Mass Extinctions & Their Consequences

Taxonomic diversity of skeletonized marine animal families during the Phanerozoic

Spindle diagram of family diversification/extinction
The role of extinction in evolution
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ABSTRACT: The extinction of species is not normally considered an important element of evolution theory, in contrast to the opposite phenomenon, speciation. This is surprising in view of the special importance Darwin attached to extinction, and because the number of species extinctions in the history of life is about the same as the number of originations; present-day biologists do not regard the study of viable populations of extinct species as an important part of evolution theory. This paper attempts to remedy this neglect of extinction as a primary evolutionary force, as it is for a demographer or a geneticist. In the past decade, there has been a resurgence of interest in extinction, yet research on the topic is still at a reconnaissance level, and our understanding of the role of extinction in evolution is weak. Despite some evidence, extinction probably occurs less frequently than speciation. As a result, extinction may have a much more important role in evolutionary processes than is commonly recognized.

Background vs. Global Mass Extinction Events

- Background Rates = 96% of all extinctions.
- Phanerozoic average @ ~25% per 1 Myr.
- Geographic range & larval life styles regarding survivorship.
- Selective opportunities for diversification.
- The Red Queen Hypothesis.

Distribution of extinction intensities across Phanerozoic yields a mean of 25% per 1 Myr, which is the reciprocal of the mean species duration of ~4 Myr.
Extinction rates of marine animal families during the Phanerozoic

How long does a species of marine bivalve exist?

Better adapted for the long haul!

Geographic range affects the survivorship of species!
Changes in the number of known families of insects

Changes in the number of known species of vascular land plants

Changes in the number of known families of nonmarine tetrapod vertebrates
Rates of origination of marine animal genera in 107 stages of the Phanerozoic

The history of diversity of the three “evolutionary faunas” in the marine fossil record

(A) Cambrian fauna

The history of diversity of the three “evolutionary faunas” in the marine fossil record

(B) Paleozoic fauna
The history of diversity of the three “evolutionary faunas” in the marine fossil record

Diversity-Dependent Competition
Is there a target equilibrium?

Summation of diversity of the three “evolutionary faunas” in the marine fossil record

Taxonomic survivorship curves

(A) Hypothetical curves

Extinction is constant
Older taxa less likely to go extinct
Younger taxa more likely to go extinct
~Constant Probability of Extinction

- Red Queen Hypothesis: Must keep running to stay in same place.
- Constant evolution by competitors, predators, and parasites.

The BIG FIVE of the Phanerozoic

<table>
<thead>
<tr>
<th>Extinction Episode</th>
<th>Age, Ma</th>
<th>% Extinction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cretaceous (K/T Boundary)</td>
<td>65 Ma</td>
<td>76</td>
</tr>
<tr>
<td>Triassic</td>
<td>215 Ma</td>
<td>76</td>
</tr>
<tr>
<td>Permian (P/T Boundary)</td>
<td>250 Ma</td>
<td>96</td>
</tr>
<tr>
<td>Devonian</td>
<td>365 Ma</td>
<td>82</td>
</tr>
<tr>
<td>Ordovician</td>
<td>440 Ma</td>
<td>85</td>
</tr>
</tbody>
</table>
The Permo-Triassic Boundary: The Mother of all Mass Extinctions

- Came close to losing all multicellular life.
- Considered one of the four major advancements.
- Box score of exterminations: 96% of all spp. & 50% of all families.
- Selectivity of the P/T Boundary.
- Multiple Causation Hypothesis.

The Four Major Advancements in Evolutionary Biology

- Origin of life
- Origin of multicellular life (Eukarya)
- Cambrian Explosion
- P/T Boundary Mass Extinction Event
P/T box score of exterminations

Rem: 96% of all spp. & 50% of all families
• 8 of 27 insects
• 21 of 27 reptiles
• 6 of 9 amphibians
• 70% of marine invertebrate genera including most corals.
• 1 major order of forams (the only time this has happened!).

Selectivity of the P/T Boundary

• 35% cosmopolitan genera vs. 93% endemic genera went extinct (same pattern as background extinction).

• END of the Trilobites as opposed to other marine arthropods.

Multiple Causation Hypothesis aka “World-went-to-hell” hypothesis

• Researchers tend to search for a single unified cause….climate change, sea level change, oceanic anoxia, flood basalts, acid rain, etc.
• As much as 5 Ma separation period!
• Bolide impact hypothesis?
Multiple Causation Hypothesis

The Siberian flood basalts aka Siberian traps associated with super volcanism

Extremely acid Permian lakes and ground waters in North America

Impact Event at the Permian-Triassic Boundary: Evidence from Extraterrestrial Noble Gases in Fullerenes

The Permian-Triassic boundary (PTB) event, which occurred about 251.4 million years ago, is marked by the most severe mass extinction in the geologic record. Recent studies of some PTB sites indicate that the extinctions occurred very abruptly, consistent with a catastrophic, possibly extraterrestrial, cause. Fullerenes (C_{60} to C_{70}) from sediments at the PTB contain trapped helium and argon with isotopic ratios similar to the planetary component of carbonaceous chondrites. These data imply that an impact event (potentially of cometary) accompanied the extinction, as was the case for the Cretaceous-Tertiary extinction event about 65 million years ago.

Probable competitive displacement of brachiopods by bivalves

(A) Diversity

Clade 1

Clade 2

Time

Probable competitive displacement of brachiopods by bivalves

(B) Permo-Carboniferous mass extinction

Paleozoic

Mesozoic

Cenozoic

542 488 444 416 359 299 251 220 145 65.5 0
Models of (A) competitive displacement and (B) incumbent replacement

e.g., Spore-bearing vs. flowering plants

e.g., Dinosaurs and mammals at K/T

Echinoid diversity increased during the Mesozoic and Cenozoic

K/T Boundary – Impact extinction

• 60 to 80% kill of all spp.
• END of the Ammonites as opposed to other marine molluscs.
• Bivalves were less selectively hit, broad range survival.
• Sea Urchins were selectively hit as well.
Marine bivalve genera with wide geographic ranges were less likely to become extinct at the K/T boundary.

NB: Biogeographic provinces are regions that share similar floras and faunas.
Selectivity of extinction among sea urchins at the K/T due to nutrient supply with selection on benthic adults more than planktotrophic larval stages.

The extinction intensity of all marine animal genera measured across the Phanerozoic. (b) Sea-urchin lineages that survived the K/T mass extinction, showed a dramatic drop in body size. The sea urchin Cycloster is shown, the Danian specimen being 2.1 cm and the Maastrichtian 3.6 cm in length.

The Human “Meteor”

- Pleistocene Megafauna of N. America vs. African Megafauna (Ecological naïveté).
- Polynesian Birds are dropping like flies.
- Habitat destruction and global warming, our biggest experiment.
- Fortuitous Contingency of Cosmic Explosions?

History suggests that humans cause extinction

>80% of megafauna extinct in N. Am., S. Am., Australia
Extinction of Pleistocene Megafauna

Bird extinctions on oceanic islands

60 species extinct in last 1500 yrs in Hawaii, following human colonization.

An estimated 2000 species of flightless rail used to live on islands in the Pacific…
…only 4 species remain today.

Approximately 1/5 of all bird species in the world have gone extinct in association with human colonization of the Pacific islands.

Forest bird extinctions on ‘Eua (Tonga)
Current estimated extinction rates vs. the Big Five

- Based on rates of deforestation and patterns of tropical diversity and endemism ... in the next 30 years, 5-10% of Earth’s species will go extinct.

- Such a rate is 100 to 1000 times the background extinction rate.

- How about when global warming kicks into high gear?

- Given the current rate of human population growth, this rate is likely to continue long enough to result in a mass extinction.

- This will be the first mass extinction caused by an organism.

The effect of magnetic fields on γ-ray bursts inferred from multi-wavelength observations of the burst of 23 January 1999


Cosmic Explosion - Gamma-ray bursts are the most powerful explosions known in the Universe