$)

z = 1 (no skew)

z = 2 (skew)

$$\phi(T_t^H) = (T_t^H / T)e^{-\kappa(T - T_t^H)}$$





Lessons

- Economic parameters may affect the collapse and renewal of a protected population.
- Policy-induced oscillations more pronounced for changes in P and W, as opposed to F.
- Over-investment in anti-poaching enforcement may lead to unintended consequences (for some range of κ).
- Differences in model structure affect outcomes (Cromsigt *et al.*, 2002).
  - Density-dependence assumptions are crucial: $(X/K)^z$
  - Implications for large animals ($z\uparrow$) and bush-meat ($z\downarrow$) species.
- Choice of utility function form is important.