Matrix Population Models for Wildlife Conservation and Management

27 February - 5 March 2016

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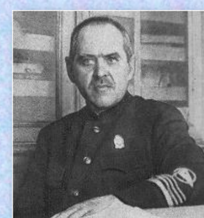
Lecture 7
Exploited populations, the comparative approach, management and conservation

Fedor Illyich BARANOV,
An officer of the Russian fleet,
and a pioneer of the
theory of exploited populations.

W.E. RICKER taught himself
the Russian to be able to read
BARANOV's works.



Sensitivity analysis
Survival

$M \rightarrow M_h = (1-h)M$ $MV=\lambda V \Rightarrow (1-h)MV=(1-h)\lambda V$

Hence M_h $V = (1-h)\lambda V$

$\lambda \rightarrow \lambda_h = (1-h)\lambda$, asymptotic structure V unchanged

x % change in all $s_i \rightarrow$ x % change in λ

The elasticity of λ wrt to $\{ s_1, s_2, \ldots, s_i, \ldots\}$ is 1

Sensitivity analysis
Survival

$M \rightarrow M_h = (1-h)M$ $MV=\lambda V \Rightarrow (1-h)MV=(1-h)\lambda V$

Henc

$\lambda \rightarrow \lambda_h = (1-h)\lambda$,

$s_i \rightarrow s_i\,(1\text{-}h)$
if harvest or incidental mortality
entirely before of after natural mortality.
Then $\lambda \rightarrow \lambda\,(1\text{-}h)$

x % change in all $s_i \rightarrow$ x % change in λ

The elasticity of λ wrt to $\{ s_1, s_2, \ldots, s_i, \ldots\}$ is 1

Exploitation in continuous time: mortality and exploitation as competing risks *(Baranov, 1918)*

"natural" dynamics of death : $n(t+dt) - n(t) = -m\, n(t)\, dt$

with exploitation : $n(t+dt) - n(t) = -(m+h)\, n(t)\, dt$

m, h: natural mortality and harvest *instantaneous rates*

two sources of mortality assumed additive, with total rate z= m+h

However, the number of individuals at risk for both sources of mortality varies with total mortality z as $n(t) = n(0) \exp(-z\, t)$

Exploitation in continuous time: mortality and exploitation as competing risks over [0, T]

Number of natural deaths $\int n(t)\, m\, dt = m/z\; n(0)(1-e^{-zT})$
Number of deaths from exploitation $= h/z\; n(0)(1-e^{-zT})$
Proportion of deaths from exploitation $H = h/z\,(1-e^{-zT})$
Overall proportion of survivors $S = e^{-zT}$
Proportion of survivors if no exploitation $S_0 = e^{-mT}$

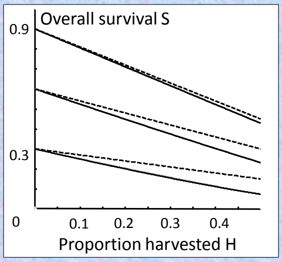
$\Rightarrow$ a complex relationship between S, H, and S_0 :

$$1 - H/(1 - S) = \log(S_0) / \log(S)$$

… S cannot be worked out as a simple function of H and S_0

Exploitation in continuous time: approximation of additive competing risks

However, for high S_0 or low H, is well approximated by line: $S = f(S_0, H)$ (continuous lines), $S \approx S_0(1-H)$ (dashed lines)

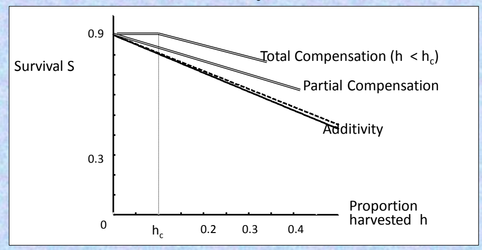


Similar results for variable rates m(t) and h(t)

For low S_0, split in shorter intervals

Compensatory mortality

Does survival decrease with harvest h less rapidly than under "additive" mortality effects: $S > S_0(1-h)$?



Compensatory mortality and Density-dependence

- Compensatory mortality implies m decreases for high h
- Such a change can be mediated by density-dependence
- h=10 % totally compensated
  iff - 10% in numbers ⇒ + 10 % survival
- Weak partial compensation expected in most cases
- Controversial evidence (Anderson & Burnham , 1976)
- Compensatory recruitment/reproduction ?

Individual Frailty

Lindberg et al. unpub.

- Canvasback
  Aythya valisineria
- 2 classes of "demographic quality" (purely phenotypical)
  POOR and GOOD
- A discrete mixture model for a continuous heterogeneity
- "POOR" individuals more vulnerable to hunting than "GOOD"

Individual Frailty

Lindberg et al. unpub.

	AGE	1	1	2+	2+
	QUALITY	POOR	GOOD	POOR	GOOD
AGE	QUAL ITY				
1	POOR	0	$a_{1g}*f_{gp}*S_{1p}*(1-h_p)$	$a_p*f_{pp}*S_{1p}*(1-h_p)$	$a_g*f_{gp}*S_{1p}*(1-h_p)$
1	GOOD	0	$a_{1g}*f_{gg}*S_{1g}*(1-h_g)$	$a_p*f_{pg}*S_{1g}*(1-h_g)$	$a_g*f_{gg}*S_{1g}*(1-h_g)$
2+	POOR	$S_p*(1-h_p)$	0	$S_p*(1-h_p)$	0
2+	GOOD	0	$S_g*(1-h_g)$	0	$S_g*(1-h_g)$

Individual Frailty

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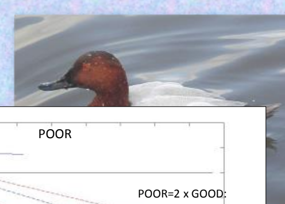
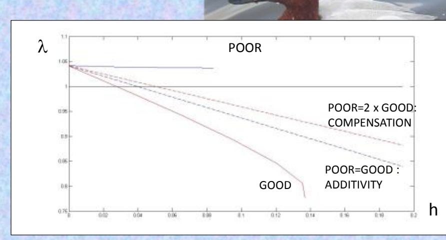
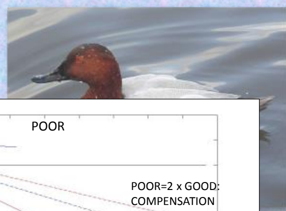


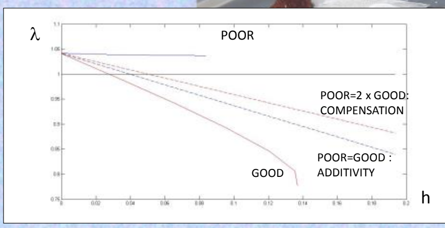


"POOR" individuals more vulnerable to hunting than "GOOD"
"Die from hunting before dying from other cause" = compensation
Even under exchange between POOR and GOOD

Individual Frailty

Lindberg et al. in prep.





Intimately linked with "REPRODUCTIVE VALUE"

P1 = 0.1544 G1 = 1.1233 P2+ = 0.2233 G2+ = 1.1233

Contribution to future growth = common currency

Individual Frailty *Lindberg et al. 2013.*

$\lambda(h) \approx \lambda(0)(1-bh);$

where b is the ratio of harvest proportion weighted by reproductive value of a quality class (h_{rv}) and harvest proportion irrespective of reproductive value (h). Harvest proportion irrespective of reproductive value is:

$$h = \frac{\sum_{i=1}^{n} w_i h_i}{\sum_{i=1}^{n} w_i}$$

and harvest proportion weighted by reproductive value is:

$$h_{rv} = \frac{\sum_{i=1}^{n} w_i v_i h_i}{\sum_{i=1}^{n} w_i v_i}$$

Here, W = stable structure, V = Reproductive value

Individual Frailty *Lindberg et al. 2013.*

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Reproductive Value (RV) and compensation

Compensation by heterogeneity

=

harvest of low reproductive value

Biologically significant iff RV strongly uneven

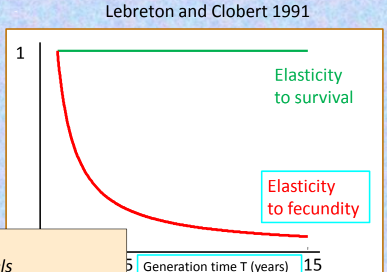
RV (autumn)	<	RV(spring)
RV(young)	<	RV(adult)
RV(sink)	<	RV(source)
RV(ill)	<	RV(healthy)

Jean Clobert

Sensitivity analysis

Fecundity and Survival

Lebreton and Clobert 1991



Valid for

- *multistate models*
- *exploitation in continuous time*

Sensitivity analysis and Generation time

Albatross, T≈24 y:

-30 % in Fecundity ⇒

-1.25 % in growth rate

In any sharp-decline of a long lived species, first suspect a change in survival

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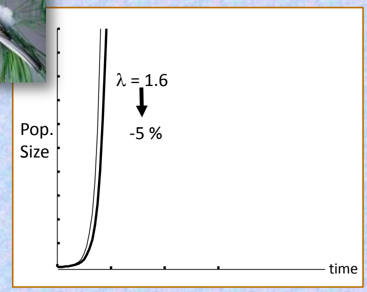
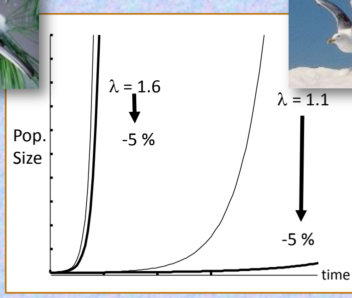
In any sharp-decline of a long lived species, first suspect a change in survival

Ok, but does not say WHY long-lived species so often face conservation problems?

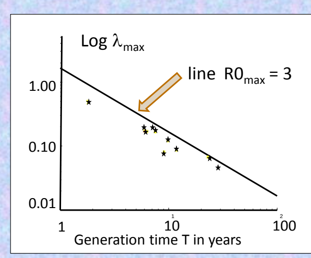
Effect of exploitation on growth rate



Effect of exploitation on growth rate

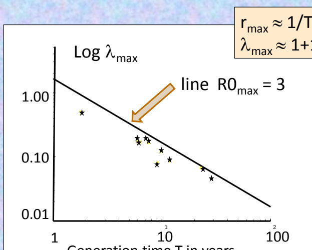


Constancy of MGR per Generation among Bird species (Niel & Lebreton, 2005)



Constancy of MGR per Generation among Bird species (Niel & Lebreton, 2005)

$r_{max} \approx 1/T$
$\lambda_{max} \approx 1+1/T$ for large T



Generation time and conservation status (IUCN)

118 species with decently complete demographic info

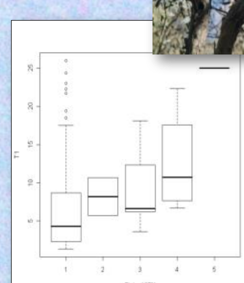
Susceptibility to harvest ←→ Max growth rate

Max growth rate ←→ Generation time

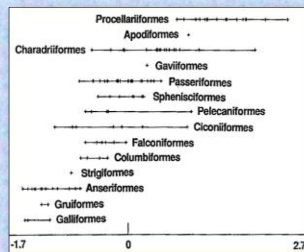
Generation time ←→ Conservation status

⇩

Susceptibility to harvest ←→ Conservation status



The slow fast gradient

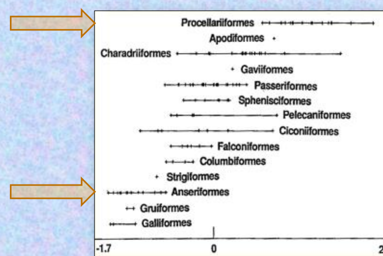


← Fast 1st PC Slow →

PCA of Log Age at 1st repro., Log Ad. life expectancy, Log Fecundity, ***corrected*** for body size

Gaillard et al. 1989, Oecologia

The slow fast gradient



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Adult survival among Anseriforms

Devineau Ph.D., Devineau et al., in prep.

- 53 species, with replications over populations
- Estimated annual adult survival probability (CMR, Recoveries)
- Categorical index of hunting pressure

h = 0 No hunting

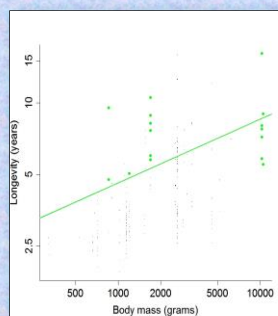
h = 1 low

h = 2 medium

h = 3 high

Espèce	Information chasse	HP
Anas acuta	"hunter effort (...) was consistently high"	2
Anas superciliosa	"exposed to heavy hunting pressure"	3
Anas platyrhynchos	"regulations were stable and relatively liberal"	2
Anas platyrhynchos	"regulations were restrictive"	1
Anser a. albifrons	"restrictive measure have been imposed on shooting"	1
Aythya collaris	"the population (...) is heavily harvested"	3
Lophodytes cucullatus	"because of their low harvest rate"	1

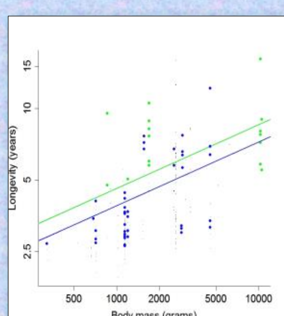
Adult survival among Anseriforms



F(S) = a + b Log W + c h under h=0

Small (TEAL) ←→ large (SWAN)

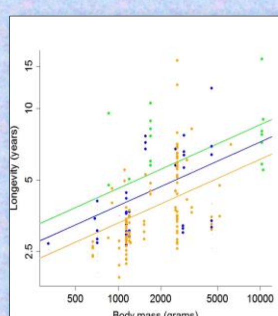
Adult survival among Anseriforms



F(S) = a + b Log W + c h under h=0, 1

Small (TEAL) ←→ large (SWAN)

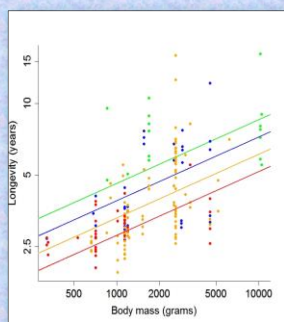
Adult survival among Anseriforms



F(S) = a + b Log W + c h under h=0, 1, 2

Small (TEAL) ←→ large (SWAN)

Adult survival among Anseriforms

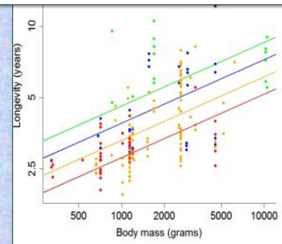


F(S) = a + b Log W + c h
under h=0, 1, 2, 3

Small (TEAL) ←→ large (SWAN)

Adult survival among Anseriforms

- Survival does increase allometrically with Body mass
- Survival does decrease with hunting pressure
- Hunting level quantifiable from change in survival



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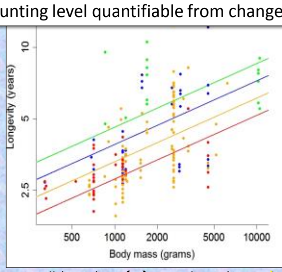
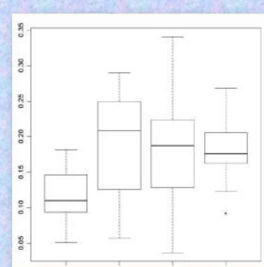


$S=S_0$
$S=S_0\cdot(1-H_{low})$
$H_{low} \approx 11\%$
$S=S_0\cdot(1-H_{medium})$
$H_{medium} \approx 26\%$
$S=S_0\cdot(1-H_{high})$
$H_{high} \approx 45\%$

Small (TEAL) ←→ large (SWAN)

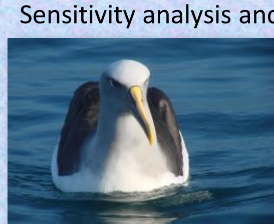
Management choices match estimated max growth rate

Estimated maximum growth rate 1/T



Index of hunting pressure 0 1 2 3

Sensitivity analysis and Generation time



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-1.25 % in growth rate

In any sharp-decline of a long lived species, first suspect a change in survival

Longline fisheries and Black-Footed Albatross

- Demography similar to other albatross
- (adult survival ≈ 0.93)
- Matrix model: T ≈ 25 y

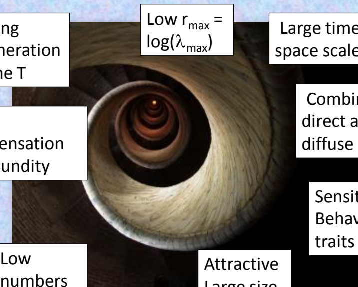
- 60 000 pairs => 300 000 individuals
- 1/T ≈ 0.04 => Maximum by-catch < 12 000
- Other sources of man-induced mortality (plastic ingestion…)
- ⇒ A warning of deleterious character of by-catch by longline fisheries (≈ 12 500 ind., Melvin, pers.comm.)
- Confirmed since by detailed analyses and modeling

The malediction of long-lived species

- Long generation time
- Low maximum growth rate
- Man-induced exploitation, even incidental, often not sustainable

As a capital with a low interest rate, they cannot sustain the tax of human impacts

The malediction of long-lived species



Long generation time T

Low r_{max} = $\log(\lambda_{max})$

Large time and space scale

No compensation by fecundity

Combination of direct and diffuse impacts

Sensitive Behavioral traits

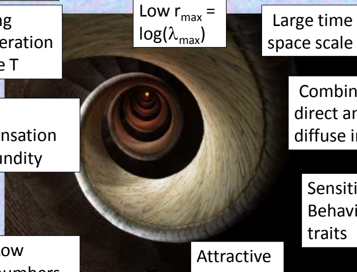
Low numbers

Attractive Large size

The malediction of long-lived species

A good proxy

A Key feature



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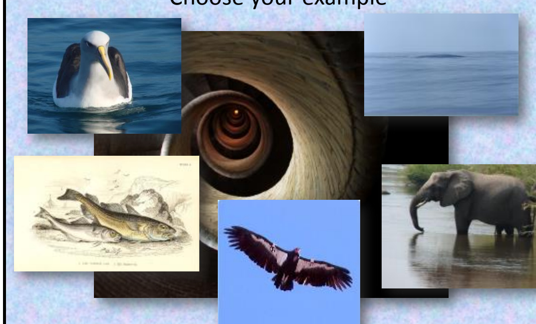
The malediction of long-lived species

Choose your example



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