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PART ONE

# The unknown: why a Census?

CHAPTER 1

# Planet Ocean

We are a species that breathes air rather than water, which biases our view of the watery Planet Earth. We might better call a globe with 71% water cover and more than 99% of its living biosphere in marine waters Planet Ocean, as noted years ago by the writer Arthur C. Clarke (Figure 1.1). We are far less familiar with the ocean than the land. Even for scientists working in the ocean for all of their lives there are surprises. Shocked to see a recent photograph of a clam named *Pholadomya candida* that was thought to have been extinct since the late 1800s, a Colombian scientist spent many days diving and searching where the photograph had been taken. Just before his scuba tank ran dry one day, he found a living specimen a little deeper and in colder water than expected, rescuing it, at least temporarily, from the list of extinct species. Deep-water samples my research team recently

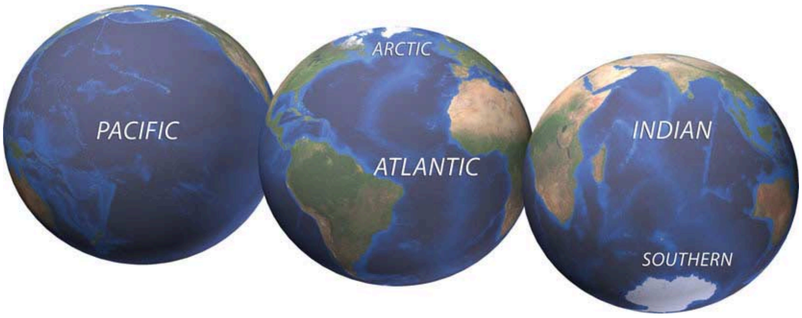


**Figure 1.1 The predominance of water on Planet Ocean.**
Census scientists explored marine life in all realms of the world's oceans, visualized here on a Blue Marble image.

collected from Eastern Canada were examined by a world authority on marine worms, who was surprised that half of the species had never been named. This novelty appears to be the norm for many deep-water environments, where as much as 85% of the species in a sample can be new to science.

These anecdotes illustrate how little we know about Planet Ocean and what lives in it. The ocean is changing, and it is changing before we have really appreciated all that it now contains. What lives in the ocean? Where do they live? How many are there? In three words, what is their diversity, distribution, and abundance? We are further from answering these basic questions than even most scientists realize.

To address these three major questions, marine experts from around the world banded together in the year 2000 in an international initiative called the Census of Marine Life. In the decade of discovery that followed, as this book summarizes, the Census and others focused new "binoculars" of technology to look into the ocean and propelled forward the understanding of diversity, distribution, and abundance of marine life. Through the chapters that follow, we will visit the different areas of the ocean and use these new "binoculars" to see and understand single-celled microbes and whales, and everything in between, in ways not possible only a decade ago. In short, Planet Ocean is coming into focus, and is becoming more transparent.

The array of marine life and how they live varies immensely. The size of marine organisms ranges a hundred million million million fold, from drifting bacteria through blue whales. From the smallest to the largest organisms, from the shortest to the longest lived, from the slowest to the fastest, and from the drab to the flamboyant, living organisms have developed an amazing range of strategies to survive. Some species, such as bacteria, may only live for hours, but they can also replicate in that time and produce multiple generations in the time it takes us to get a good night's sleep. At the other extreme, as impressive as specimens of 200-year-old rockfish and 400-year-old clams may be, these long-lived species pale in comparison with deep-water corals that can live in excess of 4,000 years (Table 1.1). Imagine that when this coral first settled to begin life, Egyptian and Minoan cultures were flourishing, and Tutankhamun had not yet begun his reign. Indeed, this coral would have been over 1,000 years old when Buddha and Aristotle were born!

Some species are prolific and others are not. Many long-lived species produce few offspring after many years, in contrast to many species that produce millions of offspring, sometimes only months after they themselves

**Table 1.1 Maximum age estimates of individuals from the wild in various marine taxa**

| Taxa | Species | Location | Age (years) |
|---|---|---|---|
| Marine mammal | *Balaena mysticetus* (Bowhead whale) | Alaska, United States | 211 |
| Seabird | *Diomedea epomophora* (Royal albatross) | Unknown | >58 |
| Marine reptile | *Chelonia mydas* (Green sea turtle) | Hawaii, United States | >>59 |
| Marine fish | *Sebastes aleutianus* (Rougheye rockfish) | Unknown | 205 |
| Echinoderm | *Strongylocentrotus franciscanus* (Red sea urchin) | British Columbia, Canada | 200 |
| Bryozoan | *Melicerita obliqua* | Weddell Sea | 45 |
| Arthropod | *Homarus americanus* (American lobster) | Unknown | 100 |
| Pogonophoran | *Lamellibrachia luymesi* | Louisiana slope (~550 m) | 250 |
| Mollusk | *Arctica islandica* (Ocean quahog) | North Icelandic Shelf (80 m) | 407 |
| Cnidarian | *Leiopathes glaberrima* (Smooth black coral) | Oahu and Big Island, Hawaii, United States | 4,265 |
| Sponge | *Xestospongia muta* (Giant barrel sponge) | Curaçao | >2,300 |

were born. Mobility also varies. Corals are affixed to a single seafloor location, but other species move quickly and far. Sailfish can rocket through the water at 110 kilometers per hour. Atlantic bluefin tuna can move quickly, too, but take their transatlantic migrations of 5,800 kilometers at a more leisurely single kilometer per hour. Sooty shearwaters complete their 64,000 kilometer roundtrip migrations at 40 kilometers per hour, faster than most of us can move as we commute to work! The real marathon swimmers are humpback whales that complete 8,400-kilometer migrations, and Pacific tuna that make triple crossings of the Pacific.

Tricks of survival are many. Whereas species such as flounder can adjust their color to blend in with the environment and make themselves invisible to predators, nudibranch sea slugs alert predators that they are poisonous through bright colors. The diversity of life, its size, and its longevity reflect a wide range of adaptations evolved through time to survive in Planet Ocean (Figure 1.2).

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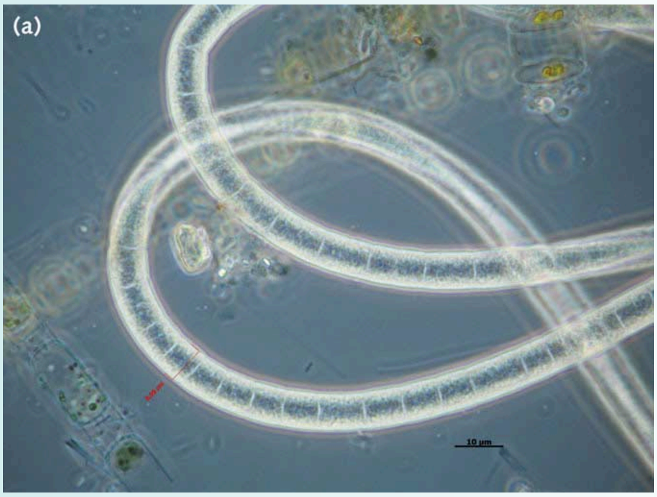
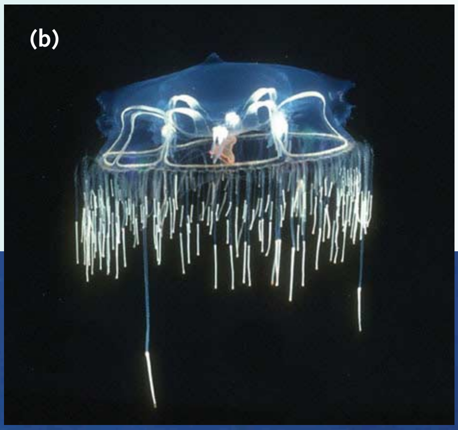
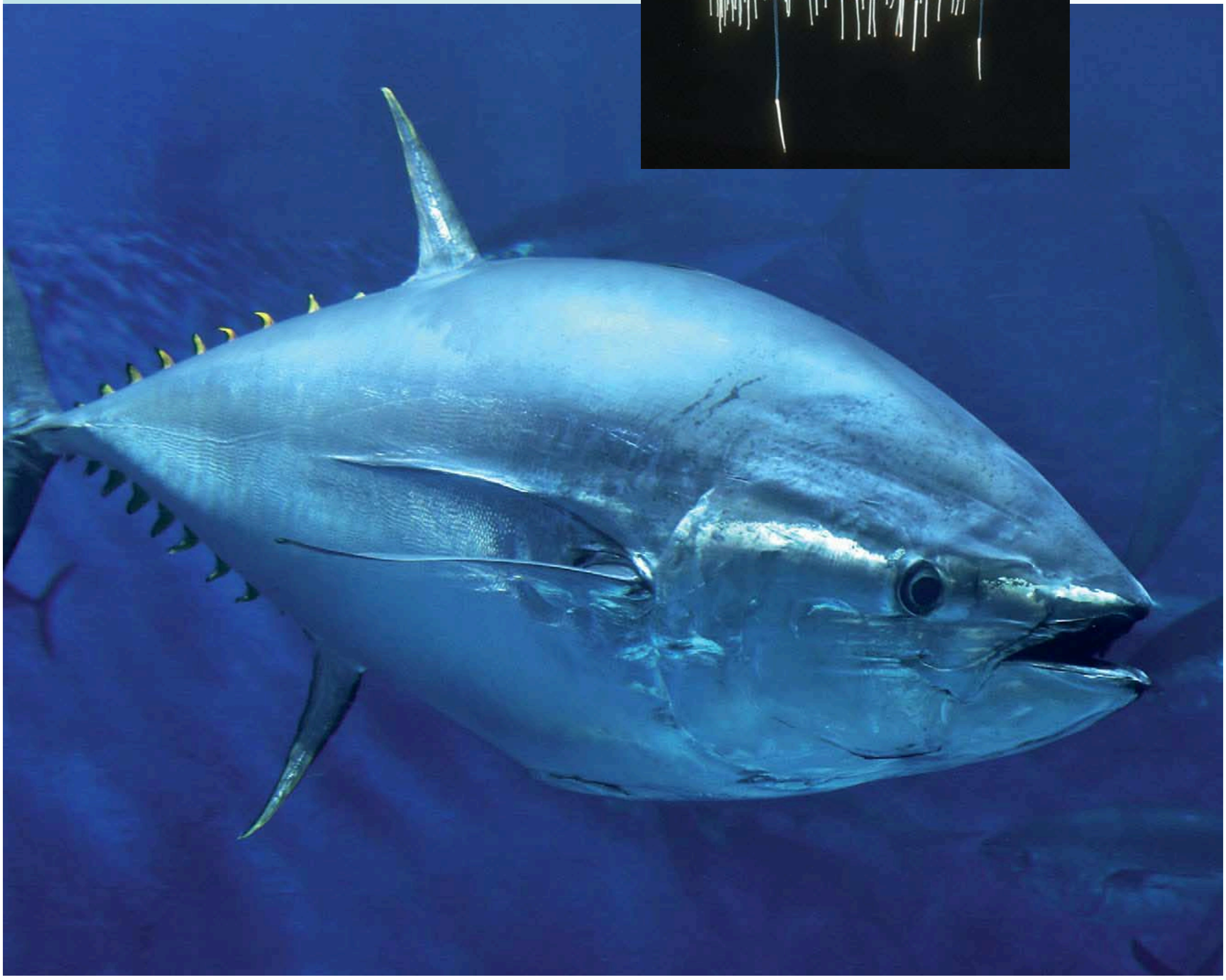
**Figure 1.2 The diversity of marine life.** These images from branches of the evolutionary tree of life illustrate the range of species and forms of life living in Planet Ocean.
**(a)** Giant sulfur bacteria inhabit anoxic sediments, devoid of oxygen, in the South Pacific. Though most bacteria require a microscope to be seen, these giants can be seen with the naked eye. See Chapter 8.
**(b)** *Halicreas minimum*, a jellyfish, drifting as zooplankton as deep as 300 meters. It lacks any stage that attaches to the seafloor. Its fertilized egg changes directly into a larval stage bearing tentacles, which then changes into the small medusa form in the photograph.
**(c)** The prized Atlantic bluefin tuna, *Thunnus thynnus,* swims in the open sea, hunting sardines, herring, mackerel, squid, and crustaceans. The Census tagged tuna to track their long migrations. See Chapter 7.



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**(d)** Shown here is an amphipod, the small crustacean *Eusirus holmi*, that swims through the water as it searches for small prey to seize with its powerful, miniature, claws.
**(e)** In 2009 Census scientists found this flamingo tongue snail, *Cyphoma gibbosum*, near Grand Cayman, British West Indies. They listed it in the Gulf of Mexico biodiversity inventory amassed by the Census.
**(f)** The bioluminescent lure that anglerfish dangle in front of their mouths attracts potential prey and gives them their name. The ceratoid anglerfish of the genus *Lophodolos,* found by Census scientists, may be a new species.

 

## Why a Census?

Beginning with environmentalist Rachel Carson's *The Sea Around Us* and continued by Jacques Cousteau's films, interest in oceans grew through the 1970s. Books and television brought the beauty of the ocean into living rooms of homes around the world. The complexity of the *neritic* (coastal) environment and the size and remoteness of the *pelagic* (offshore) environment awed people. *Environment* is the sum total of physical, chemical, and biotic factors (such as ocean currents, nutrients, prey) that act upon an organism or an ecological community and ultimately determine its success and failure. The environments that awed people supported fisheries that in turn supported many economies around the world. But by the 1960s and 1970s, some fisheries were obviously declining, and as the environmental movement took off, interest in living organisms was rising. Scientists began to appreciate the array of life in the ocean, debated the patterns and causes of diversity in coral reefs, and fueled interest in the myriad species that had been discovered in the ocean.

Much of this interest was confined to a few specialists, and interest in diversity and the underlying taxonomy declined by the early 1990s. Soon after that, the rise of conservation biology, projections of millions of unknown species in tropical rainforests, and E. O. Wilson's and J. F. (Fred) Grassle's writings about diversity on land and sea revived interest in species diversity.

Wilson helped to bring to the public the term *biodiversity* for the variability in genes, species, and ecosystems of a region, evolving it from the more general term *diversity*. Although some scientists continued to study biodiversity patterns in coastal areas and the deep sea, and the processes that contributed to those patterns, major funding and effort to study marine biodiversity did not materialize.

Meanwhile, the collapse of major fisheries once thought to be inexhaustible alarmed the public. Though explaining year-to-year variation in abundance had vexed biologists for a century, and although many fisheries had waxed and waned over the years, the global scale and gravity of the fisheries collapse hit home in the 1990s. The effects of removing the top predators from whales to sharks to fishes cascaded onto other species. The cascade of effects from the ocean surface to the seafloor provided evidence of unintended consequences of fishing on ocean productivity. Effects on biodiversity extend far back in time. These concerns shifted fisheries managers away from focusing on single species to viewing entire ecosystems. They recognized the negative impacts of fishing on habitats and food webs.

An additional wrinkle was the new idea of ecosystem services. This concept refers to the key services from living organisms that benefit all life on Earth and, in many cases, benefit humans directly. In the ocean, these services include breakdown of sewage and other waste, nutrient cycling, shoreline stabilization, and provision of food and oils. Scientists argued that because biodiversity made ecosystems healthy, changes in biodiversity could diminish ecosystem services. This concern offered a practical application to move biodiversity research beyond a descriptive exercise to finding how oceans actually work, and then apply those findings to management. The role of biodiversity in ecosystem services matters because major changes have taken place and continue to occur in the ocean. Human production of pollutants and climate-change gases, plus fishing in the ocean caused many of the changes. Will changing biodiversity in the ocean influence ocean productivity and other ecosystem services?

## Ocean biodiversity

During the late 1990s, some experts estimated that less than 5% of the biodiversity in the ocean had been described. Indeed, some estimated less than 1%. Even comparatively well-known seas, such as the shallow waters of northern Europe and the northeastern United States, continue to yield new discoveries of species and surprises about the life they contain. Much of the ocean remains unsampled. Biological data for the deep ocean beyond 200 meters depth exist for only a few square kilometers of the 300 million square kilometers of Planet Ocean. Much of the biodiversity on coral reefs remains to be sampled. And we are just now starting to learn about the diversity of microbes, whose unknown biodiversity could explode our estimates of the number of marine species.

During the last few decades, our understanding of life on Earth has broadened from one of life divided into five all-encompassing groupings to a new recognition of three domains. The first domain, the Eukarya or *eukaryotes*, encompasses the animals, plants, fungi, and microbial *protists*, (single-celled, simple organisms such as amoebas), all of which have nuclei and other specialized organelles within their cells. The other two domains, the Bacteria and bacteria-like, but different, Archaea, comprise the *prokaryotes* that lack most of these organelles. The broadened view of the diversity of life on Earth includes understanding how species have evolved. Molecular tools that tell how groups of organisms are related in an evolutionary context made this new view possible. Our view of life on Earth has been reorganized.

## Counting all the fish in the sea

In 1995, the United States National Academy of Sciences emphasized the need to fill major gaps in understanding ocean life. The ensuing inaction discouraged Fred Grassle, a leading voice on marine biodiversity. One summer afternoon in 1996 he walked into the office of Jesse Ausubel, a program officer with the Alfred P. Sloan Foundation, and lamented the discouraging problem. They explored what to do about it. To some extent, a coincidence of geography – strong ties to Woods Hole Oceanographic Institution – brought Grassle and Ausubel to the same small town and marine science Mecca, where I wrote these chapters as a seasonal guest. As Rachel Carson noted almost 50 years ago, "Woods Hole is a wonderful place to come for research. Biologists come from all over. If you want to talk to them, you just come here in the summer instead of traveling all around the country to find them in winter."

At the time, the Sloan Foundation was supporting the first Digital Sky Survey to map the one hundred million objects in the sky. Grassle's concern intrigued Ausubel, and after further discussions, they developed the idea of "mapping" life in the ocean. Some weeks later, Ausubel strolled with one of his Sloan colleagues towards Aquinnah on the island of Martha's Vineyard and, while inhaling salt air and scanning the ocean edge, announced, "We've helped astronomers count all the stars in the sky; let's help marine scientists count all the fish in the sea." Appropriately, Aquinnah (formerly Gay Head) stood at the beginning of a sampling line established by Howard Sanders, one of the fathers of deep-sea biology, in the 1960s. The line ran all the way to Bermuda and its study changed our understanding of marine biodiversity. Grassle's passion for marine diversity, and especially the *invertebrates* or animals without backbones, ensured that "fish in the sea" would not be taken literally, and his dream of a global program in marine biodiversity began to become a reality.

During the next three years, marine experts from around the world gathered to talk, identify research gaps, and formulate a strategy to understand life in the ocean. They came from wealthy countries and poor ones, from polar research labs and the tropics, and with interests from whales to bacteria. They met in marine centers around the United States and United Kingdom, and in Greece and Thailand. A plan emerged to undertake an unprecedented 10-year census of the world's marine life in an international program called the Census of Marine Life. The overarching goal of the Census would be to understand the diversity, distribution, and abundance of marine organisms across all ocean realms from the shoreline to the ocean abyss, and to consider their past, present, and future. The task was formidable, because the concept was global in scope and aimed to sample the vast oceans and their diversity of life. Unlike the censuses that count the single species of humans with fixed addresses in single nations, this Census would consider all species and ocean habitats. Most of the ocean has never been sampled or seen because much of it is thousands of kilometers from land and several kilometers deep. And some of the most species-rich waters of the ocean are near developing countries with little funding and infrastructure for research and exploration.

The ocean constantly changes as the sun rises and sets, as wind blows and seasons change, and as such phenomena as El Niño wax and wane. Many waters straddle national and international boundaries and organisms move through entire ocean basins in a matter of weeks and months. Until the Census began, marine biology lacked coordination in biodiversity research, particularly internationally. Scientists had worked together on fisheries problems in groups such as the International Council for the Exploration of the Sea, but the groups focused largely on single species targeted by fisheries. Uncoordinated efforts to study biodiversity produced findings, but could not capture the broad variability in space and time of marine diversity, distribution, and abundance in the global ocean as the planned Census hoped to do.

Bringing together experts from around the world facilitated coordination. The gatherings introduced individuals from developing nations with limited equipment, ships, and knowledge of sampling, to experts from developed countries with more scientists, resources, and links to multinational programs. The gathered scientists discussed objectives, oceanographic cruises, sampling, and analytical methodologies so they could work together to tackle big questions that no individual or nation could hope to answer alone.

Indeed, the crowning achievement of the Census may not be the thousands of scientific papers it has catalyzed and their many findings. Rather the crown may be exciting and unifying global researchers toward the common objective of understanding life in the ocean and managing ocean resources effectively.