

Extinction: Then and Now

A fossilized trilobite is embedded in a light-colored, textured rock matrix. The trilobite's body is clearly visible, showing its segmented abdomen and thorax. The rock surface is cracked and uneven, providing a natural frame for the fossil.

Andrew H. Knoll
Harvard University



Dusky Seaside Sparrow

Extinction is the inevitable fate of species.

P. W. Sykes

commons.wikimedia.org/w/index.php?curid=3958903

Georges Cuvier (1769-1832)

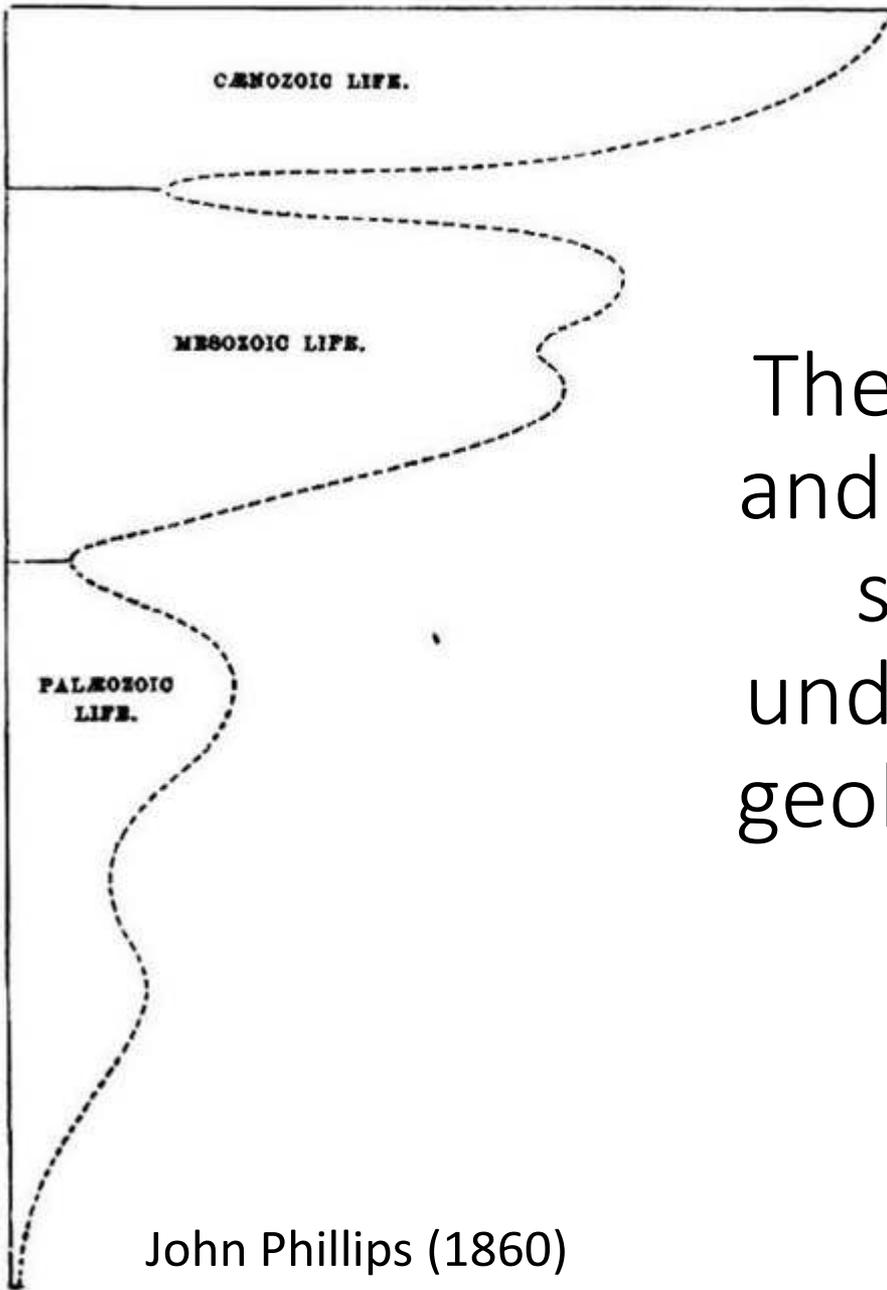
Extinction and catastrophe
(but no evolution)



Mammoth

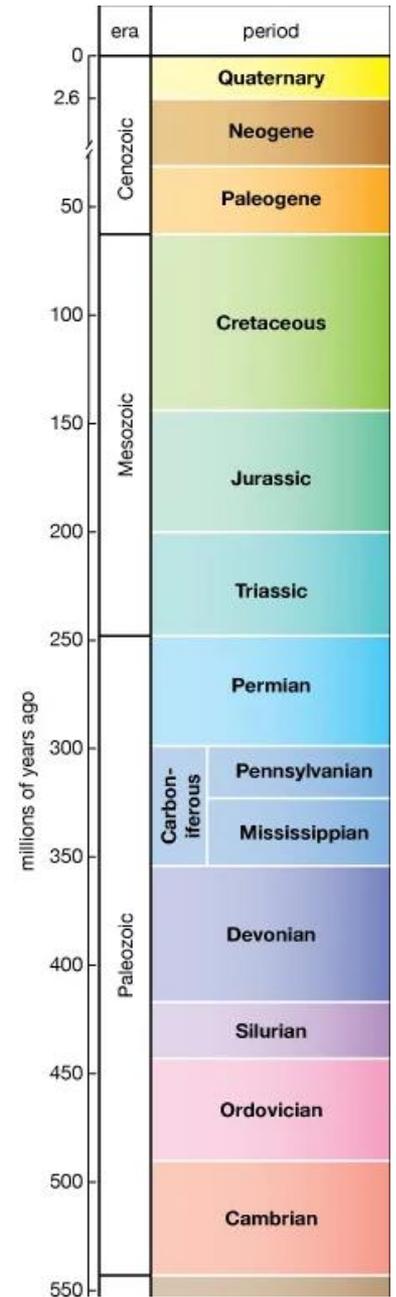


Mastodon



John Phillips (1860)

The comings and goings of species underpin the geologic time scale.



Encyclopedia Britannica

How did paleontologists come to think about extinction?



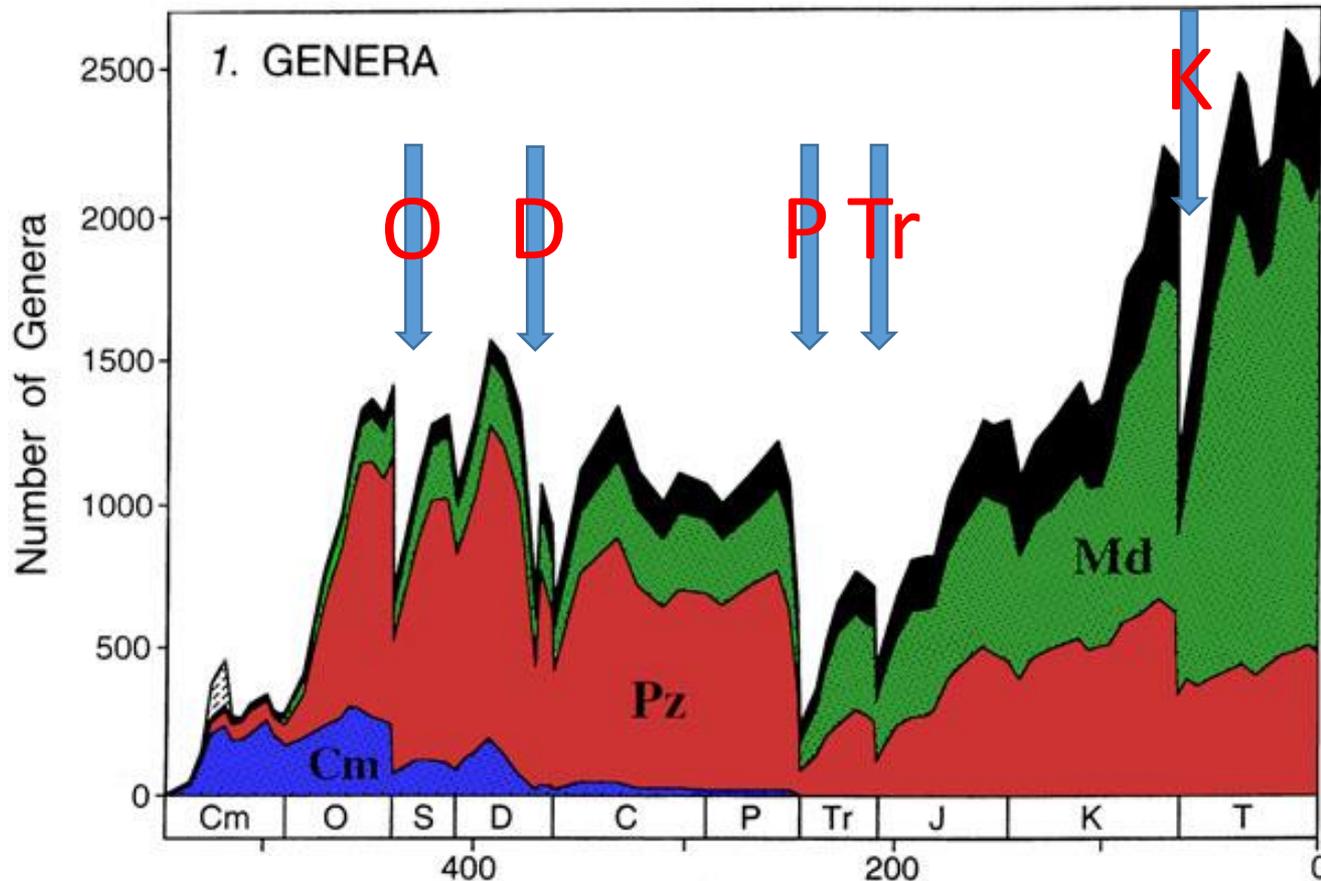
Tempo and Mode in Evolution

George Gaylord Simpson

A Columbia Classic in Evolution

*With a new introduction by
George Gaylord Simpson*

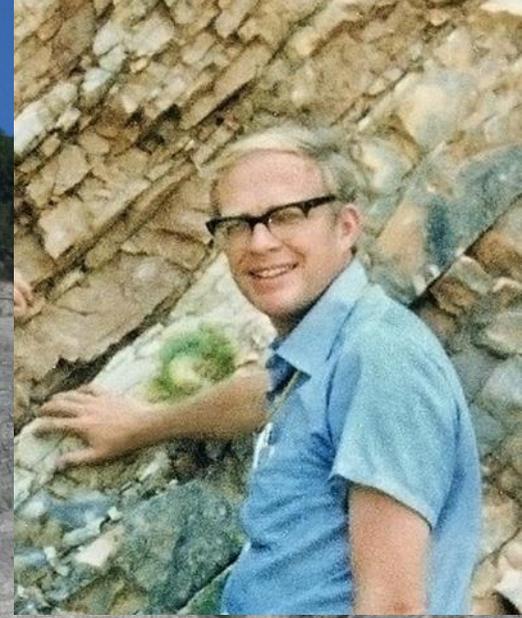
What Simpson missed: Extinctions are clustered in time. Earth has experienced five major mass extinctions in the past 500 million years.



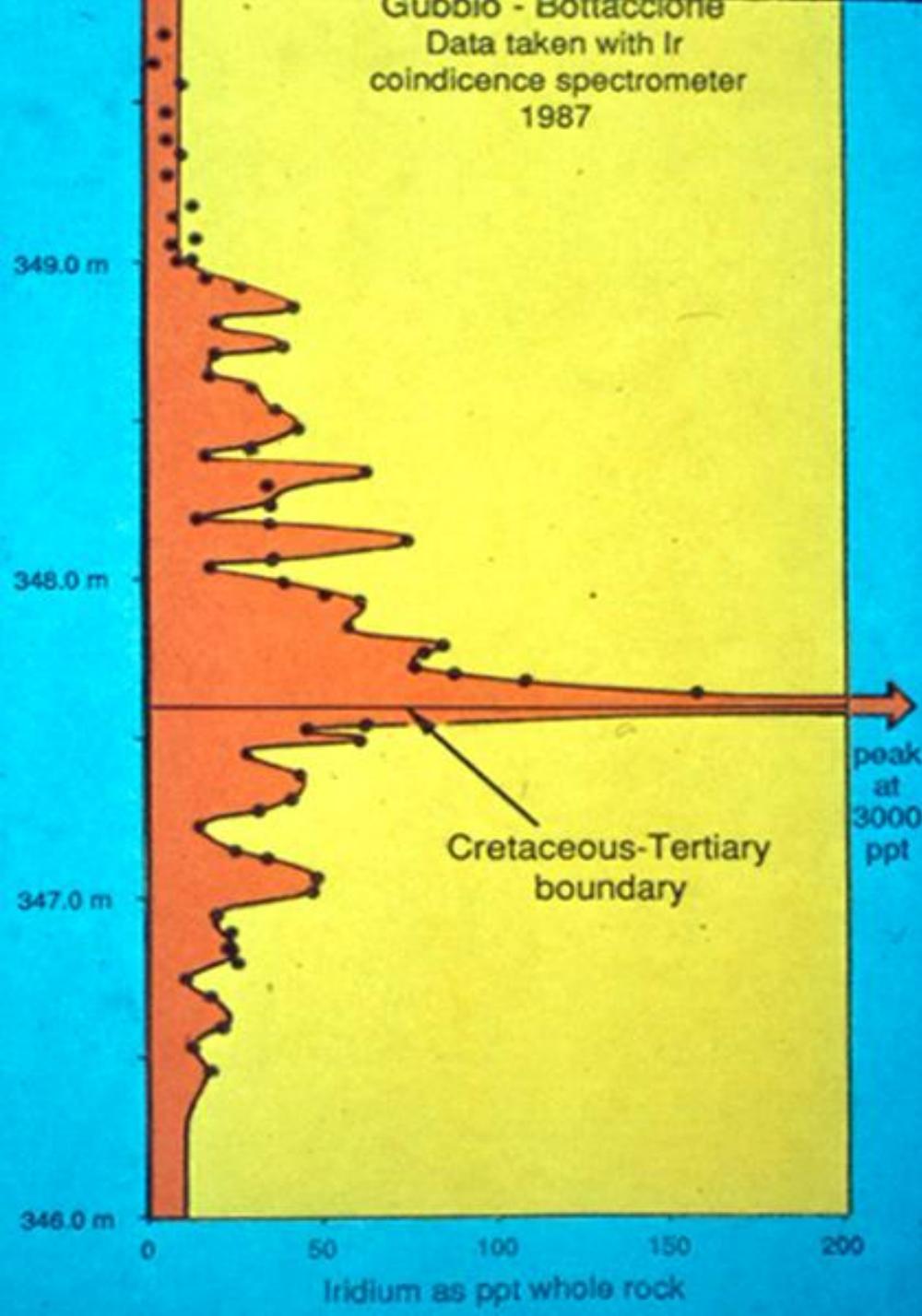
Compilation by Jack Sepkoski

A sea change: Gubbio, Italy

(Alvarez et al., 1980)





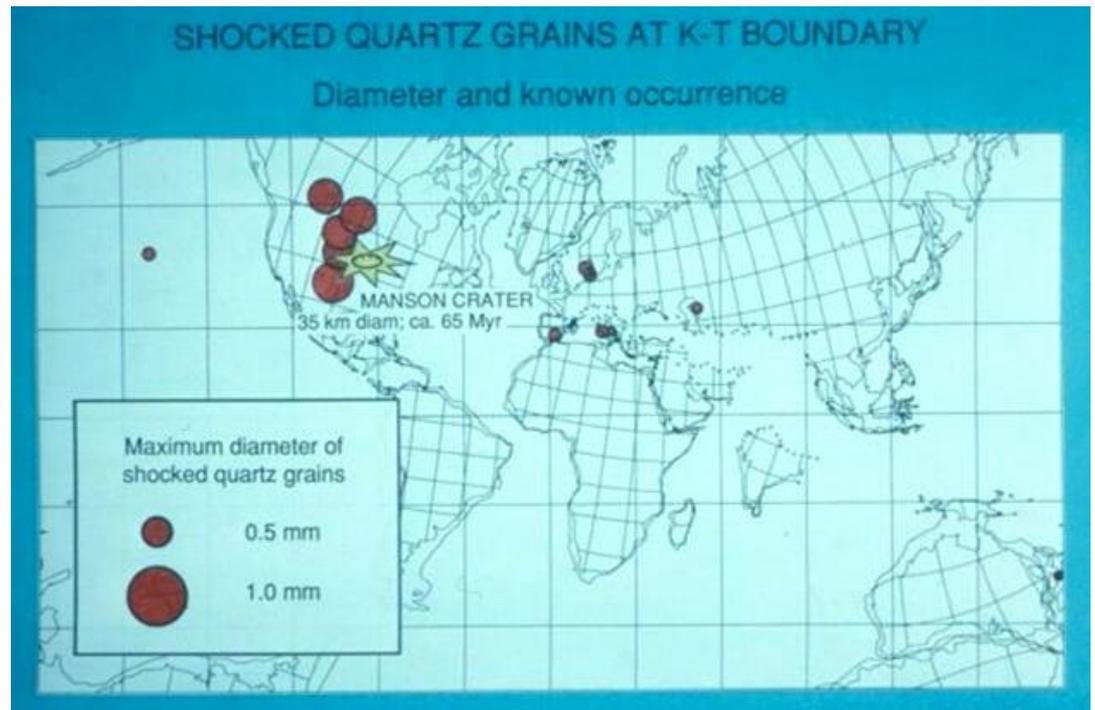


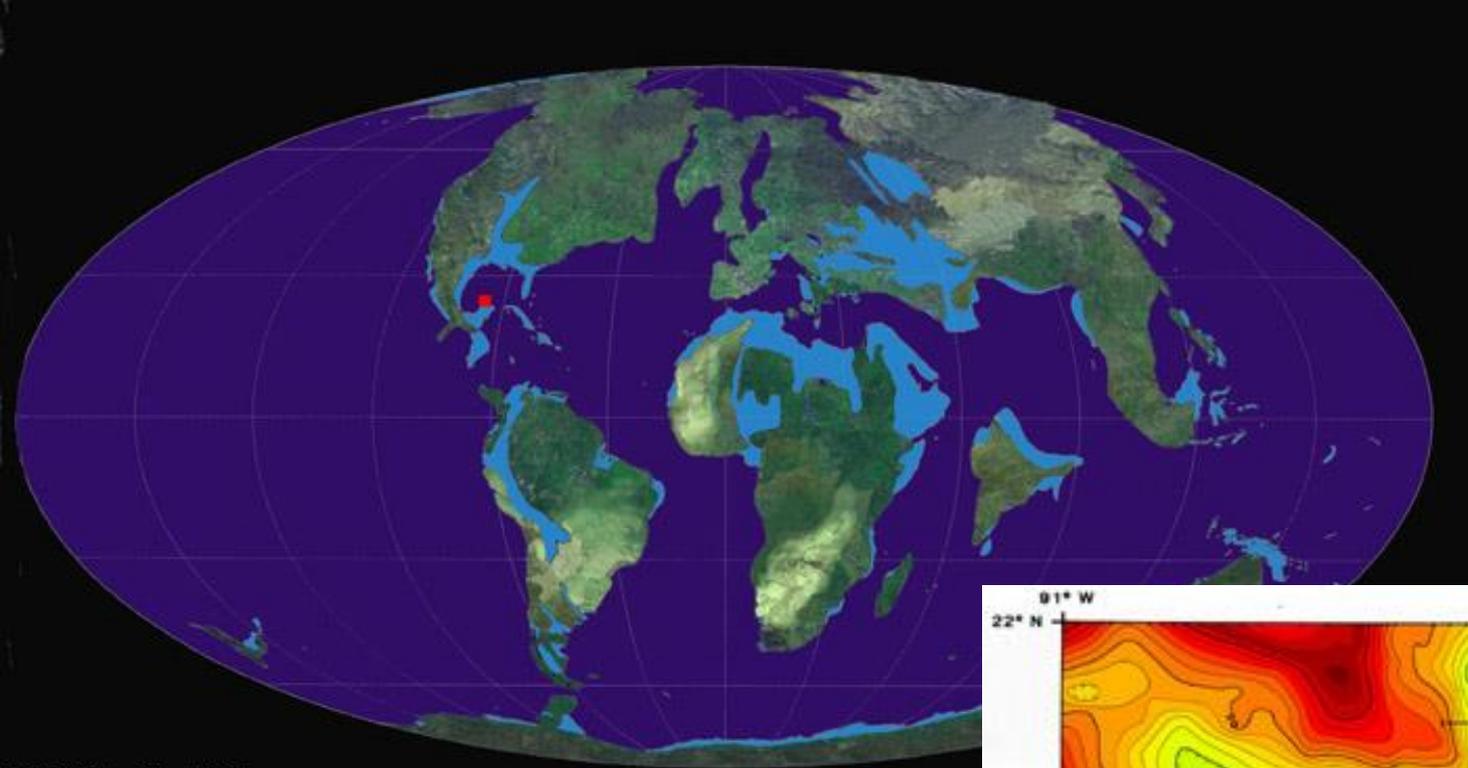
Anomalously
high
concentrations
of iridium
suggested a
giant meteorite
impact.

Stevns Klint, Denmark (the signature is global)



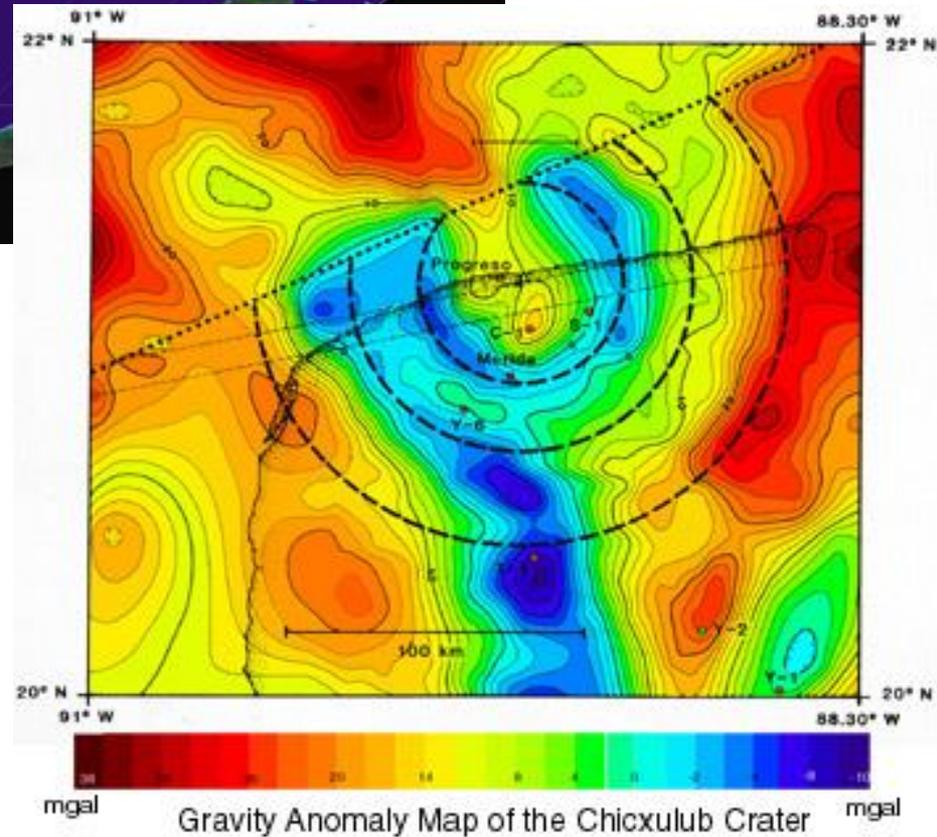
Shocked quartz grains provide independent evidence of impact at K-P boundary





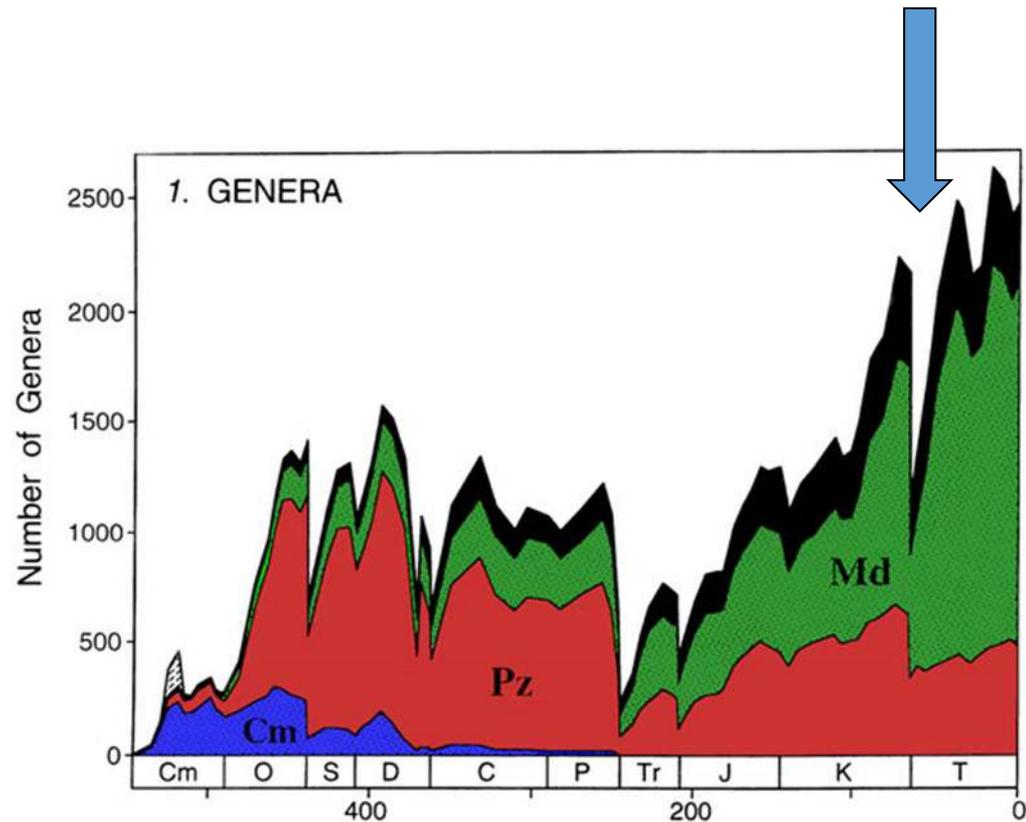
© 2000 by Jake Bailey
Adapted from "Atlas of Mesozoic and Cenozoic Coastlines" (Smith et al. 1994)

Chicxulub Crater



What changed at the end of the Cretaceous Period?

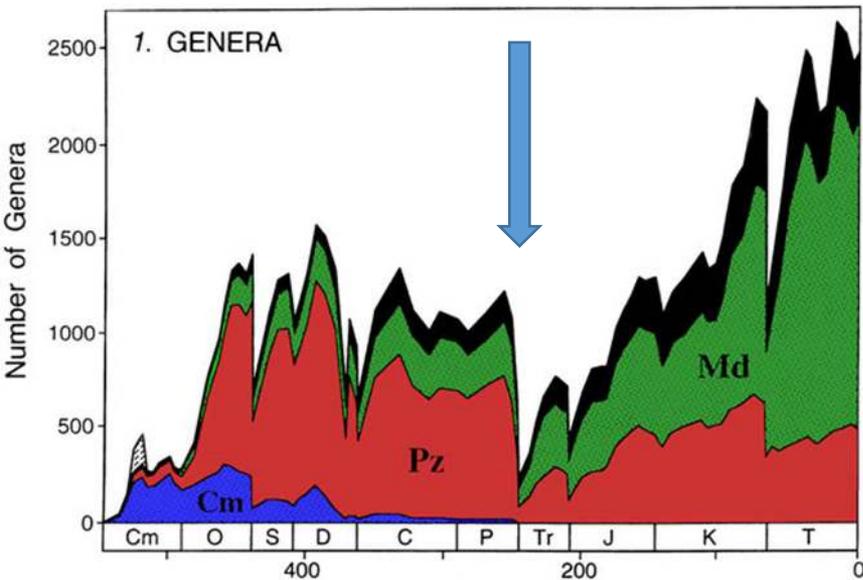
- Era-ending extinction: **Our modern biota is made up of the survivors of this event.**
- 47% of marine genera, > 70% of species
- Particularly strong effect on calcareous marine plankton
- Dinosaurs
- Ammonites
- First extinction to be recognized as **rapid**



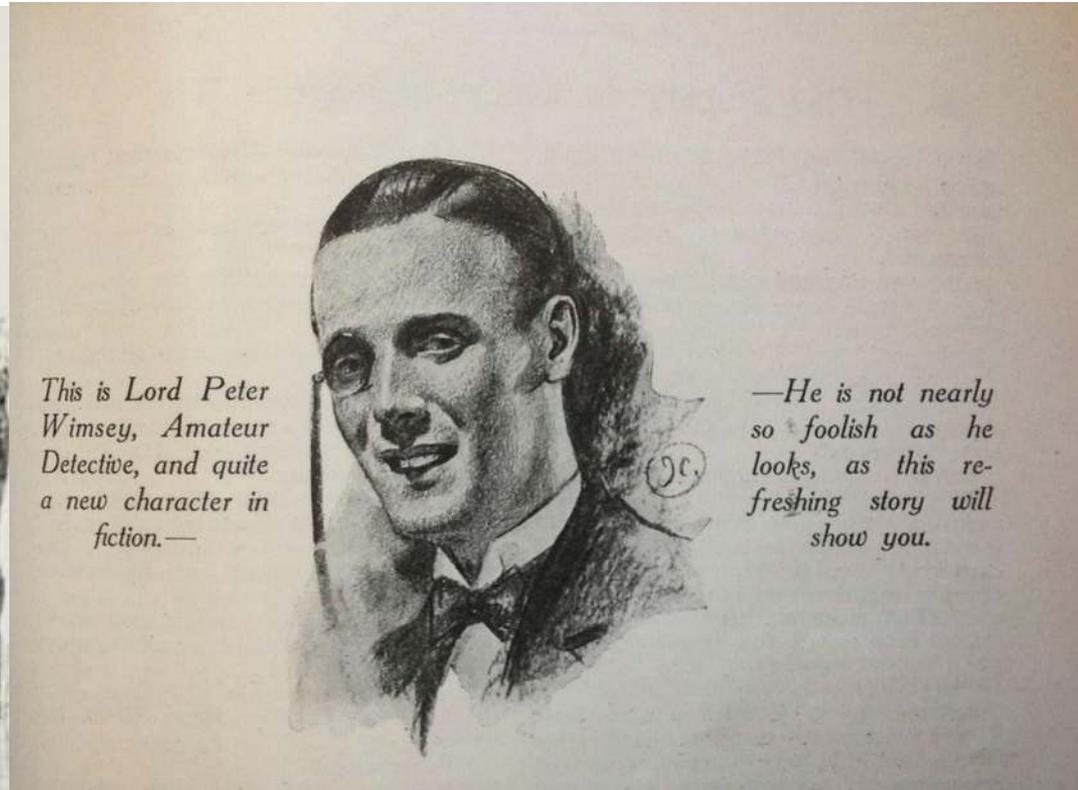
Sepkoski online database:
<http://strata.ummp.lsa.umich.edu/jack/>

The Big (and relevant) One: 252 million years ago

Once again, the
extinction event is
rapid



How science works, with thanks to Steve Gould



<http://tweedlandthegentlemansclub.blogspot.com>

<https://bakerstreet.fandom.com/wiki>

My serendipitous moment



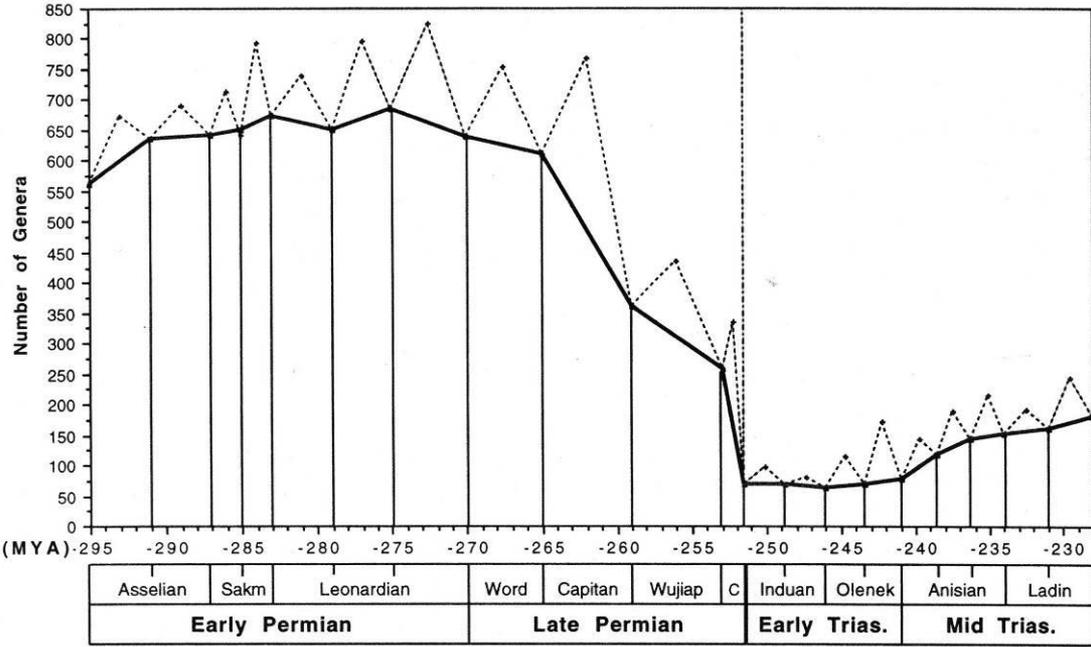
Could a rapid increase in $p\text{CO}_2$ underpin end-Permian extinctions?

1. Global warming
2. Decrease in ocean pH – ocean acidification
3. Oxygen decline in subsurface oceans
4. Hypercapnia – direct physiological effects

How do these affect organisms?

Predicted vulnerable taxa

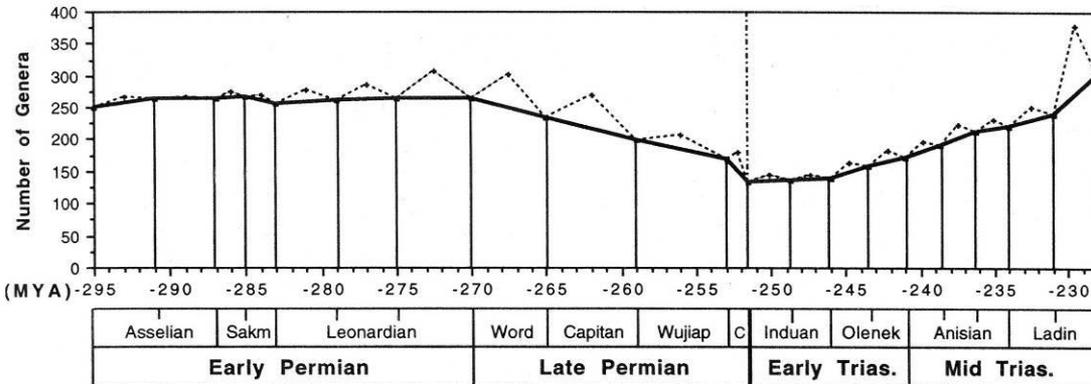
A.



Selectivity
with respect to
CO₂

Predicted tolerant taxa

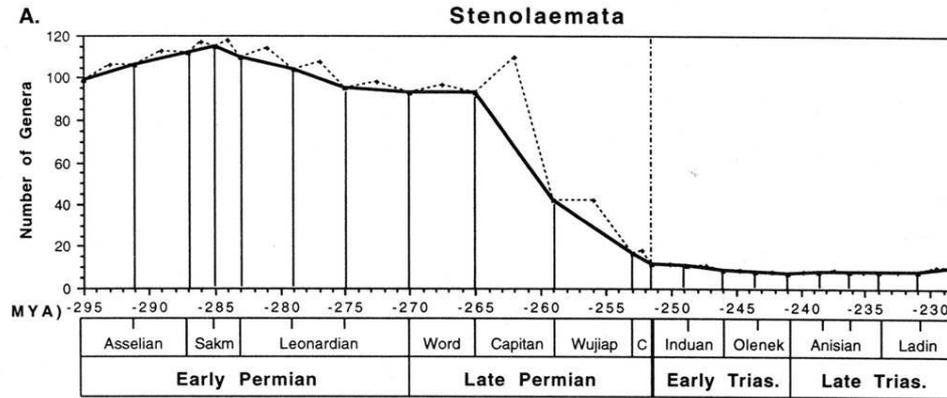
B.



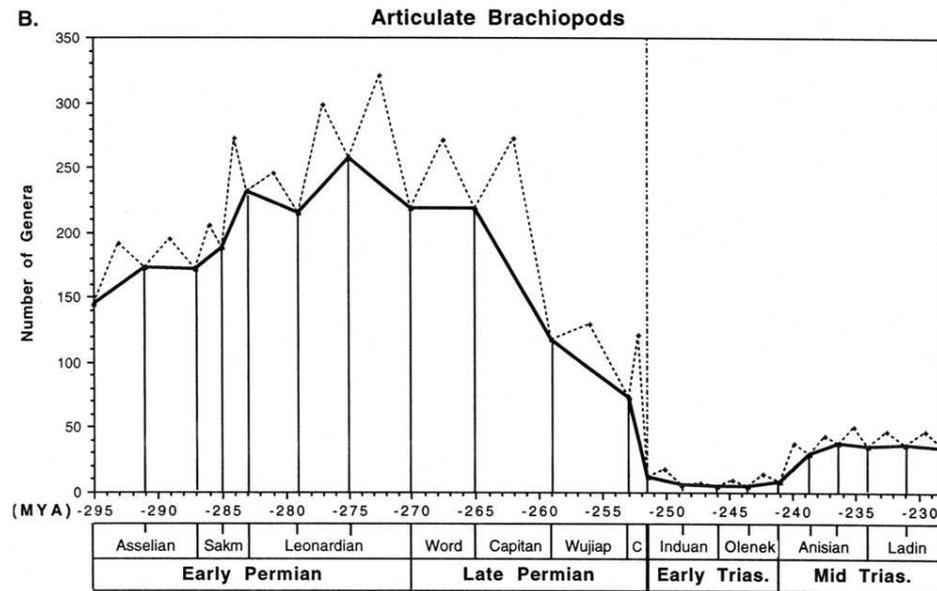
Skeleton
Metabolic Rate
Anatomic Complexity
Epifauna/Infauna

Lophophorates (bryozoans and brachiopods)

Heavy
Carbonate
Load
and
Limited
Physiological
"Buffering"



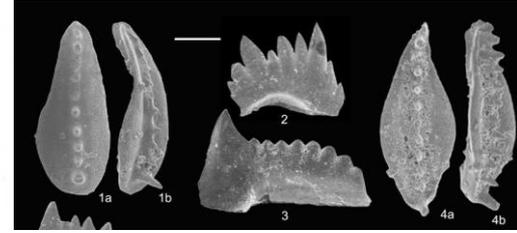
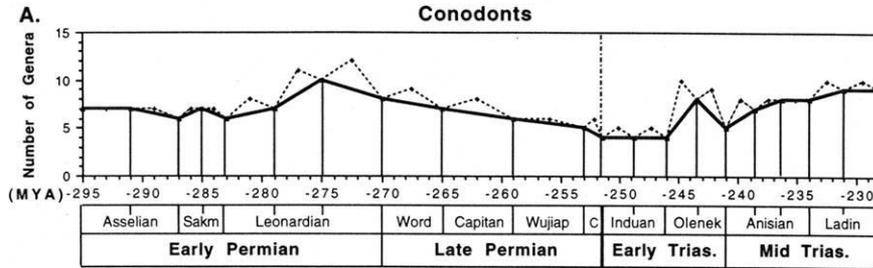
Drydredgers.org



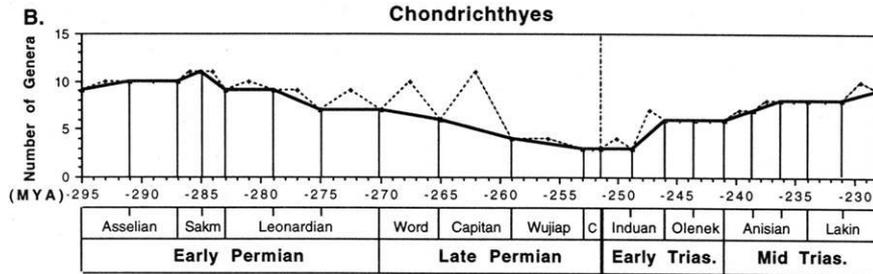
Wikipedia

Marine Vertebrates

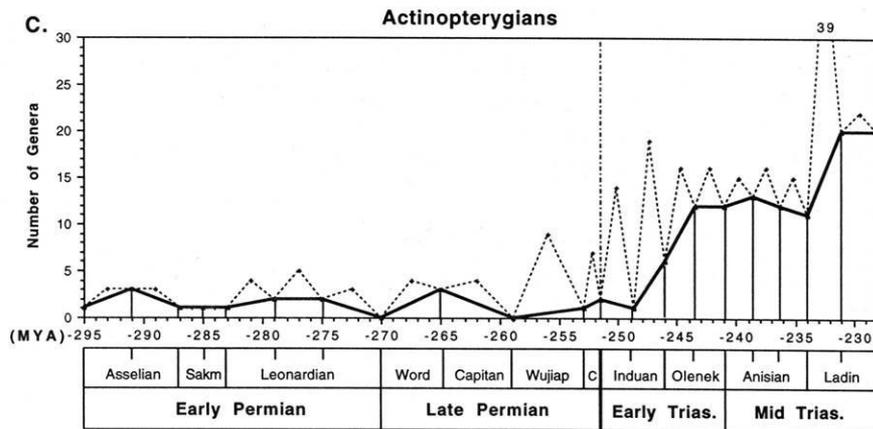
No
Carbonate
Load
and
Much
Physiological
“Buffering”



Lai et al. (2018)



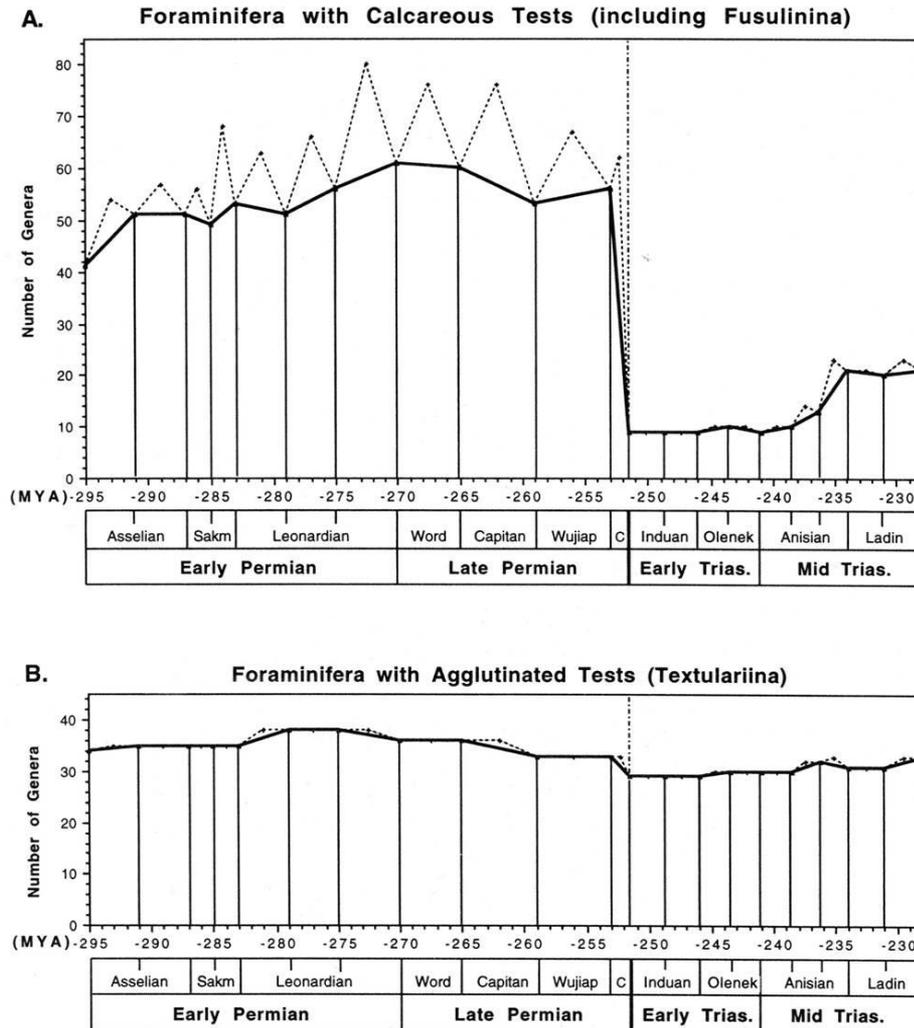
nps.gov



Wikipedia

Calcified vs. Agglutinated Foraminifera

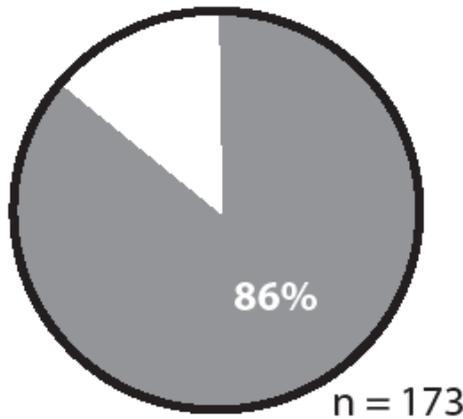
Heavy
Carbonate
Load
and
Little
Physiological
“Buffering”



Handwiki

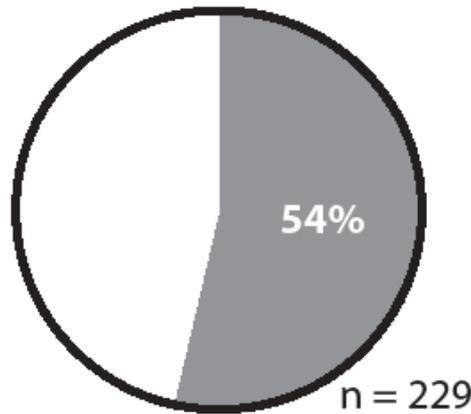
No
Carbonate
Load

Skeletal biology in general



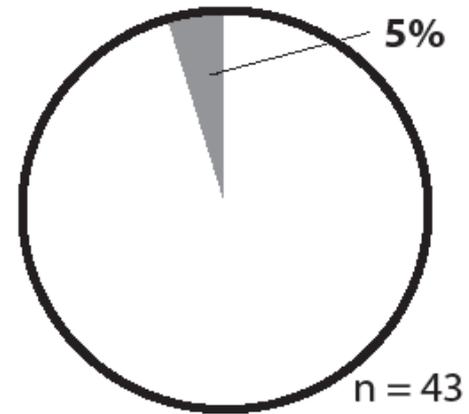
**Heavy CaCO₃ skeleton
(relative to metabolism)**

- Rugosa
- Stenolaemata
- Rhynchonelliform brachiopods
- -Orthida
- -Strophomenida
- -Spiriferida
- -Rhynchonellida
- -Terebratulica
- Acrotretida
- Crinoidea



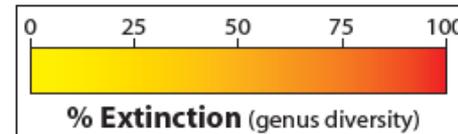
**Moderate CaCO₃ skeleton
(relative to metabolism)**

- Gastropoda
- Bivalvia
- -Infaunal burrowers
- -Epifaunal, attached
- Nautiloidea
- Ammonoidea
- Ostracoda
- Malacostraca
- Echinoidea



Little or no CaCO₃ skeleton

- Ctenostomata
- Lingulida
- Polychaeta
- Holothuroidea
- Conodontophorida
- Chondrichthyes



Knoll et al. (2007)

Siberian Traps: Volcanism a million times
larger than anything witnessed by
industrial humans





Lindy Elkins-Tanton

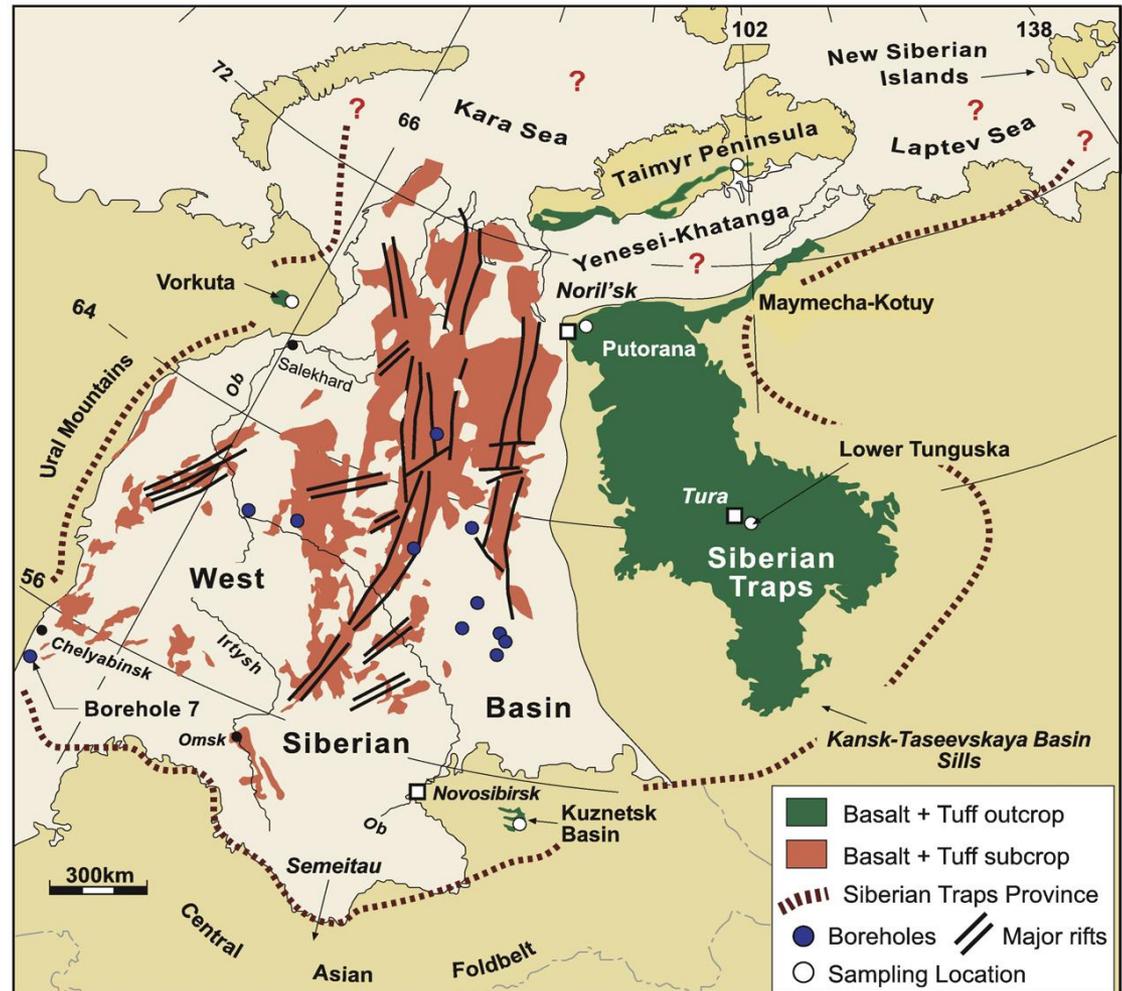
Siberian flood basalts
252 million years ago
3,000,000 km³



Lindy Elkins-Tanton

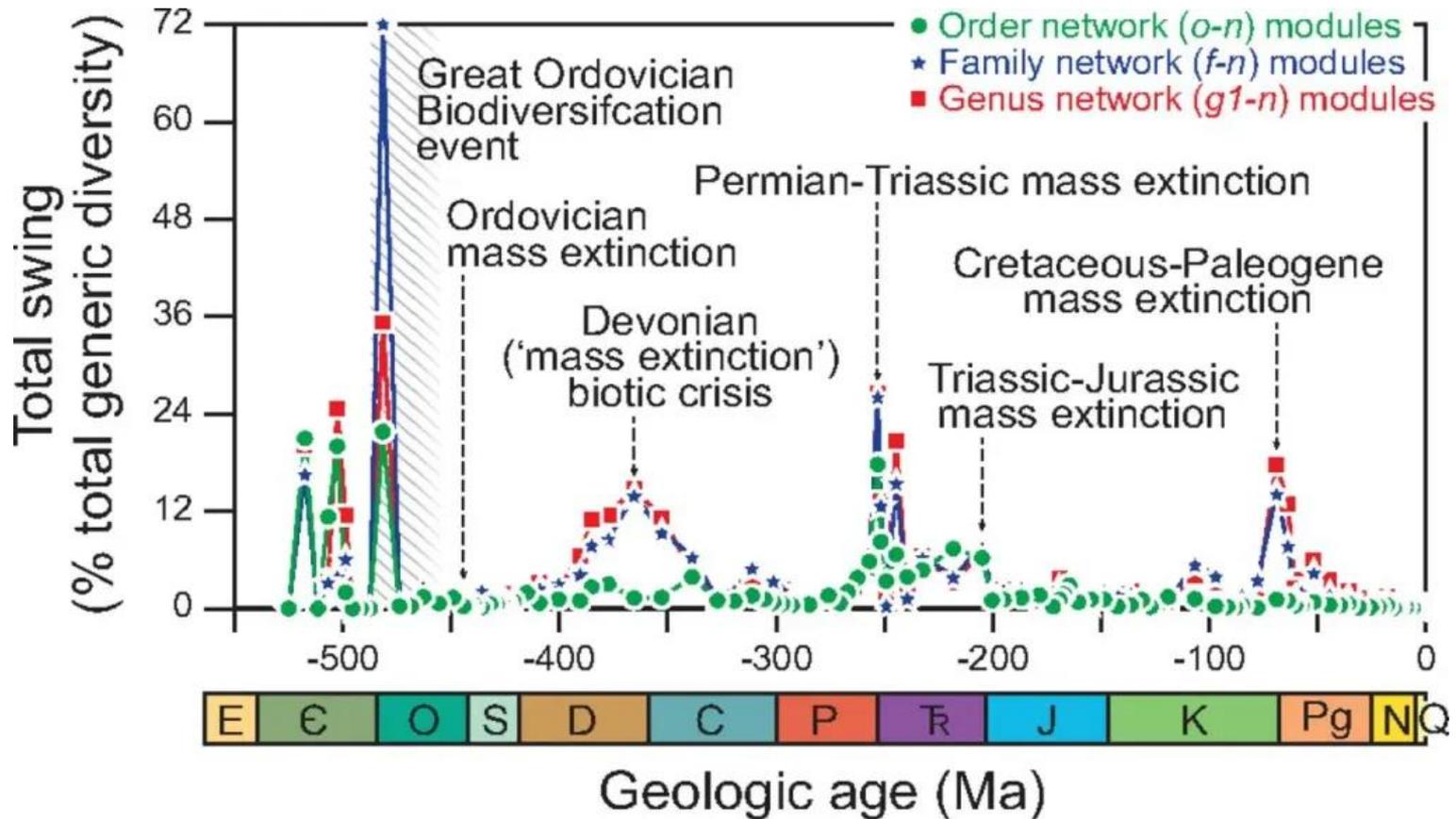
Likely Scenario

- Outpouring of Siberian flood basalts (plumbing through carbonates, erupt onto peats = high CO₂ and, possibly, thermogenic CH₄)
- Greenhouse gasses global warming
- Expands anoxia in oxygen-minimum zone
- Ocean acidification
- Rapid global warming, ocean acidification, anoxia and hypercapnia all occur – a distant mirror on the present.



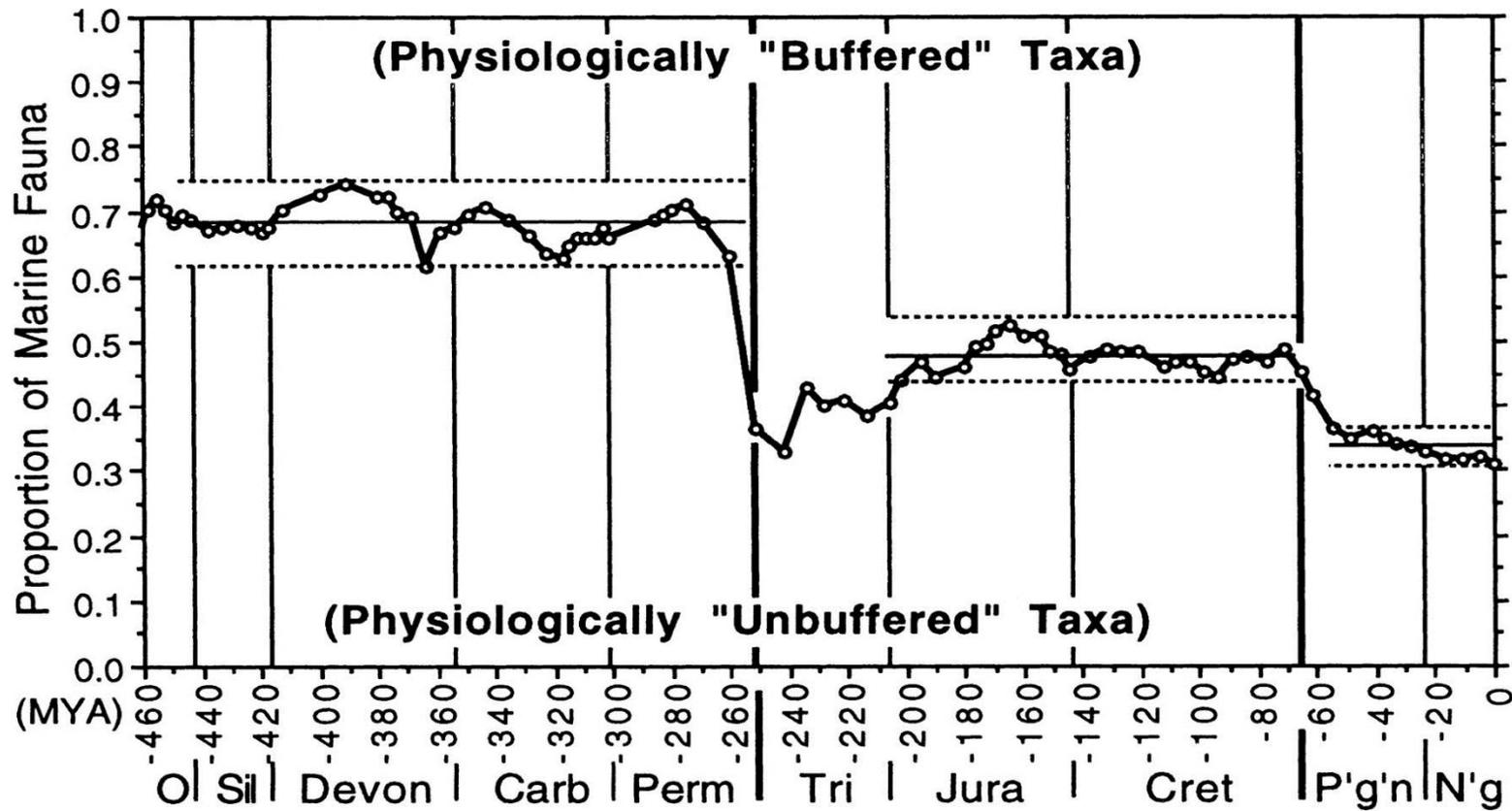
Reichov et al. 2007

Mass extinctions change the biological world, as Phillips envisioned in 1860.



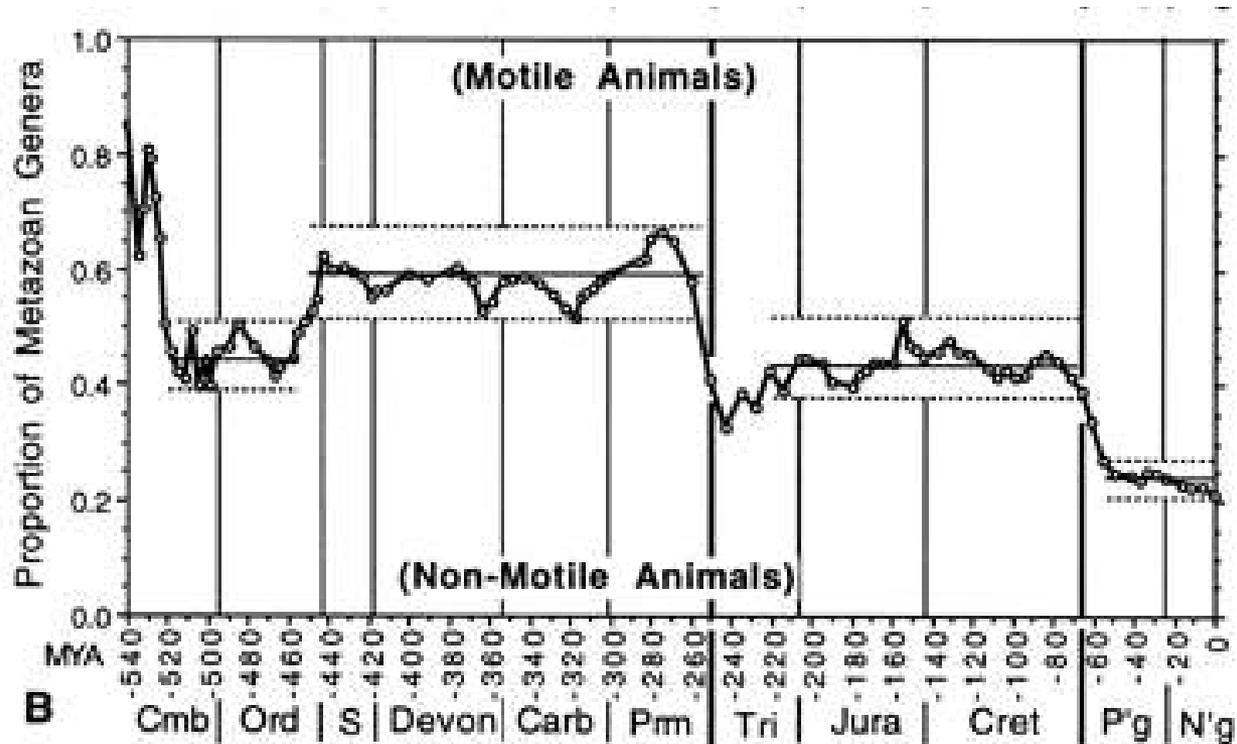
Muscente et al. (2018)

Consequences of Mass Extinction: Changing Ecology of the Oceans



Bambach et al (2002)

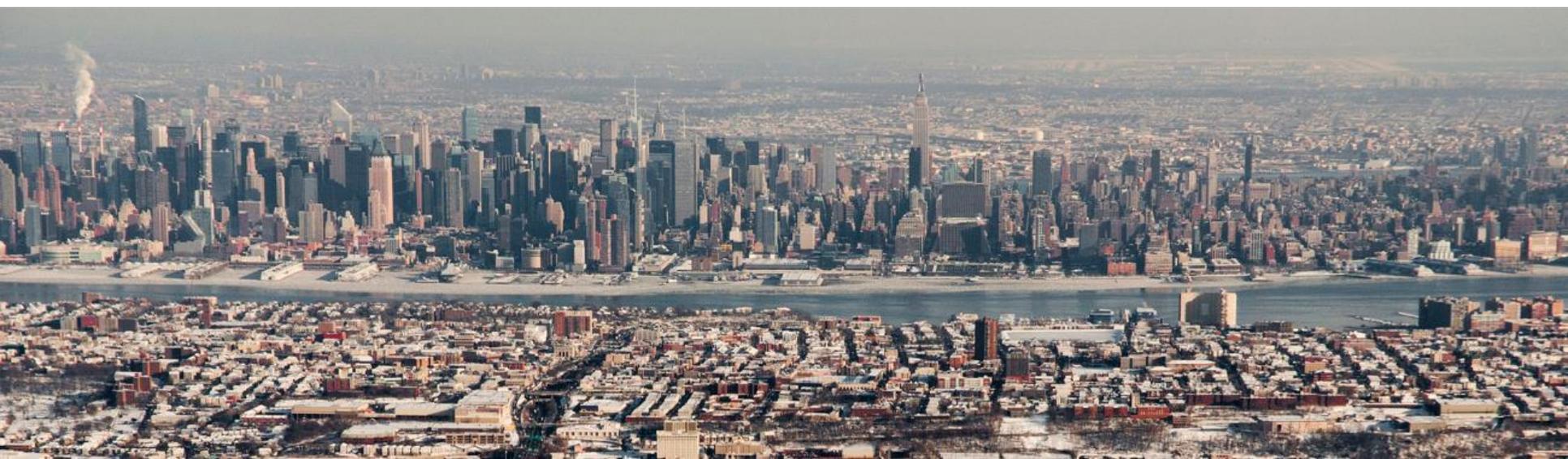
Consequences of Mass Extinction: Changing Ecology of the Oceans II



Bambach et al (2002)

The Anthropocene Epoch

1. You live at a geologically unusual time.
2. Increasingly influenced by human activities, the Earth is changing **rapidly**.
3. The past illuminates our potential future.



Humans: The price of success

FIG. 48.1 Growth of the human population over time. The human population has grown exponentially over time. Currently, humans number nearly 8 billion people. *Data from the Center for Innovation in Engineering and Science Education, <https://ciese.org/curriculum/popgrowthproj/worldpop/>.*

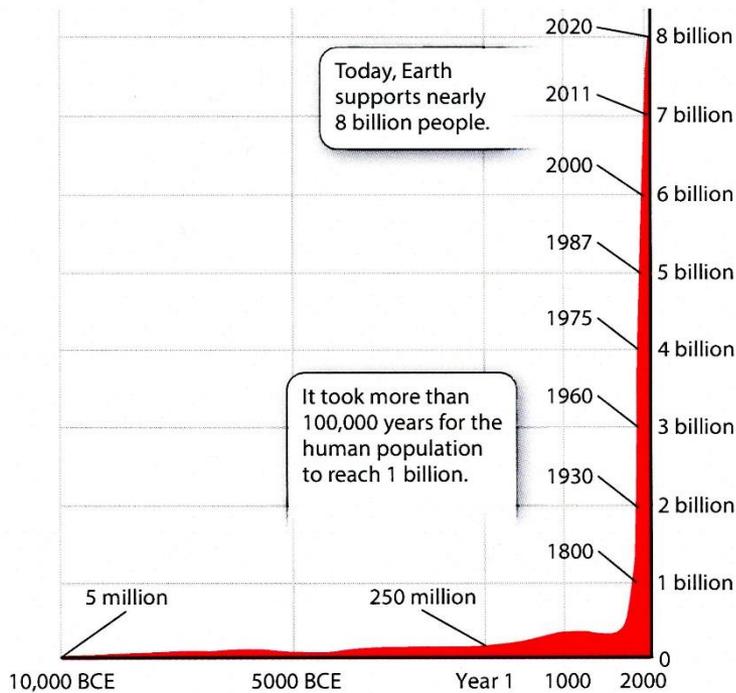
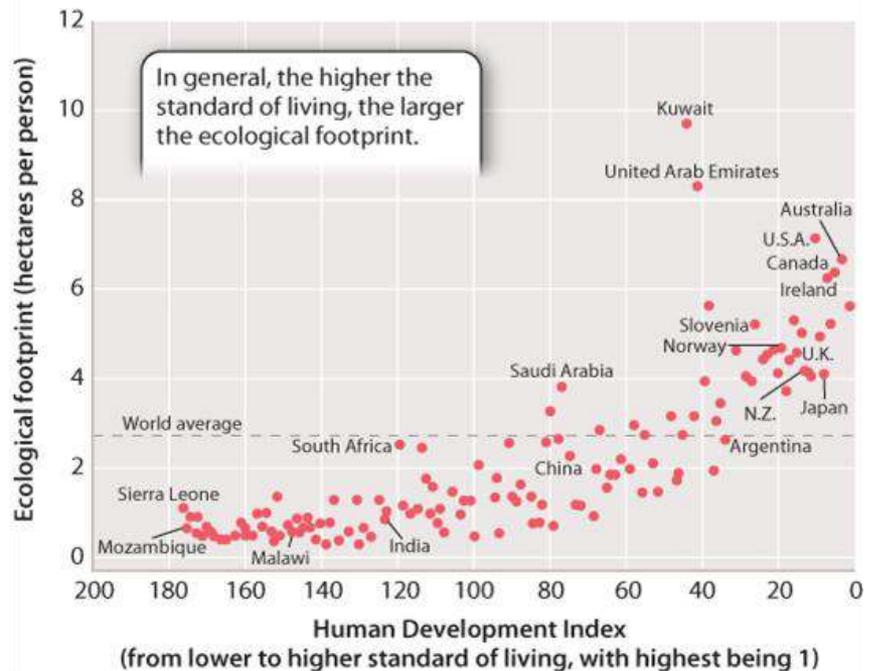
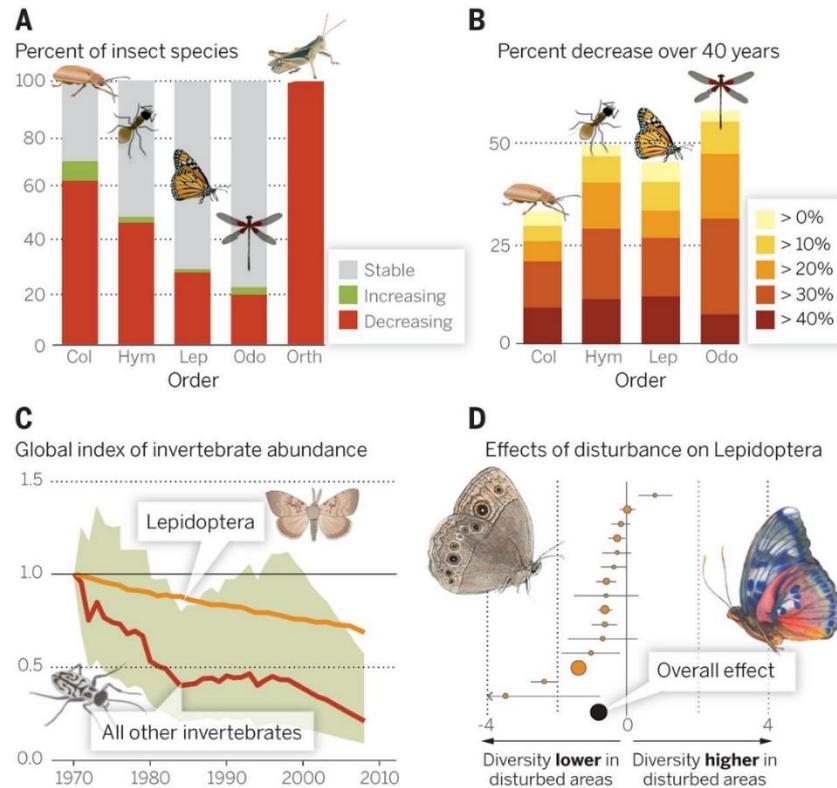


FIG. 48.3 Our ecological footprint. The graph shows the number of hectares needed to support an average person compared to a ranking of the Human Development Index, a measure of standard of living.



The news on biodiversity is sobering: Widespread decreases in population size



Dirzo et al. (2013)

In North America, bird populations have declined by 30% since 1970.

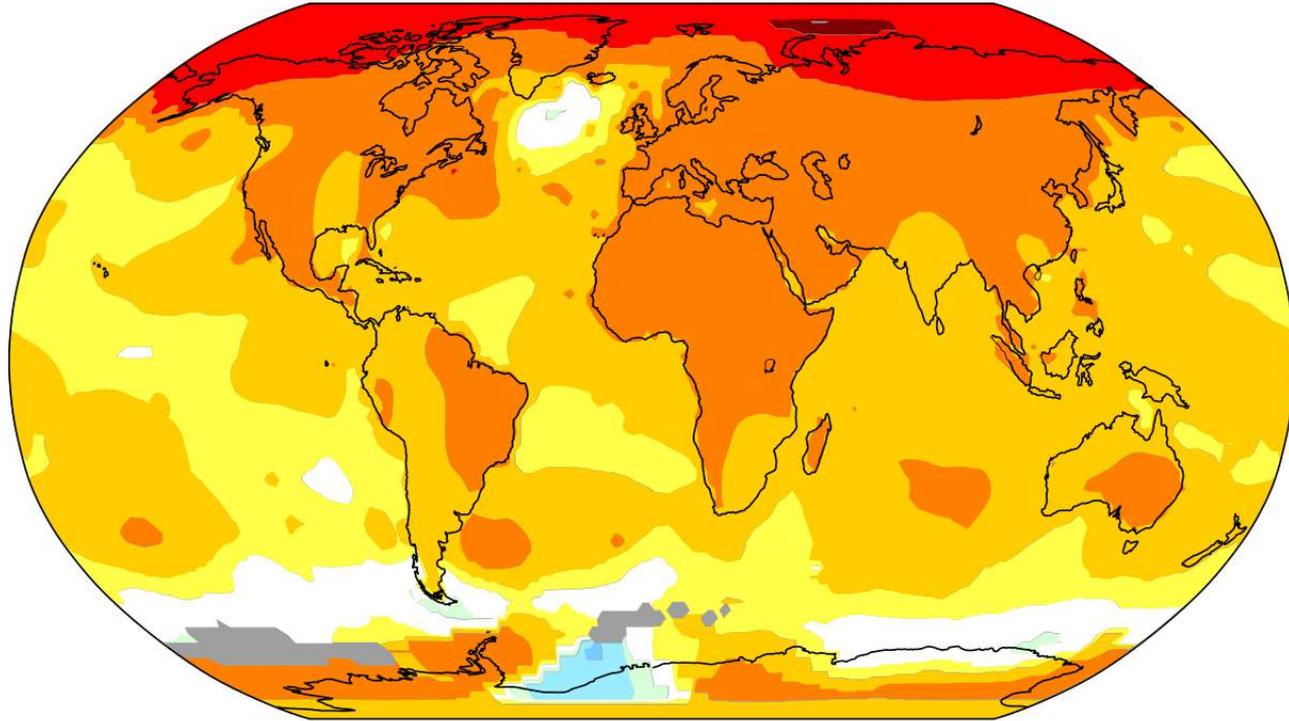
In Germany, insect biomass, abundance and number of species declined by 67%, 78% and 34%, respectively, from 2008 to 2017.

In Australia, 50% decline in coral reef coverage on Great Barrier Reef, 1985-2010

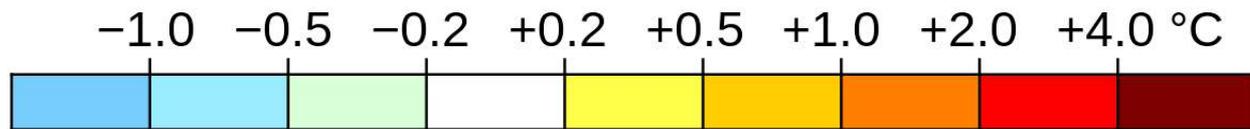
Mostly due to land use change, pollution, overexploitation.

The biggest changes are just revving up: Global warming

Temperature change in the last 50 years



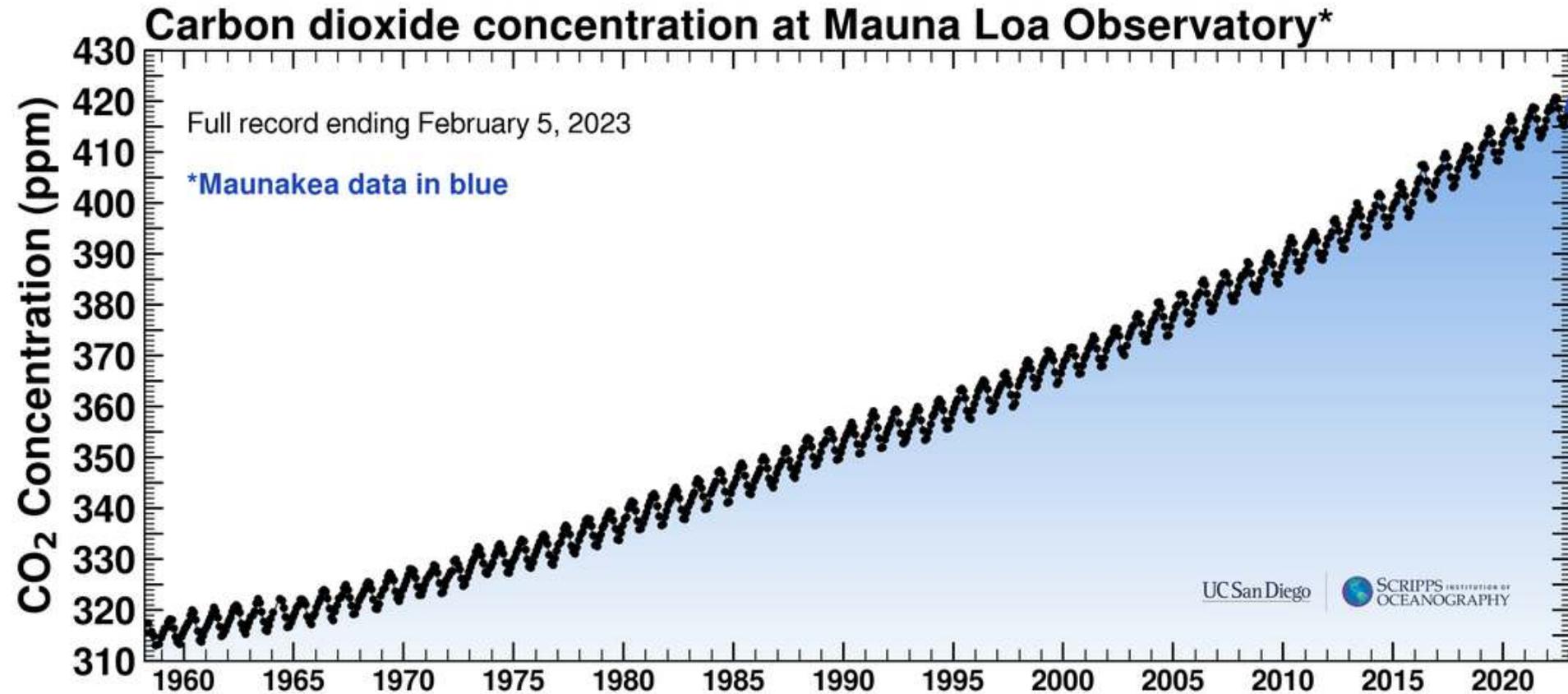
2011–2021 average vs 1956–1976 baseline



-1.8 -0.9 -0.4 +0.4 +0.9 +1.8 +3.6 +7.2 °F

Wikipedia

Why? **Rapidly** increasing CO₂ in the atmosphere

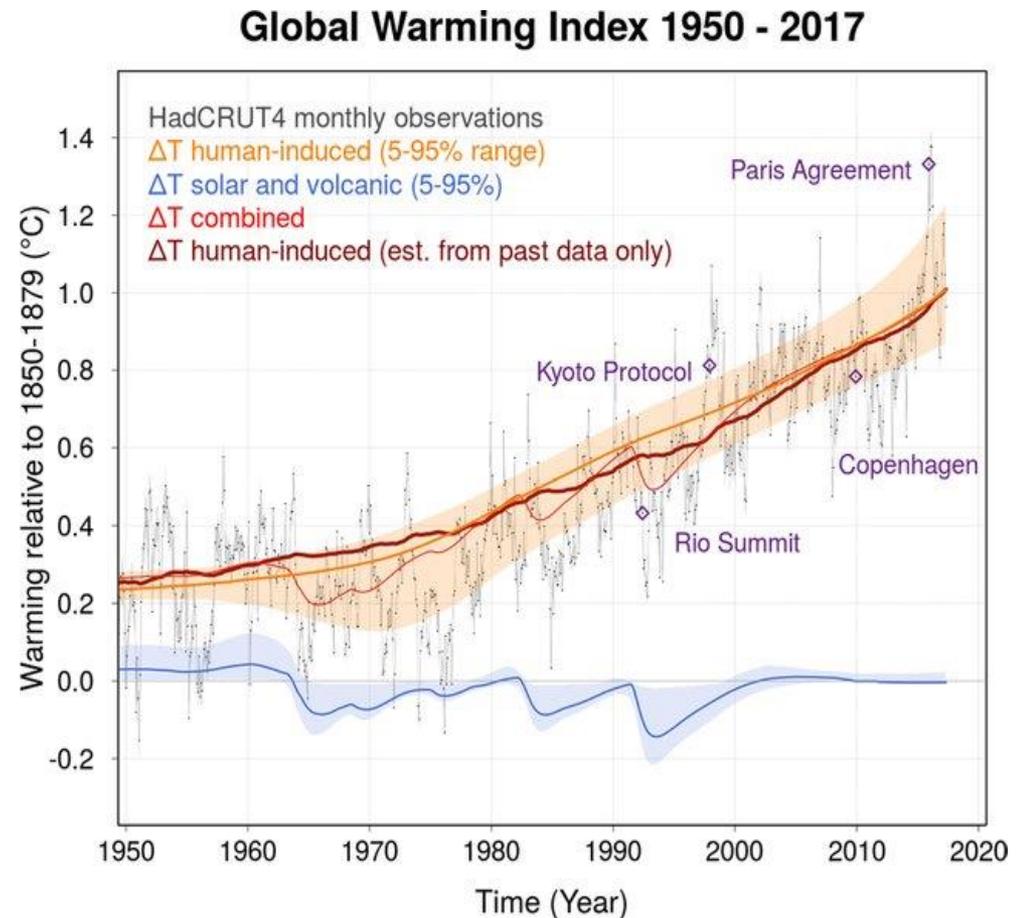


CO₂ is a greenhouse gas.

Keelingcurve.ucsd.edu

How do we know that humans are responsible for all this?

1. **Measurements** show that Earth is warming.
2. **Measurements** show that atmospheric CO₂ is increasing.
 - a. CO₂ is a greenhouse gas.
 - b. Data indicate the warming associated with each molecule of CO₂ (radiative forcing)
3. **Isotopes of carbon** show that source of CO₂ is largely fossil fuel bringing.
4. **Measurements** of sun and volcanoes show that these cannot explain observed warming.
5. Annual human emissions of CO₂ some 100 times those of all Earth's volcanoes combined.



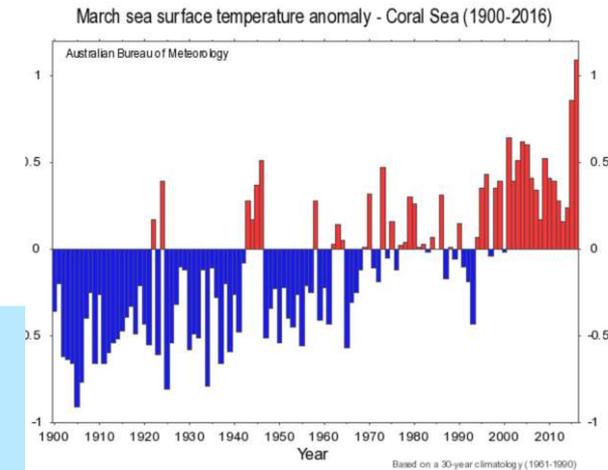
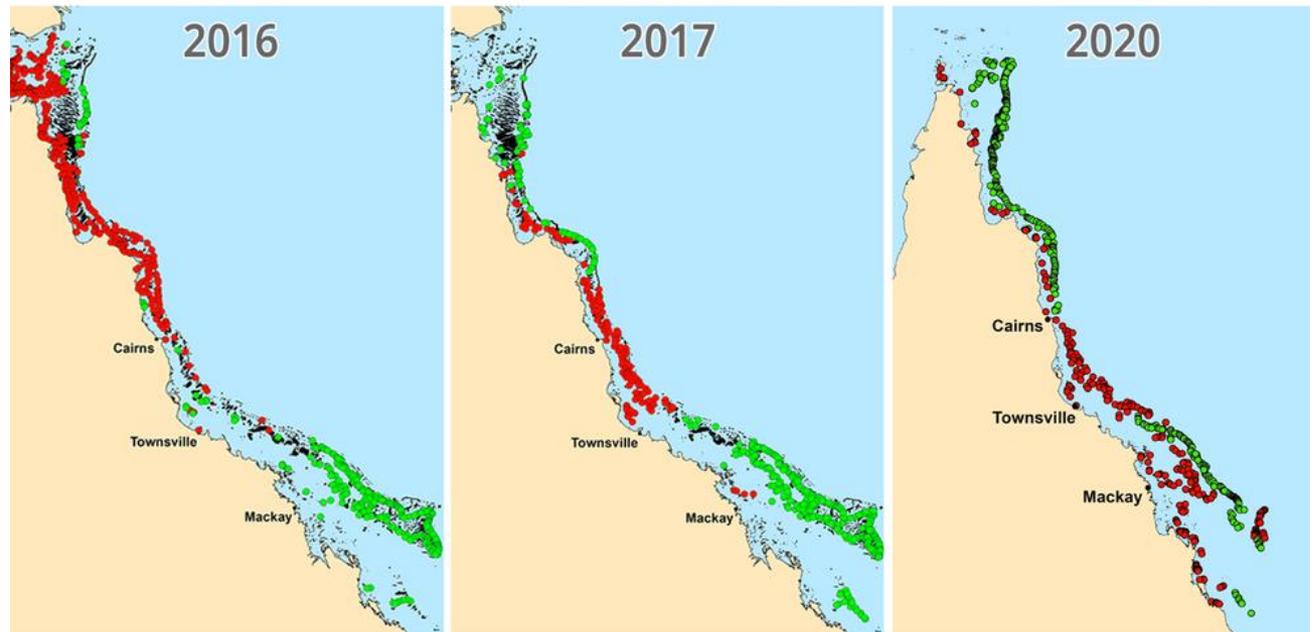
Haustein et al. (2017)

Extreme weather: Half of reef corals on northern Great Barrier Reef killed by 2016 bleaching. More in 2017 and again in 2020.

The last three mass bleaching events

The severity of the last three mass bleaching events on the Great Barrier Reef

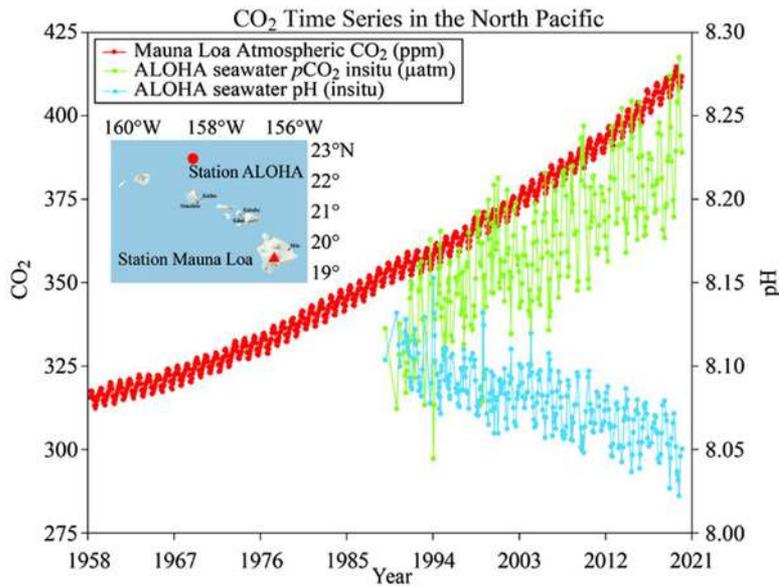
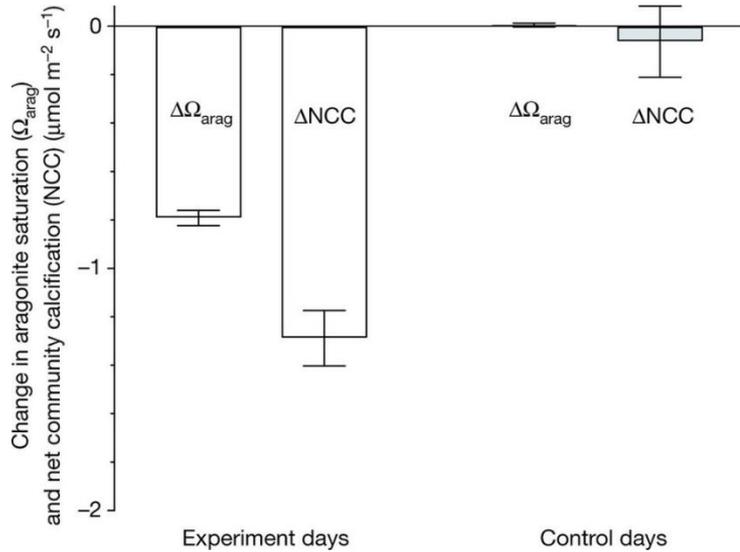
■ Most severe bleaching ■ No or negligible bleaching



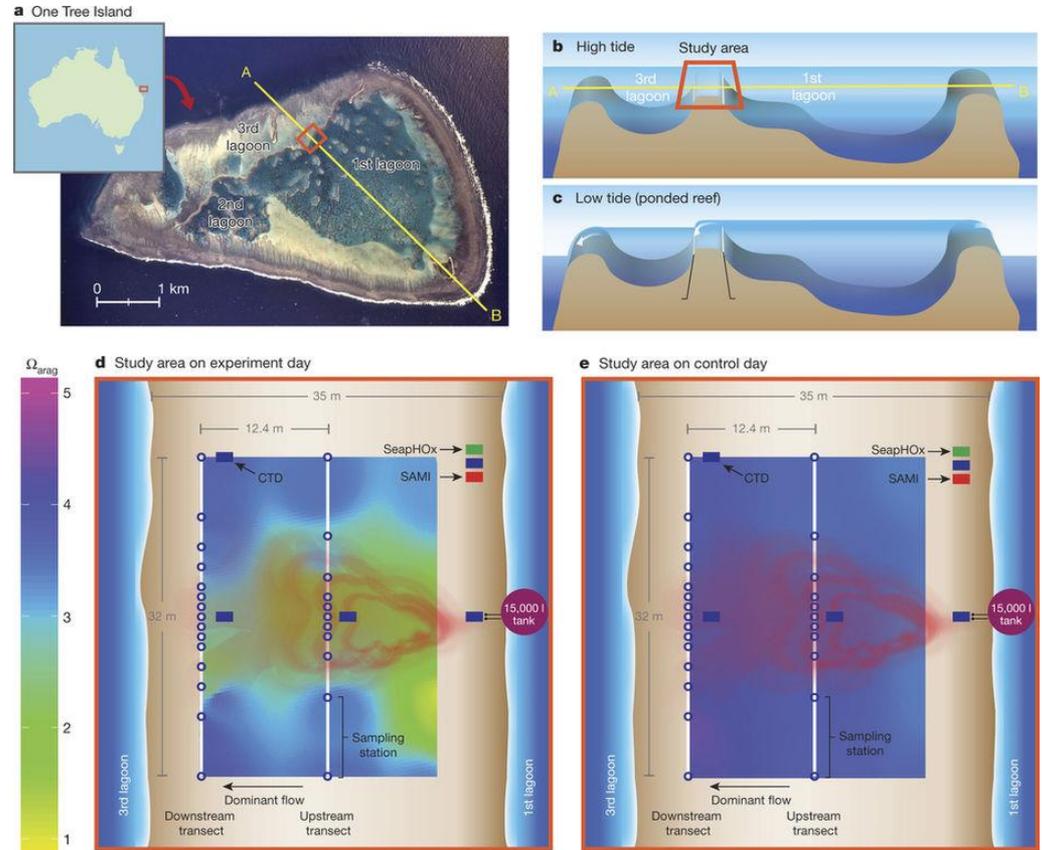
Pollution,
overfishing and
ocean
acidification
stresses, as well.

Ocean acidification:

(Rebecca Albright et al., 2018)
 Experimental increase in $p\text{CO}_2$ to levels predicted for 2100 causes a drop in pH and coral calcification in Great Barrier Reef



noaa



What kind of world will our grandchildren inherit?



The end-Permian record is like Dickens' ghost of Christmas yet to come

Summarizing a decade of experimental physiology of responses to rapid CO₂ increase, Melzner et al. (2009) stated that **“All more tolerant taxa are characterized by high (specific) metabolic rates and high levels of mobility/activity.”**

Personal choices: food, heating and cooling our buildings, driving and flying, voting

Societal choices: renewable energy sources, new batteries, CO₂ removal technology, “green” cement, investment in parks and refuges (corridors)