Extinction: Past and Present

Professor Barry W. Brook

Sir Hubert Wilkins Chair of Climate Change
Director, Research Institute for Climate Change and Sustainability
School of Earth and Environmental Sciences
The University of Adelaide
Email: barry.brook@adelaide.edu.au
The diagram shows the relationship between Evolutionary Biology, Extinction Biology, and Ecology. The areas A, B, C, and D represent different intersections and overlaps of these fields.
Defining extinction
• Proving an absence?
- Proving an absence?
- 50 year rule
- Proving an absence?
- 50 year rule
- Local, regional, global...
Ambiguities and probabilities
<p>| | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1590</td>
<td>1591</td>
<td>1592</td>
<td>1593</td>
<td>1594</td>
<td>1595</td>
<td>1596</td>
<td>1597</td>
<td>1598</td>
</tr>
<tr>
<td>1600</td>
<td>1601</td>
<td>1602</td>
<td>1603</td>
<td>1604</td>
<td>1605</td>
<td>1606</td>
<td>1607</td>
<td>1608</td>
</tr>
<tr>
<td>1610</td>
<td>1611</td>
<td>1612</td>
<td>1613</td>
<td>1614</td>
<td>1615</td>
<td>1616</td>
<td>1617</td>
<td>1618</td>
</tr>
<tr>
<td>1620</td>
<td>1621</td>
<td>1622</td>
<td>1623</td>
<td>1624</td>
<td>1625</td>
<td>1626</td>
<td>1627</td>
<td>1628</td>
</tr>
<tr>
<td>1630</td>
<td>1631</td>
<td>1632</td>
<td>1633</td>
<td>1634</td>
<td>1635</td>
<td>1636</td>
<td>1637</td>
<td>1638</td>
</tr>
<tr>
<td>1640</td>
<td>1641</td>
<td>1642</td>
<td>1643</td>
<td>1644</td>
<td>1645</td>
<td>1646</td>
<td>1647</td>
<td>1648</td>
</tr>
<tr>
<td>1650</td>
<td>1651</td>
<td>1652</td>
<td>1653</td>
<td>1654</td>
<td>1655</td>
<td>1656</td>
<td>1657</td>
<td>1658</td>
</tr>
<tr>
<td>1660</td>
<td>1661</td>
<td>1662</td>
<td>1663</td>
<td>1664</td>
<td>1665</td>
<td>1666</td>
<td>1667</td>
<td>1668</td>
</tr>
<tr>
<td>1670</td>
<td>1671</td>
<td>1672</td>
<td>1673</td>
<td>1674</td>
<td>1675</td>
<td>1676</td>
<td>1677</td>
<td>1678</td>
</tr>
<tr>
<td>1680</td>
<td>1681</td>
<td>1682</td>
<td>1683</td>
<td>1684</td>
<td>1685</td>
<td>1686</td>
<td>1687</td>
<td>1688</td>
</tr>
<tr>
<td>1690</td>
<td>1691</td>
<td>1692</td>
<td>1693</td>
<td>1694</td>
<td>1695</td>
<td>1696</td>
<td>1697</td>
<td>1698</td>
</tr>
<tr>
<td>1700</td>
<td>1701</td>
<td>1702</td>
<td>1703</td>
<td>1704</td>
<td>1705</td>
<td>1706</td>
<td>1707</td>
<td>1708</td>
</tr>
<tr>
<td>1710</td>
<td>1711</td>
<td>1712</td>
<td>1713</td>
<td>1714</td>
<td>1715</td>
<td>1716</td>
<td>1717</td>
<td>1718</td>
</tr>
<tr>
<td>1720</td>
<td>1721</td>
<td>1722</td>
<td>1723</td>
<td>1724</td>
<td>1725</td>
<td>1726</td>
<td>1727</td>
<td>1728</td>
</tr>
<tr>
<td>1730</td>
<td>1731</td>
<td>1732</td>
<td>1733</td>
<td>1734</td>
<td>1735</td>
<td>1736</td>
<td>1737</td>
<td>1738</td>
</tr>
<tr>
<td>1740</td>
<td>1741</td>
<td>1742</td>
<td>1743</td>
<td>1744</td>
<td>1745</td>
<td>1746</td>
<td>1747</td>
<td>1748</td>
</tr>
<tr>
<td>1750</td>
<td>1751</td>
<td>1752</td>
<td>1753</td>
<td>1754</td>
<td>1755</td>
<td>1756</td>
<td>1757</td>
<td>1758</td>
</tr>
<tr>
<td>1760</td>
<td>1761</td>
<td>1762</td>
<td>1763</td>
<td>1764</td>
<td>1765</td>
<td>1766</td>
<td>1767</td>
<td>1768</td>
</tr>
<tr>
<td>1770</td>
<td>1771</td>
<td>1772</td>
<td>1773</td>
<td>1774</td>
<td>1775</td>
<td>1776</td>
<td>1777</td>
<td>1778</td>
</tr>
<tr>
<td>1780</td>
<td>1781</td>
<td>1782</td>
<td>1783</td>
<td>1784</td>
<td>1785</td>
<td>1786</td>
<td>1787</td>
<td>1788</td>
</tr>
<tr>
<td>1790</td>
<td>1791</td>
<td>1792</td>
<td>1793</td>
<td>1794</td>
<td>1795</td>
<td>1796</td>
<td>1797</td>
<td>1798</td>
</tr>
</tbody>
</table>
Life at the dawn of time
Cyanobacteria – 3.6 Ga
- Cyanobacteria – 3.6 Ga
- Eukaryotes – 1.6 Ga
- Cyanobacteria – 3.6 Ga
- Eukaryotes – 1.6 Ga
- Snowball Earth – 750 Ma
- Cyanobacteria – 3.6 Ga
- Eukaryotes – 1.6 Ga
- Snowball Earth – 750 Ma
- Ediacran biota – 580 Ma
- Cambrian explosion – 540 Ma
- Cambrian explosion – 540 Ma
- Conquest of land – 425 Ma
- Cambrian explosion – 540 Ma
- Conquest of land – 425 Ma
- A close run thing – 250 Ma
- Fossil record patchy
• Fossil record patchy

• Fossils of modern species?
- Fossil record patchy
- Fossils of modern species?
- Modern diversity x extinction rate
- Fossil record patchy
- Fossils of modern species?
- Modern diversity x extinction rate
- Lagerstätten
Extinctions in Earth’s deep past
- Out-competed (new or invasive)
- Out-competed (new or invasive)
- Failing to adapt to change
- Out-competed (new or invasive)
- Failing to adapt to change
- Random ‘shocks’
Phanerozoic Climate Change

<table>
<thead>
<tr>
<th>Cm</th>
<th>O</th>
<th>S</th>
<th>D</th>
<th>C</th>
<th>P</th>
<th>Tr</th>
<th>J</th>
<th>K</th>
<th>Pg</th>
<th>N</th>
</tr>
</thead>
</table>

- **Low Frequency Mode**
- **Short-Term Average**

**HOT**

**COLD**

Glacial Periods

$\delta^{18}O$ (parts per thousand)

Millions of Years Ago

542 500 450 400 350 300 250 200 150 100 50 0
Global Sea Level Fluctuations

Exxon Sea Level Curve

Hallam et al.

Exxon Sea Level Episode

Last Glacial Episode

Millions of Years Ago

Exxon Sea Level Change (m)

N  Pg  K  J  Tr  P  C  D  S  O  Cm

0  50  100  150  200  250  300  350  400  450  500  542
Kill Curve

Species kill (percent)

Mean waiting time (years)

100 million year event

10 million year event

1 million year event
Mass extinctions
Mass extinctions

- Major loss of global biodiversity
Mass extinctions

- Major loss of global biodiversity
- Taxonomic impact not random
Mass extinctions

- Major loss of global biodiversity
- Taxonomic impact not random
- Survivors pre-adapted to cope with threats
Mass extinctions

- Major loss of global biodiversity
- Taxonomic impact not random
- Survivors pre-adapted to cope with threats
- Synergistic and cascading impacts
Mass extinctions

- Major loss of global biodiversity
- Taxonomic impact not random
- Survivors pre-adapted to cope with threats
- Synergistic and cascading impacts
- Unfold rapidly – evolution overwhelmed...
Phanerozoic Climate Change

- Low Frequency Mode
- Short-Term Average

HOT
COLD

Glacial Periods

δ¹⁸O (parts per thousand)

Millions of Years Ago

542 500 450 400 350 300 250 200 150 100 50 0
Five Million Years of Climate Change From Sediment Cores

Equivalent Vostok $\Delta T (^{\circ}C)$

Millions of Years Ago

$\delta^{18}O$ Benthic Carbonate (%)
Post-Glacial Sea Level Rise

Meltwater Pulse 1A

Last Glacial Maximum

Thousands of Years Ago

Sea Level Change (m)

Santa Catarina
Rio de Janeiro
Senegal
Malacca Straits
upper bound
Australia
Jamaica
Tahiti
Huon Peninsula
Barbados
lower bound
Sunda/Vietnam Shelf

GWA 2006
The first hunters
e.g. Brook et al (2007) Quat Sci Rev 26: 560
The image shows a graph indicating the percent survival of large mammal species over time in different regions. The x-axis represents log(time) KYA (Kilo Years Before Present), and the y-axis represents the percent survival of large mammal species. The key indicates that H. sapiens enters the continent and large mammal population of the continent.

The graph includes the following regions:
- Africa
- Australia
- North America
- Madagascar

Another graph on the right side of the image shows the timeline of extinct fauna and artifacts, with key indicators for presence, absence, and climate change.
Time period since last fire
- Long
- Medium
- Short

a) Pre-human Fire Regime
b) Aboriginal Fire Regime
c) European Fire Regime
Sarga: Year 57

Fire
Recent extinctions
Locally Extinct Mammals

Numbers of species
Most vulnerable?
Most vulnerable?

- Restricted geographical range
Most vulnerable?

- Restricted geographical range
- Low dispersal (minimal rescue effect)
Most vulnerable?

- Restricted geographical range
- Low dispersal (minimal rescue effect)
- Small population size
Most vulnerable?

- Restricted geographical range
- Low dispersal (minimal rescue effect)
- Small population size
- Low genetic diversity
Most vulnerable?

- Restricted geographical range
- Low dispersal (minimal rescue effect)
- Small population size
- Low genetic diversity
- Co-evolved complexes
Extinction ‘rules’

The histogram shows the proportion of species with different percentage differences in diversity ($H$). The critical value for $T < NT$ is marked with $\pi = 0.77$.
Habitat loss

Pollution

Over-exploitation

Exotic species

Small, fragmented isolated populations

Demographic stochasticity

Catastrophes

Reduced $N$

Environmental variation

Reduced adaptability, survival and reproduction

Inbreeding Loss of genetic diversity

EXTINCTION VORTEX
Generalizations for extinction
Generalizations for extinction

- Large population size provides resilience
Generalizations for extinction

- Large population size provides resilience
- Geographic range and dispersal are buffers
Generalizations for extinction

- Large population size provides resilience
- Geographic range and dispersal are buffers
- Rate of impact determines adaptability
Generalizations for extinction

- Large population size provides resilience
- Geographic range and dispersal are buffers
- Rate of impact determines adaptability
- ‘Extinction prone’ context specific – new stress
The most dangerous animal!
Extinctions per thousand species per millennium

- Distant past (fossil record)
- Recent past (known extinctions)
- Future (modeled)

Projected future extinction rate is more than ten times higher than current rate.

Current extinction rate is up to one thousand times higher than the fossil record.

For every thousand mammal species, less than one went extinct every millennium.

Long-term average extinction rate.

Source: Millennium Ecosystem Assessment.
The century of consequences...

The diagram illustrates the magnitude of change in temperature (°C) over various time scales. Key events and time periods include:

- **21 to 0 ka**: This represents the time period from 21,000 to 0 years ago, marked by a significant temperature change.
- **50 to 36 ma**: This denotes a period from 50 to 36 million years ago.
- **Regional High Latitude 10°C/100 yrs.**: This indicates a regional high-latitude temperature change of 10°C per 100 years.
- **Regional >10°C/18 kyrs.**: This refers to a regional temperature change of more than 10°C over 18,000 years.
- **Hemispheric 5°C/18 kyrs.**: This signifies a hemispheric temperature change of 5°C over 18,000 years.
- **2 X CO₂**: This represents a doubling of CO₂ levels.
- **End of Younger Dryas**: This marks the end of the Younger Dryas event, a period of rapid cooling.
- **Mid-Holocene warm period 0.5 to 2.0°C/6 kyrs.**: This indicates a mid-Holocene warm period with temperature changes ranging from 0.5 to 2.0°C over 6,000 years.
- **Little Ice Age 0.4 to 0.8°C/50 yrs.**: This refers to the Little Ice Age, a period of cooling with temperature changes of 0.4 to 0.8°C over 50 years.
- **Regional 5°C/50 yrs.**: This signifies a regional temperature change of 5°C over 50 years.

The diagram also highlights the log rate of change (°C/1,000 years) along the x-axis, providing a visual representation of the rate at which these temperature changes occurred over time.