
CREAM Open Conference
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Fibonacci Sequence in Nature
Fibonacci Sequence

Year 1202:

A page of Leonardo Fibonacci's Liber Abaci from the Biblioteca Nazionale di Firenze showing (in box on right) the Fibonacci sequence with the position in the sequence labeled in Latin and Roman numerals and the value in Hindu-Arabic numerals.
Today’s Topics

• Roots of population modeling
  – Especially as related to ecological risk assessment (ERA)

• Key milestones in the development of population modeling for ERA

• Key issues for the future of chemical risk assessment???
Birth of Scientific Demography: Graunt 1662

Bill of Mortality:
London, 11-18 February 1661

<table>
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<tr>
<th>Disease</th>
<th>Males 1647</th>
<th>Females 1647</th>
<th>Buried Males</th>
<th>Buried Females</th>
<th>Plague</th>
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<tr>
<td>Cancers</td>
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<td>103</td>
<td>11</td>
<td>16</td>
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<td>Small-pox</td>
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<td>Scourvy</td>
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<td>Winde</td>
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</tbody>
</table>

Source: Hutchinson 1978 after Guildhall Museum Library in London
Exponential Population Growth - The Malthusian Model, 1798

\[
\frac{dN}{dt} = r_{\text{max}}N
\]
Darwin’s Struggle for Existence: Geometrical Ratio of Increase, 1859

• “A struggle for existence inevitably follows from the high rate at which all organic beings tend to increase”

• From a single pair of elephants, “after a period of from 740 to 750 years there would be nearly 19 million elephants alive”
There are Limits to Growth, 1683 - 1838 - 1925

Maximum sustainable population size, now known as ‘carrying capacity’ $K$

$$\frac{dN}{dt} = r_{\text{max}}N \frac{(K - N)}{K}$$

Logistic population growth

St. Paul Island, Alaska
The Roots of Population Modeling in ERA (1)

1662 – Birth of scientific demography, Graunt: *Natural and Political Observations… upon the Bill of Mortality*

1683 – Maximum sustainable population size, Petty: *Another Essay in Political Arithmetic*

1798 – Exponential population growth model, Malthus

1838-1847 – Logistic population growth model, Verhulst

1859 – Darwin: geometric ratio of increase after Sir William Hale 1677

1925 – *Elements of Physical Biology*, Lotka
1925 – *The Biology of Population Growth*, Pearl
Population Fluctuations can be Oscillatory or “Chaotic”

Lemmings, far North

Pied Flycatcher, Netherlands

Saether et al. 2002

Stochasticity or Time Delays in Population Models Produces ‘Chaotic’ Fluctuations

http://www.simulistics.com/files/examples/popdy/pop5c.gif

1948: Differential logistic equation with time delay, G.E. Hutchinson

Early 1970s: Discrete logistic, Robert M. May
1963 IUCN Red List and 1966 Endangered Species Act Sparked the Bloom of PVA
The Roots of Population Modeling in ERA (2)

Year 1980
- 1979 – Fish cohort growth model, DeAngelis et al.
- 1978 – Population viability analysis (PVA) minimum population size, Shaffer
- 1975 – Simple-delay logistic model applied to data: chaos theory, May
- 1974 – Ecological Modelling, Sven Jorgensen (ed.)
- 1972 – JABOWA forest model, Botkin et al.

Year 1970
- 1970 – Use of GIS in regional planning sets the stage for spatial models Cellular automata, von Neumann
- 1969 – Metapopulation model, Richard Levins
- 1964 – Douglas fir forest IBM, Newnham
- 1964-1974 – International Biological Program, systems perspective

Year 1960
- 1950s - von Bertalanffy general system theory; Ricker Spawner-Recruit
- 1950s – Stochastic population modeling
- Mid 1940s – Population ecology blooms
- 1945 – On the use of matrices in certain population mathematics, Leslie

Year 1940

1945 – On the use of matrices in certain population mathematics, Leslie
The Modern Era (1)

Year 1990

1990 – Density-dependence form and strength affects extinction risk, Ginzburg et al.
1989 – *Structured population models: a tool for linking effects at individual and population level*, Nisbet et al.
1987 – Fish population models: life history, uncertainty and exploitation, Barnthouse et al.

Year 1980

1984 – IBM and chemical stress, Kooijman et al.
1982 – Ecosystem modeling O’Neill et al. 1982
1982 – Quasi-extinction as a risk concept, Ginzburg et al.
1980’s – Development of population models for pesticides+, Grant et al. +
1980s-90s – Population viability analysis (PVA) blooms
The Modern Era (2)

2002 – Compensatory response mitigates pesticide effects, Moe et al.

2000 – Multiple model types applied to pesticide ERA, Bartell et al.
2000 – Stochastic population models with endpoint fraction of K, Iwasa et al.
1998 – EPA *Guidelines for Ecological Risk Assessment*
1998 – Action at Distance metapopulation modeling, Spromberg et al.
1997 – First use of population modeling in Superfund ERA, Munns et al.
1996 – IBM for pesticide effects on lumbricids, Baveco and DeRoos

1990s – Population modeling for pesticide risk assessment, Stark et al.

1991 – *Use of RAMAS to estimate ecological risk*, Ferson et al.
Counter-intuitive Outcomes

“A risk-analytic summary such as the risks of population decline, rather than any simple hazard quotient or scalar estimate of population growth, is the appropriate endpoint for ecological risk assessment”

Source: Ferson et al. 1996
Use of Population Modeling in EPA Superfund Program

Source: Munns et al. 1997
Spatially Explicit Population Modeling Expands in the 1990s and 2000s

Source: Charles et al. 2009

Figure 7.1 ALMaSS screenshot of a typical 10x10 km landscape used for simulations. In this case the red dots indicate the overwintering positions of simulated beetles. Note that the map resolution is much finer than displayed on screen.

Source: Topping et al. 2009
The Modern Era (3)

2013 – Assessing Risks to Endangered and Threatened Species from Pesticides, NRC
2012-2013 – MODELINK
  2012 – First ABM in Superfund ERA: mink population, Luxon et al.
  2011 – Population models evaluate residual effects of Exxon Valdez, Monson et al. 2011
  2009 – Integration: AChE inhibition, feeding, growth, and population models, Baldwin 2009
2008 – Demographic Toxicity, Akcakaya et al.
2005 – Individual-Based Modelling and Ecology, Grimm and Railsback
2005 – DEBtox models with Leslie matrix, Lopes et al.
2004 – First ABM-landscape model combination: skylark, Topping and Odderskaer 2004

2002 – Herring gull extinction risk from DDT, DD matrix model, Nakamaru et al. 2002
The Future is Here!

• Essential elements for integrating population modeling into regulatory programs
  – Harmonization / Consistency / Credibility of models
  – Simplicity of risk communication
  – Risk metrics development (precautionary)
  – Population-relevant and cost-effective toxicity tests
  – Decision framework
  – Guidance documents
The Future is Here!

• Research issues
  – Behavior of models relative to reality
    » Pattern-oriented modeling
  – Density dependence
    » Form & strength for focal species
    » Toxicant interactions
  – Landscape effects and scale
  – Comparison of different kinds of models
  – Quantification of compounding conservatism
Effects of Compounding Conservatism need to be Explicit

Figure 7.4  Simulated vole population depressions after the application of pesticide under two scenarios, 100% exposure or realistic application to orchards.

Source: Topping et al. 2009
Creative Exploration of Risk Metrics is Needed to Address Today’s Issues

T = Extinction Time

Metric Type Affects Risk Perception

Source: Applied Biomathematics and Woodlot Alternatives 2003
$N_{eq}$ can be used as an Assessment Endpoint

Note: $N_{eq}$, equilibrium population size, is normalized to $N_{eq}$ for 30 $\mu$g/L

Source: Hayashi et al. 2009
Is $N_{eq}$ More Sensitive than $\lambda$ to Toxic Chemicals?

- Uniform density-dependent model for fathead minnow
- Ricker function ($e^{-bN}$) for all matrix elements

Source: Hayashi et al. 2009
Are Key Metrics Related? **Maybe Not!**

Source: Hendriks et al. 2005
Toxicity Test Design Affects Uncertainty

Concentration-response functions and uncertainty bands for the effect of chronic trifluralin exposure on the average annual recruitment of Gulf menhaden *Brevoortiupatronus*.

(A) Life-cycle test data for the species of interest
(B) Life-cycle test data for a surrogate species
(C) 96-h LC50 for a surrogate species
(D) QSARs

Source: Barnthouse et al. 1990
Using Demographic Models to Aid Design of Toxicity Tests

Ecotoxicology
DOI 10.1007/s10646-012-0904-5

Decomposition analysis of LTREs may facilitate the design of short-term ecotoxicological tests

Natnael T. Hamda · Dragan M. Jevtić · Ryszard Laskowski
Life History Traits Sensitive to Toxics Have Low Elasticity for PGR

- 4 species
- 54 data sets

Source: Forbes et al. 2010
Population Modeling of Various Life History Types Gives Insight to Population Regulation

\[ \mathbf{X} = \text{Fish} \]
\[ \mathbf{A} = \text{Algae} \]
\[ \mathbf{B} = \text{Benthic macroinvertebrate} \]
\[ \mathbf{D} = \text{Daphnid} \]

Source: Forbes and Calow 2002

Risk Assessment on the Basis of Simplified Life Histories
Calow et al. (1997)
Criteria for Soil, Sediment or Water Quality

Comparison of the cumulative distributions of the concentration at $\lambda = 1$ for various dose–response models

Source: Lin and Meng 2009
First Spatially-Explicit ABM for Mink used to derive Sediment Criteria at a Superfund Site

Source: Windward Environmental 2013 (related paper by Luxon et al submitted to IEAM)
Mink Spatially-Explicit ABM (cont.)

Note: Additional detailed steps on habitat acquisition removed for brevity.

Source: Windward Environmental 2013 (related paper by Luxon et al submitted to IEAM)
Acceptable Population Risk Translated to Sediment Remedial Goal for PCBs - Mink ABM

- ≤30% decrease in kit production caused no effect on population size
- Uncertainty in the PCBs exposure model translated to 95% CI on the remedial goal (RG)

Source: Windward Environmental 2013 (related paper by Luxon et al submitted to IEAM)
‘Standard’ Models and Decision Frameworks for Modeling are Needed

- MODELINK
- Roskilde workshop on Integrating Population Modeling in Ecological Risk Assessment
- Decision framework for pesticide risk assessment based on population modeling
Flexibility is Essential

Source: Kapustka et al. (in prep.) for Intrinsik, Inc
Linking Population Models - The ATLSS Approach by DeAngelis et al.

Source: Pastorok 2000 SETAC meeting based on DeAngelis et al. 1998
Various Model Types for a Pesticide (Diquat Dibromide) Case Study

Daphnia IBM – based on Hallam et al. 1990

CASM Ecosystem Model

Bluegill Matrix Model

Source: Bartell et al. 2000 and DeAngelis et al. 1989
What Kind of Model and How Complex?

“The issue is not model complexity or population versus ecosystem models but identifying the necessary and sufficient model structure and processes that produce useful and reliable estimates for specific risk assessments and management decisions based on risk”

Climate and Wildlife Population Growth

Yellowstone is getting dryer
- values < 0 indicate drought

Fig. 2. Annual PHDI of the Yellowstone Drainage region between 1895 and 2007 (25). Values above zero indicate a wet year, and values below zero indicate drought conditions. Best fit linear model of PHDI values (not shown) has slope = -0.057, adjusted $R^2 = 0.33$, and $P < 0.001$.

Tiger Salamander (AT)
(Ambystoma tigrinum)

McMenamin et al. (2008) PNAS
Conclusions

• Population modeling will undoubtedly play a major role in chemical risk assessments in the near future.

• We’ve come a long ways, but significant issues in risk expression and communication remain.

• The effects of climate change will pose new challenges for risk assessors.

• CREAM has already contributed a great deal.

• We can look forward to significant ongoing scientific contributions by CREAM fellows.
BIBLIOGRAPHY


1 This bibliography is based on the professional experiences of R.A. Pastorok from 1972 to present and is intended to accompany a keynote presentation titled Population Models for Ecological Risk Assessment of Chemicals: The Past, CREAM, and the Future delivered on June 11, 2013 at the CREAM Open Conference in Leipzig, Germany. This bibliography is not comprehensive and is based mainly on references used for the presentation.


Fibonacci, L. 1202. Liber Abaci, from the Biblioteca Nazionale di Firenze, Florence, Italy.


Graunt, J. 1662. Natural and political observations made upon the bills of mortality. London, UK.


Petty, W. 1683. Maximum sustainable population size: another essay in political arithmetic.


