
Sea
FEVER

# SEA FEVER

## – PEOPLE AND THEIR OCEAN PLANET –

**Luc Cuyvers**

THE GALLIFREY FOUNDATION

# FOREWORD

*"I really don't know why it is that all of us are so committed to the sea, except I think it's because in addition to the fact that the sea changes, and the light changes, and ships change, it's because we all came from the sea. And it is an interesting biological fact that all of us have in our veins the exact same percentage of salt in our blood that exists in the ocean, and, therefore, we have salt in our blood, in our sweat, in our tears. We are tied to the ocean. And when we go back to the sea - whether it is to sail or to watch it – we are going back from whence we came."*

These words were spoken at a 1962 dinner for America's Cup crews by John F. Kennedy, himself an avid sailor. We quote them because JFK managed to encapsulate the essence of sea fever in a few lines, describing a mix of feelings: some intensely personal, others deeply embedded in all of us. Even though spoken more than half a century ago, his words are recognizable. He could have said them yesterday and they would have made perfect sense, just as much as they would have a hundred years earlier. They are timeless, their meaning unlikely to be changed by the passage of time.

As Dr. Cuyvers points out in this book, there exists another type of sea fever, implying the sea is running a fever. We can interpret it literally – after all the sea *is* warming up, just like the rest of the planet, or figuratively, as in the sea not being healthy. What is of concern here is that JFK would have been hard-pressed to see that coming. When he was sworn in as President in 1960, there were signs that our increasing reliance on the sea could have unintended effects, but there had been no massive oil spills, most fish stocks had not yet been depleted, there were few, if any, dead zones at sea, and plastics or acidity were not what came to mind when referring to the sea. This type of sea fever didn't quite exist 50 years ago. But it certainly has become an issue in what is, in historical terms, no more than a blink of an eye.

Nonetheless, amidst the bad news there are some hopeful signs; things we handle better now than during JFK's presidency. Visiting a beach at that time often involved stepping onto tar balls: small weathered globules of oil that were formed after oil tankers released ballast water and tank washings at sea. Today you are more likely to step onto weathered plastics (less messy but not exactly an improvement), but the tar balls are largely gone. They are gone because ships, especially tankers, are forbidden to discharge their ballast water at sea. There obviously is much more involved than a simple prohibition. There are penalties, strong regulations, near-universal compliance and effective monitoring and enforcement, all of which contribute to one of the few success stories in the global fight against marine pollution.

There's something else that is involved, and it precedes this regulatory mechanism. For international rules to be that efficient they need public support. These strong measures would not have materialized if there hadn't been a publicly-backed mandate to reduce oil pollution at sea. True, that demand resulted mostly from the sight of oil-smothered beaches and birds as a result of accidents rather than the annoying tar balls, but it was strong and unified and compelled governments to tackle the problem, in spite of the fact that the required decisions could and would have economic implications.

There are other positive developments in our efforts to restore, or at least maintain, the ocean's health. Like the mandate to reduce oil pollution, they tend to be backed, if not initiated, by a public demand to protect or preserve anything from whales to sea turtles or a particular marine habitat. Picking the right battles requires a public that knows what is worth demanding, that realizes what is at stake and gives governments and international organizations a mandate strong enough to change things, rather than just discuss them. That, in turn, demands a higher level of marine literacy than currently exists.

When referring to literacy we tend to associate education but for reasons that are not entirely clear to us, school curricula do not devote a great deal of attention to the seven-tenths of the planet that are covered by water. We hope that may change at some point, but in the meantime there are some things that we can do as well. This book provides a small example. Six chapters focusing on various ways we relate to or use the oceans, each one of which designed to promote an understanding of the ocean's importance. We invite you to read it and to share it. The Gallifrey Foundation is pleased to make this digital edition available at no cost to help make sure that the ocean decisions we make in the next half century will be more enlightened than the ones we made in the past.

John Vermilye and Antoinette Stagnetto Vermilye
The Gallifrey Foundation
Geneva, Switzerland

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*I must go down to the seas again,*
*for the call of the running tide*
*Is a wild call and a clear call*
*that may not be denied*

**John Masefield**
*Sea Fever*

# INTRODUCTION

When I was a kid we used to vacation at the coast every other year or so. It took two or three hours to get there, and I remember those drives well. There was a keen sense of anticipation as we approached our destination, with five children peering into the distance, as the first to spot the dunes fringing the coast would receive the first ice cream cone. But that's not why I was so excited. By then I was dying to climb up the stairs leading to the boardwalk to see the sea again, after an absence of a year or so. I remember that moment well. It was like greeting an old friend. I just stood there for a while, staring at the North Sea in all its majestic greyness.

The following weeks were blissful: day after day of exploring the beach and tide pools, catching shrimp and crabs, watching the flooding sea reclaim our fortresses. Like most children, I suppose, I spent hours watching the ferries to England dip beneath the horizon, wondering what lay beyond. And like all of them I was mesmerized by the sea's rhythms: the tides moving in and out, waves endlessly building and breaking. It was as if I sensed a presence there; sometimes friendly, sometimes not.

Today, half a century later, not much has changed. That sense of awe and wonder is still very much the same whenever I am near the sea. In retrospect, those trips to the beach of many years ago were as much a pilgrimage as they were a vacation. Even then I realized there was something more there; something larger than ourselves. Even then, I had sea fever...

But some things have changed. In those fifty odd years, our collective relationship with the sea has changed dramatically. Driven by the need for additional space and resources, we built the machinery to explore and exploit the sea, even to its deepest reaches. We apportioned it, and have sought to live or relax along its shores in growing numbers. For the first time, we also acquired the ability to affect the sea, and even irreversibly change it.

Much of this was, at least initially, accompanied by a sense of optimism. During the 1960s the annual food yield from the sea increased rapidly. New and valuable mineral resources were discovered, and later recovered, from the seafloor. Shipping methods were revolutionized. New ocean uses were proposed: obtaining clean energy from temperature differences, for instance, or from waves and tides. Scientists suggested that new and promising drugs could be obtained from a variety of marine organisms. And faced with a growing amount of waste, some felt a good proportion of it could be safely and conveniently discarded in the oceans.

It didn't take long for this sense of optimism to become marred by a number of incidents. First a small fishing village in Japan made the headlines. The people of Minamata were poisoned and killed or crippled for life by industrial pollutants which had been discharged into the sea. Other incidents occurred, seemingly with increasing frequency. There was concern over radio-active pollution, caused by fall-out from nuclear tests. Pesticides like DDT began to affect the coastal environment. Valuable fish stocks disappeared, fished to near-extinction by increasingly effective fishing fleets. Massive oil spills, from platforms as well as vessels, smothered beaches and birds, visualizing, for the first time perhaps, that the sea no longer was immune to change.

That was sea fever too, but a fever of an entirely different kind...

This book is about these two types of sea fever. One is individual, personal even: a manifestation of our close bond with the sea. The other is the result of collective action, caused by our increasing need for space and resources. One is positive, accompanied by a mixture of feelings: exhilaration, fear, respect and wonder. The other is negative, accompanied by symptoms that make clear that not all is as well with the sea as we would like to believe.

Much of the first chapter is about the personal side of things. Not so much what you and I think and feel, but what those who came before us thought and felt, and how they expressed it. If anything, it reflects a striking similarity. Much of the theme of novels like *Moby Dick* was reflected in stories of Creation conceived thousands of years earlier. Turner's romantic seascapes of the 19th century too were anticipated hundreds of years earlier. And sea poetry bears a remarkable similarity throughout history. Perhaps most excitingly, these works, created by people who lived hundreds or even thousands of years ago, conjure images and feelings that are familiar.

Of course, recognizing familiar emotions in the works of people long gone doesn't prove that everyone feels that way. In fact, many people then and many people now may not really care... But I doubt it. Listen to Ishmael, prior to setting out in search of Moby Dick: "*if they but knew, almost all men in their degree, some time or other, cherish very nearly the same feeling toward the ocean with me...*" It couldn't be phrased any better. There is a bond between people and their ocean, though admittedly most people remain unaware of it.

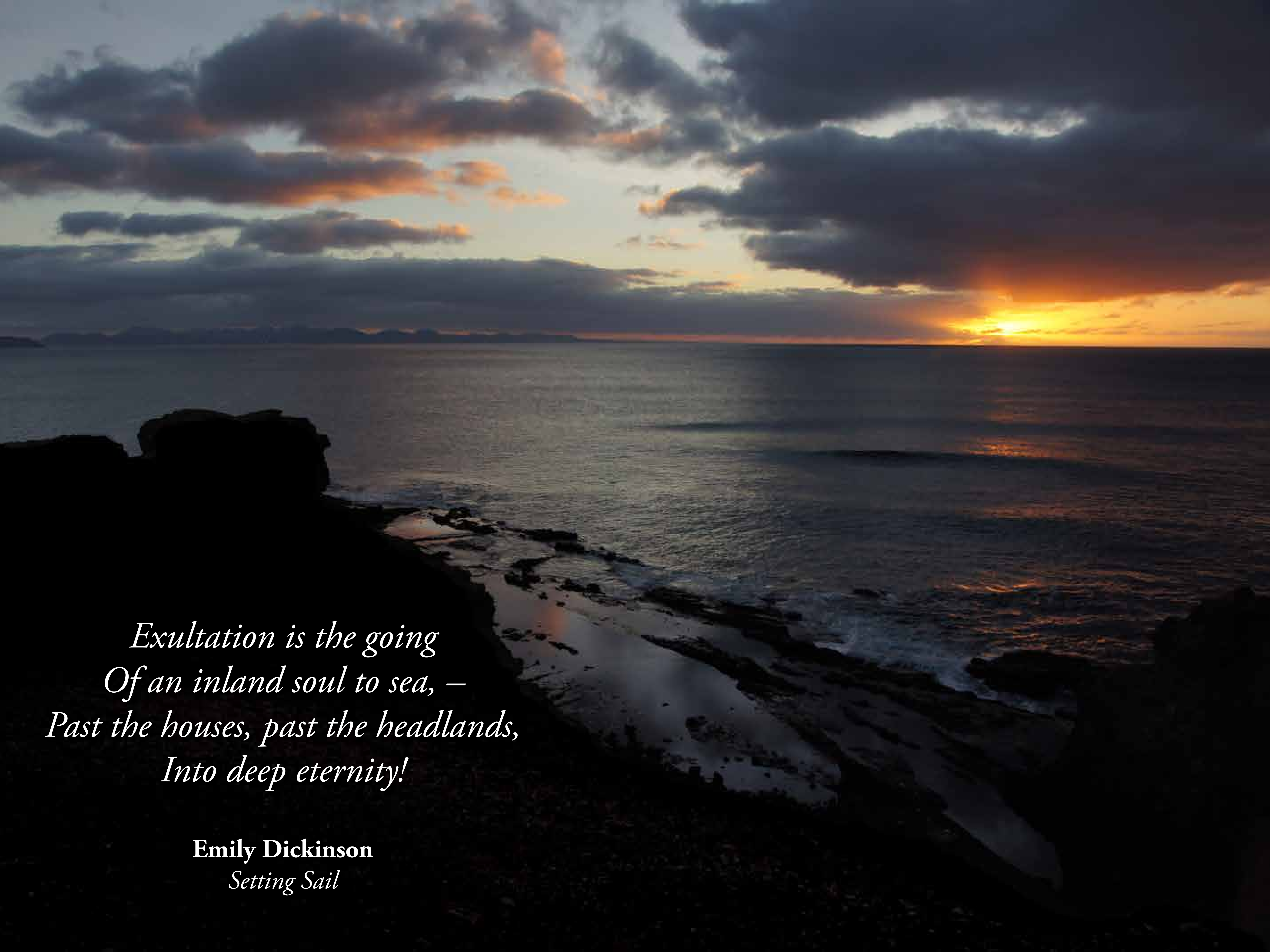
That bond still exists. And many people still do not recognize it. But they do express it. Not as lyrically as Melville and others, but through their annual pilgrimage to the beach, for instance. Or by visiting marine theme parks and being mesmerized by dolphins and whales. Or perhaps simply by watching television, staying with remarkably similar underwater programs time after time because they offer a glimpse into a world that is both alien and familiar.

The remaining chapters focus in more detail on how we use and, in many instances, misuse the ocean. They cover the role of the sea in food provision, weather prediction, the recovery of minerals and energy, the search for new drugs, marine transportation and waste disposal.

Each is treated historically, to help explain how we came to be where we are. And that, in turn, reveals there is a need for a fundamental change in attitude. We don't necessarily treat the ocean any worse than those who came before. But there are far more of us than ever before, all aspiring to a higher standard of living. Under those conditions, things simply can't go on the way they have before.

Nonetheless, this book does not intend to preach. It was written to convey the immense role of the ocean upon the human experience – emotional as well as pragmatic – in the hope that this will broaden our perspective and make clear that there are ocean issues other than sharks, whales and oil spills that deserve our attention. It grew out of the conviction that the greatest danger to the oceans is not pollution or overfishing but rather the ignorance and apathy that allows these things to happen in the first place.

Our relationship with the sea is a complicated affair. On the one hand there is a collective element which, for better or for worse, has grown rapidly in recent years. On the other is an individual component, over which the sea still firmly holds control. Today they are no longer synchronized. We need to restore the balance. If collectively we could show as much respect for the sea as we feel intuitively, the future of this blue planet would look a lot brighter...



*Exultation is the going*
*Of an inland soul to sea, –*
*Past the houses, past the headlands,*
*Into deep eternity!*

**Emily Dickinson**
*Setting Sail*

# ORIGINS

There isn't much I remember about being in first grade, aside from the first day perhaps. After all, it had been built up, as in "from now on you are young men". We weren't "young men", of course. We were children but still felt that our newly acquired status enabled us to look down on the toddlers that scurried around the playground in kindergarten next door. Later there was the magic of learning to read. What was one day an indistinguishable scribble became an "A" the next, and strings of scribbles became apples. Wonderful stuff all that, but what I remember best was the art work. My first grade teacher always managed to brighten the blackboard, and our days, with wonderful images illustrating whatever we were learning at the time. Most of the drawings had to do with the words we were learning to write, but occasionally they showed other things.

Seven of these images still stand out in my mind. He made them early in the year; seven pictures all the way along the top of the blackboard, each one of them neatly drawn in a square. The first was dark, except for a few blue ripples at the bottom. The second was much lighter, with a light blue sky above the water. The third showed not only water, but also land, and on it were some trees. The fourth looked much brighter, presumably because now the sun was shining. On the fifth, my favorite, there were fish and whales in the water, and a few animals on land. The sixth showed two people walking around some trees, and the final one showed everything – people, animals and plants – set in blissful surroundings. That was the prettiest one, full of life and with the sun shining happily above.

The seven drawings completed, my teacher told us the story of creation, writing "Day 1" and "Day 2" neatly under the first two squares, and moving on until "Day 7" when, so he told us, God gazed at everything he had just created, decided that it was good, and then called for a break. It was a beautiful story and it made eminent sense. After all, on Sundays we had the day off too, and the smiling sun in the picture seemed to confirm that these things weren't simply pulled out of a hat.

Many years later, I find myself thinking back of these images. Especially the first one; the dark picture showing what existed before God got to the point of creating the world. There was nothing, we were told, except for water, or "the Deep" as my teacher called it. So there was *something* before the creation. There was water, a vast ocean it seemed, before anything had been created at all.

Christianity, I found out much later, wasn't the only religion to imagine the creation in this manner. Elsewhere too people sensed the importance of water. They usually named the planet for the safety of the land, but in the expanse of the sea they assumed its origin. And that belief they almost universally recorded in their legends of creation.

The ancient Egyptians, for instance, believed in a primordial watery mass, from which heaven and earth were formed. They held varying beliefs on who was responsible for the creation, although both Re-Atum, the sun god, and Osiris, god of death and fertility, played prominent roles. Other theories proclaimed the world originating from a sculpture, a hill, or even a primeval egg but whatever the theory, all accounts agreed on their starting point: before creation there was a watery chaos from which everything else derived.

Further East, in the land between the Tigris and Euphrates rivers, the Sumerians also believed that the universe had been formed out of a primal sea. It was ruled by the goddess Nammu, but she did not create the earth. Instead there were three gods who were responsible for its formation: Enlil – god of the wind and air, Anu – god of the heavens and Enki – god of the sea. Enki figures prominently in the *Eridu Genesis*, the only account of the creation the Sumerians left. It describes the clever sea god living in a magnificent palace in the Persian Gulf, from which he controlled the creation – pouring water into rivers, planting reeds and sowing grains, and making sure it rained now and then to keep everything from drying out.

*The Egyptians, like most ancient civilizations, believed that the world around them had been created from a primordial ocean personified by Nun. Interestingly Nun was not only seen as the creator, according to some myths he will also be responsible for its destruction.*

It is a charming story but there was more to it than that. Over the years the people of Eridu noticed that the land near the coast appeared to be growing, and they assumed that all land had been created this way. Of course, it was not the sea that was depositing this land, but the river. And it was not the river that made organized life and the earliest forms of civilization possible in this region, but the hard-working Sumerians themselves. But they did not know this. As far as they could tell something was adding land onto the coast, and they credited their god of the sea.

The Babylonians and Assyrians, who later ruled the land between the two great rivers, adopted most of the Sumerian myths. The Babylonian creation legend, for instance, substitutes Enki with Marduk, the leading god of the Babylonian pantheon. “All the lands were sea,” so it starts. “There was movement on the midst of the sea. At that time Eridu was made…”. The story then describes how Marduk created the Earth by placing a reed on the face of this primeval sea. He went on to fashion people and animals, along with rivers, marshes, trees and even buildings and cities. When the Assyrians took over, they substituted their principal deity Assur in the role of creator.

The stories aren't exactly the same. The names of the various protagonists are different, for instance, and the Christian god left the building of houses and cities to people rather than to divine intervention. But aside from that, they are similar enough to suspect they had a common origin. Which made sense. After all, the peoples of the ancient Near East traded with one another. In the process they interacted and shared stories. And one of the stories they shared told of the beginning of the world, explaining why their creation myths share the presence of a dark watery mass before there was anything at all.

Eastern religions reflect similar beliefs. The cosmic ocean recurs in Hindu mythology, for instance. Vishnu's many avatars include a fish that saves humanity from the doomsday flood, a tortoise at the bottom of the cosmic ocean, and a boar that rescues the earth from the waters of the deep. These incarnations are derived from myths originally associated with other deities, but they too point to a single myth of creation from the waters of chaos.

Still further East, the Japanese story of creation is just as imaginative. It tells of a nebulous, moving chaos from which seven generations of gods spontaneously emerged. The *Kojiki, the Chronicles of Ancient Matters*, compiled early in the eighth century, meticulously lists their names, although the first six generations vanished without a trace. But the seventh generation stayed. It consisted of Izanagi and Izanami who were given the “jewel spear of heaven” by the celestial gods, and ordered to descend to create the terrestrial world.

Izanami and Izanagi did so in a most original manner. Standing on “the floating bridge of Heaven”, presumably a rainbow, Izanami thrust the “jewel spear” in the ocean be-

*In the Far East as well, many cultures perceived the sea as the origin of everything. One of the most imaginative accounts is provided by the Japanese story of creation, as recounted in the Kojiki. In it the brother-sister pair of Izanagi and Izanami are said to be responsible for the creation of Japan.*

*The Samoans believed that Tagaloa, their supreme deity, was responsible for all creation. He created their islands by rolling massive stones from heaven into the sea. But unlike most supreme deities Tagaloa wisely did not claim credit for the creation of humans. They, so the story goes, developed from worms.*

neath and when it was raised, the brine on the lance coagulated and dropped, forming a small island. Both gods then descended and, united as man and wife, gradually engendered the eight islands of Japan, from the humble island of Awaji to the great central island of Honshu.

The *Kojiki* is supplemented by the *Nihongi*, or *Chronicles of Japan*, which was completed somewhat later. Influenced by Chinese ideas, its account of the creation is more complex but like the Kojiki it speaks of a cosmic ocean from which the same seven divine generations unfolded. The *Nihongi* extends this lineage to the Emperor, implying that Japan was a divine country, without peers. In fact, later commentaries invariably pointed out that other lands were merely created of sea foam and mud, suggesting they were vastly inferior.

If so, sea foam and mud combined to create some pleasant settings to the south, in the central Pacific Ocean. The Polynesians, who inhabited this region, also gave the sea a very prominent role in their cosmology. As far as they could see, even from the highest mountain top, they were surrounded by a vast expanse of water. How did the few islands, scattered among this watery mass come about? Simple – they were pulled out of the depths by Maui and his magical fish hook, as the legend goes in Hawaii. Or, as the Samoans believe, it was Tagaloa, the god of the sea, who threw rocks into the sea that became the islands of Samoa, Tonga and Fiji.

This notion of the sea as the origin of things is common to the legends of creation of countless other cultures, from Scandinavia to the Persian Gulf and even landlocked South and North American regions. In some cases there was a logical explanation for its inclusion, as when the Sumerians observed siltation off their coast and reasoned all land had been formed this way. In other instances people might have been awed by the sea's relentless power. And perhaps there also was a measure of intuition as well, recognizing water as essential in the creation of life.

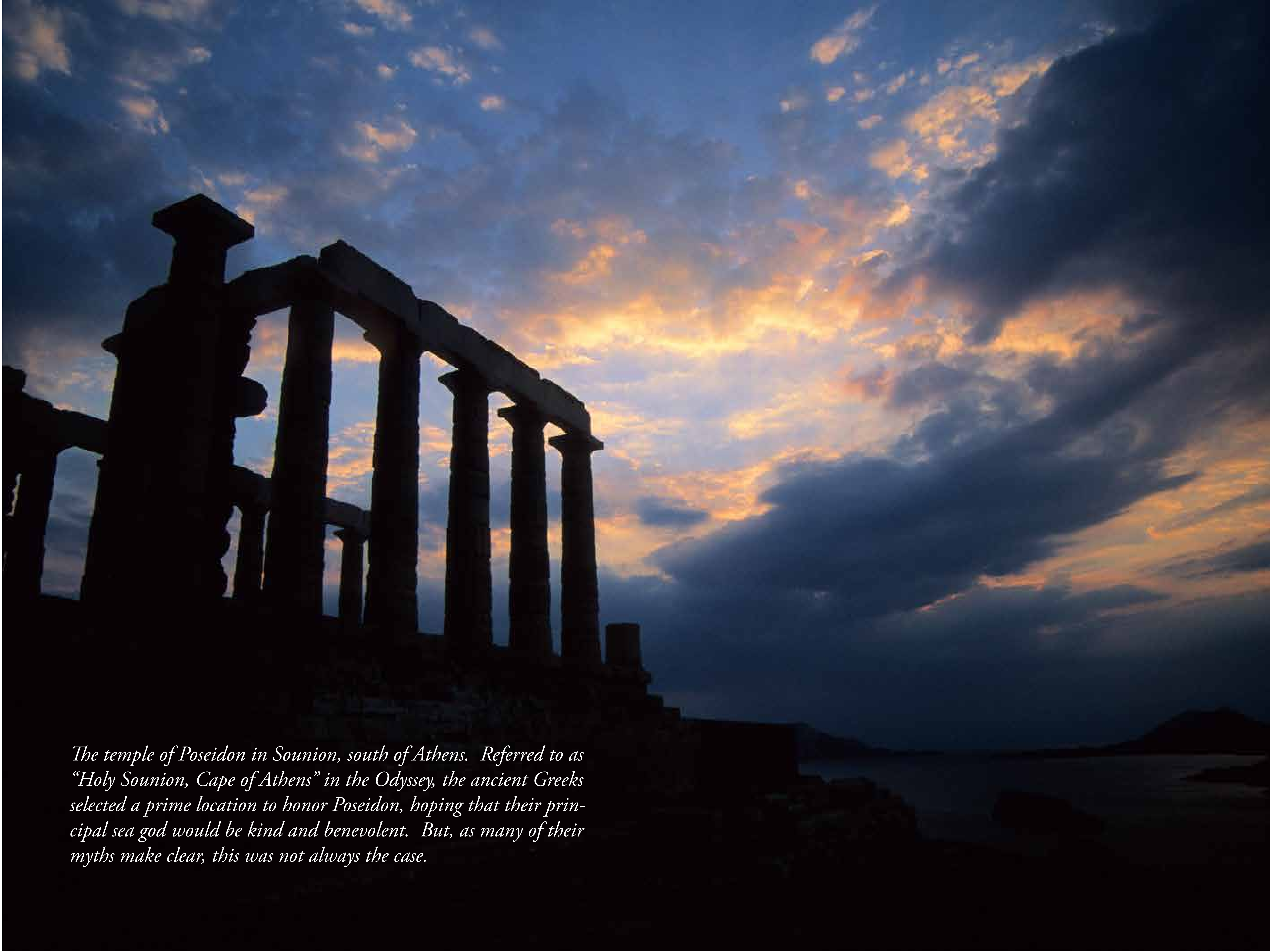
We do not know why our various ancestors came to that conclusion. But we do know one thing. Whatever the explanation, that intuition foreshadowed the conclusions reached by modern science thousands of years later.

It comes as no surprise that the ancient Greeks also speculated about the origin of things. But they held widely diverging views. The poet Hesiod, for instance, said that earth was the principal component of the universe, while Cretan philosopher Epimenides thought it was air. Thales of Miletus, on the other hand, believed it was water, while Hieronymus of Rhodes and historian Hellanicus countered in favor of water and earth. Others believed the universe had begun with a spiritual principle like Zeus, or perhaps an abstract element, like Time or Chaos.

There also was a theory which combined all of these elements. According to Homer, its author, the ocean was the origin of all things. He called it Oceanus and described it as an enormous river which circled the earth. But Oceanus could be seen as the origin of things in more than a strictly material sense, he suggested. It could be considered a spiritual principle, personifying all gods, or an abstract element, representing the primordial chaos.

Homer is of course much better known for his writing than for his thoughts on the creation. Traditionally assumed to be the author of the *Iliad* and the *Odyssey*, he is universally regarded as one of the founders of western literature. The *Iliad* describes the mighty deeds of the warriors who fought at the siege of Troy around 1200 B.C. Following the fall of the city, the surviving Greek heroes returned home but for one of them – Odysseus, King of Ithaca – it became a particularly long and dangerous voyage. His account is recited in the *Odyssey*, the first sea story ever written.

The *Odyssey* can be followed on the map for a while, but before long it passes into an expanse of strange events and monstrous creatures, many of which seem to have symbolized particular ocean hazards. A giant whirlpool, for instance, is characterized by the monster Charybdis. A surf-beaten cliff becomes treacherous Scylla. And there are others: Polyphemos, the one-eyed Cyclops, who devours Odysseus' companions; Circe, a sorceress who changes his men into swine; the seductive Sirens who lure sailors onto rocky shores; and the nymph Calypso, who hides the wandering hero for eight years. To further complicate matters these episodes are usually preceded by a violent storm, un-



*The temple of Poseidon in Sounion, south of Athens. Referred to as "Holy Sounion, Cape of Athens" in the Odyssey, the ancient Greeks selected a prime location to honor Poseidon, hoping that their principal sea god would be kind and benevolent. But, as many of their myths make clear, this was not always the case.*

*Odysseus' ship passing the Sirens, as depicted on a red-figured vase, now in the British Museum. Pottery is not the best medium to show ships and the sea, but this vase demonstrates that Greek artists managed to do so in a very original manner.*

leashed by Poseidon, the supreme god of the sea. In much of the *Odyssey* Poseidon plays a malignant role – an expression perhaps of a level of distrust of the sea.

There probably isn't much of a historical base to the *Odyssey*. If anything, there might have been an Ithacan king named Odysseus who, upon his return from the Trojan War, killed his wife's suitors. But Homer's version of the ten years it took him to get to that point derives largely from folklore and imagination. In fact, most of the story is much older than Homer or even Odysseus, dating back to the time when people first began making sea voyages. Those lucky enough to survive storms and other mishaps gave imaginative interpretations to their encounters, which worked themselves up over the years. Homer, in other words, was not necessarily relying on factual information when he wove these stories into the *Odyssey*. But his rendition is significant in that it reflects how the ancient Greeks felt about the sea. And if the *Odyssey* provides any indication, it is clear they were often frightened by it.

A similar perspective is found in another Greek epic – the legend of Jason and the Golden Fleece. As in the *Odyssey*, it is difficult to distinguish fact from fancy in Jason's search, in no small part because the story was told and retold for a thousand years before it was ever written down. But at its heart is an actual voyage of discovery; the first, in fact, ever recorded. It is now generally believed that the *Argo*, Jason's ship, sailed east, from Iolcus in northern Greece into the Black Sea, possibly not long after Odysseus' travels.

No one is quite certain what this elusive Golden Fleece represented. According to the ancient Greeks it was the golden skin of the horned ram Chrysomallus, which had been dispatched by a nymph to save her children. Greek heroes tended to like that sort of mission, but the real Jason probably had something more tangible in mind. Some feel he was looking for gold, which could be collected from rivers by tying fleeces into the water; others assume the Golden Fleece symbolized the golden grain of the Crimea, or even rain – often in short supply in parts of Greece. Whatever the explanation, legend holds that Jason brought the fleece to Greece, thereby opening the Black Sea to Greek trade and colonization.

Unfortunately this achievement was not rewarded with a happy end. Jason returned not only with the Golden Fleece, but also with Medea, his wife. At first they lived happily together, but when Jason fell in love with a younger woman, Medea put a curse on him, causing him to lose everything: his wife, his family and even his reputation. For several years he roamed unhappily about. In the end, he returned to Iolcus and decided to see the *Argo*, the symbol of his great days of exploration. Pulled onto a beach, the ship was in bad shape but Jason was glad to see her, caressing the hull with his hand. Then, the story goes, he rested. No sooner did he lie down or the ship's bow broke from the rotten frame, crushing him to death.

In spite of tragic endings, the adventures of Odysseus and Jason were very popular. People wanted to see these exciting adventures visualized and Greek artists responded, depicting some of the perils faced by both heroes with startling originality. Odysseus' escape from the lure of the Sirens, for instance, is shown on a red figured vase, painted some time during the fifth century B.C. True to Homer's description, the hero is bound to the mast while his companions strain at the oars, their ears plugged with wax. Though a vase surface doesn't allow for expansive renderings, the twisted shape of the rocks and the strange creatures aloft convey the supernatural element so strongly woven into the *Odyssey*.

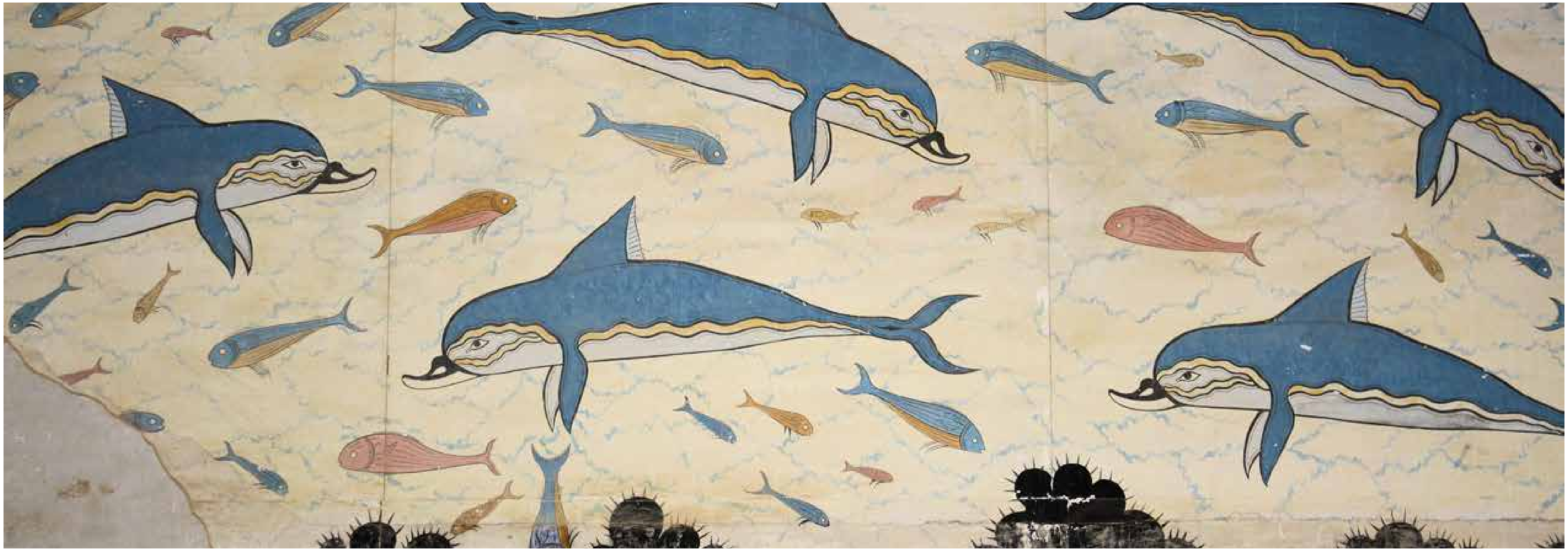
Greek artists also used other myths to visualize the magic and mystery of the sea. Their work often personified it as Poseidon or his consorts, who represent the restlessness of water and its desire to engulf the land and its inhabitants. In doing so, they expressed their feelings toward the sea. And their work, like Homer's, reflects fascination, but also a certain apprehension of the expanse of the Mediterranean.

The ancient Greeks, in short, left us an elaborate ocean-inspired record. Writers and poets recounted great sea epics and legends, artists visualized scenes from literature as well as daily life and scientists like Aristotle began to extend their search for order and certainty to the shore. Though different in their approach, all sought a fundamental truth about the sea. And in doing so, they left us a vivid record of how they felt about it.

There were other great seafaring peoples in the ancient Mediterranean, but we do not know a great deal about their maritime inclinations. The Minoans of Crete, quite possibly the first great mariners of the Mediterranean, liked to engrave pictures of ships and fish on seals but the drawings are naturally small and sketchy. Still, some of the compositions are quite original, showing dolphins frolicking off the bow of a ship or sailors fighting a sea monster.

North of Crete, on the island of Santorini, some splendid murals were discovered in the excavated city of Akrotiri, among them one with an entire fleet. They date from Minoan times, but whether this is Minoan rather than Aegean art has not been settled. Written documents do not add a great deal of information either for the simple reason that the Minoans' original script has never been deciphered. In later years a readable script emerged, but by that time the Minoans' heyday had long passed. In fact, much of their civilization was destroyed sometime after 1500 B.C. by a spectacular volcanic eruption on Santorini, and subsequent invasions from the Greek mainland. The disappearance of this great maritime power was so sudden that it may even have given rise to the legend of Atlantis.

Phoenicia, another great maritime power, left poor records for a different reason: its merchants were far more interested in



*A detail of the (restored) dolphin fresco, from the palace of Knossos near Heraklion, Crete. Some of the Minoans' artwork seems to indicate they enjoyed the sea and the creatures that live in it. Unfortunately, little is left, most of their art having been destroyed during the calamity that befell them around 1500BC.*

making profits than in chronicling their maritime exploits. But their lack of interest in art and literature had sensible commercial roots. The Phoenicians simply reasoned that the less their competitors knew, the less likely they would make inroads on their trade routes. Phoenician traders even spread lies to discourage them, claiming that the area beyond the Pillars of Hercules, beyond what we know as the Strait of Gibraltar, was inhabited by dreadful monsters. If this was intended to discourage others it worked, because their ships maintained control over the profitable sea trade with these regions for many years.

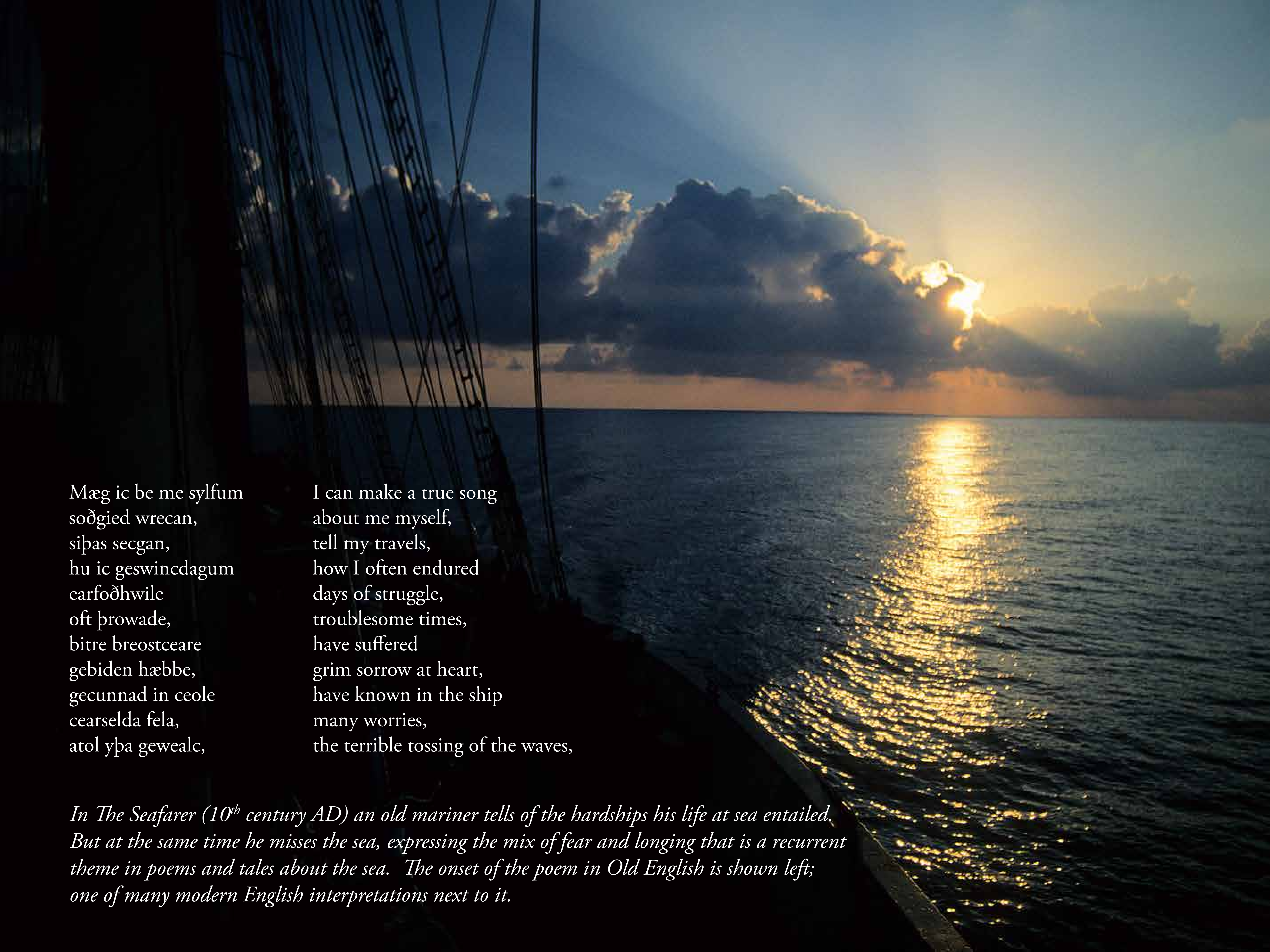
Much more is known about Rome's feelings toward the sea, but the record is not very maritime minded either. For much of their history the Romans were farmers and foot soldiers; landlubbers, in short, who did not particularly care for the sea. When they went to sea, they did so out of necessity, to defend or expand the Empire. They eventually became very good at it but even then, Rome remained a land power first and foremost.

This terrestrial orientation is reflected in its artistic record. Ships and the sea turn up as motifs in Roman art, but not very frequently and not always with the originality displayed in Greek art. Roman literature also gives few accounts of the sea. There is no equivalent of the *Odyssey*, though the story did inspire Roman artists, who sometimes depicted Odyssean scenes to adorn the villas of wealthy citizens.

Some Roman scholars wrote about the sea from a scientific perspective. Caius Plinius Secundus, better known as Pliny the Elder, wrote elaborately about the wonders of the sea in his *Natural History*, explaining, or rather trying to explain anything from the sea's saltiness to the effects of the sun and the moon on marine life. Naturally most of it was incomplete, though not according to its author. Pliny described 176 sea animals, for instance, and concluded that was the extent of life in the sea. "And yet, by Hercules!" he exclaimed, "in the sea and the ocean, vast as it is, there exists nothing that is unknown to us. It is with those things that Nature has concealed in the deep that we are best acquainted".

As conclusions go this one was a bit premature, but stretching the facts never bothered Pliny. Even so, his work reflects that there was an interest in the sea, though the Romans, as a nation, never expressed any great affection for it.

During the Middle Ages, people's interest in the sea rapidly waned. These were the so-called Dark Ages – a time of turmoil, strife and great hardship throughout much of Europe. Although the sea undoubtedly continued to play an important role in trade and as a source of food, it hardly figured in art and literature. Among Chaucer's Canterbury pilgrims is a Shipman, or sailor, *Hardy*, and *wise in all things undertaken, by many a tempest had his beard been shaken*. A capable sailor, in other words, but it doesn't tell us much about how people felt about their watery surroundings. More insight can be gained from *The Seafarer*, a powerful



Mæg ic be me sylfum
soðgied wrecan,
siþas secgan,
hu ic geswincdagum
earfoðhwile
oft þrowade,
bitre breostceare
gebiden hæbbe,
gecunnad in ceole
cearselda fela,
atol yþa gewealc,

I can make a true song
about me myself,
tell my travels,
how I often endured
days of struggle,
troublesome times,
have suffered
grim sorrow at heart,
have known in the ship
many worries,
the terrible tossing of the waves,

*In The Seafarer (10th century AD) an old mariner tells of the hardships his life at sea entailed. But at the same time he misses the sea, expressing the mix of fear and longing that is a recurrent theme in poems and tales about the sea. The onset of the poem in Old English is shown left; one of many modern English interpretations next to it.*

poem or song about a man's travels at sea, written or copied in the early 10th century. Unfortunately, modern translators don't quite agree on its meaning. Does the anonymous narrator like the sea, as some contend, or is he thoroughly frightened by it? It is difficult to say, though the frequent mention of shipwrecks, floods and other sea-related calamities might infer a realistic rather than romantic mood.

The sea also plays a prominent role in northern European epic poems like the Finnish *Kalevela* and the tales left by Viking explorers. The latter in particular are honest accounts, which speak of unimaginable hardships encountered on icy northern seas. Given the brutal conditions they describe, it is tempting to look for secondary meanings. But to the people that experienced these tales and then told and retold them for hundreds of years, the sea probably was exactly that – cold, dangerous and very cruel. Notions of the sea as the realm of the romantic sublime didn't quite exist at that time. People were far more concerned with day-to-day survival.

At times the sea was portrayed in the visual arts of that time as well. Religious art flourished, for instance, and wherever the sea played a role in biblical themes like the Creation or the Flood, it was included. But the monastic painters of the early Middle Age had no more than a rudimentary notion of the sea. In fact, removed as they were from the material world, many probably had never even seen it in person. Their works thus picture the sea somewhat naively in perspective and proportion, almost as if a child had drawn it. They are often great works in their own right, beautifully composed and richly colored, but few of them would qualify as a realistic rendering of the sea.

Ships and the sea also appeared in pictures of contemporary events like William of Normandy's crossing of the English Channel, meticulously portrayed in the Bayeux tapestry. Woven in England during the late 11th century, the tapestry vividly shows the events that led to the conquest of England, albeit with a Norman bias to justify William's claim to the English throne. The naval scenes include Harold's trip to Normandy, the building of the invasion fleet, and William's arrival on English soil, before the Battle of Hastings. The ships with dragon-head prows and their crews are shown in great detail, but the sea itself is portrayed by simple curving lines, gently lapping against the bows of the crossing vessels. As a composition, it is an outstanding work of art. But a realistic portrayal of the sea it clearly is not.

The expansion of seaborne trade during the late Middle Ages revived interest in the sea, and this evolution is reflected in the art of that time. Manuscript illustrations, no longer restricted by religious themes and conventions, began to include everyday activities. Ships and the sea were portrayed with a new richness in color and decorative effect, providing remarkable insight into the maritime doings of that time.

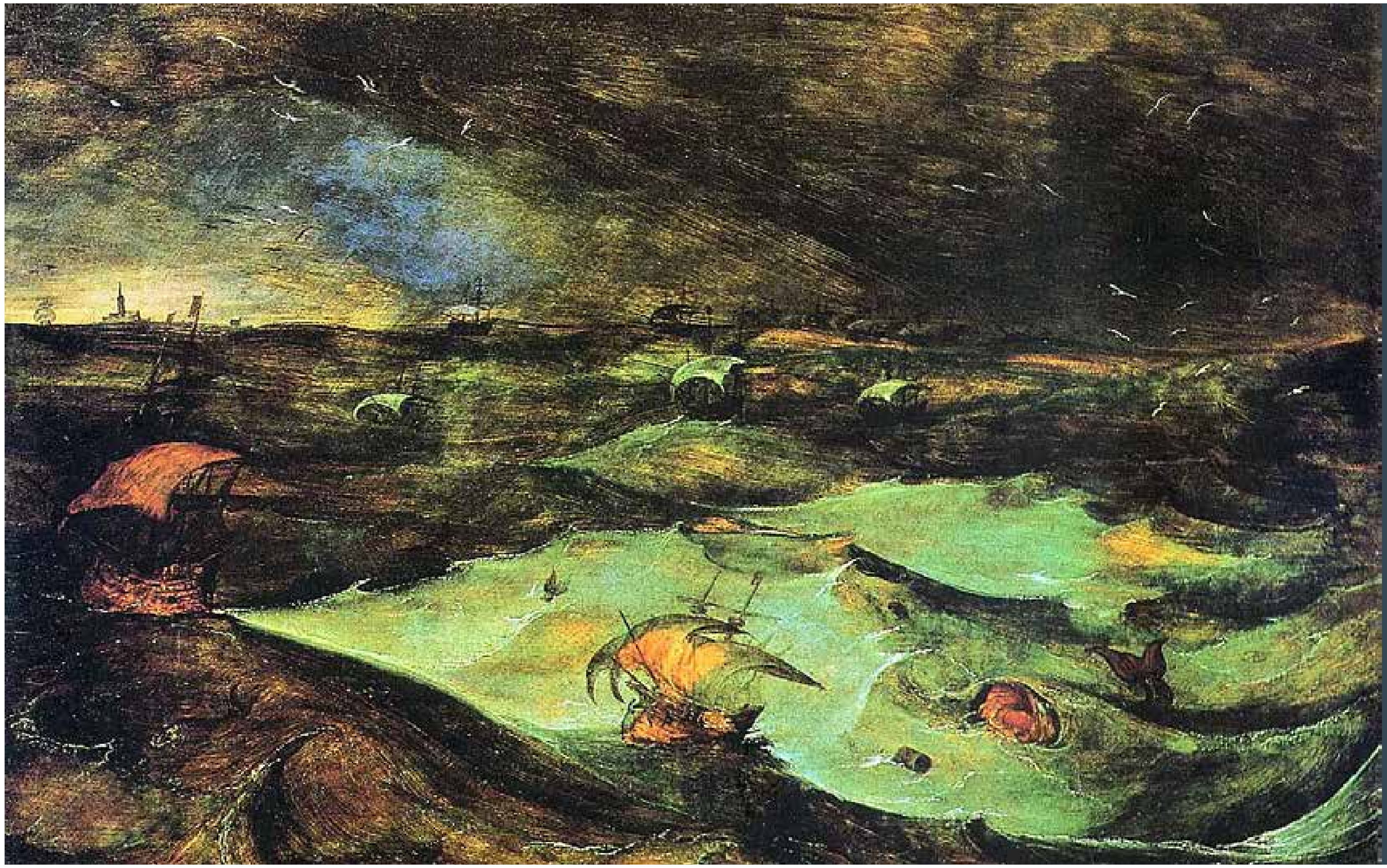
Early in the fifteenth century western sailors began to venture further at sea, despite the common belief that the waters at the edge of the earth harbored all kinds of unpleasant things. Not surprisingly, Saint Nicholas, patron saint of sailors, was often called upon to aid ships in peril. In some


*Nearly 70 m (230 feet) long and 50 cm (20 in.) high, the Bayeux tapestry shows the events leading to and including the Norman conquest of England in 1066. Several of its 50 scenes show the invasion fleet, from its construction to the crossing of the Channel. As in most medieval art, the sea is portrayed somewhat naively, with simple curving lines.*

instances the surviving crews were so grateful for his intervention that they commissioned a painting to commemorate whatever calamity befell them. Intended to be placed near a small altar devoted to the saint, these works weren't necessarily painted by great artists but they are interesting in that they start showing the sea as an element in its own right rather than the stylized setting depicted by earlier artists.

In subsequent years depictions of ships and the sea became increasingly realistic, in paintings with religious themes just as much as in those showing contemporary events. Some of the works of Pieter Brueghel the Elder stand out in this respect. Brueghel obviously enjoyed drawing ships and Antwerp, where he lived for many years, provided a wonderful source of inspiration. His ships are generally drawn or painted perfectly,

*Brueghel's Fall of Icarus, on display in Brussels' Museum of Fine Arts, reveals him as an accomplished painter of ships. Together with some of his Flemish colleagues, he also started painting a far more realistic sea, glimmering and gentle in this painting and …*



*… chaotic and turbulent in Storm at Sea, which can be seen in Vienna's Kunsthistorisches Museum. But the sea shown here plays more of a symbolic role, a representation perhaps of the difficult times his home region endured.*

as can be seen in his *Landscape with the Fall of Icarus*, on display in the Brussels Museum of Fine Arts. Prominently figured on the right side of the composition is an imposing 16th century cargo vessel, with bulging sails, heading into the sunset. The sea too is beautifully rendered, with gently lapping waves right near the spot where Icarus disappears under the surface.

Brueghel painted very different conditions in his *Storm at Sea,* completed in 1568 and now on display in Vienna. The raging sky, the surge of the waters and the dramatic light portray a frightening storm on the North Sea. It is not necessarily a realistic rendering of the tempest because such conditions would force ships to carry less sail. Much the same way, the open-mouthed whale would have stayed far below, in calmer waters. But it doesn't quite matter here. As much of Brueghel's work, the painting carried a moral undertone, with the tiny ships symbolizing man's fragility and the entire scene reflecting the turbulent times during which it was painted. From a technical perspective, *Storm at Sea* demonstrates that artists had acquired the desire and ability to paint the sea in all its moods. Technically and symbolically Brueghel's final seascape was a harbinger of the great marine art that was yet to come.

Brueghel died one year later, in 1569. By that time, many new lands and ocean passages had been "discovered", and a few ships had even sailed around the world. Portugal and Spain, in their quest for new trade routes to the East, pioneered this oceanic expansion, ushering in the Modern Period. But neither showed much interest in producing an artistic record of these exploits.

The Portuguese sent scientists and observers on some of their voyages, but none produced a literary record until Luís de Camões wove his experience on a trip to India into *The Lusiads*, a lyrical account of Portugal's maritime exploits which later developed into the country's national epic. With Portuguese ships venturing all over eastern seas, there were many other interesting voyage accounts, but none of those qualify as sea stories. They are chronicles, detailing what happened during the trip and what was to be found along the way. In virtually all of them the sea plays a secondary role. If storms wreak havoc and ships disappear, this is reported matter-of-factly, almost as if par for the course. Some of the writers express fear when confronted with a ferocious storm, but none seem particularly interested in waxing lyrically about these events or their significance.

By the end of the sixteenth century, Iberia's maritime glory began to wane. Portugal still maintained an extensive trading network, but was beginning to lose its grip on the eastern trade to Holland and England. Spain, meanwhile, continued to systematically plunder the great empires of Central and South America, but experienced a series of devastating naval losses closer to home. Only half of its mighty Armada, sent to the conquest of England in 1588, limped back to port. And time after time Spanish squadrons were beaten by ships from the rebellious Dutch provinces further north. Though still a formidable power, the country – like its Armada – no longer appeared invincible.

In Holland there was pride over these victories, compelling a number of artists to paint pictures of them. One of the most successful was Hendrik Corneliusz Vroom (1566–1640), who specialized in depictions of important naval

*The Arrival of Fredrick V in Flushing, by Hendrik Cornelisz Vroom (Frans Hals Museum, Haarlem). Vroom, often considered the father of Dutch marine painting, specialized in large canvasses showing important naval events. Meticulously detailed ships are invariably the main focus in his work, reflecting Dutch pride in the young nation's maritime achievements.*

events. Vroom's work wasn't necessarily objective, with the Dutch fleet usually shown far more dominant than it actually was, but that is what his clients wanted to see. With patriotic pieces in high demand, Vroom was never short of work. Unlike many of his colleagues, he retired a rich man.

Vroom's paintings were more concerned with ships, portrayed in meticulous detail, than with the sea itself. There was a good reason for this. The Dutch were proud of the ships that not only secured their independence, but had also become the means to expanding trade and wealth. As a result paintings with ships and shipping scenes became increasingly popular, providing a livelihood for many Dutch and Flemish painters. By the mid-seventeenth century there were enough of them to speak of a specialized school of marine painting.

During the short period of peace that followed Holland's independence in 1648, the sea itself began to play a larger role in the work of Dutch marine painters. There were fewer battles to record at this time and the attention of painters shifted toward typical every day scenes. Sea and sky were given their own pictorial value while ships became incidental features, much like a cottage might be shown in a rural scene. Painters like Vroom's pupil Jan Porcellis, Simon de Vlieger, Jan van de Cappelle, Jan van Goyen and Jacob van Ruysdael, amongst many others, demonstrated that an attractive seascape did not require an imposing subject matter. All produced splendid paintings, leaving a wonderful record of the maritime doings on which the Dutch built so much of their strength.

The renewal of war in the second half of the seventeenth century, this time with England, brought about a revival of the marine battle picture. Willem Van De Velde the Elder and his namesake and son proceeded to perfect it.

The son of a merchant mariner, the elder Van de Velde often traveled along the coast to draw the Dutch fleet in various locations; a practice that established his reputation as a superb ship's draftsman. But Van de Velde would become known foremost as a war artist. When war between Holland and England broke out in 1652, the Dutch States General employed him to record the engagements. In this capacity Van de Velde often accompanied the fleet in a smaller ship, which sailed around the action so that he could sketch it. One of the resulting works shows him on deck with a book on his lap, making sketches of the devastation unfolding before him.

More concerned with the accuracy of his work than with atmosphere, Van de Velde preferred to complete his work in pen on a prepared white ground – a technique known as the grisaille or pen picture. Grisailles were well suited for fine detail, and Van de Velde excelled at them, including astonishing amounts of information in his scenes. He taught the technique to his oldest son, but Willem van de Velde the Younger was more interested in expressing mood and atmosphere. That called for oils, not pens, and he quickly built a reputation as an outstanding marine painter.

*A view of an Estuary by Jan Van Goyen. Once the Dutch had gained their independence, their marine painters switched from large patriotic themes to smaller seascapes in which sea and sky took on a far more prominent role.*

*A Ship at Sea caught by a Squall, now at the Rijksmuseum in Amsterdam, is one of Willem van de Velde the Younger's finest works. It shows a British warship in trouble after a sudden gust has broken her mainmast. And it shows so much more…*

Father and son worked together in Amsterdam until the early 1670s, when Charles II invited them to come to England and record the other side's naval achievements. They accepted the invitation, which may seem somewhat unpatriotic in hindsight, but they had no choice. Holland had been invaded by French troops and its coast was blockaded by the English fleet. There was little, if any, interest in art at the time, causing many artists to seek work elsewhere.

Though neither of them spoke English, the two Van de Veldes appear to have enjoyed their new surroundings. Given a studio in Greenwich and a handsome salary, they now devoted themselves to recording English, rather than Dutch, naval victories. When the hostilities finally ended in 1674, their work shifted to peaceful maritime events, such as the arrival of state yachts or ships battling storms. It led to some of their most brilliant works.

The Van de Veldes stayed in England for thirty years, exerting a presence that greatly influenced marine painting there. In fact, it did much to popularize the genre, creating a growing market for shipping pictures and stimulating many a painter to specialize in seascapes. Peter Monamy, who often copied Van de Velde paintings, became one of England's first and finest marine painters. He and his colleagues held closely to the Dutch example until the eighteenth century, when painters like Charles Brooking and Samuel Scott developed a specifically English style. But Brooking and his contemporaries, and even great romantic painters like Turner, would often turn to the Van de Veldes' work. They indeed achieved a quality of technique and composition that would set the standard for a long time to come.

Across the Atlantic, eighteenth century America also had a strong interest in the sea. America began as a sea nation: its settlers had crossed the Atlantic to get to their new land, and for most life was intrinsically linked to the sea. It connected their colonies to the rest of the world and provided people in the north with an abundant supply of food, without which many would have perished. Moreover, during the years of strife with England, the sea provided protection. Without this barrier, it would have taken the country a good deal longer to obtain its independence.

The young nation clung fiercely to the coast. Virtually all of its cities were busy seaports, eagerly looking across the sea for prosperity in trade. American merchant vessels were among the finest and swiftest in the world. New Englanders also operated the largest whaling fleet in the world, with hundreds of vessels scouring the Antarctic and South Seas to bring home the oil that lighted almost all the lamps in the country.

American art of this period reflects this involvement with the sea. At first, the paintings recorded life in colonial America, showing a port or the portrait of a trader, with some ships in the background. But with the growth of the country's maritime influence, marine painting became more sophisticated. It featured great romantic seascapes in the works of Benjamin West or John Singleton Copley, or shipping and coastal scenes influenced by the British school, painted by artists like Robert Salmon and Thomas Chambers. A generation later this legacy would be continued by painters like Washington Allston, James Hamilton, Thomas Eakins and, probably the greatest American marine artist of all – Winslow Homer.


*Breezing up by Winslow Homer, now at the National Gallery of Art in Washington, D.C., shows a man and three boys along with their catch heading back to port. Homer himself called the painting "A Fair Wind", and a fair wind it is indeed, with all aboard enjoying the ride. Many of Homer's paintings, in contrast, depict a sea that is far less benevolent.*

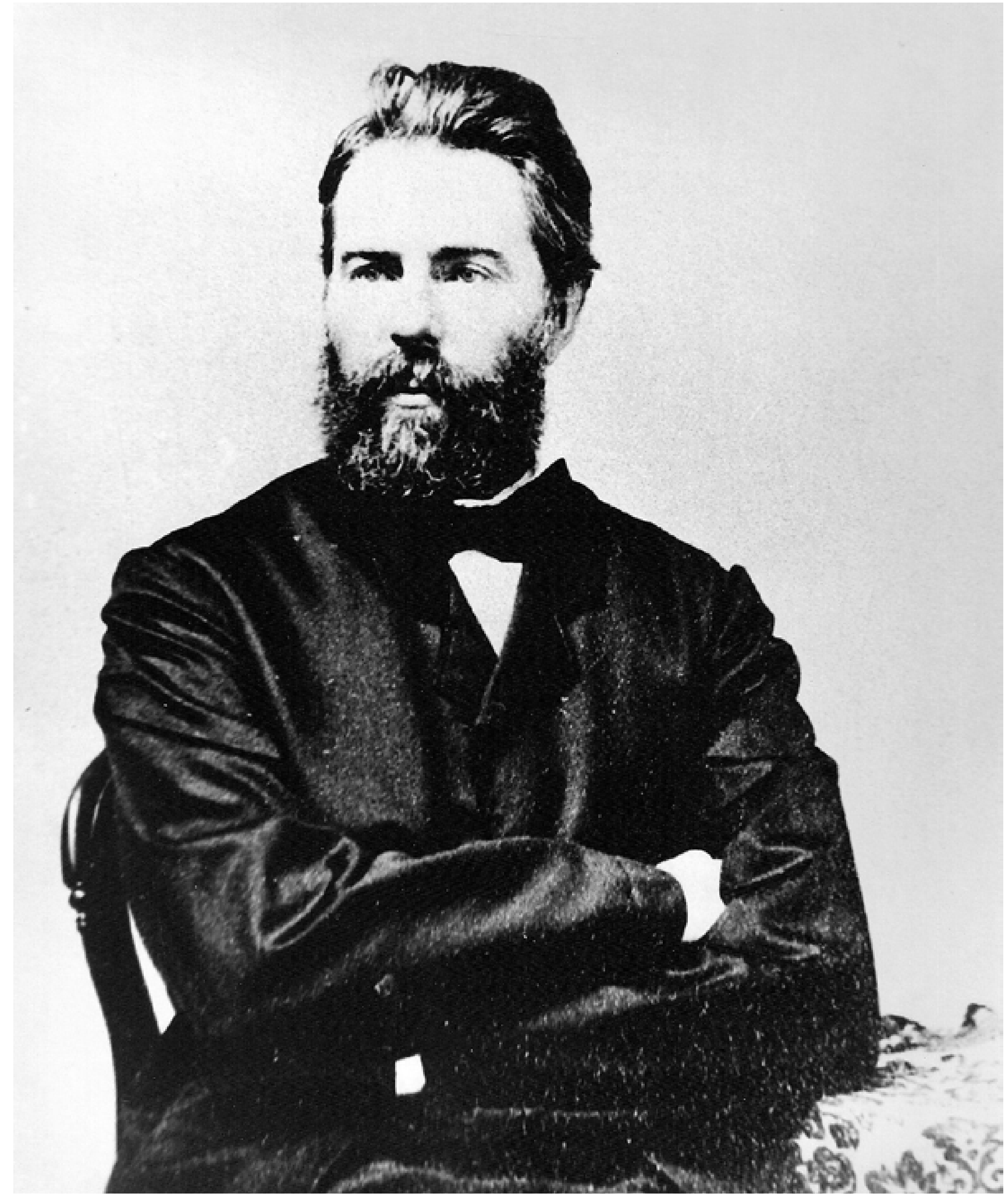
American painters produced a splendid record of the country's dependence on the sea, but there were other ways to express this relationship. Before Americans turned west, where new opportunities took up their energies, they often went to sea, shipping out on merchant and whaling ships, or joining the country's newly formed navy. Some of them later wrote about that experience, creating a new literary genre of sorts.

The first sailor-writer to do so was James Fenimore Cooper, who served as a midhipman in the American Navy. Although Cooper would become best known for stories about life in the forest and the prairie, his recollections of life aboard played an important role in his early work. *The Pilot*, for instance, is set off the English coast during the American Revolution. Cooper's view from the quarterdeck was a romanticized version of life at sea, but his descriptions of the sea's various conditions were very astute and realistic, giving people who had never been there a good feel for the sea's power during a storm and its hypnotic appeal during the calm that followed. First published in 1823, the book became quite popular, appreciated not only by the general public but also by writers who would later write powerful sea stories of their own.

In 1836 Richard Henry Dana, a young lawyer from Boston also set sail, in his case aboard the brig *Pilgrim*, bound for California via Cape Horn. Unlike Cooper, Dana shipped before the mast, as a member of the crew. Coming straight out of Harvard, he must have seemed a bit out of place there, but young Dana did not mind. He wanted to know what life was like as a common sailor.

Dana published his diary of the journey in 1840. Entitled *Two Years before the Mast*, it became a bestseller. Like any good sea story, it combined elements of heroism, adventure and the conflict of personalities aboard the *Pilgrim*, but it did more than that. *Two Years before the Mast* provided the first realistic glimpse of life at sea. It turned out to be an eye-opener, because few people were aware of the sometimes barbaric ways in which ordinary sailors were treated. Fortunately Dana's account went some way in helping to improve these conditions in subsequent years.

One year later a young, restless New Yorker followed in Dana's footsteps. Just 21, Herman Melville, shipped aboard the whaler *Acushnet*, on her maiden voyage from Fairhaven, Massachusetts to the whaling grounds of the Pacific. A year and a half later, the ship reached the Marquesas Islands where he deserted. After spending a month among the "cannibals" of Nukahiva, Melville escaped on the Australian whaler *Lucy Ann*, which took him to Tahiti. There he refused duty along with several of his shipmates, was imprisoned by the British consul, but again managed to escape. Following a brief stay on the nearby island of Moorea, the young sailor joined the Nantucket whaler *Charles and Henry*, from which he was discharged in April of 1843. Six months later, he signed on as an ordinary sailor aboard the Navy frigate *United States*, bound for the East Coast. It wasn't until late 1844 that the vessel reached Boston. Melville discharged to rejoin his family. He had been away for nearly four years.



*Herman Melville, c. 1861, some ten years after the publication of Moby Dick. Melville never experienced the critical acclaim his masterpiece continues to receive up to this day.*

Back home, the young sailor turned writer. His adventures in the South Pacific were detailed in *Typee* and *Omoo*, two books which won him instant acclaim. Launched as a popular author, he described an earlier trip aboard a merchant ship to England in *Redburn*, and his experience with the Navy in *White-Jacket*. Now only his service aboard whalers remained, and out of these memories grew his most ambitious venture yet.

Initially Melville set out to write a romantic comedy but the themes continued to shift and haunt him, and the tale took on tragic proportions. What was planned as an authentic description of the search for a white whale became the story of an amazing voyage through space and time instead, led by the obsessed Captain Ahab. Melville completed *Moby Dick* in 1851, but its reception was a disappointment. Reviewers thought the book long and tedious and ignored it. Melville tried his hand at some other works and even some poetry, but none attracted much notice. In 1891, forty years after the publication of *Moby Dick*, he died, almost entirely forgotten.

History treated Melville more kindly. By the 1920s Moby Dick was considered a masterpiece. Hidden beneath its descriptions of whaling facts and fiction, reviewers uncovered a powerful mix of fate and symbolism. Melville had made clear what to expect, however. *It is of the horrible texture of a fabric that should be woven of ships' cables and hawsers* he wrote to fellow author Nathaniel Hawthorne, to whom he dedicated the book. *A Polar wind blows through it, & birds of prey hover over it…*

Since then critics have filled hundreds of volumes analyzing *Moby Dick*, often disagreeing about the ultimate meaning of the novel. Some say it is an expression of the classic struggle between good and evil, others see an allegory of man's place in the cosmic order, or his search for knowledge and meaning. But *Moby Dick* does more than that. This not only is a story about a whale and the people that chase it, but about the sea itself. In fact, much of the first chapter is devoted to its meaning and significance, with Melville's Ishmael commenting on our fascination with the sea. Go to New York City, he says, on a dreamy Sabbath afternoon and you will see thousands of people, *posted like silent sentinels fixed in ocean reveries. Here come more crowds, pacing straight for the water. Strange! Nothing will content them but the extremest limit of the land. They must go just as nigh the water as they possibly can without falling in.*

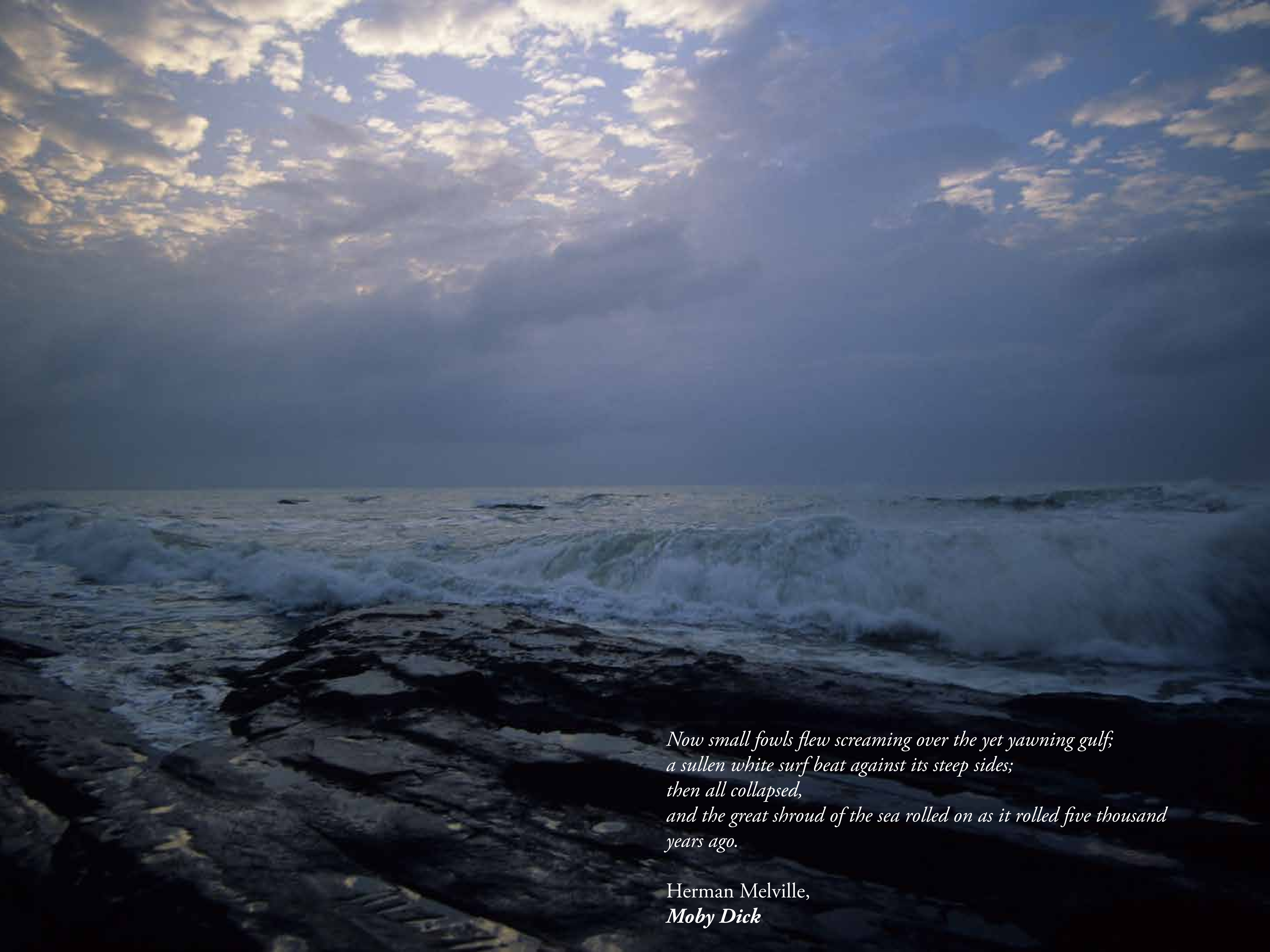
What compels people to do this? What is this fascination with the sea? *Why is almost every robust healthy boy with a robust healthy soul in him at some time or other crazy to go to sea? Why upon your first voyage as a passenger did you feel such a mystical vibration, when first told that you and your ship were out of sight of land? … Surely all this is not without meaning?*

Ishmael, or rather Melville, answers these questions. Like Narcissus, he suggests, we see ourselves reflected in all rivers and oceans. *It is the image of the ungraspable phantom of life; and this is the key to it all.* These aren't simple words; they may even sound far-fetched or meaningless. And yet, they represent a recurring theme, as fresh, strong and prevalent in *Moby Dick* as it was in creation myths compiled thousands of years earlier.

In the end, Ahab goes down with his ship but it wouldn't take him long to resurface, given new names and new ships by writers like Jack London, Joseph Conrad and Rudyard Kipling. One of his most popular reincarnations is the mysterious Captain Nemo, who travels not on, but rather below the ocean surface in one of the most popular sea stories of all time: Jules Verne's *Twenty Thousand Leagues under the Sea*.

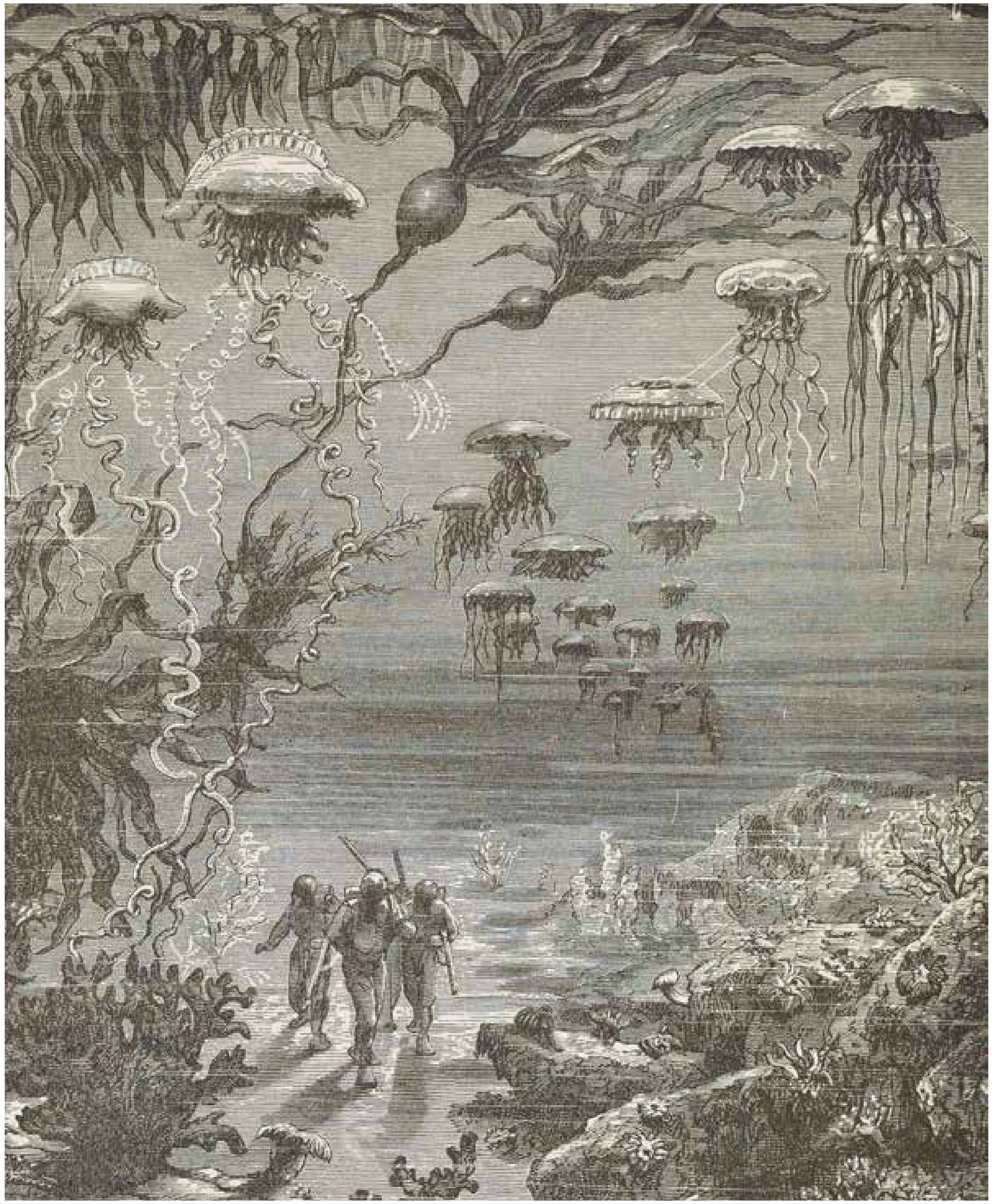
Like Melville, Verne was bitten by the sea bug at a tender age. Growing up on the Île de Feydeau near Nantes, he was literally surrounded by the lure of the sea. Fishermen brought in their catch and dried their nets; ships from exotic places tied up nearby; their crews came ashore, mesmerizing him with tales of peril and adventure. One summer day in 1839, eleven-year old Jules snuck out of the house, walked to a sailor's inn, and was rowed to the *Coralie*, a bark about to take off for the West Indies. But his father discovered the plan, and managed to overtake the ship before it reached the open sea. Young Jules was accordingly dragged home where his attention was distracted from adventures at sea to more immediate concerns, like finding ways to sit comfortably on a few sore spots.

Father Verne practiced admiralty law and decided his oldest son would go to law school, but Jules had other plans.



*Now small fowls flew screaming over the yet yawning gulf;*
*a sullen white surf beat against its steep sides;*
*then all collapsed,*
*and the great shroud of the sea rolled on as it rolled five thousand years ago.*

Herman Melville,
***Moby Dick***



*Twenty Thousand Leagues under the Sea quickly became one of Verne's most popular books. The superb illustrations by Alphonse de Neuville and Édouard Riou in no small part added to its appeal.*

While in Paris studying law, he became involved in literary circles and decided to become a writer. His career was slow in taking off but after some time Verne hit on a formula that was particularly well suited to his interests. Combining scientific innovation and geographical exploration in a fictional setting, it allowed him to explore the future and predict developments his audience might yet experience. Written during a time when science and technology were still regarded as a guarantee of humanity's fulfillment on earth, Verne's stories quickly found an audience. They also turned out to be quite accurate. By the time his 65 books had been published, Verne had foreseen just about every major development of the twentieth century.

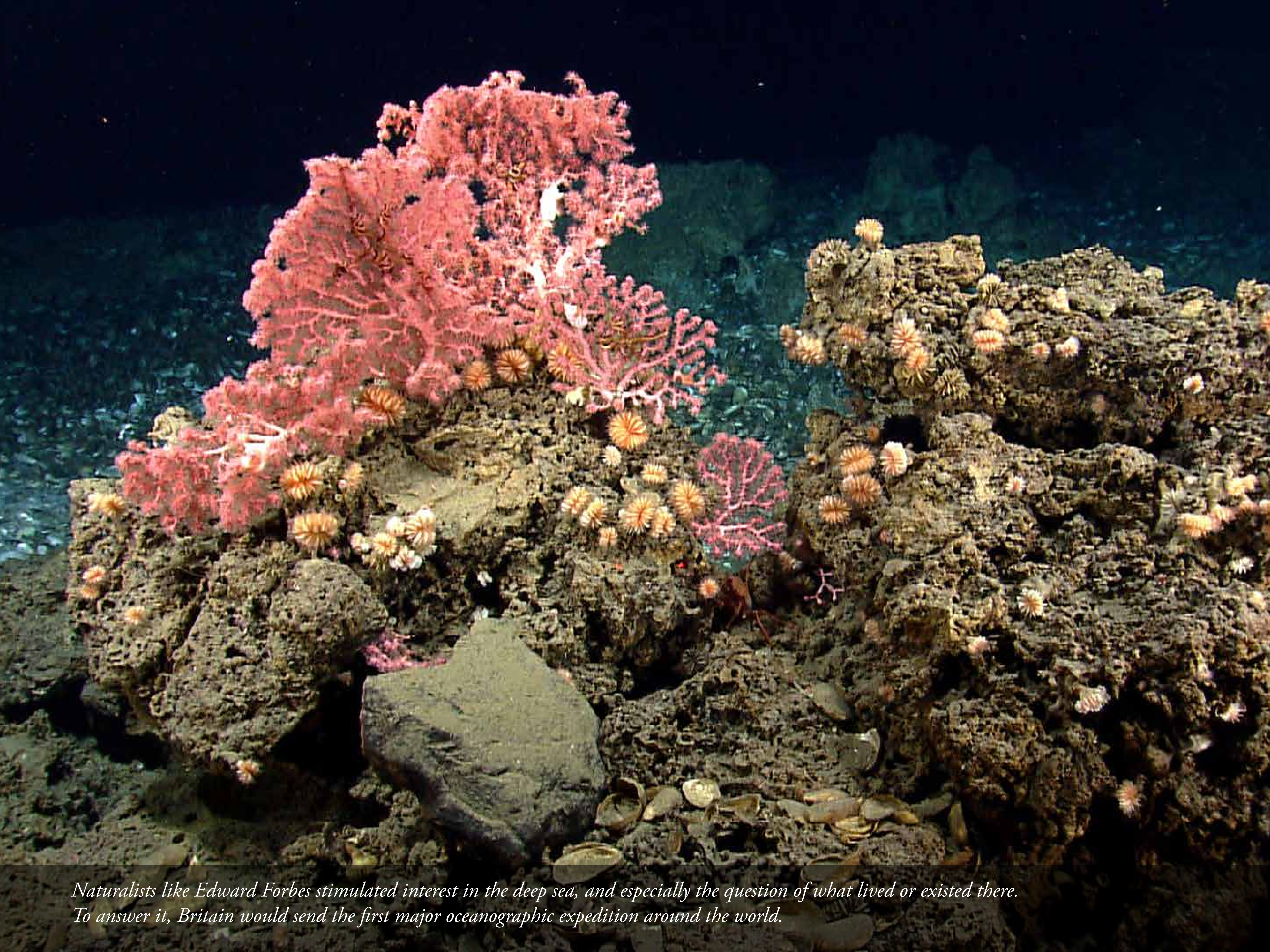
Verne's interest in the sea shows up in several of his works, of which *Twenty Thousand Leagues under the Sea* is the most important. The book tells the story of Professor Aronnax (who bears an uncanny resemblance to Verne) and two companions, who accidentally end up aboard the *Nautilus*, a submarine that serves as both home and laboratory for the enigmatic Captain Nemo.

At first Nemo seems a content man, who lives in harmony with his strange surroundings. *The sea supplies all my needs*, he tells Aronnax during one of their first meetings. *Sometimes I put out my nets and when I draw them in again they are full to bursting*. And the sea provides much more. *This prodigious inexhaustible provider* as Nemo calls her, also produces everything from the clothing aboard the *Nautilus* to the perfume on her dressing tables. *I now receive everything from the sea*, Nemo concludes, *just as the sea some day will receive me*!

Aside from these material needs, the sea supplies Nemo and his crew with minerals and sufficient energy to propel the *Nautilus*. And it provides Nemo with something else he sorely needs: a refuge. *The sea does not belong to tyrants*, he exclaims at one point. *On its surface they can still exercise their iniquitous rights, fighting, destroying one another and indulging in other earthly horrors. But thirty feet below its surface, their power ceases, their influence dies out and their domination disappears! Ah Monsieur, one must live – live within the ocean! Only there can one be independent! Only there do I have no master! There I am free!*

For much of the voyage, the *Nautilus* represents a self-sufficient microcosm, deriving all its needs from a benevolent sea. Unlike Ahab a mere twenty years earlier, Nemo no longer seems adrift in an essentially uncontrollable environment. Science and technology have provided him the tools to control his destiny. But like Ahab, Nemo is an obsessed man and this obsession will become his downfall. After a voyage lasting 20,000 leagues, the *Nautilus* is claimed back by the sea in a giant maelstrom. Only Aronnax and his two companions escape, and live to tell the story.

*In Twenty Thousand Leagues under the Sea* Verne did more than write an exciting sea story. He predicted future developments, describing submarines and mechanisms that allowed people to breathe under water amongst many other things. Making such predictions required a sound technical background, but Verne always did his homework meticulously. In fact, some of the works he consulted are mentioned when Aronnax visits the *Nautilus*' 12,000 volume library.



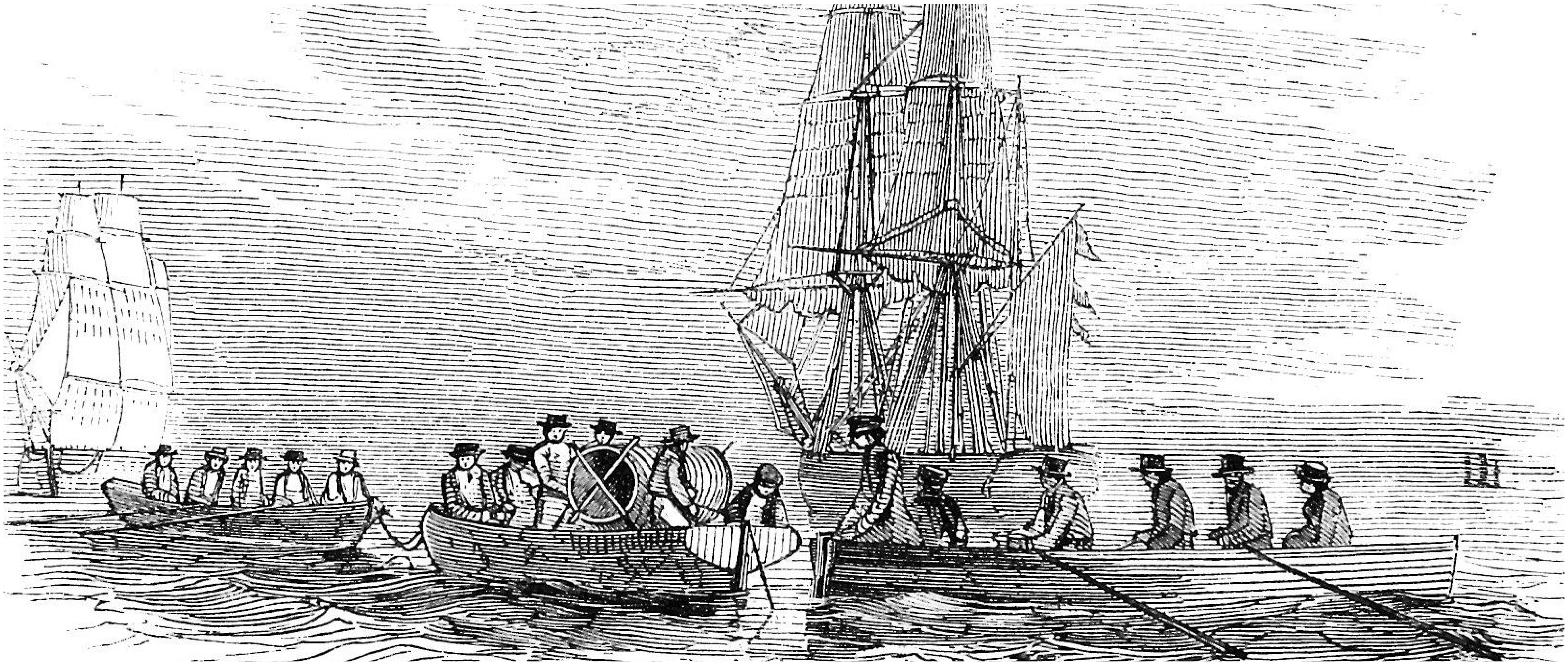
*Naturalists like Edward Forbes stimulated interest in the deep sea, and especially the question of what lived or existed there. To answer it, Britain would send the first major oceanographic expedition around the world.*

Among them was the work of Edward Forbes, who taught at the University of Edinburgh during the 1840s and 50s. A geologist, zoologist and naturalist, Forbes was interested in the distribution of marine life in deeper waters. To explore what existed there he designed a small dredge and used it to collect bottom organisms in deep water off the British coast and in the Mediterranean. This work revealed that life in the sea was just as complex and varied as that on land. Forbes noticed that in shallower waters he retrieved more organisms than further down, which led him to believe that the lack of light and motion, as well as its enormous pressures, ruled out the existence of life in the deep sea. The theory was later proven wrong, but that did not really matter at the time. Forbes' popularity and influence contributed in no small measure to the development of early oceanography.

Also in Nemo's library was the work of Matthew Fontaine Maury, the head of the U.S. Navy's Depot of Charts and Instruments in the mid-nineteenth century. Commander Maury was the driving force behind the publication of wind and current charts, which would have been found aboard every vessel, including the *Nautilus*. He also wrote *The Physical Geography of the Sea*, one of the first texts on oceanography. Scientists didn't particularly like Maury, who relied on divine intervention to explain things that weren't totally clear to him, but laymen loved his work. In fact, *The Physical Geography of the Sea* became one of the most popular science books of the era.

Next to Maury's book was the work of the Swiss-born naturalist Louis Agassiz, a professor of natural history at Harvard's School of Science. Agassiz assembled an enormous collection of marine plants and animals, and published several works on their natural history. He did not get along with Maury, reflecting the conflict between the self-taught military man and the university-educated specialist, but on Nemo's shelves their works leaned brotherly against one another, as indeed they should.

In 1870, when Verne completed *Twenty Thousand Leagues under the Sea*, these books were the state of the art. They reflected what was known about the oceans at that time, helping him to write a fascinating story about the sea and address questions that were very much on the mind of 19th century marine scientists.



*A naval crew takes deep soundings during the mid-19th century. Every time samples came up with new life forms, the notion of a lifeless zone in the deep sea became less probable.*

Chief among those was the question of the depth of the sea, or rather the depth at which life could be found in it. Since Forbes' investigations during the 1840s, scientists had dredged increasingly deeper, retrieving living organisms with each haul and thus continually pushing back the presumed limit of life. But most scientists remained convinced that somewhere in the darkness of the abyss life would have to come to a halt. If it wasn't the perpetual darkness of the deep, its unimaginable pressures would see to that.

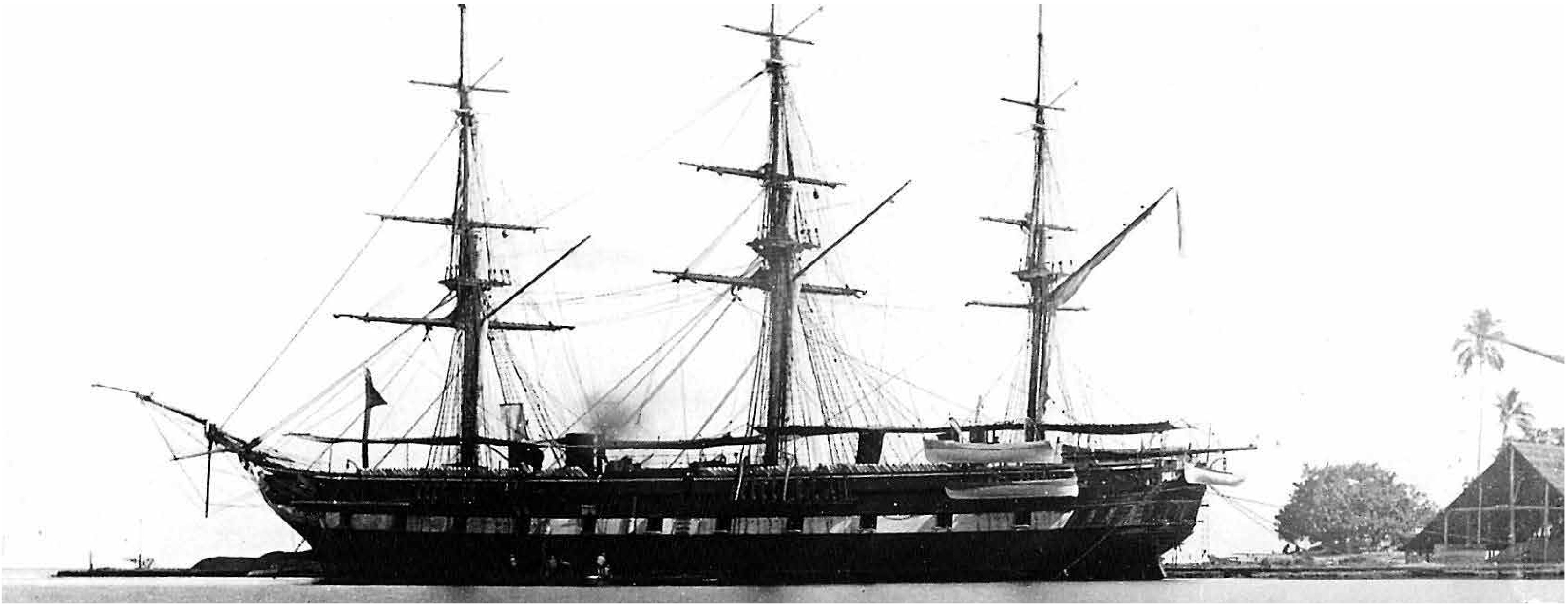
During the 1860s this belief was finally refuted. Better dredging techniques allowed the deepest parts of the ocean to be reached and, though the resulting bottom samples should have been devoid of life, they still revealed plenty of animals. It then began to become clear that all of the ocean was inhabited by life. Even more intriguing, the dredges collected some strange animals from these depths – animals which, in fact, looked rather primitive.

Some naturalists began thinking of these archaic animals as living fossils. If Darwin was right, they reasoned, and all of the earth's living organisms were constantly adapting to their environment, then evolution would have been slower in the sea than on land, where seasons and climates changed much more rapidly. And from there it was but a small step to suggest that deep sea animals, which lived in a place that hardly ever changed, should have evolved the slowest of all. The abyss, in other words, was the most logical place to look for ancient life forms.

This reasoning created a lot of excitement and, as more "primitive" animals were hauled up from great depths, the belief grew that a community of living fossils did, in fact, exist in the sea's deepest reaches. Darwin's friend Thomas Henry Huxley added to the fever by discovering tiny granules on top of deep sea mud samples. While examining the particles under a microscope, he noticed that they slowly moved in a thin layer of mucus-like jelly, bringing him to the conclusion that they were a very early form of life.

Huxley called the jelly-like protoplasm *Bathybius haeckelii*, in honor of the great naturalist Ernst Haeckel. Others too observed the moving particles and became similarly convinced that they were a very primitive form of life. Before long no one doubted any longer than the deep sea was inhabited. In fact, its previously imagined sterility had now been replaced by speculations of great diversity which not only held the key to the evolution of life, but also to its origin.

No matter how intriguing, these theories remained speculative. To ascertain whether they were true, some living fossils, or better yet some living *Bathybius*, would have to be collected from the ocean depths. But this demanded more than coastal dredg-



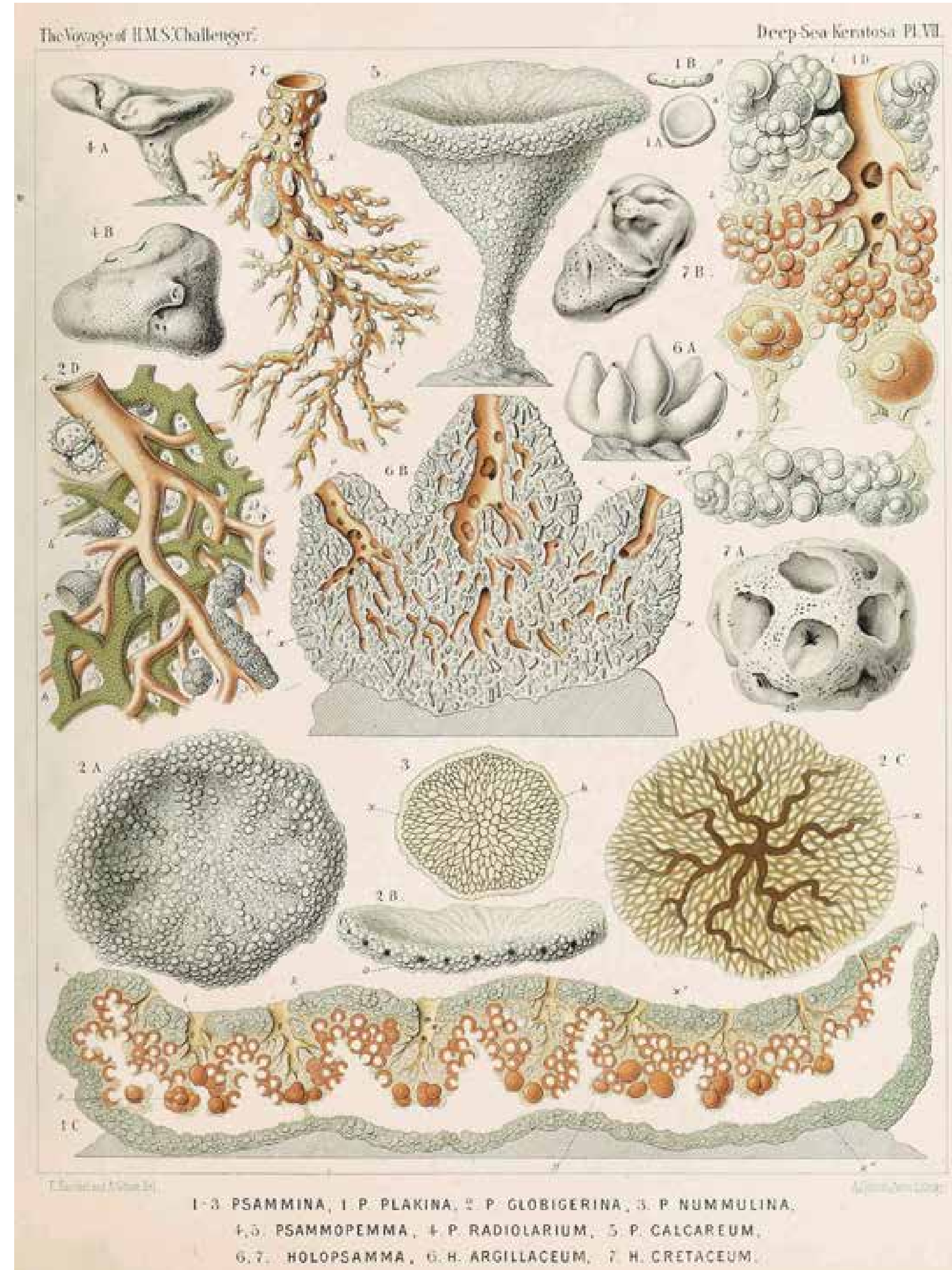
*HMS Challenger was selected to undertake the first global oceanographic expedition; a task that took her and her crew on a 68,930-nautical-mile (127,580 km) journey.*

ing. It called for a major expedition; a voyage that would actually search out the deepest parts of the ocean and then retrieve samples of what existed there. The Royal Society of London felt such a task called for British initiative. After a serious lobbying effort Parliament agreed, and requested the Admiralty to provide a suitable vessel and crew. The ship chosen for this mission was the 2,300 ton naval corvette *Challenger*. In little more than a year the expedition was organized, fitted, and ready to go.

On December 21, 1872, the *Challenger* left Portsmouth for what would turn into a 68,930-mile search for "the conditions of the Deep Sea throughout the Great Oceanic Basins." Three and a half years later, in May of 1876, the ship returned, with hundreds of seafloor deposits, 1441 water samples, and some 13,000 kinds of plants and animals.

Many of these had been obtained from great depths and looked quite interesting, but none qualified as missing links in the great zoological family tree. Even *Bathybius*, the primordial slime thought to be at the root of life, failed to show up in a living state. In fact, John Buchanan, the ship's chemist, discovered that *Bathybius* was no more than a chemical substance, which precipitated when alcohol and seawater were mixed. With that, its connection to the origin of life went down the drain.

Despite these disappointments, the *Challenger* expedition left an impressive legacy. For nearly twenty years scientists throughout the world sorted and described its immense collection. Their results and conclusions were published between 1880 and 1895 in fifty bulky volumes, collectively known as the *Challenger Report*. Though primarily concerned with zoological observations, they contained information on everything that had been studied during the voyage, neatly summarizing what was then known about the ocean. For this reason the expedition, and especially its lengthy follow up, is often regarded as marking the birth of modern oceanography.




*One of the nearly 30,000 pages from the Challenger Report, showing sponges retrieved in the course of the voyage. It took nearly 20 years to publish all results from the expedition.*

The success of the *Challenger* gave impetus to other expeditions, including circumnavigations by Russian, German and Italian ships. In the United States too there was growing interest in oceanography, enabling Louis Agassiz's son Alexander to organize a number of coastal expeditions. And French oceanography received a major boost when Monaco's Prince Albert began to invest much of his time and fortune in marine scientific research.

Because these investigations were mostly concerned with describing the contents of the ocean, they yielded a relatively static picture of what went on below the surface. This worked well enough for seemingly static disciplines like marine biology and geology, but others required a different approach. Accordingly a group of Scandinavian scientists began to look at the oceans from a dynamic perspective, trying to unscramble the complexities of a sea in motion.

By the beginning of the 20th century, the foundations of the four major ocean sciences had been laid. Marine biology – the study of life in the sea – continued to dominate the field. One applied element of this branch – fisheries research – was growing very rapidly, especially in northern Europe. Physical oceanography – or hydrography as Scandinavian chemists and physicists preferred to call it – began unraveling the secrets of the ocean's circulation. Chemical oceanography – concerned with determining the various constituents of seawater and their distribution – developed into a separate field, while marine geology – the study of the seafloor and its deposits – benefited from a rapidly growing collection of bottom samples.

These disciplines attracted devoted followers but, aside from its impact on fisheries and navigation, oceanography did not seem to have much practical value. But that changed when the world went to war in 1939.

From the onset of the Second World War, German submarines proved a lethal threat to Allied shipping. To counter it, acoustical techniques, designed to locate submarines by listening to them, became vital. Better detection measures demanded more data about the topmost four or five hundred feet of the ocean: salinities, temperatures, pressures, densities, animals, currents and bottom deposits – all of which affected the propagation of sound in the sea. The Allies also needed information about wave and surf conditions to aid amphibious landings. That required data on the interaction between the ocean and the atmosphere, and the effects of wind, waves and currents – topics which, until then, had never been systematically studied.

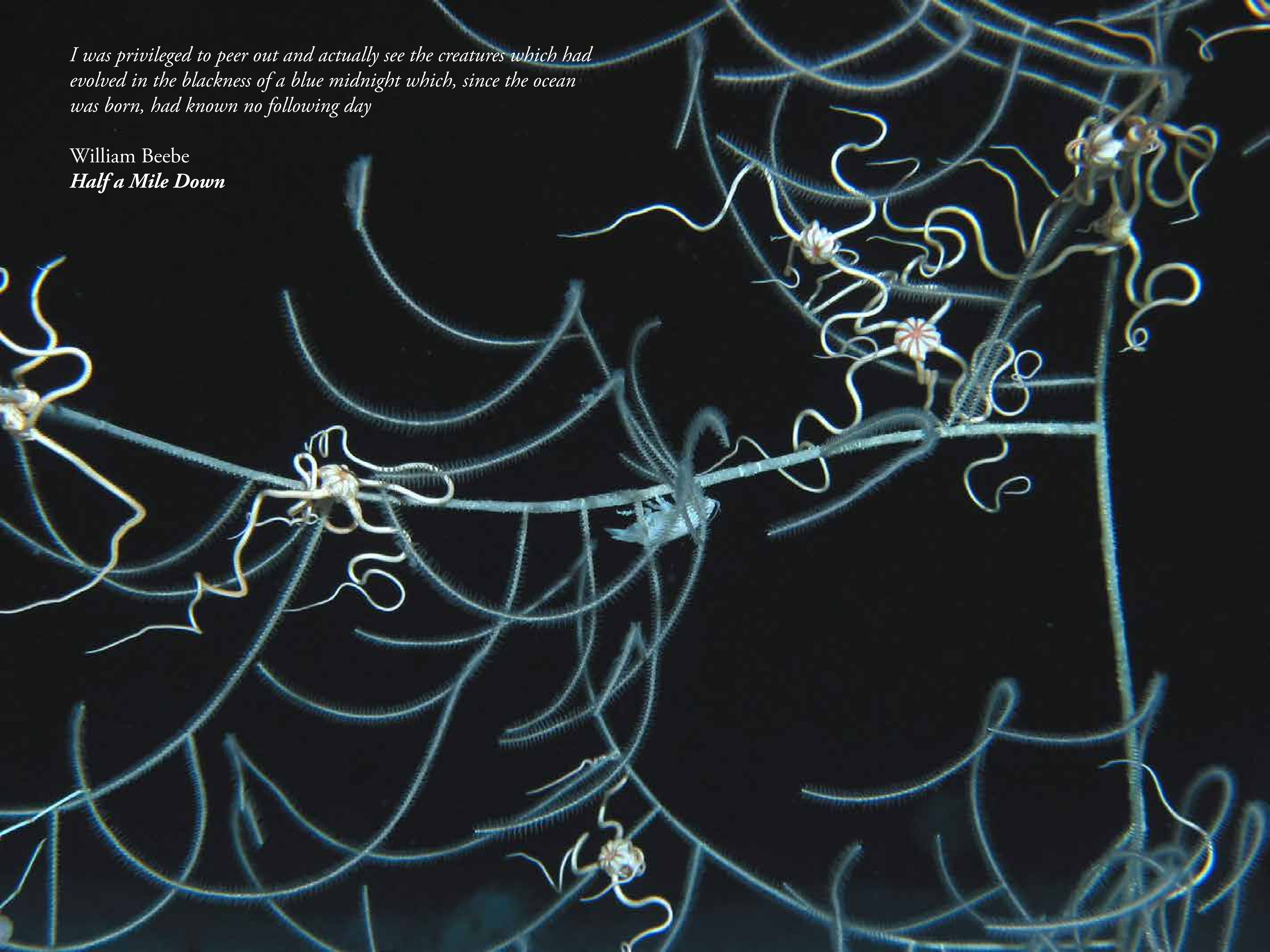
Most of this research was centered in the United States, where a vast number of scientists was put to work to solve these problems. Not surprisingly, this infusion of manpower and money changed the structure and scale of oceanography. War needs determined which studies would be pushed and which were to be shelved. Almost overnight oceanography changed from a small-scale private enterprise to a large-scale operation, irrevocably tied to government support.

This reorientation continued after the war. The acoustical studies, initiated to meet anti-submarine warfare (ASW) needs, led to new experiments on the physical and chemical properties of the oceans, while investigations of waves and tides, made in anticipation of amphibious landings, placed a new emphasis on ocean dynamics. Geological and geophysical studies expanded as well, benefiting from new measuring techniques that had been developed during the war.

*William Beebe and his bathysphere. Beebe and Otis Barton, the sphere's designer, were the first men to descend into the deep sea (© New York Zoological Society).*

*I was privileged to peer out and actually see the creatures which had evolved in the blackness of a blue midnight which, since the ocean was born, had known no following day*

William Beebe
***Half a Mile Down***



These changes changed the field forever. Gone were the reveries of early oceanographers and their leisurely long collecting trips. Gone also was their pleasant, anecdotal style. Sources of support were tied to results and oceanographers became more factual and logical, which did not necessarily make for exciting reading. Fortunately, some scientists were also good writers, able to excite readers about their work and its relevance.

One of the first was ornithologist-turned-marine biologist William Beebe, head of the Department of Tropical Research of the New York Zoological Society. During the 1920's Beebe often joined the Department's oceanographic cruises, where he noticed that the only means to observe deep sea life consisted of hauling it up in a net or a dredge. Realizing that this was hardly sufficient, Beebe began thinking about a deep sea observation chamber that could be lowered to great depths. A few years later he and engineer Otis Barton designed a bathysphere- a steel ball, four feet nine inches in diameter – which they hoped would do exactly that.

After a few test dives off Bermuda, Beebe and Barton descended to depths of 1426 feet in June 1930, 2200 feet in September 1932, and finally 3028 feet – more than half a mile deep – in August of 1934. *From here down, for two billion years there had been no day, no night, no summer, no winter, no passing of time until we came to record it*, Beebe wrote in *Beneath Tropic Seas* – one of the first books about the deep sea. His record-setting dive was described in *Half a Mile Down*, which became a bestseller: *the sun is defeated, and color is banished forever, until a human at last penetrates and flashes a yellow electric ray into what has been jet black for two billion years*. Beebe's enthusiasm was contagious and stimulated many of his readers to appreciate the sea and the immense variety of life in it.

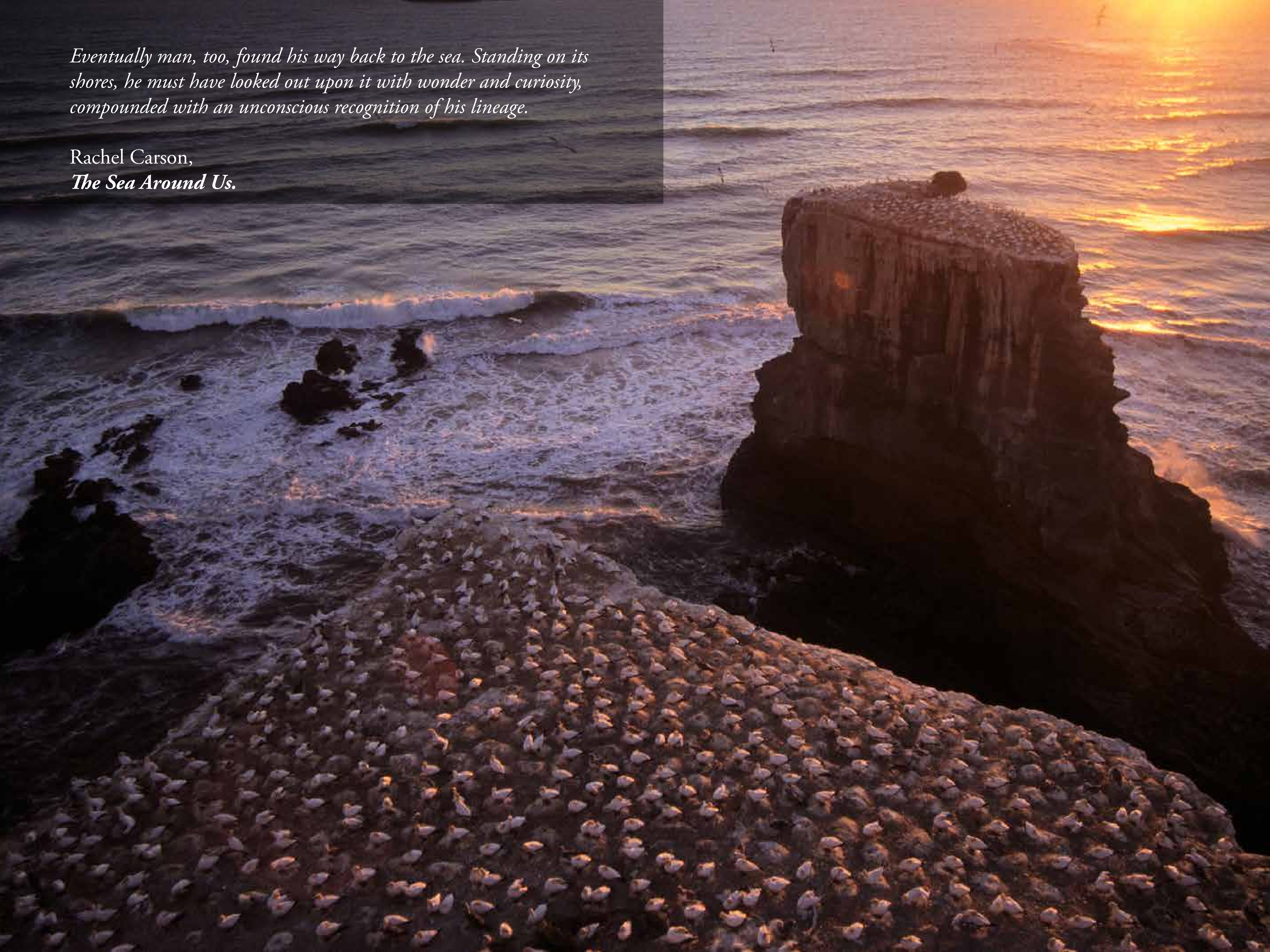
A few years later Rachel Carson, a biologist with the U.S. Fish and Wildlife Service, wrote a series of exquisite books about the sea. Her first book, *Under the Sea Wind*, was published in 1941. *To stand at the edge of the sea, to sense the ebb and the flow of the tides, to feel the breath of a mist over a great salt marsh, to watch the flight of shore birds that have swept up and down the surflines of the continents for untold thousands of years, to see the running of the old eels and the young shad to the sea, is to have a knowledge of things that are as nearly eternal as any life can be*, she wrote, establishing a lyric quality that few biologists would ever match.

Ten years later *The Sea around Us* revealed the science and poetry of the sea from its earliest history through the latest scientific achievements. A superb work, it was acclaimed as the first book to capture the true meaning of the oceans: *Eventually man, too, found his way back to the sea. Standing on its shores, he must have looked out upon it with wonder and curiosity, compounded with an unconscious recognition of his lineage. He could not physically re-enter the ocean as the seals and whales had done. But over the centuries, with all the skill and ingenuity and reasoning powers of his mind, he has sought to explore and investigate even its most remote parts, so that he might re-enter it mentally and imaginatively.*

In 1955 followed *The Edge of the Sea*, a vivid description of life along the shore and in 1961 *Silent Spring*, Carson's most influential book, which chronicled the harm done by the indiscriminate use of chemical pesticides like DDT. Unfortunately, *Silent Spring* was also her last book. Rachel Carson died two years later of cancer at age 57.

Today, Carson's tradition is carried on by others; gifted writers and scientists who possess the ability to translate scientific jargon into clear layman's language. But people spend far more time watching television or surfing the internet than reading books these days. Our ocean spokesmen no longer are writers or scientists. Instead, they are television personalities who, outfitted in wetsuits and diving gear, or standing on the deck of their fishing boat, take us to the remotest corners of planet to explore what lies below the surface.

The impact of television and the internet on our perception of the sea has been remarkable. For one, we no longer need to be at sea, or even see it, to experience its mysteries. Television and computers provides that in seconds. We also no longer need books to know something about the sea. Modern media inform and, more importantly, do so instantly to millions. As a result, today's generation knows more about the sea than any before. Its information is no longer based on first-hand experience, nor is it necessarily of high quality, but modern communication methods have made it available to a much broader audience.



*Eventually man, too, found his way back to the sea. Standing on its shores, he must have looked out upon it with wonder and curiosity, compounded with an unconscious recognition of his lineage.*

Rachel Carson,
***The Sea Around Us.***

Our vision of the sea has been altered by this growth in public awareness. No longer is the ocean so much a place of danger and menace; instead it has become a place to live and relax, considered beautiful and romantic. In it live creatures not like the white whale that destroyed Ahab's ship, but rather gentle cetaceans, that need to be protected. The monstrous kraken that attacked and destroyed so many medieval ships now is portrayed as the timid, shy octopus. And the list goes on. Only sharks, especially great white sharks, haven't quite made the list of loveable sea creatures. But even they, and rightly so, are moving up the list of species we need to cherish and protect.

These are small changes, perhaps, but they reflect we feel more comfortable and familiar with the sea. Of course, we still realize the sea can be very dangerous. It can change from calm and inviting to violent and murderous in seconds, as the tragic tsunamis of December 26th, 2004 and March 11, 2011made clear. And we want it remain mysterious. The mind delights in grand conceptions of supernatural beings and the sea, like space, provides unlimited possibilities. What lurks beneath the surface, in the eternal darkness of the abyss? Even if science gradually reveals the answers, less factual interpretations often seem more compelling.

Perhaps these visions demonstrate that our increasing familiarity has not necessarily altered our individual relationship with the sea. It still awes and inspires, and creates fear and wonder. No matter how much we know about it, the sea continues to cast its spell. A spell so wonderfully described by Rachel Carson. A spell that enables us to identify with Ishmael and Aronnax, or recognize themes in creation stories compiled thousands of years ago. A spell that allows us to detect the similarity between seascapes painted hundreds of years ago and our own perceptions.

We are all affected by the sea, as were all who came before us and all who will follow, bound by a common heritage. It is inevitable. For that ungraspable phantom of life Melville described is not only reflected in the sea. It also flows through our veins...

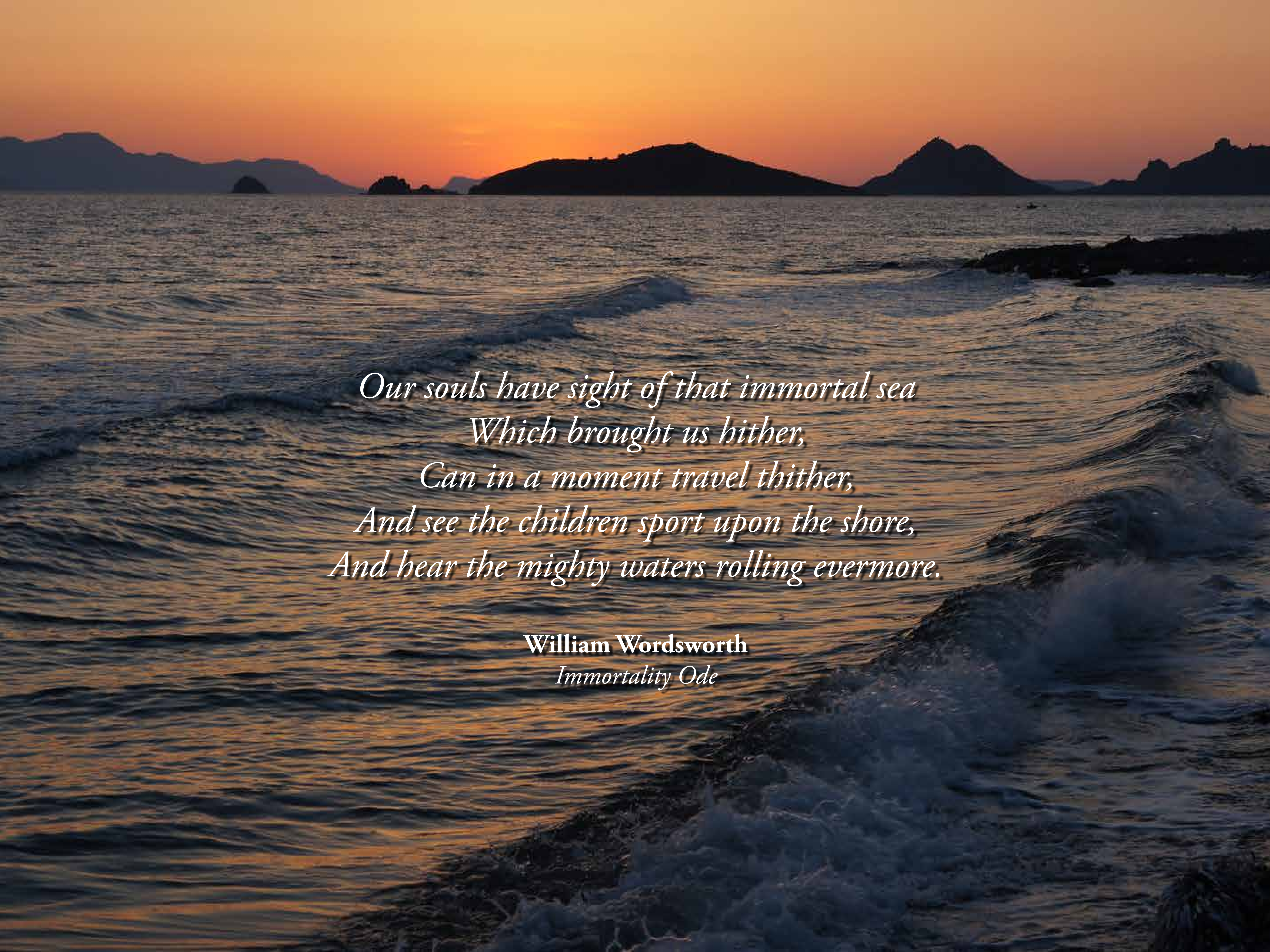
# SUMMARY

*Before there was anything, there was water, or a watery chaos, from which everything was created. That assumption, almost universally recorded in creation legends, is the first indication of people being aware of the significance of the sea to their lives. The innate realization that water is essential to life, that this planet could never have developed and sustained life without the seas that cover more than seven tenths of it.*

*Throughout history people have conveyed that bond in art and literature, leaving a visual and written record of how they felt about the sea. And though so much has changed over time, that record reveals familiar emotions. Hundreds or even thousands of years ago artists, poets and writers captured feelings we recognize. Perhaps it is because of all natural elements, the sea is best at mimicking our own. It can be playful, soothing and alluring but also mean, mad and ruthless. More so than anything else, the sea reflects our own complex mind.*

*For most of us the sea means something less abstract. Its expanse and seeming simplicity – just sea and sky and an endless horizon – allows us to dream, of far-away places or a less complicated world. It invites us to escape, even if just for an hour or two, from every-day life and concerns. And in doing so it invigorates and recharges the spirit.*

*Sea fever is a mix of all of this: an inborn cognizance of the sea's importance just as much as pure enjoyment. A recognition of the many moods that binds us all, past and present. It is an essential part of the relationship between people and their ocean planet. And as it entails awe, affection, understanding and above all respect, it is key to restoring that relationship.*


*Our souls have sight of that immortal sea*
*Which brought us hither,*
*Can in a moment travel thither,*
*And see the children sport upon the shore,*
*And hear the mighty waters rolling evermore.*
**William Wordsworth**
*Immortality Ode*

# HEALTH

Sponges are among the simplest of all marine organisms. They have no brain, no senses nor any of the other tissues and organs present in higher animals. But some sponges have an internal fibrous skeleton, which makes for a splendid cleaning material. People have known about this for thousands of years, finding many additional uses in the process. Their ability to soak up water, for instance, made sponges useful as canteens for travelers; dipped in honey they kept infants quiet; and soldiers used them as padding under their armor or as bandages.

Most of the ancient world's sponges came from the clear waters around Greece and it was there that, thousands of years ago, a diver named Pontius Glaucus found a sponge with healing properties. As with most such legends, not much is known about where Glaucus found this sponge or what exactly it cured, but there is no doubt that he used it quite a bit himself because he became immortal. Glaucus reappears as the builder and pilot of the Argo, for instance, and his love life became legendary. Until modern times he was also revered as the patron saint of Greek divers, fishermen and sailors.

Glaucus was lucky. Mortals usually had to do far more heroic things to be granted immortality. Having divine blood as a result of a divine affair helped. So did a heroic death on the battlefield, but it was by no means a guarantee. Immortality remained the exclusive domain of the gods. Still, that never deterred mortals from dreaming of, or even searching for it.

One of these searches is told in one of the oldest stories in the world: the epic of the Sumerian king Gilgamesh. Having lost his closest friend Gilgamesh, so we are told, became obsessed with the fear of death. To ease it, he abandoned his throne and set out in search for the secret of immortality.

Gilgamesh walked for days and weeks, through dense forests and lifeless deserts, until he reached a seemingly impassible mountain range-- the boundary of the mortal world.

No one had ever gone beyond and returned but Gilgamesh pushed on. He entered a cave and stumbled on for days on end, until he reached a magnificent garden at the other end. There he found Siduri, the guardian of the shore, who asked him what he sought. When told, she lectured Gilgamesh on the folly of his quest. “You will never find what you are seeking” she sighed. “When the gods created mankind, they appointed death. Eternal life they kept in their own hands.” Siduri advised Gilgamesh to be content with ordinary human pleasures: a loving wife, children, happiness, but Gilgamesh was undeterred. He convinced her to lead him to Utnapishtim, the guardian of immortality, who lived on an island in the distance.

Utnapishtim was waiting for Gilgamesh when he reached the shore, and asked why he came. He too shook his head when the king finished his story. “There is no permanence in the world”, he spoke. “Birth and death are bound together in man’s destiny”. But Gilgamesh could not be persuaded to leave and eventually the old man relented, sharing a secret that would let him taste of immortality, but not obtain it. At the bottom of the sea, he explained, was a magic plant, guarded closely by the waters above it since the dawn of time. It had the power to restore youth and so eternally to renew life. If Gilgamesh could obtain it, Utnapishtim continued, it would make him young again.

Gilgamesh immediately set out to the ocean, tied stones to his wrists, and plunged into the water. He swam deeper than any mortal ever had, found the plant and seized it. Clasping it tightly, he surfaced and let the current carry him ashore. On the long journey home, Gilgamesh never lost sight of his prize, except for one single moment. Just a day or so from home, he halted at a spring to refresh himself, and carefully laid the plant along the edge. As he immersed himself, a snake slithered up from the pool and snatched the plant away. Instantaneously, it shed its skin, as if to demonstrate the power of Gilgamesh’s prize, and slid into the spring to return the plant to where it belonged.

The king was devastated. He had held the key to immortality but lost it in an instant of mortal weakness-- a moment Utnapishtim had known would come. But at the same time Gilgamesh realized the futility of his quest. He returned to his city where he lived out his days in dignity. Then too came the day that Gilgamesh was laid to rest. In time nothing remained of the king, except for his story...

Gilgamesh's quest is a story of the joy of friendship and the anguish of bereavement, but it is above all a story about the fear of death and the search for immortality. His is a futile quest for, as Gilgamesh is told, "to live forever is not the lot of man". Other legends and mythological accounts repeat this message. Though they hint at a level of immortality in another world, people are not satisfied. They seek to obtain it here on earth, spurred by fear or a burning curiosity to know what comes beyond. Hence Gilgamesh is followed by others, from Alexander the Great who sought the spring with the Water of Life (he failed and died a few years later at age 32) to the Spanish conquistadors, who looked for the Fountain of Youth in their newly "discovered" territories. None succeeded or, if they did, they never returned to tell.

There is another intriguing parallel among these stories. Whether it is Alexander's pursuit of the spring of eternal life, Gilgamesh's quest for the magic sea plant or the search for the elusive Fountain of Youth, these legends often allude to water and the sea as having the power to either cure or restore youth. Many folk stories and fairy tales do so as well. One recurring theme is that of the sailor or fisherman who spends some time in a mysterious palace on the bottom of the sea. Though treated exceptionally well, he longs for his family after a few days, and is allowed to return– albeit with a stern warning. When emerging, he realizes why. The world is a very different one: home, family, and friends have vanished. Each day spent in the sea equaled many years on land, and hundreds of years have passed. It is a sad story, for the lonely splendor on the bottom of the sea is replaced by loneliness in unfamiliar surroundings. But it is an interest-

*This is what is called a million-dollar view, and the ocean accounts for a good part of that. To many of us the sea is an essential ingredient of natural beauty.*

*The Dalmation coast, Croatia*

ing theme in which water, once more, is seen as prolonging the life we know on land.

Why water? And why the sea? Water cleanses the body, of course, and cleanliness not only gives a sense of well-being; it is essential to health.

Water also cleanses the spirit. Christianity relies on baptism to wash away sins, and so do many other religions. The religious practices of the Brahmins, for instance, specify that bathing in the sea at full and new moon has the effect of cleansing the soul. In places as far apart as Lebanon, Thailand and Zanzibar, this practice takes place in association with the New Year and each time it has the same effect: to purify the soul, wash away any sins, and start the year with a clean slate.

Aside from being beneficial to body and spirit, water is often regarded as being good for the mind. It relaxes us. Why else would we spend hours on beach towels or folding chairs watching the waves roll in? Why else would a dentist put an aquarium in his waiting room rather than, say, a hamster cage? The reasoning behind these feelings of relaxation and ease is not easily defined. Some scientists believe our reactions may have something to do with the soundwaves emitted by water. Others feel there is a connection with the visual appeal of water. Water is playful, it is refreshing. To most of us, water is an essential ingredient of natural beauty. It is as if we need it as a visual component for a scene to be truly satisfying.

Our affinity for the world of water may also have an intuitive aspect, reflecting the importance of water to life. Water made life possible on earth. Without it, there would have been no atmosphere and conditions on the planet would have been far too extreme for life to develop. Moreover, the earliest life forms originated in water and all of us carry traces of these watery origins. Every human embryo, for instance, evolves through various evolutionary phases before adopting mammalian forms. Equally remarkably, the blood that runs through our veins is similar in the composition of its salts to seawater. So is the amniotic fluid in which the embryo floats for the duration of its gestation period. No wonder then that babies appear to thoroughly enjoy a warm bath. Even more interesting, when immersed in water, newborns swim spontaneously and fearlessly, as if it were their natural element. Natural buoyancy keeps them at the surface but even when submerged they seem comfortable and content, occasionally bobbing to the surface to breathe.

Some scientists believe that the high fat content of the human body, as well as its hair patterns and upright position, point to an aquatic phase in early hominid evolution. In their view, our ancestors would have spent a good deal of their time in the balmy waters of tropical seas, rather than in trees or on grass flats. The theory is by no means universally accepted, but it addresses a number of inconsistencies in conventional theories of hominid evolution. It may also explain our affinity with dolphins and whales, mammals that joined our ancestors' migration to the sea, but stayed there and readapted to fish-like forms and habits.

Given our watery origins and the reminders of this ancestry that are still within us, it is no wonder that we have accorded water a special role in legends, religion and mythology. It is water that people use to refresh body, mind and spirit; a process that millions of us repeat each year on our annual trek to the beaches. It is water, as Achilles and Alexander believed, that contained the secret to immortality. And it is in the sea that Gilgamesh and Glaucus found the key to eternal youth.

Today, science is turning to the sea as well to help us lead longer and healthier lives. All of us are subject to disease and aging and while medical science has made phenomenal progress in prolonging life and treating disorders, much more can be done. To achieve this, we need to understand how life processes function or malfunction, and how substances like drugs affect these processes.

That knowledge demands a fundamental understanding of life. No disease or disorder can be diagnosed unless we know what went wrong, how the disorder differs from a healthy system, and how it can be treated. Since human life processes are very complex, medical scientists usually

*Goa, India*

*A Caribbean reef squid (Sepiotheutis sepioidea). Like all squid this species propels itself by ejecting water from a chamber between its body and mantle, a process that allows it to move with lighting speed. In this case the mechanism even allows the squid to escape predators by shooting out of the water and "flying" for distances of up to 10 m.*

rely on models of life processes in simpler organisms, before trying to understand the same process in the human body.

The sea provides a great variety of such models. Some are the descendants of ancient life forms which changed little in the relative protection of the sea, providing us access to primitive life processes that have long since vanished elsewhere. Other organisms contain particularly well developed systems – the result of millions of years of adaptation to specific conditions found only in water. And still others are particularly accessible or provide us with insights not found in terrestrial organisms.

To serve as an effective biological model, an animal must meet two basic requirements: it must have a relatively simple structural and physiological makeup and the process in question must be comparable to its counterpart in humans. Few animals meet these requirements as well as Doryteuthis pealeii, better known as the longfin inshore squid.

In southern Europe squid are known as calamares-- a word derived from the Latin term for pen, which could be a reference to the squid's anatomy (its skeletal structure resembles an old-fashioned pen holder) or the its tendency to eject "ink" when trying to escape. The English name, in contrast, is more descriptive of the animal's behavior, having been derived from "squirt", which is exactly what the squid does to propel itself. To move, the animal draws seawater into a chamber between its body and outer mantle and then ejects it, producing a water jet which propels it forward and backward with lightning speed. The mechanism provides the squid with an effective means of escape, which is essential for it is heavily preyed upon by a variety of animals.

The squid's claim to medical fame lies in the workings of this escape mechanism. Like other organisms, its nervous system communicates information by means of a complex mesh of nerve cells, which transmit messages to other nerve cells through long extensions called axons. In the squid these axons are unusually large. In fact, the axons that activate the mantle are nearly as thick as a pencil lead-- thousands of times larger than axons in vertebrate organisms. Moreover, the squid's nervous system is relatively simple, consisting of a

## CLASSIFYING MARINE LIFE

Like life on land, plants and animals in the sea exhibit an enormous diversity in size, form and function. The range in size taken by itself is truly impressive: from microscopic one-celled plants and bacteria to the blue whale, probably the largest animal ever to live on the planet. Yet even more impressive is the range in form and activity. Several systems of organizing animals and plants in group have been developed to classify this enormous diversity.

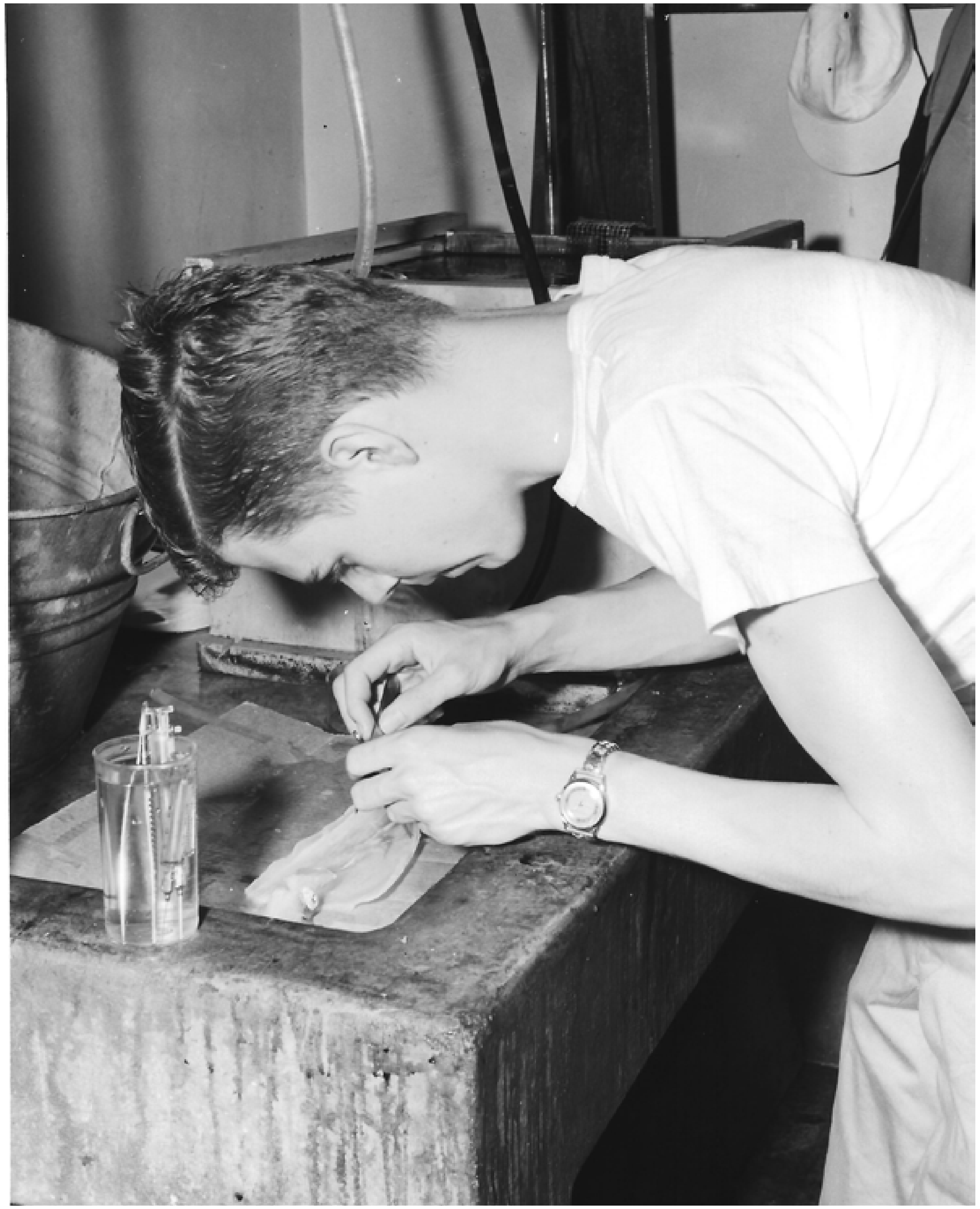
Taxonomy is based on the genetic relationships that exist between all living organisms. Its purpose is to categorize plants and animals into natural units by tracing the lines of their evolution and identifying similarities among them. The smallest unit of taxonomic classification is the species. Members of the same species form a homogeneous genetic unit: they represent a group of closely related organisms that can interbreed, forming fertile offspring. The next step in the taxonomic hierarchy groups as a genus those species which are judged to have a common ancestor. Every (known) living organism has a scientific name, consisting of its genus and species, both of which written in italics. Several plants and animals mentioned in this chapter are identified with these names to make clear they refer to a particular organism. Genera are grouped into families, which, in turn, are organized into classes and orders until finally all living organisms are classified in more than 30 plant and animal phyla. There are separate phyla for fungi, protozoans and bacteria as well.

Another way to classify marine organisms is according to where they live. The benthos includes animals living on the bottom (epifauna) or in the sediment (infauna). Benthic organisms exhibit a great variety of habits. Animals like oysters and barnacles attach themselves to a hard substrate. Others secure themselves to the substrate by means of a root-like structure. Several familiar invertebrates simply lie unattached on the bottom or crawl and propel themselves along the surface of the seabed. If they seem defenseless and somehow still manage to thrive, they probably contain a substance that makes them unappealing or toxic to potential predators.

Pelagic organisms, in contrast, inhabit the water column. They are generally classified into two groups: plankton and nekton. Planktonic organisms maintain a specific gravity very close to that of seawater. Since they have little or no capability of horizontal motion, they are carried along with the current. Plant members of the plankton are called phytoplankton. They are mostly microscopic, either single-celled or loose aggregates of a few cells. The animal plankton is referred to as zooplankton. Its members range in size and complexity from single-celled organisms to multi-cellular animals. Some of the larger zooplankton have vertical swimming abilities, but most float more or less passively along with the current.

The larger actively swimming marine animals belong to the nekton. This group includes all marine mammals, many fish and invertebrates like squid and some shrimp. In many instances, these clear-cut distinctions between groups of organisms living under similar environmental conditions breaks down. Some species occupy only one habitat over their entire life span, but many fish, for instance, change their habitat systematically during their life cycle, developing from a temporary planktonic larval stage to nektonic animals as their size and swimming abilities increase.

*Coral reefs always host both benthic (bottom-dwelling) and pelagic (free-swimming) organisms. Also present but invisible to the naked eye are planktonic plants and animals.*



*A researcher dissects a squid to extract its giant axon. Since the middle of the past century, thousands of squid have undergone this fate, contributing enormously to our understanding of human neurology.*

brain and a pair of relay stations, called stellate ganglia, from which the axons carry the nerve impulses to the muscles.

Despite its simplicity, this nervous system is comparable to the human nervous system, where thousands of axons transmit information from nerve cells in or near the spinal cord to the peripheral nerves, causing them to contract or relax, as dictated by the brain. The squid thus provides a splendid neurobiological model: its nervous system is relatively simple yet comparable to its counterpart in humans and, above all, it has a very large and accessible axon, which is easy to dissect, examine and manipulate.

The contribution of this axon to neurobiology has been phenomenal. Prior to its discovery in 1909, theories of how nerves work were a matter of speculation. The most comprehensive work was developed by German biologist Julius Bernstein who, in the late 19th century, suggested that nerve impulses were triggered by the passage of ions through the nerve cell membrane. Bernstein believed that impulses were electrical as well as chemical events but, for lack of suitable materials, he could never prove his hypothesis.

The discovery of the squid's axon made empirical work possible, and during the 1930s scientists of the Marine Biological Laboratory in Woods Hole, Massachusetts and the Marine Laboratory in Plymouth, England, set about proving Bernstein's theory. Their first success came in 1936 when the electrical properties of the axon were measured, seemingly confirming Bernstein's hypothesis. Three years later, they devised a method to insert minuscule electrodes inside the axon, enabling them to obtain measurements of the electrical currents. In 1947 this technique helped them in determining that the tiny electrical impulses that activate a nerve were generated by a fast exchange of sodium and potassium ions across the nerve cell membrane. A few years later it was shown that this flow of ions depended on specific ionic channels in the cell membrane, which open and close in response to changes in the electrical charge of the membrane.

Since those early days, scientists have converged to the Marine Biological Laboratory in Woods Hole each summer to continue their studies of the squid's giant axon. Their visits coincide with the animal's annual spawning run to the waters off Cape Cod, so they never lack for an abundant supply of the valuable axon. During a typical summer, some 15,000 squid are dissected, their axons extracted and, in turn, subjected to a wide variety of tests and procedures. Axons are injected with various substances to examine how different drugs act on the nervous system, and they are studied from every possible electrical, chemical and biophysical angle. In the process, our knowledge of how nerve impulses are carried along a cell, across the gap (or synapse) between nerve cells, and onward toward the brain continues to be refined.

Scientists are also using the giant axon to determine how nutrients and cellular particles are transported inside cells--a mechanism which is essential to the health and maintenance of all cells. Breakdowns in these transport systems are believed to be at the root of degenerative disorders of the nervous system like Alzheimer's disease and amyotrophic lateral sclerosis (ALS), also known as Lou Gehrig's disease. Alzheimer's is caused by a progressive degeneration of nerve cells in the brain, hampering the passage of impulses from cell to cell, and resulting in memory loss. Lou Gehrig's disease, in contrast, is caused by a deterioration of the motor nerve cells that control the body's major muscles. Both diseases are irreversible, currently untreatable, and ultimately fatal. The squid axon enables scientists to experiment with various molecular therapies and drugs to determine how abnormal axonal transport could be restored to its normal state. In time, these studies may help provide treatments, perhaps allowing a number of nerve disorders to be removed from the list of untreatable diseases.

The horseshoe crab also figures prominently among the ocean's medical stars. A crawling helmet with nine eyes, a dagger-like tail, and two rows of spidery legs underneath, the horseshoe crab not only looks like a living fossil; it actually is one. Fossil evidence shows that horseshoe crabs have survived and flourished virtually unchanged for over 200 million years. For any animal to survive that long, it clearly must be doing something right.

In the horseshoe crab it is the eye which is of interest to scientists, and particularly the fact that it possesses one of the largest and most accessible optic nerves in the animal kingdom. In addition, the animal's eye is simple: there are only about 1,000 individual rods and cones. Human eyes, in contrast, contain about 150 million of these. Despite these differences in scale, vision in horseshoe crabs is fundamentally similar to that of higher organisms, making it a perfect model for studying how human eyes encode and transmit visual information.

Most of this work was pioneered by Haldan Keffer Hartline, who developed the first vision model at Woods Hole's Marine Biological Laboratory. Using the horseshoe crab as a model, Hartline went on to formulate the basic mechanisms of retinal function, describing how visual systems can detect contours and enhance contrast between borders – a process known as lateral inhibition. But he was mistaken in one assumption. By focusing on excised eyes to develop his theories, Hartline assumed that the horseshoe crab's vision

*A crawling helmet with nine eyes, a dagger-like tail, and two rows of spidery legs underneath, the horseshoe crab (Limulus Polyphemus) has managed to survive virtually unchanged for more than 200 million years.*

*The Californian sea hare (Aplysia californica) has helped us understand the mechanisms of circadian clocks as well as of learning.*

was relatively simple, with information essentially going from the eyes to the brain via the optic nerve.

Robert Barlow, one of Hartline's students, continued this work and discovered that, by leaving the nerve intact, its physiology became radically different. Not only was information being sent to the brain, but the brain in turn sent information back to the eye. He later found that the origin of these signals was a circadian clock in the brain which not only dramatically increased visual sensitivity when needed (such as in dim light) but also allowed the crab to keep track of time without external clues, so that it knew when to lay its eggs. That ability has clearly been central to the animal's survival over millions of years.

Circadian clocks, we now know, play an important role in every living organism. Derived from the Latin circa (about) and dies (day), they regulate the organism's circadian rhythms– 24-hour cycles of activity and rest, which affect a variety of physiological and cellular changes. While circadian rhythms correspond roughly to the rhythm of day and night, they run independent of it, and continue to function even in absence of external clues. In other words, if an organism is put in total darkness and deprived from any sensory information regarding day and night, it will continue to maintain a 24-hour cycle of rest and activity, triggered and regulated by its internal circadian clock.

Much of what we know about circadian clocks and rhythms is the result of studies conducted on the Californian sea hare or sea slug (Aplysia californica). A strange looking mollusk, the sea hare first established a reputation in medical research because of its pigmented nerve cells, which are up to fifty times larger than those of higher organisms. These cells provided an excellent model in studies on the cellular mechanisms of learning; a process which involves long-lasting modulations in the excitability of neurons. More recently they also proved to be excellent models for the study of the daily activity cycle.

Much of this work is conducted at the Marine Biological Laboratory as well. During the 1970s scientists located a cluster of specialized neurons in the sea hare's eye, which emitted spontaneous electrical discharges that varied rhythmically in the course of the day. It turned out to be the animal's circadian clock, responsible for controlling its daily locomotor activity. Next, the researchers sought to determine how this clock works. They discovered that a rhythmic pattern of protein synthesis was responsible for stimulating the nerve cell membrane, which in turn emitted the electrical impulses that control the sea hare's activity cycle.

Studying the sea slug's internal clock may seem a rather esoteric effort, but there are very practical considerations. For one thing, humans also have a circadian clock; or rather two. They are located in the hypothalamus, the portion of the brain which controls the autonomic nervous system. Researchers believe that certain cyclic mood disorders like manic depression develop when these two clocks are not in tune with one another. At the Marine Biological Laboratory it was determined that lithium, which is commonly used to treat manic depression, extends the period of the sea hare's single circadian clock. The drug probably does the same in humans, extending the cycle of one of the clocks and thus allowing both to run synchronously. It is just one way in which an ungainly creature like the sea slug provides clues to disorders and how to treat them.

Other invertebrates that are currently being studied for a variety of life processes include lobsters, which are known to contain serotonin, a chemical compound implicated in aggressive behavior. Researchers at Harvard Medical School isolated the nerve cells in lobsters that control the release of the chemical in the lobster's blood. They hope that, once the crustacean release mechanism is fully understood, it might also be controlled, thereby offering a means to regulate aggressive behavior not only in lobsters and other invertebrates, but also in humans.

Marine vertebrates too serve as models for life processes. The liver of the nurse shark, for instance, is similar to the human liver and has provided a model to study liver physiology and hepatic disorders. Similarly, the dogfish has served as a model in understanding liver disorders like

*Sockeye salmon (Oncorhynchus nerka) and other Pacific salmon species die after returning from the sea to a river to spawn; stealhead trout (Oncorhynchus mykiss) and Dolly Varden trout (Salvelinus malma), in contrast, manage to survive the process. Understanding how trout, seen here below the salmon, manage to reverse arteriosclerosis helps us understand the process in humans and possibly figure out how to curtail its effects.*

jaundice, which develop if and when this mechanism is not functioning properly.

Fish have helped scientists a great deal in understanding anything from the complex function of the human kidney to the aging process. The formation of arteriosclerosis (the hardening of the arteries) and the role of this disease in aging, for instance, has been studied extensively in migratory Pacific salmon and steelhead trout. Both of these species return to inland rivers to spawn but the salmon dies after doing so. The trout, in contrast, often manages to return to the sea. It was found that returning salmon develop fatal arteriosclerosis among other disorders. Trout develop similar disorders upon entering fresh water, but these disappear during the run back to sea, allowing many of the fish to survive. From further studies on the trout, we may hence learn more about the complex process of arteriosclerosis and, more importantly, the possibilities of its reversal.

The angler fish, which makes a living in the deep sea by dangling a bioluminescent lure in front of its mouth, may teach us something about tissue acceptance, which is crucial to human grafting and organ transplantation. Angler fish have developed a most unusual way of reproducing. After locating a mate, the male angler fish bites into the flesh of the female. His tissues subsequently fuse to her, resulting in a permanent bond, and the two fish remain together for the rest of their lives. In time, all of the male's vital organs degenerate with the exception of the gonads, which become oversized and provide a ready supply of spermatozoa.

Female angler fish have been found with up to four males attached their sides and belly. What is so interesting about this phenomenon is that none of these males were "rejected". While it may be difficult to physically "reject" such a persistent mate, the body's immune system usually fights intrusions of this nature by triggering tissue rejection mechanisms. But the angler fish demonstrates that some vertebrates possess an immune system which allows certain types of tissue acceptance, while presumably fighting unwanted invasions. Understanding the biochemistry and physiology of this immune system could have biomedical significance by helping to find ways that inhibit tissue rejection mechanisms without interfering with other immune responses.

Marine organisms can do more than help us understand basic life processes. They can also provide us with substances like drugs to help cure or alleviate disorders.

About half of the drugs we use today, including staples like aspirin and morphine or antibiotics like penicillin, are derived from living organisms. Most of these come from terrestrial organisms, particularly plants, but there is nothing to preclude the sea from being a rich source of biologically active substances as well. In fact, the sea may be an even richer source of useful compounds because nearly 80 percent of all life on earth inhabits the ocean. Moreover, many species occur primarily or exclusively in the sea.

We have only recently begun to explore the sea's potential for drugs, but the returns seem quite promising. It has been found, for instance, that more than ten percent of marine organisms contain biologically active substances, i.e. substances which are capable of eliciting reactions in living systems. These are either cytotoxic (i.e. they are toxic to cells) or cause effects on the circulatory or central nervous systems. In similar tests of terrestrial organisms only two to three percent of the tested species showed biologically activity.

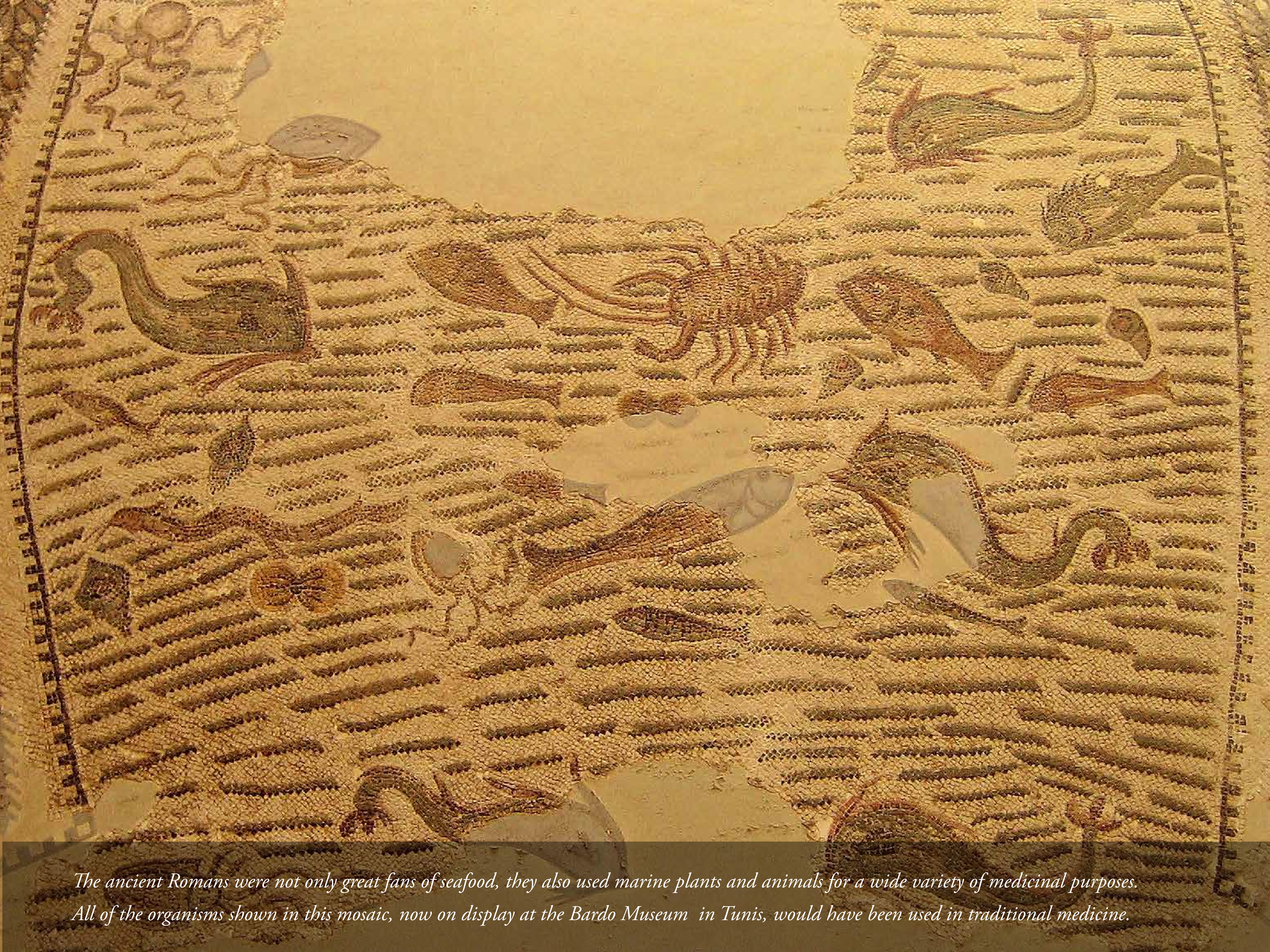
As a result the sea is increasingly being screened for new and promising drugs to treat disorders ranging from cancer to AIDS. But pharmacognists – scientists who investigate the characteristics and uses of drugs from natural substances – are faced with a considerable problem: where to start? The sea is enormous, and it contains a bewildering variety of different organisms– more than 250,000 known ones and far more unknown ones. Moreover, the majority of the ones that are known are difficult to obtain.

Fortunately, there are clues. Nature provides some hints, but for one lead we don't even need to go to sea. It relies on the wealth of information contained in folk medicine. People have sought to cure diseases and disorders by relying on natural cures and substances for thousands of years. Some of the resulting concoctions are pure quackery or work because people want them to work, but others appear to be quite effective. And these merit a closer look because they may contain active compounds which, either in isolation or in conjunction with others, achieve certain therapeutic effects.

Traditional medicine is largely based on terrestrial organisms for the simple reason that people have been far more familiar with life on land than its counterpart in the sea. Nonetheless, there are several ethno-historical leads involving the use of marine organisms for medicinal uses. The most interesting come from Asian cultures, some of which have used the sea extensively for thousands of years. There are also interesting examples from the Pacific, but their record is incomplete because many of these cultures lacked written languages for most of their history. Westerns folk medicine also contains a number of intriguing references, though many of those are not only old, but also questionable.

We now know that fish are very nutritious but the ancient Romans went a step further, seeing in fish the cure to just about any ailment under the sun. Pliny the Elder, for instance, recommended fish for internal and external disorders no less than 340 times. Bitten by a dog and in need an antidote? Pickled fish, applied topically, should help out. Suffering from a toothache? You probably forgot to rub your teeth once a year in the brains of a dogfish, boiled in oil, and kept for that purpose. If this concoction isn't at hand, try the cinders from the burnt spine of a stingray, mixed with vinegar, to relieve the pain. Women suffering from hysteria? Simple, according to Pliny. "Lint, greased with a dolphin's fat and then ignited" produces a remedy. Should this fail "the meat of a conch, left to putrefy in vinegar" should do the trick. And the list goes on, each remedy stranger than the one before.

Pliny was not the only advocate of fish's healing powers. Though Greek and Roman practitioners differed in regard to which fish cured what ailment, they enthusiastically



*The ancient Romans were not only great fans of seafood, they also used marine plants and animals for a wide variety of medicinal purposes. All of the organisms shown in this mosaic, now on display at the Bardo Museum in Tunis, would have been used in traditional medicine.*

concurred that there wasn't much that couldn't be treated through some piscean remedy.

Some eastern remedies are equally interesting. Chinese traditional medicine uses some 2,000 medicinal drugs, mostly plants but also minerals and animal products. The drugs are classified according to the four energies– cool, cold, hot and warm– and according to the five flavors– sour, bitter, pungent, salty and sweet. In line with the Chinese Yin and Yang principles of deficiency and excess, the energy and flavor of a drug determines its application. Thus a 'cool' drug like mint is prescribed for a 'hot' ailment like fever. Practitioners typically prescribe a balanced formula of herbs and drugs, which the patients boil into a tea that is taken once or twice a day.

While most of these remedies are based on terrestrial herbs and plants, the sea has not been neglected. The curative powers of seaweeds in particular are highly regarded in Chinese traditional medicine. Chinese texts provide numerous recipes which are believed to treat a plethora of disorders, ranging from hair loss to syphilis and stomach trouble. While most won't actually cure much of anything, there are some that have a therapeutic effect. The 16th century Pen Tsao Kan Mu, for instance, lists several seaweeds as a cure of goiter, a swelling of the thyroid gland that is often accompanied by toxic symptoms. We now know that goiter is caused by iodine deficiencies and all of the seaweeds listed in the Pen Tsao Kan Mu contain high concentrations of iodine.

There is at least one other instance of a remedy which has been substantiated, using the kainic acid found in certain red seaweeds as an anthelmintic, i.e. a drug that kills parasitic intestinal worms. Most other seaweed remedies in Chinese pharmacopeias appear to have no scientific basis, though this should not necessarily nullify their therapeutic usefulness. In fact, seaweeds can be regarded as a valuable food supplement since they contain high concentrations of essential minerals and vitamins.

Chinese traditional medicine also makes use of a considerable number of marine invertebrates. The shells of mol-

*Seahorses are a staple in Chinese traditional medicine because of the longstanding belief that they enhance male virility. There is not the slightest proof for that claim, but Chinese medical beliefs are near-impossible to eradicate. In the meantime, millions upon millions of seahorses are caught each year to end up as yet another aphrodisiac.*

*Limu make o Hana, the deadly seaweed of Hana, turned out to a soft coral (Palythoa caesia). Though innocuous looking, the organism contains one of the deadliest toxins in nature.*

lusks like mussels, abalone and clams, heated, ground and mixed with terrestrial herbs, are touted to treat anything from hepatitis to impotence. Fish figure prominently in the literature as well. Stewed with chicken or rock candy, the backbone of the whale shark, the largest fish in the sea, is said to cure headaches. Mixed with vinegar, the ground spine of the stingray cures cancer of the stomach or the esophagus. Ashed and mixed with millet wine, the moray eel takes care of hemorrhoids. And the fried intestines of the pipefish, mixed with honey and millet wine, deal with impotence, sterility and insomnia– not such a strange combination if one comes to think of it. Many Chinese swear by these remedies even though in most cases there is little scientific evidence of their therapeutic value. But then again, in China, as anywhere else, autosuggestion can be a very powerful cure.

Remedies from the Pacific can also contain clues because people there always had access to a vast diversity of marine organisms. Unfortunately, few of their medical uses have been recorded and when the old healers die, a potential source of clues vanishes. New Zealand's Maoris, for instance, used certain sponges which, when applied to wounds, promoted their healing. It is possible that this was effective since it has now been determined that some sponges contain anti-inflammatory agents. But it is difficult to trace which sponges the Maoris used because traditional practices were replaced by modern medicine.

Sometimes ethno-historical leads put us on a different track. One of the best examples comes from Hawaii in the form of Limu make o Hana, the deadly seaweed of Hana, which had long been known to the people of Maui. During the 1960s researchers tried to find out more about this seaweed. From historical records it was clear that whatever limu contained, it was likely to be extremely toxic. Not only had it reportedly been used in the past to poison weapons, there also was a legend that explained that limu only grew on the spot where the ashes of an executed murderer had been discarded.

Another lead came from one Abraham Kauhi, who wrote to a Hawaiian newspaper in 1877. “Editor, Greetings” he penned, “Please permit me to tell something of the poisonous seaweed of Muolea at Hana.” Kauhi went on to describe the seaweed and its effects. “If you should pick it up with your fingers, they will rot and break off…”. He concluded by saying that limu was more potent than the deadliest poison, and that everybody was prohibited from going to the spot where it grew. Apparently, Hawaiian priests had placed a taboo on the area, warning that serious harm and misfortune would come onto anyone who disturbed it. Perhaps they feared that, if the deadly seaweed fell into the wrong hands, it could be used for evil purposes.

Naturally this sort of description perked the interest of researchers even more, but the ancient taboo continued to cast its spell-- the people of Hana on Maui simply did not want to discuss the matter. They warned that it would not only harm the scientists, but also bring themselves bad luck. Nonetheless, a few researchers persisted and in 1961 Philip Helfrich finally discovered the elusive organism in a small tide pool. It was collected on December 30 of that year. Curiously, that same night a fire destroyed the Hawaiian Marine Laboratory which housed the investigation, as if to confirm limu’s reputation for bad luck.

It was quickly determined that limu was not a seaweed, but rather a coelenterate; a group of animals that also includes jellyfish and sea anemones. Its toxin was isolated and proved to be one of the deadliest naturally occurring substances. Known as palytoxin, it has effects on the cardiovascular, gastrointestinal, respiratory and renal systems, and causes severe bleeding and histological (tissue) damage. It apparently does so by activating sodium channels in the cell membrane and thereby producing a massive increase in the permeability of cells to positive ions. The primary cause of death from palytoxin is congestive heart failure, triggered by vasoconstriction-- the narrowing of the blood vessels leading to the heart.

Substances like palytoxin are obviously far too potent to serve as drugs but they do have medical benefits. When diluted, toxins can exhibit biological activity that affects life processes in positive ways as, for instance, by strengthening the contractions of a weak heart. They can also serve as a model for synthesis or improvement of other drugs or allow us to gain insight in the biochemistry and physiology of life processes. For this reason, researchers examined whether palytoxin or a derivative, in a diluted form, could have beneficial effects on the heart. Others studied its potential use as an anti-tumor agent, designed to kill cancer cells, though the toxin also proved useful as a tumor promoter, i.e. a compound used to help understand the process of carcinogenesis.

There are other ethno-historical leads involving marine toxins, but finding such substances really requires going to sea directly rather than sifting through books. And actually the sea doesn't make the task too difficult, because it provides plenty of hints and clues. If an organism is slow and defenseless but somehow seems to thrive, it probably acquired some sort of toxin, or at least something very unpleasant, as a defensive mechanism. Otherwise, it would have vanished a long time ago.

Throughout their evolutionary history many marine organisms adopted that strategy to survive. The standard work on the subject, Bruce Halstead's Poisonous and Venomous Marine Animals of the World, ran more than 1450 pages when updated in the late 1980s and was still far from complete. Each of the organisms described in it is a potential source of a biomedically interesting substance.

The list of organisms that make use of venoms, and the bizarre means by which they manage to do so, reads a bit like a horror story. A number of fish possess venomous spines in their dorsal and pectoral fins and, while they generally use these only as a last resort, the wounds they inflict can be terribly painful. The sting of the weaver fish (Trachinus), for instance, is legendary. One fisherman actually amputated his finger on the spot in a desperate attempt to get rid of the excruciating pain. The stings of rabbit fish (Siganus), lionfish (Pterois) and the marvelously camouflaged stonefish (Synanceia) and scorpion fish (Scorpaenidae) are equal-

*Lionfish (Pterois sp) sport venomous spines that inject neurotoxins through puncture wounds. Several other fish species use the same strategy to protect themselves from predators, but few advertise it as conspicuously as lionfish do.*

ly dangerous. In several cases, they have been lethal and it is a most unpleasant death, with the victim trashing about in agony before losing consciousness and succumbing to cardiac or respiratory paralysis. Some invertebrates, such as the crown of thorns starfish and sea urchins, also protect themselves by means of poisonous spines.

The stinging cell is the prime defensive (and offensive) weapon of the animals of the phylum Cnidaria, which includes corals, jelly fish, sea anemones and hydroids. The stinging mechanism consists of tiny poisonous darts called nematocysts, which are coiled in a venom sac and shot into the prey upon contact. Most nematocysts are designed to paralyze small fish or invertebrates, but some animals possess venom that is powerful enough to affect, and even kill, man. Examples include Millepora, the so-called fire coral, and Physalia, also known as the Portuguese man-of-war. But the threat from these organisms pales in comparison to the danger presented by the box jellyfish (Chironex fleckeri). Box jellyfish have been responsible for some 75 documented deaths in Australia since 1884, and undoubtedly many more undocumented fatalities, especially in Southeast Asia. The animal's stings cause such intense pain and paralysis that many of the victims drown before the venom itself kills them. It has now been shown that the venom causes potassium leakage from cells into the blood, which in turn can lead to cardiovascular collapse.

Other organisms use fangs to inject venom, as do a number of sea snakes, or apply an array of specialized organs, as does the stingray with its tail or the cone shell (Conidae), which injects a long proboscis tipped with a venomous tooth. The blue-ringed octopus (Hapalochliaena), on the other hand, uses glands that inject a powerful toxin into open wounds created by its powerful beak. All of these animals have been responsible for human fatalities. In several cases, the toxin and its pharmacology remain unknown.

A number of animals have developed a more defensive strategy, producing poisons which become harmful only after they have been ingested. The sea hare, for instance, already mentioned as a model in neurological research, would seem an easy prey to any predator. It is relatively slow and seems defenseless, were it not for its ability to isolate certain noxious halogenated chemicals from its diet of algae, store these compounds in a special gland, and transport them to the skin where they are secreted as a mucus. This, in turn, gives the animal a very unpleasant taste, discouraging potential predators. Nudibranchs rely on a similar defense mechanism, using chemicals from their diet of sponges, and even advertising their unpleasant taste by a spectacular array of colors.

In similar fashion, a number of reef fish concentrate ciguatoxin, one of the most potent neurotoxins known. Ciguatoxin is produced by a tropical dinoflagellate and is passed on through the food chain from plankton-eating fish to their predators. In this case there may not be a biological advantage, because the toxin doesn't necessarily protect or affect the fish. In fact, it appears that only people, who are at the top of the food chain, can be affected. Since there is no method to detect the contamination, the toxin has been responsible for thousands of cases of ciguatera poisoning each year in the Pacific region. Mild cases of ciguatera produce gastric distress and numbness of the arms, legs and lips. More serious cases are fatal, causing central neurological depression, convulsions and respiratory failure.

Another relatively inconspicuous fish that has claimed its share of human victims is the puffer fish, also known as the globe fish, swell fish or blow fish– names derived from its habit to puff itself full of air or water into a balloon to intimidate potential predators.

Puffer fish conceal a more formidable defense mechanisms in their intestines, where bacteria produce the extremely lethal tetrodotoxin. People have known this for a long time; in fact, warnings about the puffer fish have been found among 5,000-year old Egyptian hieroglyphic inscriptions. Nonetheless, the puffer continues to claim its share of victims, particularly in Japan where some people consider the puffer fish, locally known as fugu, the epitome of gourmet dining.

*Nudibranches are slow and seemingly unprotected and would make for an easy prey if it weren't for their ability to isolate toxins from their diet of sponges. Several species make clear they make for a most unpleasant meal through a spectacular color pattern.*

*Fugu are being readied for auction at a fish market in Japan. In spite of their poisonous intestines the fish are served regularly at restaurants. Provided they are properly cleaned and prepared by licensed chefs, the fish make for a safe and delicate meal.*

When properly cleaned and prepared, fugu is safe. There are some 30 steps prescribed by law before the fish can be served, and fugu chefs are subjected to stringent tests before they are licensed. Fugu fanatics pay a good deal of money for a single serving, relishing the mild euphoria caused by traces of the poison. But some go too far, especially when they order preparations involving the use of internal organs. One of the most notorious deaths took place in Kyoto in 1975 when Mitsugoro Bando, one of Japan's most famous kabuki actors, lost the gamble. Bando had chosen pretty heavy stakes, however, consuming four servings of fugu liver-- a practice which is now strictly prohibited.

Tetrodotoxin was identified by researchers at the University of Tokyo as one of the most potent non-protein toxins known – about 100 times as toxic as potassium cyanide. It blocks nerve impulses and, in sufficient doses (about one milligram for the average size adult) will shut down the entire nervous system. Tetrodotoxin is actually found in or used by several marine organism, including the blue ringed octopus, some starfish and snails amongst others, indicating that the toxin is biosynthesized by symbiotic bacteria in several species. Despite its violent action, tetrodotoxin has proved useful as a neurophysiologic tool. In extremely minute concentrations, it also has been used as a painkiller, particularly for terminal cancer patients.

Sessile invertebrates such as tunicates, sponges and soft corals have proven to be a rich source of biologically active substances as well. Most of these animals are literally sitting targets; in order to survive they absolutely needed some sort of chemical protection. Several of the compounds they developed in the process have shown interesting pharmacological activity.

Sponges in particular are prolific sources of active compounds, confirming that Glaucus might have been onto something. While they won't mysteriously heal wounds or grant immortality, many sponge species do contain antibiotics and anti-viral as well as anti-inflammatory compounds. A good example is provided by Cryptotethya crypta, a massive Caribbean sponge, which yielded compounds that are used in the AIDS drug AZT and several anti-viral and anti-cancer drugs. Some sponge extracts have also been shown to have effects on the cardio-vascular system. Similar substances have been found in soft corals, sea anemones and sea cucumbers.

Gorgonians or sea fans have been found to contain lophotoxin, an extremely potent neurotoxin which blocks impulses between nerves and muscles. Lophotoxin has been very useful in studying the transmission of chemical signals between nerves and muscles, and in much smaller dosages may become the basis of a drug to treat disorders associated with the faulty transmission of these signals. But the sea fan's claim to medical fame came in 1969, when a number of Caribbean gorgonians were found to contain large amounts of prostaglandins– powerful chemical transmitters that function as pain detectors and can create hormone-like effects in the human body. The discovery electrified the biomedical community because until then prostaglandins had only been available in very small quantities. Pharmaceutical companies suddenly became aware of the potential of marine organisms as a source of interesting compounds and started active collection programs, at least until they learned to synthesize prostaglandins in the laboratory.

While toxicity is one clue to biological activity, there are many more leads. Organisms that prevent overgrowth, for instance, usually contain a compound that keeps other organisms from growing on or near them. In some cases these substances have been found to exhibit strong anti-microbial activity. Other clues may be provided through symbiosis, or by examining chemicals that seem to trigger behavioral changes in other organisms.

Even obscure and primitive animals such as the tunicate, or sea squirt, may teach us something. From one, an immune-suppressor was extracted that prolongs skin graft survival in mice. Since mice have an immune system similar to that of humans, a substance like this could be effective in inhibiting immune responses that cause rejection problems in human organ transplants or tissue grafts. It was also

*A gold mouth seasquirt (Polycarpa aurata), one of about 3,000 species of tunicates. Tunicates are relatively simple organisms, but they are able to isolate certain chemicals to prevent overgrowth and impart an unpleasant taste to predators. These chemicals have often shown interesting biological activity.*

*A close-up of boulder brain coral (Colpophyllia natans). Aside from providing a ready supply of food, the zooxanthellae in coral also provide the coral polyps UV absorbing agents, allowing them to stay exposed to sunlight for long periods of time. That same substance can also be used in sunscreens for humans.*

found that tunicates are one of a few types of organisms that accumulate uric acid and calcium oxalate crystals. In people these become kidney stones, which can be very painful and need to be removed. The sea squirt, in contrast, doesn't possess a kidney. Instead, it manages to dissolve the stones in its renal sac, using a chemical that appears to be twenty times more powerful at inhibiting crystallization than urine. Obviously that sort of compound could be of interest to medical researchers as well.

Corals provide one of the best examples of how behavioral aspects may provide clues to interesting substances. Coral reefs are the result of a symbiotic relationship between coral polyps, which are animals, and zooxanthellae, which are unicellular plants. This unique symbiotic relationship allows the polyps to build enormous structures like the Great Barrier Reef in northern Australia, but it also creates a problem for them. Plants need sunlight for photosynthesis, and hence need to be relatively close to the surface. Animals, on the other hand, need to protect themselves from the harmful effects of ultraviolet (UV) light. While the effects of ultraviolet radiation gradually diminish with depth, they are powerful enough to have significant biological consequences up to a depth of several meters, where many corals grow.

Clearly coral polyps had to have some sort of protection to survive constant exposure to the sun. Scientists at the Australian Institute of Marine Science decided to figure out how they did so. In the process, they found out that the zooxanthellae gave the polyps more than a ready source of food; they also provided them with UV absorbing agents which protect the animals from the damaging effects of ultraviolet radiation.

Next the researchers wondered whether this substance, if isolated, would work for humans as well as it does for coral polyps. They were able to isolate the UV absorber, and it quickly became clear that the substance worked on humans just as well as it does for the coral polyps. In fact, the resultant commercial product is just as effective as anything on the market today, yielding yet another product from the sea that can help treat, or rather prevent modern disorders. Equally important, the sunscreen does not adversely affect the corals themselves, as do chemicals like oxybenzone in commercial sunscreens. Thousands of tons of sunscreen wash of swimmers, divers and snorkelers every year, contributing to coral bleaching and affecting coral reproduction. The sooner these products can be replaced by less harmful compounds, the better the chance of coral reefs to withstand the onslaught of environmental challenges they are being confronted with.

Another example of a marine organism contributing to an understanding of human disorders is provided by the shark. Scientists have long been intrigued by the fact that they didn't find many tumors in sharks. Among tens of thousands of sharks examined worldwide over the past twenty five years, a proportionally small number of tumors were found. And of those, few appeared to be malignant. Tumors also appeared rare in close relatives like skates and rays which, along with sharks, comprise the order of cartilaginous fish (Chondrichthyes). On the other hand, tumors are certainly no rarity in bony fish (Osteichthyes), as any fisherman can attest.

To solve this mystery, scientists first turned their attention to the shark's blood, discovering antibodies which had the ability to destroy a wide variety of cancer cells. But it was determined that the active agent was of no use in human cancer treatment because, when injected, the human immune system destroyed it. Yet there was more that seemed worth investigating. Possessing an effective immune system does not necessarily explain the absence of tumors. There probably was something else at work; a substance or compound which prevented tumors if not from occurring, then at least of controlling their growth.

Tumors require a significant amount of blood to sustain their prolific growth. They usually do so by forming a mass of blood vessels– a process which is known as vascularization– and diverting nutrient-rich blood from other tissues. To achieve this, the tumor cells secrete a substance which stimulates the growth and spread of new blood vessels to the tumor site. Once diverted, the blood supply allows the

*Though they were long thought to immune to cancer, sharks do get tumors and may die as a result of them.  But it is very difficult to induce cancer in sharks and close relatives like rays, which seems to imply the animals are able to deal far better with carcinogens than other vertebrates.*

tumor cells to rapidly increase in size and number and become a life-threatening problem.

In the shark, this didn't seem to happen. It appeared as if there was an inhibitor; a substance which actually prevented tumor cells from obtaining their own blood supply. A clue to this inhibitor came in the late 1970s when Robert Langer at the Massachusetts Institute of Technology showed that cow cartilage contained a substance that prevented the growth of new blood vessels. In fact, when injected into rabbits and mice, this substance stopped tumor growth. His results called for further study, but were hampered by a shortage of source material since it took up to 25 calves to obtain one pound of cartilage. But Langer knew there were animals whose entire skeleton consisted of cartilage: sharks. If their skeleton contained the same inhibitor, his supply problem would be solved.

Much of this work was continued by Carl Luer at the Mote Marine Laboratory in Sarasota, Florida – an institution with a strong reputation in shark studies. Luer actually used two approaches to determine how sharks deal with cancer. In the first, he exposed the animals to potent carcinogens, known to cause cancer in most vertebrates, to check whether the disease could be induced in sharks. It proved impossible, even after more than ten years of testing. Nothing resembling even the earliest stages of a tumor was ever observed. To understand how sharks are able to handle these carcinogens, Luer and his colleagues turned their attention to the detoxification process in the animal's liver, because it obviously was doing something which most vertebrates, including humans, are not able to do.

Luer's second approach follows Langer's line of work on cow cartilage. He has shown that the shark's skeleton too contains a substance which inhibits the spread of new blood vessels. How or why this happens is not yet clear. Luer and his colleagues hope that this research may eventually lead to cancer therapies that limit the harmful side effects of current treatments which, while designed to kill tumor cells, often damage other cells in the process.

The process of purifying and testing potential tumor inhibitors will take years, but unfortunately some people were not willing to wait that long and started marketing shark cartilage as an effective treatment for a variety of diseases, including cancer. In the meantime, a variety of studies have clearly demonstrated that these cartilage-based dietary supplements will not cure anything, least of all cancer since the proteins involved in inhibiting the formation of new blood vessels are digested when taken orally, ruling out any therapeutic action. In spite of the evidence, there still is a strong demand for the product, often from patients with few prospects for recovery. That demand in turn has intensified the shark fishery, already under pressure from the equally nonsensical craving for shark fins. There was an appeal at one point to the notion that one of the ocean's most dangerous animals, often portrayed as its ultimate villain, could help us defeat the ultimate villain among human disorders. If that is ever to be the case, killing sharks for cartilage or fins is not the way to go about it.

No matter how well we look for toxic or behavioral clues, with hundreds of thousands of different organisms in the sea, many of them poorly studied, we are likely to miss a number of potentially useful substances. To avoid this, scientists have developed a screening approach. It essentially involves collecting a wide variety of organisms without paying any particular attention to clues, and then testing (or screening) their extracts for biological activity.

The advantage of this approach is that it is very methodical and unlikely to overlook potential drugs. The disadvantage is that it is very time-consuming. First, crude extracts from all the collected animals have to be prepared, usually by grinding the organisms in alcohol and filtering the mixture. The biological activity of this mixture is then tested by means of a series of bioassays, involving a line of cells or lab animals. If the mixture shows some activity, further bioassays are needed to gradually purify the extract. Once the active substance has been isolated, chemists are called in to identify the compound, or at least assign it to a general class of chemicals.

## HEALTH BENEFITS

Modern disorders are to some extent the result of where and how we live as well as what we eat. The where part is not always under our control, but how we live and what we eat involves personal decisions. And here too the sea can make a contribution. It has long been known, for instance, that eating fish is healthy because fish protein contains an excellent combination of essential amino acids, which cannot be synthesized by most animals and must thus be supplied already manufactured. There also is strong evidence that the oils in some fish may help in reducing heart disease, which remains the principal cause of death in most industrialized nations.

Clues to this observation came when Danish scientists sought to explain the low incidence of heart disease in Greenland Inuit, as compared to their compatriots on the mainland. One of the principal differences they noted was in the diet: the Inuit ate a lot of fish, while the people in Denmark were fond of dairy and meat products. These differences showed up in the two populations' cholesterol levels: the Inuit had a very low level of blood cholesterol, while that of the mainland Danes was far higher. These results were later confirmed by other studies. One compared the diets in two Japanese villages– one a farming community, the other a fishing village. Here too the incidence of heart attacks was much lower in the fishing village, where people naturally eat more fish.

Scientists have determined that these differences are caused by the composition of fats in fish. Fish fats are different from the fats found in meats or dairy products. They keep the blood thinner, preventing it from clotting around cholesterol plaques in arteries. This reduces the chances of ailments like arteriosclerosis and myocardial infarction – a heart attack caused by coronary obstruction, still one of the main causes of death in modern society.

Most nutritionists are not ready to recommend daily fish oil capsules, but few will disagree that a regular dose of fish in the diet is a healthy practice. Some scientists believe that fish may have additional health benefits by reducing the incidence of chronic diseases like arthritis and migraines. While it is too early to confirm these benefits, it does show that there are many ways in which the sea can help us lead healthier lives.

*Good news for humans but bad news for fish: eating a regular serving of fish, especially fatty fish, will lower reduce the chance of heart disease.  A recent study also confirmed that the omega-3 fatty acids in fish like mackerel, salmon and sardines will also lower the incidence of colon cancer, especially if those fish servings replace red meats.*

Screening is increasingly being used to search for substances with advanced pharmacological activity, such as anti-cancer and cardiovascular drugs. The Natural Products Branch of the National Cancer Institute in Bethesda, Maryland, for instance, has been combing the planet for possible anti-cancer agents and anti-viral drugs for several years. The program is not limited to the oceans, devoting a good deal of attention to tropical rain forests where only a fraction of organisms have ever been tested for bioactivity. But with the potential of marine organisms becoming increasingly clear and the means to collect them available, the oceans are certainly getting the attention they deserve.

Among the organizations that were contracted to supply interesting substances was the Harbor Branch Oceanographic Institution in Fort Pierce, Florida, which searched the oceans for all sorts of organisms, many of them obtained from great depths with deep-diving submersibles. The National Cancer Institute has also requested other organizations and institutions to send promising compounds. A laboratory has been set up in Frederick, Maryland, capable of screening 10,000 substances a year against 100 cancer cell lines and against the AIDS virus. Any substance that clears these screens goes through further tests and is eventually sent to clinical trials, to check whether it is safe to use in humans.

Few marine compounds make it from discovery to market, but there are promising signs. In the late 1970s, Ken Rhinehart, a chemist at the University of Illinois, discovered an interesting group of chemicals in colonial tunicates. Since the animals formed a green leathery crust on rocks as well as organisms, Rhinehart assumed the chemicals were produced to prevent overgrowth. When subsequently tested, the compounds indeed showed strong anti-viral and anti-microbial activity along with strong anti-tumor properties. In fact, the most potent of the chemicals, didemnin B, underwent clinical trials and was been tested against a variety of human cancers, including leukemia, melanoma, and breast, ovary and kidney cancer. Unfortunately the compound caused severe allergic reactions in several patients, forcing the trials to be halted.

*The Harbor Branch Oceanographic Institution's Sea-Link submersibles proved perfectly suited for collecting marine organisms from depths to 3,000 feet. The submersibles were retired in 2011 after a career spanning nearly 40 years.*

*The tunicate Ecteinascidia turbinata was the source animal for ET-743, one of the first cancer drugs of marine origin.*

Rhinehart and his colleagues had better luck with Ecteinascidin-743 (ET-743), a potent compound which was isolated from *Ecteinascidia turbinata*, a Caribbean tunicate. As with other biologically active compounds, the organism relied on symbiotic micro-organisms to produce minute quantities of ET-743. In fact, it was estimated it would take five tonnes of tunicates to produce the 5 grams needed for clinical trials. For that reason it was essential to figure out how to produce ET-743; a task that took several years of additional research and testing. ET-743 is now on the market as a treatment of for prostate, breast and pediatric cancers. The compound interferes with the DNA of tumor cells and prevents them from replicating.

Another ocean-based possibility is provided by dolastatin 10, a compound first found in the sea hare *Dolabella auricularia*. As with ET-743 the compound is produced by micro-organisms that are part of *Dolabella's* diet. Here too the concentrations of the compound in the sea hare were found to be extremely small, with one ton of the animals yielding no more than 29 mg of the valuable chemical. Fortunately its structure proved to be relatively simple so that subsequent testing did not have to depend on live animals. Dolastatin 10 showed potent anti-cancer activity, especially against melanoma, and in 1997 was placed in Phase I clinical trials. Its effect on the human body proved less effective than in test animals but derivatives of the compound showed more promise, with one synthetic derivative now on the market and being used in conjunction with antibodies in the treatment of a variety of cancers.

Other candidates include bryostatin, a compound obtained from bryozoans, which not only shows promise as a cancer-fighting drug but is also being tested for the treatment of Alzheimer's. Bryostatin indeed has been shown to enhance and possibly restore memory by rewiring previously damaged connections in the brain. Even marine plants contribute to our array of weapons against cancer, with green algae *Bryopsis* containing bacteria that produce kahalalide F (KF), a compound that has proven very adept at destroying prostate and breast cancer tumor cells. KF has also been found in a number of sea slugs, which feed on these algae, and appears on its way to become another potent weapon in our struggle to combat and hopefully defeat cancer.

How many more marine drugs will make it to the market is unknown. Discovering and isolating a compound with interesting properties from a marine organism is one thing; producing a drug another. In fact, developing a drug typically takes 10 to 15 years and requires massive investments. These budgets are outside the range of most scientific organizations; they require the active participation of the pharmaceutical industry. But drug companies, with a few exceptions, have remained cautious, preferring to let science do the screening before committing the massive investments required.

Whatever the outcome, as we begin to uncover the sea's biomedical potential, it is worth reflecting on some of the ancient legends. Glaucus discovered a sponge with healing properties and became immortal; Gilgamesh retrieved a magical sea plant which restored youth. They and others instinctively turned to the sea to discover the secrets of life and health. Increasingly so are we, seeking and hoping to confirm mythology's belief in the sea's healing powers. But that hope and that search can only be realized if we strive to maintain the ocean's health as much as we seek to improve ours.

*Evia, Greece*

*Tradition holds Glaucus found his healing sponge in these waters off the Greek island of Evia. Though his story is no more than a myth, we are turning to the sea as well in our quest for longer and healthier lives.*

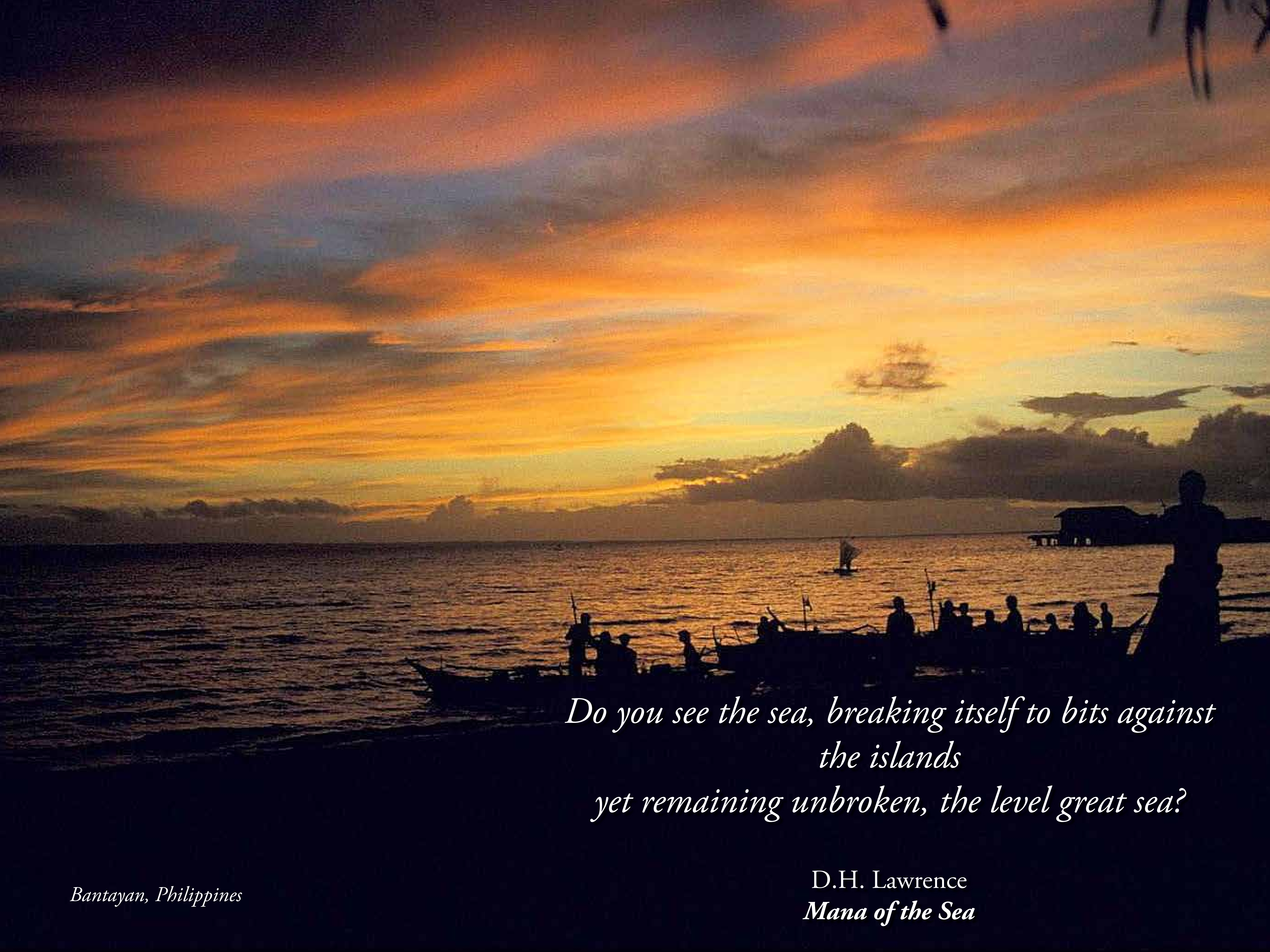
# SUMMARY

*Several myths and legends accord the sea healing powers because it cleans and refreshes both body and spirit. But this healing role may also contain an intuitive element. Without the sea conditions on the planet would have been far too extreme for life to develop. Moreover, the earliest life forms originated in water and all of us carry traces of these watery origins in our embryonic development. Equally remarkably, the blood that runs through our veins is similar in the composition of its salts to seawater – a reminder of whence we came.*

*Today, science is creating other ways the sea can help us lead longer and healthier lives. We are all subject to disease and aging and while medical science has made outstanding progress in treating disorders, more can be done. To do so we need to understand how life processes function or malfunction, a process aided by studying their equivalent in simpler organisms. The sea provides many possibilities for this. Some are the descendants of ancient life forms while others contain particularly well developed systems, or yield insights not found in terrestrial organisms.*

*Marine plants and animals can also provide us with substances like drugs to help cure or alleviate disorders. At present most natural drugs are derived from terrestrial organisms, particularly plants, but there is nothing to preclude the sea from being a rich source of biologically active substances as well.*

*Finally, the sea also offers a healthy source of food, with seafood providing high-quality proteins and fish containing fats that lower the chance to some of modern society's principal disorders. But for us to benefit from that offering we have to start managing the sea's living resources far better than we have to this day, as will be discussed in the next chapter.*



*Do you see the sea, breaking itself to bits against the islands
yet remaining unbroken, the level great sea?*

D.H. Lawrence
***Mana of the Sea***

*Bantayan, Philippines*

# HARVEST

Seated on the dirt floor of a small hut, the man picks up a small soda bottle and checks it carefully for any signs of damage. Once approved, he begins to fill it, first with sawdust, then very carefully with some powder, and more sawdust to top it off. He packs it tightly with his finger, and inserts a fuse. Alongside the fuse he places a match, its head facing outward. The same ritual is repeated three or four times. Then the bottles are gently placed in a reed basket and taken to a fishing boat.

The scene is a small fishing village in the Philippines, but it could have taken place in Indonesia or far-away Tanzania. Fishermen in tropical waters know that fish tend to congregate around reefs. And they know that it is difficult to get to them. Nets get stuck on the coral, fishing with line and bait takes time, spearing the fish is tiring and sometimes dangerous. So they've come up with a different solution: they simply bomb the reef, using crude home-made devices packed with gun powder. As fishing techniques go, it is a pretty effective one.

The boat motors out for a couple hours, until the land is no more than a thin green line along the horizon. Then it stops, and the anchor is thrown out. A young boy, eleven or twelve perhaps, jumps in the water. He has a set of goggles and one crude wooden fin tied to a foot, takes a deep breath, and dives. His shape can be followed as he reaches the reef a few meters down, and furiously paddles along it for a while. Then he surfaces, jabbering excitedly.

A smaller boat is launched, the basket with bottles is gently lowered into it, and then the man and the boy paddle away. Every so often, the boy puts his head in the water, peeking below. At one point they stop. The man stands up, grabs one of the bottles and lights the fuse. He holds it for a while, to make sure the fuse has lit, and then he throws it out. With a graceful arc, the bottle hits the water and sinks. Then there is a massive blast, and a geyser of water shoots high into the air.

It is quiet for a moment, but not very long. A few more boys put on their goggles, grab a small net, and jump over board. The water is murky at first, but they quickly swim to the site of the explosion. Where the bottle landed, massive chunks of coral have overturned. Even further out, the coral has been irretrievably damaged, with sections sheared clear by the blast. Throughout the devastation are fish: many of them dead, others simply stunned by the explosion, and unable to move. The boys dart from one to the next, grabbing and stuffing them into the net before heading to the surface for a breath of air.

Once the reef is picked clean, the boats move on. The same routine is repeated three more times that day. Three more times the bottle bombs destroy a reef that took hundreds of years to build; all this for no more than a few days' worth of food.

Reef bombing is easy to condemn. After all, it seems so appallingly shortsighted. The destruction will take years to rebuild. Most sites won't see fish for months, or even years. Efforts have been made to halt this destructive practice, with governments cracking down on the perpetrators. The results are beginning to show. Reef bombers won't go out in broad daylight any longer. They wait for dusk or the cover of night, or have switched to less noticeable ways of scouring the reefs.

It is easy to criticize, but how different have our supposedly more refined fishing methods been? In every sea and every ocean, fish stocks have been chased to near extinction. Our instruments don't quite make as loud a bang as a home-made bomb, but they have been no less destructive.

It seems we all have something to learn when it comes to harvesting the sea.

Fishing, or rather food gathering, was our first use of the sea. Long before they ever ventured out at sea in a boat or a raft, people searched for its bounty along the shore, collecting shellfish like mussels and oysters. We don't know

*Holding his breath, a young boy collects dead and stunned fish from a bombed reef.  It will take years for the reef to recover, if ever it does. Though illegal, the practice still continues in the Philippines, Indonesia and Tanzania.*

when they began doing so; only that they did so hundreds of thousands of years ago. The shell mounds they left near stone-age dwellings are proof of that.

Some 40,000 years ago, people began catching fish with spears and harpoons. They also developed something called a gorge: a small bone rod, pointed at both sides, with a line attached about the middle. Baited with small fish, a pull on the line wedged it in the throat of the fish that tried to swallow the bait, so that it could be pulled in. It doesn't take a great deal of imagination to see this simple tool as the precursor to the fish hook, though that step took many more years.

The first hooks, carefully crafted out of bone, date back to the Neolithic Age, some 10,000 years ago. By 5,000 B.C. copper hooks were in use, and shortly thereafter nets and traps had been developed, allowing people to capture fish in larger quantities. Around this time they also began to venture out in boats or rafts in search of more and larger fish. On land people were gradually turning from hunting to herding and farming at the time, but at sea they remained hunters. Many still are until this very day.

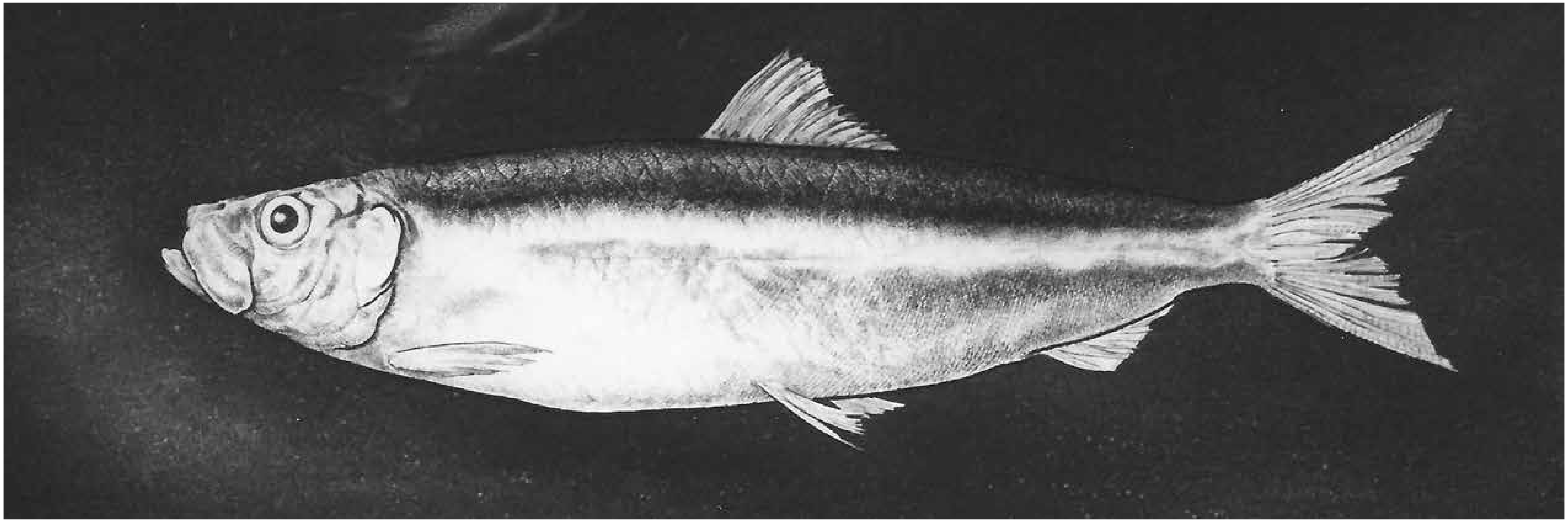
Fishing was widely practiced throughout the ancient world. Egyptian murals and boat models show that the early Egyptians were accomplished fishermen. The Minoans, Greeks, Phoenicians and Carthaginians also harvested the sea and in ancient Rome seafood was an important, and highly appreciated, commodity as many Roman mosaics show. In the East as well, the sea was a vital source of food. Fishing techniques were described by Chinese writers many thousands of years ago, revealing that the fishing methods used in the West – nets, traps, spears and hooks – were well known. Similar methods were used in Polynesia, North America and northern Europe; in short, wherever people lived near the sea.

Over the years, fishing methods gradually improved. Nets and traps were made from hemp rather than grasses or reeds, and fishing techniques were adapted to particular fish. It was found, for instance, that pelagic fish like herring and mackerel, which inhabit the water column, could be captured with drift nets: vertical walls of netting

*Ancient art often depicts fishing practices, revealing fish and other seafood were an important part of the diet.*

which caught the fish as they attempted to swim through. Bottom dwelling fish like cod and haddock, on the other hand, were better taken by towing a bag-shaped net, or trawl, or by using baited hooks. And still other fish could be gathered, it was found, by setting traps or by spearing them. Year after year, the sea hunter perfected his techniques though his tools– hook, spear, net and trap– remained largely the same.

Better fishing methods allowed fishermen to take more fish than they needed. To keep the surplus edible, it had to be preserved. This could be done by drying the fish in the sun, though rainy regions obviously had to rely on something else. Fish sauces and fish pastes, most of them fermented, provided one alternative. Elsewhere the catch could be smoked or pickled in salt, so that it could be retained for many months.



*The Atlantic herring (Clupea harengus). Abundant, easy to catch and preserve, herring played a vital role in European history.*

Salting fish proved particularly important, in no small part because of the demographic changes Europe experienced during the 11th and 12th centuries. People were moving from farms and villages to towns and cities, which rapidly expanded. The rising demand for food was only partially met by increases in agricultural productivity. There was need for more, especially for inexpensive animal protein, and salted fish, especially salted herring, provided the answer. During the long winter months and extended periods of Lent, many people in northern Europe ate salted herring. Cheap and plentiful, it proved a blessing.

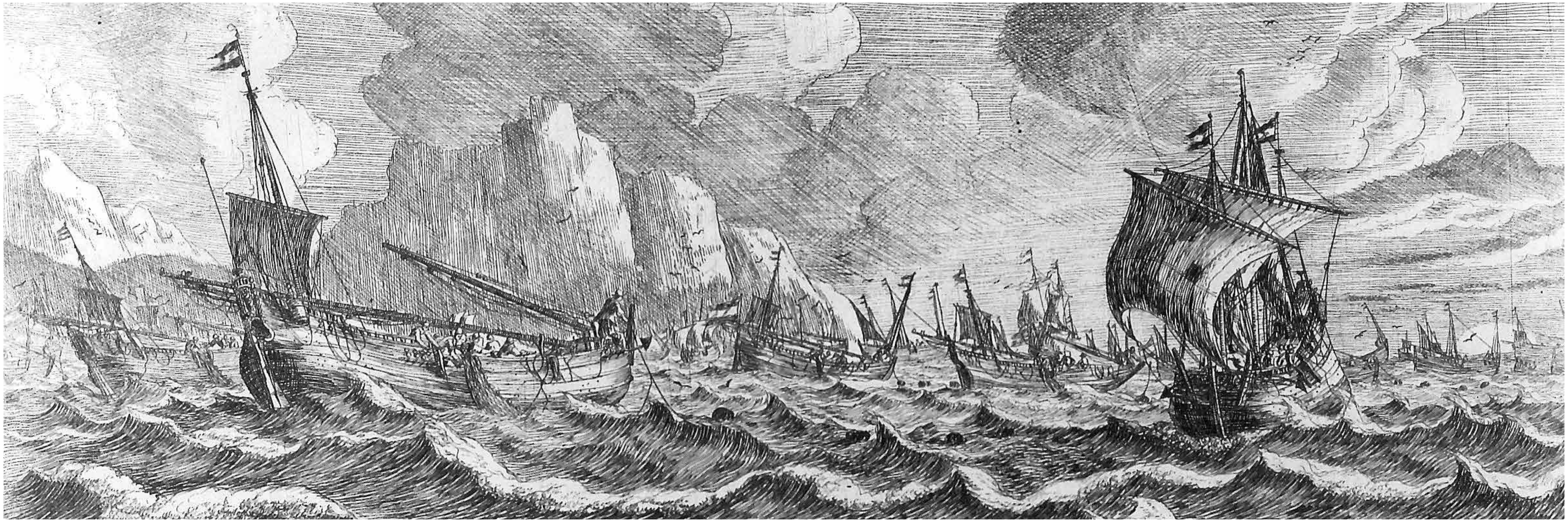
From the tenth through fourteenth century, the herring fishery was centered in the Baltic Sea. Every year Danish and Swedish fishermen hauled in large catches which were smoked or packed with salt, and then sent throughout northern and central Europe. But early in the fifteenth century, the Baltic herring schools abruptly disappeared. No one knows exactly what happened, though it appears that a change in currents altered the fish's food supplies and larval drift. Within years, the stocks had collapsed, depriving thousands of people in Denmark, Germany and Sweden of their livelihood.

From the Baltic, the herring and the fishery moved to the North Sea, where Holland quickly seized the initiative. Before long its fishermen ranged all over the area, hauling in massive numbers of the silvery fish. By the early 16th century they were using large, three-masted vessels called busses to handle the rapidly growing demand for herring. This was a radical improvement because it allowed the vessels to stay on the fishing grounds, rather than spend time ferrying back and forth to port. After the nets were brought in, the catch was gutted aboard and packed head to tail in wooden barrels with a layer of salt between each layer of fish. The barrels were then made as airtight as possible, which allowed the fish inside to be kept edible for up to a year.

The Dutch government kept a close eye on the fishery. In 1519, for instance, it enacted a herring law which prescribed the quality of wood for the barrels and the kind of salt to be used for the brine, amongst other things. More important, the new law regulated the mesh size of nets and limited the length of the fishing season to approximately six months. No herring could be caught before the feast of John the Baptist in late June or after Christmas, when the fleet returned to rest and refit. These were sensible measures, because they helped ensure that young herring would be given a chance to mature.

During the 16th and 17th centuries, the fishery grew at a phenomenal rate. Dutch merchant Pieter de la Court estimated in 1662 that there were 1,000 herring busses and some 5,000 other fishing boats in Holland, crewed by 30,000 fishermen. The vessels operated all over the North Sea, from the Shetland Islands in July to northeast England in late summer, and further south as fall progressed. De La Court estimated that some 450,000 people– nearly a quarter of the Dutch population– were employed one way or another in fishing or related industries.

By delivering a quality product at a low price, Holland monopolized the important herring trade, growing



*A fleet of Dutch herring busses at work off the English coast. Their activities would lead to the first major conflict over fish.*

wealthy in the process. In fact, the Dutch owed much of their maritime strength and wealth to the humble herring. People were not exaggerating when they said that Amsterdam was built on herring bones. Holland's mastery of the sea also extended to trading, and by the 17th century its merchant fleet was the largest and busiest in all of Europe.

While this showing of maritime strength made Holland a country "that all other nations and countries do admire", as Tobias Gentleman wrote in 1614, not all of his countrymen shared that admiration. English fishermen in particular were not happy with the thousands of Dutch fishermen off the coast. To limit their activities, James I in 1609 issued a proclamation, announcing that anyone fishing off the British coast would henceforth need a license. But the Dutch ignored it, and simply continued fishing. For lack of adequate naval power James could not enforce his decree, but that was not the end of it. England was determined to teach the Dutch a lesson.

At first, the controversy was limited to discussions over the legality of the English claim. To justify Holland's position, the Dutch government turned to Hugo Grotius, a young lawyer, who argued that the sea "since it is as incapable of being seized as the air" could not be attached to the possessions of any particular nation. Moreover, "because it is so limitless" the sea belonged to everyone. Anyone should be free to fish, Grotius concluded, because the sea was inexhaustible.

Grotius was asked to represent these views on two occasions, first during a meeting in London in 1613 and two years later in The Hague. Though there was a serious effort to settle the matter amicably, it soon became clear that neither side was willing to budge. The Dutch insisted that the sea was common to all, while the English claimed they


*Hugo Grotius apparently showed legal skills at a very early age. He would later become known as the father of international law.*

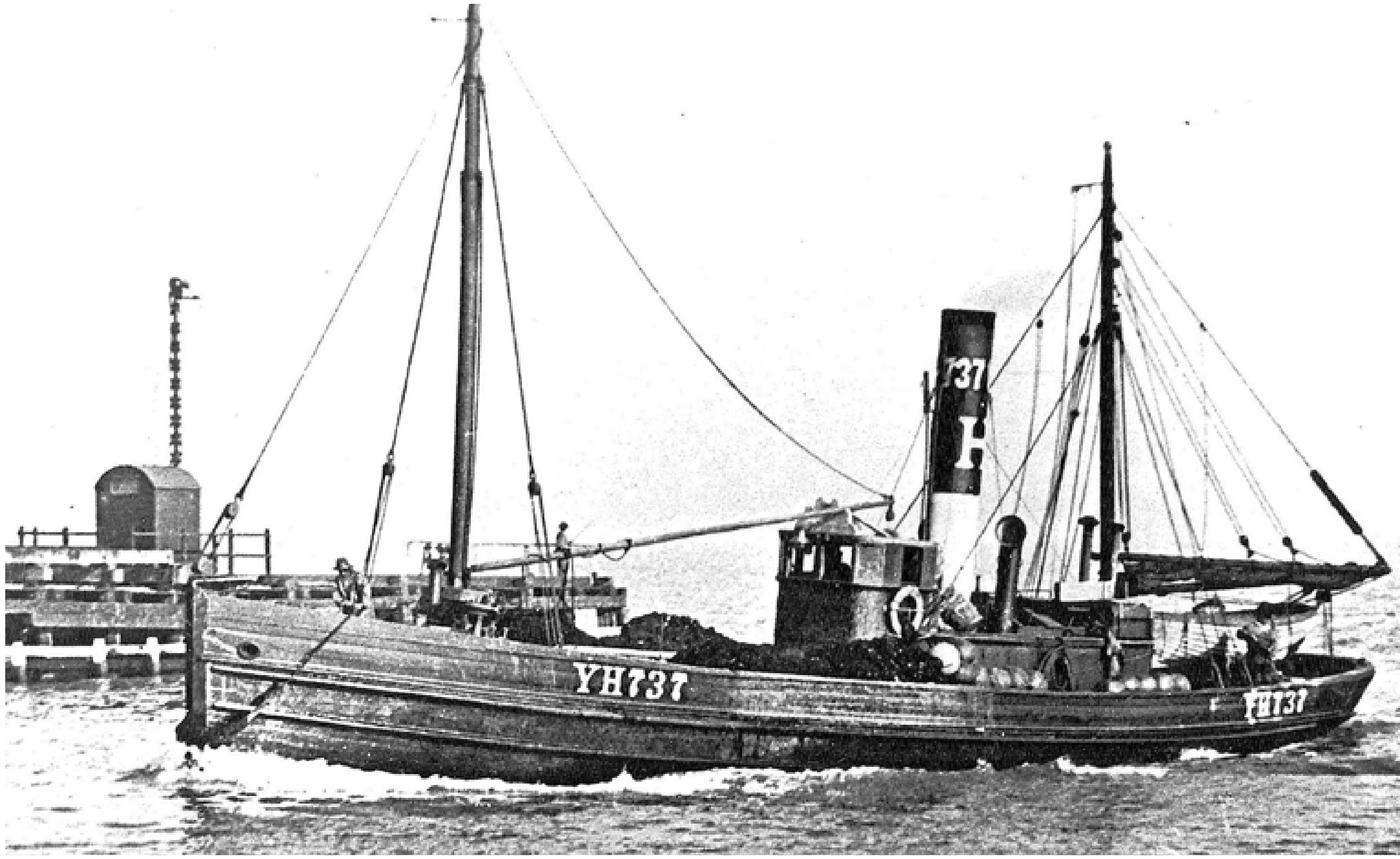
could hold sovereign rights over it. Holland and England also competed for trade with the East and West Indies, which created even more tension. By the middle of the 17th century war had become inevitable.

Three bitterly fought naval wars followed, from which the Dutch never fully recovered. Thousands of their fishermen were killed, and Holland's great fishing fleet naturally dwindled into a much smaller one. But the Dutch did score a legal victory of sorts. While Grotius did not live long enough to see the outcome of the conflicts, his views on the freedom of the sea would survive for a long time to come. In fact, it did not take England long to realize they made sense, especially to countries with maritime ambitions. By the late 17th century the country had reversed its position, and turned into one of Grotius' staunchest advocates.

The decline of the Dutch fishery allowed the British herring industry to expand, and later Norwegian, German and Swedish fishermen became active on the North Sea's fishing grounds as well. Their crews followed the herring schools on their annual migration, often staying away for weeks at a time. It was brutal work. The long drift nets had to be set, which could take anywhere from one to two hours, and then hauled in, hand over hand, while removing the fish; a task that required six hours of backbreaking labor. On many boats, the catch was then gutted so that it could be pickled and stored away.

Though the vessels were many and the work hard and dangerous, there was certain harmony to it all. The sailing fleets never took away too much, leaving sufficient fish for next year's harvest. But during the late nineteenth century, sailing vessels began to be replaced by steam drifters. Fishing was now less at the mercy of winds and tides, allowing the vessels to stay longer on the fishing grounds and landings quickly increased. The introduction of ice aboard helped catches stay fresh longer, while the development of railroads allowed for quicker transport to growing urban populations.

Throughout the early twentieth century, the demand for herring and other fish steadily grew and the fleets expanded




*A Great Yarmouth steam drifter returning to port. Hundreds of these vessels would follow the herring schools throughout the North Sea during the fishing season. Steam vessels were much faster at hauling nets and returning to port, and catches rapidly increased. Only one of the drifters remains: the Lydia Eva (YH89), now permanently docked in her homeport.*

accordingly. Holland and Germany fielded drifter fleets of hundreds of vessels, most of them active around the Shetland Islands. Danish and Swedish fishermen pursued the stocks in the eastern North Sea. Belgian and French vessels covered the southern North Sea, while a combined English and Scottish fleet of more than a thousand vessels sailed for the herring grounds from Lowestoft and Great Yarmouth.

Following the Second World War, technological innovations succeeded one another in rapid succession. Drift nets were replaced by trawls and purse seines. Synthetic fibers permitted the use of larger nets, which were swiftly hauled in with power blocks. And sonar became available to locate the fish. Not surprisingly, catches soared. Between the end of the war and 1955, in just ten years, the North Sea's

*Great Yarmouth became the largest herring port in the world. In 1913 more than a thousand vessels regularly used the port, bringing in up to 800,000 fish a days which were cured and processed quayside. By 1970 there were only 5 herring vessels left. Today there are none.*


herring catch increased fifteen-fold to nearly one and a half million tons. So much fish was taken that a good portion of the catch had to be sent to factories to be converted into fishmeal for livestock feed. It was boom time in fishing ports along the North Sea. Fishermen invested in more and even larger vessels, confident that catches and profits would rise even higher.

Elsewhere fish landings also increased spectacularly. During the 1950s and 1960s, the world's total fish catch rose at an astonishing rate of six percent per year, from 20 million tons in 1950 to nearly 65 million tons in 1970. This increased flow of food was, of course, perceived with much optimism. Fishing was one area, it seemed, where technology had paid off. But had it really?

The answer first became clear in the North Sea. During the mid-sixties, the herring stocks began to disappear. In 1964, the Southern Bight herring stock collapsed, forcing Dutch and Belgian fishermen to move elsewhere. A year later, the Dogger Bank stock ceased to exist, and further north the Buchan stock disappeared. One by one, year after year, the herring populations vanished, leaving the fleets idle.

By the early seventies, the bubble had burst. In 1975 it was estimated that the entire North Sea herring population had been reduced to less than a tenth of what it had been just 15 year earlier. Holland had to lay up its immense herring fleet, while the German fleet was halved. Danish and Norwegian purse seine trawlers, which had decimated the stocks, switched to sprat and mackerel. The great East Anglia fleet of steam drifters was laid up, as did the herring fleets from Humber and Scotland. But it was too late. The North Sea's most important fishery, which had fed millions of Europeans for hundreds of years, was largely gone.

No one was sure what caused the disappearance of the Baltic Sea herring 500 years earlier, but in the North Sea it was all too clear what triggered the collapse of the herring stocks: too many fishermen and far too many boats. Europe's fish factories had demanded more fish, and fishermen obliged, pursuing the stocks to such relentless extent that they all but disappeared. Even worse, no one could claim the collapse came unannounced. It had been building up for years, and for all this time fishery scientists had sounded warnings. They observed how fishing with trawls and purse seines, rather than with drift nets, hauled up all the herring, including immature fish which should have been left until the following year. They noticed that each year's record catch left fewer fish to replenish the stocks. They warned their governments that a crash was inevitable. But their advice went unheeded and true to their predictions the North Sea's herring fishery collapsed.

Other fish stocks were being depleted too. Aided by sonar, larger nets and stronger engines, fishermen throughout the world hauled in increasing amounts of fish. Before long, the North Sea's cod and haddock stocks declined.

*All the way on top of the marine food chain are humans. Reported catches average some 80 million tons a year – providing more than 10 kg of caught seafood for every person on the planet. With freshwater and aquaculture yields added, the per capita total nearly doubles. On average 15–20 percent of animal protein consumption is ocean-derived, meaning the sea plays a very important role in global food production.*

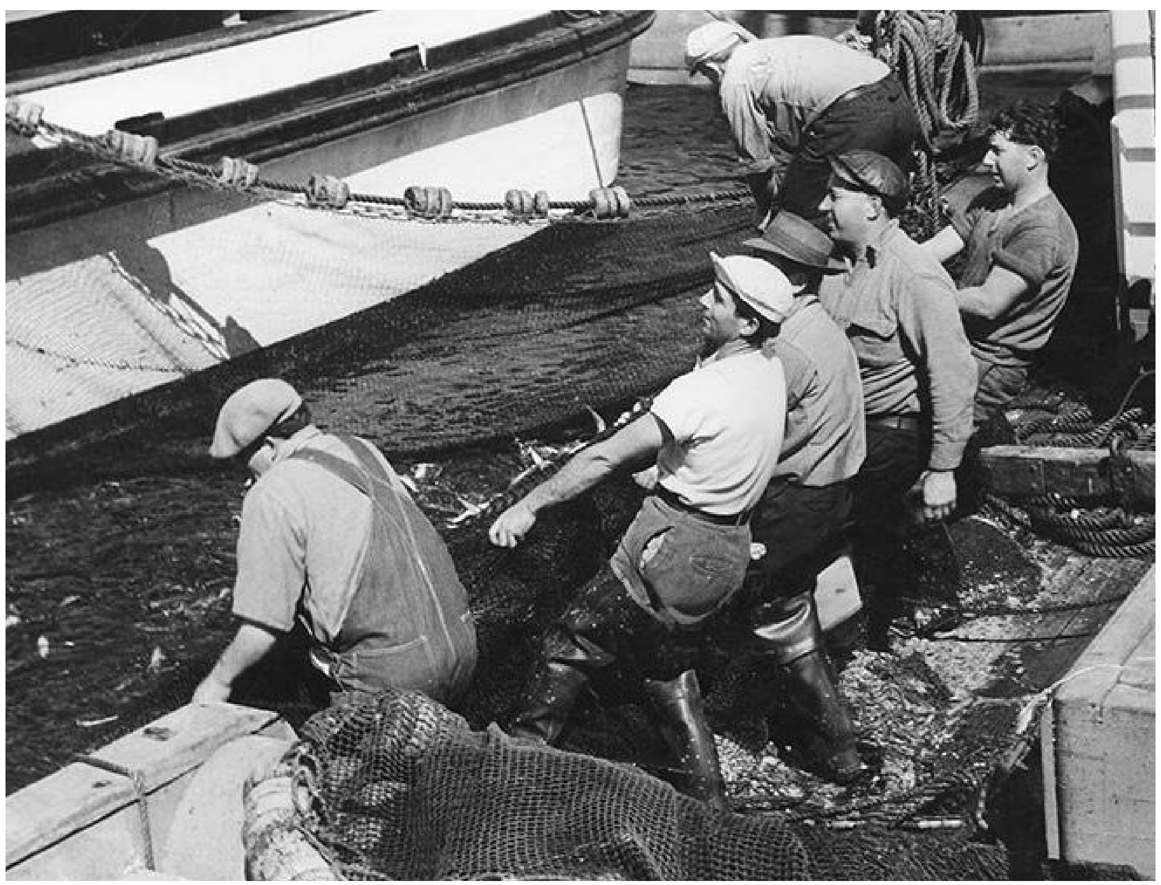
## MARINE FOOD CHAINS

All plants and animals can be classified by their trophic associations; a term which clarifies different paths of energy capture or, in simpler terms, who eats what (or whom). Two major types of energy capture exist: autotrophy and heterotrophy. Virtually all plants are autotrophic, or self-nourishing. They do not depend on other organisms for food; instead they take inorganic compounds like water, carbon dioxide and nutrients to produce more complex organic compounds. Heterotrophic organisms, in contrast, are unable to produce their own food from inorganic substances and depend on (=eat) other organisms for nourishment. This provides them the matter and energy to carry out metabolic activities.

Virtually all life on Earth depends on this flow of energy which originates in the sun, enters the biosphere through the photosynthetic activity of plants, and is transferred from one organism to another in chemical form as food. In this system, plants are referred to as primary producers, which places them in the first trophic level. All higher levels are occupied by heterotrophic organisms. Animals adapted to feed on plants are herbivores, forming the second trophic level, while carnivores occupy the third and higher levels.

The paths of nutrient and energy that flow through the living portion of the marine ecosystem are called food chains or food webs. With few exceptions, the first level of the marine food chain is occupied by widely dispersed microscopic plants known as phytoplankton. Their minute character imposes a size restriction on the occupants of higher trophic levels, since most animals are not adapted to feed on organisms many orders of magnitude smaller than themselves. As a result, herbivores in the sea, in contrast to herbivores on land, tend to be small. That, in turn, implies that food chains at sea are far longer than those on land, with the fish we catch and consume often occupying the fourth or fifth (or even higher) level in the chain. Those levels on land are occupied by top predators like lions and tigers. No one would even think of hunting or raising those for human consumption; every top predator at sea, in contrast, is considered fair game (or rather catch).

Further west, the rich fishing grounds of the Northeast Atlantic, systematically scoured by industrialized fishing fleets from Eastern Europe, were being depleted. In the Pacific, the great California sardine fishery, immortalized in John Steinbeck's *Cannery Row*, collapsed. South of there, along the Peruvian coast, the anchovy fishery– the largest in the world– dropped from a yield of 13 million tons to less than two million tons in three years. In this instance the decline was at least partially caused by a change in weather conditions, but Peru too had miscalculated the yield. And Japan, faced with overfishing in its coastal waters, sent its fishing fleets further away, in search of new stocks and more fish.



*Californian fishermen haul in another catch of sardines. Just like North Sea herring, sardines were easily caught and thus easily overfished. And just like in the North Sea, fishermen managed to do that several times.*

During the early 1970s, the world's total fish catch began to level off. The ocean no longer seemed inexhaustible. It left fishermen scratching their heads, blaming the system. Technology had proved both a blessing and a curse to the fishing industry. A blessing because it allowed fishermen to work more efficiently but a curse because it enabled them to take far too much. They ignored that their work, despite all the modern trappings, remained a hunt. And they brushed aside the undeniable fact that hunters must keep track of how much they remove.

On land, people had often learned this the hard way. Unfortunately the same mistakes were made at sea. History repeated itself time and again, with stocks ranging from the humble herring to the mighty whale.

In retrospect, there are several reasons that help explain what happened. Most important perhaps, no one really knew how much fish could be taken from a fish stock without damaging it. It was easy to figure out how many head of cattle could be removed from a herd without impairing its survival, but to do so for a fish population hidden beneath the sea's surface, was an entirely different matter.

Around the turn of the century, European fishing nations began realizing that they needed this information to properly manage their fisheries. As a result of the increasing mechanization of the industry catches were rapidly growing at the time, and yet no one knew what effect this had on the fish populations themselves. Some years the catches were outstanding; other years they were far below average. Were these fluctuations caused by man, by nature, or both? No one was certain.

To obtain some answers representatives from several West European fishing nations in 1899 established an organization devoted to fisheries research: the International Council for the Exploration of the Sea, also known as ICES. At the organization's first meeting, the participants agreed to organize research cruises to collect data. Soon there was a vast amount of data on the abundance and location of various commercial fish stocks, though the various pieces of information did not always fit together.

Under the aegis of ICES, fishery scientists set to work to solve the puzzle. In Denmark, Johan Peterson studied plaice – Denmark's most important catch at the time – and discovered that there were different stocks of plaice in the North Sea, which did not mix freely. In Germany, Friedrich Heincke discovered a similar situation for herring: there apparently were different stocks which did not interbreed and appeared to confine their movements to specific areas. This had never been realized before.

To determine whether catch fluctuations were caused by fishing or by natural changes, Danish scientist Johan Hjort sifted through years of catch statistics and discovered that, regardless of human intervention, in some

*Sines, Portugal*

*Determining sustainable yields for a particular fishery requires a detailed analysis of each stock. Some of the required information is available in fishing ports, where fishery biologists can examine a fraction of the catch and collect insight on the stock's abundance and location. That doesn't tell the whole story, but in combination with other data this information can be inserted in computer models and provide estimates on the stock's size and hence also on the amount of fish that can be removed from it.*

## FISHERY SCIENCE

To determine the effects of human intervention (or fishing) on a fish stock, scientists rely on population dynamics: the study of life and death in a population of living organisms. Like other animal populations, fish stocks are maintained by the balance between their birth and death rate. Each year a number of young fish or recruits enter the stock and all the fish put on weight. This increase, in turn, is balanced by natural mortality – the number of fish that die because of predation, disease or infection, or simply as a result of old age.

Fishing disrupts this natural balance by adding another mortality factor. Since it removes a number of fish that would otherwise have died of natural causes, it does not necessarily reduce the stock. In fact, if the catch remains lower than the difference between losses caused by natural death and the gains resulting from recruitment and growth, the stock can even increase. On the other hand, if the catch goes beyond that point, the stock will fall. As in unexploited populations, there is a point where the stock is neither increasing nor decreasing. That point is the point fishery biologists want to determine, because there the catch is sustainable: it can be removed year after year without harming the size of the stock.

Pinpointing sustainable yields for a particular fishery is not easy, however. For one thing, fish stocks constantly interact. One may think large fish will prey upon and thus mostly affect smaller fish, but quite often the small fish prey on the larval stages of what will once become their predator as well, making prey-predator interaction far more complicated than on land. Estimating population size is also difficult and subject to interpretation, with scientists and fishermen nearly always disagreeing on how much fish are left (unless they are gone). Recruitment too can fluctuate widely, since female fish carry thousands, or even millions of eggs. But as a general rule, fishery scientists have become pretty adept and estimating what is there, and what can safely be removed. If only they had been heard…

years the catches were high while in others they were low. He then turned his attention to the various age groups in a fish stock and suggested that the abundance of a stock depended on the success or failure of its recruitment, a term used to describe the number of fish that joined the stock every year. The question then became one of determining what made one year class of recruits so much better than another.

Since the success of a year class obviously depended on the amount of eggs that hatched and survived, Hjort and his colleagues focused on the larvae. They knew that larval survival was related to a variety of factors, including weather, currents and the number of predators, but there was one, it seemed, that was predominant: the availability of food. Fish larvae feed on microscopic plants called plankton. When there was a lot of plankton, chances were good that many larvae survived. The availability of plankton, in turn, depended on the amount of nutrients in the water, which was affected by winds and currents. In stagnant waters the nutrients slowly drifted to the bottom, but in waters mixed by surface winds and currents, they were constantly stirred up, and available for plankton growth.

Slowly the pieces of the puzzle started to take shape, but it was a complex picture that emerged. There were no simple answers to the question of fish stock fluctuations: everything was interdependent. Winds, storms and currents stirred up the nutrients needed for plankton blooms. In some years the winds came later than others, so that the fish larvae missed the blooms and starved to death. In others, the larvae drifted into massive blooms, greatly increasing their survival rate and the strength of their year class.

The biology of fish populations thus turned out to be far more complicated than anyone could have imagined. And now scientists were asked to add the effect of fishing to this complex picture and figure out how this affected it.

In the hundred or so years since these questions were first asked, improved data gathering and advances in computer modeling have enabled fishery scientists to develop models that show

*Most fish rely on a shotgun approach for reproduction, releasing thousands, sometimes millions of eggs, hoping that just a few of those survive to adulthood to maintain the population. Weather, currents and other factors that have nothing to do with fishing affect how many of those eggs and larvae will actually join the stock, making population estimates a complicated affair. That uncertainty has sometimes been used by fishermen and politicians to ignore scientific advice.*

*During the 20th century, more fishing boats with far more powerful tools and equipment began chasing the fish. The global fishing fleet comprises more than 4.7 million vessels, which is far too many. A fleet half that size would probably be sufficient to take the amounts we catch today.*

*Essaouira, Morocco*

what happens when people start exploiting a fish stock. Some of these are very advanced programs, following several stocks at the same time and predicting how they are affected when only one of them is fished. Unfortunately, making more accurate predictions proved no guarantee for intelligent management. There were other factors at play; factors which had less to do with the laws of nature than they did with the laws of man.

Chief among those was the notion that the sea was common property, as Hugo Grotius had proposed in the 17th century. As long as the sea appeared inexhaustible, Grotius' concept made sense. But during the 20th century more fishermen with far more powerful equipment began chasing the fish. Fish stocks declined, and in some instances collapsed. The freedom of fishing concept had begun to include the freedom to overfish. It quickly became clear that the sea was not inexhaustible at all.

To illustrate what happened to common property resources under such circumstances, American sociologist Garret Hardin wrote an intriguing article about the communal pastures found in most 17th century English villages. At first, Hardin observed, each farmer kept one cow on those commons, as should have been the case. But then one farmer added a second cow, reasoning that either no one would notice or that one more cow could not possible make a difference. Unfortunately, other farmers though exactly alike and before long every farmer in the community was running as much cattle on the commons as possible. Each farmer, in other words, pursued his own short-term interests regardless of the long-term effects. It didn't take long for the number of animals on the common grazing ground to become greater than the land could support, and the commons as a productive unit was impaired, if not destroyed.

Hardin called this process the tragedy of the commons, and explained that the system failed because it enticed people to obtain as large as possible a share of what was designated common property. But Hardin wasn't just talking about something of historical interest. He argued that the issue remained relevant because the problem also applied to common property resources like water and air, which people or companies could pollute or affect in other ways. Fish, it turned out, were no exception either.

## FISHING REGULATION

Since fishermen won't necessarily stop fishing to conserve the stocks, there is a need for measures to reduce what is generally known as fishing effort. Fishermen usually dislike regulations because they call for restrictions on their part, leading to higher costs and lower profits or, in many cases, even greater losses. Closed areas and closed seasons, for instance, which prohibit fishing in certain areas or during specific times, compel them to switch to other stocks or steam further out to keep busy. Quotas, which designate a maximum amount of fish that can be taken from a particular stock, are not popular either because once filled, no more fishing is permitted until the next season. Moreover, while these measures may ensure that the correct amount of fish is brought in, they never do so at the lowest cost because quotas force fishermen to work intensively when the season opens in order to obtain the largest possible share of the limit.

When quotas were introduced in the Pacific halibut fishery during the 1930s, the season dropped from nine months to less than two months in one area, and from seven months to barely three weeks in another. On the positive side, the quotas allowed the Pacific halibut stocks to recover. They remain in relatively good shape, though the season became even shorter. In the early 1990s, a few areas even saw their allowable catch brought up in less than a day! For that reason the decision was made to assign quotas to individual boats. That way the fishers could decide for themselves when to bring in their share, rather than be forced to join a mad rush for the catch.

In some fisheries, lower effort is obtained by requiring fishers to use restricted or even inefficient gear. A classic example of this approach is the oyster dredging fishery on the Chesapeake Bay, which is restricted to sailing vessels. To see this fleet at work is a very pretty sight, but forcing fishermen to use sail power to harvest oysters is not very efficient. Another example exists along the West Coast, where the Pacific salmon fishery is regulated by limitations on fishing equipment and vessels. Such restrictions may allow a larger number of fishermen to stay on the job, but they certainly don't ensure that the harvest is brought in at the lowest economic or even social cost.

A more pragmatic way to reduce total effort is by limiting the actual number of fishers; something which can be achieved by selling licenses or assigning fishing rights and exclusive quotas. Known as limited entry or limited access programs, it took some time for these schemes to be implemented because they invariably forced some fishers out of business, causing hardship and unemployment; exactly the kind of conditions no politician likes to be associated with. But when implemented they quickly proved their worth, in fisheries as diverse as the Australian prawn fishery and the Alaska salmon fishery. They work because they impose hard choices, permitting only a certain number of fishers to work the fishing grounds. There no longer is freedom of fishing, or even freedom of the seas in those instances. Limited access is what eventually saved the commons from total destruction. It clearly is also essential to preserve and protect the sea's natural resources.

It could easily be shown that fishers behaved somewhat like the farmers Hardin described. As long as there were plenty of fish, they deployed more vessels in order to bring in the largest possible share of the catch. But increasing input in a fishery did not necessarily lead to greater output, as it does in most sectors of the economy. Initially this was true, and catches increased, but at some point the harvest combined with natural mortality became greater than recruitment, causing stocks and catches to decline.

The amount of effort expended by fishers should be reduced at that point to enable the stock to recover, but the common property nature of fish did not allow for this. What a fisher left for tomorrow would not necessarily be there the next day; more likely someone else would have taken it. As a result fishers seldom restrained effort on their own initiative. They kept on fishing until the stock, like the commons, was destroyed.

There are means to improve this situation. Nothing can be done about the population dynamics of a fish stock, of course, but the number of fishers chasing it can be reduced. Or the legal nature of the stocks themselves can be altered, by assigning property rights, for instance, to get rid of the notion that these resources belong to all.

Yet no matter how clever a regulatory scheme, it won't be effective without proper enforcement. And that caused serious problems as well. Any country could enforce its restrictions against its own fishermen but until well into the past century, there wasn't much it could do about the foreign fishers off its coast. Coastal nations, it was generally agreed, only had jurisdiction over fisheries in their territorial sea and fishing zone, provided they had declared one. Beyond that, in international waters, foreign fishermen could operate freely, taking as much fish as they pleased.

Not surprisingly, this state of affairs didn't do much to promote effective fishery management. Self-imposed restrictions only benefited others, it seemed, unless the long-standing freedom of fishing principle could be phased out. During the late 1950s, the international community began discussing how to approach this issue, but it never agreed to anything

*Kozhikode, India*

*Artisanal fishermen throughout the world number in the millions but take only a small proportion of the catch. Powerful fishing vessels, many of them foreign, operate far offshore, and remove the bulk of the catch. The world fish catch, in other words, is a bit like the distribution of wealth, with half of it taken by a relatively small number of well-equipped vessels and companies and the other half by millions of small-scale fishermen who are barely scraping by.*

*The net is hauled aboard an Icelandic trawler – in it mostly redfish and a solitary cod who tried to escape through the mesh. Fishing and related industries are the single most important sector in the Icelandic economy, explaining why the country was so determined to protect its fishing grounds.*

specific. Frustrated, a number of countries decided to take the law into their own hands. They felt they needed more control over their fisheries. To get it, they began extending their reach over coastal waters on their own accord.

A number of South American nations had already done so by claiming wide territorial seas but those claims were never universally recognized, or even taken seriously. But when Iceland started extending its jurisdiction over its surrounding seas that proved more difficult to ignore. Because many Western European nations had long been fishing in those waters, and had no desire to be evicted from them.

It set the stage for a major confrontation. On one side the Icelanders, whose livelihood depended on fishing. On the other side West European fishers. For hundreds of years Iceland had shared the rich fishing grounds surrounding it with their fleets, but during the 1950s it became clear that stocks and catches were declining. It was the same story all over: too many boats were hauling in too much fish. To try to gain some control over the situation the Icelandic government in 1958 decided to extend its fisheries jurisdiction from four to twelve miles.

Other nations quickly protested. Germany and especially Britain, whose fishers had long been active in Icelandic waters, claimed that Iceland had no right to claim the fish off its coast. When the new twelve-mile limit went into effect, most foreign trawlers left, except for British and German ships. To prevent the Icelandic Coast Guard from harassing British trawlers, London even dispatched a few naval vessels. A first cod war had arrived. It took more than two years before an agreement between the three nations was worked out. Both Germany and Britain recognized Iceland's twelve-mile fishing zone in return for permission to withdraw their vessels over a three-year period.

Ten years later Icelandic fishery scientists warned that the country's fishing grounds needed additional protection. More vessels were operating around the island in international waters and, more important, they had grown far larger and more productive. To the Icelanders it was clear what needed to be done and in 1971 they announced that their fisheries zone would be extended again, this time to

*An Icelandic gunboat narrowly avoids a collision with a British trawler during the Cod Wars of the early 1970s. This cat-and-mouse conflict at sea signaled the end of the long-standing freedom of fishing principle.*

50 miles. Not surprisingly, Germany and Britain refused to comply. They even took their case to the International Court of Justice but Iceland declined to play along. It simply didn't show up at the hearings and made clear it would not accept the Court's jurisdiction.

Before long British and Icelandic ships were harassing one another again, and a second cod war ensued. A third one followed three years later when Iceland extended its fisheries zone a final time, this time to a massive 200 miles – 370 km – from the coast. Icelandic gunboats were sent out to cut the nets of British trawlers. British naval vessels, in turn, were dispatched to keep the gunboats away. When shots were fired, the incident made headlines around the world. To most people it seemed odd that industrial nations were willing to go to "war" over something as trivial as cod, but the disagreement was over much more than that. Nothing less than the freedom of the sea, and the freedom of fishing in particular, were at stake in the rough waters of the North Atlantic.

It did not take long before other coastal states began following the Icelandic example, forcing foreign fishers from their traditional fishing grounds. Their governments protested, arguing that extensions of coastal jurisdiction ran counter to international law. More conflicts followed, from tuna wars in the Pacific to shrimp wars in the Caribbean, but the tide was turning. This had become a disagreement the proponents of free and open seas could no longer win.

In a remarkably short time the international community accepted the concept of extended fisheries jurisdiction. This change of heart did run counter to the long-accepted principle of the freedom of the sea, but that had become an outdated concept anyway. For hundreds of years it had meant freedom of fishing and navigation, but now it had begun to include the freedom to pollute and exploit, and the freedom to do so irresponsibly. Clearly this attitude needed to be changed. Reasoning that nations, like individuals, take better care of their own property than of what belongs to everyone, the international community turned from a free and open sea to one that was becoming increasingly closed.

With this change, most fish stocks now fell under some nation's jurisdiction or control. Of course, fish stocks did not respect the boundaries coastal nations drew on their maps, but fishers had to do so. Governments could exclude foreign fishers from their zones, and they could limit the number of their own fishers. For the first time, it seemed, the tools were in place to effectively manage most of the world's fisheries.

In some instances, extended coastal jurisdiction improved the situation, as the North Sea herring makes clear. But it still didn't come easily. In 1972, with falling stocks and catches a reality, the North Sea countries agreed to closed seasons. Unfortunately these first measures were so weak that they had no effect whatsoever on the dismal condition of the stocks. Two years later it was agreed to set a total allowable catch and divide it into national quotas, but that too proved nearly impossible. Though everyone realized catch reductions were needed, none of the countries involved was willing to accept concessions. The first North Sea herring allowable catches, as a result, were set so high that most countries even failed to obtain their allocated share.

When scientists the next year recommended a ban on industrial fishing for herring, the proposal failed yet another time because of objections by Norway and Denmark, both of which operated large industrial fishing fleets. It wasn't until 1976 that the first serious quotas were implemented, but by then it was too late. Most of the stocks had collapsed and fishery-wide bans had to be imposed to permit them to recover.

For three or four years hardly any herring was taken from the North Sea. Many vessels were sold for scrap or converted for other fisheries. It created hardship among fishing communities but the restrictions were having a positive effect, and during the early 1980s the stocks gradually recovered. Unfortunately, it did not remain like that for long because soon fishers were again hauling up too much herring. Fishery biologists warned of a new collapse but just like ten years earlier, their advice was mostly ignored. By the end of the 1980s it became clear that the stock was rapidly declining. To prevent a second collapse, catch restrictions were quickly agreed and imposed. Since then the fishery has been relatively well managed. It now sustains a catch of about half a million tons; considerably higher than the disastrous seventies, but still far below what it once was.

In spite of the many mistakes, important lessons were learned from the North Sea herring case. Perhaps most importantly, it demonstrated that the long-term benefits of fishery restrictions outweighed the short-term social hardships. For those fishermen who had lost their jobs that was little consolation perhaps, but without restrictions on the number of boats and fishers the entire stock would have collapsed, leading to even greater unemployment. The stock's subsequent recovery also seemed to indicate that the sea could be tolerant of our mistakes. Fish populations can recover, it seemed, provided they were given a chance to do so. But that proved not entirely true. For stocks like herring and mackerel, a relatively quick recovery appeared possible. But species like cod, also overfished, took a great deal longer. In fact, in some areas it is still not clear whether cod populations will ever recover.

Unfortunately, the mistakes made in the North Sea would be repeated elsewhere. The rich fisheries of the Northwest Atlantic should have benefited from the fishery management laws enacted by Canada and the U.S. during the mid-1970s, but they did not. While they did restrict the amount of foreign fishing, they caused a massive expansion of local fishing effort. As a result, the number of Canadian and American fishermen increased rapidly and the situation deteriorated. Once the foreign fleets left, in other words, domestic fishers proceeded to do what had previously been blamed on their foreign colleagues: they emptied the sea.

Every single warning sign that had appeared in the North Sea appeared here as well, but to no avail. National greed and shortsightedness simply took over from foreign greed and shortsightedness, allowing one stock after another to be fished to commercial extinction. Only when the fish were gone, did conservation measures go into effect. But they proved far too late. Both the fish and the fishermen were in far worse shape than ever before. Just as earlier in the North Sea, the collapse had been predicted. And just like there, a bit of foresight, political courage and discipline by government and industry would have prevented the collapse of a fishery that had fed millions for centuries.

The same scenario was repeated throughout the world. Wherever larger fishery zones went into effect, fishing effort expanded rather than decreased. As a result marine fish catches increased during the 1980s, reaching a total of 86 million tons by the end of the decade. But to reach this total, several important fish stocks were overfished. Catches subsequently fell, leveling off at around 80 million tons during the early 1990s. A few years later, the total harvest rose again, mostly by increasing catches of species lower on the food chain like anchovy, pilchard and mackerel. By the end of the millennium, it was approaching the 100 million ton mark. Since then the total world catch has started falling again, averaging between 90 and 95 million tons a year.

*A fisherman brings in his catch on the island of São Tomé. Even though it consists of no more than a few fish, this is the only source of income for him and his family. Fishing and aquaculture supports the livelihoods of one tenth of the world's population.*

## THE WORLD CATCH

During the 1950s and 1960s fish catches rose spectacularly, with total landings sometimes growing as much as six percent annually. This increased flow of food was perceived with great optimism. Little was known at the time about food production in the sea and its sheer size, coupled with a lack of information, led to the belief that the sea's food resources were inexhaustible. Historian Arnold Toynbee summed up widely held feelings when he stated that the sea was "a vast accessible field for mankind's enterprise, and also a sure guarantee for our race's survival even if our descendants are going to be ten times as numerous as we are today." Popular accounts on the sea's food potential flourished, contributing to misconceptions that prevailed for a long time, and sometimes still do.

Meanwhile reality has caught up with these misconceptions. The increases in the world's fish catch that led to such optimism half a century ago are a thing of the past. Over the past 10–15 years the world marine fish catch has levelled off at about 80 million metric tons, give or take a few percentage points. The fresh and brackish water catch adds an average of 10 million tons, bringing global capture production to around 90 million metric tons. Almost half of this is taken by a handful of nations: China, Indonesia, The United States, India, Russia and Peru – though the latter only in non-El Niño years.

Global catch statistics are compiled by the Food and Agriculture Organization (FAO) of the United Nations, which collects data submitted to it by various government agencies. There is general agreement that we remove considerably more from the sea than what is officially reported. It is estimated, for instance, that as much as 30 percent of total landings is bycatch – fish and other marine organisms that are discarded because too small or unwanted. The catch of isolated communities also is often poorly recorded, not to mention that of IUU (illegal, unreported and unregulated) fishing practices which are a major threat not only to certain stocks but also to fishermen who abide by the rules. If added in, we are probably taking closer to 125 million tons every year which, by most estimates, is well beyond what we should remove.

It will take a major management effort to maintain this level. Thirteen of the seventeen major fisheries in the world are now depleted or in decline. The other four are fully exploited. Just about everything, in other words, has reached or exceeded its maximum yield. Fishery scientists agree that the only way to stabilize these catches is through much better management and regulation, so that the stocks can recover and be properly controlled. That will take several years and a much higher level of political commitment and intelligence than the sea has ever witnessed.

Better management and conservation can maintain conventional catches, perhaps even slightly increase them, but there are other ways to increase our harvest from the sea. Rather than hunting fish, we can start herding them. Rather than fishing, we can farm the sea.

Though it may seem a relatively recent development, the practice goes far back in time. In fact, sea farming, or mariculture as it is also known, was practiced in various parts of the world well before the Christian era. The Japanese, for instance, have been farming oysters for more than 2,000 years. By including fresh water species, in which case the broader term aquaculture is used, we can recede even further into history.

Carp culture in China is believed to date back over 4,000 years. As early as 475 B.C. the practice was described by a certain Fan-Li in the first known treatise on aquaculture. Some attribute to him the proverbial "give a man a fish and he will have food for a day, teach him how to grow fish and he will have food for a lifetime" but that doesn't necessarily make much sense. Freshwater fish like carp can be grown without too much of a hassle but raising marine fish is quite difficult. Not that this should discredit the wise Fan Li. His words have simply been altered a bit to serve the cause of modern aquaculture.

Growing fish or other aquatic animals is difficult for many reasons. For one thing, since we are land dwellers we put most of our efforts into land animal production. Our knowledge of aquatic animals and plants lagged far behind,

*China reports both the largest catches and aquaculture yields every year. While there is uncertainty about the reliability of reported catches, there is no doubt that the country's aquaculture production is far higher than anyone else.*

*Clams are sorted at a fishing port in Japan. Mollusks are prime candidates for culturing. They do not need to be fed since they filter their food from the water and can basically be left by themselves for much of the time. But do they need excellent water quality: parasites or diseases can ruin an entire crop in a short time.*

seriously limiting the capacity to grow or raise them. There are also a number of biotechnical factors that hinder the development of aquaculture. Water rather than air is the environment in which the animals are reared, which means that unused food and metabolic products surround them, making continuous flushing a necessity. Unused feed and excreta on land farms, in contrast, are usually disposed of more easily.

Another interesting difference is that many land animals, after weaning, eat the same food as their parents. Most aquatic animals, in contrast, do not. Their larvae undergo several transformations from hatching to the adult stage, during which they neither resemble the parents nor consume the same food. Supplying five different types of food to raise fish or shrimp merely to a post-larval stage is an expensive and time-consuming proposition.

Fortunately aquatic animals also possess some qualities that make them intriguing candidates for farming. With a body nearly the same density as water, they spend little energy on supporting their weight, devoting it to growth instead. They also don't spend energy on thermoregulation, since most of them are cold-blooded. And a body of water is a three-dimensional growing space. If properly used, it can yield very substantial yields.

Yet for most of history, the obstacles to fresh or seawater farming clearly outweighed the advantages. Operations were restricted to fresh water fish like carp and sessile marine invertebrates like oysters and mussels; animals which pretty much took care of themselves. In retrospect this state of affairs made sense. After all, most aquatic animals could be freely gathered from the sea or from inland waters. As long as they remained abundant there, there was no need to go through the trouble of farming them.

But times have changed dramatically. We now know that the sea is far from inexhaustible. In some regions shortages caused by overfishing were overcome by switching to other fish, or perhaps by moving further out to sea or to a different region, but that approach clearly could not go on forever either. Countries with a great demand for seafood began looking into farming to meet their needs, like sea farming. And one country in particular led the way.

Japan depends heavily on the sea. Seven eighths of the country is mountainous, leaving only one sixth of its total area suitable for agriculture. What Japan lacks in arable land, it has to make up from the seas that surround it. As a result, sea food has long been a key component of the Japanese diet. Even today, with plenty of other food sources available, more than half of the Japanese animal protein intake comes from the sea.

One of Japan's favorite seafood dishes is red sea bream, known to the Japanese as tai or *madai*. Sea bream is highly regarded for the firm texture of its meat, but there is also a long-standing association of red sea bream with good fortune. For that reason *madai* is often served at celebrations like weddings and birthdays, creating a strong and extreme-

*Red seabream are highly regarded in Japan. Not only is the fish appreciated for its fine texture, there also is a wordplay of sorts with its Japanese name – madai or simply tai – implying good fortune. For that reason the fish often graces the menu at celebrations like weddings or the birth of a child.*

ly stable demand. After all, people do have birthdays and love to celebrate a wedding.

During the 1960s, mostly as a result of overfishing and industrialization, red sea bream catches began to decline in Japan's Inland Sea. As elsewhere, the government proposed measures to protect the fishery, but by the time they were implemented, the stocks had collapsed. Realizing that rebuilding the stocks would take many years, the government decided to invest in sea bream culture. This indeed was not a matter of simply importing madai from elsewhere. The Japanese were pretty picky about their fish, and especially about this one.

At first, the fish were raised by placing naturally born juveniles in net cages and keeping them there until they reached marketable size. But soon young sea bream supplies were dwindling as well, and research began to focus on rearing the fish from egg to adult in order to control its entire life cycle.

This was not an easy undertaking. It took several years before scientists succeeded in raising sea bream through their successive larval stages. Their work made clear that it would be difficult to produce large quantities of young sea bream at a reasonable cost, so a major effort was initiated to develop mass larval rearing techniques. Some researchers devised methods to produce large amounts of live food for the different larval stages, including microscopic plants and zooplankton. Others focused on determining optimal water and light conditions, or studied diseases, to increase the survival rate of newly hatched larvae.

Within a few years hatcheries along Japan's Inland Sea began producing millions of sea bream fry. Most were, and still are, shipped to fish farmers and stocked in net cages, but large quantities were also released into the wild in order to help rebuild the natural stocks. Seabream stocks recovered more rapidly than if they had been left to rebuild by themselves, but the process was expensive. Raising the fish indeed calls for constant monitoring of temperatures, salinity, light and many other parameters. It also requires different feeds for the various larval stages, and a considerable amount of manpower. The failure of one link in the system, say an unexpected disease or a drop in temperature, could wipe out the entire crop. But the many years of experimen-

*A fish farm in a small bay in Greece. Twenty years ago this would have been a rare sight, today fish farms are appearing all along the coast in southern Europe. Mariculture has more than made up the shortfall in fish supplies caused by declining catches.*

tation paid off, allowing fishers and fish farmers to deliver a steady supply of *madai* at a reasonable cost.

There are many successful sea farming ventures in Japan. Yellowtail, shrimp, prawn, oysters, scallops and abalone are just a few of the species that are raised in sea farms dotted along the Japanese coast. Like the culture of *madai*, these operations are labor and capital intensive, leading to high costs. They succeed because the Japanese, the world's largest seafood consumers, were and are willing to pay the price.

The rest of the industrialized world caught up rapidly. As in Japan, catches of fish stocks were dwindling, providing the incentive to experiment with mariculture. It took longer for the industry to establish itself, in no small part because the demand for fish and shellfish in many western countries was not as strong, or rather inelastic, as it was in Japan. While western consumers generally lik seafood, they readily switch to other foods if and when prices become too high. In addition, mariculture competed for space with longstanding marine activities like navigation, recreation or even waste disposal. And finally, while all fish can theoretically be raised from egg to adult, for a lot of overfished species that could not be done commercially.

Even so, some species are widely farmed throughout Europe and the United States. This is particularly the case with mollusks like oysters and mussels, where mariculture has helped cover shortages caused by pollution and a loss of natural grounds. Commercial ventures have proven successful because the demand for these shellfish is relatively stable. Moreover, they do not require the intensive monitoring and care that fish and crustacean culture demands, since the animals exist on plankton, filtered from the surrounding water. Major operations include the oyster culture of France and the United States, and the mussel farms of Galicia in northwestern Spain and the Netherlands, which produce some of the highest yields of meat per unit area of any form of farming.

The most important marine fish cultured in Europe and the United States is salmon. Two types of culture systems exist: ocean ranching and pen-rearing. The first technique relies on the salmon's homing behavior: the fish are hatched and reared in hatcheries until they can be released. After four or five years in the open ocean, they return to their home river where they can be harvested. Pen-rearing, in contrast, involves the enclosure of young salmon in net cages or brackish water ponds. The young fish are then grown to market size in the shortest possible time.

In Europe, salmon is farmed in Norway, where enclosures placed in the fjords account for most of the production. Considerable quantities are also produced in Scotland and Ireland, also from net enclosures. Pen-rearing of salmon also takes place in Chile and the United States, particularly along the northwest coast. There hatcheries also release enormous quantities of fingerlings in the ocean. This restocking program contributes to the commercial fishery since up to eight percent of the salmon eventually make it back to their home river to spawn.

As a result of these activities, salmon now is a good deal less expensive than it was a few decades ago, which is (mostly) good news for consumers. In addition, hatchery release programs are helping to rebuild the natural stocks, which is equally important. But salmon farming also creates problems, especially in the case of large-scale operations located in enclosed or semi-enclosed waters like fjords or lakes. The large numbers of salmon that are reared in these areas create vast amounts of waste, which the environment cannot always handle. Overcrowding also increase the chances of disease and parasites, which can affect the natural stock. And it appears that eating too much farm-bred salmon is not necessarily a good idea because the fish may concentrate certain additives from their feeds which can be passed on to consumers. For that reason, the industry needs to be tightly monitored and controlled.

Crustaceans like shrimp, lobster and prawns also command good prices and a stable demand, creating a climate favorable for commercial culture. Because of lower labor costs, the most successful shrimp farms are located in Southeast Asia and Latin America. Ecuador, for instance, now produces about a quarter of the world total of farmed shrimp. The

*Salmon are one of mariculture's success stories, with the yield from farms now nearly three times larger than catches of wild salmon.  But the industry also faces problems and health concerns which require constant monitoring.*

*Milkfish (Chanos chanos) are uniquely suited for aquaculture. The fish tolerate a wide range of salinities and feed low on the foodchain, eliminating the need for expensive feeds. That way the fish can be produced at low cost and sold at a price affordable to local consumers.*

industry earns the country a considerable share of its foreign income. The remainder of the harvest is produced in India, Indonesia, Bangladesh, Thailand and the Philippines: all of them countries with a suitably warm climate and sufficient coastal space for ponds and other installations.

Shrimp and prawn farming have developed into one of mariculture's success stories. Thirty years ago there were few commercial operations; today there are no less than 50,000 shrimp and prawn farms which account for more than half of the world's shrimp harvest. But this success story has negative side effects as well. Virtually all operations need a lot of space, much of it in relatively fragile coastal regions. Ecuador lost 200,000 acres of mangrove forest during the past thirty years, and this has had a major effect on the health of its coast as well as the fish stocks that live alongside it. Similar problems have occurred in Southeast Asia, including concerns about extremely poor working conditions. Here too much stronger regulation will be needed to limit the negative impact on the coastal environment and the people that live there.

There also is no question that the culture of seafood luxuries like shrimp and prawn will not do much to feed the world's poor. In fact, most of these animals grow best when offered feeds with a protein composition similar to their own. To feed fish and shrimp with ground-up fish certainly will not help a great deal in terms of fighting hunger. Fortunately some of what was learned farming high-value organisms like sea bream or prawn can be applied to sea farming applications that can make a more significant contribution to food supplies. The milkfish, an important part in the diet of millions of people in Southeast Asia, provides a good example.

Milkfish are well suited for aquaculture. First and foremost they are herbivores which feed on the bottom of the food chain, so there is no need for expensive feeds. Moreover, they tolerate a wide range of salinities, which suits them well for brackish water culture. But the fish do not sexually mature in confined waters like fresh or brackish water ponds, forcing farmers to rely on naturally caught fry to stock their ponds. This was fine as long as there were enough of those congregating off the beach but some years the fry were far less abundant, leaving the grow-out ponds only partially filled and making it difficult to meet demand.

During the 1980s scientists succeeded in inducing female milkfish to spawn by injecting hormones. It proved a major development, finally doing away with the unpredictable dependence on naturally caught milkfish fry. Interestingly the breakthrough was made by similar efforts to get sea bream and salmon to spawn in captivity, proving that research on luxury species could help the development of mass rearing techniques for species lower on the food chain. As a result of these advances, the milkfish harvest has grown rapidly in recent years and is now approaching the 700,000 ton mark. Most important, this harvest is consumed locally. It benefits locals, rather than far wealthier overseas consumers.

Efforts of this nature in a very real sense exemplify the changes that are taking place, from hunting and fishing to herding and farming. Moreover, they produce a food product at a relatively low cost so that it can feed many people, rather than a select few. Prawn or lobster cultivation in high-tech hatcheries may appear more innovative, but for sea farming to succeed it must also focus on protein species. Only then can it contribute to food supplies in places that need it rather than merely those who can afford it.

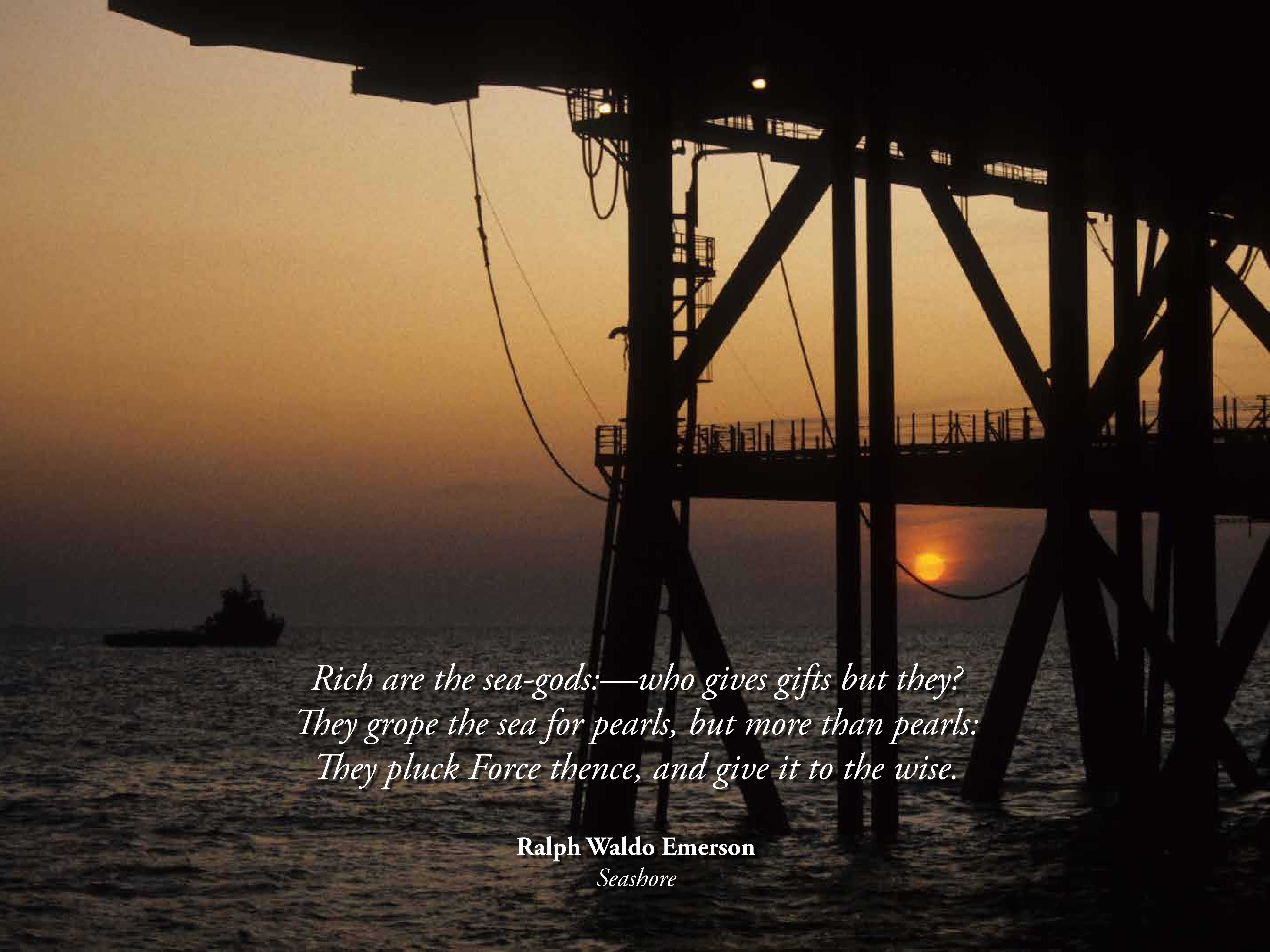
Due to the decline of natural stocks, mariculture production has grown far more rapidly than anyone expected just 25 years ago, approaching half in weight of what is caught annually. That doesn't mean that one out of three fish is farmed, since much of production in weight consists of mollusks like oysters and clams, meaning a lot of that weight consists of shells. But there is no question that the switch from fishing to farming is having an enormous impact on our harvest from the sea. For some time to come fishing will remain our principal means of harvesting the sea, but it won't be long now before the share of farmed seafood on our plates will take be greater than its naturally caught component.

# SUMMARY

*Archeological evidence in the form of shell mounds and fishhooks reveals that the sea has provided food for as long as people have lived along its shores. The ancients relied on the fisheries of the Mediterranean, and at the height of its Empire, Rome's colonies supplied the Imperial City with preserved seafood of many varieties. During the Middle Ages this reliance on the sea's food resources increased, particularly in coastal areas but also far inland as a result of the development of better preservation techniques.*

*Tens of thousands of years after people started to fish, they are still doing so as hunters. Until about a hundred years ago the sea could handle this but then populations grew, the demand for fish increased, preservation methods improved, and both ships and gear became more powerful and efficient. The digital revolution continued this trend, allowing fishermen to locate, even pinpoint, the fish. At first fish catches grew, then they started to fall. What had seemed an inexhaustible source of food for thousands of years was overfished and sometimes even depleted in the course of a single generation.*

*We still expect the sea to play an important role in providing food to an ever-increasing world population, but if this is to be the case, important changes – social, legal, technological and economic – need to be made in the way we treat the sea's living resources. The change from hunting and fishing to herding and farming is one important development, as is the notion that fish stocks are no longer a free-for-all. What still is still missing is more respect, not only for the sea but also for the wealth of life that calls it home.*



*Rich are the sea-gods:—who gives gifts but they?*
*They grope the sea for pearls, but more than pearls:*
*They pluck Force thence, and give it to the wise.*

**Ralph Waldo Emerson**
*Seashore*

# WEALTH

It became the most expensive dinner in history. According to an astonished Pliny the Elder, writing nearly 2,000 years ago, it was the result of a wager between Cleopatra and Marc Anthony. To win it, the Egyptian queen removed her pearl earrings, crushed them and dissolved one in her wine goblet, the other in his. They then toasted each other and drank, gulping down two perfectly matched pearls. Pliny reported they were worth some 60 million sestertii. Granted, Pliny had a tendency to exaggerate about almost everything, but it would undoubtedly have been a considerable amount.

Aside from confirming the couple's extravagance, the story makes clear that pearls were highly regarded in those days. People actually treasured them as a symbol of purity and perfection. The Bible went as far as comparing the quest for the perfect pearl with the search for the kingdom of heaven, and the Koran and the Talmud too ranked pearls very highly. In Rome, the pearl craze reached its height, with Roman socialites spending staggering amounts on them. Vitellius, one-time military commander and later Emperor, was reported to have financed an entire voyage by pawning one of his mother's pearls, and it was rumored that Julius Caesar invaded Britain "by hope of getting pearls". And then there was Cleopatra's stunt, enough for Pliny to conclude that pearls were the queen of gems, first in value among all precious things.

This queen of gems is the product of a remarkable natural process. Oysters and other shell-covered marine animals have strong, muscular bodies that are very sensitive to external irritation. To protect them from the rough interior of their shells, they secrete a smooth substance known as mother of pearl, or nacre. If a piece of shell or a grain of sand accidentally enters the body, it is coated with this substance to reduce the chance of injury. The result is a rounded pearl, though rounded doesn't necessarily mean perfectly round. Its symmetry and beauty depends on the size and shape of the intruding material as well as on its position within the shell. It depends, in short, on pure chance.

Perfectly rounded natural pearls are very rare; finding them a matter of luck. Thousands of oysters had to be collected and pried open to find only a few natural pearls and most of these would be irregularly shaped disappointments. Nonetheless, the fortunes paid for perfect pearls kept a thriving industry in business, particularly in and around the Persian Gulf, which supplied most of the world's pearls until well into the last century.

During the 1920s the Japanese unlocked the secret of the pearl's formation by discovering that the oyster's mantle secreted the elusive mother of pearl. Confirming their knack at copying just about anything, they quickly replicated the process, producing perfectly rounded artificial pearls by inserting a small spherical nucleus as well as a piece of mantle in the animal's body. It didn't take long for cultured pearls to replace their exorbitantly priced natural cousins.

As a result few pearl divers still search the seabed for the queen of gems. But the quest for Neptune's treasures has not ended. Pearl divers have been replaced by submersibles and sophisticated equipment searching for a different kind of treasure: minerals– especially deposits that are scarce on land or, if not exactly scarce, located in politically unstable regions. They are known as strategic minerals.

Strategic minerals comprise a wide variety of materials but they all share some characteristics. First, they have to be relatively scarce or difficult to obtain. Sand and rock are minerals, but they can hardly be considered strategic because most nations have both of these in abundant quantities. Strategic minerals also have to possess properties which make them unique and irreplaceable. Not every nation possesses marble, for instance, but it isn't a strategic mineral since it can be replaced by other building materials. And finally, strategic minerals have to be essential. Precious stones such as opals or rubies are scarce and unique but, since society can function without them, they are not strategic.

Because of their essential properties, strategic minerals tend to have a major impact on the world's economy. Of course, what was a strategic mineral a thousand, or even a hundred years ago, is no longer necessarily as vital. During the Bronze Age copper and tin, the ingredients of bronze, were the principal strategic minerals. The nations that controlled their supply became wealthy and powerful. Later it was discovered that iron provided stronger tools and utensils and it replaced copper and tin as the principal strategic mineral. As society's needs and capabilities increased, some materials became less strategic, while others grew in importance. Of bronze's ingredients, copper is still considered a strategic material, while tin is hardly considered essential. Metals like cobalt, chromium or nickel have taken its place in the refined alloys we use today.

Strategic minerals are also defined by access. Oil, which is a strategic mineral by any definition, is less strategic to the oil-rich Persian Gulf states than it is to western nations, which consume enormous quantities of it. The same is true for metals like cobalt and chromium, which occur in extensive deposits in central and southern Africa. There they are not exactly vital, but to western industries they are essential.

For much of history access to strategic materials was a matter of claiming them. The history of conquest and colonization had much less to do with spreading faith and culture than it did with gaining access to essential resources, whether they be food, spices, gold or strategic minerals. But by the end of the nineteenth century, most of the world's landmasses had been explored and claimed by the great European powers. The enormous British Empire stretched from one end of the globe to the other. Germany, Belgium and France had carved up much of Africa– the Dark Continent– and its fabled mineral resources. The Netherlands controlled territories from Southeast Asia to South America. And Japan, the United States and Russia showed expansionist ambitions as well, quickly moving to claim whatever was left. Following the example set by European powers, native peoples were never asked whether they agreed to foreign domination. In the long history of colonization, there often was little choice between annexation or annihilation.

By the 1960s many of the world's colonies had gained independence and the great powers lost their direct access to vital mineral deposits. At first strong ties with the colonial power ensured that the supply of resources was not immediately cut off, but the political instability that often followed in the wake of newly gained independence no longer guaranteed a stable flow. Western nations therefore began looking towards alternative sources. They did so at a time when science and technology were opening up the last and greatest untapped mine on the planet: the ocean.

To understand the sea's mineral potential it helps to know something about its formation. Although no one knows when exactly the oceans were formed, the first stage began shortly after the formation of the Earth when water vapor was squeezed out of molten rock and began to form a primitive atmosphere. As the surface of the young planet cooled and solidified, the atmosphere condensed and heavy layers of clouds began to release rains. At first, the rains steamed straight back into the atmosphere, causing an uninterrupted flow of water lasting hundreds or even thousands of years. With the passing of time, the surface became cool enough for water to remain liquid and the rains collected in pools, created rivers and filled up large depressions which would become seas and oceans.

The early ocean was only faintly salt but as the water of rivers and the primeval sea itself began to erode the continents, their minerals were dissolved or deposited in thick layers on the ocean bottom. When life developed in the sea, its remains drifted to the bottom as well, forming extensive deposits of shells and other organic materials. Finally, the tectonic forces (see p. 176) that shape our planet also forced minerals from the earth's molten interior into the ocean. Some consolidated in thick deposits near centers of spreading or volcanic activity, while others were dissolved in the water or formed hydrogenous deposits on the deep seafloor.

*Lava from Kilauea flows in the ocean off Hawaii. Massive amounts of molten lava enter the oceans from volcanoes, especially undersea volcanoes located at the boundaries of tectonic plates. The process can create new land, as here in Hawaii, or new ocean floor, as it does at spreading ridges.*

## PLATE TECTONICS

Until the early twentieth century, it was generally believed that the oceans were relatively static features on the planet. Ever since its formation the Earth had been cooling – on that everyone could agree. Once the crust consolidated, the thinking went on, the cooling process had shrunk it, wrinkling the planet's surface, not unlike the skin of a drying apple. Not everyone believed that this was all there was to the story but, then again, no one else had come up with a theory that explained such inconsistencies as shells that were found on mountain tops or identical rock layers on continents separated by thousands of miles of ocean.

Early in the 20th century, the first dissenting opinions were voiced. In 1912, for instance, German meteorologist Alfred Wegener asserted that the continents were not fixed, suggesting in a lecture to the Geological Association of Frankfurt that the various landmasses on the planet were constantly in motion. He subsequently summarized these ideas in his 1915 book *The Origin of Continents and Oceans*. It suggested that hundreds of millions of years ago there had been only one continent, which he called Pangaea. Some 200 million years ago, this landmass broke into several pieces, which would become the continents as we know them today. Over a period lasting millions of years, the separating continents inched their way through the ocean floor to their present location. At their bows were earthquakes and young mountain ranges, Wegener wrote, while in their wake new ocean floor was formed.

The reaction to these ideas was, to put it mildly, less than enthused. Few geologists had the desire to contemplate how their theories, all based on the assumption that continents and ocean basins were permanent features, would have to be reformulated if Wegener were right. But among laymen Wegener's theories quickly developed a following. Before long, the idea of continental displacement or continental drift triggered a controversy within the scientific community, the likes of which had not been seen since Darwin's thoughts on evolution. Who was right: the believers in continental permanence or the so-called drifters?

Fifty years later, geologists began to collect the information needed to settle the debate. To begin with, geologists discovered that the deep sea clearly was not the nearly featureless accumulation of sediments it was once thought to be. Instead seismic profiles showed that the bottom of the deep sea was interrupted by an enormous mountain range, hundreds of miles wide and several miles high, which encircled the globe. Even more intriguingly, sediments on the deep sea floor were surprisingly thin, compared with what one would expect if they had been drifting down and building up for billions of years. In fact, no one had ever found anything older than 70 or 80 million years– a mere one sixtieth the age of the Earth.

During the 1960s, the tools to figure out these anomalies became available. First, it was discovered that this deep sea mountain range, or mid-oceanic ridge as it came to be called, was the youngest part of the ocean floor. Then it became clear that new ocean floor was constantly being formed on either side of this ridge. And finally, the asymmetrical polarity of the ocean bottom proved that this new sea floor was being pushed laterally away from the ridges. Wegener had been right about the continents moving, in other words, though he was mistaken about the mechanism that caused them to do so. Rather than the continents barging their way through the ocean floor, it was the seafloor itself, moving like a giant conveyor belt, which carried the lighter continents across the globe.

The mechanism was subsequently exemplified in the theory of plate tectonics, which stipulates that the earth's rigid outer layer, the lithosphere, is divided into a number of plates. These float on the asthenosphere, a layer of dense, molten material. Most of the plates consist of oceanic, as well as lighter continental crust, but some are solely made up of ocean floor. New crust is constantly being formed along the axes of the oceanic ridges, where partially molten mantle material rises in irregular pulses. As the plates grow on either side of the ridge, they move in opposite directions, carrying the seafloor and the continents along with them. At the other end, some plates collide while others are bent downward and disappear into the interior of the earth, making room for what is manufactured at the ridge.

Most of this vast mineral wealth became only recently accessible, or even known. But salt – aside from water the sea's most common mineral – has been extracted since earliest times. Vital and irreplaceable, salt became history's first strategic mineral. In many regions, it was valued as treasure.

Salt is so important because it is essential to life. The two components of common salt – sodium and chloride – maintain the osmotic pressure that regulates the absorption of nutrients and the excretion of waste in cells. Without salt these processes would cease, causing death. Fortunately, most of our food sources contain enough of it to satisfy the body's needs but salt, as one anonymous author put it a long time ago, is "what makes things taste bad when it isn't in them". Before spices like pepper, cinnamon, cardamom and ginger became more widely available, that observation was even more valid than today. Salt simply spiced up a drab diet and was much sought after by rich and poor alike.

Salt did more than render unexciting foods palatable. Long before the onset of recorded history, people discovered that salt preserved their surplus food. Fish and meat, or even fruit and vegetables, could be kept edible much longer when salted, and this discovery did much to enable the development of self-sufficient communities. Salt was also used for glazing pottery, curing leather and dying fabrics, amongst countless other uses, and became indispensable.

The importance of salt is reflected in religious accounts. The Bible, for instance, makes reference to salt no less than 33 times. In virtually all of these, salt is perceived as vital and valuable, and a symbol of purity. "Ye are the salt of the earth" writes Matthew, meaning you are special and unique – a spiritual aristocracy of sorts. In Middle Eastern cultures salt came to symbolize trust and friendship, as it often still does. Jewish pacts were negotiated at a table with a ceremonial container of salt, known as a covenant of salt. In Leonardo da Vinci's Last Supper, Judas is sitting near an overturned saltcellar, symbolizing the covenant of trust and friendship that had been shattered.

In ancient Greece and Rome, salt was revered as well. Homer called salt "divine" and Plato described it as a sub-

*Salt production in China was a labor intensive process. Men are seen scooping water from the sea, kilns are fired up to boil and evaporate the water so that the residual salt can be collected. The process was accurately described by Marco Polo, who added that salt was even used as currency in some of the southern provinces.*

stance "dear to the Gods". A more mundane reference, the Latin *cum grano saltis* – with a grain of salt – has its roots in the Romans' appreciation for salt as a seasoning. In Athens and Rome salt was even used as currency. In Greece, for instance, slaves were traded for salt and those who didn't perform were considered "not worth their salt". In Rome, soldiers received a monthly quota of salt, the *salarium argentum*, as part of their wages. When we get paid it is no longer in salt, but we still use the same term.

Further East, in ancient China, salt was considered second in value only to gold. The Chinese were the first to tax salt, a practice which was later adopted in western cultures. The revenues financed anything from war to more peaceful endeavors like public works. Sometimes governments taxed salt too much, causing civil disobedience and unrest. In a few cases the ruling powers toppled as a result, profoundly altering the course of history. One of the major causes of the French Revolution, for instance, was widespread displeasure over the *gabelle*, a despised salt tax. More recently public grievance over a tax imposed by British authorities led to Gandhi's famous salt march, and eventually India's independence.

For much of history the sea was the principal source of this vital commodity. In some regions in Africa and the Middle East salt was obtained from the dried-out basins of ancients seas, but elsewhere people had to rely on what they could extract from seawater. Fortunately, this was not very difficult: all it took was shallow coastal ponds and preferably a lot of sun. After the ponds had been filled, the sun's heat evaporated the water, leaving a salty residue which crystallized and could later be collected. Further north, there wasn't enough sun or too much rain for the water to evaporate naturally. There people actually boiled seawater in shallow ceramic dishes, using peat or wood to fuel the fires.

About a thousand years ago people began to obtain salt from mines on land and sea salt lost some of its strategic importance. Nonetheless, coastal salt production remained a thriving business and producing regions retained an advantage over regions which didn't have salt of their own. It wasn't until the advent of alternative food preservation methods, like canning and refrigeration, along with the development of more reliable transportation methods that sea salt began to lose its vital position in the world economy. To us it may be difficult to imagine how such a readily available substance could have caused wars and toppled powerful rulers. But before the discovery of alternative sources and commodities, sea salt was unique, scarce and irreplaceable. As one of the world's first strategic minerals, it shaped the course of history.

Common salt makes up some 85 percent of all the dissolved materials in the sea. The majority of the remaining 15 percent is made up by what are called the major constituents

*Salt evaporation ponds at Pedra de Luma on the island of Sal, Cabo Verde.  Its name recollects the one-time importance of salt production to the island, but that time is long gone.  Today most salt is obtained from evaporated sea deposits in land mines.*

of seawater. Aside from sodium and chloride they include magnesium, calcium, potassium, sulfur, carbon and bromine.

Of these magnesium has been directly extracted from seawater since the late 19th century. The lightest of all metals, magnesium is an important component in light-weight alloys. Bromine, which was used in anti-knock compounds for gasoline, used to be obtained from seawater in France and the United Kingdom. The reduced demand for leaded gasoline along with the availability of other sources of bromine gradually phased out these operations.

Neither bromine nor magnesium can be classified as strategic ocean minerals. While essential and in some cases irreplaceable, there simply are sufficient supplies elsewhere, particularly in land-based brines or salt flats. But there are other substances in the sea that are very valuable. In fact, every known element is dissolved in seawater, making the ocean the largest continuous ore body on the planet. Though most of these elements are present only in extremely minute concentrations, this hasn't deterred efforts to recover some of them.

In the late 19th century, techniques to measure the concentrations of these so-called trace elements became available. The gold content of seawater, for instance, was reported to be around 65,000 micrograms per cubic meter of water. A microgram is one millionth of a gram and a cubic meter of seawater contains about a million grams (or one metric ton), so it was thought that there might be 0.065 grams of gold in a ton of seawater. In scientific jargon this amount is expressed as 65 ppb or parts per billion, indicating that for every billion parts of seawater there would be 65 parts of pure gold.

Unfortunately, the methods used to determine this concentration were very imprecise and by the end of the century the estimate had been brought down ten-fold. According to the new figures, there was barely 6 ppb of gold in seawater. And by the early 1920s, when more refined analysis became available, that figure was further reduced to about 1 ppb. Yet even at this extremely small concentration, the oceans could be considered a veritable Klondike. At 1 ppb, each cubic kilometer of ocean would contain about a ton of gold. And since the oceans contain some 1.3 billion cubic kilometers of seawater, they would contain more than a billion tons of gold. Not surprisingly, these figures intrigued people and a gold rush of sorts, at least on paper, ensued.

Nobody knew how to recover the gold until German chemist Fritz Haber during the 1920s decided to do something about it. Motivated by the belief that, if he were successful, his discovery could help pay off Germany's huge war debts, Haber doggedly set to work. He painstakingly determined the gold content of nearly 2,000 water samples taken from all oceans. As his methods became more exacting and more precise, the observed gold concentrations gradually dropped, first from a thousand micrograms per cubic meter (1 ppb) to a hundred, then ten, and finally no more than four micrograms: 250 times less than what he had hoped to find. Shortly thereafter Haber had to give up his quest. There simply was no way that gold could be recovered economically from seawater at these low concentrations.

Today the gold content of water has been accurately established at 11 micrograms per cubic meter, slightly higher than Haber's findings. Even so there is nothing to indicate that gold extraction from seawater is, or will be, profitable. There are many millions of tons of gold dissolved in the sea, but they remain as elusive to us as the search for gold was to medieval alchemists.

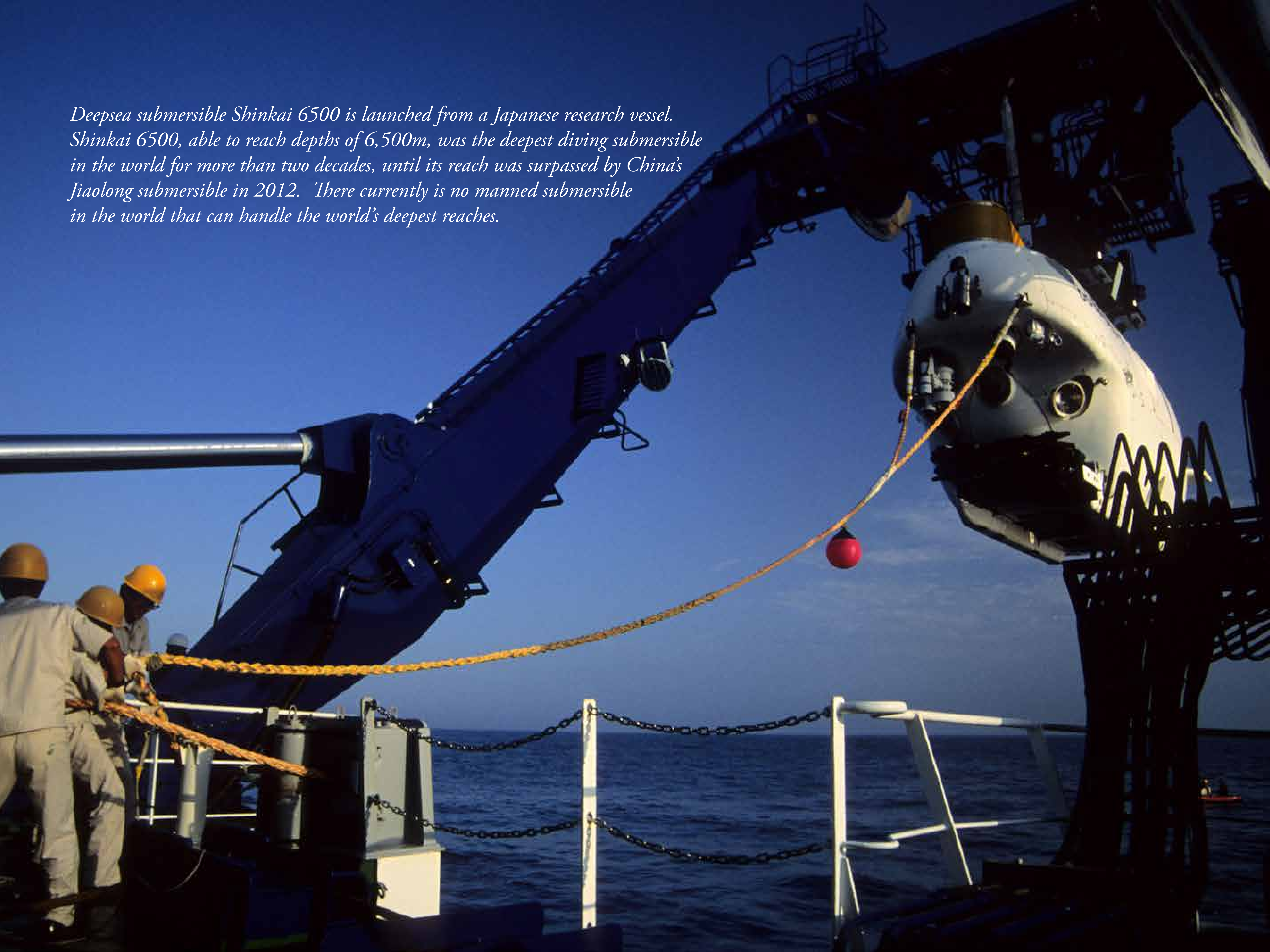
Marine organisms are far more effective in extracting trace elements from seawater. Micro-organisms like bacteria and single-celled algae are known to accumulate certain heavy metals, including gold. Seaweeds contain high amounts of iodine. Tunicates, also known as sea squirts, accumulate vanadium at concentrations millions of times higher than those of the surrounding seawater. And many marine invertebrates, which pass their time filtering seawater in search for food, also tend to store trace elements. Sometimes this is needed, as when the animals extract calcium from the water to build their protective shells, but there can also be negative effects. Oysters and mussels in polluted areas, for instance, can ac-

## THE STRUCTURE OF OCEAN BASINS

The changes seafloor spreading brings to size and shape of ocean basins are impressive. It has been determined, for instance, that the Atlantic Ocean grows about 3 cm wider each year, while the Pacific Ocean shrinks at a somewhat faster pace. That may not seem like a lot – just about a foot every ten years, a few meters in a lifetime, but when looking at the process over millions of years the distances involved become impressive, causing a massive reorientation in the face of the planet.

Since seafloor spreading also affects the oceans' wealth and topography, some terminology may be useful. The continental shelf is relatively smooth and gently sloping extension of the continent to a depth of some 200 m. It covers about five percent of the ocean's total area. Much of what is now continental shelf was exposed during the last Ice Age, some 10,000 years ago. Beyond the shelf is the continental slope, which rapidly descends to depths of 3,000–4,000 m. Thereafter the seafloor starts leveling off into the abyssal plains: flat, sediment-covered areas at depths between 4,000 and 6,000 m. These cover more than half of the total ocean area, and thus more than all land combined. The abyssal plains are interrupted by the oceanic ridges, where new seafloor is created in irregular pulses. Isolated peaks of these mountain systems occasionally extend above the surface to form islands like Iceland and the Azores.

Trenches, in contrast, are deep ocean depressions generally reaching depths beyond 6,000 m. Most of these are formed when one tectonic plate slides under another one – a process known as subduction. The Challenger Deep, named after H.M.S. Challenger (see Chapter 1), reaches a depth just shy of 11 km near Guam. It is the subsea equivalent of Mount Everest – the greatest depth registered anywhere in the ocean. The average depth of the oceans, in contrast, is 3.7 km. This may seem substantial, but when compared to the earth's diameter of 13,250 km, the ocean is but a thin film of water stretched over the Earth's surface. But that thin film of water made life possible on this planet, and is of vital importance to every living organism that inhabits it.



*Deepsea submersible Shinkai 6500 is launched from a Japanese research vessel. Shinkai 6500, able to reach depths of 6,500m, was the deepest diving submersible in the world for more than two decades, until its reach was surpassed by China's Jiaolong submersible in 2012. There currently is no manned submersible in the world that can handle the world's deepest reaches.*

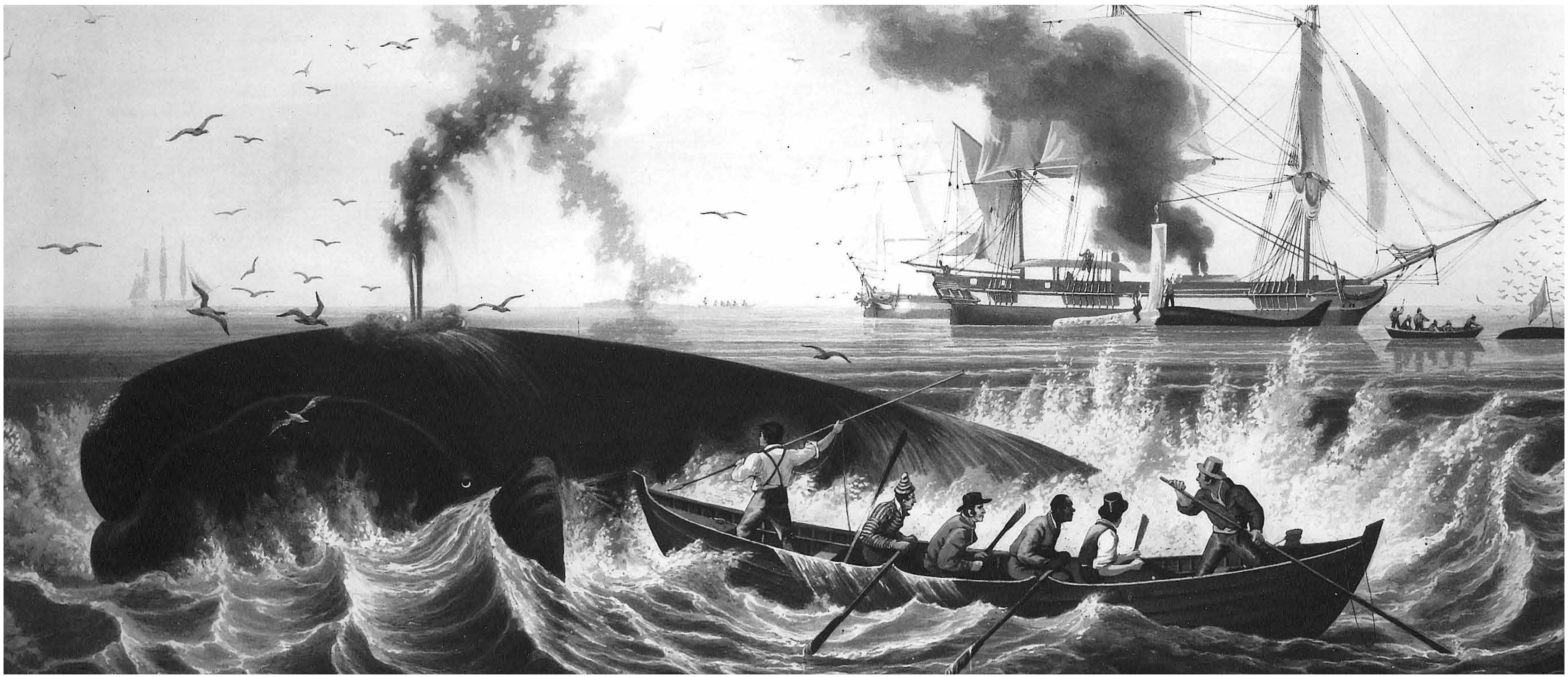
cumulate high levels of cadmium and mercury. While this does not necessarily kill the animals, it can have dramatic effects on the animals (or humans) that feed on them.

Since organisms are more effective than us in concentrating dissolved elements, they can be used to extract certain minerals. To some extent we do so with shell-bearing animals. When these animals die, their remains form massive shell deposits. In many coastal areas these deposits are mined and used as building materials. The technology does not yet exist to extract other dissolved elements but if the need arises to do soon a large scale, the best way may well consist of developing the biotechnology to let marine organisms do the work.

Marine organisms are also responsible for the most valuable mineral recovered from the oceans today. Millions of years ago the remains of micro-organisms were covered by sediments on the ocean floor, and subsequently crushed and buried to depths of thousands of feet. There temperature and pressure increases converted the organic matter into liquid (oil) or gaseous hydrocarbons that were, in turn, squeezed into the pores of rocks. The oil often escaped, causing seepages, but if there was a layer of non-porous rock (or cap) to prevent its escape, reservoirs were formed.

While oil from such natural seepages had been used for a variety of purposes, until the mid-nineteenth century most oil for lamps and even lubrication was obtained from whales. American whalers in particular had turned the hunt into a worldwide industry, involving hundreds of ships and thousands of men. They processed and refined the valuable oil and subsequently sold it to light homes and streets. In the process they were among the first to realize that the sea was not inexhaustible and that some of its stocks could be hunted to near-extinction.

This industry began innocently enough from shore-based stations along the coast of New England, with local whalers heading out in small boats in pursuit of migrating right whales. But soon there were few whales left close to shore, and New Englanders had to venture out in boats that could stay out for a few days at a time. In 1712 one of these was driven far offshore by a storm, ending up in the midst of a herd of sperm whales. The crew managed to kill one and tow it back to Nantucket, where people expressed surprise at the catch since sperm whales were thought to be extremely rare. But no one complained because the oil of sperm whales oil was of far better quality than that of right whales.



*American whalers hunted whales for oil, not for meat. Given the demand for a suitable lighting fluid, they managed to exterminate entire populations.*

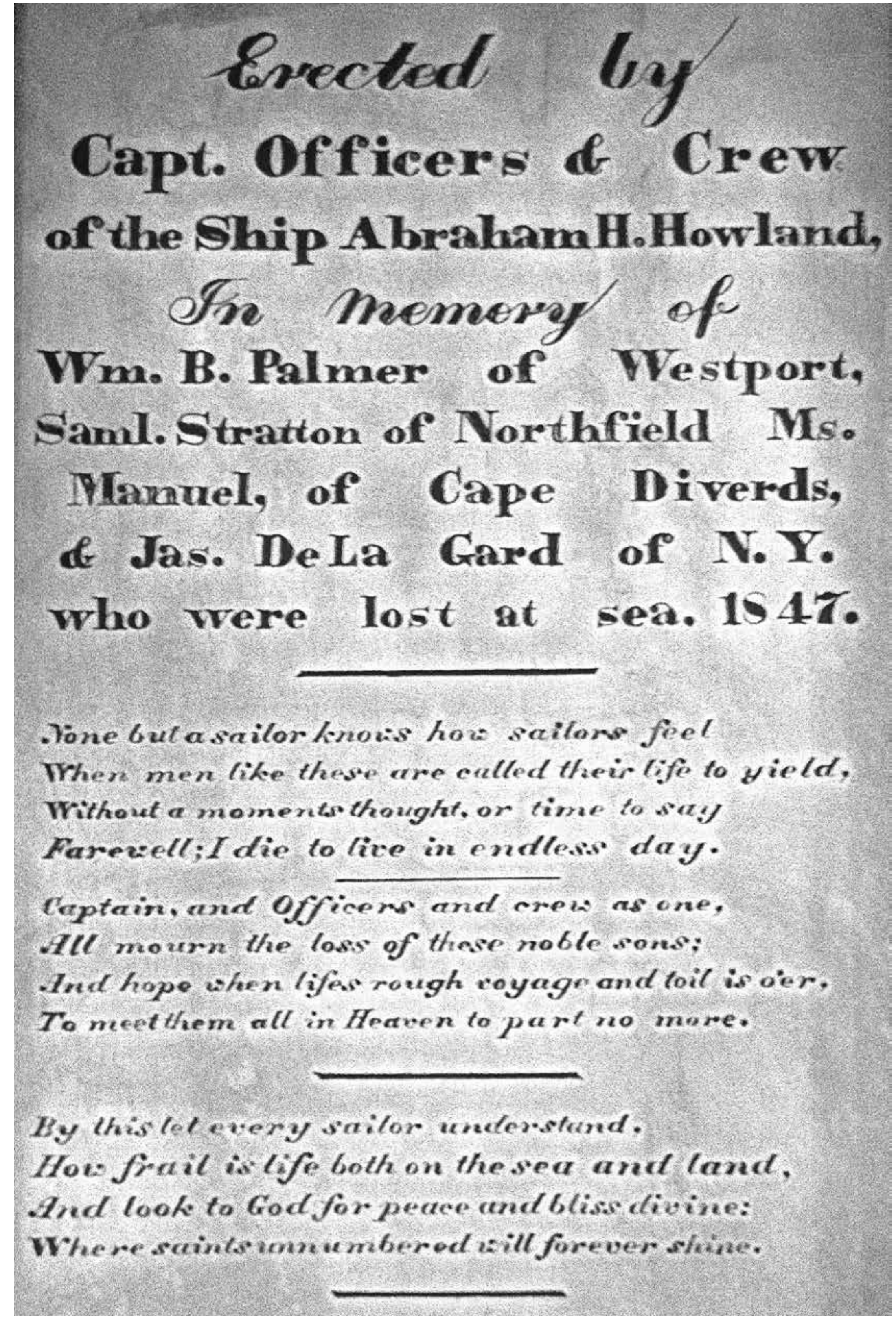
Before long Nantucket whalers set off to hunt sperm whales in earnest. They ventured over the entire Atlantic, locating sperm whale populations not only close to home in Newfoundland, but also off Bermuda, Guinea, Brazil, the West Indies and the Azores. But by the late 1780s fewer and fewer whales were to be found in these regions. Voyages grew longer as captains drove their ships to the far ends of the Atlantic in search of new populations. But none were found, and many a ship returned without a profitable cargo.

The news that large herds of sperm whales had been sighted off the coast of Chile spread like wildfire along the Nantucket waterfront and within months forty or fifty vessels were headed for the dangerous passage around Cape Horn. What they found on the other side exceeded everyone's expectations. Ships regularly returned with more than a thousand barrels of oil, making unbelievable profits in the course of a single voyage. By the turn of the century a hundred more ships had joined the hunt. The golden age of American whaling had arrived.

For a while Nantucket retained its position as the principal whaling center but as its port was too shallow for the larger whalers, these moved on to New Bedford and the neighboring port of Fairhaven. By the 1850s nearly four hundred whalers – more than half of the world's whaling fleet – were registered in New Bedford alone. Their returns were phenomenal. In 1858, for instance, the town's whalers brought in $6 million worth of whale oil, giving its twenty thousand inhabitants one of the highest per-capita incomes in the world. But this wealth came at a terrible price, as the many memorial plaques in New Bedford's Seamen's Bethel demonstrate. Hundreds of sailors were lost in confrontations with whales, and hundreds more were never seen again, their ships having vanished on the long and dangerous voyage.

There was yet another price to be paid for this wealth, though few even considered it during New Bedford's brief reign as the whaling capital of the world. In some years more than four thousand sperm whales were killed, severely depleting the population, and the whales began to become more difficult to find. Whalers never reflected on the damage they were causing. Instead, they switched to humpback and bowhead whales. Then these too began to be thinned out, requiring ships to stay away even longer. People began to realize that there were too many whalers chasing too few whales, but no one was about to show restraint. In the process, New Bedford and its neighbors committed commercial suicide. Longer voyages meant higher costs, which were tacked on to the price of whale oil. In 1845 a gallon of it could still be had for 80 cents; a few years later it had shot up to more than twice as much. At these rates lighting a house or a street became an expensive proposition. More important, at these rates it made sense to look for something cheaper.

At first, the search for alternatives was directed at obtaining a suitable lamp oil from coal. In Canada, Abraham Gesner succeeded in doing so. He called his discovery *kerosselain*, after the Greek words for oil and wax. Later, it came to be known as kerosene. In Boston, William and Luther



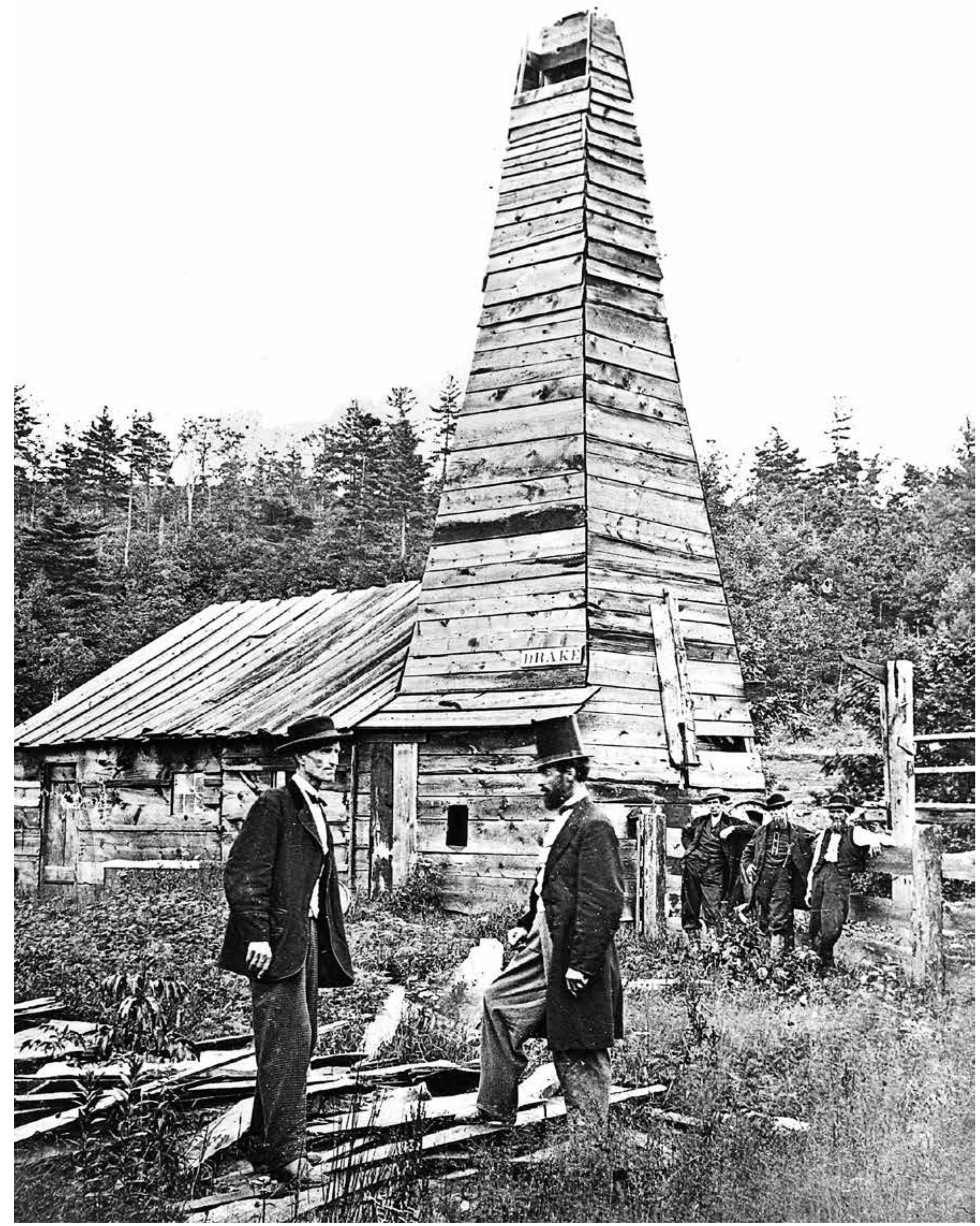
Atwood concocted something they called "*coup oil*". It was produced by mixing vegetable and animal oils with oil distilled from coal tar and could be used for illumination as well. In Britain meanwhile, James Young, a Scottish chemist, obtained a patent for "*paraffin oil*", which could be used as both lubricant and burning fluid.

Some people also began to investigate the possibilities of petroleum which, until then, was mostly considered a nuisance. Drillers for salt wells, for instance, found that it occasionally contaminated brines and fresh water springs. On the other hand, the oil was known to be flammable. George Washington, for instance, complained about a spring on his land that was "*of so inflammable a nature as to burn freely as spirits*." It was no surprise then that petroleum was destined to move up on the list of potential alternatives to whale oil.

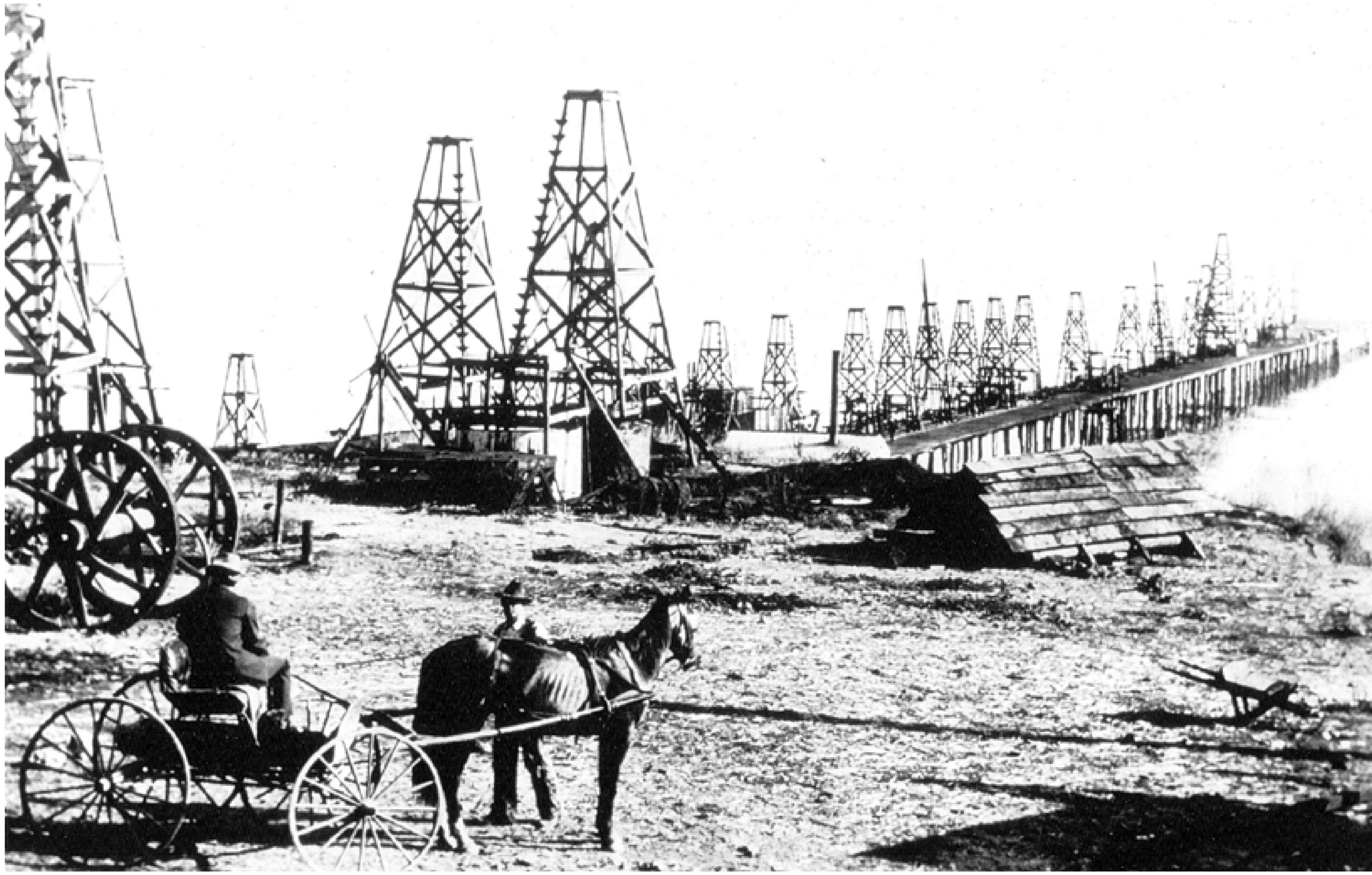
During the 1840s people managed to distill petroleum into a variety of burning fluids and lubricating oils. Though none of the resulting derivatives matched the fine quality of whale oil, they demonstrated that distillation could turn petroleum into something useful. This did not escape the attention of Samuel Kier, a Pittsburgh merchant who operated several contaminated brine wells in northwestern Pennsylvania. Since he had to remove the oil from the wells anyway, Kier set up a small distillation still in 1850 to produce a lighter fraction, which he called carbon oil. It proved quite suitable as an illuminating fluid and its price shot up quickly, from 50 cents a gallon to almost $2.00 – rates that made him and others look far more favorably upon this one-time nuisance.

The rising demand for petroleum set the stage for Edwin Drake, a former railroad conductor and jack-of-all-trades. Drake was convinced that larger amounts of oil could be obtained by drilling for it, rather than by recovering it from salt wells or oil springs, and he convinced a number of investors to finance his plans. In 1858 he arrived in Titusville, Pennsylvania and began building a derrick and engine house, much to the amusement of the locals. In August of the following year drilling started and before long the drill reached hard rock, chipping away at it at a steady rate of three feet a day. Drake assumed they would have to drill several hundred feet before striking oil, but on August 27, at a depth of barely 70 feet, the drill hit a reservoir, and oil began flowing to the surface. Astounded, the people from Titusville hurried to the derrick, where they found "Uncle Billy", Drake's loyal driller, scooping up oil in larger amounts than anyone had ever seen.

August 27, 1859 marked the onset of the petroleum era, though few people realized it at the time. In fact, the first newspaper account of the event wasn't published until 17 days later. But Drake's achievement did not stay unnoticed for long thereafter. By the end of 1860 there were 74 oil wells in and around Titusville, and from there the oil craze began spreading through northwestern Pennsylvania. In 1861, the first flowing well was struck. It produced 300 barrels per day– an unimaginable amount at that time– and people from all walks of life sped to the oil producing regions, hoping to make a fortune. Later oil was discovered in West Virginia, Kentucky and Tennessee, and further West in Texas, Oklahoma and California as well.




*Edwin Drake, with top hat, in front of the derrick that started the modern oil age.*



*By the 1890s, just 30 years after Edwin Drake started drilling for oil, the search for oil had reached the U.S. west coast. Since the oil fields extended well beyond the shore, drillers began building piers to erect their derricks and recover oil at sea.*

Oil production rapidly increased but so did demand. At first, the oil was used principally for lubrication and illumination, to replace whale oil. Then it was found to be a splendid heating source. And in the 1880s, the first gasoline-driven automobiles appeared. Before long, the increased flow of oil could hardly keep up with the new uses to which it was put, stimulating more and more companies to get involved in the business and start looking for oil.

By the late nineteenth century that search had reached the edge of the continent in California. Assuming that some oil fields extended out so sea, oil drillers built wooden piers to house their derricks and successfully recovered the first offshore oil as early as the 1890s. But these were no more than hesitant steps, never quite leaving the shore, for drilling at sea required far better technology than was available at the time.

It did not take very long for that technology to be developed. Through the first decades of the twentieth century the demand for oil rose spectacularly, especially as a result of the growing popularity and affordability of automobiles. In response American oil companies continued their offshore explorations. By the 1930s they had proven the viability of recovering oil from platforms that were no longer tied to the land. One of them, the Superior and Pure Oil Company, in 1937 drilled the first completely offshore well about a mile off the Louisiana coast, opening the Gulf of Mexico's massive oil wealth to large-scale recovery.

Just two years later the world was at war. A dependable supply of oil became a matter of life or death for the opposing sides. For the Allies that meant access to the United States and its immense oil reserves. Though hundreds of tankers were sunk by German submarines, enough oil came through to enable the Allies to push their opponents back into German territory. But America had dipped deep in its land-based petroleum reserves to secure the victory. Its government knew that it would eventually need the sea to fulfill its post-war needs.

Following the war, American oil companies ventured further out to sea. Before long they reached the three-mile limit, the extent over which the United States claimed jurisdiction. No one doubted America's rights to exploit mineral resources up to that limit. Since Medieval times and perhaps even earlier, nations had generally accepted that a coastal state exercised sovereignty over the territorial sea -- a narrow belt of ocean adjacent to its coast. But international law did not address what rules applied if a nation wanted to exploit the sea's mineral resources beyond this limit. In fact, it wasn't clear to whom this mineral wealth belonged. If the freedom-of-the-sea concept were applied, it could be argued that the oil belonged to no one. The seafloor would then be considered *res nullius* – a legal no man's land, fair game for anyone with the technology to develop it.

## OFFSHORE ENERGY

The contribution from the sea to world oil production has averaged between 25 and 35 percent over the past ten years. That share could rise because most remaining "unproven" oil reserves lie offshore, not necessarily because there is more oil there but because the industry has been recovering oil from land much longer and more intensively that at sea. But the fact that oil is derived from phytoplankton, from miniscule sea plants which became entrapped in marine sediments millions of years ago, makes clear offshore areas will continue to provide promising prospects. That potential is also confirmed by the fact that oil is found in sediments less than 150 million years old, which predominate offshore.

While most offshore oil and gas are currently produced from the continental shelf, there is plenty more in deeper water. The great prisms that lie at the bases of nearly all continental slopes, for instance, appear to contain considerable supplies, with conditions for oil accumulation near-perfect. Drilling those depths is very expensive and economically prohibitive when oil prices are low, but it can and has been done. The diatom oozes located beneath the Antarctic Ocean probably contain a lot of oil as well, and it is already clear that the Arctic Basin holds substantial oil reservoirs.

While there is no doubt that the oil companies would like to explore and develop these areas if and when prices are right, we should ask ourselves whether they should in light of the need to stop burning fossil fuels in the years ahead. Adding more and more "possible" reserves to the list of "probable" and "proven" reserves is like dangling a pack of cigarettes in front of someone trying to quit. It takes real discipline to resist the temptation, something we haven't proved very good at when it comes to our addiction to oil.

The same dilemma applies to methane hydrates, also known as methane clathrates or liquid ice, a compounds which consists of methane trapped within a crystal structure of water. Massive methane hydrates reserves have been located under marine sediments, creating another possible energy source. But while methane burns relatively cleanly, it is also a very powerful greenhouse gas, the release of which needs to be strictly controlled in the future.

*The ocean contains very substantial amounts of oil and gas, with estimates ranging anywhere from one quarter to one third of reserves. That could turn out to be an underestimate since most offshore exploration and exploitation has been limited to water depths below 3,000 feet.*

*The first offshore platforms raised legal questions as to whom offshore oil belonged. In the U.S. it took 50 years for the issue to be settled, with states like Louisiana and California being granted ownership of the seabed (and its oil) up to the old territorial sea limit (3 miles) and the federal government taking the continental shelf beyond.*

The United States made sure that the seafloor would not remain *res nullius* for long. Already during the war some of Franklin Roosevelt's advisers expressed concern over coastal resources. Harold Ickes, Roosevelt's secretary of the interior, summed up the situation in a letter to the president. "I draw your attention to the importance of the Continental Shelf not only to the defense of our country, but more particularly as a storehouse of natural resources" he wrote. "Since it is a continuation of our continent, it probably contains oil and other resources similar to those found in our States." He then went on to make a very important recommendation: "I suggest the advisability of laying the ground work now for availing ourselves fully of the riches in this submerged land and in the waters over them."

Roosevelt was taken by the idea. He sent Ickes' letter on to his secretary of state with a handwritten note. "I think Harold Ickes has the right slant on this," it said. "For many years I have felt that the old three-mile limit should be superseded by a rule of common sense." Roosevelt even went on to give an example of what he meant by that: "For instance the Gulf of Mexico is bounded on the South by Mexico and on the North by the United States. It seems to me that the Mexican Government should be entitled to drill for oil in the Southern half of the Gulf and we in the Northern half of the Gulf. That would be far more sensible than allowing some European nation, for example, to come in there and drill."

Three years later Roosevelt's successor did exactly what was needed to bring a bit of "common sense" to the law of the sea. In a proclamation dated 28 September 1945, Harry Truman asserted the United States' right to control and exploit the resources and the subsoil of its continental shelf, basically bringing all of it under American jurisdiction. There also was a proclamation on fisheries, in which the United States asserted the right to exploit and manage "certain high seas fisheries", but in that case there were no specific claims of ownership.

Prior to the proclamations being issued, their text was run by some of America's allies and neighbors to assess the reaction. Not that any reaction would have made much difference. From the records of the various meetings it is clear that Washington was not about to let others interfere. The U.S. government simply took the initiative and informed the rest of the world that nothing in international law could prevent a state from claiming the mineral resources off its own coast. It was a rather subjective interpretation of the law or rather of the lack thereof, especially since there was no precedent for a claim of this nature. But then again, at the end of the war the United States was by far the most powerful country in the world. That position allowed it to dictate the rules.

Whatever the motivations, the first Truman Proclamation became a landmark document. In retrospect, it was nothing less than the first step toward the enclosure of the oceans, a process that continues to this day. But at the time it seemed to make sense. Though some nations reacted with suspicion to Washington's claims, most thought it a good idea. Geologically speaking, the continental shelf did form part of the continent, so it seemed reasonable to suggest that its resources belonged to the coastal state. Besides, who knew what was out there, anyway?

Nonetheless, it soon became clear that the United States had opened a legal can of worms. For a start, states like California and Louisiana, which were already producing offshore oil, felt that the continental shelf should be under their control, not the federal government's. And there were not only domestic uncertainties. A month after the Truman Proclamation, Mexico decided not only to follow the American example but to go beyond. In its declaration, it claimed the continental shelf as well as its "superjacent" resources, a legal term meant to include the fish above the shelf. This position raised concerns in Washington because American fishermen operated in these waters. But with the United States having started the process in the first place, and having created new rules to suit its own needs, Washington's complaints were ignored. American fishing vessels that violated the Mexican claim were detained and forced to pay a hefty fine.

The Mexican example was soon outdone anyway. Before long Latin American and Caribbean nations began to extend not just their jurisdiction but their sovereignty over the sea and the seafloor out to a distance of two hundred miles, in effect claiming a territorial sea of that size. Argentina started in 1946, and a year later Chile, Ecuador, and Peru followed suit. Costa Rica made a similar claim in 1948, and El Salvador in 1950. Nations elsewhere began to claim larger chunks of ocean too, leading to a veritable escalation of maritime claims. Before long there was so much confusion over who supposedly owned what that the U.S. State Department geographer was forced to admit in his 1949 Annual Report to Congress that "never have national claims in adjacent seas been so numerous, so varied, or so inconsistent."

*A satellite photograph, showing the Gulf of Mexico coast from Morgan City, Louisiana until Miramar Beach, Florida – a distance of some 1,000 km. The bright spot in the middle shows oil that has risen to the surface following the April 2010 Deepwater Horizon blow-out – the largest offshore oil spill to date. Though they were very keen to own and develop the Gulf's offshore wealth, none of the states could have imagined the damage it would one day do to their coasts.*

This confusion created problems. Nations generally agreed that navigation through territorial waters was subject to "innocent passage". This meant that ships had the right to sail through any nation's territorial sea, provided their passage was not prejudicial to the peace, good order, or security of the coastal state. In practice, the rule required submarines to navigate on the surface and to show their flag when in territorial waters, since a submerged passage could be perceived as less than innocent. No one had any problems with that in the case of three– or even six-mile territorial seas, but two hundred miles was another matter. Neither the United States nor the Soviet Union wanted its submarines to have to pop up whenever they were within two hundred miles of some other nation's coast.

There were many other uncertainties, and they demanded resolution as well. Fortunately around this time the newly established United Nations embarked on its task of codifying international law, and the uncertainties of the law of the sea presented a splendid challenge. Here indeed was a situation that clearly needed clarification and, equally important, demanded international cooperation. The General Assembly accordingly requested its legal experts to prepare draft articles on the legal regime of the oceans. Seven years later they submitted four draft conventions: one dealing with the legal status of the high seas, another focusing on the territorial sea, the third examining the continental shelf, and the final one proposing measures regarding fisheries.

From February to April of 1958 delegates from eighty-six countries filed into Geneva to review these drafts and to codify them into international law. The meeting was known as the United Nations Conference on the Law of the Sea. Later, a "First" was added to the title, because more conferences would follow. But no one knew that at the time. Indeed, most delegates assumed that the meeting would do away once and for all with the uncertainties surrounding the legal status of the sea.

At the conclusion of the conference the participating nations approved four conventions, all of them along the lines of the drafts they had received. As intended, these conventions did much to clarify the legal regime of the oceans. They divided the sea into different zones over which various degrees of jurisdiction could be exercised. Coastal states, for instance, could continue to claim a good deal of control over the territorial sea. It was in fact considered part of their territory, and they could regulate it strictly, provided they respected the principle of innocent passage. In the contiguous zone, coastal states were allowed to check immigration and health provisions as well as fishery regulations. The Convention on the Continental Shelf gave coastal states exclusive rights over the resources of the continental shelf, as the Truman Proclamation had called for. And finally, the high seas remained a common zone where the freedom of the sea applied. The four Geneva Conventions thus codified the traditional law of the sea, which had developed as customary law over the centuries, along with newer concepts, like ownership over the resources of the continental shelf, which had been introduced just twelve years earlier.

*The First Law of the Sea Conference in Geneva yielded four major conventions. Unfortunately they would quickly prove out of date.*

*The Geneva Conventions also addressed the sea's living resources, though they couldn't prevent the massive overfishing that took place the following years.*

But the Conference and its Conventions failed to resolve some critical issues. While everyone accepted the concept of various jurisdictional zones, there was no agreement on how far exactly they extended. The Convention on the Territorial Sea and Contiguous Zone, for instance, did not include a uniform rule on their width because it proved impossible to reach an agreement. Some nations claimed three miles, other four or six miles, and the Latin American nations insisted on their unilaterally declared 200 miles.

The Geneva Conventions were also not very clear on how these various zones were to be divided amongst neighboring states. If anything, there was universal agreement on the fact that there was a pie, but no clear rules on how large it was or how it was to be shared. In 1958 this system was probably adequate but when it became clear in subsequent years that many continental shelf areas contained resources far beyond what had been anticipated, questions of division and delineation grew in importance (see p. 204).

Confusion also reigned when it came to determining the extent of the continental shelf. Geology generally defined the continental shelf as the gently sloping extension of the continent to a depth of some 200 meters, but law turned it into something far more confusing. During its preparations for the Geneva Conference on the Law of the Sea, the International Law Commission defined the continental shelf as "the seabed and subsoil of submarine areas contiguous to the coast, where the depth of the superjacent waters admits of the exploitation of the natural resources and subsoil." With that, the legal definition of the continental shelf was rapidly moving away from its geological counterpart.

At the Conference some coastal states supported this exploitability limit because they wanted the right to develop the sea bottom beyond 200 meters if and when technology allowed them to do so. Other nations wanted to retain a depth limit, to make sure that the extent of the continental shelf remained somewhat defined. In the end, the participating delegations agreed on a compromise, defining the continental shelf as the seabed adjacent to the coast "to a depth of 200 meters, or beyond that limit, to where the depth of the superjacent waters admits of the exploitation of the natural resources of the seabed".

Although everyone seemed more or less satisfied, this definition still failed to specify where the continental shelf was supposed to end. At the time it was not considered a serious problem, because few people thought that mining the ocean floor at depths beyond 200 meters was a realistic proposition. But they were wrong. Even as they were debating the issue, discoveries at the other end of the world ensured their carefully worded compromise would be out of date before the ink had even dried on it.

1958 was not only the year of the First Law of the Sea Conference; it was also the year the International Geophysical Year (IGY) came to a close. Implemented to gain a better understanding of the planet, the IGY stimulated interest in the deep ocean floor. Some scientists indeed believed that the deep sea held clues to the earth's origin, though they

## DIVIDING THE OFFSHORE PIE

During the 1960s offshore oil was found off the coasts of many nations, some of which began to realize that, with a little luck, they could become oil producers. In the North Sea, for instance, oil and gas deposits allowed the United Kingdom, Norway, Germany, Denmark and the Netherlands to entertain visions of energy independence. But before they could produce any oil, they had to divide the North Sea continental shelf amongst themselves. It proved easier said than done.

The Geneva conventions did not provide much help in this regard. The Convention on the Continental Shelf suggested that neighboring countries should attempt to divide their continental shelf by agreement. If that proved difficult, an equidistant line, every point of which was at equal distances from both coasts, was proposed unless special circumstances justified some other course of action. Unfortunately, the convention did not specify what it meant by "special circumstances".

Following these recommendations, Norway and the United Kingdom agreed on a median line to delineate their respective zones. Further south, Denmark and the Netherlands reached similar agreements with the British government. As far as adjoining boundaries were concerned, Norway and Denmark agreed on the proposed equidistant line, but when Denmark and the Netherlands adopted a similar course, they ran into trouble. To determine their boundary up to the median line with Britain, both countries agreed on an equidistant boundary with West Germany, but they did so without consulting their neighbor. And Bonn did not take it. If equidistant boundaries were applied Germany, as a result of its concave coastline, would obtain hardly any of the North Sea's continental shelf and the Germans were not willing to accept that. They too hoped to strike oil. The larger their sector, the better their chances of doing so.

Unable to resolve the dispute, the three countries took the case to the International Court of Justice and asked it to resolve the deadlock. In its decision the Court agreed with Germany, stating that equidistance was by no means an absolute rule. It stated that other factors should be taken into account, like the configuration of the coast, the structure of the continental shelf, and some degree of proportion. These were not exactly clear-cut rules, but they did bring Germany, Denmark and the Netherlands back to the negotiating table to work out a better agreement.

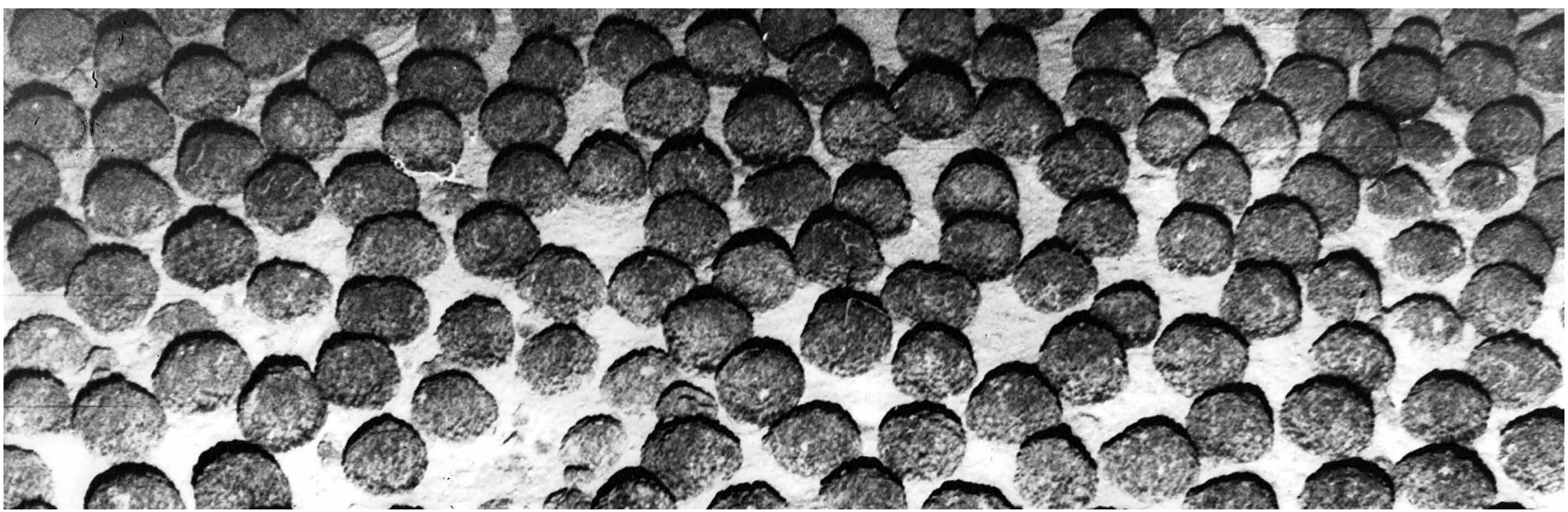
Similar issues emerged in every sea and in every ocean, and they grew more difficult to resolve as time passed. The already poor relations between Greece and Turkey deteriorated over the division of the Aegean Sea. West African countries began bickering over boundaries in the oil-rich Gulf of Guinea. In the Far East, difficulties arose over the division of the East and South China Sea and their oil, especially in the vicinity of the Spratly Islands, and even strong allies like the United States and Canada disagreed when it came to delineating the presumed oil riches of the Georges Bank. Coastal states supported whatever rule or "special circumstance" that yielded the largest possible share of the pie. No wonder then that it took long negotiations before the principal continental shelf areas could be carved up. No wonder also that many claims remain unresolved. And don't be surprised when some of those hit the headlines in the years ahead.

*The North Sea was one of the first offshore areas to be divided among the surrounding states.*

could not prove it. In fact, all they had available were a few thousand dredge samples from widely scattered locations, brought up by various oceanographic expeditions over the previous hundred years. It wasn't much to describe the deep seafloor, not to mention understanding its role in the Earth's long history.

The IGY began to fill in some of the gaps. For the first time ever scientists were able to not only systematically dredge the deep seafloor, but also photograph it. And what they saw was astonishing. Immense areas of the deep abyssal plains were covered with dark, potato-sized lumps, known as manganese nodules. Geologists from the Scripps Institution of Oceanography in La Jolla, California found them throughout the entire eastern Pacific basin. Other teams discovered and photographed massive deposits in the deep reaches of the western Pacific, the Indian Ocean and the Atlantic.

*Large areas of the deep sea abyssal plains turned out to be covered by manganese nodules.*



By the early 1960s, manganese nodules had been studied in more detail, revealing that, aside from manganese, they contained high concentrations of nickel, copper and cobalt. Some people began to study their economic potential, hinting that the deep seafloor might contain one of the largest and most valuable mineral deposits on the planet. Not only did the nodules contain important metals, they were obviously present in massive quantities. Most important perhaps, they seemed up for grabs because no one really owned the deep seabed, or did they?

Early reports contained glowing predictions on the potential of mining manganese nodules. Deposits from the Pacific Ocean typically averaged 20 percent of manganese, 6 to 10 percent of iron, and smaller amounts of copper, cobalt and nickel. In some areas, densities of 50 to 100 kg of nodules per square meter were reported. Though based on sketchy data, the overall amount of manganese nodules was estimated in the trillion ton range for the Pacific Basin, and perhaps twice as much worldwide. In one report, it was even asserted that manganese nodules were a renewable resource of sorts since their annual rate of growth appeared considerably higher than the consumption levels of the metals they contained.

In subsequent years these optimistic predictions were tempered somewhat by additional data and a more realistic evaluation of the mining costs, but few experts doubted that nodule recovery could be very rewarding. Four of the metals in manganese nodules– cobalt, copper, nickel and manganese– were of particular interest, since these metals were essential ingredients of high-performance alloys. While not exactly scarce on land, their principal reserves were located in Third World countries and what was then still the Soviet Union. Given the political situation there, that made them strategic minerals. If the potential of nodule mining had been correctly assessed, it seemed that the ocean could provide an alternative, and perhaps more reliable, source of these vital metals.

During the mid-1960s, several companies began to investigate the potential of deep sea mining. Despite the glowing reports published just a few years earlier, they soon

*Using dredges, some companies managed to recover manganese nodules from the deep sea, 5,000 m below.*

realized they faced enormous technological problems. Not only did they have to develop a mining system that would recover deposits three to four miles below the sea's surface; they also had to come up with processing technology, either at sea or on land, to extract the most valuable metals.

Given the massive investments required, the companies organized themselves into consortia, to share risks and know-how. By the mid-1970s, four of these were operating. They included virtually all of the world's major mining companies: Kennecott Copper, U.S. Steel, Standard Oil, Sun Company, SEDCO, Lockheed, and Tenneco from the U.S.; the International Nickel Corporation (INCO) and Noranda Mines from Canada, Preussag and Metallgesellschaft from Germany: Shell and Boskalis from the Netherlands; Union Minière from Belgium; Rio Tinto Zinc, British Petroleum (BP) and Consolidated Goldfields from the United Kingdom; and Mitsubishi and Sumitomo from Japan. An exclusively French consortium, including the French ocean research organization IFREMER and Elf Aquitaine, joined the group of prospective ocean miners in 1974, and a consortium of 48 Japanese companies did so in 1982.

The consortia spent millions of dollars in developing a prototype mining system. After considering a variety of options, most eventually settled on a hydraulic recovery system, consisting of a dredge head gathering the nodules on the seafloor and a pipe string to transport them to the surface. By injecting compressed air into the pipe, the rising (and expanding) air bubbles created suction, forcing the nodules to the surface. The system was tested at sea and during the late 1970s some of the companies successfully recovered a few hundred tons of nodules. It was a far cry from the millions of tons needed to make mining operations commercially feasible, but it proved that the system worked and that, with the right incentives, the technology to mine the seafloor miles beneath the ocean surface could be developed.

By that time most projections were no longer valid, however. For one thing, metal prices did not warrant further development at the time. Starting a deep sea mining operation required an initial investment of more than a billion dollars, not counting annual operating expenses, and to make such a venture profitable the prices of cobalt, nickel, copper and manganese had to rise considerably. The companies knew this wasn't likely to happen any time soon. In fact, on several occasions metal prices had collapsed, dimming the prospects for deep sea mining operations even further.

The industry was also concerned about the legal status of the deep ocean floor. When the mining consortia began their investigations in the 1960s, it could have been argued that manganese nodules did not belong to anyone, making the deposits available to whoever made the effort to recover them. But by the end of the decade that was no longer the case. Assuming that nodules represented a potential fortune, others had gotten into the picture and demanded a determination of ownership. It was clear that ocean law needed an update, even though the Geneva Conventions had only been in force just a few years.

The impetus to this review came in late 1967. In a well-prepared speech to the General Assembly, Arvid Pardo, Malta's Ambassador to the United Nations, warned against the appropriation of the deep sea by countries that possessed the technical ability to exploit it. Pardo correctly pointed out that there was nothing in international law to prevent industrialized nations from going out and claiming vast areas of the deep seabed, much the same way immense territories had been claimed by powerful nations throughout the colonial era. The analogy struck a responsive chord, especially with the many African countries that had recently gained their independence.

To prevent this from happening, the Maltese Ambassador urged the adoption of a resolution that would declare the deep sea the "common heritage of mankind'; a provision that would change its legal status from a legal no-man's land to a common area. He also proposed a treaty to ensure that nations would not unilaterally appropriate the deep sea, but that it would be developed in a manner consistent with the United Nations Charter, implying that the financial benefits ought to be used at least partially to help developing nations. This, in Pardo's view, required the establishment of an international agency, assuming control of the deep seafloor as a trustee for all countries.

Pardo's speech set of a chain reaction. By the end of the year the General Assembly had established a Committee on the Peaceful Uses of the Seabed and Ocean Floor beyond the Limits of National Jurisdiction, which mercifully became known as the Seabed Committee. After a few meetings it recommended that a permanent committee be established to review Pardo's proposals and study the international machinery to develop the resources of the deep sea.

Already at this early stage of the discussions, a rift was developing between the industrialized nations and the Third World. Developing nations endorsed the spirit of Pardo's proposal. If the deep seafloor contained the mineral bonanza they had been led to believe, they obviously wanted a share of the profits, even though they didn't have the technology to mine themselves. Some also perceived the proposal as a form of economic protection because several developing countries depended heavily on the export of minerals to make ends meet. If the market were to be flooded by massive metal supplies from other sources, their economies could be thrown into turmoil. Deep sea mining would have to take place in a manner that did not create price instability, they argued. In their view, this could only be guaranteed by an international agency.

The industrialized nations, on the other hand, were wary of international entities setting the rules. Controlled by developing nations, the proposed international mining agency would dictate prices and production rates, even though the industrial nations would have to put up the capital. It was hardly a setting that encouraged commercial operations and most industrialized nations consequently voiced their opposition. Besides, they didn't want to pin down the limits of national jurisdiction over the deep ocean. Any move in that direction, in their view, would require careful consideration of the legal consequences.

In spite of these conflicting views, the Seabed Committee succeeded in drafting a Declaration of Principles Governing the Seabed. It began by stating that the seabed and the ocean floor beyond the limits of national jurisdiction were the "common heritage of mankind", as Arvid Pardo had called for a few years earlier. It also emphasized that no state could unilaterally appropriate any part of this area or develop its resources. The resolution was adopted by the General Assembly in 1970, with 108 nations voting in favor and 14 abstaining. With it, the last legal no-man's land on earth had been given a legal status. It now belonged to the community of nations.

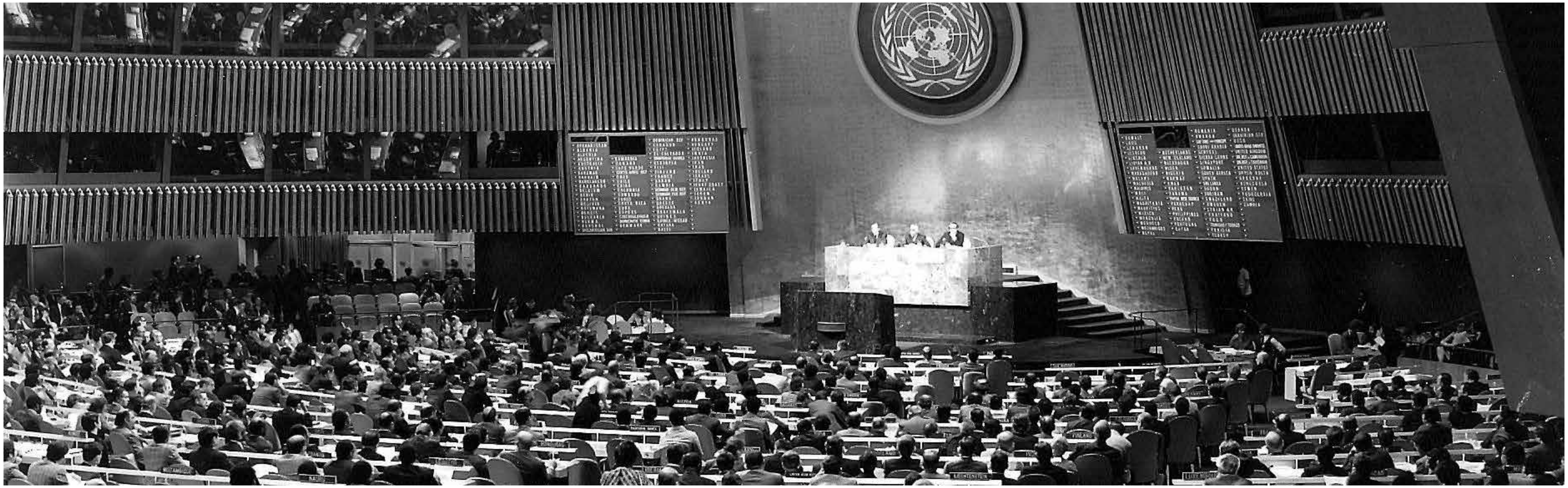
Meanwhile, the various discussions over the legal status of the deep sea began to make clear that it was difficult to focus on one area of the ocean without referring to the others. Accordingly, the General Assembly broadened the mandate of the Seabed Committee, asking it to review all legal aspects of the sea in preparation for a new Law of the Sea Conference.

Though the Geneva Conventions on the Law of the Sea had been in effect for no more than a few years, many felt this to be a wise move. For one thing, many of the newest U.N. members hadn't been around when the Geneva conventions were drafted, and they welcomed the opportunity to participate in a review. For another, some of the issues the Geneva Conventions had failed to resolve were growing more pressing. And finally, there was a strong feeling among developing nations that deep ocean mining, if at all, should proceed under United Nations control. Otherwise, the deep sea would end up being carved up by the world's industrial powers, much the same Africa way had been carved up a hundred years earlier.

Like the International Law Commission twenty years earlier, the Seabed Committee took its preparatory task seriously. Between 1970 and 1973 it held hundreds of formal meetings, generating a massive stack of documents. But amongst this pile of paper there was no draft convention. The Committee thoroughly covered every legal aspect of the sea, but the law of the sea had grown far more complex since the 1958 Geneva Conference. Three years simply was not sufficient to produce a draft that covered it all. And three years certainly was not enough to iron out the differences amongst the members of the Seabed Committee itself. Even so, the General Assembly felt that sufficient work had been done to call for a new conference: the third in the series.

The Third Law of the Sea Conference opened with a brief organizational session in New York in December of 1973. In the summer of 1974, a first substantive session was held in Caracas, Venezuela. There the work of the Conference was divided into three main committees, and each of the participating countries put forward its position on the entire range of law of the sea matters, generating a formidable set of documents.

At the onset, it had been assumed that the Third Law of the Sea Conference would follow the format of its predecessors and come to an agreement during one main substantive session. Unfortunately, a few weeks into the Caracas meeting it became clear that there was hardly anything to which any state agreed to in whole or in part. As before, the deep sea mining issue created the major stumbling block. The developing nations took the "common heritage of mankind" principle one step further and called for the direct exploitation of the seabed by an international entity. The industrialized nations, on the other hand, felt that any



*The U.N.'s New York Headquarters would host the Third Law of the Sea Conference for nearly ten years – much longer than anyone could have expected.*

deep sea mining should take account of commercial considerations. They knew that their companies would balk at the prospect of being regulated by a United Nations entity.

The Caracas session ended inconclusively and was followed by a series of meetings alternating between New York and Geneva, during which the conference slowly grew towards a consensus. In 1980, a deep sea mining compromise was finally worked out. There was little to stand in the way of a formal treaty, but the new government that took office in the United States in early 1981 decided otherwise. Committed to strengthening America's military power, the Reagan Administration took a strong stand in regard to maintaining adequate supplies of strategic minerals. The deep sea mining provisions under consideration at the Law of the Sea Conference did not comply with this new policy and the U.S. delegation was consequently ordered to withdraw its consent.

Even though there were attempts to come to a resolution in subsequent meetings, the U.S.' adamant stand precluded further progress. The Conference organizers decided to call for a vote anyway. In April 1982, a formal treaty was approved, but the U.S., along with three other countries, voted against. There were 18 abstentions, including several industrialized nations and most Eastern Bloc members. Third World countries, in contrast, voted overwhelmingly in favor.

Not counting the many years of preparatory work, it had taken nearly ten years of formal negotiations to revise the legal regime of the oceans. This was far longer than anyone could have imagined back in 1973 but, in comparison with 1958, when the Geneva Conventions were adopted, much had changed. Then the 86 participating countries had 73 proposed articles to discuss. This time there were nearly twice as many countries, each with their own interests, and 400 draft articles. Even more important was the number of interest groups and alliances that influenced the negotiations. In 1958, there were essentially two such groups: the nations that favored the principle of the freedom of the sea, and the countries that advocated extended coastal control. Twenty five years later there were regional groups, issue-oriented groups and, most significantly, the north-south alliances which dominated virtually every aspect under consideration. Given the complexity and importance of what was at stake, it was no surprise that the Third Law of the Sea Conference grew into one of the largest, longest and most complex conferences in history.

The 1982 Law of the Sea Convention went into effect in November of 1994, bringing important changes to the legal regime of the oceans. For one, it finally cleared up the issues that were left unresolved by the Geneva Conventions. The maximum width of the territorial sea, for instance, was firmly established at 12 miles. The continental shelf too was given a clearer definition. Though it too has little to do with the geological concept of the shelf, the new definition at least ensured that there is a limit, albeit a very generous one, to any coastal state's reach.

Coastal jurisdiction was complemented by the exclusive economic zone, a new concept in ocean law that reflected international agreement on the need for extended coastal jurisdiction to preserve and protect marine living resources. Extending 200 nautical miles (a whopping 370 km) from shore, the exclusive economic zone grants sweeping powers to coastal states, including rights over all its resources, control over marine research and pollution, and jurisdiction over a number of other activities, with the exception of navigation. Coastal states already had control over the mineral resources of the continental shelf but the exclusive economic zone extends that control to minerals regardless of depth, as long as they are within 200 miles of the coast.

The remainder of the ocean remains "high seas", in which the traditional freedoms of the sea continue to apply, at least so on the surface. The seafloor below the high seas is called "the Area". It is to be managed by the International Seabed Authority for the benefit of all nations. The recovery of deep sea resources will take place under a parallel mining system, whereby a company can submit two mining sites to the Authority. The organization will select one of these to be exploited by its operating branch on behalf of the developing nations. The other site can then be mined by the company for its own profit. It is by no means a simple system, but compromises usually are not. In fact, more than twenty years after the entry into force of the Law of the Sea Convention, nations are still meeting to work out all the details. Then again, they have plenty of time. Several organizations have applied for licenses, but no one really expects deep sea nodules to be mined any time soon. There are other deposits in the deep sea that stand a better chance of being recovered first.

In retrospect, the first and the third Law of the Sea Conferences exhibited interesting parallels. Both were triggered by the discovery of valuable mineral resources in an area which had no clear legal status. In the 1950s it was about offshore oil, and especially that portion of it lying beyond the territorial sea; fifteen years later uncertainties over the

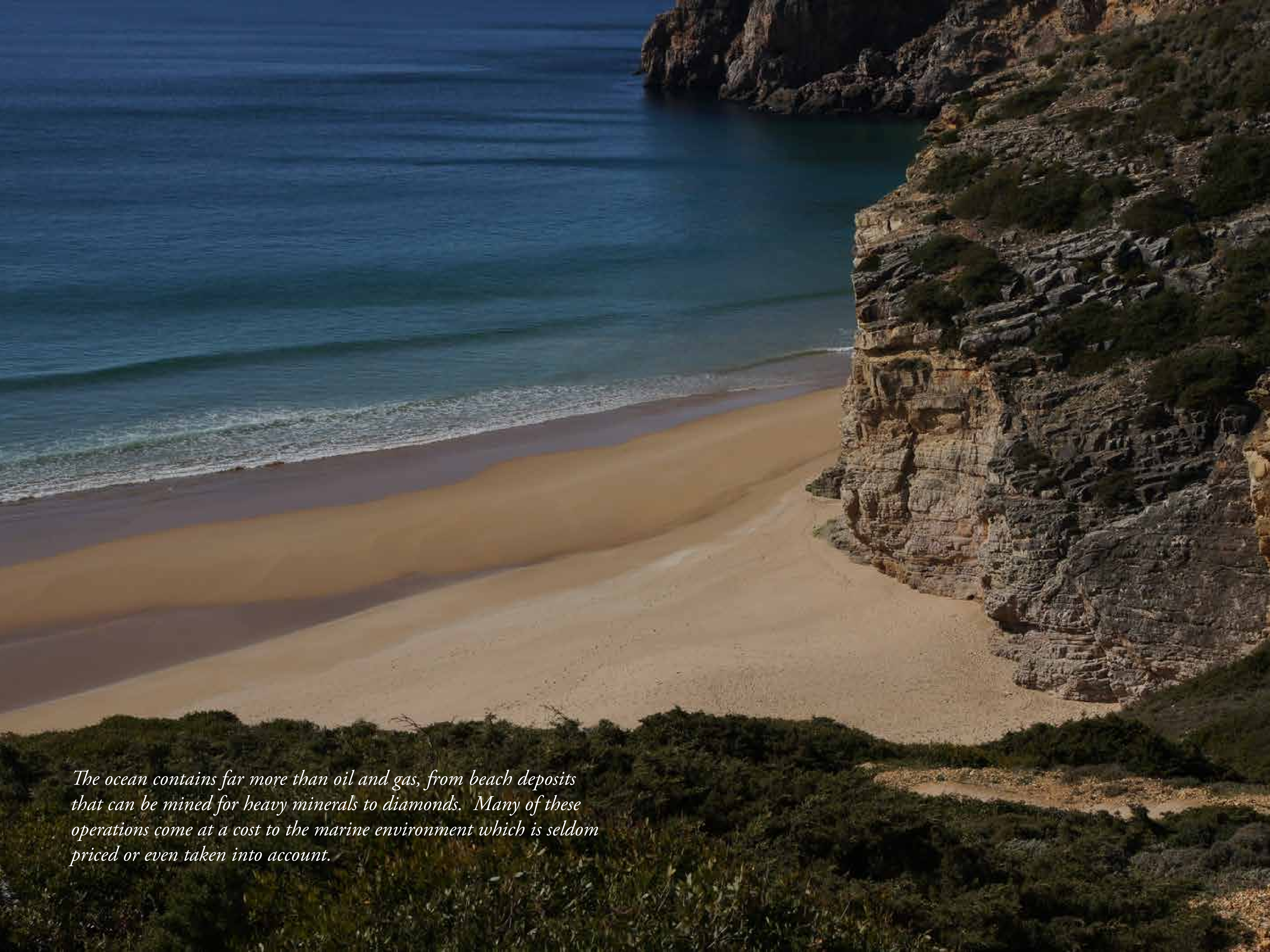
## SURFACE DEPOSITS

Oil and gas are by far the most valuable minerals mined offshore, but there are other resources to be found on the continental shelf. Most abundant are sand and gravel, used extensively in construction as well as for beach replenishment. Marine sand and gravel deposits are usually dredged, which allows for relatively quick transport from mining site to port. On the other hand dredging tends to interfere with other ocean activities like fishing and, not surprisingly, has considerably effects on the marine environment.

Iron sands, rich in such minerals as titanomagnetite, ilmenite, rutile, zircon and monazite occur in drowned beach deposits in many areas, particularly India, Egypt, Brazil, Australia, New Zealand and a number of Southeast Asian countries. Monazite may well become the most important of the lot, containing not only rare earth metals but also significant amounts of thorium, which could become a more environmentally acceptable fuel for nuclear reactors. Ilmenite is mined principally as a source mineral for the light-weight metal titanium. Australia remains the largest exporter of ilmenite ores, followed by South Africa, Canada, China and Norway. More African mineral sands mining operations are becoming operational as well, substantially increasing supplies.

Cassiterite, an important tin ore, has been mined offshore in Southeast Asia since the early 1900s, although large-scale operations moved beyond sheltered bays only in the second half of the past century. By the end of the past century these operations became largely unprofitable but the high demand for tin (for use in a variety of electronic gadgets) has revitalized the offshore sector. Indonesia in particular has seen a growth in small-scale operations, endangering not only the people forced to work the deposits, but the coastal environment as well.

Diamonds can also be found offshore. During the 1970s and 1980s they were actively mined off the Namibian coast, using smaller vessels at depths of up to 40m. Recently more successful offshore diamond recovery has been initiated, using sophisticated vessels that can operate to depths of up to 300 m. These are expensive operations but with deposits off the Namibian coast estimated at over 1.5 billion carats, diamond mining is rapidly becoming a profitable offshore activity.



*The ocean contains far more than oil and gas, from beach deposits that can be mined for heavy minerals to diamonds. Many of these operations come at a cost to the marine environment which is seldom priced or even taken into account.*

ownership of deep sea resources similarly initiated a major revision of ocean law. And in both instances science played an important role. Whilst government were discussing how to adjust ocean law to new realities, scientists indeed continued their efforts to understand the planet. And their findings turned out to have major political and economic implications.

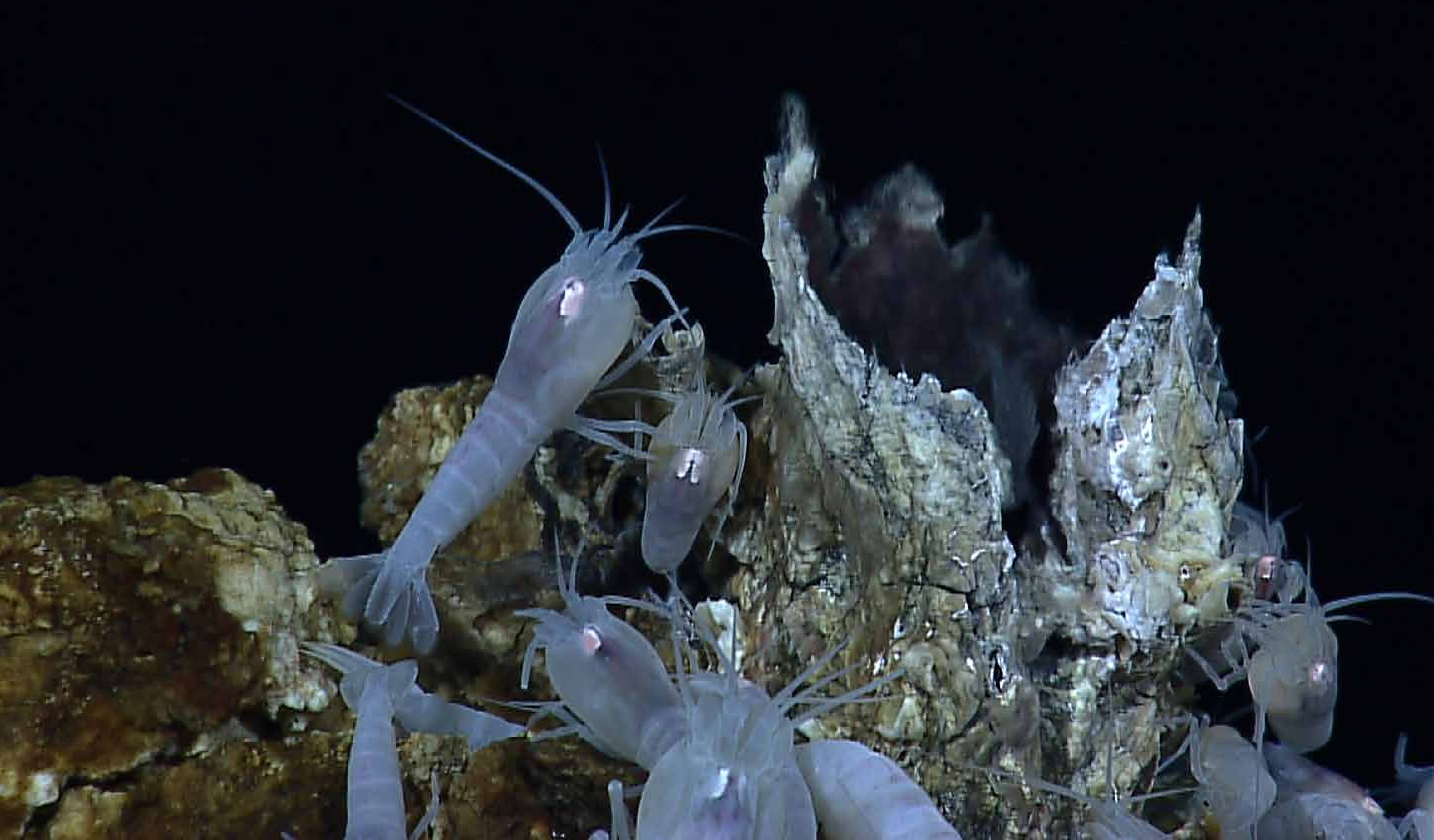
At first, it was thought that the theory of plate tectonics, which explains how the Earth's outer layer is broken up in various plates, would not do much for the mineral potential of the deep sea. The deep seafloor's young age near spreading centers seemed to preclude the formation of significant mineral deposits, as one would have expected to find in ocean basins that had been subject to billions of years of sedimentation. But when scientists in the late 1970s descended to the mid ocean ridge to observe plate tectonics first-hand, they were astonished by what they saw. In some areas, they found a veritable oasis of life consisting of mussels, giant clams, large tube worms, barnacles, anemones and fish, in depths of water that had never received sunlight. And not far from those communities, they saw large chimney-like vents spewing dark, hot water into the deep sea. They became known as black smokers.

After examining the organisms and sampling their environment, scientists concluded that this astonishing deep sea ecosystem relied on chemotrophic bacteria, which obtain energy by oxidizing the sulfides that spewed from the vents. But the vents contained more than sulfides. It was determined they were also extremely rich in minerals. As the crustal plates in their vicinity pulled apart, seawater entered the cracks and became superheated, dissolving a variety of metals and other elements in the process. When this mineral-rich water shot to the surface, the minerals precipitated in the chimney-like structures. Sometimes these became too tall and collapsed, creating large mounds of metal-rich rubble at their base.

Samples from these deposits were found to contain significant amounts of metals like zinc, copper and lead, and in some instances precious metals like gold and silver as well as rare earth elements. But this time mining companies did

*A mass of anomuran crabs are crowded near a hydrothermal vent at a depth of 2,600m. Scientists were astounded to find veritable oases of life when they descended to tectonic plate boundaries to study hydrothermal vents (NOAA).*

*Several deepsea shrimp (Rimicaris exoculata) crawl atop a deepsea vent in the Mid-Atlantic Ridge to feed on microorganisms. This unique shrimp thrives in warm sulfide-rich water at depths up to 3,600 m.  Deep sea mining could wipe out entire communities like this. Fortunately this hydrothermal community is safe, having been designated a Marine Protected Area (MPA) by the Azorean government (NOAA).*



not rush to examine the potential. Metal prices remained low, their supplies steady and reliable, and the costly experience with manganese nodules was still fresh in memory. Moreover, many hydrothermal deposits were located within the exclusive economic zones of coastal states. This time there was no need for protracted legal discussions over ownership, prices and production rates. According to the new law of the sea, these deposits belong to the coastal state. Just as with the oil on its continental shelf, it could decide what to do with them: leave them untouched or license them to the highest bidder.

In subsequent years additional deep sea deposits were discovered. Geologic cousins to manganese nodules, cobalt crusts occur as pavements on undersea volcanoes or seamounts. Firmly cemented to a hard substrate, they are often found in somewhat shallower water, about a mile deep. The two to four cm thick crusts contain high concentrations of manganese and iron, as well as cobalt, nickel, lead, molybdenum, and several other metals. Cobalt in particular appears to be present in high concentrations, ranging from 0.9 to 1.9 percent– up to five times the concentration in rich land-based ores. Like their geologic cousins, cobalt crusts represent a potential resource, though they are not likely to be mined any time soon because not enough is known about how they could be extracted on a commercial scale. The only certainty is that, judging from manganese nodule test mining experience, the cost of doing so would be phenomenal.

The metal-rich sulfides that are associated with hydrothermal vents appear to offer more viable prospects, with several companies actively seeking licenses and contemplating mining operations. Recovering the deposits, though still a formidable challenge, would be easier since there would be no need to separate deposits from a substrate; in the case of polymetallic sulfides it is mostly a matter of getting the metal-rich chimneys – collapsed or whole – to the surface. The applications claim minimal impact on the deep sea environment, but that assertion appears to be based more on wishful thinking and a lack of data. Most metal mining tends to leave a major mess and there's no reason to believe that would be any different in the deep sea than it is on land.

While some mining companies may beg to differ, there is no urgent need to mine the deep sea because land-based supplies of strategic minerals are far less expensive to develop and easier to monitor. They also remain relatively reliable. In fact, following the collapse of the Soviet Union and political developments in Africa, the supply of several strategic minerals is now more reliable than it was for much of the past century. But long-term political stability is not a given in this world. Should future developments impair the flow of strategic minerals and metals, this could create new and perhaps stronger incentives to turn to the deep sea.

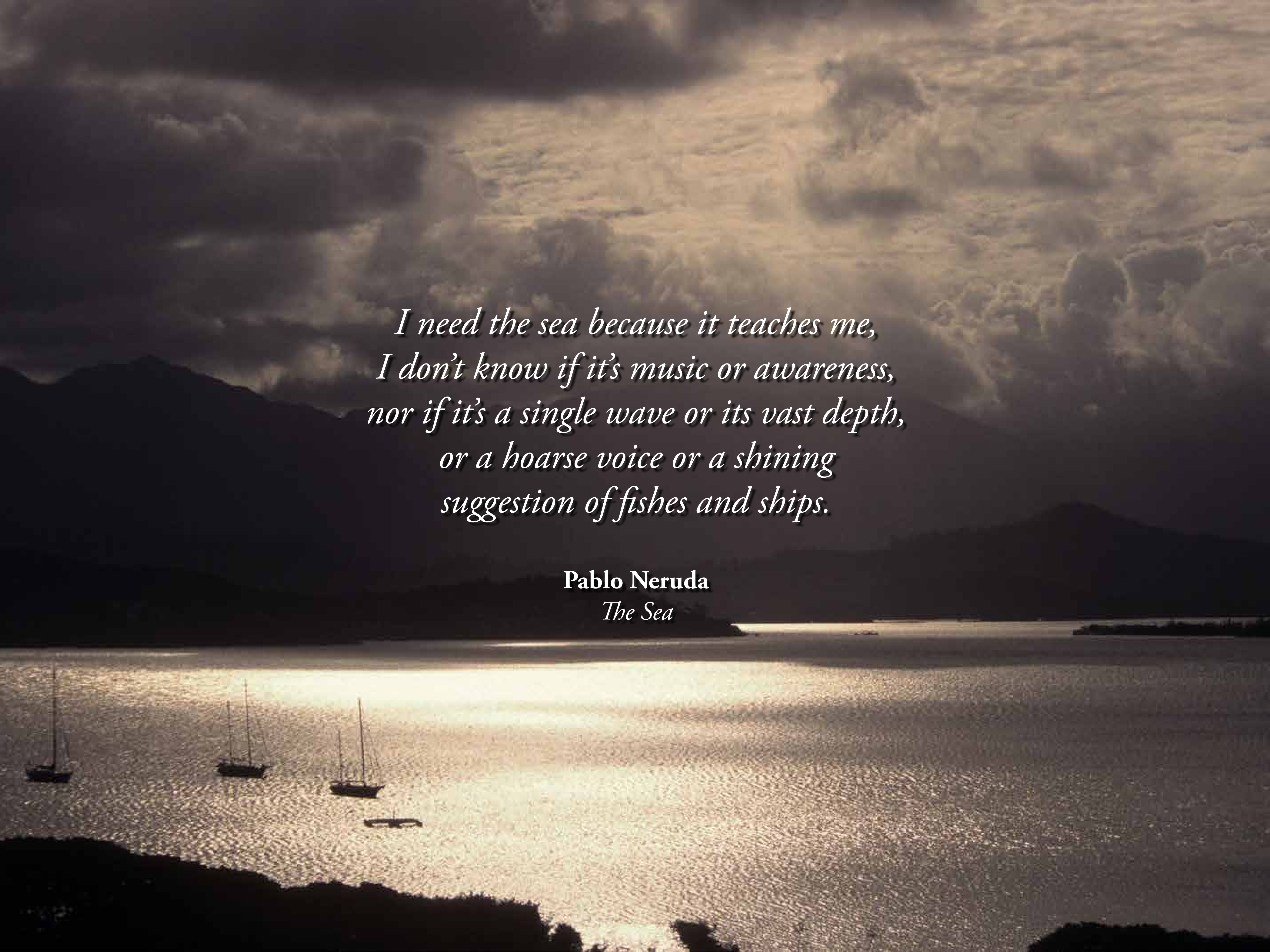
Hopefully we will have acquired sufficient information by then to do so without adversely affecting one of the last untouched areas on the planet. After all, true wealth is never measured in currencies. There may indeed be valuable minerals down there, but there are also unique biological communities, unknown organisms and an ecosystem we have hardly begun to explore. Making sure they are not damaged is the very least we owe not only ourselves, but especially those that have to live with and on the planet we leave them.

# SUMMARY

*Because the oceans are so wide and so deep, statistics on their resource potential are impressive. Each cubic km of seawater, for instance, contains about 35,000 tons of solids, making the sea the planet's largest continuous ore body. Aside from dissolved materials, minerals have also been deposited in thick layers on the ocean bottom. When life developed in the sea, its remains drifted to the bottom as well, forming extensive deposits of organic materials like oil and gas. Finally, the tectonic forces that shape our planet continually force minerals from the earth's molten interior into the ocean, some of which have consolidated in thick and possibly valuable deep sea deposits.*

*Since the middle of the past century considerable interest has developed in this mineral wealth. This has resulted in the intensive exploration for and development of a number of marine minerals, a process made possible by the rapid growth of science and underwater technology. The search for marine minerals has been accompanied by major changes in ocean law to determine who exactly owns any potential resources.*

*Estimates of the potential of the sea's mineral resources have grown considerably in recent years, with figures ranging from billions and even trillions of tons. In spite of their magnitude, many of the sea's minerals are currently not economically recoverable because of the technological challenges involved in mining the sea, and especially the deep sea. At the same time, there is little doubt that if and when needed, these supplies can and will be tapped. We can only hope that this will happen without repeating the mistakes that were made on land. For that to happen it is essential that the legal regime of the sea not only determines who owns what, but also assesses a fair cost to any environmental effects.*


*I need the sea because it teaches me,*
*I don't know if it's music or awareness,*
*nor if it's a single wave or its vast depth,*
*or a hoarse voice or a shining*
*suggestion of fishes and ships.*
**Pablo Neruda**
*The Sea*

# KNOWLEDGE

During the early 1970s the largest fishing nation in the world was a bit of an unlikely contender. One could be forgiven for assuming it was the former Soviet Union or Japan perhaps, where people ate more fish than anyone else. But it wasn't either of these. It wasn't China or the United States either, or a European country for that matter. Instead the answer was to be found in Latin America. It was there, along the continent's western coast that Peru hauled in more than ten million tons of fish every year, far surpassing anyone else. But its record was not perfect. Some years the massive schools of anchovies that congregated off the Peruvian coast disappeared and catches dropped to much lower levels. The country still pulled in a million or even two million tons of the silvery fish those years, but nothing close to what it was in other, in normal, years.

Peru owed this bounty to a process called upwelling. The northerly winds and currents along its coast, in combination with the rotation of the Earth, cause surface waters to be moved offshore. Replacing them is colder water, rich in nutrients which trigger massive plankton blooms. These, in turn, support the anchovies, along with huge flocks of seabirds. In fact, before the Peruvians turned to exploiting the fish, one of their principal exports consisted of guano: the dried droppings of sea birds. Working the guano grounds was a distinctly unpleasant business, but the product was highly sought after throughout the world as a superb fertilizer.

Peru's cool coastal waters also provide the country with a much more pleasant climate than a position so near the Equator would suggest. But it isn't always like this. Every few years, warmer waters invade Peru's coast. Upwelling still occurs, but it no longer reaches into the deep, nutrient-rich waters. Instead it merely churns up the surface waters, triggering heavy rains and much warmer weather. Since this phenomenon usually occurs around Christmas, Peruvian fishermen started calling it El Niño– the Child– in reference to the birth of Jesus. But this isn't a benevolent child: instead El Niño causes the fishery to fail, affects the weather, and for countless Peruvians makes for a miserable Christmas.

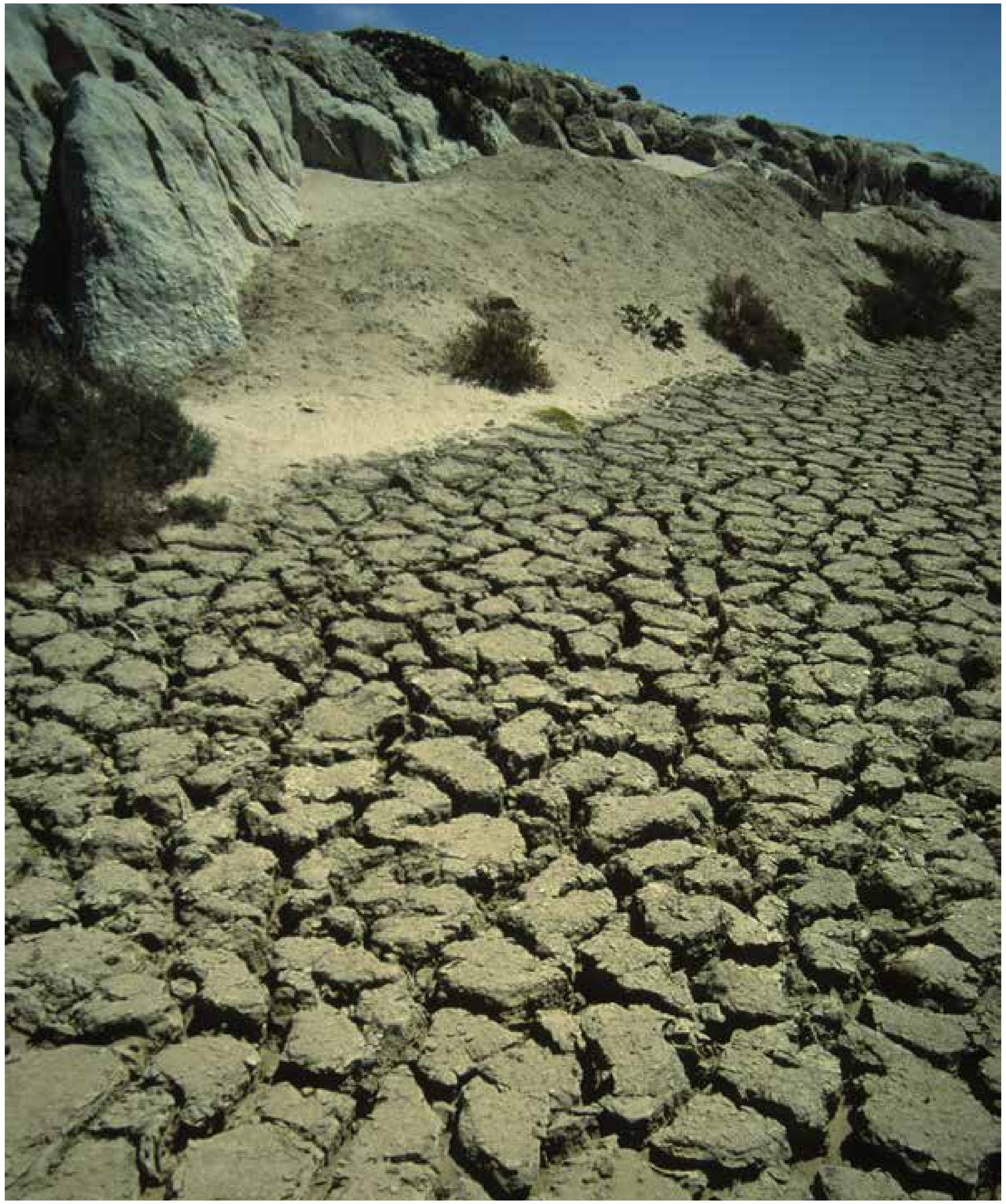
There is no regularity to El Niño. Sometimes it recurs every other year; other times five or six years go by without any sign of it. Its strength is also unpredictable. Usually El Niño remains a regional affair, affecting the countries along the northwestern coast of South America. But some years it is much stronger. The El Niño that arrived in late 1982, for instance, was unusually strong. A massive amount of warm water, measuring 7 degrees C above normal, moved in from the central Pacific. It virtually halted the fishery and sent torrential rains over much of the country. And its effects ranged far beyond Peru. Much of the world was influenced by the 1982 event, often with dramatic consequences.

Halfway around the globe, Australia suffered its worst drought of the century. With little to eat or drink, millions of sheep and livestock perished. Drought also affected much of the Philippines and Indonesia, where hundreds of people starved to death. Millions of acres of tropical rain forest were damaged, causing "one of the worst environmental disasters of the century", as the International Union for the Conservation of Nature put it. Further west, in India and Sri Lanka, the monsoons failed, causing a devastating drought and ruining fall crops. And in southern Africa, El Niño added to the misery caused by two dry years by blocking much-needed rains and causing widespread drought and malnutrition.

Meanwhile, some regions received more water than they could handle. Heavy rains caused the worst flooding of the twentieth century in southern Brazil, Peru and Ecuador. Some places received an astonishing 100 inches of rain in six months. Deserts turned into swamps, and hundreds of people died in mudslides caused by the rains. At the same time, the American west coast was battered by intense winter storms, record rains and massive snowmelts. Driving rains also hit the U.S. Gulf states, where many areas were affected by severe flooding.

Other regions experienced abnormal weather as well. Drought continued to imperil the African Sahel countries. Western Europe had a remarkably wet spring, followed by an exceptionally hot summer. Russia experienced some of its most unusual weather ever, including a wet and mild winter which caused torrential rainfalls, floods, mudslides and huge volumes of freezing rain. No one knew whether El Nino was responsible for this as well, but the coincidence was difficult to ignore.

When El Niño finally subsided in 1983, it left thousands of casualties in its wake, an estimated eight billion dollars' worth of damage, and unimaginable hardship and suffering. Many regions had been devastated by drought; others were swamped by floods and torrential rains. The social and economic consequences of El Niño, to rich and poor alike, were staggering. It certainly wasn't the first El Niño to wreak havoc, but it was the first one to be noticed globally. What previously had been a phenomenon known mostly to meteorologists and Peruvians had all of a sudden gained international notoriety.



*El Niño events tend to bring extreme weather to many regions, from torrential downpours in South America to devastating droughts in parts of Asia, Africa and Australia.*

Not surprisingly, these effects stimulated a great deal of interest in El Niño. Around the world, scientific efforts were initiated in an attempt to understand what was going on. No one harbored hopes that science would be capable of halting or modifying the event, but it seemed that a lot of misery could have been avoided if there had been more of an advance warning. Farmers could change crops in anticipation of wetter or dryer weather; areas prone to flooding could be reinforced; and people likely to be affected could be alerted.

Much has been learned about El Niño in the years since its disastrous 1982 appearance. Scientists noticed, for instance, that higher seawater temperatures were not limited to the coast of Peru and Ecuador. Instead, during strong El Niño years warmer seawaters covered much of the equatorial eastern and central Pacific. They also observed a relationship between El Niño and the Southern Oscillation, a shift in high and low atmospheric pressure zones in the Pacific and Indian Ocean. Normally atmospheric pressure is high in the South Pacific and low in the Indian Ocean. But every few years these conditions reverse: pressure is low in the South Pacific and high in the Indian Ocean, leading to heavy rains in normally dry regions and extremely dry conditions in normally wet regions – exactly the anomalies that were characteristic of El Niño. But recognizing the nature of these anomalies didn't quite explain them. What caused the higher than normal seawater temperatures off the coast of Peru, and throughout much of the central Pacific? What caused the shift in pressure zones of the Southern Oscillation? What was playing havoc with the weather?

The answer, upon a first examination, seemed simple: changes in prevailing winds. It was easy to show that changes in wind stress induced an eastward movement of warm water to the eastern and central Pacific, bringing along unusually heavy rainfall. But what then caused the change in these wind patterns? Again the answer appeared simple: a change in seawater temperatures. Unfortunately this explanation began to sound like the chicken and egg conundrum. Which came first: changes in water temperature, or changes

*The first signs of a coming El Niño event appear in the western equatorial Pacific. Many of the islands in the area experience hotter and dryer days. Of most concern is the increase in frequency and severity of major storms like hurricanes.*

in wind direction? Obviously they were related, but no one knew what started it all.

Solving the El Niño puzzle, it was agreed, called for a better understanding of the atmosphere and the ocean, and the interaction between both. It demanded nothing less than an understanding of how the two most complex dynamic systems on the planet affected one another. It was a daunting task, but El Niño provided the perfect impetus. Not only was it was the largest climatic event on earth, it also demonstrated the extent to which the ocean affects the atmosphere, and hence our climate. And, perhaps most important, El Niño was not just a theory. It was very real. It affected millions of lives all over the world.

If the effects of the 1982 El Niño caught forecasters by surprise, imagine how people in the past must have felt about weather anomalies. Modern forecasting technology at least gives us a warning of what lies ahead. Thousands of years ago, people had no idea of what the weather might have in store. To them it was something akin to magic, determined at the whim of the gods. There was a sun god and a rain god, and gods of winds, storms and thunder. At times these deities were benevolent: they sent rain when needed and favorable climes. Other times they were cruel and capricious, depriving areas of much needed precipitation or dumping torrential amounts of it, while frightening people with bolts of thunder and lightning. Misery ensued when the weather gods were angry. There was little that could be done, other than appeal humbly for relief.

In many cultures people developed sun and rain dances and other rituals to plead for favorable weather. Sometimes it seemed as if they worked, but most of the time they had no effect whatsoever. Even so, remnants of these rituals still exist. Farmers in many regions of the world pay tribute to their gods or saints, hoping they will send good weather and a rich harvest, and there is hardly a fishing community in the world that doesn't conduct some sort of blessing of the fleet or the sea, or preferably both.

Even so, sailors knew it took more than a ceremony to survive at sea. While it didn't hurt to placate the gods, even the strongest ship was no more than a tiny speck in the immense vastness of the sea, and a very frail one at that. At sea, more so than on land, people were at the mercy of the elements. There were no rocks or trees to protect against the fury of a blizzard. There was nothing stable to hold on to. Even the surface itself moved wildly and chaotically. Mariners knew it was important to stay in port if bad weather threatened. But before they could do that, they had to learn how to foretell it.

Sailors, and no doubt their worrying wives, set about the task with zest, learning to look for warning signs in just about anything that flew or swam, dead or alive, animate or inanimate. Clouds, for good reason, play an important role in this folklore. There are hundreds of weather clues derived from clouds; some silly, others perceptive. Cumulus clouds, for instance, were called thunderheads because they portended stormy weather. Cirrus clouds, in contrast, were known as mares' tails or goat's hair, while alto-cirrus clouds were called mackerel skies. And "Mackerel skies and mares' tails, make lofty ships carry low sails..." as sailors said, meaning stiff winds lay ahead.

The sun and the moon too were closely watched for clues. A good deal of importance was attached to rings around the moon, a phenomenon known in Scotland as a cock's eye and a sure sign of stormy weather. The density of the ring foretold how bad the storm would be and, even more convenient, the number of stars within the halo indicated how many more days before the storm would hit. A halo around the sun had a similar meaning, and sailors carefully observed how both sun and moon rose and set, because "if the sun sets clear as a bell, it's going to blow sure as hell..." In some places the moon was believed to control precipitation. Hence it was important to observe a new moon carefully. Some seamen believed that if the tips of a new moon pointed up so that water could not run out of it, a month's worth of relatively dry weather lay ahead. If the tips pointed down, on the other hand, there was a lot of rain in store.

*Even the strongest sailing ship was no match for an angry sea. For that reason their crews became very adept at foretelling bad weather, using whatever clues sea and sky provided.*

The size and color of sun and moon also gave some indication of what lay ahead. A large bright moon was seen as a portent of cold weather; a dull moon indicated a hot day ahead. In addition sailors carefully observed the light cast by sun and moon on the water, because "an easterly glint is a sure sign of a wet skin". The color of the sea itself was watched as well. A dark, gray sea, as could be expected, was not a good sign; a bright sea, in contrast, promised fair weather. In France sailors thought that if the sea appeared a deeper blue than usual, a south wind would follow. If the blue verged on black, a north wind and rougher weather was approaching. Elsewhere, a white or even a reddish hue was seen as a sign of a change in weather, usually for the worse.

Marine animals too were regarded as good weather indicators. Fish in particular were thought to be endowed with special instincts to foretell the weather. Fishermen believed, for instance, that fish bite well two or three days before the onset of rough weather, but that they wouldn't touch the bait when a storm was imminent. Dolphins, porpoises and other marine mammals were also closely observed. In some regions, leaping dolphins foretold a storm, in others cetacean exuberance was considered a sign of fair weather. Birds gave important clues as well. Seabirds flying toward land were seen as an ominous sign because "when seabirds fly to land, a storm is at hand". But not only marine animals were observed. In the days before weather forecasts, anything from the cat's position in front of the fireplace to the grunting of the neighbor's pig could and would be examined for what it indicated about the coming weather.

Finally, sailors also relied on their own intuition. Some old salts could 'feel' a storm because their joints ached, or because old injuries became more painful. These signs were perhaps not taken as the sole indication of changing weather, but when the clouds looked threatening, and the sea took on a darker hue, and the fish stopped biting, some stiff joints made many a sailor proclaim with confidence that rough weather lay ahead. And if none of the usual clues were available, there was always the galley– the focal point on any ship. If the tea kettle boiled quicker than usual, or if the smoke rose straight up, a change in weather was in the offing. Some seamen even used the rate of rise of bread dough to make their predictions.

While colorful, many of these clues turned out to be quite useful and even accurate. Perhaps this was understandable: like much of folklore they were based on years of observation and carefully handed down from one generation to the next. No doubt some tales or rhymes were pure nonsense but, if so, they didn't stay around long. Sailors seldom stuck with things that did not work, especially in something that could mean the difference between life and death.

Moreover, upon closer examination, many of the sailor's clues made sense. Suppose the tea kettle 'sang' or the bread dough expanded quicker than usual– that would simply be a sign of a change in barometric pressure, which always precedes a weather change. In fact, most of the signs sailors depended on were caused by barometric changes, whether they related to the color of the sky at sunset or the smell of the sea. But most important, sailors did not simply rely on one single clue: they looked for many signs– in the sky, on the sea and even in animals– and then made their deductions. They didn't look for explanations; most wouldn't have understood them anyway. Instead, it was the integration of several signs, many of them now forgotten, that made their predictions so valuable.

Not surprisingly, waves play a prominent role in marine weather folklore as well. After all, waves are the sea's most visible phenomenon. They bring it to life and seem to reflect its many moods. Sometimes the sea's waves are gentle; other times they are destructive, and they can change from friend to foe in a remarkably short time.

Ancient mythology accorded waves a divine nature. In Greece, Poseidon was believed to rule the waves, which were personified by sea nymphs. In Rome, it was Neptune who controlled them, while ancient Scandinavians believed the waves were the daughters of Rana, the sea goddess. Finn-

*Red sky at night, sailor's delight – it is just one of many weather sayings used by mariners. While not always true, it does contain a grain of truth because a reddish evening sky may be a sign of high pressure and favorable weather. The same light in the morning, on the other hand, can portend a change in the weather, not necessarily for the better.*

ish, Polynesian and Japanese mythologies also include wave gods. Seafaring peoples regularly paid tribute to these deities because, when displeased, their anger could be fatal. Few sailors who encountered their wrath returned to tell the story.

Today, we describe waves in less picturesque terms. Waves are caused by wind moving over the sea, so the scientific explanation goes. As the wind blows over the surface, the drag between the air and the water stretches the surface, and ripples are created. Stronger winds create waves, and larger waves generate swells. While it sounds simple, waves are extremely complex. There are, for instance, no two waves in all of the oceans at any one time that are exactly the same.

Despite this complexity, waves can be understood. Even the confusion of a mid-oceanic wave field can be comprehended, and it doesn't take elaborate instruments to do so. Thousands of years ago the Polynesians used their knowledge of waves and swells to guide them in their travels between the islands of the Pacific Ocean. Through careful observation they learned that for most of the year the Pacific's steady winds pushed up long swells moving in parallel lines across the sea. With constant winds, the direction of these swells remained steady for weeks and even months on end, enabling skillful navigators to maintain course by keeping a constant angle between their boat and the lines of swells. Yet sometimes two or three swell systems interacted, and the process of maintaining a correct angle became far more complicated. Navigators then relied on the peaks of the swells as they merged to determine their course.

Polynesian navigators, known as palu learned to recognize eight ocean swell systems, corresponding with the eight octants of a compass. The most dominant were the north, northeast and east swells, created by the strong winter trade winds. As the winter trades slackened during spring, swells began to move from the southeast and south. And in late summer and early fall, when winds sometimes blew from the west, southwest, west and northwest swells occurred. The result of years of observation, the system was reliable

*Long lines of swells reach the coast of New Zealand. Under steady winds these swells will hardly change direction for hundreds, sometimes thousands, of miles. The Polynesians learned to "read" these swells to navigate to the most distant islands on the planet.*

*Hokele'a in the central Pacific, on its way to Tahiti. Master navigator Mau Pialug steered the replica voyaging canoe across 4,000 km of open sea without a single navigational instrument. He used a memorized star compass to set a course, and an understanding of waves and swells to maintain it.*

enough to assist the early Polynesians in successfully colonizing the vastness of the Pacific – an endeavor requiring phenomenal navigational skill. "How shall we account for this Nation spreading itself over this vast ocean", a puzzled James Cook wrote upon discovering Hawaii in 1778. "We find them from New Zealand in the South, to these islands to the North and from Easter Island to the Hebrides..."

Today, this ancient form of navigation, called pukulaw or 'wave-tying', has all but vanished, replaced by western navigational instruments. But fortunately some traditional navigators remained. Best known among them was Mau Pialug, a master navigator from the island of Satawal in the Central Carolines of Micronesia. Mau gained fame in 1976 when he guided Hokule'a, a replica of a traditional double-hulled Polynesian voyaging canoe, from Hawaii to Tahiti without charts or navigational instruments. For 2,500 miles, he relied solely on a star compass, based on the rising and setting positions of the stars along the horizon, to determine latitude, and on ocean swells to maintain direction. At dawn and dusk, he checked the swells' direction against the stars. During overcast nights, when there was no moon to light the swells, he steered the canoe by sensing the pitch and roll of the double hull in the seaway.

Mau made the trip on Hokule'a several more times. Each time, he successfully guided the vessel from one speck in the ocean to another, thousands of miles away, relying on nothing but the stars and the movement of the sea. Along the way he taught Nainoa Thompson, then a young Hawaiian, the art of the Polynesian navigators. Afterwards Nainoa summed up his admiration for Mau's skills: "He knows the waves like he knows an old friend". And like old friends, they "show him the way, no matter how they are covered up".

To achieve this, Mau Pialug and other navigators had to create an order out of the complexity of the sea; an order which enabled them to read the waves. But it took more than Mau's half century of experience to gain this mastery. It took centuries of observations by his ancestors and, most importantly, the integration of the sea's and the sky's many clues. Polynesian navigation, in short, is far more than an interesting technique to get from one place to another. It symbolizes the key to understanding: observe and analyze, and then assimilate.

By the time the Polynesians had spread over an area half the size of the globe, western sailors had barely ventured out of sight of land. Of course, they had less of a need to do so. Most of their destinations involved short crossings in well-known waters. Like seafarers elsewhere, western sailors navigated by the sun and stars as well as natural phenomena. But European waters did not have the constant winds needed to create identifiable swell patterns. Instead, sailors used the winds themselves to help set a course.

As early as the eighth century B.C., Greek seafarers were using four particular winds to aid their navigation. They were Boreas, the north wind; Euros, the east wind; Notos, the south wind; and Zephinos, the west wind. Later, four more winds were added, and the system became a wind-rose; a circular arrangement on which the eight winds corresponded with the eight octants of a compass. Wind roses enabled early mariners to identify the direction of the wind against the sun or the pole star, and thereby maintain a relatively steady course.

The eight-wind system was also used by the Romans, who gave the winds their own names. There was the Tramontana, a cold northerly wind that blew down from the Alps; the Levanter, a strong easterly wind from the countries of the Levant; the Sirocco, a hot and dry wind from North Africa to the south; and the Maestro, a rainy wind from the west. The wind-rose was later expanded to twelve winds, then to sixteen, and finally to thirty-two. That level of detail was too cumbersome to be of much practical use but it demonstrated that, through years of observation, sailors were able to detect a regularity to wind patterns, even in regions with quite a variable climate.

As European sailors ventured out into unknown waters during the Age of Discovery, they noticed there was a global regularity to the wind as well. Throughout the trop-


*Prior to the introduction of the compass in the late 12th century, Western mariners relied on their understanding of the wind to help maintain a course. Of course, winds can be variable so this technique could only be used in certain areas and during certain times of the year, and even then provided no more than a rough indication at best.*

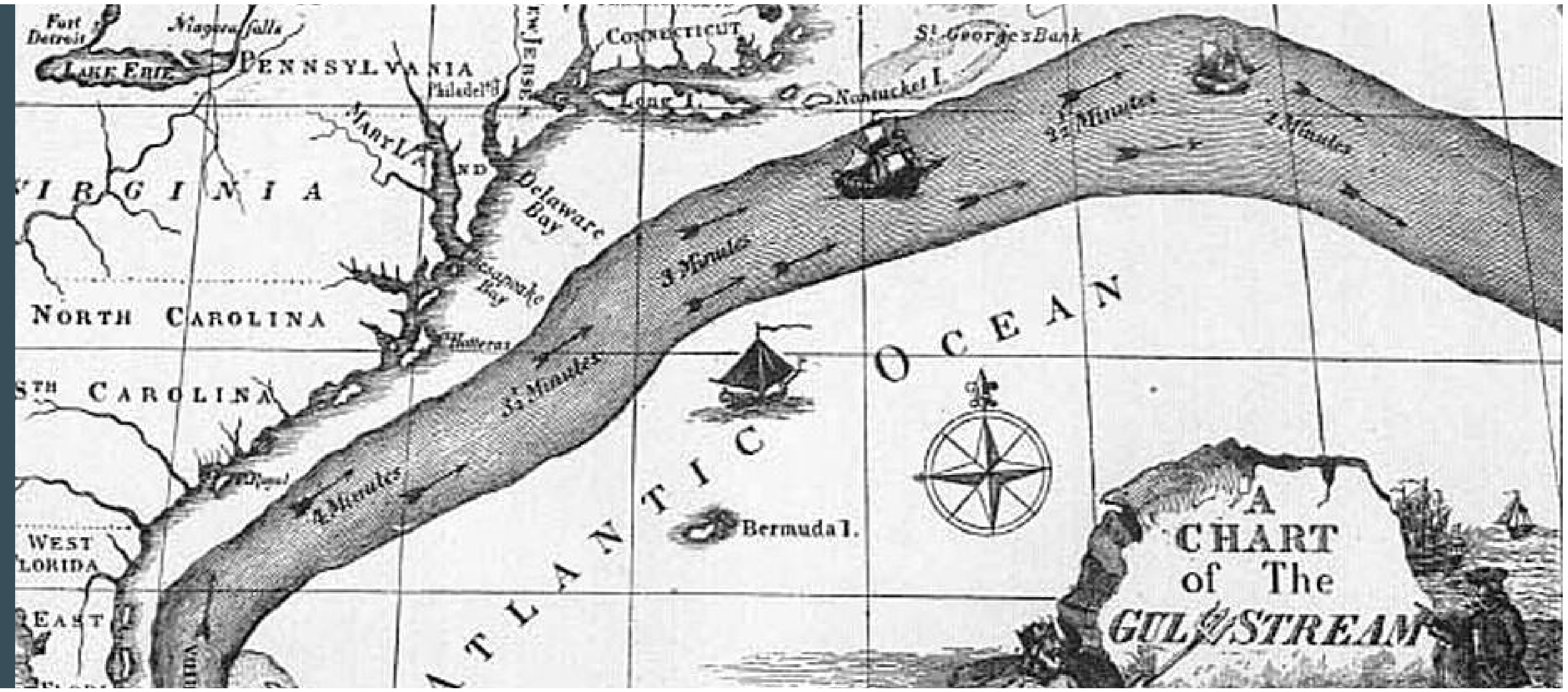
ical Atlantic and Pacific Oceans they found steady winds, blowing from the northeast in the northern hemisphere and from the southeast in the southern hemisphere. Since these winds took them to distant trading areas overseas, they became known as the trade winds. Where the northern and southern trade winds met, near the Equator, there was an area noted for calms, which often kept ships captive for days and weeks on end. Drifting along was dull, dangerous and frustrating, and this region became known as the doldrums.

Temperate zones in both the northern and southern hemisphere were characterized by strong west winds, called westerlies. Where the westerlies met the trade winds, around 30 degrees latitude, there was another region of calm seas. It became known as the horse latitudes, possibly because sailing ships carrying horses to America were sometimes forced to throw their cargo overboard to lighten the vessel and take advantage of the slightest breeze. In the Indian Ocean, sailors found steady winds which blew southwest from April to October, and reversed direction to northeast during the rest of the year. They called them monsoons, after the Arab word mussim, which means change or season.

Winds were not the only force that affected a voyage. In many regions there were narrow bands of water that flowed like currents along the sea surface. Sailors quickly learned that, if the current flowed with the ship, this would shorten their voyage. If, on the other hand, the vessel had to stem it, the trip could be considerably longer.

Several strong currents existed in the Atlantic. Spanish vessels sailing to and from South America during the early 16th century often found themselves stuck in a strong west-flowing current near the Equator. The flow of water curved toward the north in the Caribbean, making it difficult for sailing vessels to pass into the South Atlantic, unless they sailed east into the open sea before heading south. Further north the flow of water was found to veer off the American mainland in the direction of northern Europe. Though the pattern was complicated, ship captains soon learned to take advantage of it. To reach the New World, they set a southerly course to the Canary Islands, and then turned west to take advantage of the Equatorial Current. On the return trip they followed the northerly current, or Gulf Stream, as far as Cape Hatteras, before turning east and setting course for home.

As the number of sailing voyages across the Atlantic increased, so did information about its currents. But no one bothered to collate it until Benjamin Franklin, Deputy Postmaster of the British Colonies in North America, in 1769 received a complaint from the Board of Customs in Boston. Why, the Board wanted to know, did it take English mail packets two weeks longer than American ships to deliver the




*Franklin's map of the Gulf Stream helped mariners take advantage of the current while crossing the Atlantic.*

mail from Europe? Intrigued, Franklin took the question to his cousin Timothy Folger, an experienced Nantucket whaling captain, who quickly provided the answer. American sailors, he explained, made an effort to avoid the Gulf Stream on their westward crossing. British captains, in contrast, always seemed to buck it. Folger even recounted how, during whaling voyages, they had crossed the Gulf Stream to advise British ships that they were fighting a three knot current. But the English captains, he added, "were too wise to be counseled by simple fishermen."

Franklin asked his cousin to draw the contours of the current as best as he could, hoping that a chart of the North Atlantic with a precisely marked Gulf Stream would help speed up the mail packets. He then sent copies of the chart to England, where it was promptly ignored. Even so, Franklin remained intrigued with the Gulf Stream. On his trips between England and the colonies, and later between England and a newly independent America, he studied the Gulf Stream as the ship kept along its edge. He dutifully lowered a thermometer

in the water several times a day and noted that the Gulf Stream had its own color and carried more seaweed than the surrounding waters. Even on his last trip from England to America, at age 79, Franklin continued to take notes, correctly surmising that this "accumulation of water" was caused by the wind.

Other than Franklin's chart of the Gulf Stream, there was little to help 19th century sailing captains with advice on winds and currents. This situation struck U.S. Navy navigator Matthew Fontaine Maury as a shortcoming. Navigators, also known as sailmasters, were required to select the best routing for their ship; a job which relied on a keen knowledge of winds and currents. As a young navigator Maury tried to find charts which would help him with this task, but discovered that there was no cooperative pooling of this nature. Moreover, when asking others for advice, he invariably ran into a wall of secrecy. Captains and navigators, it seemed, were reluctant to share hard won personal intelligence with others.

Maury made several long sailing voyages, including a trip aboard the USS *Vincennes*, the first U.S. Navy vessel to circumnavigate the globe. Each voyage increased his skills, but Maury didn't want to keep this expertise to himself. Instead, he was convinced of the need for a systematic collection of data on winds and ocean currents; something which would have helped him greatly a few years earlier. For that reason he carefully kept all his notes, hoping to publish them later, when his days at sea were over.

Later came much sooner than expected. In 1839, just 33 years old, Maury suffered a stage coach accident which left him permanently crippled. The mishap ruled out further sea duty, but fortunately the Navy did not let him go. Instead, Maury was assigned to the newly established Depot of Charts and Instruments in Washington. There he quickly seized the opportunity to provide mariners with better sailing directions, requesting information on sea and wind conditions from his sailing colleagues. Cooperation was slow in coming, but Maury was undeterred. Instead of waiting, he began sifting through the logbooks of naval vessels, which

*Upwelling brings cold, nutrient-rich water to the surface. The fertile water sustains massive fish populations which attract fishermen or here, along the sparsely populated Namibian coast, huge herds of seals.*

## THE OCEAN IN MOTION

Currents have long been known and used by mariners, but understanding them is important for a lot of other reasons. They indeed not only carry along the ships that want to take advantage of them but also energy or heat—whether positive or negative — from different latitudes, which has profound effects on weather and climate. Currents also disperse nutrients and floating organisms like plankton, which can affect fisheries. But pollutants and waste products can be carried along as well so that pollution, by definition caused by humans, has reached the most remote sections of the world ocean.

Aside from horizontal motion generated by surface currents, there are also several types of vertical motion in the sea. Of global importance is what is known as thermohaline circulation (THC), whereby warm water from the tropics is transported towards the poles. When it reaches higher latitudes the water cools, becomes heavier (denser) and sinks towards the bottom. There, being constantly replenished, it is pushed towards lower latitudes where it will eventually rise again to complete the cycle. THC is also referred to as the ocean conveyor belt or the global conveyor belt since it constantly moves throughout the world ocean, albeit at a very slow rate: it may take as long as 1,000 years to complete one full cycle. In spite of this slow pace, the ocean conveyor belt has a major influence on climate.

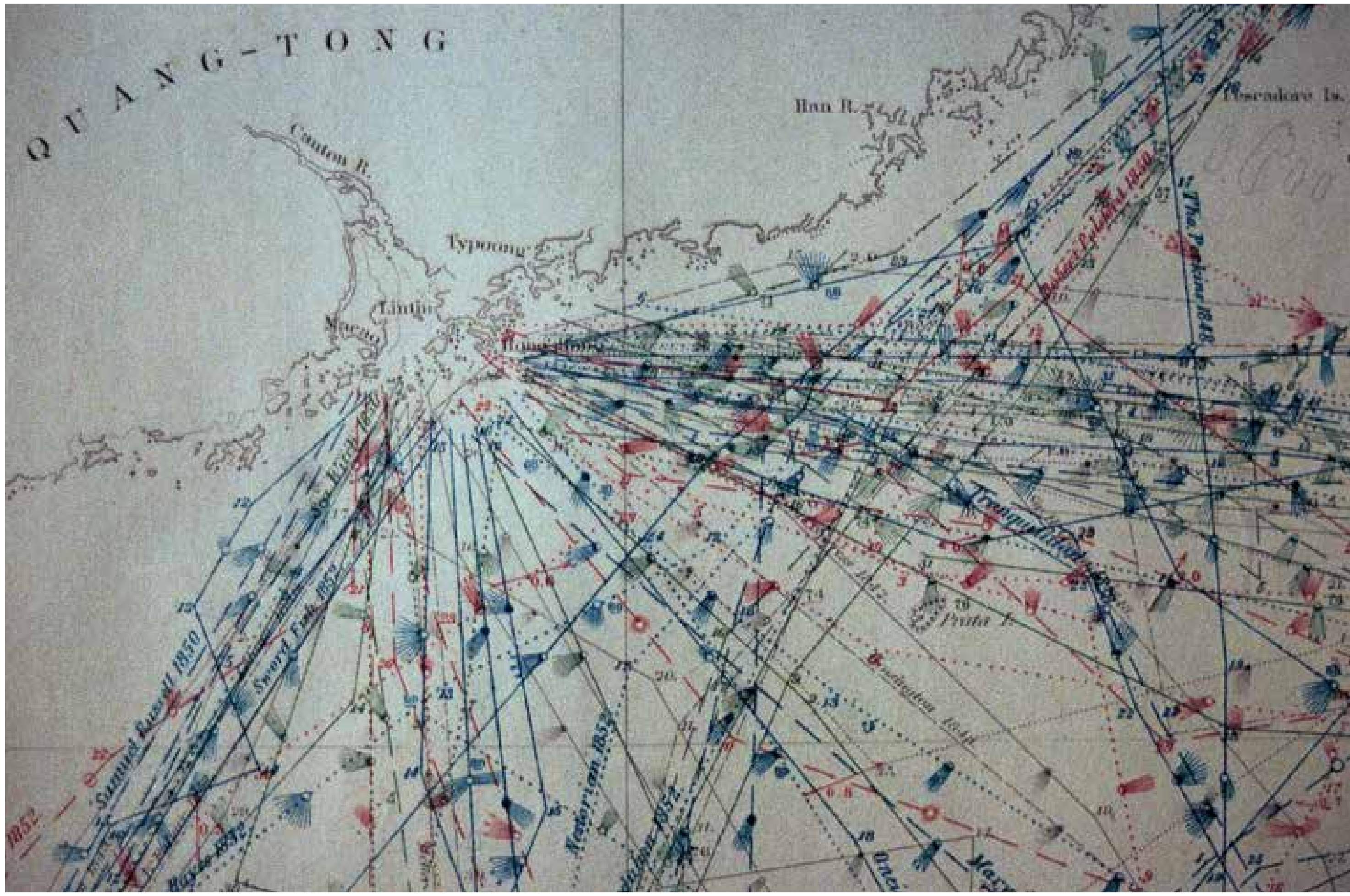
There also is a quicker exchange between surface and deeper waters, known as upwelling. As mentioned at the onset of this chapter, upwelling is a particularly conspicuous phenomenon along the western coast of the continents. In these areas winds run along the coastline and push surface water-masses offshore. To replace the surface layers deeper waters to rise to the surface, to the discomfort of swimmers (because it is much colder) but often to the advantage of birds and fishermen because water from greater depths is full of nutrients and thus very fertile. The most important areas of coastal upwelling coincide with the Canary and California currents in the Northern Hemisphere and with the Peru and Benguela currents in the Southern Hemisphere – all of them known as particularly rich fishing areas.

were stored at the Depot. In them he found exactly what he sought: the conditions of sea and sky for every day and every voyage undertaken by every U.S. Navy vessel over the previous 50 years.

It was a treasure trove of information and Maury set about compiling the logs' meteorological and oceanographic data onto charts. Before long, it became clear that this was extremely valuable work. Secretary of the Navy George Bancroft was so impressed with the possibilities of the charts that he ordered all naval vessels to record the information Maury sought in specially devised log books. Maury also talked whalers and merchant captains into filling out his log forms, promising them free copies of his charts and sailing directions in return.

With the needed data now flowing in, the painstaking task of preparing accurate charts began in earnest. In 1847 the first of Maury's Wind and Current Charts was published. It covered the North Atlantic and contained information on average winds and currents, and the prevalence of storms, fog and calms. During the following years, charts on other regions of the world became available, accompanied by a set of Explanations and Sailing Directions. Ship owners and captains quickly realized the charts enabled them to cut their sailing times considerably. The passage from Rio de Janeiro to New York, for instance, was shortened by ten days. Across the Atlantic, the savings could amount to two weeks. Even more impressive, the long haul from New York to California around Cape Horn was often cut by a full month.

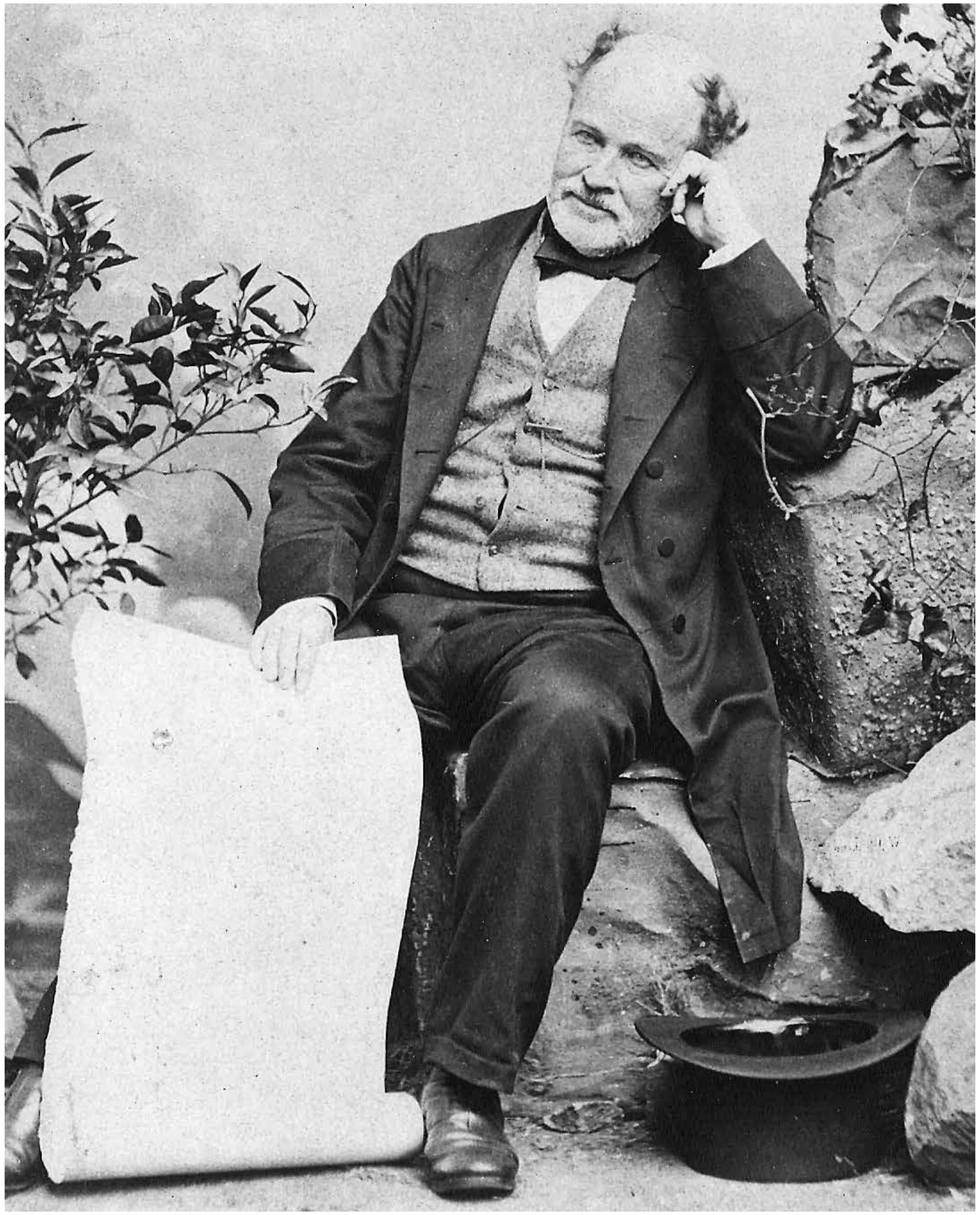
Following the success of his charts, Maury pursued other interests. He played a leading role in the first International Maritime Meteorological Conference, held in Brussels in 1853. At the meeting a worldwide system for reporting meteorological observations at sea was organized, and the participating nations agreed to use Maury's standard forms. He also persuaded the Navy to let him conduct soundings in the North Atlantic; an undertaking which paved the way for the laying of the first underwater cable linking Europe and America. And in 1855 he published *The Physical Oceanography of the Sea*, the first oceanography text ever.




*A detail from one of Maury's Wind and Current Charts, showing the approaches to Canton (Guangzhou). American and British clippers competed with one another to get tea to New York or London as quickly as possible. Maury's charts helped them shave days, sometimes weeks, off the long passage.*

The book became so popular that it ran nineteen editions and was translated into six languages. Nonetheless, these achievements did not impress the Navy command. That same year the Navy Retirement Board, without as much as a single hearing, placed Maury on its retirement list and removed him from active duty. It took two years of intense lobbying before Maury saw himself reinstated.

During the Civil War Maury joined the Confederate Navy and became an agent in England, trying to locate foreign support for the Confederacy. Not surprisingly, the North branded him a traitor, forcing Maury to move to Mexico after the war. It wasn't until 1868 that he was pardoned. Shortly thereafter Maury moved back to the United States, but he returned a broken man, having lost a son in



*Matthew Fontaine Maury, holding one of his Wind & Current Charts. Scientists did not always agree with Maury, who relied too much on religion to explain his theories. But mariners loved the way he compiled oceanographic data onto his charts.*

the conflict as well as his reputation. Five years later he died. His grave monument paid him the following tribute:

> *Matthew Fontaine Maury*
> *Pathfinder of the Sea*
> *The genius who first snatched*
> *From ocean and atmosphere*
> *The secrets of the sea*

Maury was not the first to snatch the sea's secrets. Polynesian navigators had done that as well, relying on the same information. But Polynesian navigators had a long tradition of observation and integration. Maury did most of it in a single lifetime, analyzing a vast mass of data taken at widely scattered times and places, and then constructing a meaningful picture from it. By most accounts Maury was not an easy person to live or work with, but his far-reaching efforts deservedly earned him his epitaph.

Maury was convinced that the ocean and the atmosphere were interrelated. "He who contemplates the sea must look upon it as a part of the exquisite machinery by which the harmonies of Nature are preserved" he wrote, but the significance of these elegant words did not sink in with his colleagues. Rather than integrating ocean and atmosphere, they usually treated them as separate entities, with physical oceanographers concentrating on the sea and atmospheric scientists focusing on the ocean of air that surrounded the planet.

In the process much valuable work was achieved. Atmospheric scientists, for instance, determined that winds were caused by uneven heating. In the tropics the sun warms land and sea, and both surfaces transfer this heat to the air above. The air, in turn, expands, becomes less dense and slowly rises. Since it is constantly replenished, masses of air are pushed away from the tropics towards the poles. There they are cooled, becoming more dense, and sink to the surface. Thus a giant cycle, or convection cell, is set up, whereby warm rising air in the tropics is continually replenished by cold dense air from the poles.

Early meteorologists determined that the speed and strength of these moving airmasses were related to differences in pressure areas. In the tropics, where warm air rises from the surface, pressure is low; near the poles, where cold air sinks, it is high. And like high pressure air escaping from an inflated tire, air always rushes from a high pressure area to fill a low pressure area. The higher the difference between the two, the stronger the wind.

If the Earth's surface were made up of a homogenous substance, like water or sand, it would be relatively easy to figure out how these air masses would flow and thereby affect the weather. But the planet's surface is made up of many substances, which absorb various amounts of heat and reflect sunlight in varying quantities. Moreover, winds have to travel over mountain ranges which can deflect them, or over seas and lakes, which affect humidity, and hence the density of air.

If that weren't enough, moving air masses are also affected by the rotation of the Earth. Since the Earth turns around its axis, places on different latitudes spin around at different speeds. Near the equator, that speed exceeds 1,000 miles per hour; at the poles it is virtually negligible. Air masses moving north from the equator are thus deflected to the right, or east, as they reach areas which are spinning at a lower speed. Conversely, dense air masses which travel south from the 'slower' North Pole are seemingly deflected to the right, or west, as they hit regions which are turning around faster. A mirror image of this exists in the southern hemisphere, with moving air masses deflected to the left.

This deflection is called the Coriolis Effect after the French mathematician Gaspard de Coriolis, who first described it. Though it complicates the movement of air masses along the earth's surface, the Coriolis Effect accounts for global wind patterns quite well. In the northern hemisphere, for instance, warm air rising from the Equator travels north, and curves right to the east. Around 30 degrees latitude, the air has cooled and sinks, creating a high pressure area. The sinking air spreads out as it reaches the surface: some of it returns to the tropics to be heated and lifted again. On its way to the Equator, this air is deflected to the right. This creates an east-to-west motion of air along the surface below 20 degrees latitude: the northeasterly trade winds. The remainder of the sinking air is pushed northward. It also is curved to the right, creating a west-to-east motion north of 30 degrees latitude: the westerlies. Meanwhile, very cold air from the pole moves south, and is deflected to the west as it progresses, creating the polar easterlies. At 60 degrees latitude, this cold air meets the westerlies, forcing the milder west winds aloft and creating another low pressure zone. The lifted air spreads out at higher levels, with most of it heading on toward the pole and the remainder moving south.

While atmospheric scientists gradually figured out global wind patterns, oceanographers focused on the ocean's major surface currents. To determine their flow patterns, they used information from ship passages as well as drift bottles. The latter technique simply consisted of throwing sealed bottles overboard with a note in them, stating the time and location of their release. Then, if and when the bottles were retrieved somewhere, it was possible to gain an idea of their, and by implication the current's, track.

One of the most motivated practitioners of this technique was Prince Albert I of Monaco, who did much to establish oceanography in and around French waters. Trained as a navigator and mechanical engineer, the prince purchased a schooner in 1873, called her the *Hirondelle*, and for the next 12 years sailed her through European coastal waters. Along the way Albert earned a reputation not only as a skillful navigator but also as an acknowledged oceanographer. Before long, the *Hirondelle* turned into a research vessel and in 1885 she took off on her first major oceanographic cruise. The expedition's goal was to study the Gulf Stream.

At the time not everyone was convinced that the Gulf Stream actually crossed the Atlantic. Albert was determined to settle the question and packed 20 beer barrels and 150 glass bottles aboard the Hirondelle. Near the Azores 169 floats were set adrift, each one with a polite message in 10

*Prince Albert I of Monaco aboard the Hirondelle. European oceanography received a major boost when the prince began to invest his time and fortune into marine scientific research.*

## CURRENT GYRES

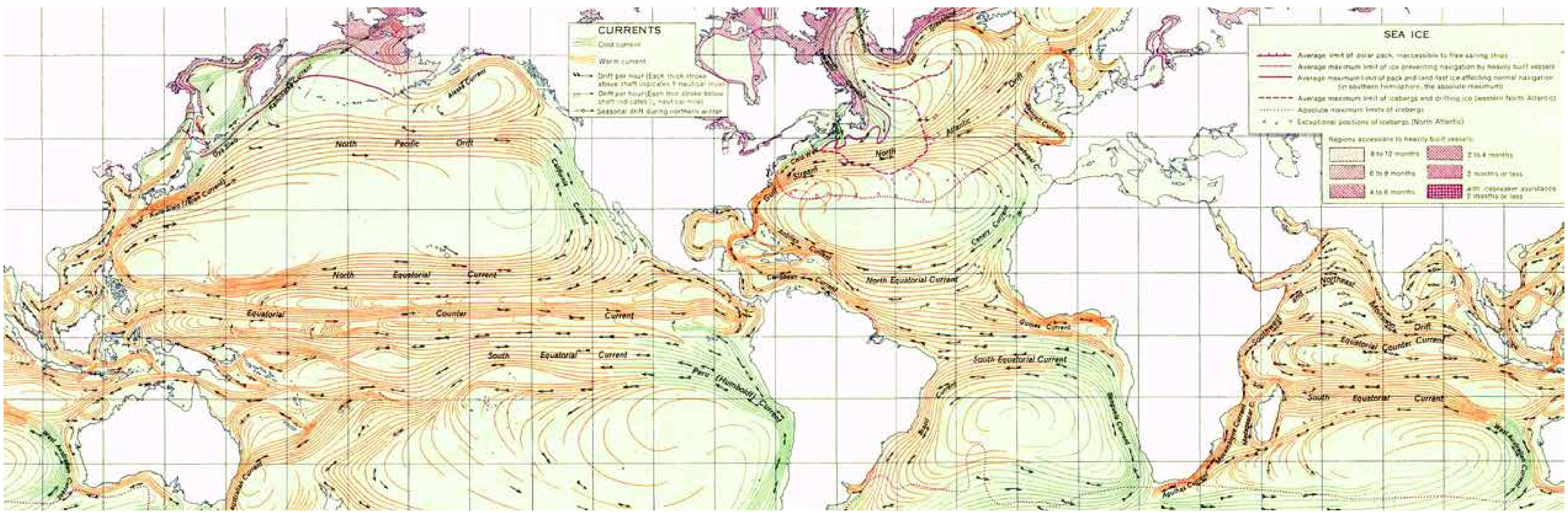
The realization that all oceans appeared to possess massive current gyres intrigued oceanographers. By the early 20th century they had come to the conclusion that a variety of factors were involved, including the position of the continents and the contours of the sea floor. The Coriolis Effect was found to play an important role as well, since water masses, just like air movements, are affected by changes in rotational speeds when moving between different latitudes. They are thus deflected to the right in the northern and to the left in the southern hemisphere. In fact, just as it does for the movement of air masses, the Coriolis Effect helps explain the particular patterns of surface currents.

In the northern hemisphere, for instance, the northeast trades cause the surface water to move in a northwesterly direction. The westerlies further north push the water in a southeasterly direction. Both water masses meet in the vicinity of 30 degrees latitude, creating a high pressure (water) ridge in this region. Water, like air, flows from high to low pressure—in this case from the high pressure area at 30 degrees towards regions of lower pressure to the north and south of it. But, as the water begins to move, it becomes subject to the Coriolis Effect and is deflected to the right. After turning 90 degrees, it cannot turn further without flowing 'uphill', and the water loses momentum. Before long, it starts moving again in response to the pressure gradient until it is forced to the right a second time, and this continues until a balance is reached between the pressure gradient and the Coriolis Effect.

Due to the position of the continents, the net result of this process is that the water moves endlessly in gyres around regions of high and low pressure. The motion is clockwise around high pressure ridges (30 degrees N) and counterclockwise around low pressure regions, which occur where prevailing winds cause water to be pushed away. Low pressure regions occur in the northern hemisphere near 60 degrees latitude and just north of the Equator. A mirror image of this circulation pattern exists in the southern hemisphere.

languages requesting notification of the place and time where the bottle was retrieved. The following year 510 bottles were released in the southern part of the English Channel, and on a subsequent trip another 931 bottles went overboard, this time between the Azores and Newfoundland. Eventually, 227 replies were received, indicating the Gulf Stream did make it all the way across the ocean and, in fact, seemed to form part of a circular current system, or gyre, which turned around endlessly in the North Atlantic.

In subsequent years, similar gyres were discovered in the South Atlantic, the North and South Pacific, and the Indian Ocean. All oceans have a subtropical gyre, which is particularly well developed in the northern hemisphere. In




*A 1940s map showing surface ocean circulation. Even relatively primitive techniques like drift bottles enabled oceanographers to map the major ocean currents.*

the Atlantic Ocean it consists of the Gulf Stream system. Its counterpart in the Pacific is the Kuroshio system. An offshoot of the Gulf Stream, the Irminger current, combines with the East Greenland current to produce a counterclockwise subpolar gyre in the North Atlantic. A similar pattern exists in the North Pacific, where the Alaska current flows along these lines. Sometimes the gyres cannot develop because the continents are positioned too close to one another. This happens for instance in the equatorial Atlantic where the proximity of Africa and South American interfere with the development of a gyre.

By the early twentieth century, the principal circulation patterns of ocean and atmosphere had been well documented. Much of this work confirmed a regularity of wind and current patterns on a seasonal basis, much the same way Maury had outlined on his Wind and Current Charts. But since no one could predict how these patterns behaved on a day to day basis, their forecasting value was limited. In fact, many people began to doubt whether forecasts were even possible because the patterns, atmospheric as well as oceanic, were so complicated.

Even so, some meteorologists were convinced that future atmospheric conditions, or future weather, could be predicted. They believed that the atmosphere, regardless of its complexities, conformed to the same physical laws that governed the rest of the universe. In their view the future of the cosmos could be calculated by a complete specification of the universe at any single instant and the laws of Newtonian mechanics. Of course, one needed more than that to make these calculations, but that was not the point. What mattered was the perception that it was possible. Much needed additions like the laws of thermodynamics and electromagnetic radiation would follow in time.

By the turn of the century these laws were sufficiently well known to begin to consider numerical calculation as a means to predict natural events like weather. In 1904 Norwegian physicist and meteorologist Vilhelm Bjerkness published a paper on the issue. The central problem of the science of meteorology was the prediction of future weather, he stated, before proposing a course of action to go about solving this problem. He phrased it as follows:

> *"If it is true, as every scientist believes, that subsequent atmospheric states develop from the preceding ones according to physical law, then it is apparent that the necessary and sufficient conditions for the rational solution of forecasting problems are the following:*
> *A sufficiently accurate knowledge of the state of the atmosphere at the initial time.*
> *A sufficiently accurate knowledge of the laws according to which one state of the atmosphere develops from another".*

Bjerkness thus defined weather forecasting as an initial value problem, and demonstrated that future values of winds, temperature, pressure and atmospheric density could be determined from their current values by using the proper formulas. In doing so, he summarized what it would take to predict the weather: a comprehensive overview of what the atmosphere was doing at any given time plus a sound understanding of the laws that governed it.

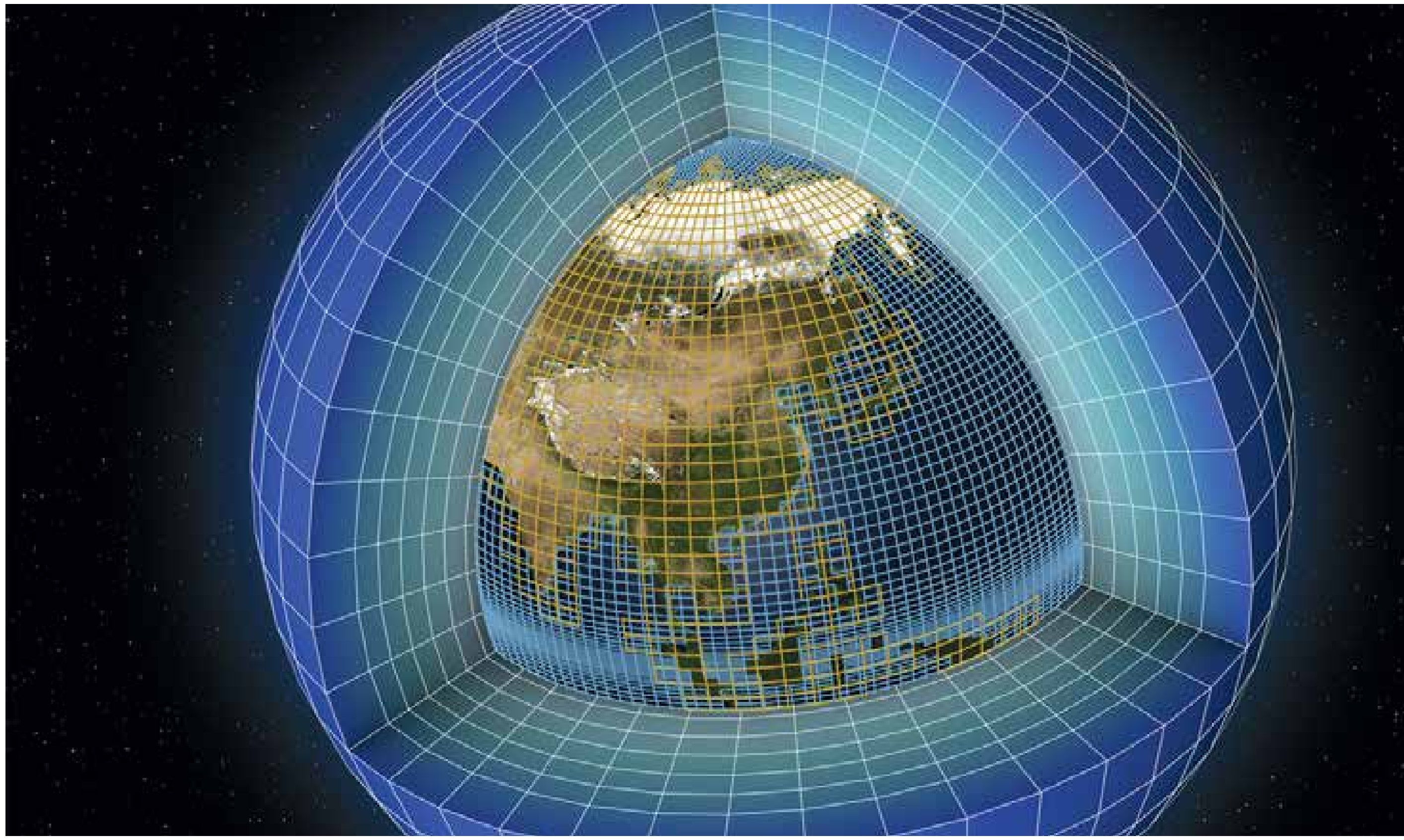
Lewis Fry Richardson, a British meteorologist, was among the first to gain a sense of the practical difficulties involved in Bjerkness' elegantly stated summary. While serving as an ambulance driver in France during the First World War, Richardson began to formulate equations for the physical laws of atmospheric motion. Having done that, he tried to derive a weather forecast by inserting his observations into the equations and subsequently solving them. Unfortunately the equations were so complex that it took him nearly two years to work them out by hand to obtain no more than a single six-hour forecast.

The forecast was obviously useless but Richardson was not discouraged. He published his findings in a remarkable book: *Weather Prediction by Numerical Process*. Published in 1922, it revolutionized meteorology by providing a blueprint for a numerical model of the atmosphere. In it Richardson also explained why his own forecast was so far off the mark. For one thing, he knew he needed data for the entire atmosphere rather than just the surface data he had collected. For another, he desperately needed far more rapid means to work through the tremendous volume of computations. Richardson fantasized how to go about these shortcomings, describing a 'forecast factory' to handle the complex equations. The factory would be staffed by human calculators, which he called 'computers', working in concert to derive accurate weather forecasts. He figured it would take 64,000 of these human computers to keep the forecasts ahead of the developing weather.

Twenty years later, as a result of another world war, this 'forecast factory' was becoming a reality. In it were not 64,000 human calculators, but rather 17,468 vacuum tubes. It was called ENIAC, the Electronic Numerical Integrator and Computer- the first electronic computer, developed in part to provide the US military improved weather forecasts. At the same time the Air Force was collecting high altitude meteorological observations for its aviators. By providing better data about the atmosphere on the one hand and a means to crunch through the vast volume of computations on the other, the war effort brought weather forecasting closer to practical reality.

Meteorologists were quick to see the peace-time potential of computers like ENIAC. Under the direction of John von Neumann a team was assembled to test the role of the electronic computer in numerical weather prediction. Richardson's equations were simplified, the data were plugged in and ENIAC was set to work. In April 1950, the first experimental weather predictions were obtained. The forecast covered only a single variable for a 24-hour period but it turned out to be accurate. Though the result was of little practical value, meteorologists had finally been able to calculate a forecast before the day's weather had made it obsolete.

Since those early days, much has changed. The number crunching capacity of modern computers has increased dramatically, allowing weather forecasters to use far more realistic models of the atmosphere. At the same time, observational ca-



*General or Global Circulation Models (GCMs) divide the atmosphere into a grid so that computers can calculate how a number of atmospheric variables are expected to behave. The smaller the elements, the better the forecast (in theory). GCMs generally perform well on short term forecasts; whether they also provide reliable insight into future climate remains a matter of debate.*

pabilities have been vastly enhanced by satellites and remote sensing technology. Previously, most data had to be collected individually. Today, satellites continually monitor the planet's surface and atmosphere and instantly relay information on temperatures, surface winds and other atmospheric conditions to supercomputers, so that the data and models inside them can constantly be kept in touch with the real world.

The most advanced models, called General Circulation Models (GCMs), divide the earth's atmosphere into a three-dimensional grid. Wind speed, humidity, temperature and atmospheric pressure data for each layer of the grid, collected by weather balloons, weather stations and satellites, are averaged out, and then the computer calculates how each parcel of air is expected to behave over a short period of time. When that is done, the next period of time can be forecast, and so on until a one, three or ten-day forecast has been completed. Depending on the number of variables, this can involve a phenomenal number of calculations.

The U.S.' National Weather Service, for instance, bases its weather predictions on the forecasts churned out by supercomputers capable of handling trillions of calculations per second. Equally powerful machines are deployed at the British Meteorological Office, the European Centre for Medium-Range Weather Forecasts in Reading, England, the French meteorological service and the National Center for Atmospheric Research in Boulder, Colorado. Short-term global weather forecasts can now be obtained in minutes; medium to long-term forecast obviously require more time but they are far more reliable because the mind-boggling capacity of the computers allows them process coupled models, which integrate ocean and atmospheric data. And since the reign at the top of the supercomputer scale is short, even better predictions can be expected in the future. Machines that are thousands of times faster than the current generation will be in operation soon, and no one can predict when or where that evolution will eventually come to a halt.

Today's atmospheric models enjoy mixed results. There simply is, and probably may never will be, a computer which can keep track of all atmospheric variables on earth in a reasonable length of time. Three-dimensional grids try to overcome this limitation by averaging out atmospheric data in individual boxes, but inevitably many important climatic phenomena are missed. The grid elements in Global Circulation Models, for instance, are still miles in size. In time, more powerful computers will enable meteorologists to decrease the size of the elements, but unless they are fine enough to resolve phenomena like individual clouds, which affect surface temperature by reflecting sunlight, atmospheric models can only approximate reality and can hence give no more a rough indication of what lies ahead.

Moreover, scientists now believe that the atmosphere is not indefinitely predictable, as the deterministic philosophies of the 19th century suggested, because the atmosphere is affected by too many feedback mechanisms. When cold weather causes a snowfall, for instance, temperatures drop further because snow reflects sunlight, and thus absorbs less solar energy than bare ground. For this reason it is important to know the exact extent of the snowfall. Clouds are another example: sometimes they keep the surface cool by blocking sunlight, other times they warm it by trapping heat. The effects of these particular feedback mechanisms are known, and the most advanced models include parameters to account for them, but they still represent no more than an approximation of reality.

In spite of these complications, atmospheric models are quite successful at short-term forecasts. The one-day forecasts, on which local weather reports are based, are generally reliable, even though they remain limited to 'ranges' of expected temperatures and 'chances' of precipitation. Atmospheric models also generate reasonably successful three-day forecasts, but the accuracy of anything beyond that quickly deteriorates, for the simple reason that, if one of the initial assumptions is wrong, the errors increase in magnitude. Medium-range (4 to 10 days) forecasts therefore remain cautious, limiting themselves to general predictions of wind-flow patterns and temperature ranges.

On occasion, even one-day forecasts can be dreadfully wrong, especially when dealing with erratically moving phenomena such as thunderstorms or hurricanes. The National Weather Service, for instance, issues warnings for only 60 to 75 percent of the severe thunderstorms that hit the United States per year. Moreover, many warnings are inaccurate, which causes huge problems and immense damage and suffering in a country that faces about 10,000 severe thunderstorms, 5,000 floods, 1,000 tornadoes and 10 hurricanes a year.

Inaccurate forecasts can have dramatic consequences, as was shown in southeast England on the night of October 15, 1987. Hit by an extremely violent storm, the countryside was ravaged as it had not been in more than 300 years. Weather forecasters had seen the storm forming, but they expected it to take a different track. The public, as a result, was left with little, if any, warning.

In response to the deaths of 19 people, more than 15 million toppled trees and damage exceeding well over a billion pounds, the British government commissioned an investiga-

*Clouds complicate weather forecasting. Sometimes they trap heat radiating back from the earth's surface, keeping temperatures high, but they can also have the opposite effect by blocking sunlight. That will affect both land and sea, and hence also the atmosphere.*

tion. It came to the conclusion that weather forecasters had relied on incorrect computer predictions. The culprit was the British fine mesh forecasting model, which uses a small grid to model atmospheric conditions above Britain. Though highly regarded, the model predicted the storm's track to run much further south than it actually did. Ironically, the larger grid models were more accurate in assessing the storm's course and even medium range forecasts for that night, made between 3 and 10 days earlier, proved more reliable.

According to the investigation, the fine-mesh model's failure was caused by a lack of data over the Bay of Biscay, where the low pressure system had initially developed. With few weather stations in the area, the model based its predictions on inadequate data, and this proved fatal. Although the inaccuracies were small at first, they expanded as the model continued its calculations, causing the computer to conclude that the worst of the storm would actually bypass England.

That sort of error is no longer likely to go undetected. Weather models have not only become more accurate; there are also more of them to consult. But forecasting errors can never be ruled out and with some regions experiencing more extreme weather as a result of global warming, they will continue to have dramatic consequences.

If forecasting tomorrow's weather can be prone to errors of this magnitude, imagine how difficult it is to predict large-scale climatic anomalies like El Niño. While weather can be forecast with some success by relying solely on atmospheric models, climate is the composite of prevailing weather conditions over a much longer period. During this period, the atmosphere can be affected by a variety of factors that have little to do with meteorological conditions. Just about everything we do, from driving cars to clearing forests to raising cows has an effect on the atmosphere. It is possible to average out elements like the amount of carbon dioxide emitted in the course of a year, but others simply cannot be accounted for.

Natural disasters like volcanic eruptions provide a good example. Given their unpredictability, it is impossible to anticipate the effects of eruptions even though the ejected dust clouds can affect global weather by preventing solar heat from reaching the surface. After the eruption of Tambora in 1815, for instance, the annual mean temperature dropped by one degree C and 1816 became known in Europe and North America as the year without a summer. Similarly, the massive eruption of Krakatoa in 1883 may have lowered world temperature by two degrees. And the 1982 eruption of El Cichón in Mexico produced a dust cloud that not only circled the globe, but spread as far as thirty degrees latitude on either side of the Equator. The resultant reduction in solar energy reaching the surface of the earth may actually have contributed to that year's unusually strong El Niño. Similarly the 2010 flare up of Iceland's Eyjafkallajukull volcano not only affected air traffic to and from Europe, but its weather as well.

In the wake of the destruction caused by the 1982 El Niño event, the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU) initiated a ten-year research effort to determine what lay at the root of El Niño and the Southern Oscillation. Designated as the Tropical Ocean and Global Atmosphere Program, or simply TOGA, the program had with three major objectives: gaining a description of tropical ocean and atmosphere in order to determine to what extent the system is predictable; studying the feasibility of coupling ocean and atmosphere models to improve this predictability; and providing the scientific background for a new data transmission system to support coupled ocean-atmosphere models.

Meeting these objectives required better information on oceanic and atmospheric conditions in the tropical Pacific and Indian Oceans. To achieve this, scientists from many nations expanded the existing data base. Some worked from research vessels and gathered information on salinity, currents, and the thermal field of the upper layers of the ocean. At the same time an arrangement of 69 deep sea buoys was anchored across the equatorial Pacific, transmitting temperature, wind and humidity data via satellite to shore stations.

The research program also made use of commercial shipping lines, which crisscross important regions far more regularly than research vessels. A number of shipping lines agreed to assist in data collection by taking along expendable bathythermographs (XBTs), which measure the heat stored in the upper layers of the ocean. The devices were thrown overboard at regular intervals and helped greatly in mapping the thermal field of the tropical Pacific and Indian Oceans. Atmospheric data collection needed to be improved as well, so upper air stations were established in data-sparse regions like South America and Africa. At the same time, new automated surface meteorological stations and rain gauge stations were established to improve information on winds and humidity.

Scientists also delved into the past, trying to determine the regularity of El Niño before weather records were kept. They discovered corals could help them in this task, by reflecting past weather conditions in their skeletal growth bands. By placing cores drilled from coral heads under ultra-violet light, this built-in weather recorder was revealed, providing information on the conditions of summers and winters of centuries past. Climatic information that dated even further back was gathered from deep ocean sediments and Antarctic ice cores. This enabled scientists to create a picture of El Niño's patterns not just in the past centuries, but as far back as 1,000 years.

With people and facilities from many nations working side by side, information about the state of the atmosphere and the tropical ocean was vastly expanded. Major gaps in what used to be data-sparse regions were filled and were complemented by extremely sophisticated satellites to collect and transmit data uninterruptedly.

These efforts paid off quickly. In 1986 American scientists, using coupled ocean-atmosphere models and the improved flow of data, predicted an El Niño to commence later that year, albeit a weaker one than the 1982–1983 event. Although they were not able to pinpoint its exact timing or duration, Peruvian agriculture officials put the warning to good use, recommending that farmers plant crops that could handle more rain. Subsequent events have been predicted as well, including the strong El Niño that began gathering off

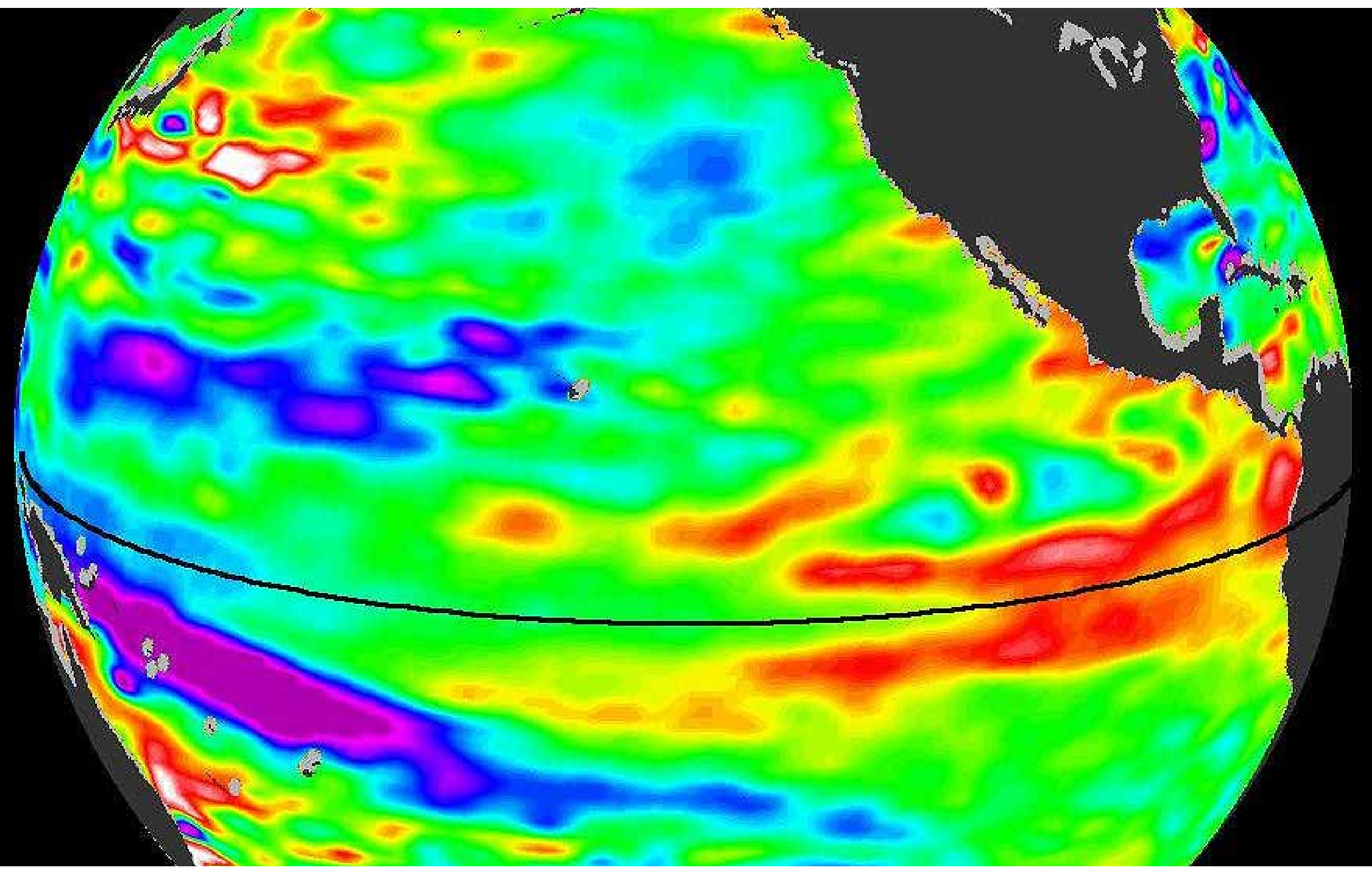

*NOAA's Ronald H. Brown (R104) is one of the most sophisticated research vessels afloat. The ship has often participated in climate-related research, hosting scientists from all over the world. That type of international cooperation is essential to understanding global phenomena like El Niño.*

the Latin American coast in late 1994 and the 1998 event, which approached what happened in 1982–83 in intensity. That El Niño too left billions of dollars of damage in its wake, but there is no question the devastation would have been far greater without the warnings scientists were able to provide. Since the 1997–1998 event, there have been additional El Niños, including one that started in late 2009 and lingered well into 2010, creating considerable storm damage in South America, and the strong 2015-2016 event, that scientists observed gaining strength almost a year prior to its arrival off the South American coast.

If El Niño works the way current thinking suggests, the origin of the event resides in the tropical Pacific Ocean. During El Niño years unusually warm water extends into the central and eastern Pacific, driven by westerly winds that blow into areas of warm air rising over the ocean. The winds subsequently push this water into the eastern Pacific, cutting off upwelling. During other years, winds blow from the east and pile up warm water in the western Pacific. This stimulates the upwelling of cold, deep water off the South American coast, increasing the temperature difference between the eastern and western Pacific and thereby strengthening winds.

The mechanism that allows for the switching back and forth between the two systems seems to involve odd ocean waves created by these pressure differences. According to the coupled models, the westerly winds that raise sea level in the east during an El Niño year send a signal that lowers sea level in the west by means of slowly moving waves, traveling just north of the Equator. The waves take a few months to cross the Pacific, and when they reach the western boundary of the Pacific basin, they are reflected. Energy is dissipated when this occurs, but the reflected waves, now moving east, carry the same negative sea level signal. When enough of them arrive back in the eastern Pacific, their negative sea signal may overcome the mechanism that raises sea level in this region, forcing the entire system to switch into the opposite mode. Winds change from west to east, driving warm water to the western Pacific and eventually raising sea level there, and the waves start moving in opposite direction, until enough of them have arrived to force the system to switch around again. Thus each warming of the tropical Pacific, which precedes El Niño, may sow the seeds of the event's regression.

Other factors may be at work as well. One theory suggests that lava flows from undersea volcanoes and fissures in the Pacific Ocean actually contribute to its abnormal warming, thereby triggering El Niño events. If confirmed, this could help explain El Niño's puzzling irregularity and varying strength. Presumably global warming also plays a role, by throwing more heat and moisture into the atmosphere. This could speed up El Niño's cycle, as seems to be confirmed by the fact that there were no less than six events in the past 20 years. But clear proof of the correlation between climate change and El Niño has not been established. Only more



*Satellite imagery showing the central and eastern Pacific. Warm (red) water is piling up near the South American coast – an El Niño event is in progress. Colder than usual water (blue) appears in the western Pacific. A basic understanding of what causes these conditions now exists; what is less clear is the puzzling irregularity of the event.*

sophisticated coupled models, faster computers and further data can confirm the mechanisms that push the atmosphere from one extreme to the other in the tropical Pacific. But at the same time there is a growing sense that some of the groundwork has now been uncovered.

Many factors have contributed to this success. The phenomenal increase in the quantity and quality of atmospheric and ocean data, along with the rapidly increasing number crunching capacity of supercomputers has undoubtedly contributed most. But the various efforts to unravel the workings of El Niño could never have succeeded without a strong level of cooperation. Most nations of the world, regardless of political inclinations, cooperate in these initiatives to solve what only a few years ago seemed a task of mind-boggling complexity.

Understanding climatic events like El Niño, in short, took far more than a revolution in computing and observational capabilities. It also took a revolution in approach. Until relatively recently, oceanographers and atmospheric scientists worked mostly in isolation, trying to understand the complexity of their respective fields. Now they work together. Like the Polynesian seafarers, who looked for clues in sea and sky to find their way, or early seafarers who carefully watched for signs to foretell the coming weather, today's scientists are crossing the boundaries that compartmentalize knowledge. Increasingly, they integrate and assimilate, realizing that interaction, rather than its components, is essential to understanding the ocean and its effects on the planet.

# SUMMARY

*I need the sea because it teaches me, so states the Pablo Neruda poem opening this chapter, elegantly summarizing its essence in a single line. We too need the sea because it teaches us. It teaches us to look at marine life to better understand ourselves, it cautions us to carefully manage its resources, both living and non-living, and to anticipate the effects when removing them. And in this chapter it faces us with the biggest challenge of all: how to predict how the sea behaves because only then can we figure out what the weather has in store.*

*Weather has always been on the mind of people, because it affects everything, from the success or failure of crops to anticipating floods and storms. Knowing what the weather has in store improves our chances of survival, and nowhere more so than at sea because a ship is no more than an insignificant speck in the expanse of the sea, and a very frail one when the ocean decides to unleash its might. So it was at sea that people first looked for clues to foretell what lay ahead and it was there that they figured out that this required searching for signs in both sea and sky, and then deducing their significance.*

*Today understanding how ocean and atmosphere interact is more important than ever. Not only does it help us predict tomorrow's weather, it can also help foretell climatic anomalies like El Niño months ahead of their onset. It may not yet tell us to what extent temperatures will rise years from now, but it will help us track the extreme weather that seems to be occurring more frequently as a result of global warming.*

*I need the sea because it teaches me, so states Pablo Neruda. We too need the sea because it teaches us. It teaches us humility and respect. It teaches us how to integrate and assimilate. If now we only remembered its lessons...*


The very deep did rot: O Christ!
That ever this should be!
Yea, slimy things did crawl with legs
Upon the slimy sea.
Samuel Taylor Coleridge
The Rime of the Ancient Mariner

# POLLUTION

In 1845 British archaeologist Austen Henry Layard unearthed two libraries of clay tablets, inscribed with odd, wedge-shaped markings at Nineveh in present-day Iraq. Along with many other finds, they were sent to the British Museum.

For many years no one had a clue about what was written on the tablets. It clearly was something more than a set of business transactions. In fact, it seemed to be a story but, since no one had figured out how to decipher the Assyrian script, no one knew what it was about. But by the late 1850s enough was known to begin an attempt and in 1872 George Smith, an assistant in the museum's Department of Antiquities, completed the translation. The tablets, it turned out, contained parts of a legend. Some sections were missing, but the discovery created such public interest that Smith was sent to Iraq to find the remainder. A year later he returned with the missing portions. Now the story was complete.

The tablets told the story of a kind and modest man who lived many thousands of years ago. One day the reeds next to his hut whispered a warning to him. The gods, they warned, were angry and had decided to wipe out humanity with a mighty flood. He should build a boat, large enough to take his family and livestock, and be prepared.

The man did as told. When he completed his work, a terrible storm hit. For six days and six nights torrential rains fell from the sky. When the weather cleared, the entire surface of the earth was covered with water. On the seventh day, the boat grounded on a mountain top. The man released a dove to see whether there was any land, but the bird returned. Next, he let go a swallow but it also returned, unable to find a resting place. Finally, he sent out a raven. This time, the bird did not come back. The man now suspected that the waters had receded enough to reveal land. He sailed on to find it, disembarked and offered a sacrifice to the gods, who told him to "dwell in the distance, at the mouth of the rivers" and repopulate the earth.

The story had a familiar ring because a remarkably similar account was found in the Bible. There it was Noah who survived, while the storm raged for forty days and forty nights. But aside from the length the protagonists floated around, the stories were so similar that they seemed to have a common origin. In subsequent years, similar versions were found elsewhere. One, discovered at the Babylonian city of Sippar, told the story of Atrahasis, who like his Jewish and Assyrian counterparts, was warned of the flood and rode out the storm in a great ark.

During the early 1900s the source of these stories was unearthed at the ancient Sumerian city of Nippur. Here it was the sea god Enki who decided to save mankind from the watery onslaught. His choice fell on the god-fearing king Ziusudra. The deluge raged for seven days and seven nights and the king's boat "was tossed about on the great waters" until the sun god Utu shed light on heaven and earth. Ziusudra was said to have landed at Dilmun, the island of Bahrain in the Persian Gulf. He left the island and on the mainland founded the city of Ur, the birthplace of Sumerian civilization.

This Sumerian account is the oldest preserved text recording the memories of the Great Flood. It spawned variants in Assyrian, Babylonian, Hebrew and eventually Christian mythology, but it is by no means the only account of a catastrophic flood in the early history of man. Flood legends are nearly universal. They are found in Indian, Chinese and Burmese mythology, as well as in Australia and the islands of the Pacific, and among the Indians of the Americas. Mythology, it appears, not only perceives the sea as life-giving; it can also be life-taking. It can be just as destructive as it is creative.

Though they differ in detail, these legends share a common pattern. First, for some reason, early man gravely offended the gods. In the Mesopotamian myths proliferating humanity apparently made so much noise that it kept the gods awake. In the Bible it is evil that triggers the deluge; elsewhere it is disobedience. Whatever the reason, the offense is so serious that the gods feel they have made a mistake in creating humanity. As punishment they unleash a torrential flood. But one man and his family are spared so that they can give birth to a new generation.

These similarities raise questions whether there was at some time a catastrophic flood during the early history of man. For some people its mere mention in the Bible is sufficient proof of a major inundation, and a few energetic souls have even searched for remains of the Ark to prove not only that it occurred but also that there indeed was a select group of survivors. But science has been looking for other evidence, particularly among the geological and climatic record. The results seem to confirm the possibility of widespread inundations some 6,000 years ago.

These floods had little to do with uninterrupted torrential rains, however. They were caused by a gradual rise in sea level, which began during the last ice age some 17,000 years ago. As the climate warmed, massive ice caps and glaciers began to melt, and slowly the sea began to rise, reclaiming low-lying lands. By the time the sea stabilized at its present level some 6,000 years ago, it had risen nearly 100 meters, dramatically altering the world's coast lines. Towards the end of this period of global warming sea level rose rapidly, perhaps as much as 10 meters in a short time. Coastal regions and river valleys, where people established their first centers of trade and civilization, were inundated. Many settlements were flooded.

People were unaware of the climatic changes that made the sea rise so rapidly. To them it was the wrath of the gods that caused the spectacular inundations in which so many perished. They had no means of recording the event, other than passing it on from one generation to the next, so that everyone would know of the great kingdoms that existed prior to the deluge and be warned of their fate.

Today, we know better. We can trace the sea's level with remarkable accuracy, and can extrapolate with some confidence that this steep rise 6,000 years ago probably coin-

## MARINE POLLUTION

What exactly is marine pollution? Can a substance harmful in one situation be beneficial in another? Is oil entering the sea through natural seepage also pollution? Many questions, revealing it is not necessarily easy to define marine pollution.

A United Nations experts' report made an attempt, defining the term as "the introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities, including fishing, impairment of quality for use of seawater, and reduction of amenities." Confusing as it sounds, the definition clearly links pollution with harm and with people, and states the principal areas in which harmful effects may be experienced.

Waste enters the oceans in four general ways. By far the most important share comes from land-based activities. It includes sewer and industrial outfalls, rivers and land runoff. Significant amounts of pollutants also reach the ocean through the atmosphere. This is often the most difficult pathway to trace to its source and to monitor with any degree of precision.

Pollutants can be discharged by ships and platforms which, in the course of normal operations, can discharge a variety of materials, including garbage and oil remnants. In addition vessels pose a threat of pollution after accidents like collisions and groundings. Finally waste products also reach the ocean through deliberate discharges of harmful substances from vessels or platforms: a practice generally referred to as dumping.

Marine pollutants can be classified into a variety of categories but most important is the division between degradable and non-degradable waste. Substances in the first group can be broken down in the marine environment. If and when discharged in reasonable quantities, they do not cause major problems. Widespread degradable discharges include domestic sewage and effluents from pulp and paper mills or food processing plants. Non-degradable pollutants, in contrast, cannot be broken down and as a result persist in the marine environment for a long time. This group includes pesticides, heavy metals and numerous industrial and consumer products like plastics.


*The major sources of marine pollution captured in a single picture. Land-based sources, especially rivers, account for the bulk of the waste load, followed by atmospheric pollution. Ships still pollute as well, but generally far less than in the past. People themselves may have taken over that dubious honor.*

cided with the deluge that troubled the legends of diverse cultures. Perhaps we smile at their explanations: the anger of the gods, triggered by too much noise, or disobedience... Yet there is something uncomfortable to all of this because after thousands of years of relative stability it is clear that sea levels are going up once more. The planet is warming, water is expanding, ice is melting, and the sea is rising. But this time, the warming isn't caused by the natural climatic shifts that have affected the planet throughout its long history. Nor are the gods involved.

This time we are causing it ourselves.

To explain how we got to this point is a long story, but a very important one. It is essentially a story about how we treat our surroundings. Just about anything we do – live, breathe, play, move, grow food or manufacture products – creates waste. And while we can try to reduce the amounts of it, there are only three areas to get rid of it: water, land or air.

From earliest times, people have been acutely aware of the need to dispose of this waste, preferably out of sight, touch and smell. And from earliest times, water was considered a splendid place to do so. For much of this time this didn't create much of a problem because water has the capability to break down natural waste products. But in closely settled communities, where human waste and garbage entered rivers directly or through primitive sewer systems, this could be a very different matter.

The ancients solved this predicament by constructing aqueducts and water mains to keep waste water separate from drinking water supplies. The facilities of the Assyrian city of Nineveh, for instance, served as a model for the Phoenicians, who took it on to Greece. From there the system went to the Romans, who perfected it and introduced it into Western Europe. But after the fall of the Roman Empire, these facilities were neglected. It didn't take long for European cities to become extremely unhealthy places to live.

By the Middle Ages several cities had constructed water mains to provide drinking water, but conditions remained appalling. Pigs ran around freely, polluting streets and wells, and waste piled up in the streets. Frankfurt was filthy. Its streets had to be filled with straw to prevent the traffic from getting stuck in mud and filth. Nuremberg was even worse. Here special stilt shoes were sold so that the streets could be walked after a shower. Other cities fared little better.

The lack of sanitation combined with crowded conditions invited disease, sometimes of epidemic proportions. During the 1340s the Plague terrorized Europe. It broke out in Paris and rapidly spread through the Low Countries, England, Ireland, Norway, Germany, Russia and even as far as Greenland. Millions of people died. Some made the connection between the unhealthy living conditions and the epidemic, but to the masses it was much easier to

*Plague victims are buried in Tournai, Belgium. Much of Western Europe was ravaged by the plague in the mid-fourteenth century, in no small part as a result of the appalling living conditions in medieval cities. In some parts of Europe more than half of the population perished between 1346 and 1352. From The Chronicles of Gilles Li Muisis, (Belgian Royal Library, Brussels).*

blame "instruments of evil spirits or their satellites". Jews were accused of poisoning the wells and massive pogroms took place in Switzerland, Germany and Flanders, in which thousands perished.

Following the Plague measures were taken to improve sanitary conditions. People who were found polluting were to be fined or otherwise punished, but these regulations were difficult to enforce. Only Berlin implemented an effective measure by authorizing ward masters to throw the waste found in front of houses back through their windows. In a remarkably short time, the garbage disappeared. Elsewhere municipal authorities simply gave up. Parisians were accustomed to throwing their liquid and solid waste through the windows on the street. All the city could do was to require people to call "garde l'eau" (mind the water) before doing so. Not surprisingly, conditions hardly improved. In Lon-


*A satirical engraving by William Heath (1795–1840), showing a woman horrified by what she might see in local water supplies. The caption reads "Monster Soup commonly called Thames Water being a correct representation of that precious stuff doled out to us!" making clear there was great concern about the filthy water quality of the Thames.*

don, the stench of the Thames during the 17th century was so oppressive that King James threatened to move the court to Windsor. A hundred years later, Queen Ann considered moving Parliament to Oxford for exactly the same reason.

Not only households polluted the waters; so did many industries. Cloth dyers were amongst the worst offenders, discharging a variety of chemicals in public waters. So did bleachers, who discharged lye, milk and starch, provoking complaints from brewers, who needed clean drinking water, and farmers, whose cattle refused to drink the polluted waters. In response to the growing number of complaints, municipal authorities ordered dyers and bleachers to specific areas so that their discharges could be somewhat controlled, but even then conditions seldom improved.

The situation grew even worse during the Industrial Revolution. City populations exploded, creating far greater amounts of domestic waste and still public authorities did not properly connect pollution with disease. It took three consecutive cholera outbreaks in the mid-19th century, claiming thousands of lives, before London authorities woke up to the need for a more effective waste disposal system. In the course of their enquiry, the city's engineers were appalled by the lack of drainage. According to one, hundreds of streets, courts and alleys lacked any drains or sewers and "how the miserable inhabitants live in such places, it is hard to tell...".

Other cities were affected by cholera outbreaks as well and responded by constructing new sewerage and water main systems. In 1856 the Berlin water works were built, in 1870 Vienna constructed its new system, and in 1874 Rotterdam, Frankfurt and The Hague followed suit. Still, there was no guarantee for safe drinking water. A satirical Hamburg pamphlet listed 16 types of vermin to be found in the city's drinking water- among them lampreys, stickle-backs, eels, worms, mussels, snails, fungi, lice, polyps, and dead animals such as dogs, cats and mice. "Not yet found, and that's a pity, are the architect and the engineer", it concluded.

The Industrial Revolution also added new and more industrial waste products to Europe's already overburdened rivers. In England, soda manufacturers produced a waste product known as black ash, which consisted mostly of calcium sulfide. Enormous amounts of it were dumped on the banks of the Mersey and into the North Sea, without regard for the consequences. Chemical factories discharged all of their waste products in rivers as well. Pollution became such a problem that iron boats could no longer navigate Sankey Brook in northwest England because the chemicals in the water threatened to corrode and dissolve the plating of the ships.

Conditions on the continent were equally disastrous. During the early 19th century Germany's chemical industry, responding to the needs of its growing textile industry, rapidly expanded and began experimenting with new products. Factories in and around Berlin and Frankfurt set the stage for Germany's chemical prowess, but they did so at a heavy cost to the surroundings. The river Main, which once teemed with fish, had become a chemical dump. "Gas bubbles up which explodes in bright white flames when it comes into contact with fire", reported the Frankfurter Zeitung in 1870.

With more waste, some of which toxic and persistent, being discharged in ever increasing quantities, this attitude inevitably led to effects on the ultimate sink of all waste: the sea. Not only did all rivers eventually deposit their pollution load in it, the sea was also being used for the direct disposal of waste and accumulated atmospheric pollutants. For some time, the ocean seemed to absorb this increased waste load, but it was clear that this could not go on forever.

It took some dramatic incidents before we noticed.

Minamata is a small coastal town on the Japanese island of Kyushu. Until the mid-1950s, most of its people lived off the sea, as their ancestors had for many generations, fishing the waters of Minamata Bay and beyond. Others farmed the gentle hillsides. And in 1907 the town's leaders managed to convince the founder of the Chisso Corpora-

*The fishing port of Minamata. A peaceful setting now, but it was here that the world received the first major warning about the dangers of marine pollution, not only for the sea and its inhabitants, but also for the people living off it.*

tion to build a chemical factory in Minamata. Everyone felt the "winds of prosperity" had arrived. Their feelings appeared confirmed when the factory continued to expand, providing Minamata with employment and a much broader economic base.

It was in this peaceful setting that the world received its first serious warning about the dire consequences of irresponsible marine waste disposal. The first signs came in the early 1950s, when dead fish began washing ashore. Shortly thereafter the town's cats became affected by a bizarre affliction that sent them into convulsive spasms. At first it appeared rather curious and even comical, and the animals' strange behavior became known as the dancing cats disease. But between 1953 and 1956 symptoms also began appearing in fishermen and their families.

By 1956 the disease had taken on epidemic proportions. Local doctors were dumbfounded. They had never seen anything remotely like it. The patients, to greater or lesser extent, shared difficulties in speaking and walking; they had severely constricted vision; and were prone to convulsions. Something was interfering with their nervous system, but no one, not even the experts from a local university, had any idea what it was. More importantly, no one knew what was affecting so many people at the same time.

If there was a clue, it was in the sea. All patients became ill after eating fish. The cats also ate fish, so the dancing cats disease and what was now known as the Minamata disease were probably one and the same thing. Meanwhile, more people had become affected and several had died. Autopsies revealed severe brain damage, including a reduction of neurons and brain cells. A Minamata disease study group was set up to examine what substances could cause these symptoms. Heavy metals were suspected, but none of the ones tested – selenium, manganese and thallium – evoked the same response. But in 1959 a member of the study group came across a British research report on poisoning by methyl mercury, an organic compound far more toxic than inorganic mercury. Its symptoms matched those of the Minamata patients, who numbered more than 200 by now,

*Tomoko Uemera in her bath, a photograph by American photographer Eugene Smith, is one of Minamata's most powerful images. Taken in 1971, it shows Ryoko Uemera bathing her severely deformed daughter, one of hundreds of Minamata victims. Tomoko died in 1977. Smith, who was at one point attacked and injured whilst working in Japan, died one year later (copyright Uemera family).*

including several infants which had been poisoned prior to being born.

Everything began to fall into place. There was only one possible source of methyl mercury in Minamata Bay: the Chisso factory. Just a few years earlier, the plant had begun to mass produce acetaldehyde and vinyl chloride-- two compounds used in the plastics industry. The production process required mercury compounds as catalysts, which led to the formation of some methyl mercury. Along with the company's other chemical waste, it was poured into Minamata Bay. There the toxin was concentrated by filter feeders like oysters, and by fish and crustaceans which pumped the contaminated water through their gills. When people ate the contaminated seafood, the methyl mercury was passed on, accumulating to

## HEAVY METALS

Heavy metals like copper, zinc, cadmium, mercury and lead reach (or reached) the ocean through every possible means of industrial disposal: outfalls, rivers, runoff, dumping and the atmosphere. Their effects on marine organisms depend on a wide variety of factors, but some generalizations can be made. First, all heavy metals are toxic to varying degrees. It is also known that the toxicity of the metal depends on its physicochemical state. Organic lead and mercury, for instance, are much more toxic than the corresponding inorganic compounds. Toxicity also varies by species and developmental stage. Generally speaking less developed and younger life stages are more susceptible to heavy metal contamination than adult organisms.

In addition, all heavy metals are persistent. They are, in fact, not destructible and can be accumulated by some organism to lethal levels. In some instances bioaccumulation will not affect the organism itself but its predators. Mercury levels in swordfish and some species of cetaceans, for example, are very high, though the high metal burden in these animals is not always the result of pollution. Most people do not consume enough seafood to be seriously affected, but heavy metal contamination can be a problem for population groups that regularly consume fish or shellfish, as was dramatically demonstrated in Minamata.

Heavy metal pollution is well documented, but the picture remains incomplete. A good portion of the data indeed focuses on acute toxicities, leaving unknowns in the understanding of sublethal, chronic and synergetic effects. Moreover, experiments tend to be conducted in a laboratory, not at sea. While more practical, the resulting data may fail to convey what happens in the infinitely more complex oceanic environment. As a result, some data may overestimate effects; others may very well underestimate the potential impact.

Given the highly publicized effects of heavy metal contamination on human health, the disposal of these substances has been effectively regulated. Isolated cases of heavy metal pollution in the sea may still occur, especially in developing regions or previous dumping sites, but generally speaking the issue is now less of a concern than marine pollution caused by organic waste like sewage or some persistent organic chemicals.

lethal levels. In the end, more than 120 people died. Hundreds more would have to live with the consequences, unable to lead anything close to a normal life.

Minamata made clear for the first time that when the sea is severely affected by pollution, so are its inhabitants and the people that live off it. But the lesson was slow to sink in. Minamata's fishermen suspected that the Chisso Corporation was responsible for the strange disease, but in absence of conclusive evidence the company refused to admit any wrongdoing. Chisso continued to pour waste into Minamata Bay until well into the mid-sixties, more than ten years after the first victim was diagnosed.

The treatment of the victims and their families was even more depressing. With the support of the local government, Chisso intimidated the fishermen and forced them to accept a small settlement. It took a highly publicized and emotional trial to finally bring justice to bear. Delivered in March of 1973, the verdict found Chisso guilty of negligence and forced the company to pay more adequate compensation. In a country where big business and the government traditionally dictate the rules, this was an historic judgment. But money could no longer compensate for the harm that had turned Minamata from a peaceful fishing town to a place in agony.

Minamata was by no means the only major incident. From the early 1960s onward, marine pollution issues began to appear regularly in news headlines. Moreover, they increasingly involved new and persistent substances.

Synthetic pesticides like DDT, invented just a few decades earlier, had been hailed as the solution to a host of agricultural problems. They were inexpensive, easy to use, and very potent. DDT in particular appeared effective in wiping out all kinds of pests. In the spirit of the times some called it a "nuclear bomb against insects" and asserted it would lead to a pest-free world. Chemical manufacturers throughout the world intensified their efforts to make that promise a reality.

At first pesticides led to spectacular successes by increasing farm yields and helping to control diseases spread by


*Believed to be harmful only to insects, DDT was liberally sprayed not only on fields, but also on beaches, in streets, schools, swimming pools and anywhere else people might benefit from a "healthy" dusting. It took Rachel Carson's 1962 book Silent Spring to make clear that DDT harmed not only insects, but all of the environment.*

insects, like typhus (carried by lice) and malaria (carried by mosquitoes). But soon they showed a darker side: insects began to develop defense mechanisms, requiring stronger doses or more toxic substances to control them. More importantly, most pesticides were very slow to degrade. As a result, their levels began to accumulate not only in plants and animals, but also in people.

This growing menace was first brought to the world's attention in Rachel Carson's Silent Spring. Published in 1962, the book detailed the harm done by pesticides and implied that they could turn into uncontrollable poisons. It led to stricter controls on pesticides, particularly in the United States, but these could no longer prevent a number of incidents. The levels of pesticides that accumulated in birds, for instance, caused females to lay eggs with extremely thin shells, which failed to hatch. The results were tragic. Falcons, ospreys and bald eagles were decimated. To bird-loving Americans, there couldn't have been a stronger warning that pesticides carried a far heavier price tag than anyone could have imagined.

Even the oceans were affected. Pesticides were not intended to show up in the sea, but invariably they did. Massive quantities entered the oceans through rivers, aerial transport and especially run-off from sprayed fields. There, like methyl mercury in Minamata Bay, they slowly accumulated, from one level of the food chain to the next. Fish eating birds like pelicans concentrated the toxins and failed to reproduce. Entire pelican populations in California and Louisiana were decimated, showing that not even the vastness of the ocean could absorb the immense pesticide load. What had started with the best of intentions seemed to have turned into a problem of phenomenal proportions.

At the same time, there was growing concern over the uncontrolled release of artificial radionuclides from energy installations and nuclear test explosions. Between 1952 and 1958, nuclear tests produced more than 4.5 million tons of fission products, most of which fell out over the oceans. In some cases nearby atolls were affected, forcing the evacuation of the islanders, but in general the fallout was evenly distributed and concentrations remained small. Even so, they could be detected in marine organisms from plankton to sharks, making clear that this form of pollution required close monitoring.

Of more immediate concern to scientists and the public was the amount of radioactivity entering the oceans from power and reprocessing plants because this input was localized, and therefore more dangerous. Nuclear power installations produced several types of waste products, including effluents, contaminated solid materials and spent nuclear fuel. There were only two ways to dispose of them: containment and discharge. The first was used to isolate high-level radioactive materials like contaminated solid materials; the second was applied to disperse and dilute low-level waste, in the hope that this would render it harmless.

## PERSISTENT ORGANIC POLLUTANTS

Chlorinated hydrocarbons are a class of synthetic chemicals that came into widespread use in the mid-20th century. Chlorination generally increases the stability of hydrocarbons to both chemical and biological degradation. Many chlorinated hydrocarbons are thus very stable and persistent, which is great for some applications but bad for the environment. For this reason, they are also commonly referred to as persistent organic pollutants or POPs. The most important POPs include organochlorine insecticides, most of which now banned, and the polychlorinated biphenyls or PCBs.

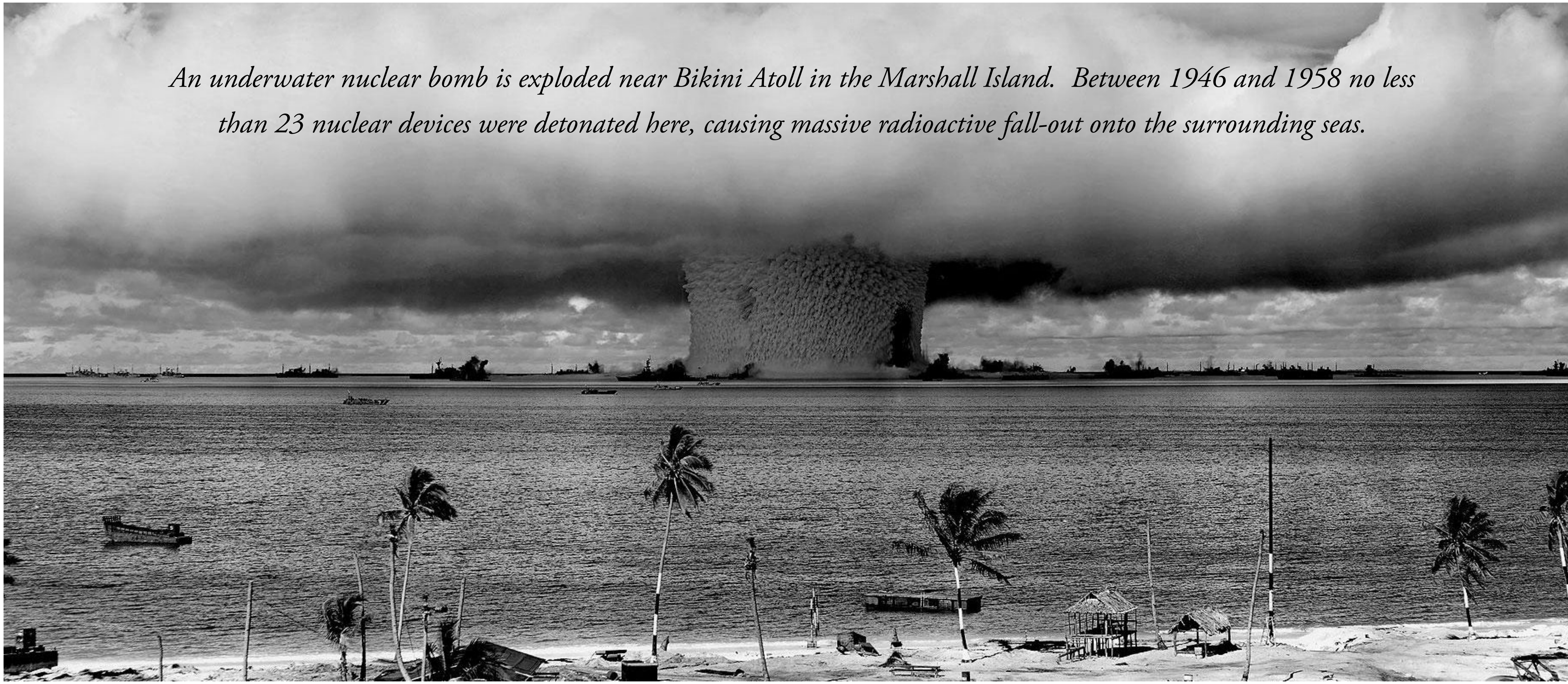
Chlorinated hydrocarbon compounds like DDT, Dieldrin, Endrin and Aldrin were used on a wide scale as insecticides. These compounds reach or reached the sea primarily through aerial transport, but significant amounts were also present in domestic and industrial effluents and especially agricultural runoff. Once in the sea, organochlorine insecticides are concentrated in sediments and in marine organisms. Since they are capable of dissolving in lipids, they are particularly concentrated in oily materials or fatty tissues. They are therefore found predominantly in animals with a high fat content and animals higher up in the food chain.

Restrictions on the use of DDT resulted in a corresponding increase in the use of insecticides like Aldrin and its by-product Dieldrin, as well as toxaphene. These compounds were even more toxic than DDT, but their residence time in the marine environment was considerably shorter. Most of these substances have been placed on the Stockholm Convention's Dirty Dozen list – an international blacklist of chlorinated compounds which are supposed to be phased out entirely, though DDT is still used in some countries for malaria control.

The second major group – the polychlorinated biphenyls or PCBs – are a group of extremely stable, fire-resistant chlorinated hydrocarbons. These properties made them ideal insulating fluids in electrical equipment like high-power transformers and capacitors. They were also used in paints, sealants, lubricant additives, hydraulic fluids and heat exchange fluids. PCBs are also included on the Stockholm Convention's Dirty Dozen list. Member states have until 2025 to phase out all PCB-containing equipment.

PCBs reach the ocean primarily through adsorption to fine particles in rivers and, to a lesser extent, by airborne particles. In spite of the production ban, they remain widely spread throughout the ocean as a result of their persistence. There is strong evidence of high chronic toxicity, which simply means that it may take anywhere from a few weeks to generations before effects caused by low-level exposure appear. Commonly observed effects in marine organisms include a reduction in reproductive capacity, diminished immunological capacities, as well as learning and behavioral deficiencies. As with organochlorine insecticides, PCBs concentrate in body fat and accumulate from one level of the food chain to the next, a process known as bioaccumulation or bio-magnification.

Human health effects resulting from (low) PCB levels include abnormal fatigue, abdominal pain, numbness, coughing, acne and headaches. There is considerable evidence that PCBs are carcinogenic, though no such link has been established as a result of PCB levels in the marine environment. Human health effects are mostly likely to be caused by elevated PCB levels in food, particularly meat, fish and poultry. As a result on the ban on PCB production, these levels are steadily declining but PCBs will remain with us for a long time to come.



*An underwater nuclear bomb is exploded near Bikini Atoll in the Marshall Island. Between 1946 and 1958 no less than 23 nuclear devices were detonated here, causing massive radioactive fall-out onto the surrounding seas.*

From the moment nuclear power plants appeared in the 1950s, the sea was used as a site to dispose of low-level waste. But uncertainties surrounding its health effects made this a controversial practice, raising questions not only in regard to the disposal options but in regard to the entire nuclear energy program. For some time the deep sea was considered for contaminated materials as well, the idea being that high-level contained waste could safely be lowered in it. But this suggestion was quickly shelved. High-level waste indeed needs storage more stable and easier to monitor than the ocean, even in its deepest reaches, can provide.

Nonetheless, it was not the heavy metals, nor the pesticides or even the radionuclides which received the greatest exposure. No matter how dangerous, all of these substances had the tendency to disappear in the sea without a trace, and most never showed any immediately noticeable effects on animals. But there was one substance which left a very visible mess when it entered the ocean.

The 1960s witnessed an enormous growth in the consumption of oil throughout the world. Most of it had to move by sea, and was carried from production to consumption sites not only in more, but also in larger ships. Between 1956 and 1966, the maximum size of tankers increased ten-fold, to well over 300,000 tons. Not all of these ships were well built or adequately manned but, in an oil-hungry world, that seemed to be the least of anyone's concerns.

Patrengo Rugiati was the proud captain of one of the first of these supertankers. His ship was the Liberian Torrey Canyon -- at 117,000 dwt. one of the largest ships afloat. The morning of March 17, 1967 found her near the Scilly Isles, some 25 miles west of Land's End, on the last stage of a voyage from the Persian Gulf to Milford Haven in Wales. But there had been a strong wind that night, and the ship was further north than Rugiati or his officers suspected. Early in the morning, the officer on watch picked up the Scilly Isles on the radar, allowing him to determine a precise position. Interestingly, the islands showed up to the ship's left, not to her right, as they should have been.

This should not have been too much of a problem, but Captain Rugiati took his time to make the needed course corrections. To be fair, nearby fishing vessels prevented him from turning a couple times, but gradually it began to dawn on him that the ship was much further north than suspected, and that she was rapidly approaching the rocks of the Seven Stones Reef. Rugiati ordered his helmsman to come hard left but by then it was too late. Within minutes the ship came to a grinding halt on a submerged rock. Almost immediately oil began to flow from the ruptured hull. The world was about to find out what a massive mess a combination of bad weather, constricted waters and a huge hull filled with oil could create.

Despite truly heroic efforts to save the Torrey Canyon, they proved in vain. Virtually all of the ship's 117,000 tons of oil escaped, and within days reached the beaches of southern England and Brittany. No one was prepared for a calamity of this nature. Large volumes of detergents were sprayed in an attempt to dissolve the oil, but they turned it into a thick sludge, which was even harder to remove from the affected coastal areas. Naval bombers were sent in to bomb the ship and its remaining cargo, in the hope that it would burn off the oil, but that too failed. Every attempt to somehow limit the effects of the disaster proved fruitless. In the end, the Torrey Canyon was bombed and sunk, but her legacy would last forever: the first warning, so to speak, on the environmental dangers of supertankers. Unfortunately, she would not be the last.

To be fair, the warning did not go unheeded. A number of commissions studied the Torrey Canyon incident in order to propose measures that could help prevent tanker disasters or, at the very least, limit their consequences. They revealed the appalling lack of preparation prior to the accident. No one had expected something like this, or anticipated its impact. They also made clear some lessons could be drawn from the accident. Detergents should not be used, it was concluded, because they killed far more marine life than the oil itself. Instead, the oil should be burned off. It was also recommended that the oil should be contained to the extent possible, using booms or other devices. Of course, while fine in theory, no one knew whether any of these would work at sea under difficult conditions.

New international measures were adopted as well. Prior to the Torrey Canyon, no one was certain whether a country could bomb a ship from another country that posed a threat to its coastline. The Convention relating to Intervention on the High Seas solved the dilemma, permitting coastal states to take any measures needed to eliminate dangers to their coastline. And what about compensation? Suppose you had a ship like the Torrey Canyon, owned by an American corporation but leased to a British company, built in the U.S. but rebuilt in Japan, registered in Liberia, insured in London and crewed by Italians damaging the coast of France and Great Britain? Who should be sued to recover damages? A new international agreement on liability was concluded to address this and similar compensation issues.

Other international agreements sought to prevent accidents, rather than treat them. New construction standards were proposed, for instance, reducing the size of the tanks and the rate of the oil's escape in case the hull was damaged. To do away with the incompetence that had been demonstrated on the bridge of the Torrey Canyon, a revised set of training regulations was proposed and adopted. They came

*The 1970s saw a long succession of tanker oil spills. Among them the Argo Merchant's sinking off the American northeast coast stands out as the pinnacle of incompetence: unqualified helmsmen, outdated charts and malfunctioning navigation equipment caused the vessel to run aground more than 40km off her intended course. The only thing that went right was the wind: it blew its spilled cargo of oil to sea rather than onto the coast.*

## OIL

Oil is one of the most publicized forms of marine pollution, in no small part as a result of the visible mess it creates. But it is not just accidents that are of concern as two landmark studies confirmed. The first was undertaken by the U.S. National Academy of Sciences (NAS) in 1975, and concluded that every year approximately 6.1 million metric tons of oil entered the ocean at that time, with tanker accidents and offshore drilling contributing 200,000 and 80,000 tons to the total. These estimates quickly proved too low because in subsequent years tanker mishaps released considerably more than that at sea. Still, the NAS study correctly pointed out that far greater amounts of oil were released by less spectacular sources like routine vessel operations and runoff from land.

Some 30 years later, the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) produced a similar study, allowing for interesting comparisons. By the late 20th century, the total amount of oil entering the marine environment from sea-based activities was estimated to have fallen to a total of 1.25 million metric tons, with nearly half of that coming from natural seeps. The GESAMP total did not include oil from land-based sources but concluded that the input of hydrocarbons from human activity at sea had fallen by some 80 percent over the last quarter of the century, in no small part as a result of much more stringent measures imposed (and enforced) on shipping.

Like its predecessor the GESAMP study underestimated some inputs, relying on figures prior to 2000, when the offshore industry actually did quite well in terms of limiting oil spills. That record and the corresponding image was torpedoed by the blow-out on the Deepwater Horizon platform in April of 2010, which added more than 700,000 tons of oil to the Gulf of Mexico over a three-month period: 35 times the amount the study had allocated to offshore sources. In spite of this the 2007 GESAMP study is still considered to be representative, at least as far as the marine transportation portion is concerned.

Even in reduced quantities hydrocarbons will have effects. When oil enters the sea, it tends to spread relatively rapidly. Some of the lighter fractions will evaporate immediately, while heavier compounds will be dissolved or sink. Most of the dissolved oil will slowly be degraded or metabolized by bacteria; the fractions that sink will persist much longer because deeper waters have lower temperatures and lower oxygen concentrations. In fact, once into the sediments, degradation may come to a halt if and when the sediments are anaerobic. There are justified fears that much of the oil spilled by the Deepwater Horizon blow-out will do exactly that.

The most visible effects of oil pollution are on intertidal benthic communities and bird populations. But here too the problem is not only a matter of determining the immediate (visual) effects but also of assessing sublethal and chronic effects. These may range from the gradual poisoning of certain organisms to a total disruption of the ecosystem, caused by the destruction of the more sensitive younger life stages or the elimination of food supplies of higher species. Last but not least, oil pollution interferes with other ocean activities like fishing, mariculture and especially recreation. Which probably explains the publicity...

too late for Captain Rugiati, who lost his license as a result of the ship's loss. A Board of Investigation appointed by the Liberian Commissioner of Maritime Affairs concluded that he alone was responsible for the accident.

To some extent, these measures made tankers safer and probably cleaner, but they could not prevent accidents altogether. In fact, as the number of tankers increased so did the number of mishaps, especially during the 1970s when the volume of oil transported at sea grew dramatically. Among them was the largest coastal oil spill to date.

It took place eleven years after the Torrey Canyon grounding, on the other side of the entrance to the English Channel. This time it involved an even larger tanker: the Amoco Cadiz, at 230,000 dwt twice the size of the Torrey Canyon. Like her predecessor she was registered in Liberia and, as chance had it, headed by another Italian: 35-year old Pasquale Bardari, on his first voyage in command. The vessel was on a voyage from the Persian Gulf to Rotterdam, a trip that would have taken her through the Channel and Strait of Dover into the southern North Sea. But the Amoco Cadiz never made it that far.

On the morning of March 16, 1978 her steering gear broke down, about nine miles north of the small island of Ushant at the entrance of the English Channel. To make matters worse the weather was appalling, with gale-force winds blowing the ship onto the rocky shore some 15 miles distant. There was absolutely nothing Bardari could do but call for help, and hope it arrived on time.

As it turned out, there were several deep sea tugs in the vicinity of the helpless ship, one of which arrived within a couple hours. Unfortunately, for the next hour and a half Bardari and his counterpart on the tug bickered over the conditions of the tow, causing the Amoco Cadiz to drift several miles closer to the coast. When they finally agreed, it was blowing a full gale, making it increasingly doubtful whether the tug could pull the massive tanker to safety.

Sure enough, as soon as the tug began to pull full force, the towing line snapped, and more time was lost to pass and secure a second line. By then it was becoming clear that the tug was not able to make sufficient headway. In fact, both ships continued to drift towards the shore, and around 9:00 P.M. the Amoco Cadiz grounded. A set of swells lifted her off the rocks, but only to take her further inshore. By 10:00 P.M. the vessel was stuck. She grounded precisely at high tide; the worst possible time to do so. Within minutes oil began to flow from her damaged tanks. When the vessel broke in two early the next morning, France woke up to the worst tanker pollution disaster the world had ever known.

Over the next two weeks, more than 220,000 tons of oil flowed from the stricken vessel, coating the beautiful Brittany coast in a thick black mass of crude. The area's economy was devastated; its famous oyster beds and fisheries were destroyed; its tourist season ruined before it had even begun. Once again, local authorities found themselves utterly unprepared. In the wake of the Torrey Canyon incident France had devised an oil spill response plan, but it had never been tested and envisaged a spill of no more than 30,000 tons. Here, all of a sudden, the country was faced with a spill more than seven times that size.

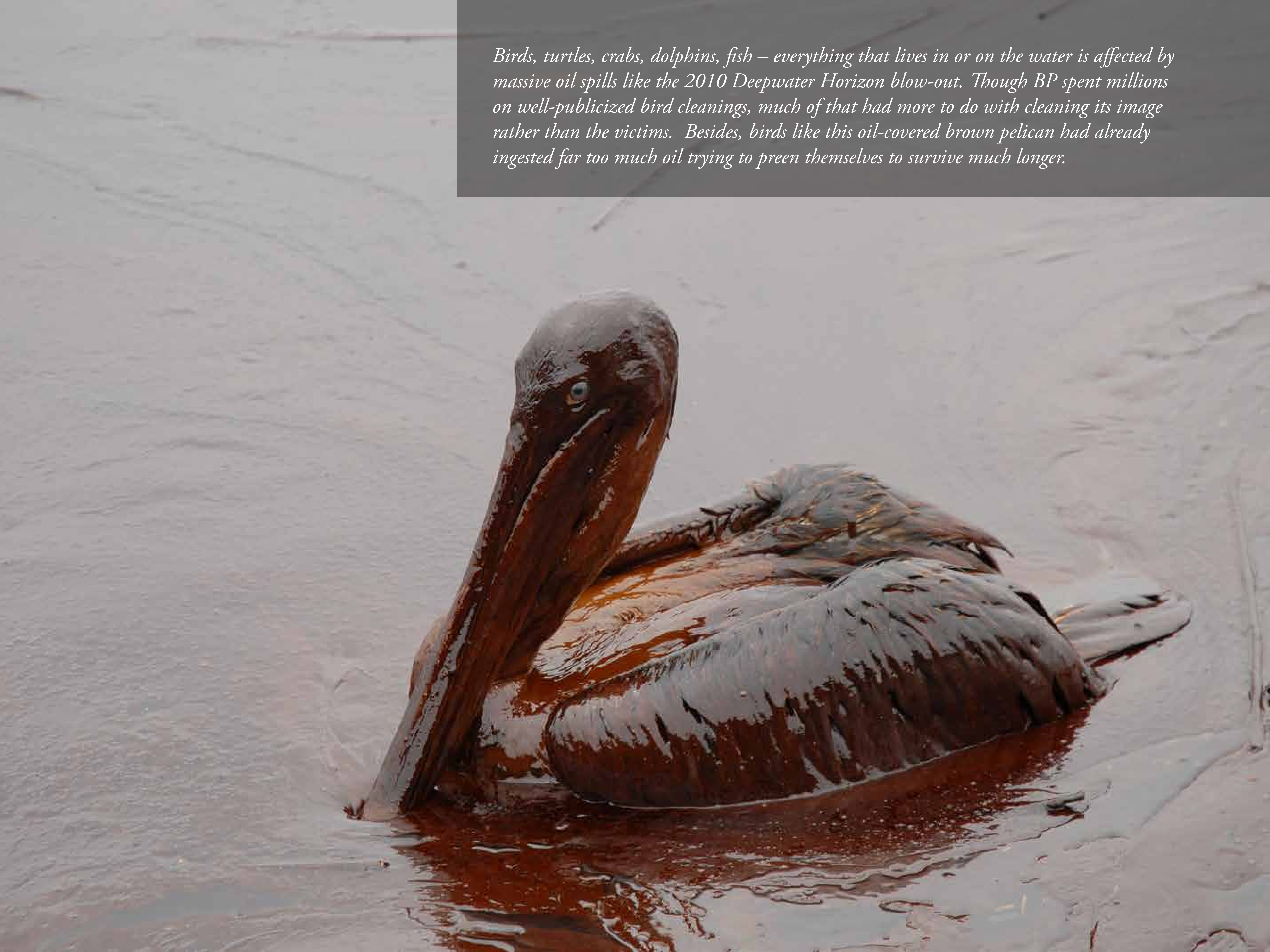
To cope, the French government decreed the accident a national disaster. Thousands of troops were called in to mop up as much of the gooey mess as possible. It was a painstakingly slow process. In fact, the clean-up effort was nicknamed Operation Teaspoon, for many of the cleaners were literally scraping the oil off the rocks by the spoonful.

As before, the Amoco Cadiz loss spawned a wide range of recommendations and measures. Some were designed to improve the steering gear, for instance, so that there would be a back-up to the failure that caused the accident. Others increased compensation schemes, or focused on additional structural standards. Bardari received some of the blame as well, especially for the inexcusable delay in agreeing to the conditions of the tow. Almost twelve hours had passed between the steering gear's failure and the ship's grounding. Experts agreed that this should have been sufficient to tow the ship out of danger. Then again, it was realized that a novice captain could not be expected to take such the decisions by himself. Bardari was probably waiting from instructions from Amoco headquarters.

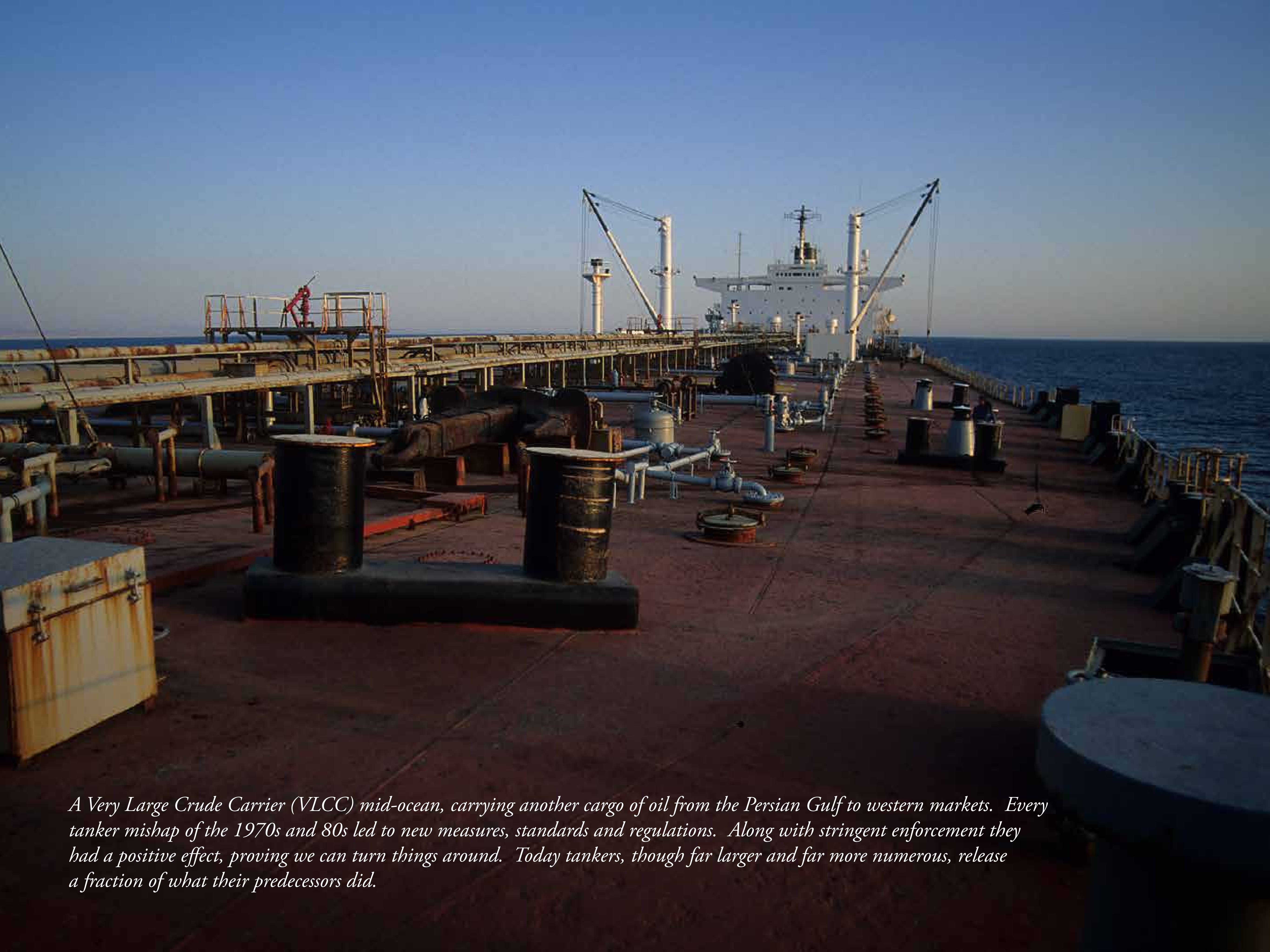
Though some of the measures had an effect, they couldn't prevent all accidents, and the Amoco Cadiz would be followed by many others. Every single one reminded the world of the environmental dangers posed by tankers. Invariably thousands of sea birds perished in the resulting slicks, and their plight became international news. Who could possibly forget the pictures of oil soaked birds making pathetic attempts to leave the slick and live? This was news and more importantly, it could be shown. What we were doing to the oceans all of a sudden had become very visible.

Events such as Minamata, the decimation of pelican populations by pesticides, and the grounding of the Torrey Canyon and her many successors caused public outcries. The concerns were justified, because these incidents had been caused by people and could theoretically have been avoided. Furthermore, by showing that there were real side effects to the oceans' use as a waste dump or a highway, they lent credibility to the growing feeling that there was a limit to how much abuse the sea could absorb.

In response, several measures were taken. Once Japan had figured out the link between mercury and the dreaded Minamata disease, the levels of mercury allowed in industrial waste were curtailed. Similarly, the use of DDT and other pesticides was restricted in many industrialized nations, following proof of their effects on non-target organisms. Radioactive effluents were placed under strict controls as well, though environmental organizations argued that more could and should be done. And the avalanche of international measures that followed the grounding of the Torrey Canyon and her successors not only helped reduce accidental oil discharges but also operational pollution, which was by far the largest single source of oil in the sea until that time.



*Birds, turtles, crabs, dolphins, fish – everything that lives in or on the water is affected by massive oil spills like the 2010 Deepwater Horizon blow-out. Though BP spent millions on well-publicized bird cleanings, much of that had more to do with cleaning its image rather than the victims.  Besides, birds like this oil-covered brown pelican had already ingested far too much oil trying to preen themselves to survive much longer.*



*A Very Large Crude Carrier (VLCC) mid-ocean, carrying another cargo of oil from the Persian Gulf to western markets. Every tanker mishap of the 1970s and 80s led to new measures, standards and regulations. Along with stringent enforcement they had a positive effect, proving we can turn things around. Today tankers, though far larger and far more numerous, release a fraction of what their predecessors did.*

The results of these actions were positive. Mercury and pesticide concentrations in the marine environment dropped, at least in countries which adopted and enforced the limits. The regulations on the discharge of radioactive nuclides limited the effects on human health. And the international measures designed to curb oil pollution slowly but surely helped reduce the amounts of oil that entered the oceans, from ships as well as from offshore oil installations.

These were encouraging signs, but there were reasons for their success. In all instances, there was a clear source of pollution, or culprit if you wish. In Minamata it was Chisso's effluent pipes; radioactive wastes were released by nuclear power plants or reprocessing installations; and accidental and operational oil discharges came mostly from ships. Moreover, in each of these instances, there was a very clear cause-effect relationship between pollutant and victim. The methyl mercury discharged in Minamata Bay killed and grossly disfigured humans; DDT interfered with the reproductive processes of many animals and unquestionably had effects on humans as well; radioactive materials could cause genetic and somatic changes; and oil killed birds. It also killed many other organisms but birds, it seemed, triggered public emotions far easier than fish or sea urchins.

These were, and are, important steps, but there is little reason to assume the battle has been won. In the years since, the amounts of waste we produce have grown immensely. Volumes of domestic waste, for instance, have taken on phenomenal proportions. Most countries require some sort of sewage treatment, but coastal communities throughout the world often discharge their effluents into the sea untreated. Where this waste is quickly dispersed and introduced in reasonable quantities, this practice does not necessarily create a problem. But many inland and coastal waters have become overburdened, causing bathing and shellfish waters to be closed as a result of excessive concentrations of pathogens or creating phytoplankton blooms caused by high amounts of nutrients. When these blooms taper off, the biodegradation of the plankton often causes oxygen depletion, causing fish kills and other changes in the local ecosystem.

*Chinese soldiers remove seaweeds from the coast, in hopes of preventing further deterioration. If left unattended, the seaweeds would die and decompose, reducing the water's oxygen levels and possibly creating a dead zone.*

## SEWAGE

Liquid domestic waste (aka sewage) contains dissolved material from kitchens, laundry rooms and bathrooms. Wastewater from kitchens contains carbohydrates, fats and proteins along with small amounts of other waste. Waste from laundry rooms consists of small amounts of sand, dust, traces of oil, fats, textile and microfibers, as well as different kinds of soaps and detergents. Finally sewage may also include the effluents from bathrooms.

Before discharge these wastes can be treated to protect the environment. Treatment may include removal of solid matter (sludge) and suspended particles, the oxidation of polluted organic material, sterilization of the effluent and removal of nutrients. As the cost of purification increases with each successive step, in many instances only the first one or two steps are taken. Moreover, many communities near the sea, especially in developing nations, discharge sewage without any treatment at all.

The effects of this discharge on the marine environment depend on a variety of factors but some generalizations can be made. Sewage contains large amounts of organic material which will be broken down. The primary effect of this breakdown (or biodegradation) is a reduction of the available oxygen in the water. The second effect is caused by the increased amounts of nutrients that are released by the breakdown of organic materials, which can lead to eutrophication. In this process the high fertility of the water permits rapid and excessive growth of phytoplankton. Initially oxygen is overproduced but at the termination of the bloom the decomposition of the algae reduces dissolved oxygen levels even further, causing mortality among fish and other organisms.

Eutrophication has been observed in estuaries and along the coast, where it can create hypoxic or "dead" zones. There are hundreds of such zones in coastal areas, ranging from very small to tens of thousands of $km^2$ in size. Once considered a rare phenomenon, the spread of dead zones in coastal waters has alarmed scientists. Surveys reveal, for instance, that there were less than 50 dead zones in the 1960s, 87 during the 1970s and 162 during the 1980s, confirming a near-doubling in the number of hypoxic zones every decade.

Untreated sewage also contains large amounts of bacteria and viruses. Exposure to contaminated water or consumption of contaminated seafood can lead to gastrointestinal disorders like cholera, typhoid and infectious hepatitis. A study by the World Health Organization (WHO) estimated that bathing in polluted seas causes some 250 million cases of gastroenteritis and upper respiratory disease every year. Using the Disability Adjusted Life Year (DALY) measurement, which reflects the number of years of healthy life that are lost as a result of a disorder, the study estimated a cost to society of at least 400,000 DALYs -- comparable to the global impact of diseases like diphtheria and leprosy. The societal cost of contaminated seafood consumption is an order of magnitude larger, with estimates ranging from 3,500,000 to 7,000,000 DALYs. According to the WHO, sewage contamination leads to at least 2.5 million cases of infectious hepatitis each year. Some 25,000 of the people affected die as a result, with at least another 25,000 permanently crippled by liver damage. These are frightening numbers, causing the WHO to call the microbiological contamination of the sea a health crisis with massive global implications.

*Japan Maritime Self-Defense Force personnel in protective suits cautiously approach the crippled Dai-ichi nuclear plant in Okuma, Fukushima Prefecture on 31 March 2011, 20 days after the devastating tsunami. Radioactive isotopes from the stricken reactors were later detected all the way across the Pacific in water samples along the US West Coast, fortunately in c oncentrations no longer harmful to (most) marine life.*

The amount of industrial waste has grown as well, and every year it includes new compounds, developed by the chemical industry in response to the demand for new synthetic products. Some of these compounds end up in the ocean, often without anyone knowing their effects. In some cases there are clear cause-effect relationships which can be confirmed in laboratory tests. But a single substance can have differing effects on a variety of organisms, or even on the various life stages of a single animal. A single substance can also lead to sublethal or chronic effects, which are difficult to determine or, even more perplexing, antagonistic or synergistic effects caused by two or more substances interacting with one another. The effects of industrial pollutants on the sea and its inhabitants, in short, remain very poorly understood.

The regulatory bureaucracy set up to control these waste disposal practices has not always been effective at handling a problem of this complexity. For one thing, it is relatively slow and thus unable to cope with the rate at which new problems and challenges emerge. For another, it doesn't always receive the priority it deserves, with issues like economic growth and employment taking precedence and relegating environmental concerns to the background. Finally much of government functions in a compartmentalized manner, with different departments or ministries handling different issues. But effective pollution control requires some level of integration because all marine activities- offshore oil development, tourism, transportation, fishing and waste disposal- affect the marine environment.

Some industrialized nations have implemented more effective regulatory systems. Unfortunately, these efforts are not universal and have not been matched by developing countries because environmental protection is expensive and developing nations tend to have a different set of economic priorities. There compounds like DDT, long since outlawed in most industrialized countries, remain in use. This is a global problem because persistent pesticides have long residence times in the ocean and currents carry them along for great distances. In that sense, the ocean is a bit like soup boiling in a kettle. The spices put in by one nation are eventually tasted by all others.

There are no easy solutions to these problems. On the one hand, more waste is continually being generated and, aside from recycling, the disposal options are limited to land, water and air. Halting waste disposal in the sea could, in other words, aggravate pollution problems on land and in the air. Besides, it would not necessarily be the best way of going about these things because the ocean has the capacity to absorb certain waste products. Domestic sewage, for instance, is rapidly dispersed and broken down in the sea. Provided its release is properly regulated and monitored, the ocean may provide the best disposal option.

Other waste products are better stored on land or dispersed in the atmosphere through incineration and are regulated accordingly. Unfortunately, through rivers, run-off or the atmosphere, they arrive in the sea anyway. Sometimes the effects are known, often they are not. Substances designed to replace outlawed compounds are sometimes found to be more harmful. Poorly known long-term effects begin to appear and what is safely disposed in one area creates serious problems in another. To complicate matters, there is an impressive lack of information on the volumes and pathways of these substances. It is not a matter of science failing us; the magnitude of the problem simply defies a complete inventory.

If there are any generalizations to be made, it is that we have gone too far in some regions. Growing amounts of plastics are now being observed mid-ocean, carried and concentrated there by ocean currents. In this case the problem is not caused by "industry" or some other nameless culprit. Plastics end up in the sea because a lot of people do not care what happens to plastic bags and other packaging after they have used them. The amounts of oil in the open ocean, on the other hand, appear to have decreased, in no small part as a result of increasingly stringent regulations. Of course, some ships still disregard the rules but it is clear that there are far fewer infractions even though the number of ships worldwide has increased considerably.

*A beach in Crete. At first glance, a superb place to enjoy the ocean. Many people do exactly that, as is clear from what they leave behind. All the pictures on p. 316 were taken just a few hundred meters on either side of this idylic spot, some within sight of a trash container. It used to be convenient to blame the industry for the sea's deterioration. Many people, it turns out, behave even more irresponsibly.*

## PLASTICS

Just when we managed to curtail chronic (or operational) oil pollution from ships, we are replacing one oil-derived form of pollution -- weathered oil globules known as tar balls-- by another one: plastics. Aside from their source, both forms of pollution share a measure of visibility: tar balls polluted beaches and oceans during the second half of the past century; all kinds of plastics do so increasingly today. Also in both instances, what is not visible is more of a concern than what washes up along the shore.

There are important differences as well, especially in terms of the perpetrators. A good deal of the oil entering the oceans was the result of tank washings by oil tankers, meaning the polluter could be identified. While that was not necessarily always done or even feasible, tankers were subsequently targeted and regulated to the point where they now (should) release no more oil at sea than any other commercial vessel. Strong measures along with strong enforcement has seen to that. One small victory in the struggle to keep our oceans clean.

Marine plastics pollution, in contrast, is caused by millions, or rather hundreds of millions of smaller sources: people who go to the beach and leave their trash, or people who discard plastics like bags or wrappers or plastic utensils without bothering to dispose of them properly. Even responsible consumers contribute: every time people wash their clothes, thousands of near-invisible synthetic microfibers enter a sewerage system that is unable to filter them out, causing them to be released along with the effluent in rivers, on land or at sea. The same is true for the plastic microbeads used in cosmetics like shampoo or toothpaste. They too go down the drain into a sewerage system unable to cope, meaning a massive amount of them end up at sea. There are other sources as well: garbage dumps irresponsibly located near rivers or at the edge of sea, the plastics industry itself – the plastic pellets it uses as a raw material are all too easily lost to the environment -- as well as any sector which uses finished plastics and improperly disposes of excess materials.

There are many kinds of plastics, from polyamides like nylon and polyethylene used in plastic bags and bottles to the more durable polyvinyl chlorides used in plumbing pipes and polycarbonates used in a wide variety of applications. If released at sea they all behave differently, but some generalizations can be made. First, being largely synthetic in nature, they will not disappear. Once there, they are there to stay though like all debris they are subject to weathering and will, as a consequence, break up into ever smaller fragments. It is these fragments which are of most concern because when small enough they can be mistaken for food, even by the smallest organism, and thus end up in the marine foodchain. One might hope those fragments would be excreted without causing too much harm, but the smaller they are the more easily they are absorbed into tissues, meaning they could be ingested by organisms higher up the foodchain.

What is of particular concern in this regard is that many plastics contain additives added during manufacture, which can leach out upon ingestion. In addition it has also become clear that plastics and microplastics attract and concentrate persistent organic pollutants like PCBs or pesticides (see p 294) on their surface. In short, these are items we really do not want to enter the marine foodchain because once they do, there is no way of preventing them from ending up on our plates as well.

The millions of tons of plastics already in the ocean are there to stay and near-impossible to remove, aside from a small proportion that washes ashore and should (obviously) be picked up and properly disposed. What we have to do then is to make sure that no more plastics enters the ocean. Easier said than done because this time there are no large spills or powerful oil companies to blame. Even claiming that it the fault of plastics or the industry that makes them is no more than a lame excuse. It is not plastics that are about to create one of the great environmental disasters of modern times: it is all of us that use them in ever greater quantities, and the many of us too ignorant, apathetic or lazy to either recycle or discard them in a proper manner.

In coastal regions and semi-enclosed seas there also are examples of environmental damage; sometimes very disturbing cases. Moreover, these instances are occurring with increasing frequency. Year after year, every region on earth experiences poignant reminders of sloppy waste disposal practices. The number of dead zones increases year after year. North American and Australian beaches are affected by domestic waste; one year even medical waste washed ashore. The North Sea and Baltic Sea experienced massive seal mortalities several years in a row. Coastal regions from China to the Mediterranean, have been confronted with immense algal blooms.

These types of incidents tend to trigger reactions because they affect people directly by spoiling their vacation plans or leaving strong, emotional images. Some of the resulting measures seem to deal with the problem. But often they are no more than a bandage, quickly applied to treat and preferably cover ugly sores. Unfortunately, bandages don't heal. They treat symptoms, not their cause.

Today, there are signals that we must begin to treat more than the symptoms. For we are witnessing that our waste disposal practices are no longer limited to the medium where we discard. The effects of disposal on land, water and air are beginning to interact. Perhaps they have done so for a long time, but only now are we beginning to understand that interaction. And perhaps more importantly, now there is a visible result of that interaction: the planet is warming, sea levels are rising and the sea itself is turning more acid.

Because of climate variations, the sea has risen and fallen many times throughout geological history. When it is very cold, more of the planet's water is converted to ice and sea level drops. When it is warm, the ice melts and the water expands, and sea levels consequently rise. Not much is known about what exactly triggered these changes, though there is widespread agreement that alterations in the earth's orbit may have contributed by varying the amounts of solar energy that reach the planet. Some scientists feel that the position of the continents also played a role and that climatic changes are thus related to continental drift. Increasingly there is agreement that life can also play a significant role.

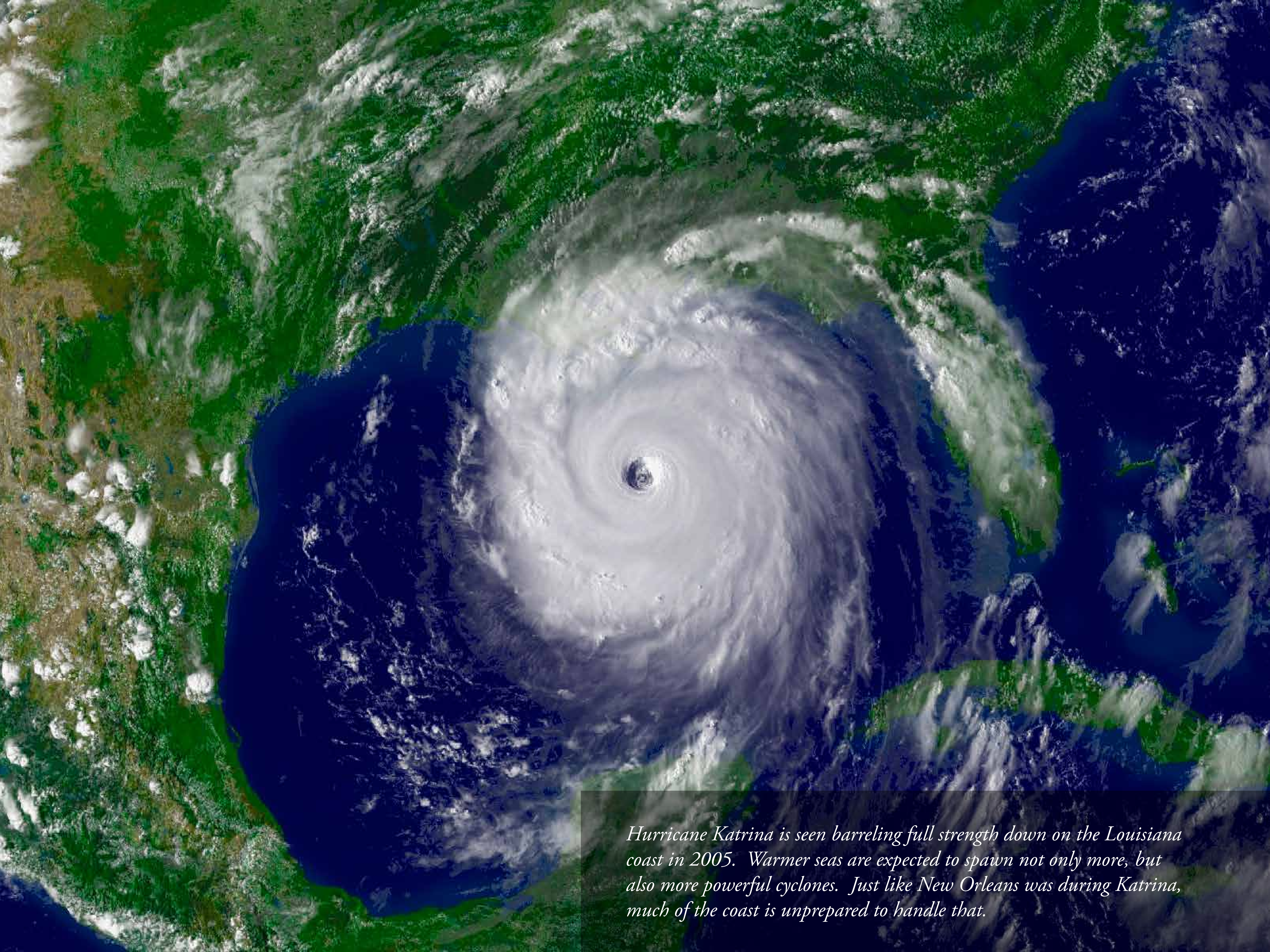
The only way that life could affect large-scale climatic changes is by altering the composition of the atmosphere. It has long been known, for instance, that gases like carbon dioxide and methane trap heat radiated from the earth's surface and re-radiate it downward. Since these gases, in effect, act like the glass panels of a greenhouse, the process became known as the greenhouse effect. High concentrations of greenhouse gases lead to warmer temperatures; smaller ones cause colder temperatures.

Since plants use carbon dioxide along with water and nutrients to produce more complex organic molecules, they can vary the amounts of carbon dioxide in the atmosphere. When a change in the planet's orbit increases the amount of sunlight, for instance, plants thrive and use up more carbon dioxide. Eventually, carbon dioxide levels decrease enough for the earth to cool which, along with a depletion of oxygen levels in the sea, causes the plants to die. Less carbon dioxide is used and its levels build up again, to create a natural greenhouse effect and another warming trend.

The process that triggers periodic climate changes is more complex than that because it also involves the physics of the planet's orbit, the chemistry of the carbon dioxide exchange between ocean and atmosphere and the geological effects that accompany the spreading of ice. Yet despite their complexity, these factors combined to create a natural cycle that has caused the earth to regularly alternate between cold and warm periods for millions of years.

It is now becoming clear that this cycle has been disrupted because one of its components is out of tune with the others. For the past few generations, people have been emitting not only their own carbon dioxide, but that of thousands of past generations as well by burning enormous amounts of fossil fuels. In the process billions of tons of carbon dioxide have been released into the atmosphere. In addition, we release vast amounts of gases that act like greenhouse gases, including chlorofluorocarbons (CFCs – used as refrigerants

*Almost everything we do – manufacturing, driving, farming, heating – releases the carbon dioxide locked up in fossil fuels into the atmosphere. In doing so we add the* $CO_2$ *fixed by life millions of years ago to our own output. Neither the atmosphere nor the ocean are able to handle that without major changes.*



*Hurricane Katrina is seen barreling full strength down on the Louisiana coast in 2005. Warmer seas are expected to spawn not only more, but also more powerful cyclones. Just like New Orleans was during Katrina, much of the coast is unprepared to handle that.*

and propellants in aerosols), nitrous oxide and methane. A process that would normally take millions of years is, as a result, being reproduced in the course of a few hundred.

Scientists are determining what this will do to the planet. There is widespread agreement about some of the large-scale effects, including the gradual warming trend that has become known as global warming. How much warmer the planet may become remains a matter of speculation, if not controversy. If we continue to release carbon dioxide and cut down forests at current rates, carbon dioxide concentrations would double in the course of the century from what they were in the early 1800s. Such a rise would increase the world's mean surface temperature between 1.5 and 4.5 degrees C (3 to 8 degrees F).

This is a considerable temperature increase, and it will have profound consequences. Many regions would become warmer, some rich agricultural lands may become deserts, ocean circulation patterns could change and the world's rainfall patterns will be altered. More extreme weather conditions like hurricanes also appear likely, not to say inevitable. But it would not become warmer everywhere. If oceanic circulation patterns change, it is possible that the Gulfstream would divert from Western Europe, meaning it could get considerably colder there. And climate change would not necessarily bring deteriorating conditions to every place on earth. In fact, some arid regions in today's subtropics could well become wetter and more productive, and agriculture would be possible at higher latitudes. But any positive influences would undoubtedly be matched by less favorable effects on today's prime agricultural belts in temperate regions. Whether one scenario is better than the other may be unclear, though this may not be the kind of thing we want to find out.

Aside from changes in existing weather patterns, it is also clear that sea level will rise. In fact, sea level has already risen some 20 cm (8 inches) since 1880, shortly after the start if the Industrial Revolution. Now it is clear it will continue to do so, although it is not known by how much. Estimates range from one to 25 feet by the end of this century. The lower range is too conservative, because when water warms it expands and even a small temperature increase can cause a considerable expansion. The upper estimate, on the other hand, would require a massive melting of the West Antarctic ice sheet. Most scientists consider this unlikely, at least in the course of this century. Still, if it were to occur two million cubic kilometers of ice would end up in the ocean-enough for sea level to rise some fifteen feet. The current thinking is that a 3 to 4 feet sea level rise can be expected by 2100, unless greenhouse gas level emissions are rapidly curtailed and even then a substantial increase is inevitable.

Computer simulations show what the different scenarios would do to the world's coasts, and they present a frightening picture. Even an increase of no more than a few feet would put vast regions of farmland under water in the United States, the Netherlands, China, Nigeria, Egypt, Bangladesh and Southeast Asia. Most of the world's major ports would face massive problems. Millions of people would be displaced in affluent as well as in poor countries. The simulations also show vast changes in weather patterns, ranging from the frequency and intensity of extreme events like droughts and hurricanes to the disruption of rainfall patterns. The impact on agriculture and the world economy would be phenomenal.

In spite of these dire predictions, until recently not much was done to prepare for the consequences. The 1997 Kyoto Protocol, for instance, suggested lowering greenhouse gas emissions over a number of years. But that reduction comes at a cost, explaining why some countries refused to sign or even withdrew their consent. There is considerable hope that the 2015 Paris Agreement will be more effective, especially since 174 states and the European Union signed the Agreement on 22 April 2016, the first day it was open for signature. Still, here too much of the agreement consists of promises rather than firm and enforceable standards. Only the future will tell whether the urgency of the situation has sunk in and whether all these good intentions will indeed be implemented once their costs become clear. As Garrett Hardin's Tragedy of the Commons (see Harvest) made clear, it only takes a few cheaters to start chiseling away at the best of intentions.

There also are (justified) calls for the increased development and implementation of alternative energy sources; something which is absolutely essential if we indeed intend

*The New Jersey coast following Hurricane Sandy's passage in 2012. Even a small rise in sea levels will affect low-lying areas. Images like these will unfortunately become more frequent in the years ahead.*

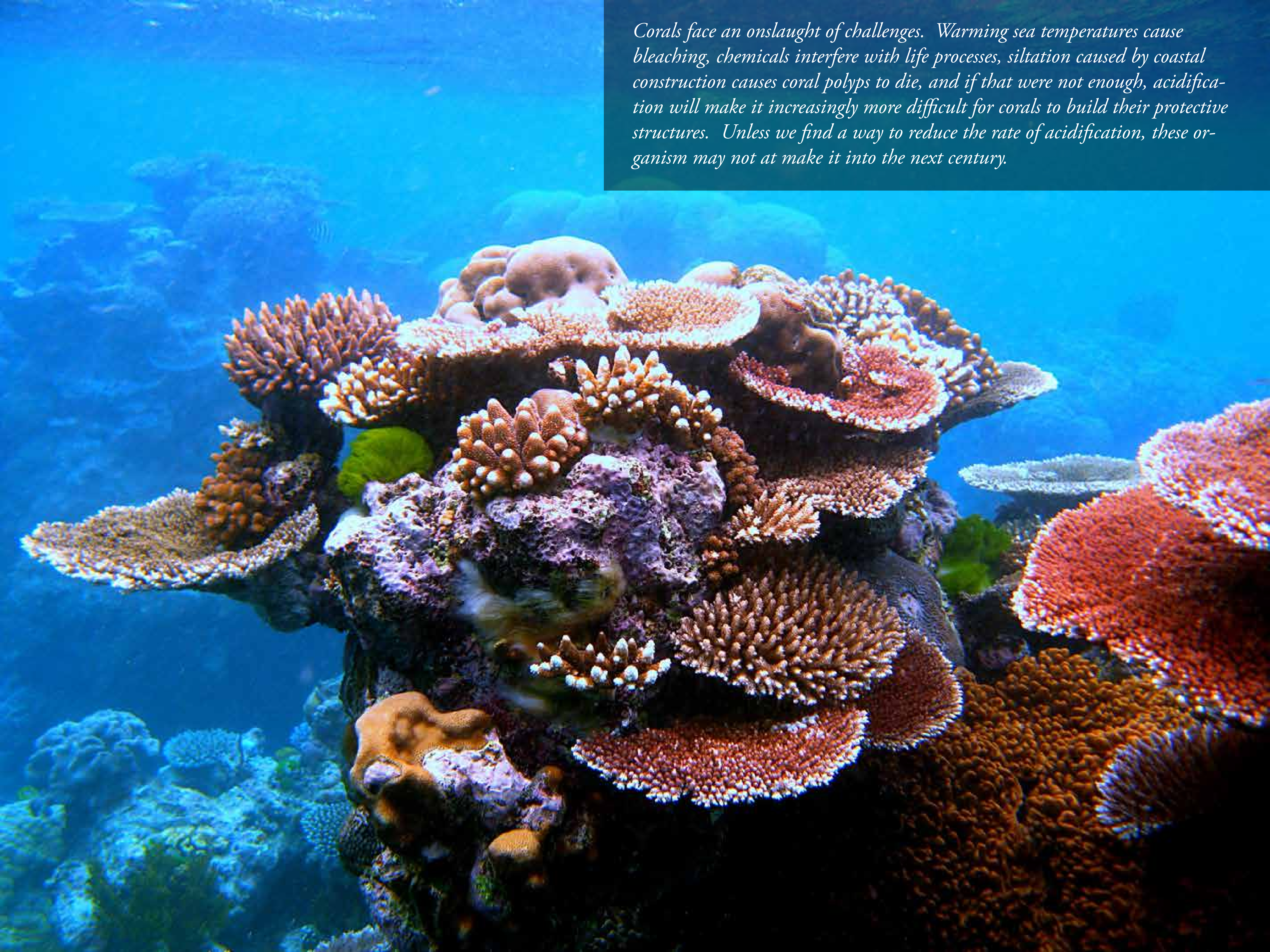
## $CO_2$ AND GREENHOUSE GASSES

The burning of fossil fuels releases massive amounts of anthropogenic carbon dioxide ($CO_2$) into the atmosphere. About 45 percent of this $CO_2$ remains in the atmosphere, contributing in no small part to the greenhouse effect, while much of the remainder is transferred to the ocean. This transfer helps mitigate the greenhouse effect, but creates a set of oceanic problems that has remained somewhat overlooked, in spite of the potential impact.

Of most concern is the process of ocean acidification – a process which can be followed by measuring the pH of the ocean. Dissolving $CO_2$ in seawater increases the concentration of hydrogen ions ($H^+$) in the ocean, thereby decreasing its pH and making it more acid. In the course of the past 250 years, the pH of surface waters has been estimated to have decreased from 8.18 to 8.07. Since the pH measures the acidity or alkalinity of a solution in a logarithmic mode, this means that the ocean's acidity has increased nearly 30 percent during this time-span. As long as the oceans are forced to absorb more anthropogenic $CO_2$, the rate of acidification will continue, with a 70 percent increase expected around the middle of the century and a doubling or even tripling of pre-industrial pH levels by 2100.

The effects of this acidification are still incompletely understood, though it is increasingly clear that marine life will face major changes. Most affected are plants and animals that rely on calcium carbonate to produce protective shells or plates, like mollusks and crustaceans, corals, echinoderms and even some plankton. As the ocean's acidity increases the concentration of carbonate ions decreases, making it more difficult for these organisms to form their protective structures. Given the speed of the current acidification process, marine life will not have time to adapt to these changes.

Climate change skeptics often state there is no proof that anthropogenic $CO_2$ causes global warming, arguing that the planet has gone through many cycles of warming and cooling well before there were any humans to supposedly trigger them. The anthropogenic source of acidification will much harder to deny because it can be easily measured and because the process is unfolding before our very eyes at a rate unprecedented over the past 30 million years.



*Corals face an onslaught of challenges. Warming sea temperatures cause bleaching, chemicals interfere with life processes, siltation caused by coastal construction causes coral polyps to die, and if that were not enough, acidification will make it increasingly more difficult for corals to build their protective structures. Unless we find a way to reduce the rate of acidification, these organism may not at make it into the next century.*

to wean ourselves off fossil fuels in the course of the century. Others propose massive reforestation, or at least a major reduction in the amounts of forests that are cleared for agriculture every year. And still others suggest it is time to start thinking of protecting low-lying areas, so that disruptions caused by rising sea levels can be minimized.

Whatever the approach, many proposals remain difficult to implement. As long as air and water are treated as (unpriced) common property resources, a free-market economy will seek to use or even abuse both at the lowest possible cost. Unless mandated and internationally supported, there won't be massive reforestation programs because developing nations insist they need additional cleared land for agriculture. And trying to convince governments to plan and spend money for something that may happen 50 or even 25 years from now has always been a difficult proposition.

Even if the release of carbon dioxide and other gases were reduced, the problem will not vanish. Greenhouse gas levels have risen enough to trigger a man-made greenhouse effect that can no longer be stopped. In fact, we are already experiencing the preliminary effects of this gigantic geophysical experiment. In many regions the 1980s were the hottest decade on record, causing excessive dry spells in some regions and abnormal rains in others. But that record did not remain on the books for long. With some of the warmest years ever, the 1990s did even better, or rather worse. And the first decade of the new millennium topped off the record once more, eclipsing the records that had been set just a few years earlier. If this trend continues, there is no question that the start of the third millennium will bring about major changes for a lot of people.

To limit these changes to the extent possible, it is clear that we must lower greenhouse gas emissions and reduce deforestation rates in the years ahead. But we must do something more than that. Our approach to waste disposal, which seemed adequate for thousands of years, now has proven itself counterproductive. We must accept that, given the planet's growing population and the standard of living we aspire to, a different attitude is needed. The "out of sight, out of mind" mentality of the past no longer applies. There are far too many of us, and the products we create, whether solid, liquid or gaseous, simply cannot be discarded wherever we choose.

Using the ocean for waste disposal is probably the least visible of all of our ocean uses. Yet there is little doubt that it is the most harmful. Uncontrolled waste disposal has created problems in many coastal areas. Time after time, it has shown that there is a dark side to the way we use the sea. Our increasing reliance has opened up the ocean and its resources, showing a great deal of promise. But it has also brought along the power to disrupt the balance between people and their ocean planet. In a very real sense, it thus carries the seeds of its own failure.

To avoid this, we must restore a sense of balance in our relationship with the ocean planet. This is not easy, for it demands changes in attitudes that have prevailed for a long time. It will require all nations to cooperate on an unprecedented level. It demands we finally begin to assess and include a fair cost for the environmental damage we cause. And it will require all of us individually to make changes as well. Pollution prevention is not merely the responsibility of governments or big industry. It also takes place at the individual level, either by practicing what we preach or by informing our governments of the priorities we wish to live by.

The sea taught us long ago how to deal with this challenge. Since earliest times it required us to work together, for a safe passage at sea required cooperation. It taught us how to do a lot with little, for space on a ship was limited. It forced us think; to see complex interactions as a system. And it demanded respect, for mistakes came at a heavy price.

Today, we need to apply these lessons to chart a safe course for the planet. We must work together to protect our common heritage. We will need our ingenuity to deal with the problems we have created and avoid them in the future. We must integrate our knowledge in order to understand how complex man interacts with this complex planet. And we must show respect for the sea and our surroundings.

For all its gifts – food, health, wealth, knowledge and life itself – this is all the sea requires in return.

# SUMMARY

*From earliest times, water bodies have been used to discard waste. Initially this created few problems because water has the capability to break down natural waste products, but from the past century onward we began to add not only increasing amounts of natural waste, but also synthetic materials, which water could no longer break down. At first streams, rivers and lakes were affected but it didn't take long for the sea to become threatened as well.*

*During the second half of the past century it became clear that pollution not only affected the sea and life in it, but also people. First a fishing village in Japan was poisoned by industrial effluents discharged in its surrounding waters. A few years later it became clear that insecticides and pesticides not only eradicated pests, but marine life as well. Then ships, especially very large ships, began losing their cargo of oil at sea, creating a massive mess and visualizing to what extent our increasing reliance on the sea affected it.*

*In response measures were taken, but usually to deal with a particular problem; to treat symptoms rather than their cause. Today, there are signals that we must do more because the effects of waste disposal on land, water and air are beginning to interact. Perhaps they have done so for a long time, but only now are we beginning to understand that interaction. And perhaps more importantly, now there are visible results of that interaction: the sea is warming and changing more rapidly than it has in the past ten million years. Restoring its health will take a level of political courage, cooperation and ingenuity we have seldom demonstrated. And that, in turn, requires a far broader and better informed oceans constituency than exists today.*

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