Public Ocean Literacy

What residents of Southern California should know.

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October 26, 2005
MCRI Aquatic Forum Report
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This is a Dynamic Document

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Contents

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Introduction

This report summarizes the results of a workshop held at the Aquarium of the Pacific on June 15, 2005. The workshop was held in response to the call for greater ocean literacy by the U.S. Commission on Ocean Policy (USCOP) report, the U.S. Ocean Action Plan, and the Pew Oceans Commission report. In the past several years, a number of reports and research papers have pointed out that while people love the ocean, they neither know much about it, nor believe that their actions affect its health. That is, they are not "ocean literate." It was also pointed out that there is a need to develop ocean education programs targeted not only at the formal education sector, but also at the general public—from pre-schoolers to senior citizens.

Aquariums have been identified as a major and trusted source from which the public acquires knowledge about the ocean, its inhabitants, and the need for conservation of its resources. Aquariums in the U.S. reach approximately 40 million people each year, and most major aquariums are affiliated with networks designed to connect the public to aquatic issues, both marine and fresh water. These networks include: the American Zoo and Aquarium Association (AZA), NSF's Centers for Ocean Sciences Education Excellence (COSEE), Coastal America Ecosystem Learning Centers (CELC), and the Ocean Project.

The U.S. Commission on Ocean Policy (USCOP) report states that a knowledgeable public is essential to generating the kinds of political and financial support needed to reverse the declines in coastal resources and promote ocean stewardship:

"Strengthening the Nation's awareness of the importance of the oceans requires a heightened focus on the marine environment, through formal and informal education efforts. …informal education aimed at the entire population is needed to foster lifelong learning."

The workshop brought together about 40 scientists to develop the first summary of what they thought all citizens should know to be "ocean literate." The focus was on the general public and the workshop took as its point of departure the principles and topics developed by the Centers for Ocean Sciences Education Excellence (COSEE) and the National Marine Educators Association (NMEA). The primary audience was the general public in contrast to that of COSEE and NMEA, which was K-12.

Based on the assumption that people are more apt to be interested in something with which they are familiar and to which they can relate, the focus of the workshop was regional—from Santa Barbara to the U.S. Mexican border. National and global ocean issues were given southern California “hooks," where appropriate. The intention was that the workshop could be a model for other regions of the U.S., to educate the general public about the ocean, how it affects them, and how they affect it.

The workshop, a partnership between CORE and the Aquarium of the Pacific, was moderated by RADM. Richard West, President of CORE, and Dr. Jerry Schubel, President of the Aquarium of the Pacific. All CORE member and associate member institutions within the Southern California region were invited to send representatives, as were organizations affiliated with CORE, including the National Offices of COSEE and the Census of Marine Life (CoML). Representatives of two CORE industrial members participated. The full list of participants and observers is included as Appendix I.

The Aquarium of the Pacific held a follow-on workshop on October 11-12, 2005 with experts in informal science education and outreach. The focus of that workshop was to use the output of the June 15 workshop to identify and describe the best strategies to engage the public in learning about the ocean. The strategies will be prototyped and tested at the Aquarium of the Pacific.

What is Ocean Literacy?

There are many definitions of ocean literacy. They differ more in style and level of detail than in substance. At the workshop, ocean literacy was defined as:

"Ocean literacy is understanding the ocean's influence on you and your influence on the ocean."

An ocean-literate person understands the fundamental concepts about the functioning of the ocean and about the influences that affect the ocean. Because we are interested in ocean-literate citizens becoming better stewards of the ocean, we would add that an ocean-literate person uses this understanding to make informed and responsible personal decisions regarding the ocean and its resources, and communicates this understanding to others.

Workshop Process

In advance of the workshop the scientists were divided into six teams with a leader for each team. Their observations were submitted prior to the workshop and incorporated in a workbook that was used for discussion at breakout sessions of the teams.

The seven guiding principles provided by COSEE were collapsed into six, by combining their numbers three and four. The wording of COSEE's initial seven concepts was also somewhat revised to arrive at the following:

1. The Earth has one world ocean with many basins, seas, bays, lagoons, estuaries, and other and other features such as submarine canyons, seamounts, volcanoes, and marine ecosystems.
2. The ocean and life in the ocean shape the Earth.
3. The ocean is a major influence on weather and climate.
4. The ocean makes Earth habitable.
5. The ocean supports a great diversity of life and ecosystems (e.g. kelp forests, coral reefs, and hydrothermal vent communities).
6. The ocean and humans are inextricably interconnected and the life of every human is affected by the ocean.
7. The ocean is largely unexplored.

This report is structured around these themes.

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3. NEEP/Roper report (www.neetif.org/Roper/elr.org)

The Southern California Bight

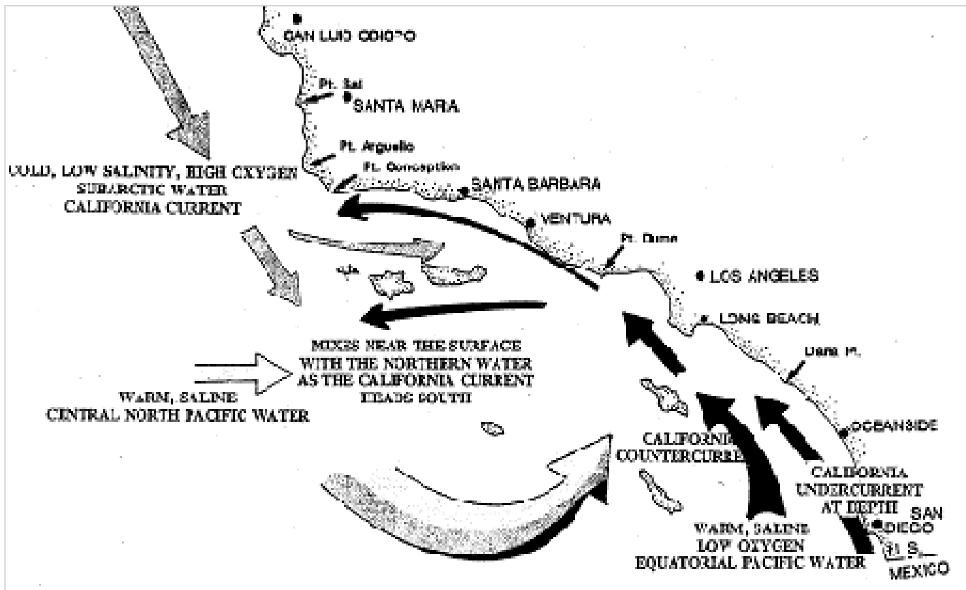
An ocean bight is defined as a broad bay formed by a concave curve or indentation in a coastline. The Southern California Bight (SCB) is bounded on the north, east, and southeast by a long curve of the California coastline extending from Point Conception (north of Santa Barbara), southeast 575 km (357 mi) to Cabo Colnett (just below Ensenada, Baja California Norte, Mexico). It is bounded to the west by the California Current, which flows southeasterly approximately parallel to the coast and the edge of the continental shelf. The bight system includes more than 59,500 km^2 (37,000 mi^2) of ocean and approximately 14,000 km^2 (8,700 mi^2) of adjacent coastal areas draining into it. Its shoreline is 300 km (186 mi) long.

Circulation and Oceanography

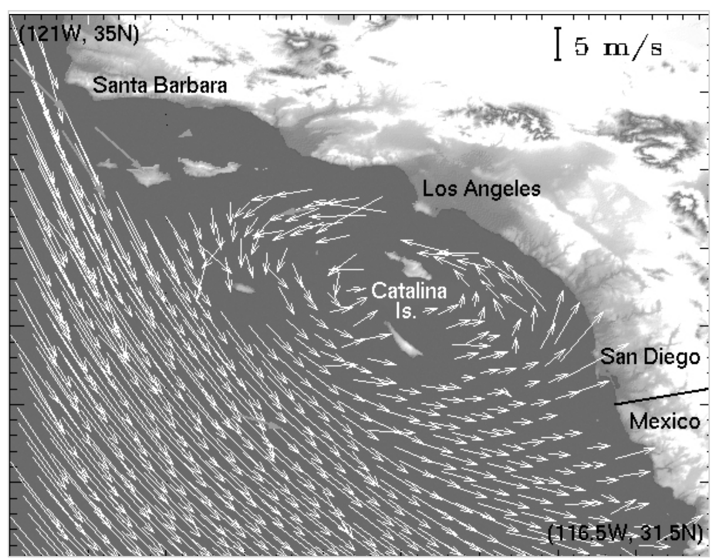
Circulation patterns within the SCB are more complex than elsewhere off the west coast of the United States. The equatorward California Current (CC), strongest during summer, is a well-described eastern boundary current and dominates flow in the region. This current branches shoreward, then northward in the SCB, forming the Southern California Countercurrent (Davidson Current), which has its seasonal maximum in winter. At times, the CC forms an eddy-like cyclonic (counterclockwise) circulation that is called the Southern California Eddy. It is strongest from summer to early fall, and weakest from winter to spring. A third current—the California Undercurrent—flows about 200 m (660 ft) below the ocean's surface and within 150 km (95 mi) of the coast. It runs northward over the SCB's continental slope. In winter months the California Undercurrent comes closer to the surface.

The primary currents in the SCB then, are the:

- southward flowing California Current (CC)
- northward flowing California Countercurrent (Davidson Current)
- Southern California Eddy
- northward flowing California Undercurrent



Ocean currents in the Bight
Source: County of Santa Barbara



Catalina Eddy
Source: JPL

The strongest equatorward winds are found during spring along most of the California coast. During this period, the California Current moves closer to shore and becomes increasingly jet-like, flowing predominantly equatorward in the SCB. Winds in the SCB are generally weaker, but more highly variable compared to the rest of California's coast. Upwelling within the SCB tends to be limited to winter and early spring. Local upwelling during summer, while strong elsewhere along the California coast, is weak in the SCB because of the large reduction in wind stress. Temporally and spatially variable local winds, as well as eight nearshore islands and numerous coastal promontories, submarine canyons, basins, and ridges introduce complexity to these large scale circulation patterns. These winds are most commonly expressed as small-scale eddies typically less than 50 km (31 mi) in diameter.

Aperiodic variations (that is, variations that do not occur at regular intervals) in the SCB include El Niño (anomalously warm) and La Niña (anomalously cold) events. El Niño occurs when the location of atmospheric high and low pressure areas in the southern hemisphere shift (hence, the name El Niño Southern Oscillation, or ENSO). During normal periods, the California Current is relatively strong, as is upwelling, and waters are cooler and more productive. During an El Niño however, the California Current weakens, water temperatures increase, and the thermocline deepens as warm, saline, oligotrophic water moves north into the SCB. The reverse occurs during La Niña events. Strong El Niño events affected the SCB in 1929-1930, 1957-1959, 1982-1983, and 1997-1998. Strong La Niña events occurred in 1933, 1975-1976, and 1988-1999. (See Key Concept 3 for additional information).

Climate and Hydrology

The climate of southern California is like that of the Mediterranean, with most of the precipitation occurring during winder months. Monthly mean temperature and precipitation for Los Angeles and San Diego are summarized in the table below. Mean monthly precipitation ranges from near zero in June, July, and August to 5-8.5 cm (2.0-3.3 in) in December, January, and February.

Freshwater enters the SCB from a variety of sources. River runoff from rain and melting snow is very seasonal. Much of the water imported from northern California through the California Aqueduct, from the high Sierra Mountains through the Owens

Los Angeles and San Diego Normal Mean Temperature and Precipitation

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Temperature ^{o} C (^{o} F)	Los Angeles	13 (55)	14 (57)	15 (59)	16 (61)	18 (64)	20 (68)	22 (72)	23 (73)	22 (72)	19 (66)	17 (63)	14 (57)
	San Diego	13 (55)	14 (57)	15 (59)	16 (61)	18 (64)	19 (66)	21 (70)	22 (72)	21 (70)	19 (66)	16 (61)	14 (57)
Precipitation mm (in)	Los Angeles	60 (2.4)	85 (3.3)	60 (2.4)	30 (1.2)	6 (0.2)	2 (0.08)	0 (0)	0 (0)	7 (0.3)	13 (0.5)	26 (1.0)	79 (3.1)
	San Diego	51 (2.0)	55 (2.2)	40 (1.6)	20 (0.8)	4 (0.16)	1 (0.04)	0 (0)	2 (0.08)	4 (0.16)	12 (0.4)	23 (0.9)	52 (2.05)

Valley Aqueduct, and from the Colorado River through the Metropolitan Aqueduct eventually finds its way to the SCB through land and subterranean runoff and discharges of wastewater.

Because of the semiarid nature of the drainage basin and the highly seasonal pattern of annual precipitation, most of the rivers draining into the SCB are small and are dry for much of the year. From north to south, the major rivers in the drainage basin are the Santa Clara, Los Angeles, San Gabriel, Santa Ana, San Luis Rey, San Diego, and Tijuana Rivers. Much of the length of the Los Angeles and San Gabriel river beds and other major drainages are now lined with concrete. Most rivers have dams and debris basins constructed upstream to aid in flood control. In southern California separate systems handle stormwater runoff, and municipal wastewater flows.

Due to the semiarid climate of the SCB drainage basin, the volume of water entering the bight from wastewater discharges is comparable to that from river and storm drain inputs. In dry years, because stormwater flow is more variable than wastewater flow, wastewater flow far exceeds that of storm water. For example, the mean treated wastewater flow to Santa Monica Bay between 1967-1982 was 1.3 million m^3/day (346 million gal/day), with the annual mean increasing from 1.2 million m^3/day in 1967 (320 million gal/day) to 1.4 million m^3/day in 1982 (379 million gal/day). Stormwater flow to Santa Monica Bay over the same period averaged 0.5 million m^3/day (143 million gal/day) and ranged from 0.2 million m^3/day in 1972 (51 million gal/day) to 1.5 million m^3/day in 1969 (400 million gal/day). However, nearly all of this stormwater flow occurred during and shortly after a few winter storms each year. Thus, the only continuous freshwater flow to the bight is treated municipal wastewater. This includes primary, secondary, and tertiary treated sewage discharged from inland treatment plants to southern California rivers and steams. This pattern of freshwater input to coastal waters is quite different from that in much of the rest of the coastal United States, where riverine and stormwater flow far exceeds wastewater flow.

Bathymetry

The waters of the SCB overlay a submerged portion of the California Continental Borderland. The borderland extends some 483 km (300 mi) seaward terminating at the Patton Escarpment, a continental slope that descends 4,000 m (13,200 ft) to the deep seafloor. Its topography is marked by a very narrow shelf, seamounts, submarine canyons, islands, and deep basins. The waters overlay an alternating series of eighteen 610-2,440 m (2,000-8,000 ft) deep basins and surfacing mountains that form eight offshore islands or island groups and several large submerged banks and seamounts. The basins are arranged roughly in rows trending northwest to southeast and converging toward the south. Seventeen percent of the area is seafloor and 63 percent basin-trough slopes. Nearshore, 12 large submarine canyons influence movement of sediments and other materials deposited on the bottom. There are also 32 submarine canyons on the continental slope bordering the U.S. portion of the bight, including 20 canyons that cut into the mainland shelf. Eighteen marine basins lie offshore. Three of these are essentially anoxic—devoid of oxygen.

Submarine canyons and deep basins are important sites of accumulation of fine-grained sediments and particulate materials from land runoff, ocean discharges, and ocean dumping. An important and distinguishing feature of the SCB is that deep water is close to shore. All slopes are steep, ranging from 5-15 percent. Island and mainland shelves are narrow, ranging from 1-20 km (0.6-12.5 mi) wide. The mainland and island shelves constitute only about 11 percent of continental borderland area. Marine basins cover about 80 percent of the borderland area.

The most important embayments of the mainland shelf are Santa Monica Bay and San Pedro Bay (separated from each other by the prominent and steeply sloping Palos Verdes Peninsula and shelf), San Diego Bay, and Todos Santos Bay in Baja California, Mexico. Although no true estuaries penetrate the mainland coast, there are at least 26 wetland systems in coastal lagoons at the mouths of transient streams and rivers in the U.S. portion of the bight. The total area of these coastal wetlands is only about 337 km^2 (130 mi^2), less than 25 percent of the area they encompassed when the first Europeans arrived in southern California in the late 1500s.

Nearshore Submarine Canyons
Source: USGS

Habitats and Natural Resources

Natural habitats and resources characteristic of the SCB include: abundant deep water close to shore, extensive coastal and offshore oil reserves, commercially and recreationally valuable fish and shellfish stocks, wildlife breeding and overwintering areas, kelp beds, beach and water recreation areas, and a climate tempered by the special oceanographic processes described above.

As a result of the local oceanographic regime, particularly the Southern California Eddy, the SCB is an enclave of communities of marine life specific to the area (except during El Niño years). It is also a trap for warm water and natural and anthropogenic materials entering the area from land, sea, and air.

Six species of seals and sea lions and the northernmost Pacific population of pelicans breed on several islands in the area. Regional populations of dolphin occur in the bight, and most of the population of Eastern Pacific Gray Whales spends a portion of fall and winter here during its annual migration between the Alaskan waters and lagoons in Baja California.

Commercially exploitable stocks of anchovies, sardines, and mackerel spawn and grow primarily in the SCB, as do bass, croakers, flatfishes, and rockfishes. Several successful mariculture operations have been established in the area. The deeper waters of the SCB host a diversity of mesopelagic fishes that spend part of their life cycles in surface waters. The benthic fauna of the continental shelf, especially polychaetes and crustaceans, are very diverse and constitute an important food source for many fish species.

Rocky intertidal and subtidal areas, which cover large areas of the shoreline of the SCB, host a rich diversity of epifauna (snails, mussels, crabs, etc.) and attached seaweeds. Beds of the giant kelp, *Macrocystis pyrifera*, which attach to the bottom and can grow to over 50 m (164 ft) in length, extend along the coast of the bight. There are more than 30 locations between Point Conception and San Diego where kelp beds are found at least periodically, at water depths ranging from 6-20 m (20-65 ft). From the 1930s to 1979, individual kelp beds occupied up to 9.2 km^2 (2,270 acres), with the total area occupied by kelp beds in the range of 48-60 km^2 (12,000-15,000 acres). The size and distribution of kelp beds varies spatially and temporally in response to changes in natural and anthropogenic conditions. Natural changes in surface water temperature and nutrient concentrations associated with El Niño events, and possibly with longer-term ocean warming trends, have resulted in declining kelp beds in some areas, and winter storms like those of 1983 and 1987 can devastate large kelp beds. These storms probably are the most important factor influencing the condition and range of kelp beds, but human activities such as boat traffic, and possibly waste-water discharges at Palos Verdes and Point Loma have also affected local giant kelp beds.

In addition to being a feeding ground and permanent habitat for many organisms, the SCB is also a migratory route and stopover feeding ground for a number of species of birds that travel the Pacific Flyway, and cetaceans moving between feeding and breeding areas. The resident/migratory biodiversity in the SCB includes more than 500 species of fish, 1,500 species of invertebrates, 250 species of birds (125 migratory), and 27 cetacean species.

Largely because of the loss, degradation, and fragmentation of the bioregion's habitats as a result of human activities, the Southern California Coast Bioregion, terrestrial and marine, has the largest number of endangered and threatened species and species of special concern in the contiguous 48 states.

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Key Concept 1

The Earth has one world ocean with many basins, seas, bays, lagoons, estuaries, and other features such as submarine canyons, seamounts, volcanoes, and marine ecosystems.

The world ocean, the single most dominant feature on the surface of Earth, covers 71 percent of the planet, and is deeper than the tallest mountains on the land.

" How inappropriate to call this planet Earth, when clearly it is Ocean."

– Arthur C. Clark

Western Hemisphere from space
Source: NASA

Earth viewed from space is an ocean where all the land masses, even continents, are islands surrounded by 360 million km^3 (40 million mi^3) of water. The world ocean covers 360 million km^2 (224 million mi^2) to a mean depth of 3,730 m (12,240 ft). Its volume is about 1,347,000 km^3 (12,237 mi^3). Earth's highest peaks, deepest valleys, and flattest vast plains lie beneath the surface of the sea.

Ocean basins are the complements of continents. Because basins lie lower than continents, they collect water and the sediments eroded from the continents. They include the ocean floor, the mid-oceanic ridges, trenches, and continental risers and shelves. The ocean basins, filled with saltwater, make up the five oceans. From largest to smallest, they are the Pacific, Atlantic, Indian, Southern, and the Arctic. The Atlantic and Arctic Oceans are active growing basins in contrast to the Pacific which, although active, is shrinking even though it has both spreading ridges and oceanic trenches.

Comparison of East and West Coast shorelines
Source: NASA's National Geophysical Data Center

Seas are relatively large bodies of saltwater that are connected to an ocean and more or less landlocked. The term "sea" is sometimes used colloquially as synonymous with ocean, e.g., "the tropical sea", "down to the seashore", or even "seawater" when referring to the ocean's water. There are about 34 salty seas worldwide.

Gulfs are arms of a sea or ocean partially enclosed by land. A California example is the Gulf of the Farallones. The Gulf of Mexico is an area of ecological concern because of its spreading “dead zone,”—a zone devoid of oxygen.

Bays are wide inlets or indentations of a shoreline that are larger than a cove (very small inlets) but smaller than a gulf. Some along the coastline of the Southern California Bight include Morro, Anaheim, and San Diego Bays.

San Diego Bay
Source: SDSU

Lagoons are bodies of comparatively shallow saltwater separated from the deeper open ocean by a shallow sandbank or exposed barrier island, coral reef, or similar feature. On the U.S.'s Mid-Atlantic Coast such lagoons enclosed by barrier islands are traditionally called sounds.

Submarine canyons are steep V-shaped canyons cut into the continental shelf or slope. They are major conduits for sediment transport from coastal areas to the deep sea. Monterey Canyon in Central California is the size of the Grand Canyon and the major topographical feature of Monterey Bay. The Southern California Bight contains 32 canyons, among them Santa Monica, Redondo, and Montrose Canyons.

Montrose Canyon, a nearshore canyon off the Palos Verdes peninsula
Source: F&G

Seamounts are mountains rising from the seafloor that do not reach to the surface of the ocean. All are volcanic in origin. They often project up into shallower zones providing habitat for sealife not found in the deep ocean. They may deflect deep currents creating upwelling that brings nutrient-rich deeper water into the upper photosynthetic zone.

Volcanoes are concentrated along midocean ridge systems and along convergent plate boundaries, such as around the Pacific Ocean's "Ring of Fire,"— the ring of plate boundaries associated with volcanic island arcs and ocean trenches surrounding the Pacific Ocean. Most active submarine volcanoes occur where tectonic plates are either moving apart or colliding.

a. The ocean is the dominant physical feature on planet Earth, covering about 71 percent of the planet.

- Earth's Surface Area — 510,066,000 km^2 (316,940,300 mi^2)
- Land Area — 148,647,000 km^2 (92,364,960 mi^2)
- Ocean Area — 361,419,000 km^2 (224,575,350 mi^2)

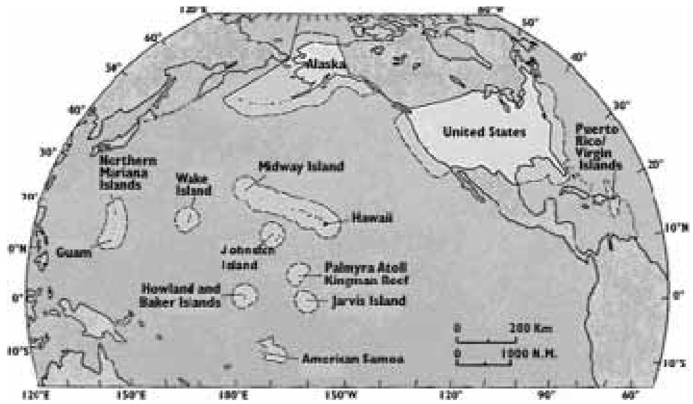
The **world ocean** is a single, large interconnected body of water. If Earth had no mountains or valleys and was one level surface, the ocean would cover Earth to a depth of 2,500 m (8,000 ft). This is called the “mean sphere depth.” The mean depth of the world ocean is 3,730 m (13,000 ft). Most of its water is contained in the five large ocean basins listed below.

Ocean	Approximate area in millions	
	km^2	mi^2
Pacific	179.7	69.4
Atlantic	106.4	41.1
Indian	73.6	28.4
Southern	20.3	12.6
Arctic	14.1	5.4

The Pacific Ocean

- *is larger than total land area of the world*
- *covers an area about 165 million km^2 (about 64 million mi^2) without seas*
- *extends approximately 15,500 km (9,600 mi) from the Arctic's Bering Sea to the margins of Antarctica's Ross Sea*
- *is nearly 18 times the size of the U.S.*
- *contains more than $^1/_2$ of the world's water*
- *at its widest point stretches from Indonesia to the coast of Columbia*
- *contains 30,000 islands, the most of any ocean*

In addition to the physical boundaries of the world ocean, there are also the political boundaries established through actions of the United Nations as Exclusive Economic Zones (EEZ). As for all nations, the U.S. EEZ extends 200 nautical miles offshore (a nautical mile is equal to 1.3 land miles), encompassing diverse ecosystems and vast natural resources,



U.S. Exclusive Economic Zone
Source: USGS

such as fisheries, energy, and other mineral resources. The U.S. EEZ is the largest in the world, spanning nearly 11,650,000 km^2 (4.5 million mi^2), an area about 25 percent larger than the U.S.'s land area and stretching along 20.921 km (13,000 mi) of coastline.

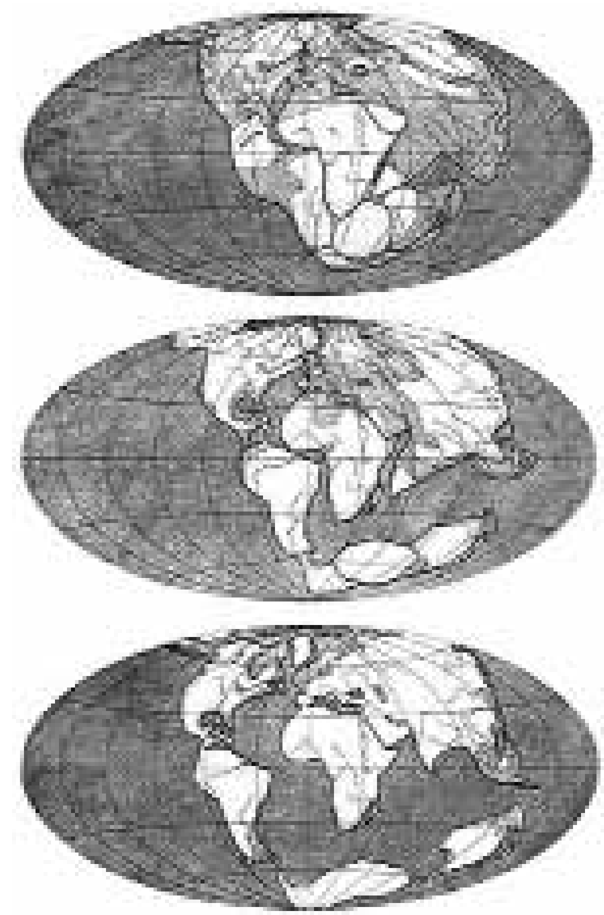
The eight states bordering the Great Lakes have jurisdiction over a significant portion of the Great Lakes. This chain of freshwater lakes and its tributaries constitute the largest reservoir of fresh surface water on the planet, containing 6.5 quadrillion gallons of fresh water and covering an area of about 247,250 km^2 (95,500 mi^2). The U.S. Great Lakes coastline is roughly the same length as the entire Atlantic Coast.

b. *An ocean basin's size, shape and features (such as islands, trenches, mid-ocean ridges, and rift valleys) are shaped by movements of Earth's lithospheric plates.*

According to the theory of **continental drift**, present day continents were the result of the fragmentation and displacement of larger landmasses over periods of many millions of years starting with the breakup of the supercontinent **Pangaea** about 225-200 million years ago. The “fit” of the presently separated continents, particularly South America and

Africa, the distribution of fossils, a similar sequence of rocks at numerous locations on the two continents, ancient climates, and the apparent wandering of Earth's polar regions were used to support the theory. Movement was believed to occur as a result of the continents simply plowing through the motionless ocean floor. This explanation was disputed by geophysicists who felt the large land masses of solid rock would break up in the process, and there was no plausible driving force. However, the basic proposition of the theory of continental drift is accepted today and incorporated into the theory of seafloor spreading and plate tectonics.

Mountain-building cannot be explained without plate collisions, and collisions are tried to seafloor spreading. Throughout Earth's history erosion moved materials from the continents to the seafloor, yet the continents are still there and the oceans are not full of sediment.



From Pangaea to Present Day
Source: NASA

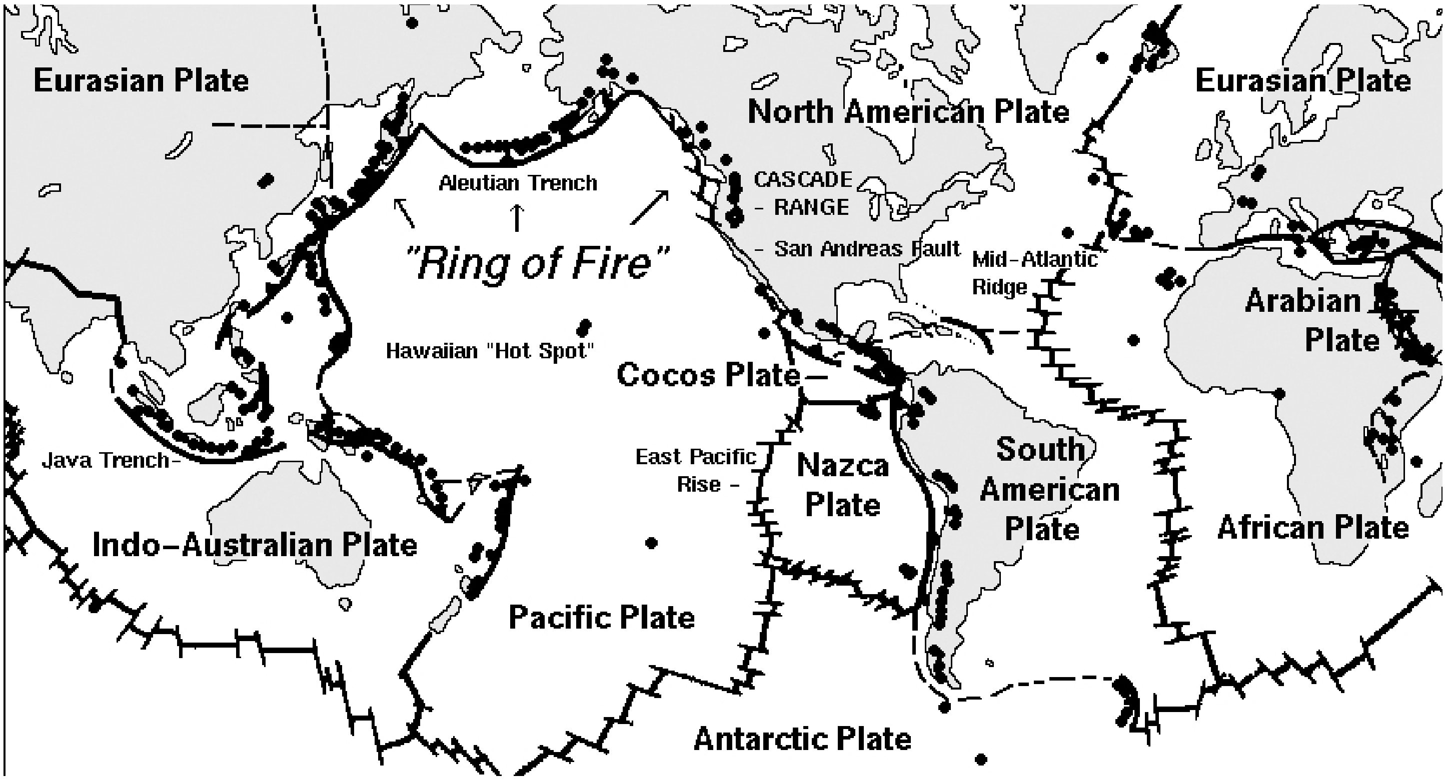
Plate Tectonics

- *Plate*: according to geologists, a large rigid slab of rock
- *Tectonic*: from the Greek root "to build." The word "architect" has the same root.
- *Plate tectonics*: A theory encompassing the plate-like construction and movement of Earth's surface.

The theory of plate tectonics, formulated in the 1960s and 1970s, is a combination of earlier theories about continental drift and sea-floor spreading (see below) plus additional information resulting from modern ocean exploration about the nature of the ocean floor, Earth's ancient magnetism, the distribution of volcanoes and earthquakes, the flow of heat from Earth's interior, and the worldwide distribution of plant and animal fossils. It has become widely accepted by scientists, although there is still debate about some aspects of the theory.

The theory states that Earth's outermost layer, the lithosphere (see description of lithosphere below) is broken into seven large, rigid pieces called plates, (African, North American, South American, Eurasian, Australian, Antarctic, and Pacific plates), and several minor plates (including the Arabian, Nazca, and Philippines plates). These plates, which cover the entire surface of the Earth, are bounded by mid-oceanic ridges, subduction zones, and transform faults.

Mid-ocean ridge systems and rift valleys, including the Mid Atlantic Ridge and the East Pacific Rise, exist where lithospheric plates are **moving away** from each other (seafloor spreading). Major trench-



Major plates and Pacific Ocean's Rim of Fire
Source: Adapted from USGS

es, such as the Marianas, and island arc systems (such as Japan) exist where lithospheric plates are **descending into** the Earth. Islands and seamounts (such as the Hawaiian Islands and Emperor seamount chain) exist throughout the world ocean and were created by mantle plumes of magna rising from the mantle core boundary or **hot spot volcanism**.

The plates are all moving in different directions and at different speeds (2-10 cm/yr, about 0.8-4 in/yr) relative to each other. The place where the two plates meet is called a plate boundary. There are four kinds of boundaries categorized by the way in which the plates meet.

- **Divergent boundaries** – where plates pull away from each other and new crust is formed. The Mid-Atlantic Ridge is spreading at the rate of 2.5 cm (0.98 in) per year, causing the Atlantic Ocean to continue growing slowly.
- **Convergent boundaries** – where crust is destroyed as one plate dives under another and sinks (is subducted). One type of convergence (oceanic-continental) created the Pacific Ocean's numerous trenches and sustains the volcanoes of the Pacific's Ring of Fire. The Nazca and Juan de Fuca Plates consist of only oceanic lithosphere. The Pacific Plate is mostly oceanic lithosphere with only a small slice of continental lithosphere in southern California and Baja Mexico. Most of the other plates consist of both oceanic and continental lithosphere.
- **Transform boundaries** – where crust is neither produced nor destroyed as the plates slide horizontally past each other.
- **Plate boundary zones** – broad belts in which boundaries are not well defined.

The ocean floor is a very complex system. Some features are described below.

Lithosphere is the solid outermost shell of a rocky **planet**, which on Earth includes the **crust** and the uppermost layer of the **mantle**. It floats on the more plastic **asthenosphere**. The thickness of the lithosphere varies from around 1.6 km (1 mi) at the mid-ocean ridges to approximately 130 km (80 mi) beneath older oceanic crust. The thickness of the continental lithospheric plates is believed to be about 150 km (93 mi). As the lithosphere thickens over time, it fragments into tectonic plates.

Asthenosphere is the region in the upper mantle of Earth's interior, characterized by low-density or partially molten rock material chemically similar to the overlying **lithosphere**. The upper part of the asthenosphere is believed to be the zone upon which the lithospheric plates of the crust move. It is

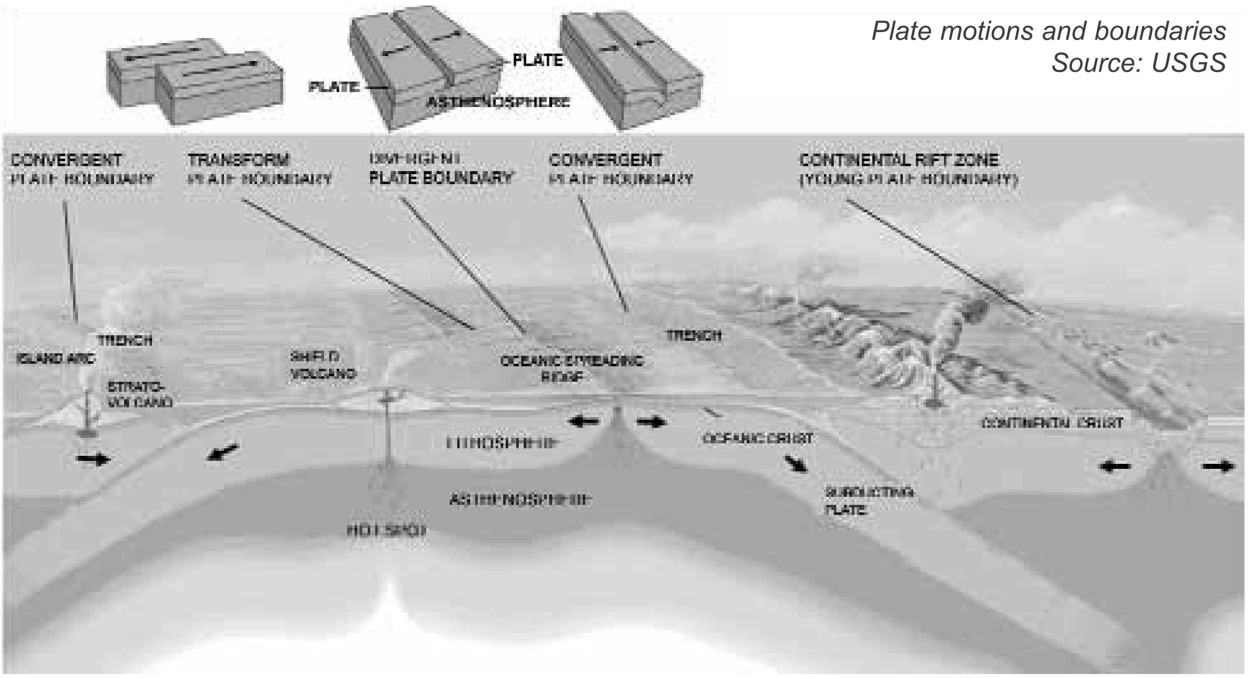
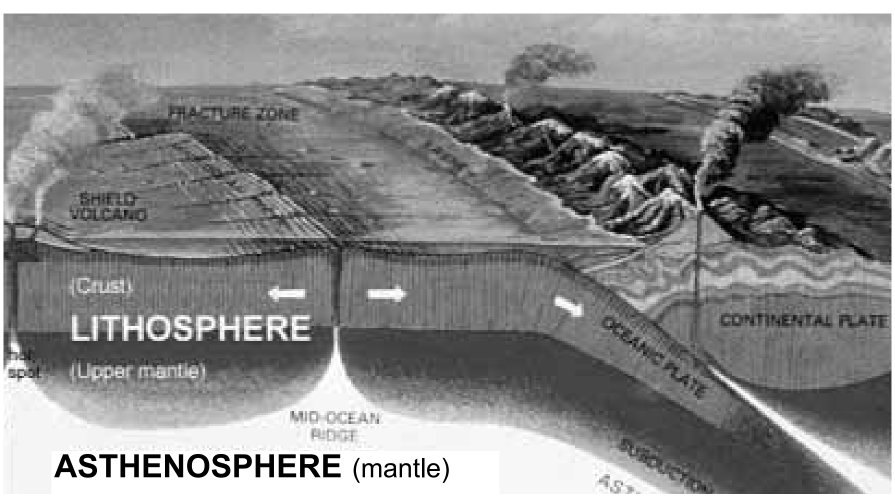
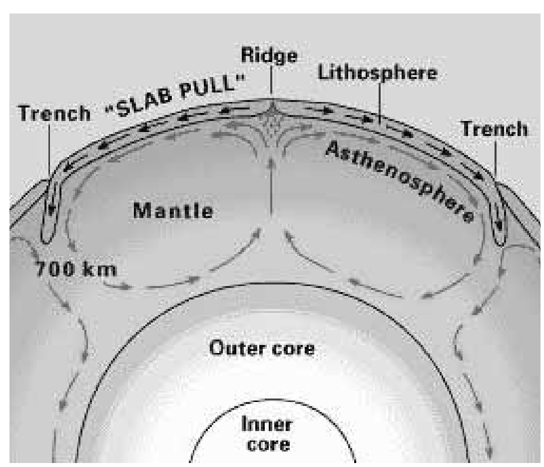


Plate motions and boundaries
Source: USGS



Source: Windows to the Universe, http://www.windows.ucar.edu

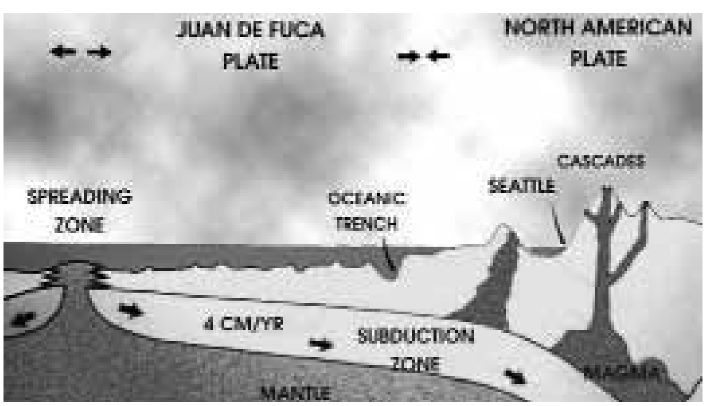


Source: Windows to the Universe, http://www.windows.ucar.edu usually located 72-250 km (45-155 mi) beneath the ocean floor; however, at mid-ocean ridges it rises to within a few kilometers of the surface of the ocean floor.

Subduction zones mark sites of convective downwelling of Earth's lithosphere. They exist at convergent plate boundaries where one plate of oceanic lithosphere converges with another and sinks below the mantle. Subduction results from the difference in density between lithosphere and the underlying asthenosphere. It causes the formation of oceanic trenches such as the Mariana Trench.

Oceanic trenches, steep-walled valleys on the ocean floor and the deepest part of the seafloor, are long but narrow topographic depressions. They are natural boundaries on Earth's solid surface between two solid plates. They occur where one plate begins to descend beneath another. They are typically parallel to a volcanic island arc and about 200 km (124 mi) from the arc. They usually descend 3-4 km (1.9-2.5 mi) below the surrounding sea floor.

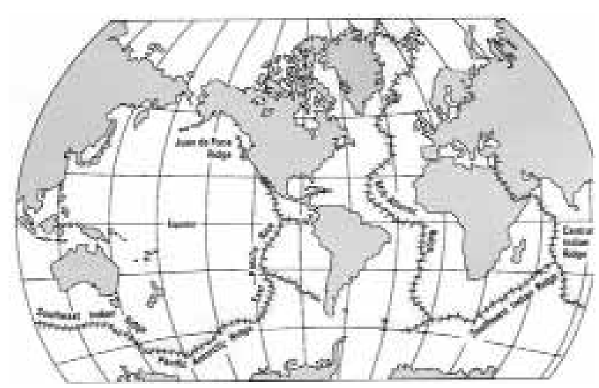
Seafloor spreading, part of the theory of plate tectonics, is the process by which continental “drift” occurs. It is driven by active spreading at spreading centers (powered by convection currents in Earth’s mantle), or passive descent (driven largely by gravity). Spreading usually begins as a rift in a continental land mass with heating at the base of the continental crust. This weakens the crust and causes it to be less dense and more deformable. The area being heated then becomes a broad dome. As the crust bows upward, fractures occur that eventually becomes rifts.



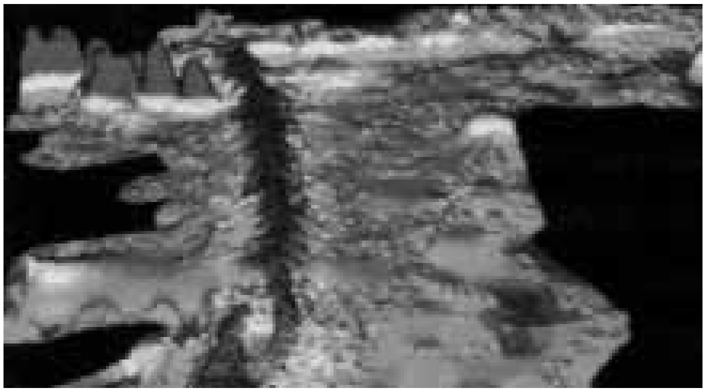
Mid-ocean Seafloor Spreading
Source: Windows to the Universe
http://www.windows.ucar.edu

Rifts are places where Earth's crust and lithosphere are being pulled apart. If rifting continues, a mid-oceanic ridge may form. The great rift valleys of East Africa mark the origin of an incipient ocean basin.

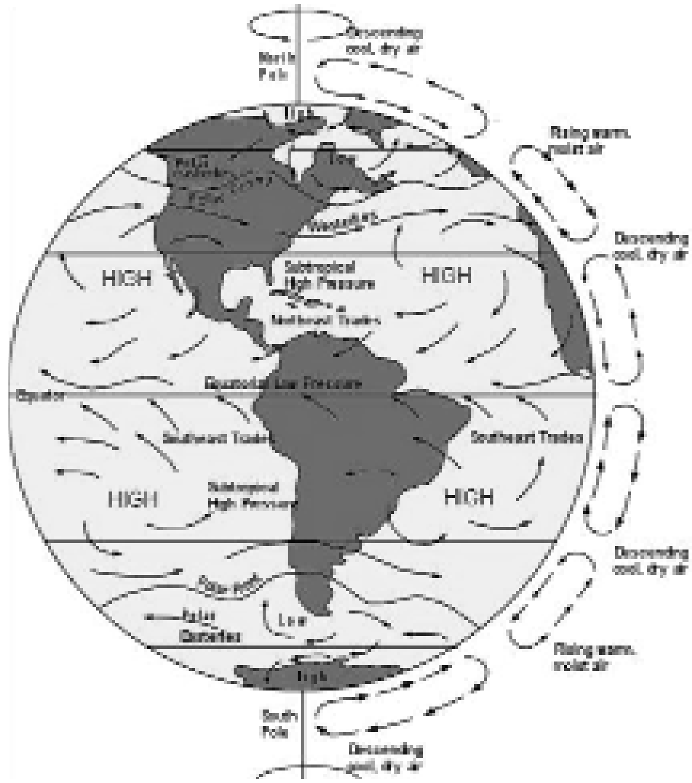
Mid-ocean ridges are mountains (and valleys) that result from an uplifting of the ocean floor that occurs when convection currents beneath the ocean floor force magna up in an area where two tectonic plates meet at a divergent boundary. The adjacent plates move apart; seafloor spreading results. The connection of the world's mid-ocean ridges forms a single global mid-oceanic ridge system that winds its way among the continents. This submarine system is the longest mountain range on Earth. It is more than 50,000 km (31,069 mi) long and, in places, more than 800 km (497 mi) across. It rises an average of 4,500 m (14,764 ft) above the seafloor. As the seabed moves away from the mid-ocean ridge, it cools and shrinks. The ocean becomes deeper until it reaches oceanic trenches where it is subducted.



Global mid-oceanic ridge system
Source: USGS's "This Dynamic Earth"



Computer-generated topo map of segment of Mid-Oceanic Ridge
Source: USGS's "This Dynamic Earth"



Source: Colorado University

Volcanoes are vents or fissures in Earth's crust through which gases, molten rock (magma), and solid fragments are discharged. The name is used for both vent and conical mountains or cones that are built up around the vent by the erupted rock materials. They are nearly always situated at boundaries between tectonic plates and over hot spots. When they form underwater they may eventually break the ocean surface as new islands.

Volcanic arcs are chains of volcanic islands or mountains located near the edges of continents. These arcs are formed as a result of tectonic plate subduction as one plate is pushed beneath another and volcanoes form near the plate boundary. Note: Not all volcanic arcs are arcuate; some are linear.

c. Throughout the ocean there is one interconnected circulation system powered by water density, wind, tides, and the Earth's rotation.

Winds drive surface currents creating the great ocean gyres that dominate ocean basin circulation. The shapes of ocean basins and adjacent land masses influence the path of circulation.

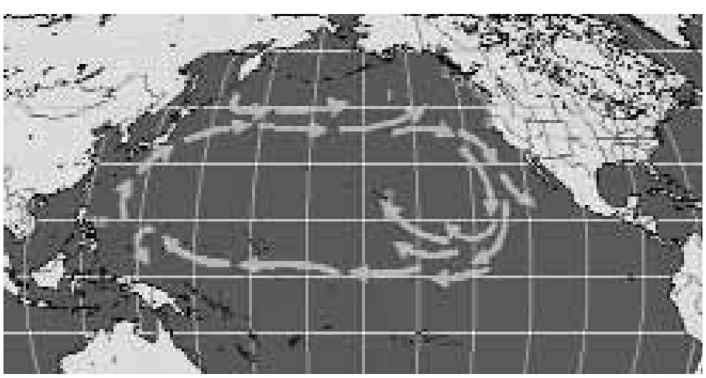
There are four prevailing wind patterns.

1. Trade winds (easterlies). Blow steadily from the east towards the equator. Trade = seaman's talk for "steady."
2. Westerlies. Blow steadily from west, near 40^{o} N and 40^{o} S.
3. Polar easterlies.
4. Monsoonal winds. Air masses that move because of differential heating of continents and the sea. Monsoonal winds vary with the seasons.

Surface ocean currents are generally wind-driven and develop their typical clockwise spirals in the Northern Hemisphere and counter-clockwise rotation in the Southern Hemisphere due to an effect whereby a body moving in a rotating frame of reference experiences the **Coriolis effect** acting perpendicular to the direction of motion and to the axis of rotation. In wind-driven currents the **Ekman spiral effect** (tendency for ocean currents to propagate at an angle to the surface winds) results in the currents flowng at an angle to the driving winds. **(See Concept 3 for additional information).**

Gyres are large-scale circulation patterns that develop in the surface waters in each hemisphere. The currents form because the driven water masses are confined to basins. The word gyre specifically refers to the circular path of the circulation. Gyres such as the North Atlantic Gyre develop and remain in motion as a result of prevailing wind patterns. They are dynamically balanced between the influences of the Coriolis effect and gravity. In the Northern Hemisphere, gyres circulate clockwise and in the Southern Hemisphere, they circulate counterclockwise. The bulk of gyre circulation occurs in the top few hundred meters of the water column, although some circulation is maintained to a depth of about 1,000 meters (3,280 mi). The pileups of warm water in the centers of the gyres result in topographic differences in the height of the ocean surface throughout the world ocean. Acting like flywheels, they also help maintain the patterns of currents. Prevailing winds drive the great gyres that dominate circulation in each ocean basin.

Currents in the North Pacific move in a clockwise gyre. These great current systems can trap debris originating from sources along the North Pacific rim. Plastics and other wastes accumulate in the region which includes the foraging areas of Pacific migrating bird colonies.



North Pacific gyre
Source: Seawifs/NASA

The **Oyashio Current** is a cold subarctic ocean current that flows south and circulates counterclockwise in the western North Pacific Ocean. It collides with the **Kuroshio Current** off the eastern shore of Japan to form the **North Pacific Current or Drift**. The nutrient-rich waters of the Oyashio Current are the basis for one of the richest fisheries in the world.

The **Kuroshio Current** is an ocean current found in the western Pacific Ocean off the east coast of Japan, where it merges with the easterly drift of the North Pacific Current. It is analogous to the Gult Stream in the Atlantic Ocean. The warm waters of the Kuroshio Current sustain the coral reefs of Japan, the northernmost coral reefs in the world. This current is also known as the "Black Stream," the English translation of Kuroshio, and an allusion to the deep blue color of its water.

The **California Current** is a Pacific Ocean current that moves southward bringing cold water past California and helping to make its coast colder than coastal areas of comparable latitude on the east coast of the U.S. (For additional information on circulation in the Southern California Bight, see the section “The Southern California Bight.”)

The Southern Ocean has the world's largest ocean current, the **Antarctic Circumpolar Current**. Uninterrupted by a land mass, the current moves continuously eastward, transporting 130 million m^3 (426 ft^3) of water per second—100 times the flow of all the world's rivers.

The winds derive their energy from the unequal heating of the Earth's surface (including the ocean) by the sun. Where the sun is high in the sky, incoming solar radiation is strong and heating occurs. Where low on the horizon, solar radiation is weak, and heating therefore is weak. Clouds reflect sunlight upward, keeping the Earth below from warming. Clouds also trap infrared rays and re-radiate them downward, warming the Earth below. **(See Concept**

3 for additional information about solar radiation).

The thermocline

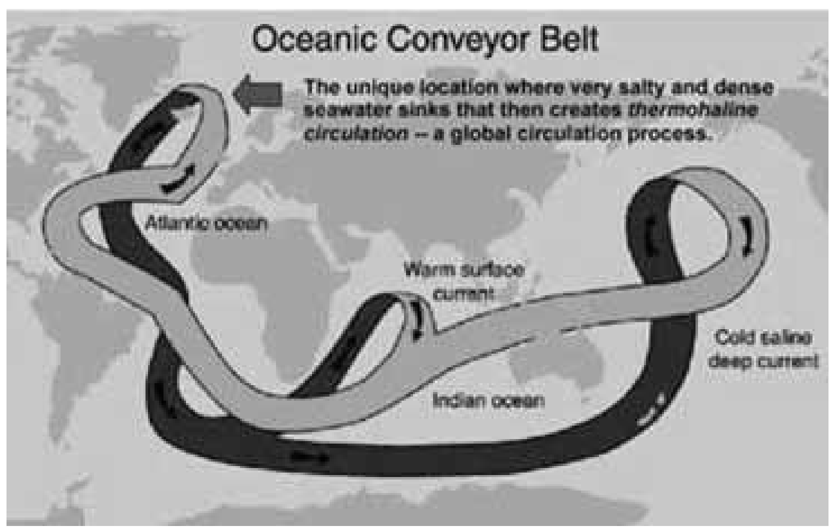
Surface currents involve the water above the **thermocline**, a distinct transition zone of rapid change in temperature that acts as a barrier or division between warmer, less-dense ocean water near the surface from colder, denser water below. The temperature change occurs rapidly as depth increases. This is a natural process occurring between the air and wind influenced surface waters. Where there is no thermocline, i.e., when the temperature is uniform throughout the water column, there is no mixing of surface and deep layers of water and the currents can reach great depth (e.g. the circumpolar current). In the summer in the ocean off southern California, the thermocline is typically about 15-20 m (50-65 ft).

The thermocline is the dominant feature of temperature distribution. Productivity is low where it is stable and high where it is broken by stirring and upwelling. The thermocline can be broken down by heavy wind and cold rain, common during summer thunderstorms. Because most photosynthesis and oxygen production only occurs near the surface, water in the deep layer becomes devoid of oxygen (anoxic) and develops an oxygen demand. When the thermocline breaks down, the oxygen-rich surface waters mix with oxygen-deficient bottom waters.

Water density is mainly a function of its temperature and salinity (concentration of dissolved solids). Many deep ocean currents are driven by gradients in density, which in turn are due to gradients in temperature and/or salinty. Along the western margins of ocean basins, fast moving currents move warm tropical surface water toward the poles.

Movement of bottom water is due to differences in density, in contrast to surface water which is kmoved by wind energy. The amount of dense sinking water is balanced by equal amounts of water rising elsewhere such as in eastern ocean basins including the west coast of the United States. Bottom water moves very slowly, taking an average of 200-300 years for deep water to surface again. Tropical water transport to the polar areas is part of the global conveyor belt for heat.

This extensive mixing that takes place between the ocean basins reduces differences between them, making Earth's world ocean a global system. As they flow, the water masses piggyback both energy in the form of heat and matter—solids, dissolved substances, juvenile organisms, and gases—around the globe. As such, the state of the circulation has a large impact on the planet's climate. **(See Concept 3).**



Source: USGS

Thermohaline circulation

Thermohaline circulation (*therme*=heat, *halos*=salt) refers to the deep ocean density-driven ocean currents. Global ocean circulation and most vertical ocean water movement are due to thermohaline circulation which is also called the "ocean conveyor belt."

Climate change and ocean circulation

Some scientists believe that there is a possibility that global climate change may lead to changes in ocean circulation. There is some indication that initial circulation changes have already begun, based on observations that the water salinity of the North Atlantic has decreased, i.e. "freshened" in the past 40 years and that the salinity of the deep ocean is now decreasing as well. These changes may signal a shift or disruption in ocean circulation and may mean a change in the deep ocean circulation. Most climate models indicate the conveyor is responsive to global warming, and on the postive side, few models project a complete conveyor shutdown within the next century. However, it has happened before.

At the end of the last ice age about 116,000 years ago, the melting of large ice sheets on the continents funneled large volumes of fresh water into the North Atlantic. This altered the formation and flow of of deep ocean currents. This is shown by analyses of ice cores, deep-sea sediment cores, and other geologic evidence. This shut down the formation of deep water currents for about a millennium between 13,000 and 12,000 years ago. The changes lasted for about 1,000 years until the deep ocean cirulation was restored. Changes in temperatures in Greenland, northern Europe, the Arctic, and elsewhere are revealed in paleoclimate records.

d. Sea level is the average height of the ocean relative to the land with the differences caused by tides taken into account.

Sea level changes as plate tectonics change or as global warming melts the polar ice caps and puts more freshwater back into the world ocean. Seawater also expands when heated and contracts when cooled causing rises and falls. During ice ages sea level was far lower than during warm interglacial periods.

World-wide average sea level is called **eustatic** sea level. Local and regional sea levels are called **isostatic** sea levels. They may differ from the world-wide average because of local or regional land movements, either up or down.

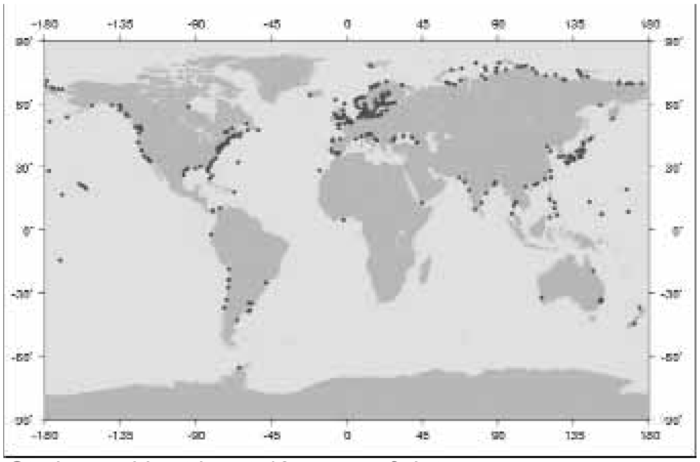
There are five major categories of physical effects of sea level rise. These are inundation of low-lying areas, erosion of beaches and bluffs, salt water intrusion into aquifers and surface waters, higher water tables, and increased flooding and storm damage. California's coastal areas experience these during El Niño events and winter storm surges.

Land loss due to relative sea level rise is a coastal area problem that is aggravated by high levels of local and regional subsidence. In the Mississippi delta area, which has the largest rate of loss in the United States, there has been a net loss of wetlands during this century of up to 100 km (124 mi) per year, and the situation will be aggravated if sea level rise increases by the amounts predicted to accompany global warming in the future. The flooding impact of the Hurricane Katrina on the area was related in part to loss of protective wetlands.

Tracking sea level changes

The basic and long-standing method of measuring sea level changes is by use of tide gauges. These instruments measure the height of the sea relative to a nearby geodetic benchmark at regular intervals. Many scientists believe that useful results are obtained only when data have been accumulated for over 50 years. The number of sites with at least 40 years of such data is shown in the graphic on page 19.

Since 1933, the Permanent Service for Mean Sea Level (PSMSL) based in Liverpool, England has been responsible for the collection, publication, analysis, and interpretation of sea level data from the



Stations with at least 40 years of data
Source: PSMLS

global network of tide gauges. The database contains over 52,000 station-years of monthly and annual mean values of sea level from over 1,800 tide gauge stations around the world received from almost 200 nations. On average, approximately 2,000 station-years of data are entered into the database each year.

Additional information about sea level change is derived from a number of sources including recovery of old and unpublished data, monitoring of crustal movements and Earth angular momentum, repeated observations of water column height, ocean modeling, artificial sources and sinks of water on land, retreat of small glaciers, satellite and other surveys of polar ice sheet elevation, and satellite altimetric determinations of global sea level. Satellite observations are proving to be an important source of information about trends that affect the ice mass balance and sea level change.

Sea level is related to extremes of climate change. As an example, at the beginning of the last deglaciation 18,000 years ago sea level was about 100 m (328 ft) lower than it is now. Future changes in ice sheet mass balance will be a complex function of accumulation and melting as well as dynamic ice sheet behavior.

Future sea level change predictions

California

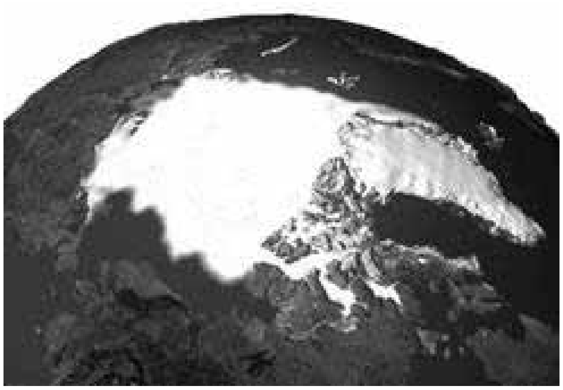
Over the past ten years sea level off southern California has been measured as rising at a rate of about 2 mm/yr (0.08 in/yr). In contrast, during the last glacial period, sea level fell along the California coast by over 200 m (600 ft). Rivers running offshore over what is now the mainland shelf of southern California cut valleys in the shelf that became submarine canyons. Once sea level rose these valleys were covered with water.

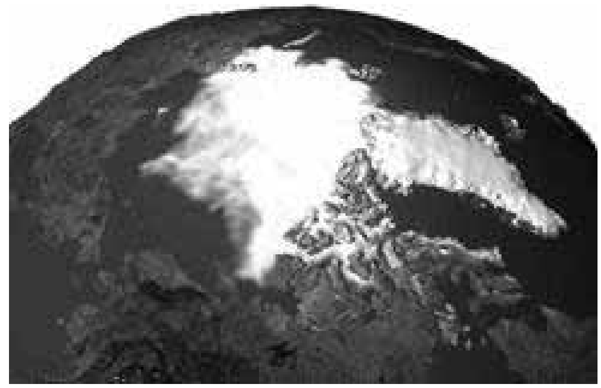
Scientists predict sea level in California will rise 25 cm (10 in) or more this century. Some suggest that the rise may be as much as 1 m (3.3 ft). Should this happen, the damage from winter swells would increase dramatically. The Union of Concerned Scientists states that a 30 cm (12 in) rise in sea level would result in a 10-year storm (a storm of an intensity that might be expected every 10 years or so) doing the damage of a 100 year storm because waves would come further into shore. In addition when a storm approaches a coast it pushes a storm surge ahead of it. Higher sea level would have a dramatic effect on coastlines.

The Arctic

Recent studies of glaciers in Alaska already indicate an accelerated rate of melting. This rapid retreat of Alaskan glaciers represents about half of the estimated loss of mass by glaciers worldwide, the largest contribution by glacial melt to rising sea level identified for any region.

The *Arctic Climate Impact Assessment,* a four year study of the Arctic climate that involved an international team of more than 300 scientists, was released in 2004. The scientists used a number of climate models and made a "moderate estimate" of future emissions of carbon dioxide and other green-





Arctic Ice Cap 1979
Source: Arctic Climate Impact Assessment (ACIA)

Arctic Ice Cap 2003
Source: Arctic Climate Impact Assessment (ACIA)

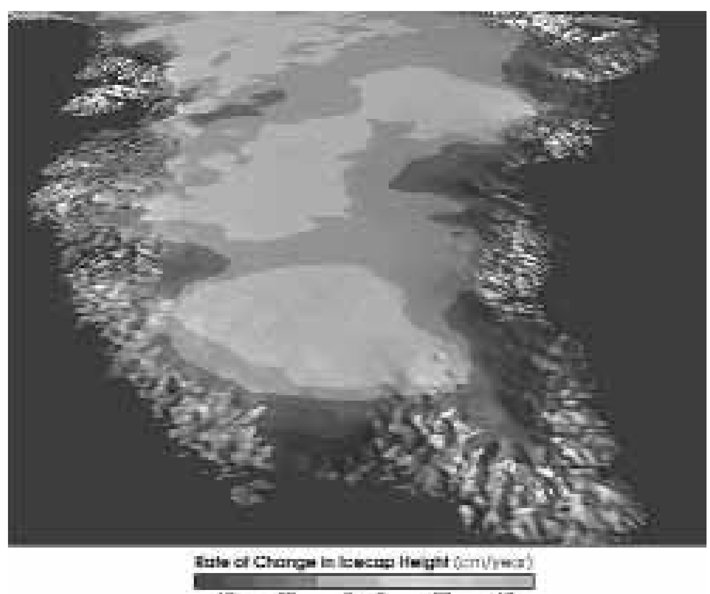
house gases that are widely believed to be contributing to the recent warming trend of the Earth's climate. A general comment was, "...sea ice is retreating, glaciers are reducing in size, permafrost is thawing, and all these indicators provide strong evidence that it has been warming rapidly in the Arctic in recent decades. The Arctic is the air-conditioner for the world and we are looking at having a much less efficient air-conditioner."

Projected Sea Ice Extent from Five IPCC Models for September

Source: NASA

Some of the conclusions given in the report about changes in the Arctic are:

- In Alaska, western Canada, and eastern Russia, average temperatures have increased as much as 3 to 4^{o} C (4 to 7^{o} F) in the past 50 years, nearly twice the global average. Temperatures are projected to rise 4 to 7^{o} C (7 to 13^{o} F) over the next hundred years.
- The rising temperatures are likely to cause the melting of at least half the Arctic sea ice by the end of the century. A significant portion of the Greenland ice sheet—which contains enough water to raise the worldwide sea level by about



Rate of change in icecap heights
Source: NASA

7 m (23 ft) would also melt with dramatic effects.

- The health and food security of some indigenous Native American and First Nation peoples would be threatened, challenging the survival of some cultures.
- Should the Arctic become ice-free in summer, it is likely that polar bears and some seal species would become extinct.
- The melting of so much ice, and the resulting addition of so much fresh water to the ocean, could impact the circulation of currents and affect regional climate.

One of the scientists said: "What's really interesting is that the past three summers (2002, 2003, and 2004) have been characterized by record or near record minimums of total Arctic sea ice area. Have we approached a threshold beyond which large parts of the ice are unable to survive the summer? We don't know."

United States Southeast Coast

The ACIA states that low-lying coastal areas in Florida and Louisiana could be flooded. A 50 cm (1.5 ft) rise in sea level could cause the coastline to move 45 m (150 ft) inland, resulting in substantial economic, social, and environmental impact in low-lying areas.

e. The world ocean has an average salinity of 3.5 percent and properties that make it unique from fresh water.

Seawater compared to freshwater

Sea salts change the normal properties of water. The freezing point of seawater is lower than fresh water, its boiling point is higher, its density is higher, its electrical conductivity is much higher, and it is slightly basic (alkaline).

Composition of seawater

Ocean water is a complex solution of mineral salts and decayed and dissolved organic matter. Most of the ocean's salts were derived from gradual processes such as the breaking up of the cooled rocks of the Earth's crust by weathering and erosion, the wearing down of mountains, and the dissolution of minerals on land. Some of the ocean's salts have been dissolved from rocks and sediments below its floor. Other sources of salts include the solid and gaseous materials that escaped from the Earth's crust through volcanic vents (and continue to do so) or that originated in the atmosphere. Earth's rocky crust is the source of positively charged ions, and gases released during volcanic eruptions, and hydrogen sulfide, sulfur dioxide, and chlorine. Hydrothermal vents both supply chemicals to the ocean water and remove them. They may play an important part in stabilizing the ocean's salt composition. It is believed that over geologic time the salt in the ocean has come primarily from volcanic "outgassing" and to a lesser extent from eroding land, chemical reactions at the seafloor, and atmospheric deposition.

Gases move between the ocean and the atmosphere at the sea surface. Atmospheric gases dissolve in the seawater and are distributed by mixing processes and currents. The most abundant gases in both the atmosphere and ocean are nitrogen, oxygen, and carbon dioxide. Argon, helium, and neon are present in small amounts but they are inert and do not react with seawater as the major gases do in photosynthesis. Dissolved oxygen concentrations vary from 0-10 mm/l (0-0.34 oz) of seawater. Concentrations are very low in the bottom waters of isolated sea basins which have little or no exchange or replacement of water.

Some of the problems confronting scientists stem from the enormous size of the ocean and the complex chemical system inherent in a marine environment in which constituents of seawater have intermingled over very long periods of time. Sodium chloride comprises about 85 percent of the ocean salt. Probably all the Earth's naturally occurring elements exist in the sea. Elements may combine in various ways and form precipitates that sink to the ocean floor. These precipitates are subject to chemical alteration because of the overlying sea water which continues to exert its environmental influence.

Ocean Water Salt Content

Sea salts	Parts per thousand
Chloride	19.30
Sodim	10.70
Sulfate	2.70
Magnesium	1.30
Calcium	0.40
Potassium	0.40
Bicarbonate	0.15
Other	0.13
Total salinity	**35.08 o/oo**

The salinity of open ocean seawater averages about 35 parts per thousand or 3.5 percent or 35.00 o/oo. Salinity is a measure of all the total solids dissolved in the seawater.

Residence Time

All dissolved materials in seawater pass through cycles. They occur on land or in the atmosphere; are transferred through erosion, diffusion, or advection in the ocean; are used by biological organisms, or directly precipitate out into deep sea sediments. The amount of time a material spends dissolved in ocean water is called its **residence time**. Residence time can range from a few hours (nitrate) to millions of years (sodium). Because the major constituents of seawater do not change their ratios to each other with changes in salinity, and because they are generally not removed or added to by living organisms, they are referred to as **conservative constituents**. Certain of the elements present in much smaller amounts, some dissolved gases, and assorted organic molecules and complexes do change their concentrations with biological and chemical processes that occur in the ocean. These are called **non-conservative constituents**.

Residence Time

Element	Time in Years	Removal Process
Sodium (Na+)	68 million	Evaporite deposition
Chloride (Cl-)	100 million	Evaporite deposition
Magnesium (Mg2+)	10 million	Reactions with newly formed oceanic crust
Sulfate (SO42-)	10 million	Reactions with newly formed oceanic crust
Potassium (K+)	7 million	Reactions with clay
Calcium (Ca2+)	1 million	Shell formation
Lead (Pb)	4 hundred	Removed by particles
Aluminum (Al)	1 hundred	Absorbed on clay particles

Seawater is a well-mixed chemical solution, mixed worldwide over thousands of years. Because of this long mixing time, the relative percentages of the various elements in a given sample of seawater are the nearly the same throughout much of the world ocean. It is believed that the ocean's salty composition has been stable for the last 1.5 billion years.

The principle of constant composition or constantcy of seawater states that regardless of variations in salinity, the ratios among the amounts of major ions in the open ocean waters are relatively constant. (This is not always the case in nearshore areas where river outflows may change the water's composition as a result of their discharges.)

The extensive mixing that takes place among the ocean basins reduces differences among them making Earth's ocean a global system. As they flow, the water masses transport energy in the form of heat and matter as well as solids, dissolved substances, juvenile organisms, and gases around the globe. As such, the state of the circulation has a large impact on the planet's climate. **(See Concepts 2 and 3).**

Changes in salinity

Variations in ocean salinity are due to several factors.

- If there is more evaporation than precipitation, then the salinity **increases** (since salt is left behind when water is evaporated into the atmosphere).
- If there is more precipitation (rain and snow) than evaporation, then the salinity **decreases**.
- If a very large river empties into the ocean, especially after a major storm or series of storms, salinity **decreases**. The runoff from most small streams and rivers is quickly mixed with ocean water by the currents and has little effect on local salinity. However, the runoff from large rivers such as South America's Amazon may change salinity regionally over substantial areas.
- Freezing and melting of ice also affect salinity. The melting of large icebergs (made of frozen freshwater and lacking any salt) **decreases** the salinity of surface waters around the berg, while freezing of seawater **increases** the salinity temporarily. This temporary increase happens in the first stages of the freezing of seawater when small ice crystals form at about -2^{o} C (28^{o} F). These tiny, needle-like ice crystals are frozen freshwater. Liquid between these crystals

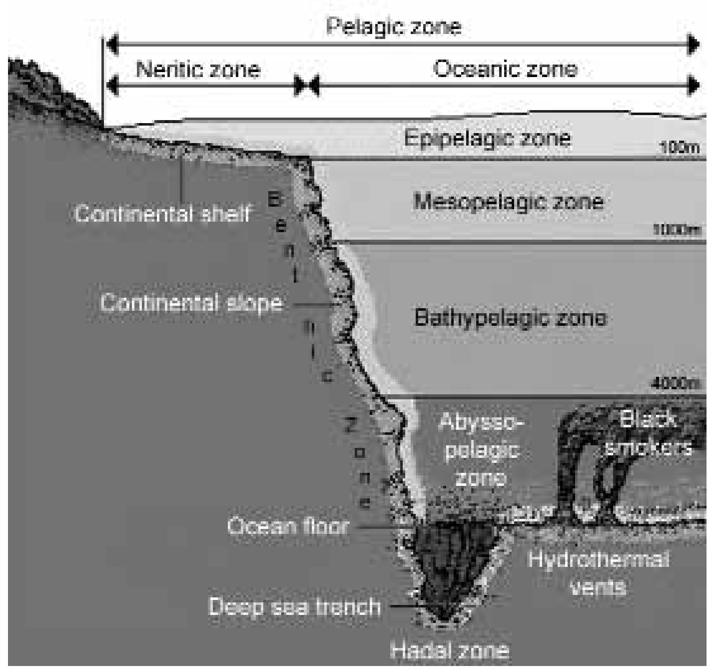
Seawater Reference Standard

In order to assure that determinations of chlorinity and salinity are done in exactly the same way in all the world's oceanographic laboratories, a standard method of analysis and a standard seawater reference have been established. The Institute of Oceanographic Services located in Wormly, England produces standard seawater adjusted to both constant chlorinity and electrical conductance. The standard is shipped worldwide sealed in glass vials as reference material.

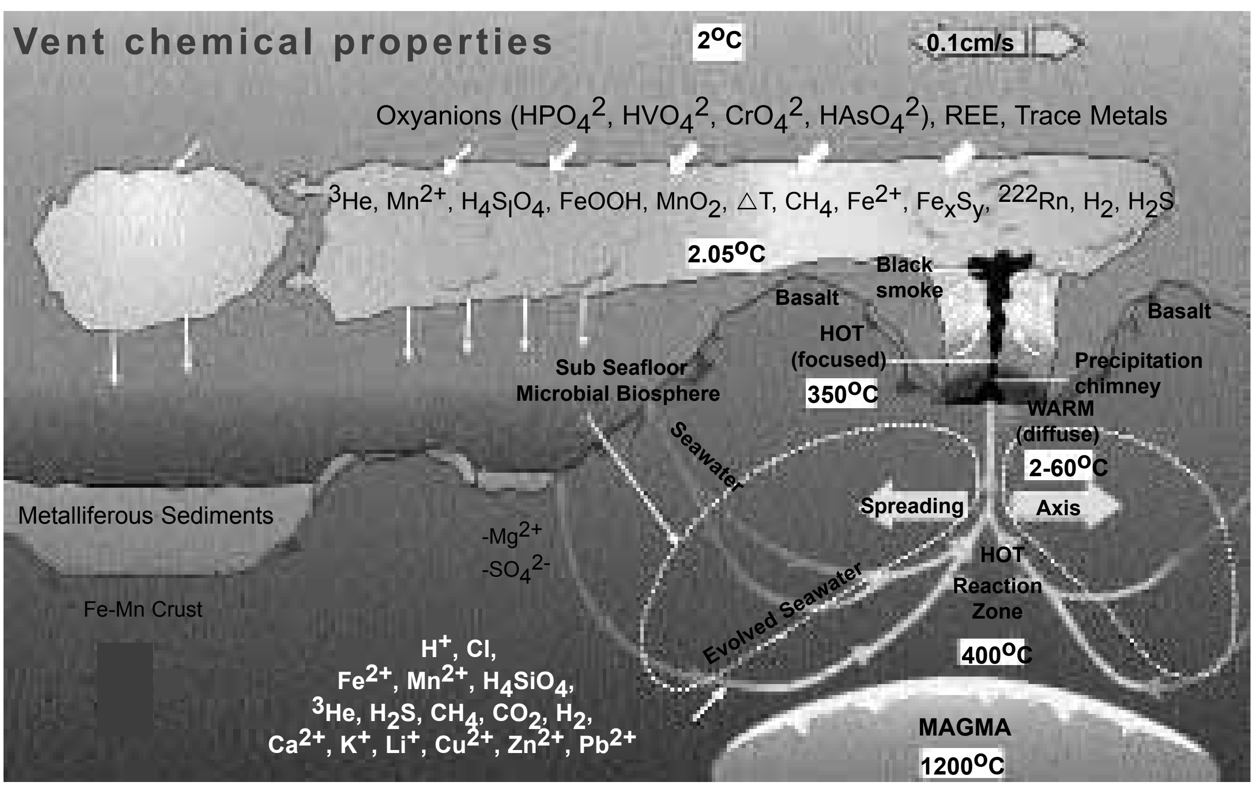
becomes increasingly salty. Being very dense (cold and salty), it sinks rapidly to the seabed. This descent drives most of the world ocean's thermohaline circulation.

Vents and seawater composition

Hydrothermal vents (underwater geysers) occur on ocean ridge systems (e.g., the mid-Atlantic ridge). They occur because cold water is sucked down into the crust through cracks and fissures where it is heated by nearby plumes of magma that cause it to expand and be forced out of openings at the top of the ocean ridges under intense pressure and extreme heat, at temperatures as high as 316^{o} C (600^{o} F). It does not boil due to the intense pressures at these depth. It has been estimated that nearly "all" of the water in the ocean eventually passes through these vents, is heated up to high temperatures, and has many minerals added or removed from it—a process that occurs continuously. This may play a significant role in total world ocean water chemistry.



Hydrothermal vent
Source: Woods Hole Oceanographic Inst.



Source: NOAA

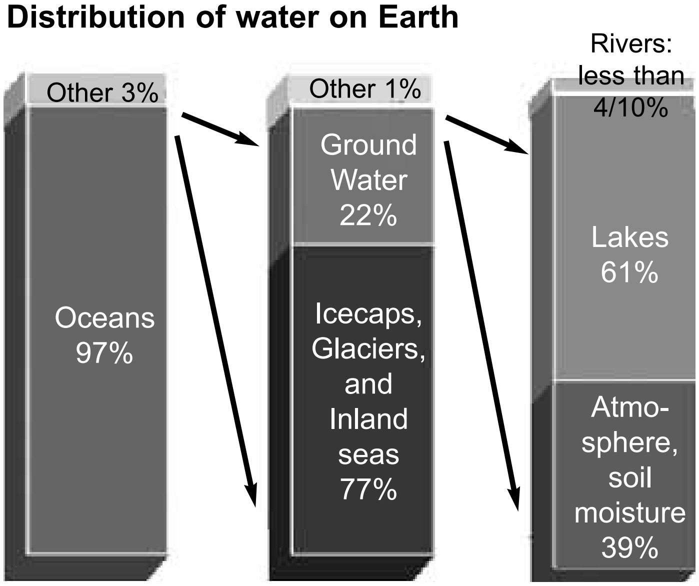
f. The ocean is an integral part of the water cycle and is connected to all of Earth's water reservoirs through water cycle processes including evaporation and precipitation.

Earth's water distribution

The main reservoir for Earth's water is the ocean; the second reservoir in importance is Antarctic ice. How is Earth's water distributed and in what form does it exist? About 97 percent of all water is in the ocean. Of the other 3 percent,

- 77 percent (most of the fresh water) is locked up in saline inland seas, glaciers, and icecaps that are mainly in Antarctica (87 percent) and Greenland (~11 percent).
- 22 percent is in ground water.
- Remaining 1 percent: 61 percent in lakes, 39 percent in atmosphere and soil moisture, and less than 0.04 percent in rivers. It is from rivers and lakes that we get most our water today.

Distribution of water on Earth



Source: USGS

The water (hydrologic) cycle

The water cycle begins with water's evaporation from the sea surface as water vapor. This invisible gas is transported by winds. Most of the vapor condenses over the sea, either near the equator or in higher latitudes. Some of the water vapor is carried onto the continents where it condenses and makes rain, rivers, lakes, and groundwater. The most spectacular example of this process is the Asian monsoon. North America also has monsoons, especially where moist air from the Gulf of Mexico enters the continent. Hurricanes are powered by water vapor and can bring enormous floods.

The cycling of water is intimately linked with energy exchanges among the atmosphere, ocean, and land that determine Earth's climate and cause much of natural climate variability.

The global water cycle includes nine major physical processes and eight others that form a continuum of water movement. The major ones are evaporation, condensation, precipitation, interception, infiltration, percolation, transpiration, runoff, and storage. Complex pathways include the passage of water from the gaseous envelope around the planet's atmosphere through bodies of water on the surface of Earth such as the oceans, glaciers and lakes, and at the same time (or more slowly) passing through the soil and rock layers underground. Later, the water is returned to the atmosphere. Typical of cycles, the hydrologic cycle has neither a beginning nor an end.

Evaporation: the physical state of water is changed from a liquid state to a gaseous state. About 600 calories of energy for each gram of water is exchanged during the change of state. Solar radiation and other factors such as air temperature, vapor pressure, wind, and atmospheric pressure affect the amount of natural evaporation that takes place in any geographic area.

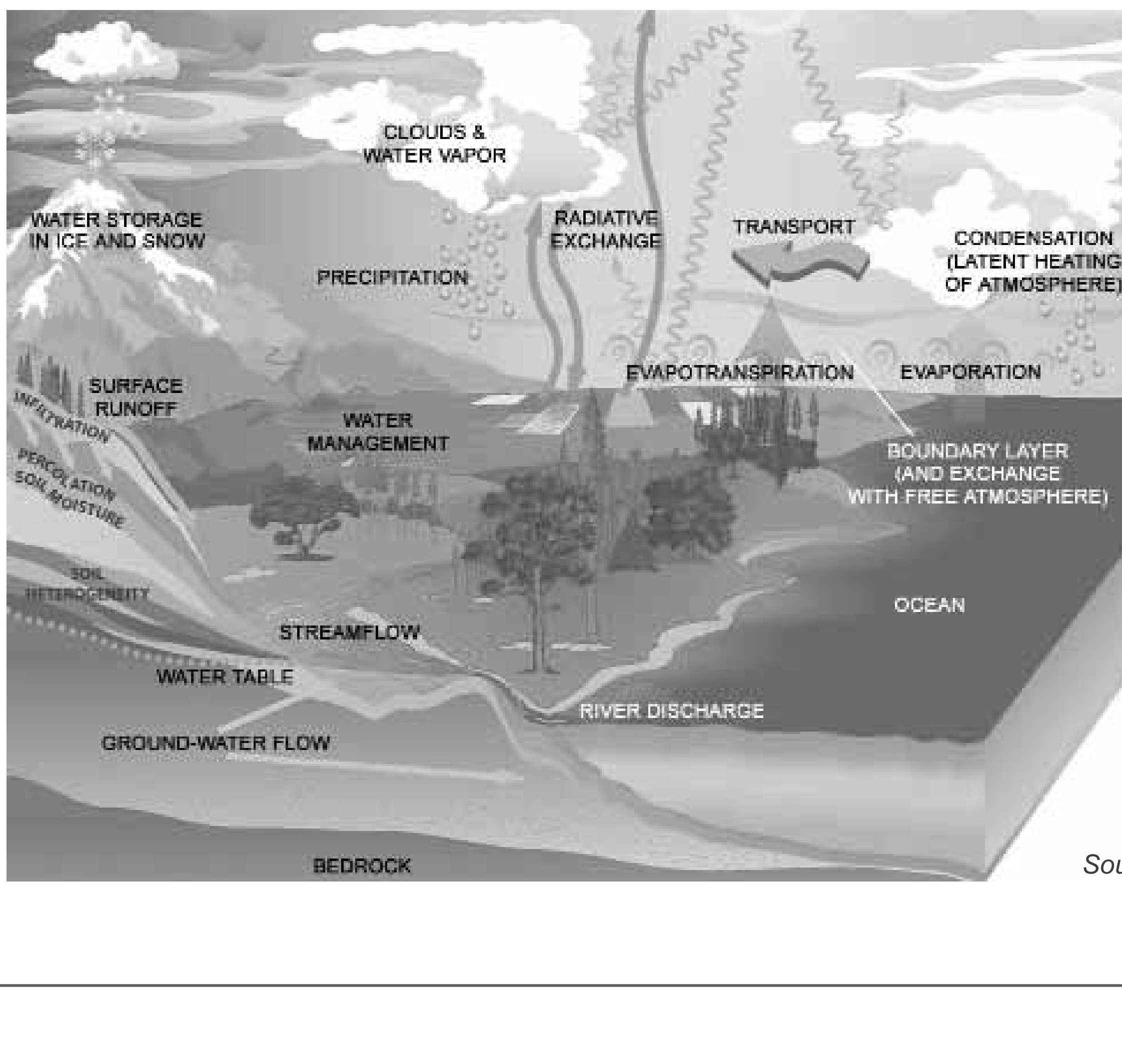
Evaporated moisture is lifted into the atmosphere from the ocean, land surfaces, and bodies of water as water vapor. Some vapor always exists in the atmosphere.

Condensation: process by which water vapor changes its physical state from a vapor, most commonly to a liquid. Water vapor condenses to form dew, fog, or clouds. The most active particles that form clouds are sea salts, atmospheric ions caused by lightning, and combustion products containing sulfurous and nitrous acids. Condensation is brought about by cooling of the air or by increasing the amount of vapor in the air to its saturation point.

Precipitation: process that occurs when any and all forms of water particles fall from the atmosphere and reach the ground. Precipitated water may fall into a body of water or it may fall onto land. It is then dispersed in several ways. The water can adhere to objects on or near the planet surface or it can be carried over and through the land into stream channels, or it may penetrate into the soil, or it may be intercepted by plants. When rainfall is small and infrequent, a high percentage of precipitation is returned to the atmosphere through evaporation.

Interception: process of interrupting the movement of water in the chain of transportation events leading to streams. The interception can take place by plant cover or storage in puddles, and in land formations such as rills and furrows.

Infiltration: physical process involving movement of water through the boundary area where the atmosphere interfaces with the soil. The surface phenomenon is governed by soil surface conditions. Water transfer is related to the porosi-



Source: NASA

ty of the soil and the permeability of the soil profile. Water that is infiltrated and stored in the soil can also become the water that later is evapotranspired or becomes subsurface runoff.

Percolation: movement of water though the soil and its layers, by gravity and capillary forces. The prime moving force of groundwater is gravity. Water that is in the zone of aeration where air exists is called **vadose water**. Water that is in the zone of saturation is called **groundwater**. For all practical purposes, all groundwater originates as surface water. Once underground, the water is moved by gravity. The boundary that separates the vadose and the saturation zones is called the **water table**.

Geologic formations in the Earth's crust serve as natural subterranean reservoirs for storing water. Others can also serve as conduits for the movement of water. Essentially, all groundwater is in motion. Some of it, however, moves extremely slowly. A geologic formation which transmits water from one location to another in sufficient quantity for economic development is called an **aquifer**. The movement of water is possible because of the voids or pores in the geologic formations.

Transpiration: a biological process. Water inside of plants is transferred from the plant to the atmosphere as water vapor through numerous individual openings in leaves. Plants transpire to move nutrients to the upper portion of the plants and to cool the leaves exposed to the sun. Leaves undergoing rapid transpiration can be significantly cooler than the surrounding air. Transpiration is greatly affected by the species of plants that are in the soil and it is strongly affected by the amount of light to which the plants are exposed.

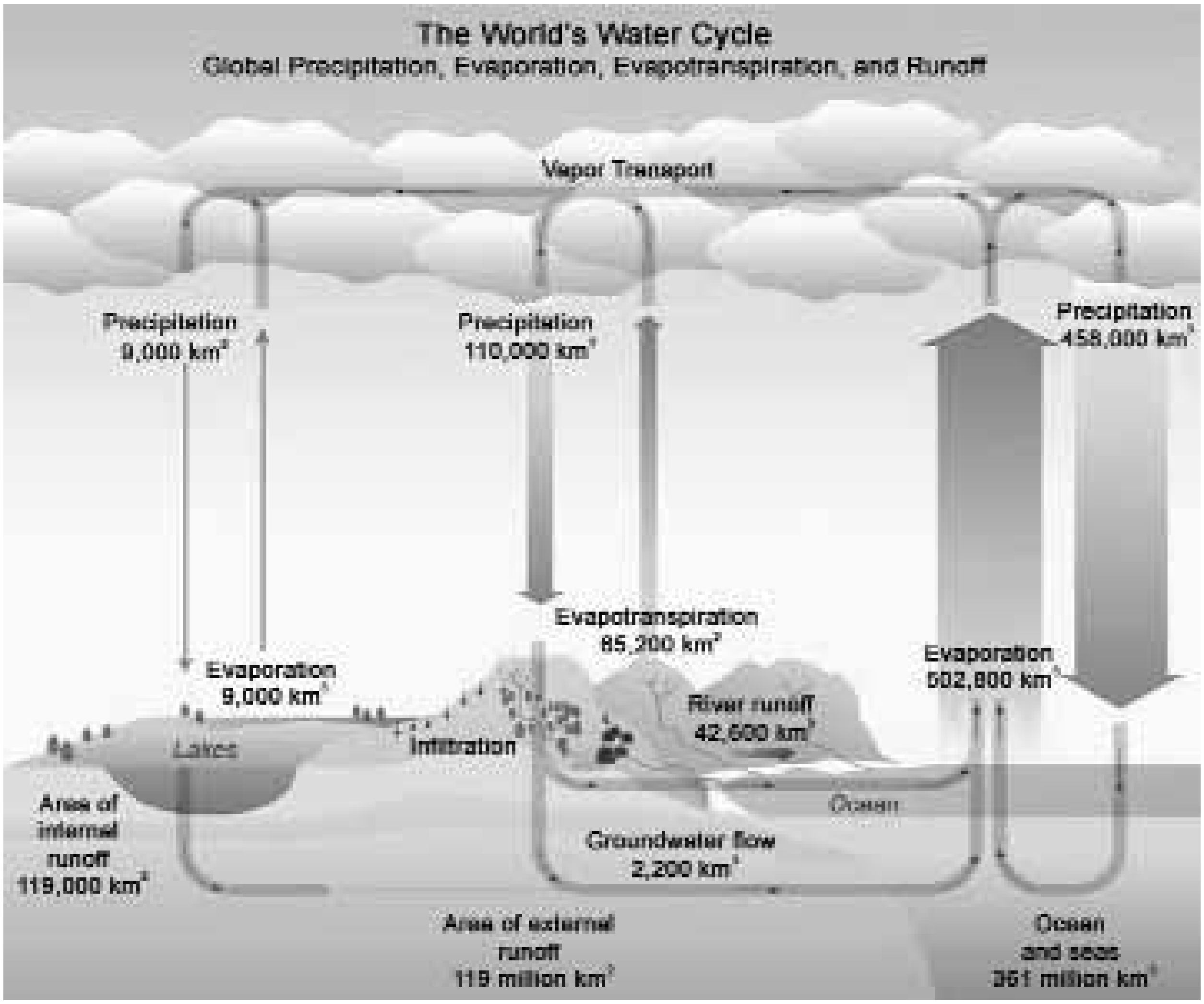
Runoff: flow from a drainage basin or watershed that appears in surface streams. It generally consists of the flow that is unaffected by artificial diversions, storages or other works that society might have on or in a stream channel. The flow is made up partly of precipitation that falls directly on the stream, surface runoff that flows over the land surface and through channels, subsurface runoff that infiltrates the surface soils and moves laterally towards the stream, and groundwater runoff from deep percolation through the soil horizons.

Storage: Three basic locations of water storage occur in the planetary water cycle. Water is stored in the **atmosphere**, on the surface of the Earth, and in the ground. Water stored in the atmosphere can be moved relatively quickly from one part of the planet to another part of the planet. The type of storage that occurs on the land surface and under the ground largely depend on the geologic features related to the types of soil and the types of rocks present at the storage locations. Storage occurs as **surface storage** in oceans, lakes, reservoirs, and glaciers; **underground storage** occurs in the soil, in aquifers, and in the crevices of rock formations.

On average, water in the atmosphere is renewed every 16 days. Soil moisture is replaced about every year. Globally, waters in wetlands are replaced about every 5 years while the residence time of lake water is about 17 years. In areas where there is not much human development, groundwater renewal can be more than 1,400 years.

World water cycle

The total water supply of the world is 1.4 billion km^3 (330 million mi^3). About 12,900 km^3 (3,100 mi^3) of water, mostly in the form of water vapor, is in the atmosphere at any one time. If it all fell as precipitation at once, the Earth would be covered with only about 2.54 cm (1 in) of water.



Source: UNESCO

Water Facts

1. *A human could survive about a month without food, but only five to seven days without water.*
2. *Today approximately 250 million people are using the same water resources that 4 million people used 200 years ago.*
3. *The average American uses about 730 liters (160 gal) of water a day. However, the average California family uses half as much water it did 20 years ago, but there are more Californians now.*
4. *More water evaporates from an acre of corn than from a lake.*
6. *Water poured down the drain, and/or put into the ground, can pollute groundwater.*
7. *One liter (one quart) of oil could contaminate 1,000,000 liters (250,000 gal) of water.*

Water uses

More than 50 percent of all accessible water on continents is now being used by people. Today more than one-third of the Earth's six billion people have inadequate and/or unsafe water supplies.

g. The ocean is connected to the land's drainage system including waterways by the watersheds that carry the drainage's outflow to the ocean.

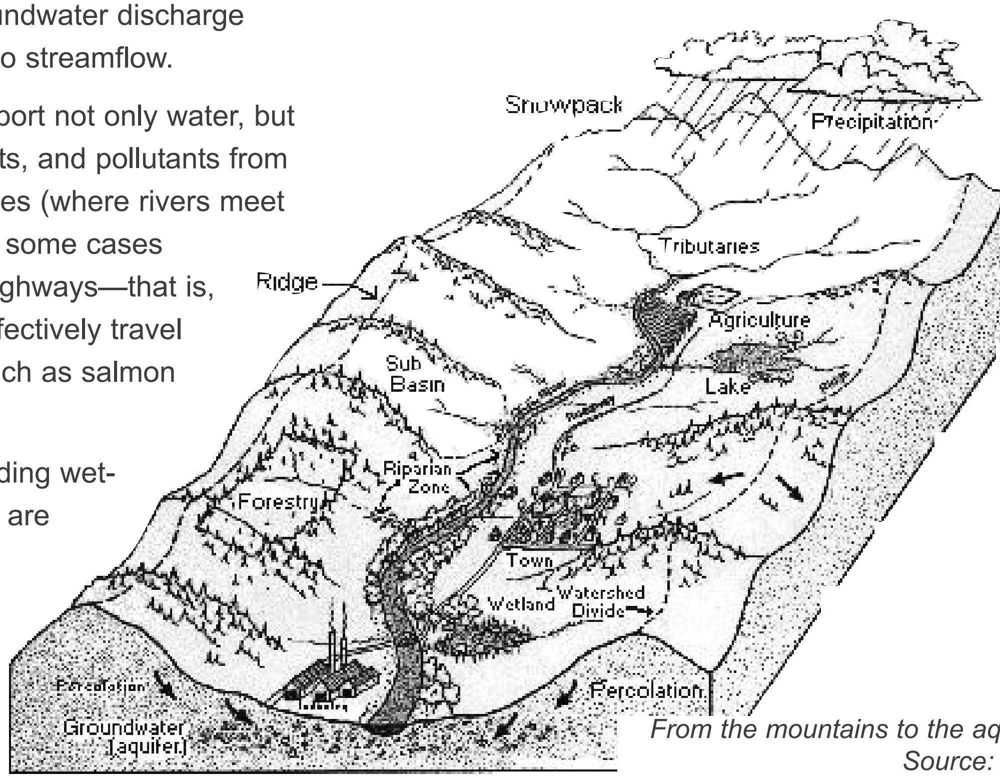
There are many definitions of **watersheds**. Here a watershed is defined as the total land area in a specific region that collects sleet, rain, snow, and runoff, and "feeds" it to a creek, stream, river, or other body of water from which it is ultimately discharged into the ocean. Earth's land and water are directly linked by the water cycle, with water becoming part of the watershed in seasonal cycles as rain or snow. Some precipitation infiltrates the soil and percolates through permeable rock to recharge groundwater storage areas, the aquifers. During dry summer months, natural groundwater discharge often is the main contributor to streamflow.

Rivers and streams transport not only water, but also nutrients, salts, sediments, and pollutants from watersheds to coastal estuaries (where rivers meet the sea) and to the ocean. In some cases they can serve as two-way highways—that is, nutrients and biomass can effectively travel up-river, in the form of fish such as salmon and steelhead trout.

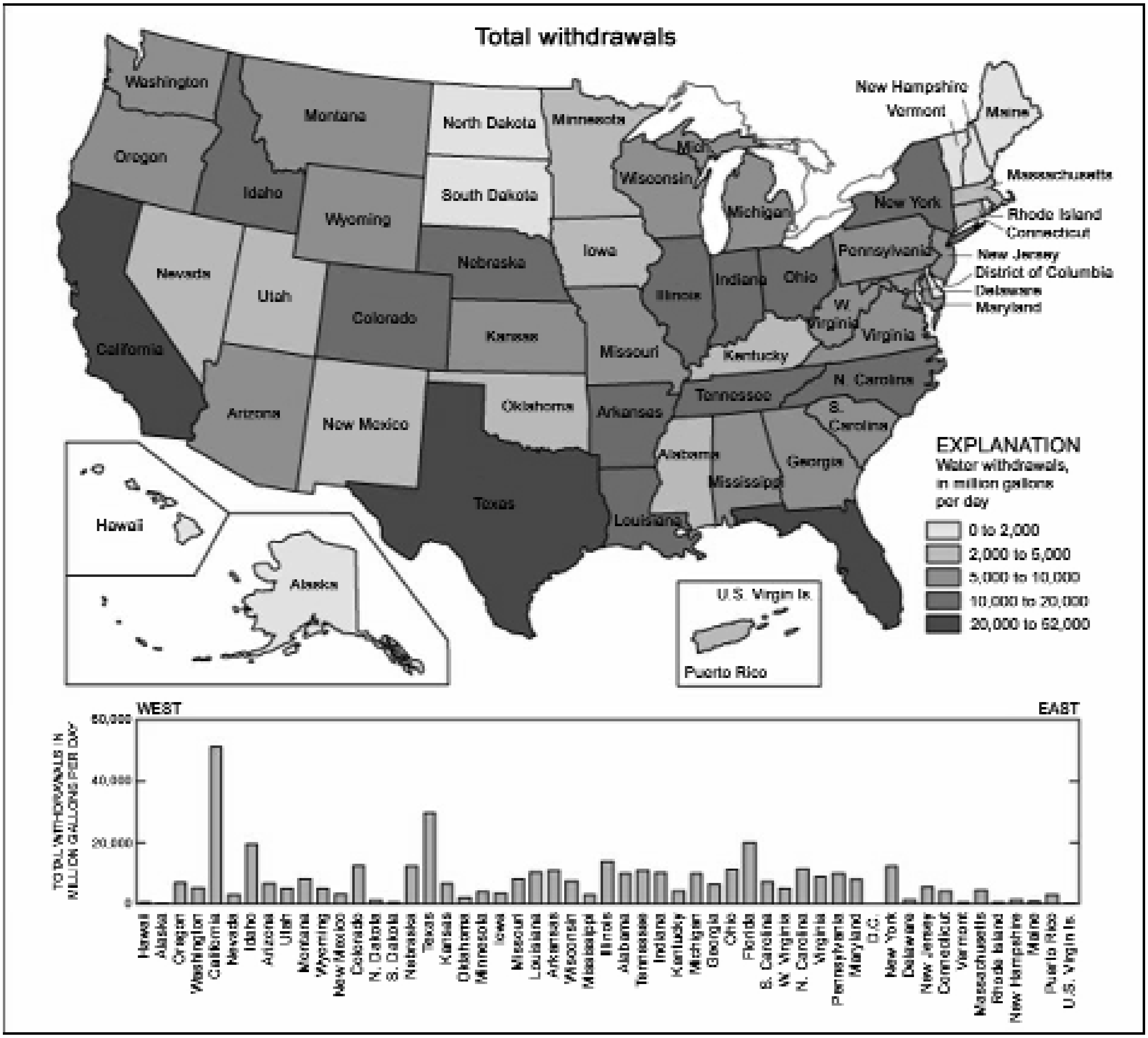
Estuarine systems including wetlands, mudflats, sloughs, etc. are among the most productive ecosystems on Earth. They are natural recycling systems that recharge groundwater supplies and help ensure pure drinking water and filters that remove nutrients and some contaminants from runoff water before emptying into streams and rivers, lakes, and estuaries. These natural systems can also function as flood control systems.

An **estuary** is a semi-enclosed coastal body of water that is freely connected to the ocean and within which sea water is mixed with and significantly diluted by freshwater. This results in the formation of low salinity water called brackish water, the salinity of which is close to that of the internal salinity of many ocean organisms making it less difficult for them to osmoregulate.

Because of up-river development, agriculture, conversion of important nearshore environments to marinas, filling-in for airports and industrial parks, point and nonpoint pollution, etc., many estuarine systems have been lost and others are declining in productivity (see grahic on page 30). In some estuaries, invasive species also pose an increasing threat to natural populations.



From the mountains to the aquifer
Source: EPA



Source: EPA

Water quality is largely determined by the soils and vegetation in a surrounding watershed, and by human activities including: livestock grazing, agriculture, recreation and urban or industrial development in a watershed. Pollution can have pronounced impacts on water quality of the receiving waters.

Common point source pollutants are discharges from factories and municipal sewage treatment plants that enter waterways from specific points, usually through pipes. Agriculture, urban construction, residential developments, roadsides and parking lots can create non-point source pollutants such as sediment, fertilizers, toxic materials, and animal wastes. Non-point sources are those that are not connected to a specific origin such as a smokestack or treatment plant discharge pipe.

h. Although the ocean is large, it is finite and its resources are limited.

(Note: See also Concepts 6 and 7.)

The ocean is being greatly impacted by overfishing, pollution of estuaries and coastal waters, invasion of non-native species, and many other assaults. Total effects are difficult to predict. Coastal management in which the ocean and land are managed as one integrated system and ecosystem-based management, in which human beings and natural resources are managed in balance, is crucial to protecting our coastal and ocean resources.

Overfishing

Overfishing is one of the most noticeable human acts on the ocean. Many great fisheries, such as the cod fishery that was central to the New England economy for over a century have collapsed from overfishing and mismanagement. Great efforts are being taken in California to prevent a similar fate for rockfish. Wild abalone has been severely depleted in southern California due to a combination of overfishing, disease, and possibly water temperature changes. This is contrasted by a thriving abalone population in northern California, which is disease free and has been managed very differently.

Over 90 percent of human fishing pressure is concentrated in coastal waters of the continental shelves, representing only eight percent of the oceanic area. Moreover, the fishing pressure is concentrated on only a very small number of ocean fish species, many of which are either near or in total collapse.

Ocean resources can be divided into living and non-living, renewable and non-renewable. **Living resources** such as fish are renewable if fisheries—the human activity of harvesting them—are properly managed, and if their essential habitats are protected. Oil and gas are **non-living resources** and are not renewable on time scales of decades, centuries, or even millennia.

Fisheries must be managed in a way that ensures their long-term sustainable use. Unfortunately, in many fisheries, this has not ben done.

The world fish catch in 2000, the most recent year for which global data are available, was reported at 94.8 million tons. After decades of steady growth, the oceanic fish catch has plateaued, and since the late 1980s, fluctuated between 85 million and 95 million metric tons. Some three fourths of oceanic fisheries are thought to be fished at or beyond their sustainable yields. Stocks are declining in one third of these.

Fisheries management practices may be the key to maintaining sustainable world fisheries. These practices vary from country to country and also for most species. Many fisheries have been unmanaged or mismanaged, resulting in their collapse. A collapsed fishery is where the target species population is reduced to where it is no longer economically feasible to continue the fishery and if severe enough may cause its extinction.

Habitat degradation and fishing for the giant totuava (a croaker that grows to as much as 300 pounds) in the Gulf of California, Mexico, has nearly driven it to extinction. A study of the Japanese tuna longline fishery in the Pacific Ocean concluded that catch per 100 hooks had dropped 90 percent and fish size had decreased by 50 to 80 percent. It is difficult, however, to reach consensus among scientists as to how this relates to actual tuna stock size throughout the Pacific. It is generally accepted that since the 1950's, with the onset of industrialized fisheries, we have rapidly reduced the world fisheries resource base and by some estimates, to less than 10 percent of what it was in the 1950s. Removing high percentages of large predator fish threatens ecosystems, with unknown global consequences.

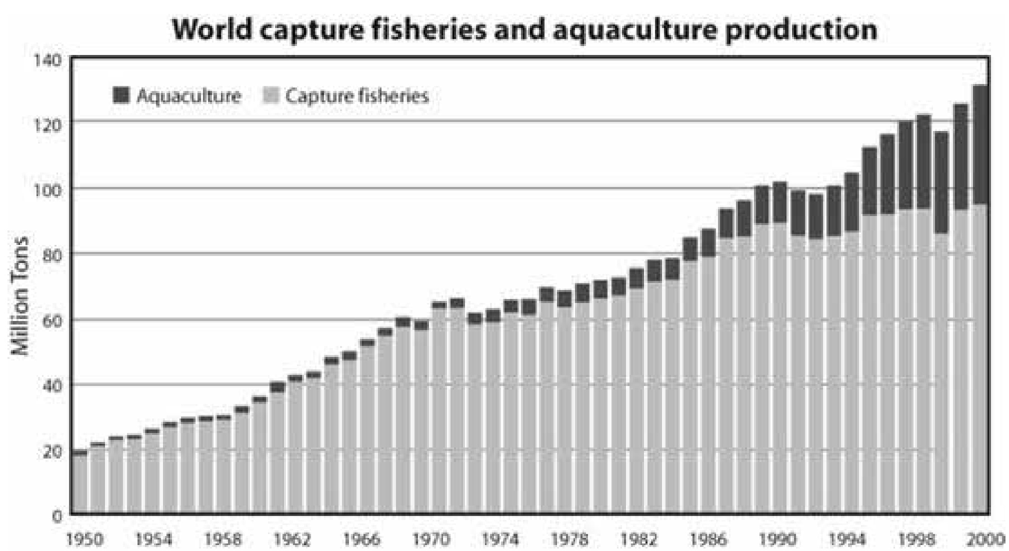
In the United States we have examples of **well managed**, healthy fisheries such as the striped bass in the Atlantic, and Pacific halibut and giant (black) sea bass in the Pacific, and **poorly managed** ones such as the Atlantic cod and Pacific rockfish. Federal and state management programs have been significantly modified in the last five years to address overfishing problems. New regulations for Federal fisheries require that overfishing be defined and corrected before long term problems can develop. Also, bycatch is now being managed to protect non-target fish populations. Marine protected areas such as those in California and Florida are now being evaluated for their role in fisheries management.

At the International level, good fisheries management practices continue to be an issue for many fisheries, fisheries that are often important to the United States. Many of the fisheries that are overfished are in international waters, and will required better cooperation among all countries involved before the overfishing can be controlled. Unfortunately, one or a few countries with a large fishing fleet can overfish a particular species regardless of conservation practices taken by others.

Is aquaculture the solution?

The USCOP report stated that as traditional harvest fisheries have approached and exceeded sustainable levels, the farming of fish, shellfish, and aquatic plants in marine and fresh waters has become a booming global industry. Since 1990, world aquaculture production has grown by almost 10 percent each year, more than twice the rate for poultry, the second fastest-growing sector of the animal protein economy. Total fish-farm production in 2000 was almost 36 million tons. In 1950, aquaculture provided less than one percent of the fish supply; now it accounts for a full 27 percent of the world fish market.

To achieve and sustain its potential, a number of environmental impacts need to be addressed. These include: the spread of disease among fish populations; genetic contamination and competition between farmed and native stocks; and effects from aquaculture operations on water quality, wetlands, and other natural habitats. There are also concerns about destruction of mangrove forests and wetlands for creation of aquaculture operations and the increased demand for fishmeal to feed farmed-raised carnivores. Obtaining fishmeal from traditional wild harvest practices increases the pressure on fisheries that may already be heavily exploited. There are examples of environmentally sustainable aquaculture operations that could serve as models. Most experts believe that it is only through aquaculture that we



*World fisheries and production over time.
Source: FAO*

can meet the increased demand for seafood and also protect wild stocks.

Marine aquaculture in the United States has been minimal compared to world aquaculture production, due largely to economic and environmental factors.

The Role of the Educated Consumers

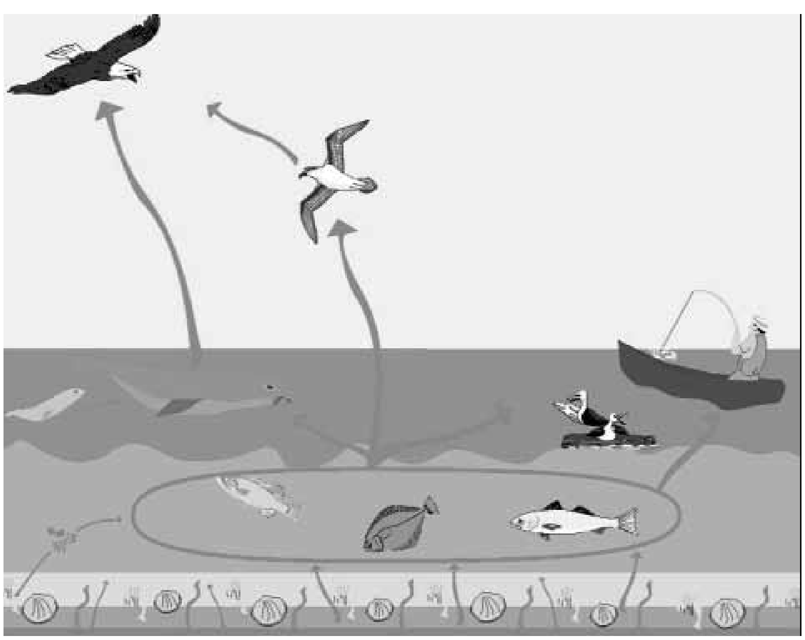
Educated consumers can contribute to sustainable fisheries by purchasing herbivorous fish and those caught from well-managed fisheries of sustainable stocks. To date the Marine Stewardship Council, an independently operated international accreditation organization, has certified 12 fisheries and 11 retailers including the Whole Foods Market which has markets in southern California. Eighteen fisheries are currently undergoing certification. West coast fisheries either certified or undergoing the process include some in Alaska that fish for salmon, pollock, and halibut, Baja California red rock lobster fisheries, Oregon Dungeness crab and halibut, Washington and British Columbia halibut and salmon, and in California, Chinook and king salmon.

The Seafood Watch Guide produced by the Monterey Bay Aquarium in collaboration with other organizations including the Aquarium of the Pacific helps consumers purchase eco-friendly seafood. King's Seafood Company with restaurants in southern California and Nevada is working with the Aquarium of the Pacific to develop a program for restaurateurs that would ensure that the seafood offered on their menus comes from sustainable stocks and is harvested in a sustainable way. Participating restaurants will agree to abide by a sustainable seafood code of ethics.

Researchers need to understand life cycles, ecosystems, population ecology, and other aspects of ocean biology before we can we can manage fisheries sustainably.

The lasting impact of pollution of DDT contamination in the Southern California Bight

From 1947 to 1983 wastewater containing the pesticide DDT was discharged into the Pacific Ocean off White Point on the Palos Verdes Shelf through the outfall pipes of the Los Angeles sewer system. Settling in the sediment on the ocean floor, it



Source: EPA

Source: CDH

remains there to this day, continuing to impact the food chain. Now declared a Superfund Site, studies are underway about how best to decontaminate the sediment.

DDT passes from sediment to plankton to bottom dwellers to fish to birds to marine mammals and to humans (see graphic on page 33).

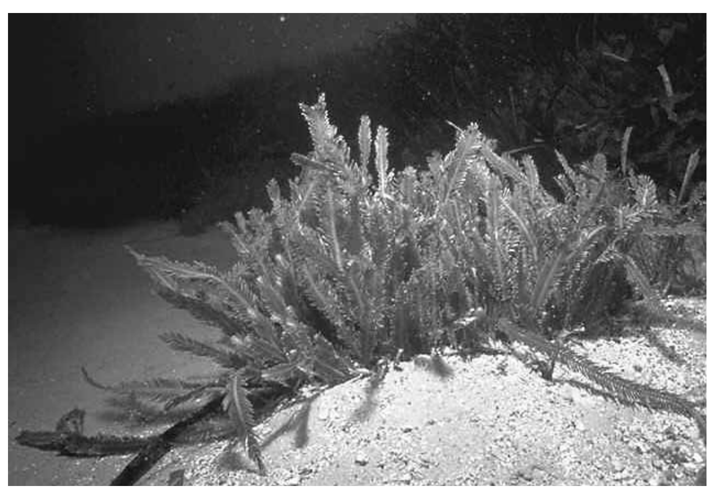
Invasive species

Established ecosystems have their own natural balance to which the plants and animals that live in them have adapted to be able to survive. When non-native species are introduced into an established ecosystem, they can upset the balance and harm the inhabitants and the ecosystem itself. While not all non-natives prove to be harmful, those that do can upset the natural balance, reduce biodiversity, degrade habitats, alter native genetic diversity, transmit disease to native species, add more threats to already endangered or threatened species, or crowd out natives because there is no predator to keep them in check. Two invasive species are described below.

Arundo (*Arundo donax*) or "giant reed" is believed to have been introduced to California in the 1890s for use as wind breaks on ranches. This destructive plant grows rapidly and vigorously in a wide range of conditions. It has been particularly crippling to Escondido Creek, the largest watershed in southern California's Carlsbad Watershed Network (CWN). It can be found in all of California's seven North County watersheds where it serves as kindling for fires during California's fire threat season and creates dams and flooding in the winter. In late 2004 the CWN launched a four million dollar project to remove *Arundo* and other destructive plants such as pampas grass and tamarisk.

"Killer" algae (*Caulerpa toxifolia*) is an extremely invasive seaweed that infests tens of thousands of acres in the Mediterranean Sea and was found in two locations in southern California, Huntington Harbor in Orange County and Aqua Hedionda Lagoon, a coastal marine lagoon, in San Diego County. This particular species is called the "aquarium species" and believed to have been introduced as a result of the discard of home aquarium contents into the ocean waters. The plant, which can grow up to 1 cm (0.5 in) per day has the ability to form a dense carpet on any surface including rock, sand, or mud crowding out native seaweeds and grasses especially eelgrass. A five million dollar effort

Arundo (Arundo donax)
Source: Carlsbad Watershed Network



"Killer" algae (Caulerpa taxiflolla)
Source: NOAA/NMFS

appears to have eradiated the plant from the two California locations. A California law passed as a result of the invasions now prohibits possession, sale, or transport of any *Caulerpa* species in California. At the federal level Importation, interstate sale including Internet sale, and/or transport of the aquarium strain of Caulerpa is prohibited under the federal Noxious Weed Act and the federal Plant Protection Act.

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Key Concept 2

The ocean and life in the ocean shape the Earth.

The ocean is Earth's most important feature. A multiplicity of ocean-processes operating on different spatial and temporal scales help to shape the Earth. Many of these geological processes occur over centuries or millennia-spans of time that humans are not used to thinking about, but which are none the less important.

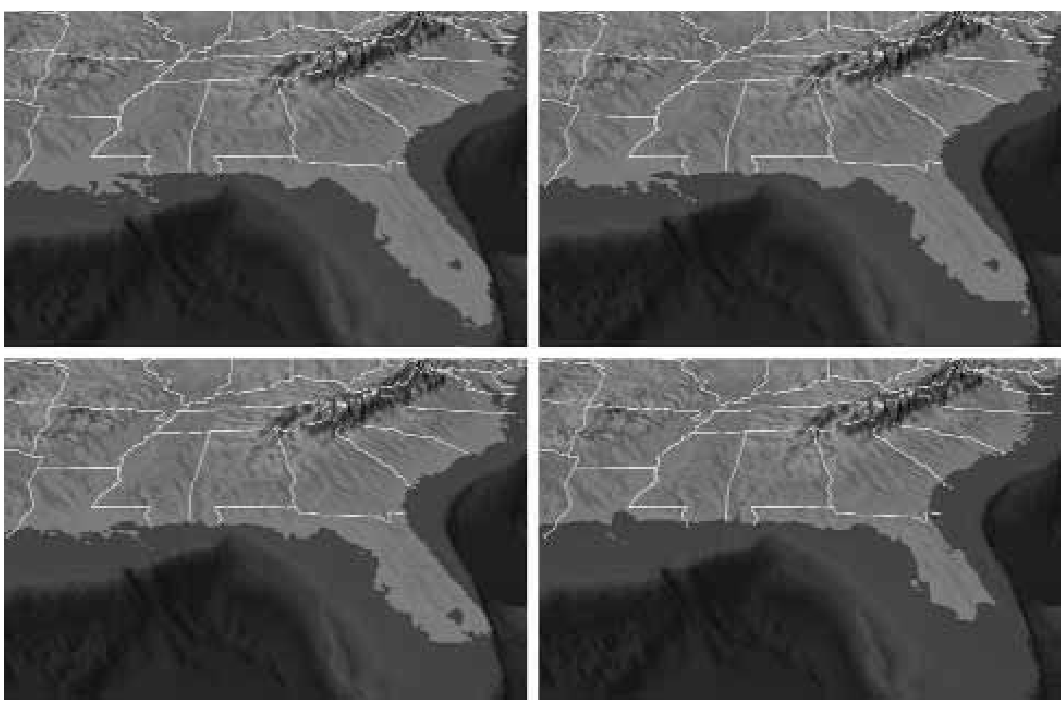
Some of the most obvious influences occur at the coast. A coast is the area where the ocean and landforms meet. The coastal interface extends from the ribbon of coast inland to the watershed. It is at this interface where some of the greatest impacts on people are seen.

a. Sea level changes over time have exposed and flooded continental shelves, created and destroyed estuaries and inland seas, and shaped the coastline and the surface of coastal areas.

What causes sea level change? Is it still happening? In part, some of these changes now appear to be clearly a result of global warming. Warmer temperatures on Earth are causing seawater to expand: they are also causing glaciers in the Arctic and Antarctic to melt increasing the volume of water the ocean and triggering a corresponding rise in sea level. (See Key Concept 3 for more information on global climate change.) Sea level change which occurs due to a change in the amount of water in the ocean is known as **eustasy**.

Sea level change may also occur as a result of shifts in land level-this is called **isostasy**. California's rugged coastline is a classic example. Over time, tectonic activity has uplifted the coast, creating the dramatic cliffs and bluffs that overlook the ocean.

Over the past million years, global sea level has fluctuated as Earth's climate see-sawed between glacial and interglacial conditions. As the oceans exposed and flooded continental shelves over time, so too have the mouths of rivers and wetlands shifted with the changing coastline.

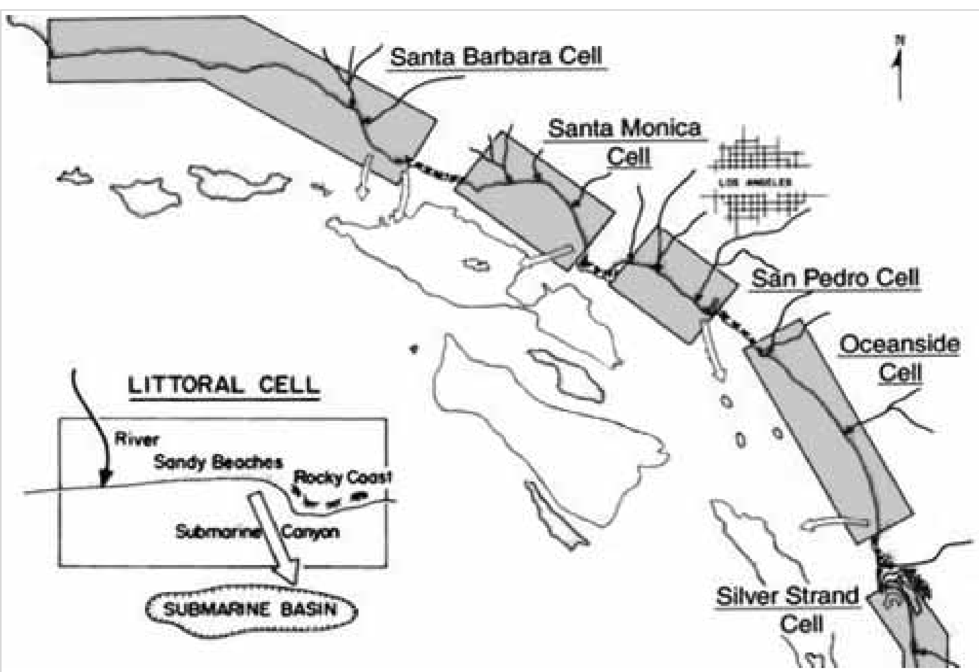


These images above show the potential impact of sea level rise in the southeast U.S. From top-left moving clockwise, these images show predicted impacts if the ocean rises 1 m (3.3 ft), 2 m (6.6 ft), 4 m (13.1 ft), and 8 m (26.2 ft) on SE U.S. coast. Source: NASA

b. Erosion—the wearing away of rock and soil—occurs in coastal areas as wind, waves, and currents in rivers and the ocean move sediments.

Because of their energy and constant presence, waves and currents are the primary movers of sediment along the coast. Climate change can also have a profound influence on the rapidity with which coastal erosion occurs. More frequent and stronger storms, and rising sea level—both consequences of global warming—accelerate erosion.

Humans have tried various methods to counter coastal erosion, especially in areas with dense urban development, including groins, jetties, sea walls, breakwaters, etc. However, in nearly all cases this coastal armoring has had unintended consequences often disrupting longshore current and often increasing the erosion of adjacent coastline. (For more information on the coast and human interaction, see Key Concept 6.)



The littoral cells of Southern California Bight. In these cells, sediment is transported towards the coast via rivers, then south down the coast. Once sediment reaches the end of a cell, it is transported offshore into steep, submarine canyons.

Source: Scripps Institution of Oceanography

c. Most beach sand is carried to the coast by rivers and redistributed by waves and coastal currents. Erosion builds and destroys beaches. Winter storm waves carry sediments away from the beach and small summer waves carry sediments back onto the beaches.

Most beach sand actually begins its journey far from the coast, at the inland headwaters of coastal watersheds. In these areas, the natural erosion of hillsides from rain and snow deposit sediments into the rivers. Eventually this sediment is carried downstream, and when it reaches the ocean is transported and deposited along shore by waves and currents in **littoral cells**. In California, up to 90 percent of the sand on our beaches comes from rivers. A significant amount of the sand supply also comes from eroding cliffs and bluffs.

Today, sediment supply to the California beaches has been interrupted by the extensive building of dams, which trap sediments behind their walls and block the movement of eroded sediments to the beaches. Without these natural "rivers of sand", the large beaches for which California is known are no longer natural. Much of the sand on southern California beaches has to be put there in beach nourishment projects. Bluff erosion now supplies the bulk of sand to the state's beaches.

A **beach** is a place where loose particles (usually sand) accumulates and covers part or all of a shore. This includes not only the observable sand but also the sediment which extends out from the shoreline underwater. In the summer months, gentle waves pile sand up onto the exposed beach, whereas in winter months powerful waves tear the sand away, depositing it in underwater sandbars. These sandbars continually migrate on and offshore as the seasons progress.

d. *Tectonic activity, sea level changes, waves and tides influence the physical structure and landforms of the coast, as well as human-built environments.*

Tectonic activity associated with California's location on the boundary between the Pacific and North American plates has resulted in spectacular sea cliffs, coastal marine terraces, and underwater escarpments and canyons. These landscapes and seascapes continually evolve in response to ongoing tectonic activity, sea level changes, and wave and current action—an ongoing cycle of uplift and erosion.

One example of how these landscapes and seascapes evolve and change on human time scales is slope failures (landslides). Just as slope failure occurs on land (e.g. La Conchita, California), large failures also occur underwater as evidenced in features such as the Goleta Slide on the northern edge of the Santa Barbara basin. Slides can result from long-term processes or can be triggered by catastrophic events such as earthquakes. Slides, both on land and underwater, can have potentially devastating effects on humans (e.g. loss of property and human life from cliff collapse, and the very small but finite possibility of underwater landslides that can trigger tsunamis).

Another striking example of how landforms are shaped by the ocean are marine terraces. The smooth faces of these terraces were cut by pounding wave action at the base of a cliff. Over millions of years, these cliffs were uplifted and as sea level alternated, new steps were cut by the waves. Some of the most extensive and best preserved marine terraces along California's coast are located on the Palos Verdes peninsula in Los Angeles County.

Cliffs along the California coast, a dramatic example of tectonic uplift.
Source: USGS

e. *Many of the sedimentary rocks now exposed on land were formed in the ocean. Ocean life laid down the vast volumes of siliceous and carbonate rocks, which we see today as a result of sea level change and tectonics.*

In California there are many examples of sedimentary rock deposits formed by ocean life now visible on the land. Many of the hills and formations near the coast were once on the ocean floor, deposited by the hard remains microscopic organisms such as diatoms. In addition, many oil deposits and reservoirs in the ocean were formed by deposition of organic matter in the distant past.

Examples:

- Cliffs in Newport Beach Back Bay – carbonate or siliceous)

- Cliffs on Santa Catalina Island (carbonate or siliceous)
- Oil in Long Beach, coastal Santa Barbara/Ventura, and Huntington Beach

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Key Concept 3

The ocean is a major influence on weather and climate.

Earth is an Ocean Planet: ocean water, vital to all life, covers more than 71 percent of its surface. Stirred and mixed by powerful currents, the ocean distributes heat across the globe and helps to regulate our climate.

Earth's climate has changed in the past—and it may soon change again. Rising atmospheric concentrations of carbon dioxide and other "greenhouse gases" produced as a result of human activities could generate a global warming, followed by an associated rise in sea level. But in order to make reliable predictions, scientists must have a quantitative understanding of the roles of ocean physics, biology, and chemistry on society's future health and, especially, on climate change. As pointed out in Key Concept 2 ocean currents are especially important in the dynamics of weather and climate.

a. *The ocean controls weather and climate by dominating the Earth's energy, water, and carbon systems.*

Water is a slow-moving fluid with a very large heat capacity. It will absorb a large quantity of heat, but rise only slightly in temperature.

Mark Twain said, "Climate is what you expect; weather is what you get." The ocean affects weather on a time scale of days. It affects climate on much longer time scales, ranging from years to decades, or even centuries.

b. *The ocean absorbs much of the solar radiation reaching Earth, then redistributes it through surface circulation, regulating the temperature of the planet.*

Like a massive flywheel that regulates the speed of an engine, the vast amount of heat stored in the ocean regulates the temperature of the Earth. The ocean's redistribution of heat keeps the ocean from boiling at the equator and freezing solid at the poles.

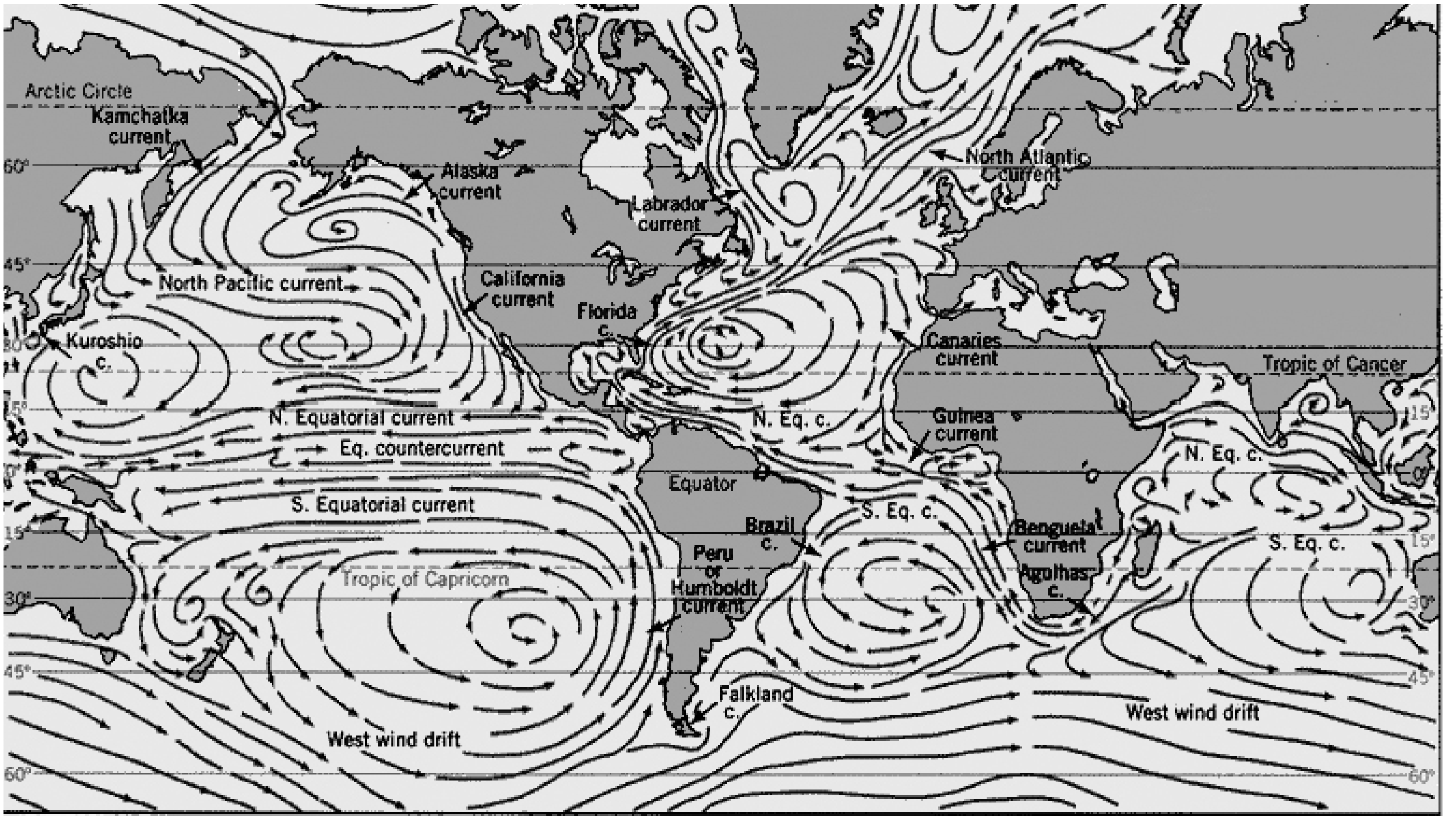
The sun is Earth's main source of energy. Roughly half of the incoming radiation from the sun is absorbed by the ocean. Together, the ocean and the atmosphere transport roughly equal amounts of heat from Earth's equatorial regions (which are intensely heated by the sun) toward the poles, which receive relatively little solar radiation. In the ocean, currents that travel poleward are often located on the far western sides of ocean basins, and so are known as "western-boundary currents."

Conversely, equatorward currents on the eastern boundary of ocean basins bring cold water from the poles down to lower latitudes. A prime example is the California Current which moves cold water from Alaska to the coast, keeping California waters relatively cool year round.

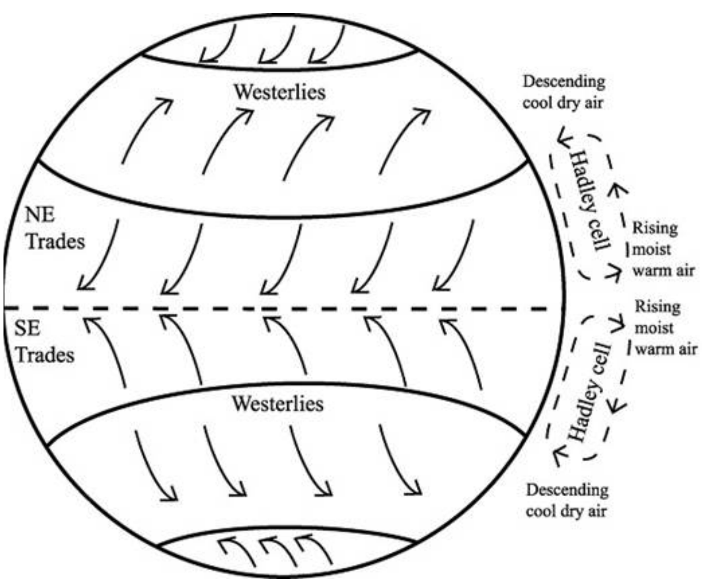
The atmosphere also transports heat through a complex, worldwide pattern of winds. Blowing across the sea surface, these winds drive corresponding patterns of ocean currents.

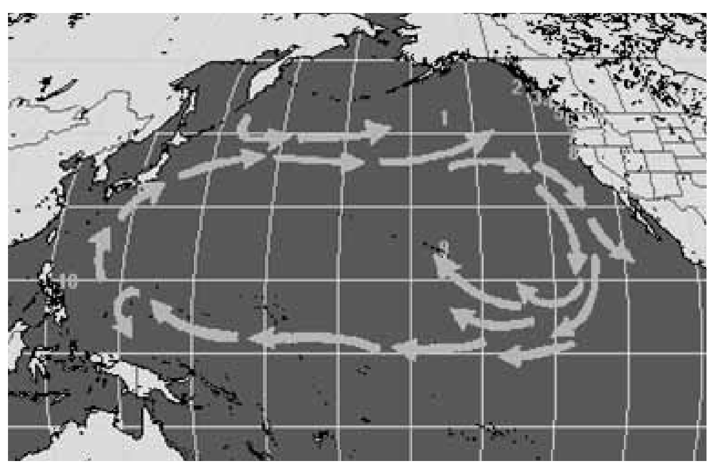
Atmospheric winds sweep the ocean's surface layer along with them. Like sloshing water in a bathtub, this piles up water on one side, raising the height of sea level downwind. The surface of the tropical Pacific Ocean, for example, is normally piled about 50 cm (20 in) higher off Asia than off South America because of the steady westward sweep of the tropical trade winds.

The combination of four forces—the sun's heat, surface winds, gravity, and the Coriolis effect (the



Ocean surface currents
Source: US Navy Oceanographic Office





North Pacific circulation (gyre)
Source: NASA

Impact of atmosphere winds
Source: UCSD

deflection of ocean currents by the Earth's rotation) create enormous "gyres" in ocean basins. Water flows in a continuous circle around the periphery of these basins.

c. ***Condensation of water evaporated from the oceans provides the energy for hurricanes, cyclones, and typhoons.***

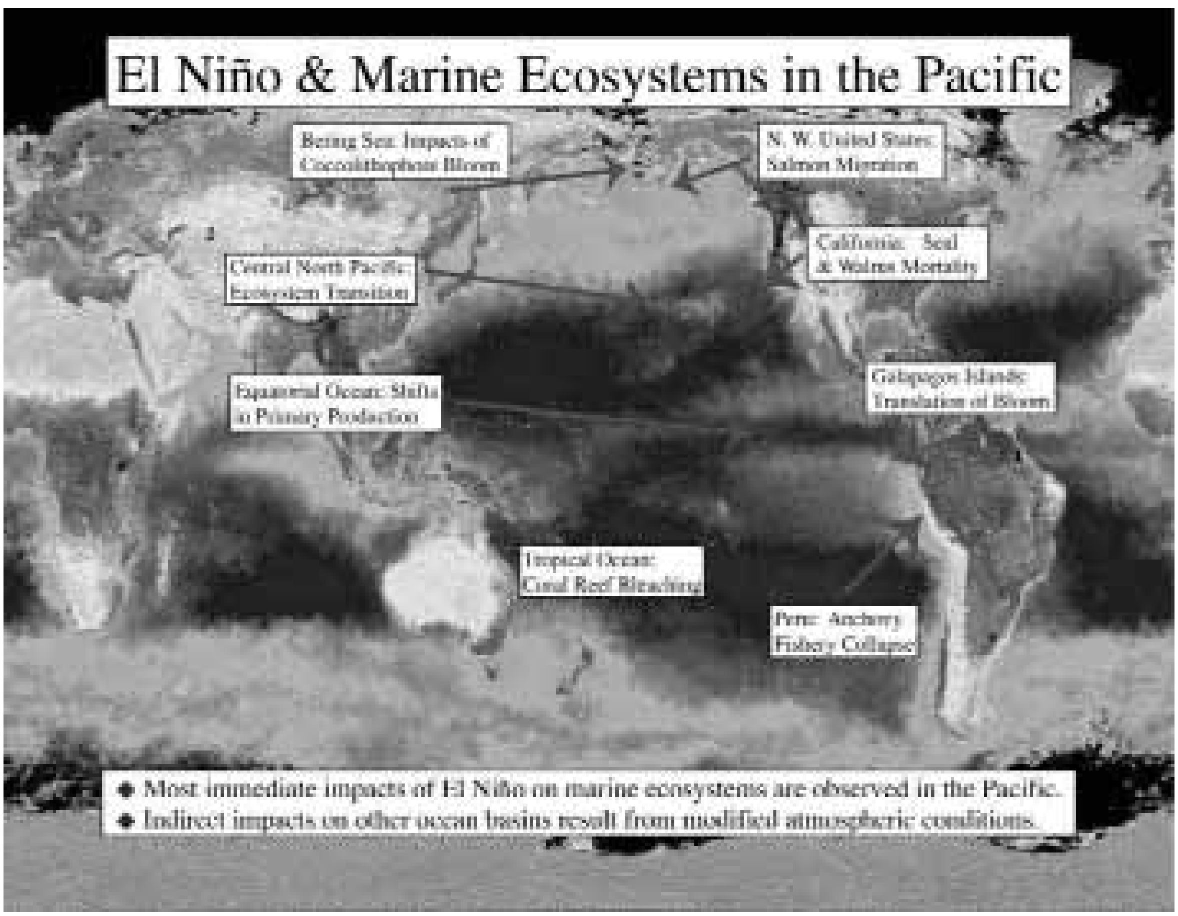
Special Weather Situations

An atmospheric circulation creates storms. When the atmosphere interacts with the ocean, it can create additional changes-such as sea breezes. In coastal southern California, sea breezes act as our natural air conditioner, and also fuel the local phenomeon known as "June Gloom."

d. ***The El Niño–Southern Oscillation phenomenon is one of the most powerful forces driving global weather.***

Many southern Californians are personally acquainted with devastating effects unleashed by El Niño, associating them with lashing rainstorms that can trigger devastating floods and mudslides. In California, damage from flooding associated with the 1997/1998 El Niño was estimated at about $1.1 billion. In the entire U.S. this El Niño was blamed for $10 billion in damages, $3 billion of which was in the agricultural sector. El Niño also reaches worldwide, devastating fisheries in Chile and triggering droughts in Australia.

El Niño is a natural phenomenon generated by



Impact of El Niño on Pacific Ocean marine ecosystems
Source: SEAWIF/NASA

the coupled ocean-atmosphere system.

Roughly every three to seven years, a giant pool of heated water forms in the Pacific Ocean. While a warm water bath may sound pleasant, this heat has disastrous implications when multiplied over such a large volume of water. The amount of heat and energy stored in this pool is vast—and as already noted, heat transfer is the main driver of global climate and weather.

In normal non-El Niño years, the prevailing winds in the Pacific blow west and push warm surface waters against Indonesia and Australia. When warm water builds up in the western Pacific, nutrient-rich cold water rises up off Central and South America, fostering the growth of marine ecosystems (an effect called upwelling).

During an El Niño event, for reasons not well understood, trade winds weaken or stop blowing altogether. The mass of heated water built up in the western Pacific collapse and the warm water begins to flow "downhill" (eastward). Heavy rains tied to the warm water move into the central Pacific-causing droughts in Indonesia and Australia, preventing coastal waters from upwelling thereby devastating fisheries in Central and South America, and altering the path of the atmospheric jet stream.

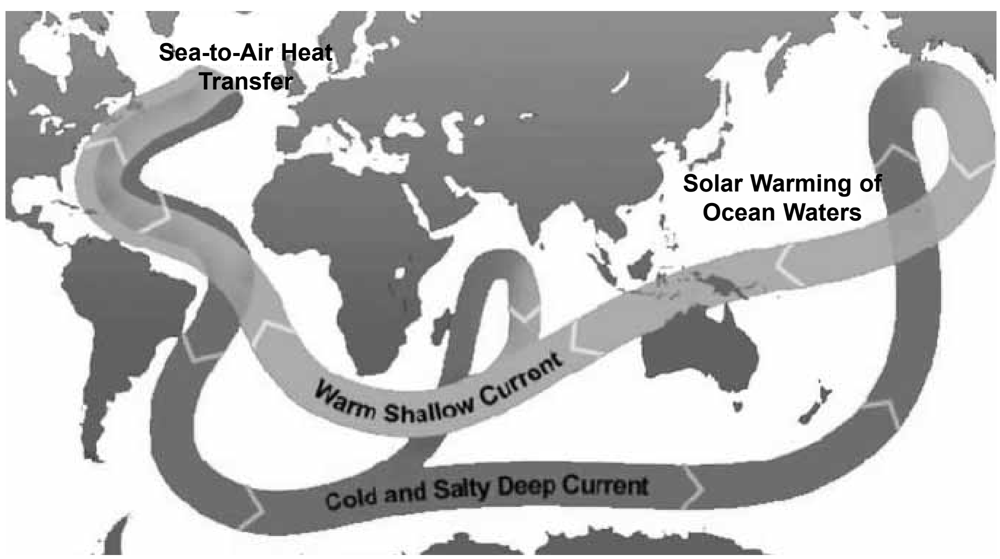
The effects of El Niño disrupt normal winter conditions throughout the Pacific Ocean and around the globe. They can persist into May or June of the following year.

In the past, El Niño conditions occurred approximately every seven years, lasting from 12-18 months, and varying in severity. There is increasing concern in the scientific community that rising atmospheric temperatures are causing El Niños to occur more frequently.

e. The ocean acts as a global conveyor belt for heat, moderating our global climate.

Along the western margins of the oceans, swift and narrow currents carry warm tropical surface waters toward the polar seas, where they lose heat to the atmosphere and then sink into the ocean depths. This sinking is most pronounced in the North Atlantic Ocean. Migrating back toward the Southern Hemisphere above the sea floor, the cold water eventually wells up to the surface layers of the Indian and Pacific oceans. This massive, global circuit of water takes more than 1,000 years to complete a cycle.

The steady oceanic transport of tropical heat to the cold polar seas moderates our climate. Conversely, human activities have the potential to influence this circulation pattern and thus alter the climate.



This conceptual illustration of the ocean conveyor belt circulation illustrates the 1,000 year long cycle. Warm, shallow water is chilled in the far North Atlantic, grows saltier, and sinks. The cold, salty current flows south near the bottom, creating a northward surface layer flow of the warm, less salty water.

Source: Argonne National Laboratory

Ocean Circulation Conveyor Belt

The ocean plays a major role in the distribution of the planet's heat through deep sea circulation. The simplified illustration on the previous page shows this "conveyor belt" circulation, which is driven by differences in heat and salinity. Records of past climate change indicate that there is some chance this circulation could be altered drastically by changes in global climate.

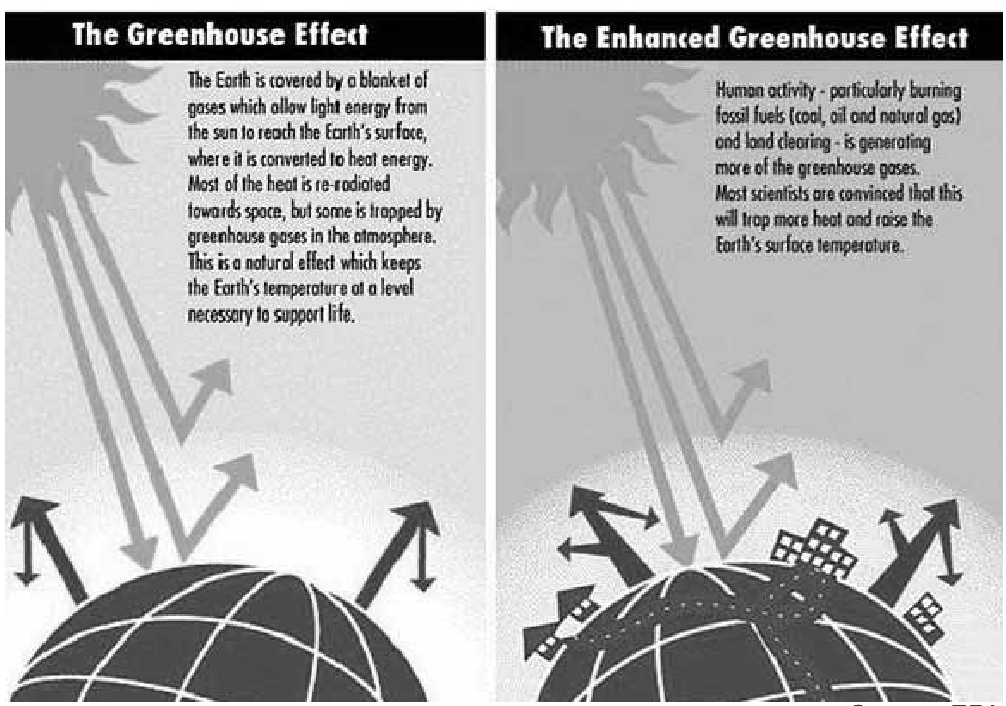
f. The ocean has had, and will continue to have, a significant influence on global climate change by absorbing, storing, and moving heat, carbon, and water around the globe.

The ocean also regulates climate by absorbing carbon dioxide (CO_2), and other greenhouse gases. When released in the atmosphere, greenhouse gases trap heat, warming Earth.

The deep circulation of the global "conveyor belt" is important because its cold waters sink, carrying CO_2 deep into the ocean, making it unavailable to the atmosphere. The ocean is the main reservoir of readily available CO_2. Were all the CO_2 in the ocean to be released to the atmosphere, Earth would be a much warmer place, and climate conditions would be drastically different.

As human activity adds more CO_2 to the atmosphere, this gas is beginning to alter Earth's radiation balance. This alteration may change Earth's climate. Scientists taking careful measurements of Earth's surface temperature have shown that global temperatures have slowly risen over the past 150 years, as CO_2 has built up in the atmosphere. In addition, atmospheric concentration of CO_2 may double in the next 100 years, increasing surface temperatures by as much as 2-8^{o} C (36-46^{o} F), according to some numerical climate models.

Increased surface temperatures will warm the ocean as well and a warmer ocean will not absorb as much CO_2. Under certain conditions, warm waters could 'melt' mineral deposits of methane hydrates on the seafloor, releasing large amounts of methane (CH_4) another important greenhouse gas into the atmosphere. In Arctic regions, increased surface temperatures could lead to massive releases of methane sequestered in large amounts in the permafrost. Some scientists are concerned that such a sudden release of greenhouse gases could trap an intense amount of heat in the atmosphere, effectively flipping an "irreversible switch" on climate change, and perpetuating a destructive cycle.



Source: EPA

U.S. residents currently account forsignificantly higher per-capita emissions of CO_2 than people in any other country. Future atmospheric CO_2 levels depend on human choices.

g. Changes in the ocean's circulation have produced large, abrupt climate change during the last 50,000 years, with far-reaching consequences for life on Earth.

Analyses of ocean carbonate sediments and of polar ice-cap deposits show that atmospheric composition and ocean circulation have both varied dramatically in the past. About 18,000 years ago, during the last Ice Age, CO_2 levels were 40 percent below today's levels and sea level was more than 100 m (330 ft) lower. Today, scientists are intensively working using satellites, numeric models, and modern technology to acquire the understanding of the ocean processes needed to interpret this history and to forecast long-term climate trends.

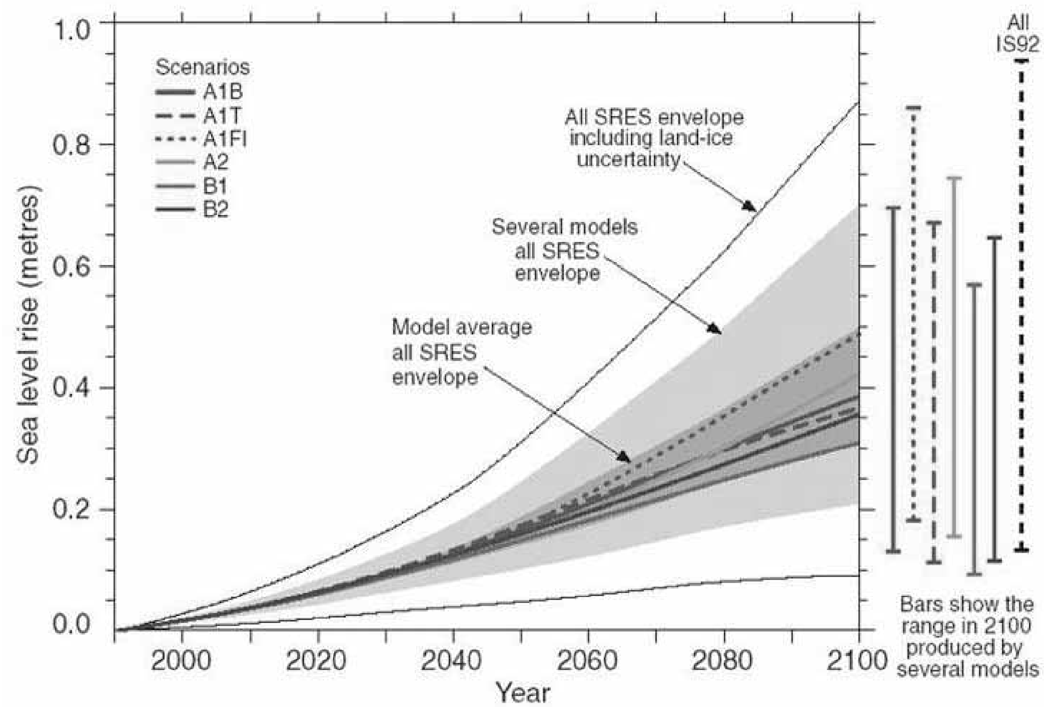
Abrupt climate variations in the distant past appear to have been traumatic for life on Earth. The Earth's biological history is punctuated by "mass extinction events" during which a large percentage of the world's species were wiped out. Although there are many possible reasons for these mass extinctions, records suggest that some of these events coincided with relatively abrupt changes in climate—changes similar in magnitude to the kind now forecast for the 21st century. Over the next 100 years conditions may be experienced that have been unknown since before the Ice Ages began many millions of years ago.

In addition to mass extinction, other effects will accompany global warming. Increased surface temperatures will melt glaciers and the Arctic and Antarctic ice caps, causing a global rise in sea level. This effect has already been observed in the Arctic, where the summer sea ice has receded far beyond its historical levels. Seawater expands as it warms. Some studies project sea levels will rise by as much as 18-60 cm (7-24 in) by the year 2050 and 24-108 cm (9-42 in) by the end 2100. While a few centimeters may seem insignificant, in reality, this would dramatically alter the world's coastlines. Low-lying, coastal areas will be flooded, but in addition coasts will experience increased erosion and accretion. Wetlands will migrate landwards (where they are not blocked by urban development). Increasingly vigorous and numerous hurricanes and storms from an already upset climate system would have even more damaging effects when imposed upon a higher sea level. Recent events such as 2005's hurricanes Katrina, Rita, and Wilma bring these catastrophic consequences home.

Projected Sea Level Rise

The global climate of the 21st century will depend on natural changes and the response of the climate system to human activities. Climate models project the response of many climate variables—such as increases in global surface temperature and sea level— to various scenarios of greenhouse gas and other human-related emissions.

Paradoxically, one of the most alarming scenarios is that global warming could plunge the North America and Europe into a deep freeze. The rapid thawing of glaciers and sea ice in the Arctic would lead to increased amounts of freshwater being dumped into the North Atlantic Ocean. Because density and heat differences drive the global conveyor belt, such a large input of freshwater could effectively shut down worldwide thermal circulation.



Climate models
Source: IPCC Third Assessment Report: The Scientific Basis - Summary for Policymakers, 2001.

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Key Concept 4

The ocean makes Earth habitable.

a. Most rain that falls on land originally evaporated from the tropical ocean.

Ninety-seven percent of Earth's water is contained in the ocean, and the ocean supplies nearly all the water that falls on land as precipitation. Global warming is also causing important changes in the world's water or hydrolic cycle. **(See Key Concept 1 for more information on the water cycle).**

b. Most of the oxygen in the atmosphere originally came from the activities of photosynthetic organisms in the ocean, making the ocean the "lungs of the planet."

Pre-biotic Earth was primarily an anaerobic world. Earth is about 4.6 billion years old and photosynthetic bacteria (the cyanobacteria) date back to about 3.7 billion years ago. Once the cyanobacteria appeared their newly found capacity for photosynthetic production released oxygen into Earth's waters and atmosphere, thus changing them from a reducing to oxygen-based world, a habitable place for life as we know it today.

More than half the oxygen you breathe comes from the ocean. Marine algae that populate the sunlit upper, layer of the ocean, like trees, use available sunlight as a source of CO_2 to produce carbohydrates. One of the byproducts of this photosynthetic process is oxygen (O_2).

What these microscopic marine plants (phytoplankton) lack in size, they more than make up for in numbers. The ocean is so vast that overall, marine plants produce as much oxygen as all terrestrial plants combined. They are the source of roughly half of Earth's primary production—that is the conversion of water, carbon dioxide, and inorganic nutrients into organic matter.

The ocean absorbs between 30 and 50 percent of the carbon dioxide produced by burning fossil fuel. Carbon dioxide is transported downwards by plankton. Any change in the temperature of the ocean water, influences the ability of plankton to take up carbon dioxide. This has consequences for the ecosystem, because plankton forms the base of the food web.

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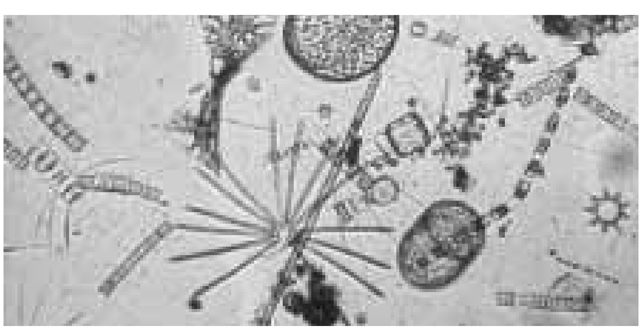
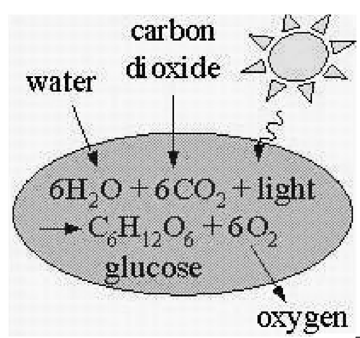


Source: University of Nuremberg



Phytoplankton examples
Source:Aquarium of Pacific

Key Concept 5

The ocean supports a great diversity of life and ecosystems (e.g. kelp forests, coral reefs, and hydrothermal vent communities).

a. Most life in the ocean exists as microscopic organisms, however, ocean life ranges in size from the smallest virus to the largest animal believed to have lived on Earth, the blue whale.

Microscope organisms including bacteria, viruses, and small phytoplankton, are the dominant life form in the ocean in terms of sheer numbers. Together, the mass of all the microbes in the world is likely to be similar to the mass of other size categories of animals. Microbes (bacteria and viruses), while the most abundant life forms in the ocean, are among the least understood.

The diversity of viruses in marine sediments in southern California is astonishing. About 10,000 distinct viral genotypes were found in 1 kg (2.2 lb) of nearshore subtidal sediment in San Diego's Mission Bay. Approximately 75 percent of the genotypes were unknown to scientists.

Data on the concentrations of various picophytoplankton (very small planktonic forms), bacteria, and viruses are given in the chart below which is based on regular sampling of microbes by scientists from the University of Southern California's Carver Laboratory. The sampling was done mid-way between San Pedro (CA) and Catalina Island, (the San Pedro Ocean Time Series station, SPOTS), from September 2000 to December 2003.

These tiny organisms play an important role in the web of life. They have much higher metabolic and respiration rates per unit mass than larger organisms. Microbes are the key controllers of elemental and nutrient regeneration and recycling, and also play a major role in structuring marine ecosystems.

Each milliliter (0.03 oz) of water contains about one million bacteria making bacteria the most abundant form of life in the ocean. However, few people other than scientists are aware of the bacteria and viruses in the ocean since they are rarely responsible for human illnesses. Most of the oceanic viruses infect bacteria and other microbes.

The role of bacteria and other microbes in the ocean was demonstrated in Upper Newport Bay Ecological Reserve (UNBER) in September 2004. A bottlenose dolphin that had taken up residence in

Microbial Sizes and Abundances in the Ocean

Picoeukaryotes
photosynthetic cells <3 microns in diameter
600-74,000 cells/ml
Bacteria
0.3-5 microns
360,000-4.1 million cells/ml
Viruses
0.0005 to 0.1 microns
3.25-101 million cells/ml

Abundances tend to be highest during the spring bloom period, which occurs from February to May, or during the fall bloom period in September or October, but can be transiently high at other times of the year as well.

For full data and methods
http://www.usc.edu/dept/LAS/biosci/Caron_lab/MO

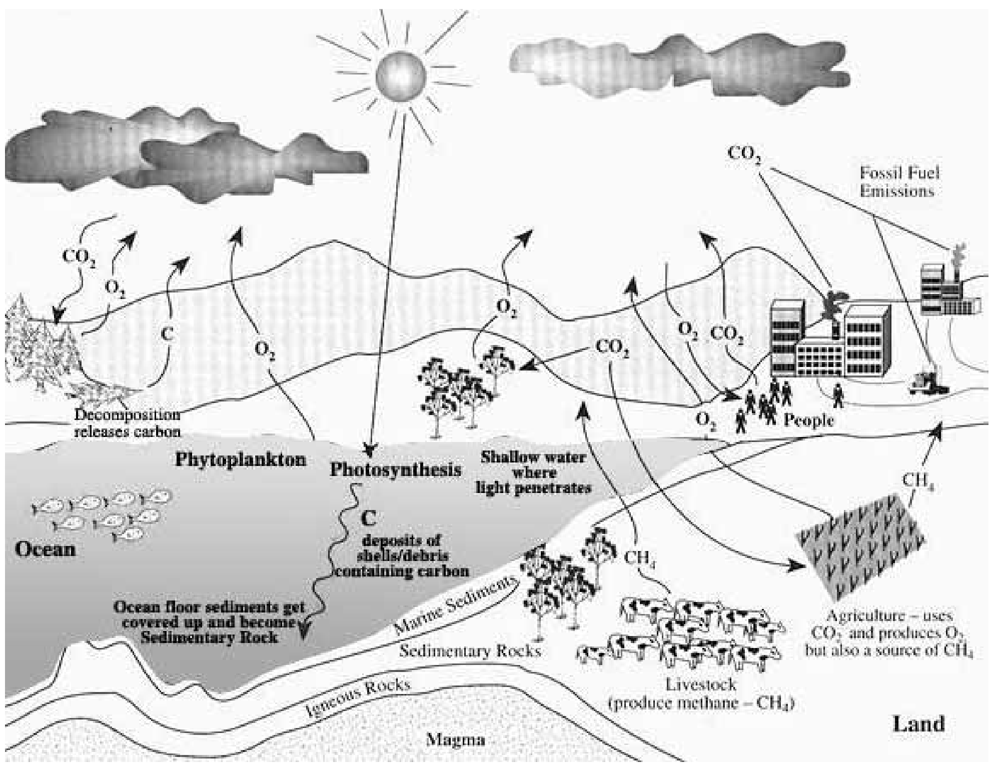
UNBER died in July 2004. In less than two weeks, bacteria and other microbes decomposed the skin, blubber, and organs of the dolphin, leaving only the bones. In time the bones will be gone as well. Bacteria and other microbes recycled all of the dolphin's fat, protein, lipids, and carbohydrates into detritus. The detritus was consumed by filter-feeding sea squirts, mussels, and clams throughout the bay. Eventually, through this process, all of the elements of the dolphin will be returned to the ocean.

b. *Microbial organisms are the most important primary producers in the ocean. Not only are they the most abundant life form in the ocean, but they also have rapid growth rates that range from hours to days.*

Phytoplankton (generally microscopic plant plankton) are primary producers of carbohyrates derived from the marine environment. Primary producers are organisms that can photosynthesize or transform electromagnetic energy (sunlight) into chemical energy (sugar). Studies in both temperature and tropical ocean basins have demonstrated that 50 to 60 percent of the oxygen we breathe comes from the ocean as a result of photosynthesis by phytoplankton and that 80 to 99 percent of the energy produced through photosynthesis is carried out by nanophytoplankton (phytoplankton less than 20 micrometers, 0.0078 in in length). The smallest phytoplankton, from 5 micrometers (0.00020 in) to less than 1 micrometer (<0.000039 in) in length, produce a high percentage of the total energy. These tiny phytoplankers have very rapid growth and reproductive rates, on the order of hours from one division to the next.

Bacteria can transform existing potential energy (e.g., dead plants and animals) into detrital particles or dissolved organic matter which is eaten by many marine life forms. This process of decomposition takes only a few days due to the very high growth rate and rapid reproduction of bacteria. Bacteria can divide and reproduce into hundreds of new generations per day that consume and convert dead plants and animals into food for other organisms.

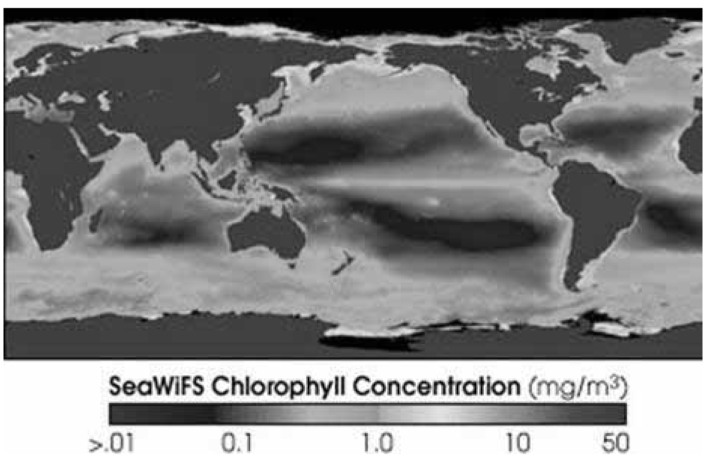
The amount of matter decomposed by bacteria is almost equivalent to the primary production (photo-



This illustration of the global carbon cycle shows how phytoplankton, algae, seaweeds, and land plants fix carbon from carbon dioxide in the ocean and atmosphere and create carbon compounds that form the basis of both ocean and land food chains and food webs.

Source: Bigelow Laboratory for Ocean Sciences synthesis) by phytoplankton. One major difference is that bacteria continue to decompose matter during the night whereas phytoplankton can photosynthesize only during the day when sunlight is plentiful. An interesting variation: hydrothermal vents, ocean bacteria use bound iron and sulfur instead of sunlight as an energy source.

Vast numbers of photosynthetic plants, primarily phytoplankton, form the base of the food chain for much of the sunlit surface waters of the ocean. New analytical techniques for processing satellite images of ocean color make it possible to measure the hue and brightness of **plankton pigmentation**. This is giving scientists tools to study growth/death rates of phytoplankton for the first time.



Source: NASA's SeaWIF Project

c. Most major groups of organisms have many representatives living in the ocean.

All animals and plants have a "niche" or role they play in ocean communities and many different types of organisms interact to form a marine community, such as that of a kelp forest. A **community** consists of groups of populations of different, often interacting, organisms in the same general area. Organisms may play different roles, such as predators, scavengers, detritivores (detritus feeders), decomposers, and primary producers. Species from many different groups of plants and animals fill these niches in a marine community. Resident species can include plants such as green, brown and red algae as well as marine flowering plants, (for example, eel grass). There may also be different animal groups such as sponges; sea anemones and jellies; marine worms; marine snails, clams, squid, and octopus; marine crabs, lobster, shrimp, and barnacles; sea stars, sea urchins, sea cucumbers, and brittlestars; and advanced animals, such as sea squirts and salps; sharks; fishes; reptiles; birds; and marine mammals.

Species diversity, the number of species present in an area, is one way to characterize the health of a marine communities. Species diversity in any marine community is higher where all the species present are native to that area and not introduced. Every year marine scientists are discovering and identifying new species. Scientists with the Census of Marine Life (CoML) report that three new fish species have been identified each week since 2000, 1,700 non-fish animal species, and numerous marine plants. Presently, 210,000 marine life forms of all types are known to scientists but it is estimated that the total count could be as much as 10 times higher if all existing species were known.

Scientists have identified 70 phyla to encompass all described animals on earth, from bacteria to blue whales. The oceans support more than 1.6 times the number of phyla on land and the vast majority of genetic diversity on Earth exists in the ocean.

Animals and plants have adapted to virtually every habitat the ocean has to offer—sunlit and dark, salty and brackish, shallow and deep, water column and ocean floor, warm and cold, rocky and sandy, rough and calm. Each species has adapted in one way or another, sometimes uniquely, to seek prey, feed, compete, reproduce, hide, defend themselves against predators, and/or move.

Examples of Adaptation

Large baleen whales: do not have teeth. Most feed primarily on tiny shrimp-like krill by straining them from the ocean waters using fibrous, fringing baleen plates made of keratin that hang from their upper jaws.

Sea cucumbers that inhabit the deep sea crawl along the bottom of the ocean and draw mud into their bodies from which they remove detritus particles of food that have drifted down to the bottom from the ocean surface or near it.

Rock fish are lurker/lungers—they sit on the bottom in shallow water on top of rocky reefs looking up for silhouettes of species of fish they eat. When they spot one, they lunge (swim rapidly) to the surface for a quick meal. Once the meal is devoured, they return to the rocky reef to again assume a lurking lookout.

Whale Falls—A Modern Interesting Discovery

One of the most fascinating recent scientific discoveries is the role played by hagfish, sharks, and bacteria in the decomposition of great whales that die and fall to the seafloor. This phenomenon is called a whale fall and where they occur is unpredictable. They can happen in areas that are often nearly devoid of marine life. The slow, but continuous, breakdown of dead whales, by fishes and bacteria, and the release of the potential energy from the dead whale support large marine communities of consumers and scavengers. Some organisms, including sharks, hagfish and bacteria, are attracted to whale carcasses on the seafloor. As dead whales are consumed, the energy in their tissues is transferred to other organisms of the deep sea, including brittle stars, sea cucumbers, sharks, and other fish. This symbiotic (living together) relationship between the whales and these deep-sea creatures is an example of commensalism. Some animals, the commensals, are dependent on the food supply provided by dead whales, while the whales are unaffected by the community of commensal animals.

Strange worms live on whale carcasses on the seafloor. These worms have symbiotic bacteria that help them digest fats and oils in whalebone. The female worms hold dozens of male worms inside them, as well as many, many eggs. Male worms are nothing more than sacs of sperm and yolk. Having the dwarf males live inside the bodies of the female worms ensures that the females can release large numbers of larvae (young worms). This, in turn, helps guarantee that ocean currents will sweep at least a few offspring to another whale carcass. Researchers theorize that the worm's unusual sex life is related to its eating habits. A colony of the worms may feed on a single whale carcass for decades. Once a skeleton is entirely consumed, all the worms at the site probably die.

This phenomenon also creates food webs and food chains—connections between the dead organism, the animals eating it, and, finally, the animals that feed off the animals that actually consume the whale.

d. Ocean biology provides many unique examples of important relationships among organisms such as symbiosis, predator-prey dynamics, and energy transfer.

All living creatures interact with other forms of life on Earth through a variety of different mechanisms. Predators consume prey. Similar species may compete with each other for needed resources such as food and habitat and also for mates.

Symbiotic relationships occur among many similar and different groups of organisms. For example, symbiotic species may both be bacteria, or they may be bacteria and algae, or a variety of other groups.

Some relationships between species benefit both species. These are **mutualistic relationships**. In a **commensalistic symbiotic relationship** between species one benefits with no impact on the species that provides the benefit. Some species may benefit to the detriment of another species through a **parasitic symbiotic relationship**.

e. There are examples of life cycles in the ocean that are not often seen on land.

Many marine organisms go through a larval phase during which the tiny larvae float on ocean currents for days or months, potentially traveling great distances. For example, California spiny lobster hatch as tiny free-living larvae that live for 6-12 months in the ocean before reaching a larger juvenile life stage.

There are some marine organisms that have

Examples of mutualistic symbiosis

Symbionts	Hosts	Habitat and Behavior
Bacteria that use hydrogen sulfide	The bodies of tube worms, mollusks, and other animals associated with hydrothermal vents on the deep sea floor.	Detoxify hydrogen sulfide to give off energy that sustains the host animals. These "chemosynthetic" bacteria use geochemicals (instead of sunlight) as an energy source.
Cleaner shrimp	Various fishes such as parrotfish, wrasses, and groupers.	The host fish gets rid of ectoparasites, and dead skin and the shrimp gets a meal.

Examples of commensalistic symbiosis

Remoras	Sharks, sea turtles	Remoras attach to the skin of sharks and the carapace of sea turtles. They get a free ride, protection from predators, and the host's leftover food. There is no harm to the host animal.
Pygmy seahorse	*Muricella* sea fan	The colour of the fish matches the gorgonian it inhabits, and the body tubercles look very similar to the polyps of the gorgonian enabling the seahorse to avoid predation.

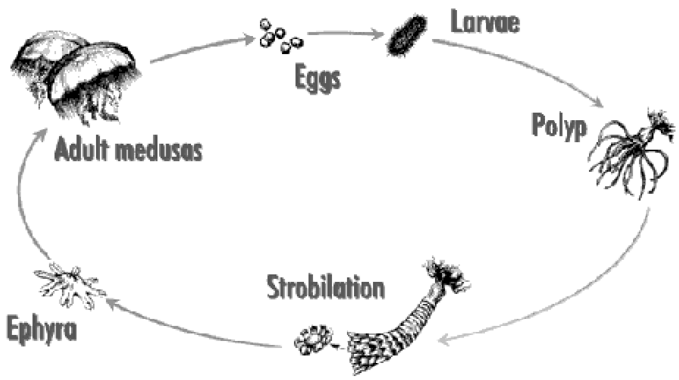
Examples of parasitic symbiosis

Tape worms	Marine mammals	The worms can ultimately kill the infected mammals
Round worms	Fishes	Worms digest and use part of the host's food

There are many other interesting symbiotic associations.

external fertilization in which gametes (eggs and sperm) are released into the ocean, a process called broadcast spawning, where the gametes fuse to form embryos. Broadcast spawning is done by organisms such as corals, clams, sea urchins, sea squirts, and many fishes.

In the cold and dark depths of the ocean where anglerfish live under high pressure, they have evolved special organs that act as lures to attract



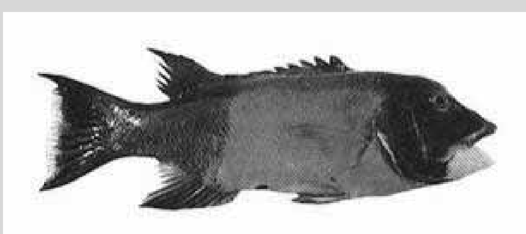
The life cycle of a moon jelly (Aurelia spp*) with its sexual and asexual phases.*
Source: Aquarium of the Pacific exhibit

both prey and potential mates. Female anglerfish entice males with a light display. During the process, the male attaches to the undersides or flank of the female and then undergoes a remarkable change. The male slowly loses all of its external body parts and most of its internal organs. Eventually all that is left of the former male fish are its testes which continue to function, producing and releasing sperm to fertilize the female's eggs. In its final form the former male appears as two tiny small rounded structures fixed to the side or underbelly of a large and highly successful female.

f. The ocean is three-dimensional, offering a great deal of living space from the surface through the water column to the seafloor. As a result, most of the living space on Earth is in the ocean.

Just as is he land, the ocean is habitat. It is not one homogeneous habitat but rather an assemblage of many different habitats. There are rocky shores

The California sheephead—a fish with a peculiar fish life



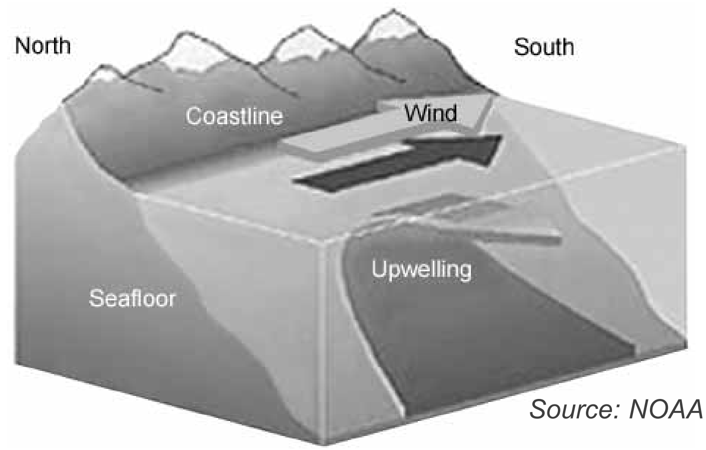
Male

Female

Source: Photos from Aquarium of the Pacific collection

All California sheephead (Semicossyphus pulcher) are born females. When they are 4-5 years of age and about 20 cm (8 in) in length, they become sexually mature and are able to mate, produce eggs, and ultimately offspring. However, when they reach a length of 30 cm (12 in) and an age of 7-8 years they change into males. Scientifically called "protogynous hermaphrodites", these changed fish are very different in appearance (see photos). Fully grown and mature males can reach a length of 1 m (36 in) and a weight of 16.3 kg (36 lb).

and sandy beaches, coral reefs and kelp forests, sunlit surface waters and dark abyssal plains. Each of these **habitats** is shaped by different forces, as are organisms that inhabit them and life can vary from habitat area to habitat area. The mussels that cling to rocks among crashing waves are very different from those on the deep ocean floor that thrive on methane. The ocean is teeming with life—from the plankton that thrive in the sunlit surface waters to the foraminifera found buried in mud in the deep ocean.



Source: NOAA

Orcas off Long Beach, California
Source: H. Ryono

g. *Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors ocean life is not evenly distributed temporally or spatially, i.e., it is "patchy" in time and space.*

Ocean life is usually not uniformly dispersed about the ocean but instead occurs in clumps or patches. The majority of known marine life can be found in the ocean's upper sunlit surface down 30 m (100 ft) and along the western sides of continents and large and small islands where upwelling (vertical water movement from the bottom to the surface, usually driven by wind) occurs.

Highly productive areas are not widespread nor comparatively large (see graphic "Upwelling." Infact there are large areas in the ocean where very few marine organisms are found. About 5 kg (11 lb) of living organisms can be found in one square meter (3.3 ft^2) of nearshore seafloor; possibly 200 gm (7 oz) can be found in the same area of continuous shelf; less than 1 mg/m^2 (3.3 ft^2) is typical for deep benthic communities. Some scientists now believe that these areas exist too far away from land and that not enough nutritive iron runoff reaches them to support adequate plant life. One example is the Sargasso Sea in the middle of the North Atlantic Ocean. Others include huge areas in the south and North Pacific Ocean. So even though the ocean is vast, there is not that much living space that is easily inhabitable by larger organisms (fish, squid, sharks, birds, and cetaceans) considering where and why the largest concentrations of life occur.

Abiotic factors, factors not due to living organisms, (salinity, pH, temperature, oxygen, light, wave shock, pressure, substratum, texture, circulation, and nutrient content of the water, etc.) affect the distribution of life in the ocean. Some of the most important abiotic factors, such as nitrogen and dissolved iron concentrations in seawater, are very low to absent in most areas of the deep ocean.

Energy produced by phytoplankton, known as primary producers, is used by many other marine animals that eat the phytoplankton. Iron is essential for photosynthesis by phytoplankton. Scientists have

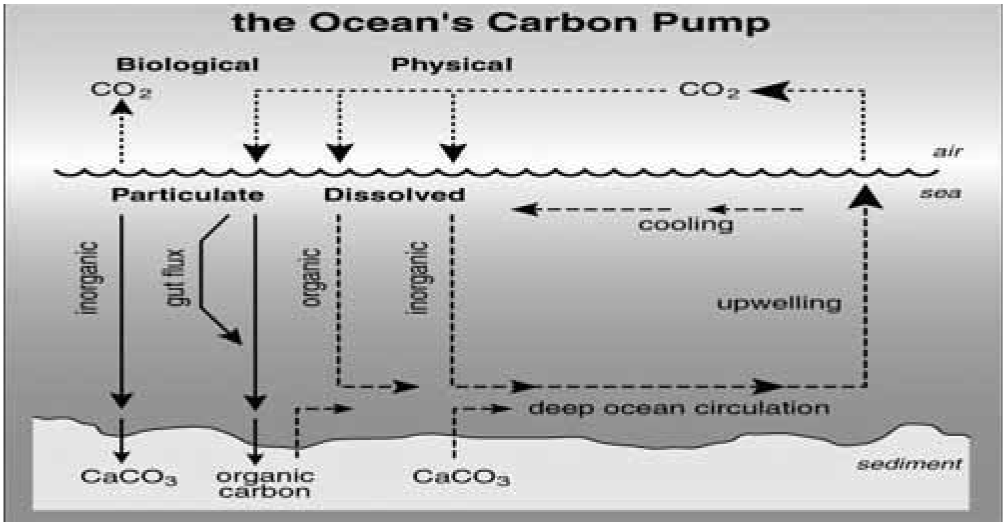
Ocean Habitats

Habitat Type	Characteristics
Coral reefs	Fringing, barrier, and atoll varieties exhibit windward and leeward differences.
Seamounts	Rocky structures in the ocean that support high biological diversity and productivity.
Low latitude central gyre	Current pattern that creates areas of high diversity and low productivity.
Hydrothermal vents	Support chemosynthetic communities that convert geochemicals to energy.
Cold seeps	Support chemosynthetic communities that convert geochemicals to energy.
Sulfureta zones	Shallow and deep waters.
Deep sea habitats	Marine snow, particulates of detritus, and pieces of organic matter drift to the deep sea to provide nutrient input for deep sea communities.
Upwelling zones	Areas of high productivity where **nutrient-rich** deep waters move upward in the water column as warm, **nutrient-poor** surface waters are blown offshore.
Frontal zones	Areas between two major currents or bodies of water that have different abiotic characteristics tend to concentrate and attract marine organisms.
Interstitial sediment zones	Support diverse meiofauna and meioflora (organisms 0.1-0.5 mm, (0.0-0.02 in) in greatest dimension).
Living surfaces (e.g. whale skin)	A moving, living ecosystem.
Tropical oceans	High diversity and low production.
Estuaries	Important role as fish and invertebrate nurseries.
Polar ecosystems	Plankton productivity severely limited during periods of ice cover because of lack of light. Spectacular plankton blooms during summer 24-hour daylight.
Ocean surface	Surface water 100-1000 times more concentrated with dissolved and particular organics, microbes and plankton than deeper water.

The temperate ocean, deep sea trenches, continental shelves and slopes, seagrass beds, salt marshes, and mangrove forests are also important habitats.

done experiments in which colloidal iron is added to these areas to determine if primary production could be increased. Preliminary results suggest that the addition of iron can significantly increase primary production in some areas of the ocean. When the experiments were stopped, the ocean areas under study returned to their original low primary productivity states.

Marine plants use carbon dioxide (removed from seawater) for photosynthesis. High levels of atmospheric carbon dioxide are partially responsible for the green house effect and the "global warming." One hypothesis, developed in the early 1980s by Dr. John Martin at Moss Landing Marine Station in California, is that high concentrations of carbon dioxide could induce phytoplankton growth and repro-



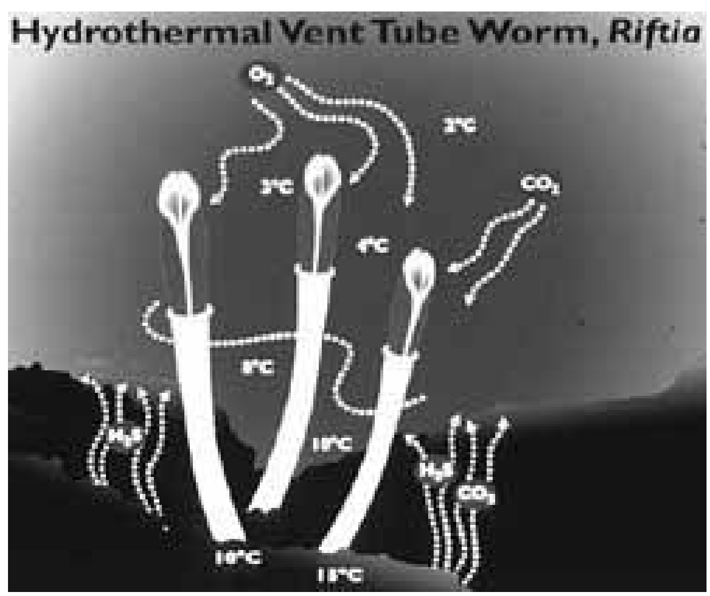
Source: UCLA Dept. of Ecology & Evolutionary Biology

duction that would actually "down pump" carbon dioxide from the atmosphere into the ocean. (See Key Concept 3.)

h. There are deep ocean ecosystems that rely only on chemical energy to support life (such as hydrothermal vents, methane cold seeps, and whale falls).

Hydrothermal vents, (seafloor geysers), are formed as a result of faults in the seafloor. As the lithospheric plates that form Earth's crust move apart openings are created in the seafloor into which seawater seeps. The water is heated by the molten rock or magma that lies beneath Earth's crust. As the water heats, it rises and seeks a path back into the ocean through the seafloor openings. The temperature of the spouting water may be as high as 400^{o} C (750^{o} F). Some hydrothermal vents or "hot smokers" are topped with chimneys formed from dissolved metals that precipitate out when the super-hot vent water meets the surrounding ocean water that is just a few degrees above freezing. Black smokers get their color from the iron monosulfide formed from the iron and sulfide in the water. White smokers contain compounds of barium, calcium, and silicon, all of which are white. The water they eject is cooler than that of the black smokers.

In 1977 a new type of marine community or ecosystem was discovered north and east of the Galapagos Islands and 3,000 m (10,000 ft) below the surface of the ocean where jets of superheated water as hot as 350^{o} C (650^{o} F) blasted from vents in the volcanic ridge. Clustered around the vents were dense aggregations of large previously unknown species of crabs, clams, sea anemones, shrimps, mussels, and unusual worms. Bacteria, the basis of the food chain for these organisms, were living in water laden with carbon dioxide, oxygen, and toxic hydrogen sulfide Eventually three species of tube worms would be identified and placed in the genus *Riftia*.



Source: Pennsylvania State University

Similar vent communities have now been identified off Florida, Oregon, and California, and in several other locations along oceanic ridges. Ongoing exploration has revealed other life forms in the vent communities such as minute lobsters called **galatheids**, and amphipods resembling sand fleas. Scientists have now identified more than 300 species living around the vents.

Where did most of the organisms living in the dark abyss where no light was available for photosynthesis get their energy? The ultimate source was determined to be hydrogen sulfide absorbed from the water by organisms such as clams and tube worms. For example, the worms' tentacles transported the hydrogen sulfide to bacteria they harbored in feeding bodies. In a process called chemosynthesis the **chemoautotropic** bacteria used the hydrogen sulfide as an energy source to convert carbon dioxide to organic molecules.

Cold seeps have also been located. They were first discovered in the Monterey canyon off Monterey Bay, California at a depth of 3,200 m (10,560 ft). Cold seeps occur where oil and methane gas are bubbling up from undersea sediment layers. In contrast to "hot" vents the temperature of the emitted water is close to that of the surrounding cold ocean water. The spewing is also slower and less vigorous than that of the "hot" vents. These areas are habitat for a larger number of species than are the hot-vent areas.

Scientists question how larvae of vent-associated species move from one hydrothermal vent to another when the vents are separated by hundreds of miles. Whale falls, which support chemosynthetic organisms, may link distant hydrothermal vent communities. The chemosynthetic communities associated with whale falls may be "stepping stones" for larvae between widely-separated hydrothermal vent communities. Thousands of whales die each year and fall to the sea floor. If enough of these dead whales accumulate between separate hydrothermal vents, then the distances larvae must travel could be far shorter than was originally thought. In addition, natural methane cold seeps may play a role in this "stepping stone" arrangement by shortening the distance larvae of vent-associated species must travel before they find appropriate conditions for settlement and growth.

i. Zonation patterns of organisms along the shore are influenced by tidal ranges and waves.

Some tidal zones (for instance the splash zone and the high tide zone of the rocky intertidal areas) are generally far up the shore from the ocean. These areas are uncovered during low tides much longer than lower tidal zones of the same shore (the middle tide zone and the low tide zone). Therefore, these high zones, and specifically the organisms that live in them, are far more susceptible to desiccation by wind and high temperatures, poisoning by contaminated runoff, predation by land-based predators and human hunters, and, of course, human development. Thus, the animals and plants that live in these zones are some of the toughest of marine creatures.

Tidal zone at mid-tide
Source: Santa Barbara Community College

Intertidal organisms must be able to protect themselves from wave shock (pounding by crashing waves) but even this disturbance has a positive side. Pounding by waves and even the removal of masses of animals or plants by loose rock impact, periodically, causes opening in the mass of animals and plants on the rocky surface. These periodic openings allow new organisms (primarily larvae) to settle and grow, an important reason for the relatively high productivity of animals and plants in intertidal areas.

An interesting example of a well-adapted organism that lives in these zones is the western rock louse, also called the sea roach (*Ligia occidentalis*), shown in the photo below. These agile cockroach-like arthropods live on rocks in the splash and high tide zones, sometimes on vertical rock faces. Rock louse constantly search for cracks and crevices in which to hide from predators such as birds. The louses can be very abundant, even in this difficult environment, because they are so well adapted to their habitats.

Rock louse (Ligia occidentalis)
Source: National Audubon

j. Coastal estuaries (where rivers meet the ocean) provide important and productive nursery areas for many marine species.

An **estuary** is a semi-enclosed coastal body of water in which seawater is mixed with and measurably diluted by freshwater. The mixing of the salt and fresh water creates brackish or low salinity saltwater. The salt content varies within the estuary depending on distance from the incoming ocean, strength of the tidal flow, and depth of the estuary.

The confluence of creeks, wetlands, salt marshes, mudflats, sand dunes and open water attracts a large variety of wildlife. The rivers and streams bring nutrients and fresh water to the estuary via runoff. Due to their shallow depths, the water in estuaries tends to be warmer. These conditions combine to make estuaries one of the best of all places for organisms to lay eggs and for tiny fish and invertebrate larvae to grow. About 75 percent of commercially important fish and shellfish in the U.S. are estuarine dependent, relying on estuaries and upper reaches of tidal rivers for early life stages, migration, and spawning.

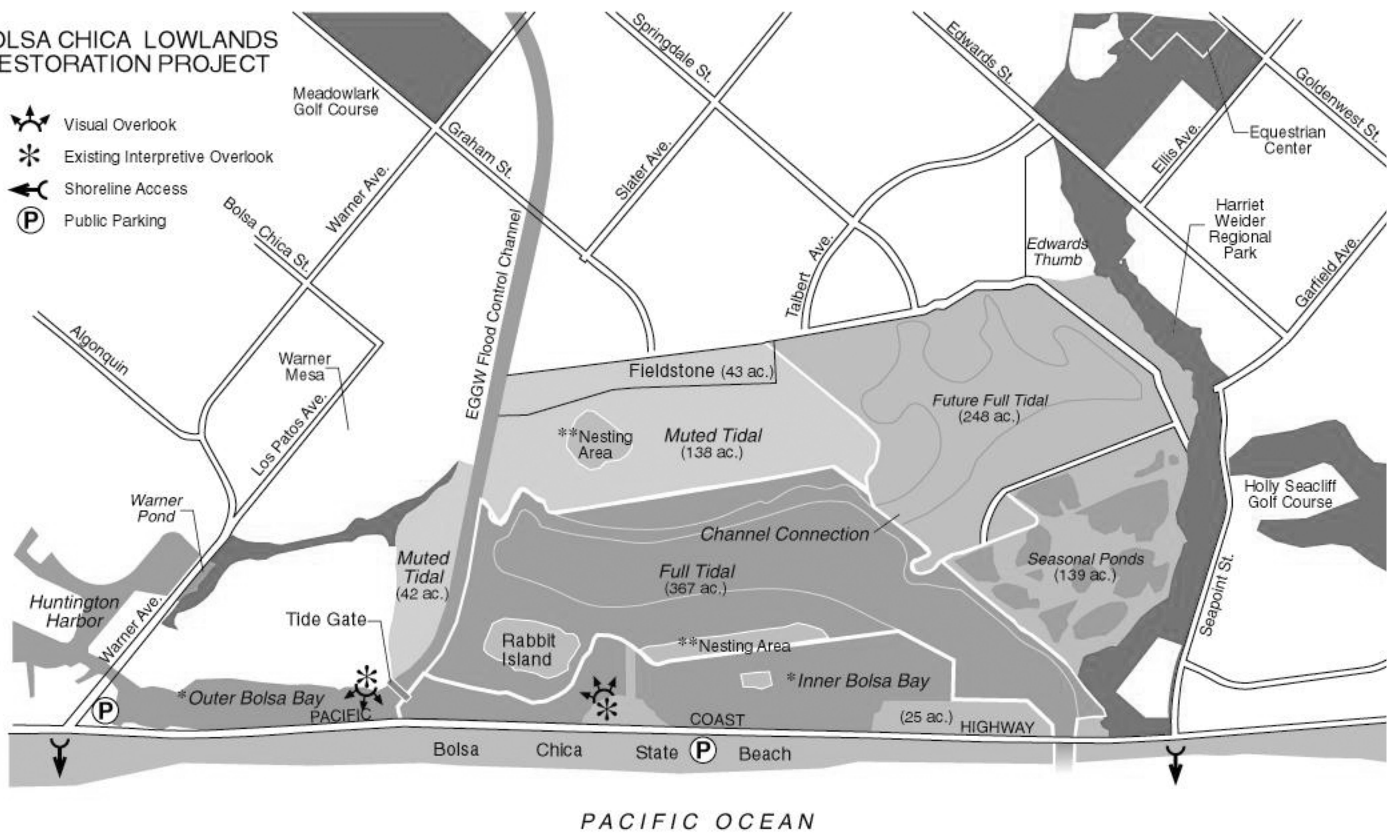
Mugu Lagoon
Source: CSUCI

Coastal wetlands, the collective term for marshes, swamps, bogs, and similar areas that develop between the ocean and dry land, are an important components of coastal habitat. U.S. regulations define wetlands as those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support vegetation that typically lives in saturated soil. Coastal watersheds currently include about 30 percent of all wetlands in the lower 48 states—a total of about 27 million acres. Like other coastal habitats, wetlands provide a variety of ecosystem services: improving of water quality providing natural flood control; recharging groundwater; stabilizing shorelines; contributing to recreational value; and serving as nurseries for thousands of species of plants, fishes, and other animals.

Adult halibut enter the Bolsa Chica wetlands to lay spawn after which they leave for ocean waters. After hatching, the young halibut may spend the first two years of their life in the estuary growing up, protected as they grow from the rigors of predators out in the ocean. This is also a spawning area for sea hares.

Prior to the 1970s federal policies encouraged the draining and filling of wetlands which were called swamps or smelly mudflats. By the 1980s the area of wetlands in the contiguous United States had decreased to approximately 53 percent of the acreage of the prior 100 years. California is a wetland loss hotspot having lost over 91percent of its coastal wetlands. Despite a 16 year policy of "no net loss of wetlands" and selected restoration, wetlands and their habitats continue to be lost due to subsidence, erosion, storms, and mostly, human activities including the conversion to other uses such as marinas, industrial parks, housing, etc.

The loss of estuaries and wetlands along the coast of southern California over the past century has been devastating to both coastal marine fish and invertebrate populations. There has been a dramatic



Bolsa Chica Ecological Reserve wetlands restoration project
Source: California State Lands Commission

decline in juvenile and, consequently adult populations of fish species associated with them. This decline has had a dramatic effect on the marine food web. Very damaged and degraded estuaries and wetlands have been and are being restored at Upper Newport Bay Ecological Reserve, the Bolsa Chica lowlands in Huntington Beach, California, and the Tijuana River National Estuarine Reserve in Imperial Beach, California. The latter is a coastal estuary where research is being conducted on invasive species ecology and management, salt marsh restoration, and sustainable development of urbanized watersheds

It was not until about 30 years ago that restoration of wetlands became a concern. Duplicating what Mother Nature created is not without its problems and many restoration projects fail. The restoration in Newport Bay and the Tijuana Slough National Wildlife Refuge in the San Diego area are success stories. It is expected that the current ongoing restoration of the lowlands in the Bolsa Chica Ecological Reserve will bring at least a partial return of species that depend on estuaries.

Estuaries are vulnerable to invasion by non-native species, such as mussels (*Musculista spp*), anemones (*Bunedeopsis spp)*, and algae (*Caulerpa spp*). From 1997 to 2005 the California Department of Fish and Game conducted a successful effort to eliminate the introduced alga, *Caulerpa spp* from several estuaries in southern California where it was beginning to take over the bottom environment by outcompeting native species. The alga was introduced through the emptying of home aquariums into protected harbors and lagoons. The sale of *Caulerpa spp* is now illegal in California. (See Key Concept 1.)

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The ocean and humans are inextricably interconnected and the life of every human is affected by the ocean.

a. The ocean supplies freshwater, moderates the climate, and influences the weather. *(These are addressed in depth in Key Concept 3 and briefly in 1.)*

- Over half of Earth's oxygen and most of its precipitation (rain, snow, sleet, and hail), come from the ocean. Ninety-four percent of water on our planet is in the ocean, four percent in the groundwater, one percent in ice and glaciers, and the rest in freshwater and humidity (soil and air).
- About 3 billion years ago our planet started to become enriched with oxygen released as a byproduct of photosynthesis by microscopic algae. For existing microorganisms at that time the oxygen was harmful and many of the cells adapted by developing thick membranes to protect themselves from this element. Only four percent of the oxygen that has been produced to date is available in its free form. The vast majority is bound in iron or sulphate form. There would be no oxygen-breathing life if the ocean had not provided the initial conditions in which micro-organisms began to photosynthesize.

b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, and serves as a highway for transportation of goods and people.

Ocean Economics

The July 2005 California Ocean Economy report, (available at http://noep.csumb.edu), states that California has the largest ocean economy in the nation for both employment and gross state product (GSP). GSP is the total market value of all the goods and services produced by a state during a specified period. Over 700,000 jobs paying $11.4 billion in wages are directly involved in the coast and ocean. The report covers: coastal construction; living resources (fish hatcheries and aquaculture, commercial fishing, seafood processing); offshore minerals; ship and boat building and repair; maritime transportation and ports; and coastal tourism and recreation.

The California ocean economy contributed more than $120 billion to the U.S. economy in 2000 with 2.3 million people employed (directly and indirectly) and $117 billion in output (Gross State Product) in 2000. This contribution was nearly 19 percent more than that of any other state. The ocean economy comprised 1.6 percent of the nation's employment—ranging from 7.7 percent of Hawaii's employment to 0.6 percent of Ohio and Indiana's employment.

The total value of all economic transactions within 19 mainland California coastal counties and four in San Francisco Bay and the Sacramento River Delta was $1.15 trillion or 86 percent of California's total state economic activity.

Food

In 1976, California's fishing fleet landed a peak of 1.3 billion pounds of fish and invertebrates, compared to landings of 650 million pounds in 2000. The California fleet fishing brought in more than $300 million in landed value in 1970 compared to $142 million in 2000 and $91 million in 2002 (NMFS). California's share of the U.S. total commercial landings fell from approximately 19 percent of the U.S. total in 1970 to about 7.1 percent of the U.S. total, and 3.9 percent of total landed value in 2000. Incalculable losses from overfishing and depletion of stocks have already occurred and will continue to do so into the future unless steps are taken that will result in recovery of California's fisheries such as designation of Marine Protected Areas (MPAs).

In the 1990's a large unregulated sea urchin fishery developed in southern California primarily to supply sea urchin roe (uni) to Japanese sushi restaurants in both California and Japan. To control overharvesting of this resource, the California Department of Fish and Game (F&G) now regulates the number of licenses issued (400), length of the fishing season, and size of the urchin. In 2004 the catch was 5.35 million kg (11.8 million lb) for a value of $7.1 million. In southern California extraction of the roe is done in seafood processing plants in Wilmington and San Diego, California.

Mariculture is the science of farming the sea. Today in California sea farming (both on land, in tanks, and in the ocean) results in the production of oysters, abalone, mussels, scallops, and selected marine fish species (white sea bass, halibut, and salmon).

Kelp harvesting in southern California is over one hundred years old. The industry, regulated by F&G, harvested about 40,000 wet tons in 2001. The peak harvest was over 150,000 wet tons in 1990. Algin, an extract of kelp, is widely used in binding, stabilizing, and modeling pharmaceuticals, and in the cosmetics, hygiene, and food industries. Kelp reforestation along the southern California coast is being done largely by volunteer divers from environmental groups with funding support from government agencies such as NOAA Fisheries Services. The hope is that by replanting key areas, the recovery of kelp forests depleted by pollution, El Niño warm water events, and storms can be speeded up.

Medicines

Marine chemists study how natural products serve the organisms that produce or accumulate them. The compounds could be chemical defenses to deter predators. For example, some fish "taste" food items before swallowing them, sometimes spitting the item out and sucking it back in several times before rejecting or eating it. Some could be natural anti-fouling agents that prevent an organism that does not move such as a sponge from being overgrown with other sea life. Others might be released into the seawater as pheromones to encourage larvae to join an existing colony or to help adults to find a mate.

These chemical substances play an important role in the interaction between living organisms and their environment. The field of study that considers the impact of naturally occurring substances in ocean environment is called marine chemical ecology. Research in this field which is still a young one, is believed to have great potential for identifying new pharmaceutical compounds.

One of the principal places that researchers look to for the next generation of medicines for treating cancer, infectious, diseases, and other conditions is the ocean's coral reefs. Most organisms on coral reefs are sessile (immobile) so, unable to make a getaway, they need to defend themselves from more mobile predators. Chemical warfare is a tactic found among sponges, corals, tunicates, and many other organisms. Some of the promising substances promote or inhibit cell growth which is of importance in cancer research. Today scientists are also looking at animals that inhabit hydrothermal vent and cold seep areas.

The ocean has already been a source of effective pharmaceuticals and compounds used in industry. After the chemical structure of an effective compound, has been identified the chemical can be synthesized for mass production. Some examples of such chemicals synthesized for pharmaceutical uses include:

- ***Pharmaceutical***
  Anti-viral (herpes infections)
  Original Source: Sponge, *Crytotethya crypta*
- ***Molecular Probes***
  Reporter gene
  Original Source: Jelly, *Aequora victoria*
- ***Medical Devices***
  Orthopedic implants
  Original Source: Coral, mollusk, seastar skeletons
- ***Enzymes***
  Polymerase chain-reaction
  Original Source: Deep-sea hydrothermal vent bacteria
- ***Cosmetic Additives***
  Anti-inflammatory
  Original Source: Gorgonian (*Pseudopterogoria elizabethae*)

Many other substances from marine life forms are in development, in advanced preclinical trials, and in various phases of clinical trials. Among the latter is an anti-cancer drug in Phase III clinical trials derived from the sea squirt, (*Ecteinascidia turbinate*).

Amazing Fact:

A substance in the blood of horseshoe crabs (Limulus polyphemus) *called* Limulus *amebocyte lysate or LAL is used by pharmaceutical companies to test for bacterial contamination of medical equipment such as syringes, IV solutions, and injectable drugs. The crabs are bled periodically to obtain LAL. Although the procedures are controlled and regulated, there is a mortality rate. Efforts are now being made to synthesize LAL to eliminate the need for the crabs to serve as blood donors.*

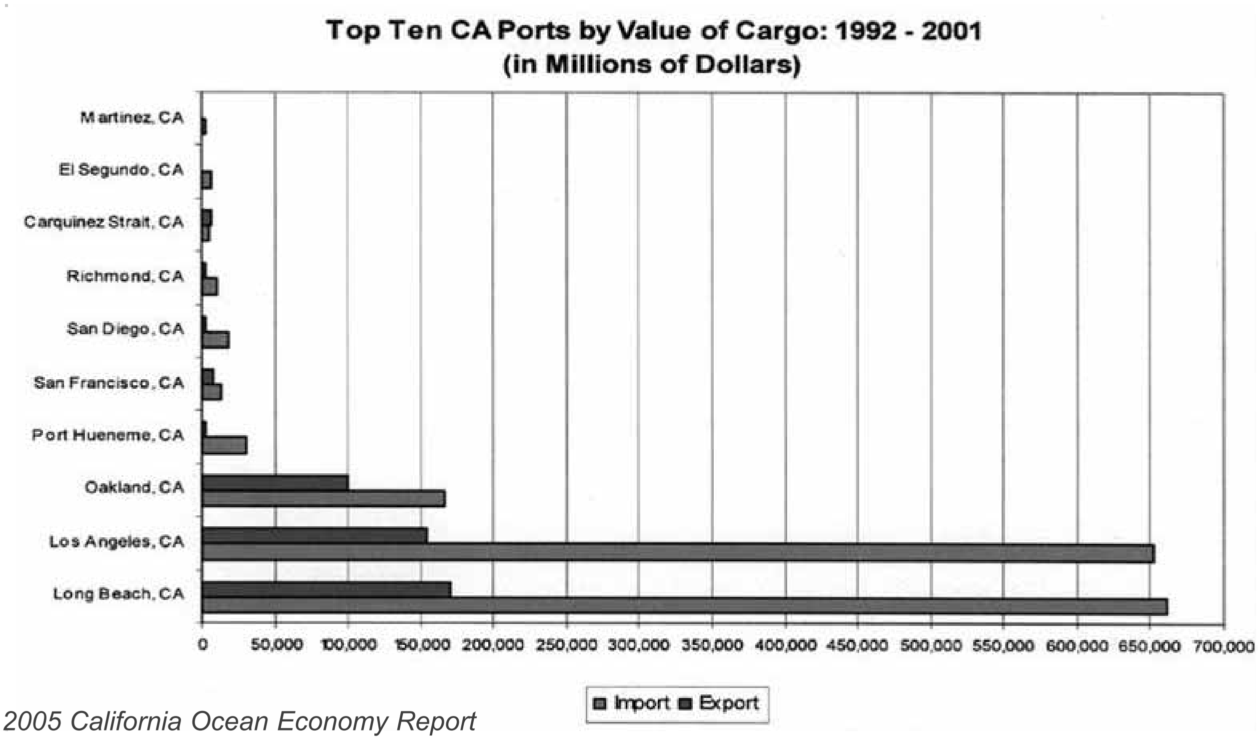
Transportation

We depend on ships as the most efficient means of transporting cargo throughout the world. Without them, the world economy would collapse. Most ports are located along the coastline and therefore are coastal dependent ocean users. Seaports provide us with goods from all over the world as well as much of our fuel, and we use our ports to supply the world with our products.

Ships sailing the oceans of the world carry more than 90 percent of cargo moved in international trade. California is the largest gateway service port in the U.S., providing access to the entire North American continent and, conversely, to the Pacific Rim, especially Asia. Waterborne commerce through California's ports accounted for 40 percent of the national total in 2000. California's seaports and the cargo handled are of great economic significance. They support industrial, retail, and agricultural sectors throughout the nation.

The Port of Los Angeles and the Port of Long Beach, while seen as separate entities by the world, together form a major complex that is node in a national and international trade and transportation network. The port complex handles more marine freight than any other port in the U.S. and is the fourth busiest seaport in the world handling over 13 million 20 foot equivalent (TEU) cargo containers per year. Every week approximately 16 ships call at one of the two ports to either load or unload cargo. Over a year, the two ports accommodate almost 6,000 ships or about 10 percent of all ship calls to US seaports. For comparison, the two ports annually handle four times the ocean freight of the Port Authority of New York and New Jersey.

Although a majority of cruise vessels fly non-U.S. flags, the United States and its ports derive substantial economic benefits from cruise industry operations. A recent study concluded that the cruise



Source: 2005 California Ocean Economy Report

industry was responsible for generating 214,901 full-time jobs for U.S. citizens. The study also concluded that the industry, its passengers and its U.S. suppliers purchased $15.5 billion of U.S. produced goods and services in 1999. In 2003, 184 cruise ships carrying 7.5 million U.S. passengers called at US ports (multiple port calls for each vessel). In all, U.S. residents accounted for 76 percent of all cruise ship passengers, worldwide. 403,000 of those passengers embarked their ships in the Port of Los Angeles and 278,000 boarded in the Port of Long Beach. [Data: International Council of Cruise Lines, iccl.org, 2004]

Offshore minerals

The Offshore Ocean Minerals sector primarily includes oil and gas production form offshore and onshore wells that tap pools of oil and gas that extend under the ocean out to three miles (the extent over which the state has direct jurisdiction). The

County	Condensate Production (bbl)	Offshore Oil & Condensate Production (bbl)	% of Offshore Production	Price of Oil ($/bbl)	Gross Value of Offshore Oil ($)
Santa Barbara	3,725,392	1,203,743	32.31	$28	$33,620,542
Ventura	8,624,069	301,591	3.50	$28	$8,423,437
Los Angeles	28,189,441	12,488,554	44.30	$28	$348,805,313
Orange	6,062,842	2,978,471	49.13	$28	$83,188,695
All Coastal Counties	**46,601,744**	**16,972,359**	**36.42**	**$28**	**$474,037,987**
Federal		**33,190,678**		**$28**	**$927,015,637**
Total		**50,163,037**		**$28**	**$1,401,063,623**

Source: 2005 California Ocean Economy Report table below shows the 2001 value. Sand and gravel, used for the creation of construction aggregate, is a smaller but important part of this. Quarrying of rock at Santa Catalina Island off southern California was the primary source for rock used in the construction of the breakwater protecting the Los Angeles-Long Beach harbor complex. Quarries on the island still operate today.

c. The ocean is a source of inspiration, recreation, rejuvenation and discovery. It is an important element of our cultural heritage.

Uses of California coastal ocean include a range of activities such as swimming, boating, surfing, fishing, cruising, bird watching, photography, kayaking, windsailing, whalewatching, jet-skiing, leisurely walks for pure relaxation, and quiet times watching a spectacular ocean sunset.

Coastal land, beaches, watersheds, and coastal waters each provide a link between the travel and tourism industry and coastal recreational industries such as swimming, surfing, cruising, sailing, and fishing. The level of participation in coastal water/nature related industries affects several other industries and sectors of the economy (i.e. hotels, restaurants, and the service industry).

California is the number one travel destination in the U.S. and beaches are the top destination for California's tourists and one of the state's greatest assets. All economic activities relating to coastal recreation are affected by the quality of the environment such as the cleanliness of the water. California has been the nation's fore-runner in beach water quality monitoring and today leads the U.S. in the amount of testing done.

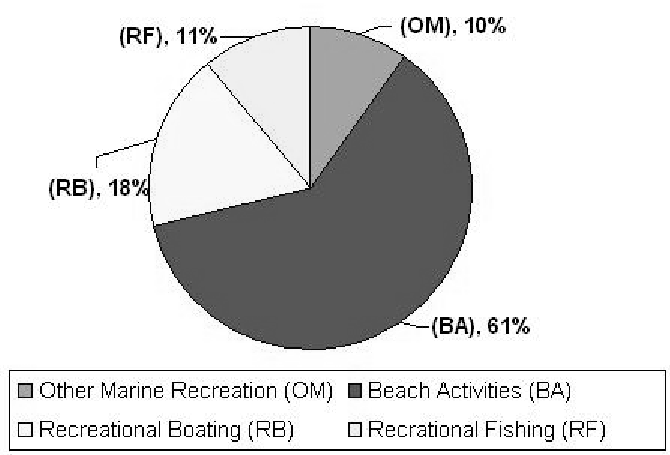
- The California Economic Report stated: "Beach-going in California is more than just an idle past time. It is a cornerstone of the California coastal economy and even California culture." It has been said that if you took the beach population of Ventura, Los Angeles, and Orange Counties on a warm sunny weekend day, the number of people would be close to that of the 8th largest city in the U.S. Since most of the population lives within 100 miles of a coastline, the coastal ocean becomes the 'playground of choice'. Here these activities compete with other uses of the littoral ocean. Multiple use conflicts arise and this is particularly true in the Southern California Bight.

Measure of Participation in Marine Recreational Activities

Recreational Activity	Number of Participants
Beach Activities	14,789,653
Recreational Fishing	2,727,286
Recreational Boating	4,221,775
Other Marine Recreation	2,321,265

Source: *2005 California Ocean Economy Report*

Proportion of Marine Recreational Activities



- Beach going represents a major economic use of the California coast and ocean. Concession stands, paid parking lots, and waterfront restaurants reveal that beach goes contribute to a thriving coastal market economy. Annual beach visitation in California likely exceeds 150 million visits. The California Ocean Economy report estimates that market expenditures by beach goes in California could substantially exceed $3 billion each year. Less obvious, however, is the economic magnitude of beach values that never enter the market. These non-market values represent the personal value that day users place on access to the beach beyond what they pay in terms of travel costs, parking fees, and tolls.

  Beaches in California represent a recreational and open space resource that provides a level of public access rarely matched elsewhere in the United States. Thanks in part to the California Coastal Act of 1972 and the California Coastal Commission created because of the act, beaches in California continue to produce annual non-market economic benefits that are on the order of $2 billion or more. Data on beach visitation is available in the 2005 California Ocean Economy report.

- In 2000, more than 2.7 million fishers participated in more than 20.3 million recreational fishing activity days along the California coast, More than 4 million people participated in marine boating related activities.

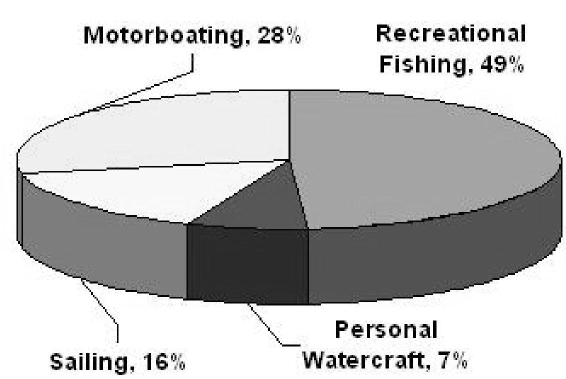
- California also has many coastal and beach state parks used by an enormous number of citizens and tourists each year for sunbathing, body and board surfing, snorkeling and scuba diving, camping, and picnicking. Why is California the tourist destination in the U.S.? In part due to its long coast and numerous opportunities for coastal recreation.

California holds a prominent political leadership position and history with respect to coastal zone and ocean management. The challenge is and will continue to be to meet the need to balance protection of California's coast and ocean resources and the needs of a growing population and economy.

Participation in Recreational Fishing and Boating Activities

Recreational Activity	Number of Participants	Number of Days	Average Days Per Person
Recreational Fishing	2,727,286	20,318,000	7.45
Motorboating	1,549,289	11,589,000	7.48
Sailing	1,087,755	6,755,000	6.21
Personal Watercraft	680,309	2,925,000	4.30
Canoeing	190,309	n/a	
Kayaking	433,209	n/a	
Rowing	280,265	n/a	
Total for Recreational Boating	4,221,775		

Proportion of Fishing and Boating Related Activity Days



Source: 2005 California Ocean Economy Report

d. Most of the world's population lives in coastal areas.

- Coastal population density is high. More than half of the U.S. population lives on just 13 percent of the land in coastal counties. In 2000, 77 percent of California's population lived in coastal countries, which represent 25 percent of the are of the state. The California coastal density is 267 people/km^2 (671 people/mi^2) compared to a population density for the entire state of 86 people/km^2 (217 people/mi^2). However, recent studies indicate that inland areas immediately adjacent to the coast are now growing faster than the California coastal area largely due to the cost of coastal housing.
- The pressure of population growth in coastal regions comes from the increasing size of the population within a fixed land area, not from a disproportionately large rate of growth. While the population growth rate in coastal areas has been consistent with national trends, the sheer size of the total population in the restricted coastal area has major impacts on the ocean and its resources.
- Economic activity in coastal regions is high. 75 percent of the nation's gross national product (GNP) came from coastal states in 2000. Almost half of the GNP came from coastal watershed counties, and more than one-third came from those counties in which states have and follow Coastal Zone Management programs.

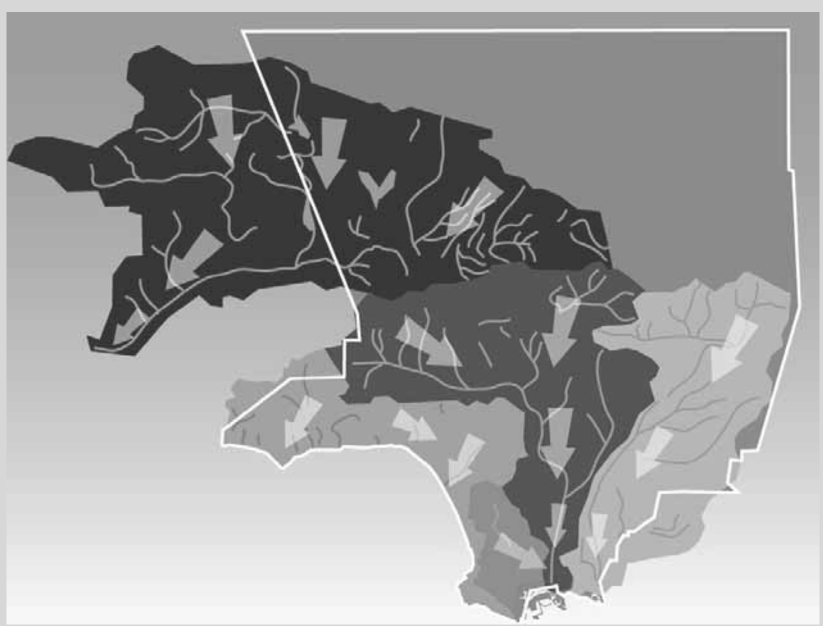
e. Humans affect the ocean in a variety of ways.

Southern California has an enormous watershed as shown in the graphic below. Wastes (such as trash, sediments, and sewage contaminants) enter the ocean from discharges from sewage treatment plants, industries, and power plants (point source pollution) and from run off (non-point source pollution). This pollution often leads to habitat degradation, harmful algal blooms, and depletion of oxygen, as

What is a "Watershed"?

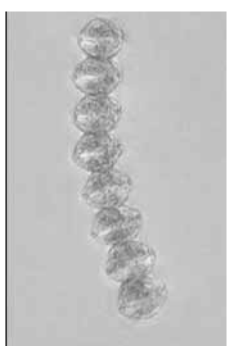
A watershed is the land area where water collects and drains onto a lower level property or into a river, ocean or other body of water. Watershed management is the integration and coordination of activities that affect the watershed's natural resources and water quality. It brings together services like flood protection, water conservation, preserving and creating open space for recreation and habitat, maintaining critical habitat space, and reducing pollution of water resources.

Source: Aquarium of the Pacific



well as the endangerment, depletion, and even extinction of estuarine ocean species. Building structures along coasts, damming rivers, and building seawalls leads to loss of beaches and increased coastal erosion. Through overfishing, humans have removed most of the large vertebrates from the ocean, either directly or indirectly by harvesting their prey. Coastal development has resulted in degradation and losses of coastal habitats and ecosystems.

River discharge and eutrophication (overgrowth of phytoplankton) is suggested to be one of the main causes for harmful algal blooms (HABs). An example is southern California's 2004-2005 season record rainfall. An image taken at that time showrd a river plume discharge around Los Angeles Harbor and the San Pedro Shelf area. The plume, detectable all the way to Catalina Island (> 40 km, 24.8 mi) offshore, was loaded with high nutrient concentrations and unusually high levels of trace metals. Such nutrient loadings into coastal waters can trigger phytoplankton blooms such as those discussed below.



Pseudo-nitzschia chain *Alexandrum sp*
Courtesy of California Fish & Games

Coastal algae blooms or harmful algal blooms (HABs) that were once a sporadic occurrence in southern California waters now occur yearly. It has been said that HABs are one of the most scientifically complex and economically significant coastal issues facing the nation today. They have direct and indirect impacts on fisheries, local coastal economics, public health, and aesthetics.

One of the most dominant harmful algae groups found along the California coast belongs to the diatom group *Pseudo-nitzschia*. Blooms usually occur between early spring to mid-summer. A severe bloom occurred in 2002 and another in 2005. *Pseudo-nitzschia* produces a toxin called domoic acid which can be accumulated throughout the food chain (algae to crustaceans to fish to dolphins to seals or sea lions and birds) and cause amnesic shellfish poisoning. The affected animals become confused and disoriented with spastic movements. They often die of dehydration or drown. In 2002 about 685 Californian sea lions and 98 dolphins died; over 500 animals were treated at rehabilitation centers (some of which had to be euthanized), and over 200 seabirds were affected. People who eat contaminated shellfish can become ill but only a few deaths have been reported.

Mussel beds are closed annually in California from May to October because of a toxin produced by a dinoflaggelate, *Alexandrum sp* that the mussels acquire.

In California rockfish harvests have been severely reduced due to overfishing and climate change. Many of the wild steelhead populations in California are now closed to all fishing and some are threatened with extinction due to a number of factors such as loss of upstream passage because of dams, groudwater withdrawal, agricultural diversions, and pollution. Additionally, some near shore ocean fisheries are subject to health quarantines due to pollution.

Mercury contamination in fish is a prime example of how activities of humans on land influence marine life, and in turn the affected marine life becomes a public health issue for humans. Contamination of ocean sediments by DDT and PCBs are other examples of how we have polluted the ocean from activities on land and are now paying a price for it. The area off Palos Verdes peninsula is a compelling example.

California's beaches, coastal bluffs, bays, estuaries, and other shoreline features are altered according to geologic conditions, the availability of beach sand, the wave and current energy impinging on the coast, and other physical processes that affect sand movement and retention. A constant supply of sand is necessary for beaches to form and be maintained along this shoreline. Many human activities reduce the supply of sand that reaches the ocean and, in turn, deprive beaches of natural replenishment. These include dam construction and river channelization. Lack of sand creates greater vulnerability for shorelines that have always been subject to varying levels of erosion. Placing sand on beaches in southern California can and has undoubtedly widened many beaches. Many of southern California's widest beaches are no longer "natural," but largely the result of sand nourishment and stabilization resulting from large coastal construction projects. The beaches in Santa Monica Bay in Los Angeles and the Silver Strand in San Diego are the best examples.

In the long-term, sand supply from inland sources may be increased through re-design of existing structures or altering water management practices. However, short-term management of shoreline erosion will likely continue to focus at the land/sea interface along the California coastline.

Two main issues facing the coast in the next few decades are (1) Getting and keeping enough sand on enough beaches to satisfy the recreational and tourist demand, so as to continue deriving the enormous economic and cultural benefits and incremental public and private property protection, depending thereon, and (2) Finding and maintaining the appropriate balance among beach nourishment, sand retention, coastal armoring, and planned retreat (of both public and private structure) that continued beach and coastal erosion will require.

f. Coastal regions, where most people live, are susceptible to natural hazards such as tsunamis, hurricanes, cyclones, typhoons, storm surges, flooding, and landslides.

Hurricanes, typhoons, cyclones are all 'meso-scale' marine-generated weather systems that depend on the thermal energy of the ocean to fuel them. With global ocean temperatures increasing, many scientists believe their frequency and intensity will also increase.

Not all coastal weather damage is caused by tsunamis, hurricanes, etc. Winter storms have a major impact, especially during El Niño years. Summer monsoonal rains can also cause erosion and heavy runoff periodically. Over geologic time, earthquakes and faulting due to earthquakes historically have shaped the coast and bluffs along all the southern California coast. Although there have not been many natural disasters that have affected the coastline of California, recent indications of sea level rise do not bode well for low lying parts of the coastline. **(See Key Concepts 2 and 3)**

g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

- It is not the natural resources of the coast that need managing, it is the activities of humans. With ocean literacy the general public can be motivated to manage its own activities and those of others to conserve national coastal and ocean resources.
- It has been said that there are no constituents for the ocean, but that is not true. All users of our coasts and oceans are constituents and should be

targeted to become the effective coastal and ocean stewards. This will happen only if we can focus on how to reach them in ways they understand and accept. Only then will they become concerned about the ocean and its problems.

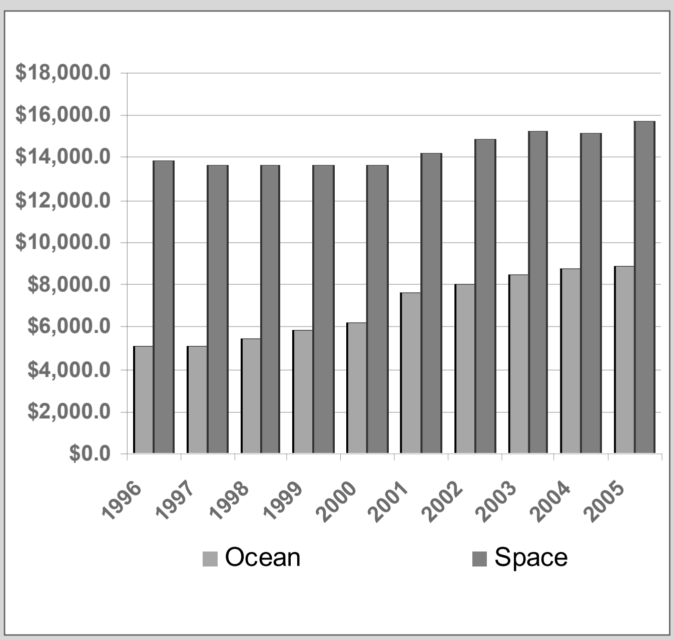
Margaret Mead said: *"Never doubt that a small group of dedicated individuals can change the world. Indeed it is the only thing that ever has."*

- Funding for ocean research needs to be increased significantly to better understand coast and ocean processes and phenomena and how human affect these. With good information people can be better informed and thus make wise decisions with regard to the ocean. See tables below indicating current and recent funding of ocean research compared to NASA funding.
- How do we get governing bodies from local to international to be proactive in protecting the world ocean and coastal waters? What mechanisms are in place now? What are their positive and negative attributes? What more is needed? Some public policy points and questions raised and related to the foregoing include:

1. Government institutions will respond to the demands of united ocean literate citizens. This has been demonstrated repeatedly by success efforts of several different public organizations such as the Environmental Defense, Surfrider Foundation, CoastKeeper Alliance, Natural Resources Defense Council, and the California Oceans Campaign.
2. In the past much of land-use planning has been delegated to small local jurisdictions that must be responsive to their citizens, and by virtue of their size virtually preclude "regional" planning approaches. More regional land-use planning, such as that demonstrated over the last 30 years by the Coastal Zone Commission, over-

Ocean vs Space Exploration Budget Comparison

(in million of $)
Source: Aquarium of the Pacific



Year	Ocean (NOAA & NSF)	Space (NASA)
1996	$5,079.6	$13,820.7
1997	$5,118.1	$13,704.2
1998	$5,492.8	$13,648.0
1999	$5,837.2	$13,655.0
2000	$6,240.9	$13,652.7
2001	$7,629.5	$14,253.2
2002	$8,054.7	$14,901.7
2003	$8,464.4	$15,231.0
2004	$8,723.6	$15,189.0
2005	$8,853.6	$15,719.0

We first need local ocean literacy, then regional, and finally global ocean literacy. The general public needs to have positive messages and examples of how to reduce their impacts on the ocean. People will respond positively when they know what to do.

Quotes below are from the NEEF/Roper report, A National Strategy to Improve Ocean Literacy and Strengthen Science Education Through an Improved Knowledge of the Oceans and Coasts available at http://oceanliteracy.org/ORAP-approved-edstrat.pdf.

"What passes for environmental education in America is actually environmental information. …True education nourishes a deeper understanding and an all-important ability to supply knowledge while information simply makes one aware of a topic and stops there."

"For environmental knowledge, this study finds that a higher level correlates significantly with a higher level degree of pro-environment behavior. Increased environmental knowledge works best for simple, easy-to-do behaviors such as consumer decisions or saving water or electricity…."

"This report also finds that environmental literacy results in more persistent and lasting impacts on pro-environment attitudes (affect) and behavior. Real changes usually emerge from educational strategies that give the students a sense of involvement and ownership…."

comes the drawbacks to using only small local jurisdiction planning.

3. Ecosystem-based management combined with critical habitat management is a far better and more effective approach to protecting species diversity and habitat than individual, localized efforts at protection.
4. Inclusion of members of all stakeholder groups in planning efforts, from the beginning of the effort to the conclusion of the plan, promotes ownership of the results and active participation in the implementation of whatever plans are created.

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Key Concept 7

The ocean is largely unexplored.

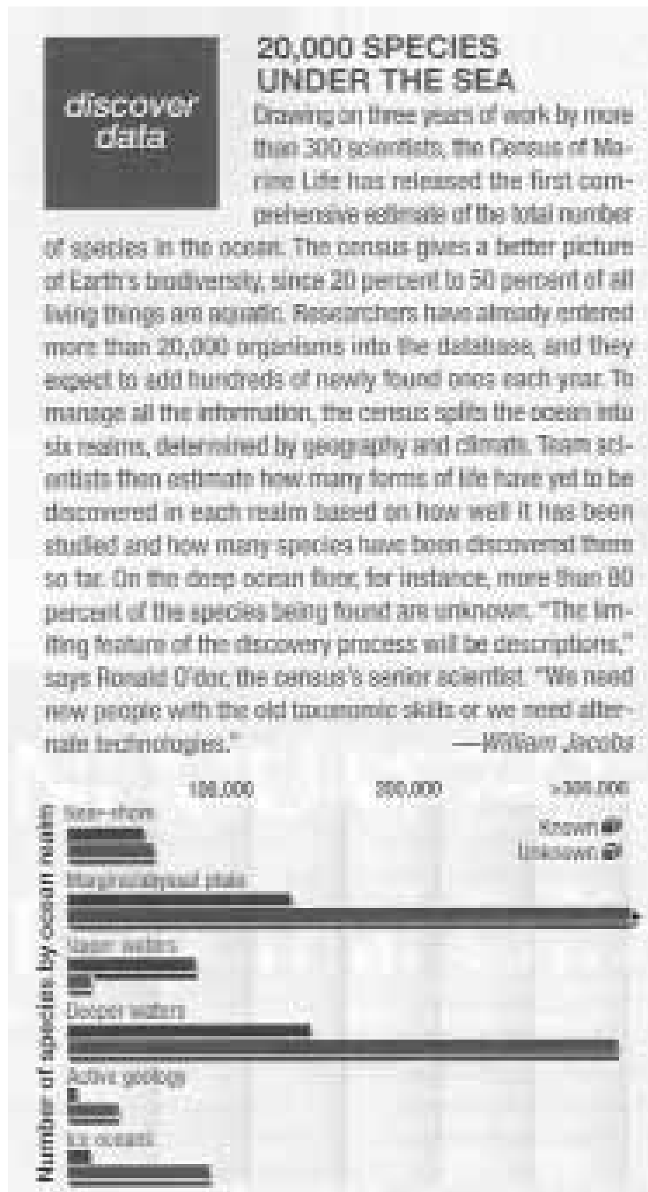
What is ocean exploration, that is **scientific** exploration of the ocean—the systematic observation of all marine facets—biological, chemical, geological, physical, archaeological, etc.— across space and time. Scientific exploration invol-ves the collection of data and the transformation of those data into information and new understanding and knowledge, to provide a legacy and insurance policy for future generations.

a. The ocean is the last, large unexplored place on Earth.

The world ocean covers 71 percent of Earth's surface. It is the largest living space on the planet and contains most of its biomass. Despite this, relatively little of the ocean has been fully explored. Less than five percent of the ocean floor—and less than one percent of its entire volume—has been visited by humans. Seafaring cultures have traversed the ocean for centuries, but only the surface of what lies beneath has been skimmed.

New species from the world ocean are described on a fairly consistent basis, and every major expedition discovers new ones. Scientists are only now beginning to understand how the oceans affect weather and climate processes, how these processes affect primary productivity of plankton, marine biodiversity, and other critical issues. Although future sustainability of ocean resources depends first on understanding the ocean, the age of discoveries about the ocean is still in its infancy.

Perhaps one of the most compelling examples of ocean exploration today is the Census of Marine Life (CoML). CoML is a decade—long international program to assess and explain the diversity, distribution, and abundance of marine life in the oceans—past, present, and future. It strives to answer three overarching questions: What *lived* in the ocean? What *lives* in the ocean? And, what *will live* in the ocean in the future under a variety of scenarios? Some CoML scientists have estimated that there may be more than a million ocean species waiting to be discovered, particularly in the unknown reaches of the deep

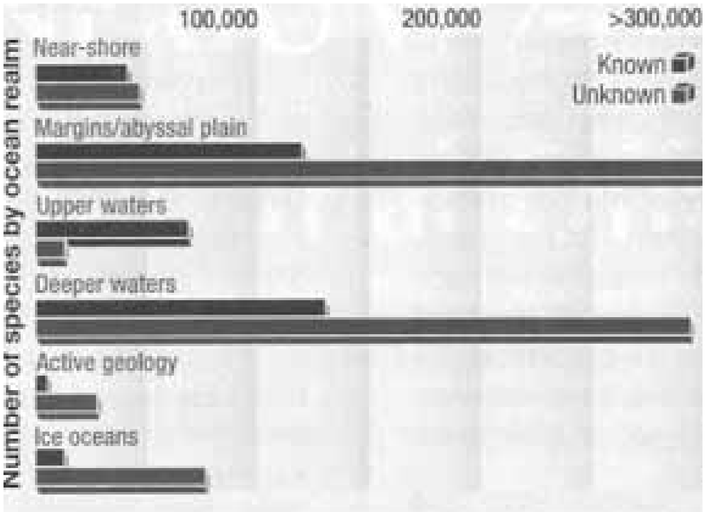


discover data

20,000 SPECIES UNDER THE SEA

Drawing on three years of work by more than 300 scientists, the Census of Marine Life has released the first comprehensive estimate of the total number of species in the ocean. The census gives a better picture of Earth's biodiversity, since 20 percent to 50 percent of all living things are aquatic. Researchers have already entered more than 20,000 organisms into the database, and they expect to add hundreds of newly found ones each year. To manage all the information, the census splits the ocean into six realms, determined by geography and climate. Team scientists then estimate how many forms of life have yet to be discovered in each realm based on how well it has been studied and how many species have been discovered there so far. On the deep ocean floor, for instance, more than 80 percent of the species being found are unknown. "The limiting feature of the discovery process will be descriptions," says Ronald O'Dor, the census's senior scientist. "We need new people with the old taxonomic skills or we need alternate technologies." —William Jacobs

Source: COML



Source: COML

sea floor. What we need are the technologies and funding to find and identify them.

The U.S. government spent $650 *million* on ocean exploration and research in 2004, a sum that pales when compared to the $15 *billion* spent on space exploration and research. Over the past 25 years, the relative investment in oceanographic exploration and research has shrunk from seven percent of the total federal research budget to only 3.5 percent today.

The U.S. Commission on Ocean Policy (USCOP) report called for a doubling of the federal research budget for oceanography within five years from $650 million to $1.2 billion. It also called for an appropriate balance between an investment in basic and applied research and a sustained investment in regional, interdisciplinary ecosystem studies.

The potential benefits to science and society of a significant and sustained program of oceanographic exploration are huge: new understanding of how ocean systems function; new knowledge to better manage human impacts on those systems; new cures for diseases from biologically-active compounds; and untapped minerals, energy, and sustainable biological resources. The potential costs of *not* exploiting this information and knowledge are even greater.

b. Understanding the ocean is more than a matter of curiosity-exploration, inquiry, and study are required to better understand ocean systems and processes.

Because understanding changes in important ocean properties, processes, and phenomena over time is important to understanding the ocean and human impacts on it, it is important that there be a systematic and sustained program for documenting significant and distinguishing characteristics over time.

There is increasing concern about the biological health of the ocean. Changes in marine ecosystems, such as increases in the frequency of harmful algal blooms (HABs), threaten their productivity. Seafood-borne diseases threaten public health. Ocean primary productivity and sediments formed by ocean life help regulate the concentration of atmospheric carbon dioxide, an important greenhouse gas, and act to slow its rapid accumulation in the atmosphere, thus reducing the rate of global warming.

Changes occurring in the ocean—both natural and human—induced-and how they affect the roles of the ocean in making Earth habitable for life as it is today and poorly understood. Where changes were once thought to occur only on geologic time scales, they are now known to occur on human time scales.

Dealing with these issues will be increasingly critical for the U.S. and the world. Dr. Robert Frosch said, "We will need to disentangle human-induced and naturally-caused environmental change, so we can know whether, when, where, and how to respond. We will need to articulate the temporal and spatial scales of environmental change. The overlapping impacts of global climate change and local pollution on regional ecosystems provide an illustrative example. In short, we will not be able to manage our environment without correctly attributing cause and effect relations."

c. *The future sustainability of ocean resources depends on our understanding of those resources and their potential.*

Ocean resources can be divided into living and non-living, renewable and non-renewable. Living resources such as fish are renewable if fisheries—the human activity of harvesting them—are properly managed, and if the essential habitats of fish are protected. Oil and gas are non-living resources and are not renewable on time scales of decades, centuries, or even millennia. **(See Key Concept 1 for more information on finite ocean resources).**

The management of fisheries must take a long view to ensure their continued, sustainable use. We need to understand life cycles, ecosystems, population ecology, and so many more aspects of the ocean before we can even think about trying to regulate or think that we can manage sustainably. Management efforts have largely failed to prevent over-fishing and in some cases total collapses of stocks (e.g. cod). The future of fisheries depends on our understanding of fish resources and their limits, and the courage and will to manage them.

d. *Enhanced and new technologies are expanding our ability to explore and understand the ocean and its resources.*

Satellites now show sea surface temperature, chlorophyll concentrations, wind directions, sea surface height, ice sheet and ice cap variations, and other important properties. Satellites were able to show the change in the ocean surface height during the Sumatran-Andaman tsnunami of 2004. Integrated Ocean Observing Systems use buoys, radar, and satellites to give real-time observations about ocean conditions and will provide scientists with a detailed look the marine ecology of the oceans over a range of spatial and temporal scales. Unmanned submersibles have made it possible to explore places where it was impossible to go before. These and other advances made it possible to continuously document ocean change.

Ocean.US (www.ocean.us) was created by the National Oceanographic Partnership Program (NOPP) to coordinate the development of an operational, integrated ocean observing system (IOOS). Information from the IOOS system will serve national

But all the 'old' hasn't been discarded

One of the first instruments to investigate the sea bottom was the sounding weight, a line with a weight at the end. Viking sailors took measurements of ocean depth and sampled seafloor sediments with this device. The depth was measured in fathoms; the distance between a sailor's outstretched arms, or about 1.83 m (6 ft). The unit is still in use today as a measure of ocean depth. Much of the equipment used in the first oceanographic explorations is still used with various modifications and improvements. For example, trawls have been used as fishing and collecting gear for centuries. Trawls are used in explorations to collect specimens and handheld dipnets are used to collect samples of whale feces to document their feeding habits.

Adapted from NOAA's Ocean Explorer.

needs for:

- detecting and forecasting oceanic components of climate variability;
- facilitating safe and efficient marine operations;
- ensuring national security ;
- managing living marine resources for sustainable use;
- preserving and restoring healthy marine ecosystems;
- mitigating natural hazards, and
- ensuring public health.

Emerging Technologies

Technologies that often are taken for granted today were considered speculative, new, or "emerging" in very recent history. Submersible vehicles can traverse the ocean floor thousands of feet below the surface, underwater cameras and viewers can go where humans are still unable to venture, and offshore oil and gas development can now take place in deep ocean waters previously thought to be inaccessible. Funding and research for such technologies by the military, other government agencies, and the private sector have been on the decline for many years, slowing the development of new technologies that could be helpful for science, ocean, and coastal resource protection, industrial development, and resource management.

Some of the newer technologies now in use and new equipment on the horizon are these.

- Synthetic Aperture Radar (SAR) in use today by JPL and UC Santa Barbara researchers to study liquid oil seeps in the Southern California Bight by analyzing SAR images
- Evolutionary changes in manipulator arms, suction devices, and rotary plankton samplers for specimen collection
- Shipboard DNA laboratories
- Active sonar
- Laser-aimed still and broadcast quality cameras
- Xenon-arc lights
- FlowCytobot and Imaging FlowCytobot. This is an underwater microscope system in which one instrument counts and measures the fluorescence of small cells and the other does the same for diatoms and takes microscope images for further identification
- Acoustic Dopler Current Profiler (ADCP) measures speed and direction of ocean currents throughout the water column
- CTD measures how temperature and conductivity in the water column change with depth
- Sondes equipped to measure temperature, conductivity, salinity, dissolves oxygen, pH, turbidity, and depths to 200 m (656 ft).

NOAA's new exploration and research ship will be a major conversion of the USNS *Capable.* The 12-18 months conversion will result in NOAA's only ship with a dedicated science-class, deep-robot or remotely-operated vehicle. This exploration ship will also be equipped with a hull-mounted, state-of-the-art multibeam mapping sonar system, a dynamic positioning system (linking ship instruments measuring wind, speed, and currents with a GPS reading from satellite) that will automatically adjust the ship's position and keep it on course, and a technology center to process data aboard. Ashore there will be special Science Command Centers that will enable scientists to exchange data and see deep-ocean images and organisms at the same time as their shipboard counterparts.

Information Technology

Ocean resource managers have the responsibility to steward, monitor, and track physical and biological resources that may lie above, below, or on the surface of the sea, in addition to the land resources that impact ocean ecosystems. For the regulated community, project costs on land or offshore can increase if environmental, economic, engineering, or regulatory information necessary to determine project feasibility or acceptability are not readily available. Timely access to geographically located information is critical for both policy makers and others who need to rapidly assemble the complicated scientific, planning, or regulatory processes that apply to specific geographic areas.

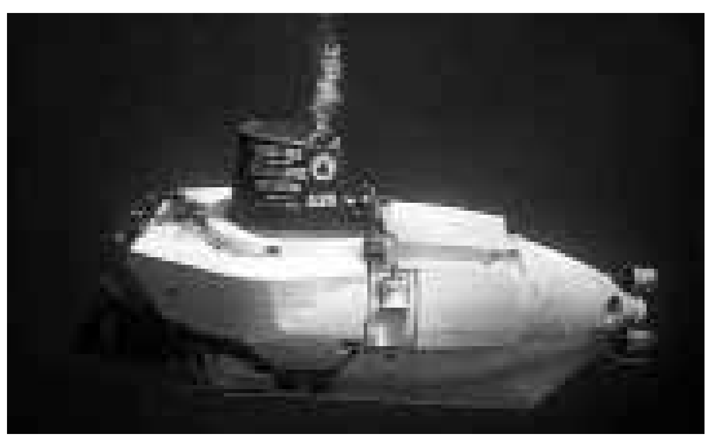
Information about the Earth's surface has been placed on maps for thousands of years. However, the complexity of information and its use have evolved substantially in recent times. Originally, maps were used primarily to depict the cosmos, specify land ownership, or as aids to navigation, but they have become increasingly important for depicting jurisdictional boundaries, land uses, vegetation types, topographic hazards, social and demographic data, population and natural resources distribution, air and water quality patterns, and many other features relevant to public and private decision-making.

The complications involved with maintaining all this information on one map required the development of theme, or thematic, maps to display specific categories of information. For a resource manager this could mean having a set of maps for wetlands, another for topography, and yet another to depict jurisdictional boundaries.

A computer-assisted geographic information system (GIS) allows multiple sets of information to be placed on a series of electronic maps which can then be viewed and manipulated alone or in combination with other thematic information layers. This tool becomes particularly important for ocean resource management because multi-dimensional data about the ocean surface, water column, and ocean floor can be displayed and analyzed individually or together on computer-generated maps, and can be quickly modified and redisplayed, rather than requiring hours or days to edit or revise a map. Resource managers, researchers, private industry, and members of the public are also interested in gaining rapid access to natural resource data and in the ability to transfer data immediately to specific locations where it can be used.

Finding fish, FADs, AUVs, Tsunami cruise, Arctic cruise

The venerable U.S. Navy research submersible, *Alvin*, is being retired and will be replaced with a sleeker, deeper-diving sub. *Alvin* took its maiden voyage in 1967 and has since been one of only a few research subs capable of descending to depths of 4,000 m (13,123 ft). More than a third of the seafloor, however, lies at depths greater than this. For this reason, *Alvin*, which is housed and operated by Wood Hole Oceanographic Institution in consortium with the National Science Foundation and the United States Navy, cannot reach the least explored areas of the ocean. It is hoped that the proposed



DSV Alvin
Source Woods: Hole Oceanographic Lab.

new sub, will be able to dive to 6,500 m (21,200 ft), making all but one percent of the seafloor accessible to it.

As with birds, fish populations can be identified acoustically by the unique sounds that certain species make. We are beginning to understand quite literally how to listen to the ocean. Real time tracking devices allow us to follow the movements of megafauna (tunas, whales, turtles) with satellites

In the same way that our understanding of weather patterns, weather forecasting, and climate change has gotten better through the use of computer models, other complex systems such as the ocean are better understood through the use of powerful **computer models.** These models allow us to understand systems that are so complex they appear to be random. With the models we have a chance of understanding and possibly predicting harmful algal blooms, tsunamis, where the fish we want to catch will be, and how the things we do affect the ocean.

The critical and rapidly changing interactions between the oceans and the atmosphere can only be modeled with the most powerful computers. Climated models can now predict and forecast the impacts of El Nino events on things like rainfall—snowfall acorss the United States. They can predict melting Arctic ice caps, tsunami, track hurricanes, and predict their landfalls. Still, it is difficult to build models with the processing power of existing computers. Millions of calculations must be performed each second in order to accurately replicate natural processes. This quest has continued for years and as larger computers are built our modles become more accurate. Comuter models have been an essential part of oceanography for decades.

e. Ocean exploration is interdisciplinary.

The ocean is like no other place. It is a constantly moving and changing three-dimensional environment. It's chemical, biological, and physical cycles are all intertwined with each other, and with ours. Ocean processes are mutually interdependent—one process affects another, which in turn may alter another, which may have ramifications for yet another.

Because the ocean is an intertwined web of physical, chemical, biological, and geological processes, it naturally follows that ocean exploration requires close collaboration among biologists, chemists, climatologists, geologists, meteorologists, physicists, engineers, computer programmers, archaeologists, and other specialists. Sharing of knowledge and collaboration are key to understanding the ocean.

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Appendix I

Ocean and Coastal-related Laws, Acts, and Regulations

Many international, federal, and state laws, acts, and regulations have been enacted that affect coastal and marine resources management ranging from aquaculture to wildlife. Most of these have been amended several times since originally adopted or enacted. Legislation has been introduced in the 109th Congress in response to the USCOP and Pew reports. Following are **some** of the legislation that impacts the Southern California Bight.

International

Convention on Wetlands of International Importance

The broad aim is to halt worldwide loss of wetlands and to conserve those that remain through wise use and management by national action and international cooperation. About 1200 sites are now listed. In April 2005 the Tijuana Slough National Wildlife Refuge near San Diego, California was designated a Wetland of International Importance.

Migratory Bird Treaty Act

Treaties between the U.S. and Canada, U.S. and Mexico, U.S. and Japan, and U.S. and Russia that are designed to protect selected migratory birds and their ecosystems.

United Nations Law of the Sea Convention (1996)

This convention is designed to regulate the use of the oceans in a single convention that is acceptable to all nations. The convention provides for a universal legal framework for the rational management of marine resources and their conservation for future generations. The treaty governs use of the world's oceans and addresses issues including navigation, use of airspace, exploitation of ocean resources, and protection of the marine environment. It provides for the designation of Exclusive Economic Zones (EEZ). The treaty has been ratified by more than 140 nations, but not the United States. The U.S. Senate ratifies treaties and some members believe that the Law of the Sea would have a negative impact on U.S. sovereignty. However, the U.S. does follow the Convention and participates in many of the UN actions pertaining to it such as the article on Highly Migratory Species. Both the USCOP and Pew reports strongly recommended ratification.

Federal

Several bills relating to the ocean have been introduced in the 109th Congress. Among them are bills to establish a national policy for our oceans, to strengthen the National Oceanic and Atmospheric Administration, to establish a Committee on Ocean Policy; to protect the ocean; to strengthen programs relating to ocean, coastal, and Great Lakes; to expand coastal and ocean observation systems; to establish a coordinated ocean exploration program under NOAA; etc. Most of these are in response to the recommendations of USCOP and Pew reports.

For information about bills go to http://thomas.loc.gov or http://www.gpoaccess.gov/bills/index.html

Act to Prevent Pollution from Ships

The Act prohibits the discharge of oil and noxious liquids and the disposal of various types of garbage in offshore waters consistent with the International Convention for the Prevention of Pollution from Ships (MARPOL). A recent amendment to the act prohibits garbage and plastic disposal in U.S. navigable waters or by U.S. flag ships worldwide.

California Coastal National Monument (CCNM)

(A Resource Management Plan (RMP) for the monument is to be finalized in late 2005.)

The CCNM, established by an Executive Order in 2000, consists of more than about 11,000 off-shore rocks, small islands, exposed reefs, and pinnacles that are part of the nearshore ocean zone. This 12 nautical mile zone begins just offshore and ends at a boundary between the continental shelf and continental slope. The monument features provide important safe havens for seabirds and some shorebirds that use the monument for breeding and nesting sites, migratory stopovers, and rookeries. The monument also provides forage and breeding habitat for mammals, including seals and sea lions, and the threatened southern sea otter. Additionally, the monument has unique geologic features and scenic values. The monument, with some exceptions, is under the jurisdiction of the U.S. Department of the Interior's Bureau of Land Management (BLM). The agency's authority extends only to the structures themselves, not to the ocean or surrounding submerged lands.

Coastal Protection and Management Act 1995

The object of this Act is to:

a. provide for the protection, conservation, rehabilitation, and management of the coast, including its resources and biological diveristy; and

b. have regard to the goal, core objectives, and guiding principles of the National Strategy for Ecologically Sustainable Development in the use of the coastal zone; and

c. provide, in conjunction with other legislation, a coordinated and integrated management and administrative framework for the ecologically sustainable development of the coastal zone; and

d. encourage the enhancment of knowledge of coastal resources and the effect of human activities on the coastal zone.

Clean Water Act

Established to restore and maintain the chemical, physical, and biological integrity of the Nation's waters in order to support the protection and propagation of fish, shellfish, and wildlife and also recreation in and on the water. Subsequent amendments have strengthened requirements for beach water monitoring, an area in which California is the U.S. lleader.

Coastal Wetland Planning, Protection, and Restoration Act

Addresses wetland loss in coastal states through acquisition, protection, and restoration projects.

Coastal Zone Management Act

(Amendments pending in 109th Congress)

In recognition of the increasing pressures of over-development on the nation's coastal resources, Congress enacted the Coastal Zone Management Act (CZMA) in 1972. The CZMA encourages states to preserve, protect, develop, and, where possible, restore, or enhance valuable natural coastal resources such as wetlands, floodplains, estuaries, beaches, dunes, barrier islands, and coral reefs, as well as the fish and wildlife using those habitats.

The CZMA requires that coastal states develop a State Coastal Zone Management Plan or program and that any federal agency conducting or supporting activities affecting the coastal zone conduct or support those activities in a manner that is consistent with the approved state plan or program.

Coastal Zone Act Reauthorization Amendments

(Additional amendments pending in 109th Congress)

A 1990 amendment to the CZMA established the

Coastal Nonpoint Pollution Control Program to improve coastal water quality. The program requires every state with a federally-approved coastal management program to identify management measures to address nonpoint source pollution of coastal waters.

Endangered Species Act
(Amendments proposed by 109th Congress)

The ESA protects species of plants and animals that are determined by NOAA or USFWS to be endangered or threatened. The charge to the agencies is to designate critical habitat and develop and implement action plans for protection and recovery of the affected species.

Magnuson Stevens Fishery Conservation and Management Act (Amended and renamed Sustainable Fisheries Act of 1996)

The Act extended federal fishery jurisdiction to the limits of the EEZ. It established eight regional fishing councils charged with preparing fishery management plans for fisheries that they determine require active federal management. Amendments 2004 USCOP and Pew reports recommended revision of the makeup of the regional fishing councils to include more general public participation. The Pacific Fishery Management Council manages fisheries in federal waters off the coasts of Washington, Oregon, and California. Amendments to the act included: preventing overfishing, rebuilding depleted stocks, reducing bycatch, and designating and conserving essential fish habitat.

Marine Mammal Protection Act (Amended by 108th Congress)

Gives NOAA responsibility for ensuring the protection and management of cetaceans (whales, dolphins, and porpoises) and pinnipeds (seals and seal lions) except walruses. USFWS has responsibility for sea otters, dugongs, manatees, and walruses. The Act also establishes parameters for human interaction with marine mammals.

Marine Protection, Research and Sanctuaries Act (1972)

Commonly called the Ocean Dumping Act, this Act established programs to control ocean dumping, conduct ocean dumping research, and set aside areas of the marine environment as national marine sanctuaries.

National Aquaculture Act

The intent of the Act is to promote aquaculture development in the United States by mandating a national aquaculture development plan and federal coordination of aquaculture activities through a joint subcommittee on aquaculture.

National Environmental Policy Act (NEPA)

NEPA requires all federal agencies to include a detailed statement of the environmental impact of a major federal action significantly affecting the human environment. Through Environmental Assessment and Environmental Impact Statement reviews (EIS), federal agencies are required to consider environmental impacts before action is taken. Established Council on Environmental Quality (CEQ) in the Executive Office for counseling the President on environmental matters.

National Invasive Species Act of 1996

The Act substantially amended the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 and strengthened it. Deals with aquatic invasive species and ballast water management. The Act provides the basis for U.S. Coast Guard regulations and guidelines to prevent introductions of nonnative species through the uptake and discharge of ship's ballast water.

Oceans Act of 2000

The Act established the U.S. Commission on Ocean Policy to carry out a comprehensive review of marine-related issues and laws and make recommendations to Congress and the President for a coordinated and comprehensive national ocean policy and system of ocean governance. The commission issued its final report, *An Ocean Blueprint for the 21stCentury*, in September 2004.

Oil Pollution Act of 1990

The Act addresses oil discharges in navigable waters and shorelines. It seeks to harmonize oil spill response mechanisms from several other acts, state and federal laws, and international conventions.

Submerged Lands Act (1953)

The Act grants to U.S. coastal states title to the natural resources located within three nautical miles of their coastlines with the exception of Texas and the Gulf coast of Florida. These two states were granted nine miles. Natural resources include oil, gas, and other minerals, all fish, other marine animals, and plantlife.

Sustainable Fisheries Act of 1996

(Amendments to be introduced in 109th Congress)

In 1996, the Magnuson-Stevens Act underwent a major revision and was reauthorized as the Sustainable Fisheries Act. The original legislation failed to direct fishery managers to prohibit overfishing, rebuild depleted fish populations, or to protect habitat for fishery resources This act corrected those deficiencies.

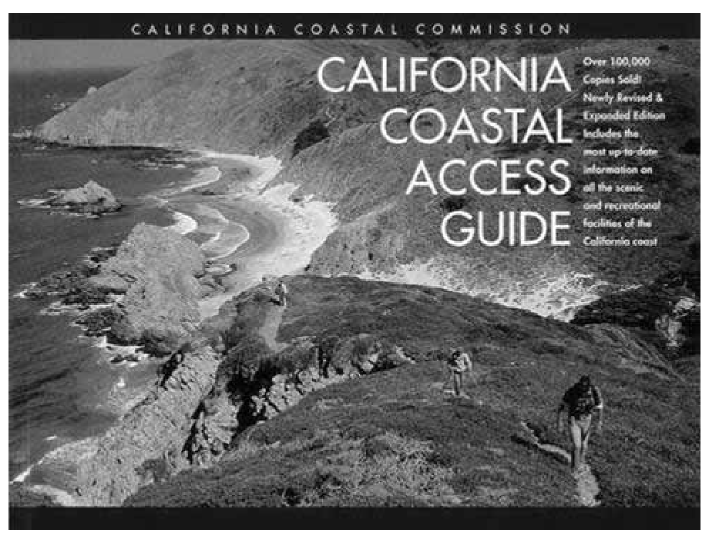
State of California

California Ocean Protection Act (COPA) (2004)

The Act streamlines and consolidates oversight of California's ocean resources under one coordinating body—the Ocean Protection Council—ending the fragmented management structures that allowed the protection of marine life to fall through cracks in the system; ensures that our oceans will be managed as a public trust.; shifts focus from individual species to the protection of marine ecosystems, recognizing that the web of life is an intricate one; promotes the use of sound science and sound ocean protection policies; facilitates the designation of marine reserves, conservation areas, and parks; and authorizes the use of existing funds for these purposes.

Coastal Zone Management Act

Requires each local government lying, in whole or in part, within the coastal zone to prepare a local coastal program for that portion of the coastal zone within its jurisdiction. Each local coastal program must contain a specific public access component to assure that maximum public access to the coast and public recreation areas are provided. Plans are to be approved by the California Coastal commission.



Source: California Coastal Commission

Also requires that the Commission prepare and publish a public access inventory to be updated on a continuing basis.

The California Coastal Zone Management Program is operated by three lead agencies: the California Coastal Commission, the California Coastal Conservancy, and the San Francisco Bay Conservation and Development Commission (BCDC). Their programs and activities combined comprise the state's federal Coastal Zone Management Program (for purposes of the federal Coastal Zone Management Act of 1972). These agencies provide: 1) the framework for the California coastal regime, and 2) a social institution that sets the rules of California coastal management, defines social practices, assigns roles, and guides interactions among the occupants of these roles.

The CZMP accords the statewide Coastal Commission significant authority to regulate development in the interest of all the state's citizens while allowing cities and counties, as well as ports and universities, to exercise authority in line with state (and federal) standards. The CZMP also uses non-regulatory economic tools to achieve its goals, primarily through the California Coastal Conservancy.

Marine Life Management Act (MLPA)

The California State Legislature passed this act in 1998 in an effort to improve management of fisheries in the state's waters for long-term sustainability. Before the MLMA, the responsibility for managing most of California's marine resources harvested by commercial fisheries within state waters lay with the State Legislature, while the Fish and Game Department and the Fish and Game Commission managed the recreational fisheries and those commercial fisheries with catch quotas that changed periodically. Management of commercial fisheries under this division of responsibility was complicated, piecemeal, and often untimely. The MLMA transferred permanent management authority to the Commission for the nearshore finfish and white seabass fisheries, emerging fisheries, and other fisheries for which the Commission had some management authority prior to January 1, 1999. *Also of importance, the MLPA broadened the focus of fisheries management to include consideration of the ecosystem—the entire community of organisms (both fished and unfished) and the environment and habitats on which these species depend.*

Adapted from the California Marine Life Protection Act Initiative Master Plan Framework, August 2005)

Some other California ocean legislation

Legislation passed between 2002-2004 protects the California coast and ocean by: regulating and restricting bottom trawling; prohibiting cruise ships from conducting onboard incineration or discharging gray water within three miles of California's shore; requiring that representation on the federal Pacific Fishery Management be a balanced representation of interested parties including NGOs and marine scientists and, not be limited as formerly to fishing and industry interests; forbiding harvesting of krill in California waters, and requiring ocean education be included in environmental education K-12, etc.

For information about actions of the California State Legislature: http://www.leginfo.ca.gov/bilinfo.html.