1 Overview

Introduction

Paleoecology is the study of ancient ecology in its broadest sense. It has been enormously successful in placing the history of life within an ecological context. As part of that understanding, it has served as a vital tool for understanding the occurrence of many natural resources. In all its sophisticated approaches, paleoecology has taught us much about the past history of life and Earth's environments. With this record of demonstrating the response of Earth's biota to past environmental change, paleoecology now stands poised as a vital source of information on how Earth's ecosystems will respond to the current episode of global environmental change.

History of study

The notion that certain objects that one finds in sedimentary rocks were once living organisms is one that humanity struggled with for a long time. Leonardo da Vinci is generally credited with being the first to write down observations on the biological reality of fossils through examination of marine fossils from the Apennine Mountains of Italy. In reality, Leonardo also made some of the first paleoecological interpretations through understanding these fossils as the remains of once living organisms that had not been transported some great distance and hence were not deposited as part of a great flood. The great utility of fossils to geologists was highlighted in the 19th century by the development of the geological timescale, and of course, after publication of "On the Origin of Species" by Darwin, evidence from the fossil record was some of the strongest available then for evolution. For the past 200 years, stratigraphic and paleontologic work has defined the occurrence of the major fossil groups that make up the record, and this general outline can be seen in Fig. 1.1, which shows Paleozoic, Mesozoic, and Cenozoic characteristic marine (ocean) skeletonized fossils.

Paleoecology as originally practiced is the use of biological information found in sedimentary rocks to help determine ancient paleoenvironments. Phanerozoic sedimentary rocks are found to have *in situ* marine fossils that we know were deposited in ancient oceans. Devonian and younger sedimentary strata that have remains of plants can be interpreted as deposited in terrestrial environments. For example, Fig. 1.2 shows the distribution within environments of various different fossil groups that have a substantial fossil record. One can see that these data are very valuable for understanding the past and past environments. So this information makes it easy to determine depositional environments

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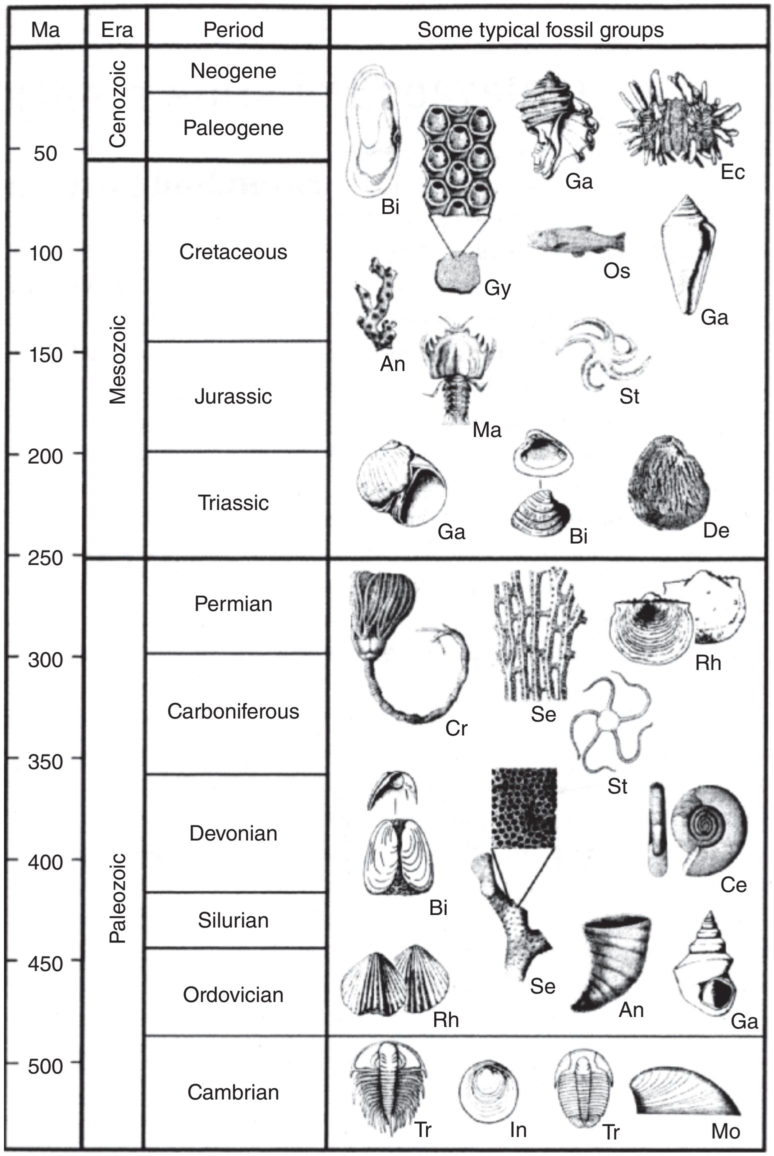


Figure 1.1 The Phanerozoic timescale with distribution of characteristic skeletonized marine fossils. Occurrence of fossils through the stratigraphic record has largely been determined through mapping efforts around the globe to characterize the surface geology of the continents. These fossil distributions have been continuously refined through the use of fossils to build the relative timescale and definition of Eras, Periods, and other time intervals. Key to classes: An, Anthozoa; Bi, Bivalvia; Ce, Cephalopoda; Cr, Crinoidea; De, Demospongiae; Ec, Echinoidea; Ga, Gastropoda; Gy, Gymnolaemata; In, "Inarticulata" (Linguliformea and Craniformea); Ma, Malacostraca; Mo, Monoplacophora; Os, Osteichthyes; Rh, "Articulata" (Rhynchonelliformea); Se, Stenolaemata; St, Stelleroidea; Tr, Trilobita. From McKinney (2007). Reproduced with permission from Columbia University Press.

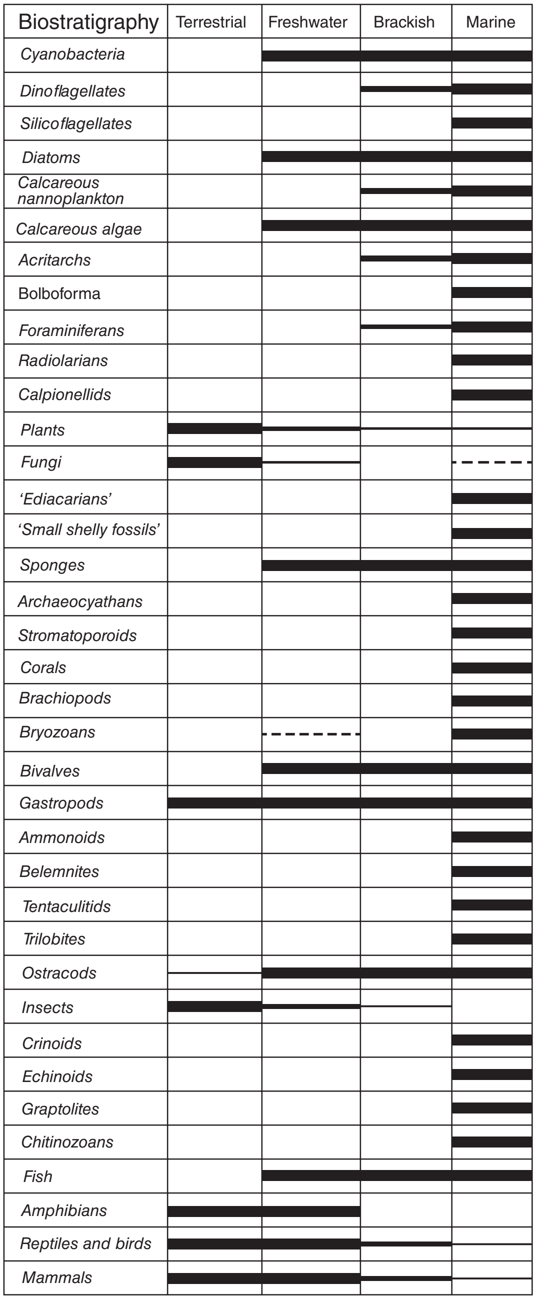


Figure 1.2 Environmental distribution of selected groups of fossils. This information largely comes from studies on the distribution of these organisms in modern environments, but also includes data on facies associations and functional morphology, particularly for the extinct groups. From Jones (2006). Reproduced with permission from Cambridge University Press.

of Phanerozoic sedimentary rocks, particularly in combination with physical sedimentary structures and geochemical indicators. Much work on paleoecology has been spurred by the petroleum industry and the need to understand ancient environments from drill cores and cuttings as well as outcrops. This need has led to much activity on microfossils, which can yield many specimens from a small piece of rock. And, through microfossils, information can be gained not only on ancient environments but also for ancient age determinations.

In the 1960s and 1970s, the study of fossil communities, or paleocommunities, blossomed. To many, the results from this research activity seemed to show that animals in the past lived the way they do today. But, as this information has accumulated, it became clear that ecology changes through time, due to both evolution as well as environmental change. The synthesis of this realization has come to be known as evolutionary paleoecology. Evolutionary paleoecology has become a group of research programs that focus on the environmental and ecological context for long-term macroevolutionary change as seen from the fossil record. For example, Fig. 1.3 displays the tiering history for benthic suspension-feeding organisms in shallow marine environments below wave base since their early evolution in the Ediacaran, synthesized in work done with William Ausich. Tiering is the distribution of organisms above and below the seafloor, and this diagram shows how the distribution has changed through time and therefore how organisms have evolved their ability to inhabit three-dimensional space. This diagram is the latest of several showing tiering, and its development in the early 1980s was part of the early history of evolutionary paleoecology.

Paleoecology and the future

Earth's ancient ecology is a fascinating subject for study, but there is more to be gained from this study as a benefit to present society. We are entering a time of widespread environmental change, in large

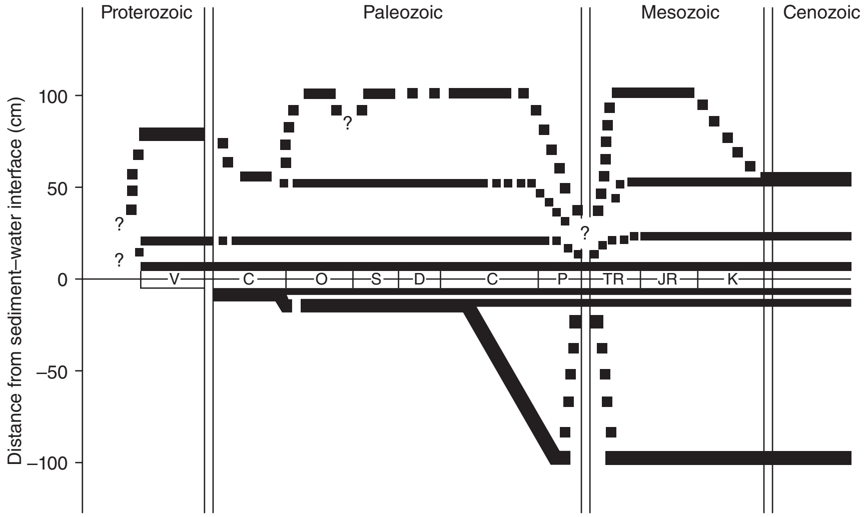


Figure 1.3 Tiering history among marine soft-substrata suspension-feeding communities from the late Precambrian through the Phanerozoic. Zero on the vertical axis indicates the sediment–water interface; the heaviest lines indicate maximum levels of epifaunal or infaunal tiering; other lines are tier subdivisions. Solid lines represent data, and dotted lines are inferred levels. These characteristic tiering levels were determined for infaunal tiers by examination of the trace fossil record, particularly the characteristic depth of penetration below the seafloor of individual trace fossils. Data on shallow infaunal tiers also came from functional morphology studies of skeletonized body fossils. Paleocommunity and functional morphology studies of epifaunal body fossils comprise the data for epifaunal tiering trends. Tiering data from the late Precambrian is from studies of the Ediacara biota. This tiering history has been updated as more data have become available. From Ausich and Bottjer (2001). Reproduced with permission from John Wiley & Sons.

part due to disruption of the carbon cycle (Fig. 1.4) through burning of lithospheric coal and petroleum and subsequent transfer of carbon in the form of carbon dioxide from the lithosphere into the atmosphere. This increase in greenhouse gasses in the atmosphere is causing rapid increased warming of the atmosphere and the ocean (Fig. 1.5). Increased warming of the ocean can lead to reduced ocean circulation which causes decreased oxygen content in ocean water and hence the growth of ocean systems characterized by reduced to no oxygen content, called "dead zones" (Fig. 1.6). Increased levels of atmospheric carbon dioxide cause decreases in the concentration of the carbonate ion in ocean water, termed ocean acidification, which makes it more difficult for many organisms such as corals to produce their calcium carbonate skeletons (Fig. 1.7).

As is discussed in later chapters, the fossil record contains evidence for a wide variety of past environmental changes, some of which are strikingly similar to current anthropogenically created changes. Thus, Earth has run the experiment in the past of what happens when there is an episode of geologically sudden global warming, termed a hyperthermal. The ecological changes that occurred during these ancient episodes can be studied to help provide data which can help manage our future interval of environmental change. This approach has been broadly developed under the new field of conservation paleobiology. In particular, one major aspect of conservation paleobiology is conservation paleoecology, which focuses on providing data from the past to manage future ecological changes.

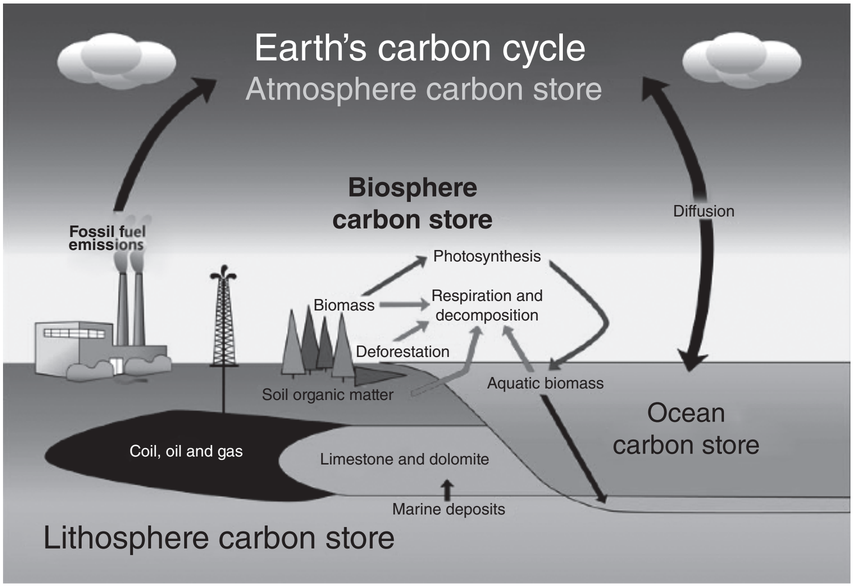


Figure 1.4 Schematic of modern carbon cycle including anthropogenic influence. Combustion of lithospheric carbon such as coal and oil is the modern cause of global warming, and a similar mechanism involving igneous intrusions through sedimentary rocks rich in carbon has been the cause of rapid global warming episodes, or hyperthermals, in the past. From the New York State Department of Environmental Conservation website: http://www.dec.ny.gov/energy/76572.html. (*See insert for color representation.*)

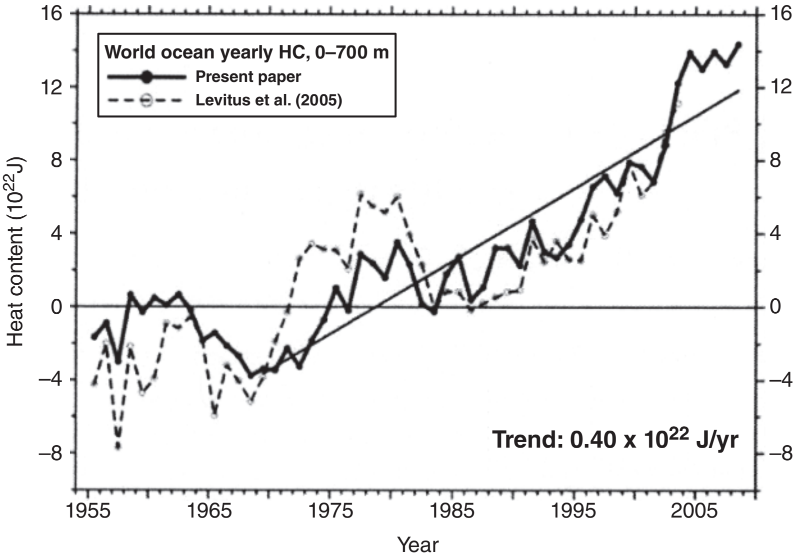


Figure 1.5 Increase in ocean heat content since 1955 shown as a time series of yearly ocean heat content in joules (J) for the 0–700 m layer. Each yearly estimate is plotted at the midpoint of the year, with the reference period from 1957 to 1990. From Levitus et al. (2009). Reproduced with permission from John Wiley & Sons.

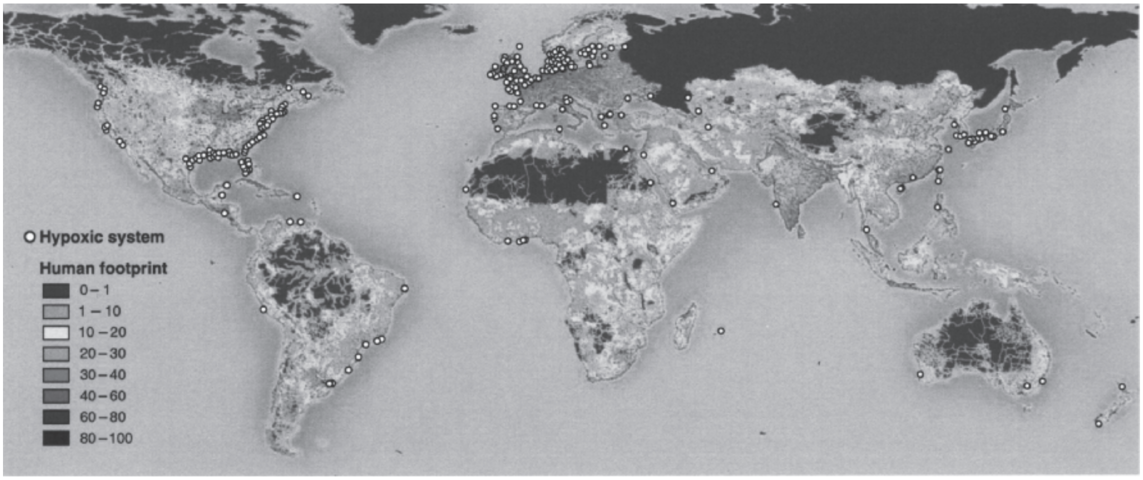
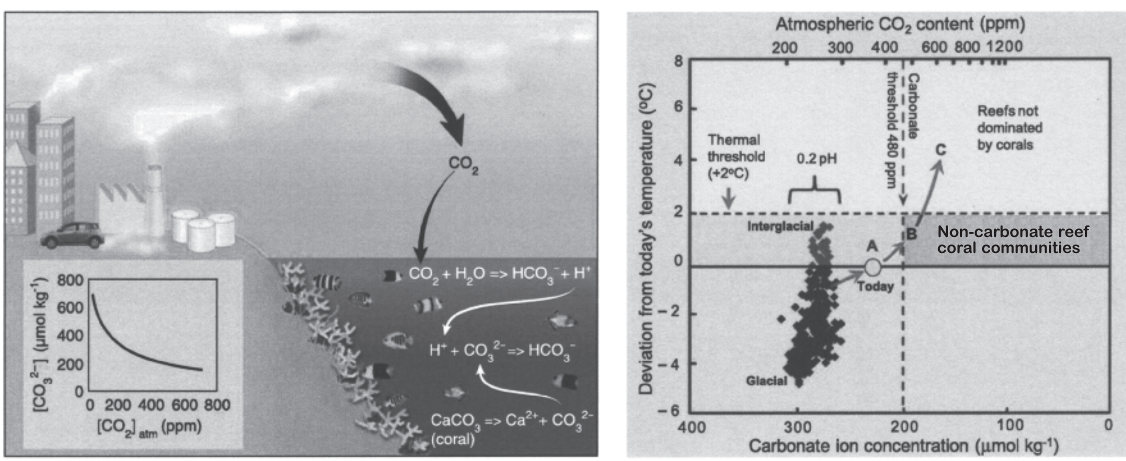


Figure 1.6 Location of hypoxic system coastal "dead zones." Their distribution matches the global human footprint, where the normalized human influence is expressed as a percent, in the Northern Hemisphere. For the Southern Hemisphere, the occurrence of dead zones is only recently being reported. From Diaz and Rosenberg (2008). Reproduced with permission from the American Association for the Advancement of Science. (*See insert for color representation.*)



(a) (b)

Figure 1.7 Increase in atmospheric carbon dioxide and its influence on ocean acidification and the resultant affect on development of coral reefs in the past, present, and future. (a) Increased carbon dioxide concentration in the oceans leads to decreased availability of carbonate ions, which are needed by corals to secrete their skeletons made of calcium carbonate. (b) Plot of temperature, atmospheric carbon dioxide content, and ocean carbonate ion concentration showing the predicted trend in the future of reefs not dominated by corals with increased levels of acidification. From Hoegh-Gulberg et al. (2007). Reproduced with permission from the American Association for the Advancement of Science. (*See insert for color representation.*)

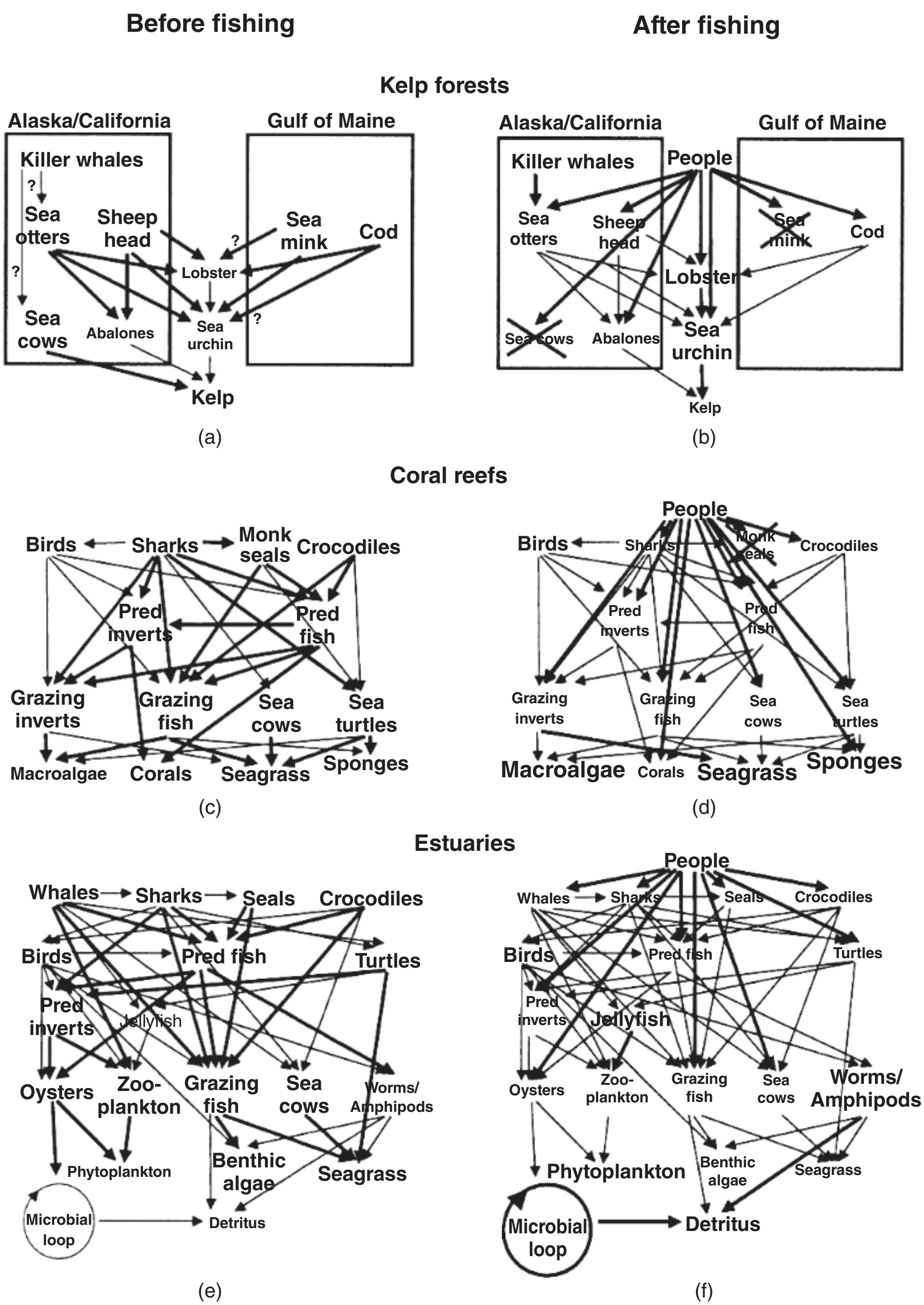


Figure 1.8 The effects of human overfishing on coastal ecosystems. Simplified food webs showing changes in some of the important top–down trophic interactions before and after fishing in kelp forests, coral reefs, and estuaries. Bold font represents abundant, normal font represents rare, "crossed out" represents extinct, thick arrows represent strong interactions, and thin arrows represent weak interactions. From Jackson et al. (2001). Reproduced with permission from the American Association for the Advancement of Science.

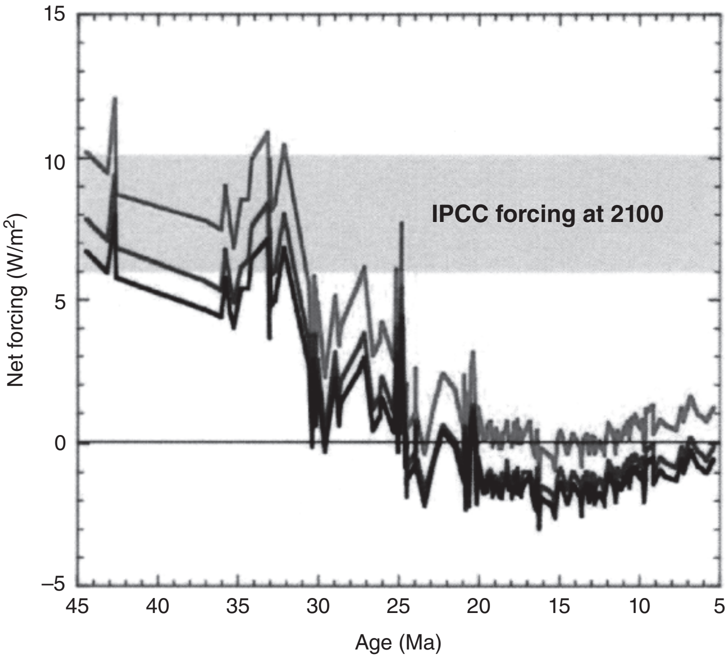


Figure 1.9 The net radiative forcing due to changes in atmospheric carbon dioxide concentration and total solar irradiance from 5 to 45 million years ago. The three curves represent the range in carbon dioxide concentration using three different proxies for ancient atmospheric carbon dioxide. The shaded area denotes the range in radiative forcing projected to occur by 2100 according to the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (2007). Net radiative forcing is in watts per square meter. From Kiehl (2011). Reproduced with permission from the American Association for the Advancement of Science. (*See insert for color representation.*)

Along with the environmental changes that are created by global warming, we also see other anthropogenic effects such as increased runoff of nutrients from human activity, which has spurred the growth of dead zones in coastal ecosystems (Fig. 1.6). Along with increased hypoxia, modern ocean ecosystems are also impacted by the anthropogenic effects of overfishing. Figure 1.8 shows the change in trophic webs that has occurred from times before intensive human fishing to after fishing in environments such as kelp forests, coral reefs, and estuaries. These sorts of impacts can also be studied and managed for the future by studying paleoecology of the last few thousand years to understand how human impact has changed these ecosystems and present another aspect of conservation paleoecology.

The import of studying past environmental change and its impact on ecosystems can be viewed through a recent study done by Jeff Kiehl (Fig. 1.9). This study calculates the net forcing in watts per square meter from 5 to 45 million years ago, using three different proxies for carbon dioxide concentration in the atmosphere. Forcing decreased from a greenhouse climate 35–45 million years ago to an icehouse climate like the one today 20–25 million years ago, with extensive ice at the poles. Also plotted is the range of net forcing that the Intergovernmental Panel on Climate Change (IPCC) report of 2007 forecasted for the year 2100. This range is the same as 35–45 million years ago, which implies that in 100 years, the Earth's ecosystems will journey from an icehouse to a greenhouse climate. The rapidity of this change is dramatic when compared with the 10–15 million years that elapsed during the Cenozoic transition from greenhouse to icehouse. It remains to be seen how Earth's ecosystems will respond to this projected episode of hyperthermal climate change, and conservation paleoecology may provide a key to managing the future.

Summary

Paleoecology has deep roots that were initiated with humankind's understanding that fossils are natural objects that provide evidence on ancient ecosystems. This is a vast subject that has only minimally been addressed, as Earth's environments have changed dramatically though the long history of life on this planet, and evolutionary changes in response to these environmental changes have been complex and varied. Within this storehouse of evidence on ecosystem response to environmental change that is available in the fossil and stratigraphic record lie many clues on how we can manage the current episode of global ecosystem change.

References

Ausich, W.I. & Bottjer, D.J. 2001. Sessile Invertebrates. *In* Briggs, D.E.G. & Crowther, P.R. (eds.), *Palaeobiology II*. Blackwell Science, Oxford, UK, pp. 384–386.

Diaz, R.J. & Rosenberg, R. 2008. Spreading dead zones and consequences for marine ecosystems. *Science* 321, 926–929.

Hoegh-Gulberg, O., Mumby, P.J., Hooten, A.J., Steneck, R.S., Greenfield, P., Gomez, E., Harvell, C.D., Sale, P.F., Edwards, A.J., Caldeira, K., Knowlton, N., Eakin, C.M., Iglesias-Prieto, R., Huthiga, N., Bradbury, R.H., Dubi, A. & Hatzioios, M.E. 2007. Coral reefs under rapid climate change and ocean acidification. *Science* 318, 1737–1742.

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjkorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J.K., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J. & Warner, R.R. 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science* 293, 629–637.

Jones, R.W. 2006. *Applied Palaeontology*. Cambridge University Press, Cambridge, UK.

Kiehl, J. 2011. Lessons from Earth's past. *Science* 331, 158–159.

Levitus, S., Antonov, J.I., Boyer, T.P., Locarnini, R.A., Garcia, H.E. & Mishonov, A.V. 2009. Global ocean heat content 1955-2008 in light of recently revealed instrumentation problems. *Geophysical Research Letters* 36, doi:10.1029/2008GL037155.

McKinney, F.K. 2007. *The Northern Adriatic Ecosystem: Deep Time in a Shallow Sea*. Columbia University Press, New York.

Additional reading

Dietl, R.G. & Flessa, K.W. (eds.). 2009. Conservation Paleobiology: Using the Past to Manage for the Future. *The Paleontological Papers*, Volume 15, The Paleontological Society.

Solomon, S., et al. (eds.). 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.