which both copies of the LXR gene have been inactivated.

Pharmacologic applications. Nuclear receptor proteins have been an attractive target for drug research because of the ability of their ligands to stimulate the synthesis of mRNA from specific genes or groups of genes and the ability of many of these small molecules to enter cells. Synthetic LXR ligands have been developed for the treatment of cardiovascular and other diseases. However, several practical difficulties have hindered their development. Although each ligand activates only a subset of genes, these ligands promote diverse and sometimes competing pathways. Synthetic LXR ligands have been developed that stimulate the regression of atherosclerotic lesions and increase high-density lipoprotein (HDL) levels (the "good" fraction of blood cholesterol) by activating the lipid transporter ABCA1, which moves lipids from peripheral tissues into the blood. Unfortunately, the same ligands usually stimulate fatty degeneration (steatosis) of the liver by activating the gene encoding fatty acid synthase.

There are differences in the DNA base sequence surrounding the LXR binding site of different genes that probably affect the competition between LXR and other receptor proteins. The identity of coactivator proteins in the transcription complex (which can number 30–50) also influences the response of individual genes to ligands. So far, the composition of these complexes for individual genes is not well defined, and it has not been exploited for drug development. However, a recent account of an experimental LXR ligand in mice with differential effects on steatosis and atherosclerosis offers hope that LXR-directed drugs can be developed.

For background information *see* CHOLESTEROL; DEOXYRIBONUCLEIC ACID (DNA); GENE ACTION; LIPID METABOLISM; NUCLEAR HORMONE RECEPTORS; NUCLEOPROTEIN; NUCLEOSOME in the McGraw-Hill Encyclopedia of Science & Technology.

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Mangrove forests and tsunami protection

Mangrove forests thrive in the intertidal zones of tropical and subtropical coasts. They have several ecological, socioeconomical, and physical functions that are essential in maintaining biodiversity and protecting human populations. Their complex architecture, combined with their location on the edge of land and sea, makes mangrove forests strategic greenbelts that have a doubly protective function. They protect seaward habitats against influences from land, and they protect the landward coastal zone against influences from the ocean. The tsunami that occurred on December 26, 2004, revealed the valuable buffering functions of mangroves.

Ecological and socioeconomic benefits. The intertidal mangrove forest exhibits a unique biodiversity with uncommon adaptations such as vivipary in trees (young plants develop while still attached to the parental tree) and the amphibious lifestyle of certain fish. Mangroves are adapted to intertidal environmental conditions such as high-energy tidal action, high salt concentrations, and low levels of oxygen (hypoxia). The large aboveground aerial root systems not only offer improved breathing for the plant but also protect more seaward and more landward areas. On the one hand, mangroves protect seagrasses and coral reefs by trapping sediments and nutrients from overland fresh-water sources that would otherwise be deposited more seaward and cause turbidity and/or eutrophication (excessive nutrient concentration with periods of oxygen deficiency). On the other hand, mangrove trees can protect the landward area against the fury with which meteorologic or oceanologic processes, such as cyclones or tsunamis, may strike. Mangrove tree species that inhabit lower tidal zones, such as *Avicennia* spp. (Grey or Black mangrove) or *Sonneratia* spp. (Mangrove apple), can block or buffer wave action with their stems which can measure 30 m (100 ft) high and are several meters in circumference (**Fig. 1**). Although probably rare, mangrove trees reaching heights between 30 and 50 m (100 and 165 ft) have been reported from Latin America, Africa, and Asia, including Mexico, Panama, Venezuela, Brazil, Colombia, Ecuador, Sierra Leone, Nigeria, Gabon, Democratic Republic of Congo, Angola, Mozambique, Indonesia, and Papua New Guinea (Fig. 1*b*, *d*). Mangrove forests are feeding grounds and a refuge for many fish, crustaceans, and other lagoon and marine species at some stage in their life cycle. Mangroves are also known to enhance the biomass of coral reef fish communities and thus help maintain their biodiversity. Important biogeochemical services of mangroves include the entrapment of sediments and pollutants, filtering of nutrients, remineralization of organic and inorganic matter, and export of organic matter. Mangroves also function as carbon dioxide sinks by removing and storing carbon dioxide from the atmosphere, which is a major contributor to global warming.

In addition to these ecological benefits, mangroves provide natural resources and perform a number of functions that are of socioeconomic importance to humans. For example, mangrove degradation has been associated with a decline in the function of lagoon and offshore fisheries, which most fishing communities rely on to provide their main supply of dietary protein. Such degradation also impacts local inhabitants, who derive important resources—such as fuelwood, timber, food items, and ethnomedicinal products—from mangroves. Mangroves maintain

Fig. 1. Density and architecture of mangrove trees and their aboveground root complex in a healthy state. (*a*) Waterfront edge of 30-m-tall mixed *Camptostemon schultzii–Avicennia* spp. mangroves in the Tipoeka and Kamora estuaries, Irian Jaya, Indonesia. These pristine forests range 10–25 km in depth (dominated by *Rhizophora* spp. and *Bruguiera* spp. in the interior) and extend for hundreds of kilometers east and west. (*b*) Seafront mangroves composed of 45–50-m-high *Rhizophora mangle* and *R. racemosa* in Darien, Panama. (d) Inside view of the physiognomy (physical appearance) and density of seaward mixed *A. marina–R. mucronata* formation in Gazi Bay, Kenya. Seaward *A. marina* can reach 20–30 m in height here, and the stems can measure several meters in circumference. (*c*) Density of frontal *R. mucronata* mangroves in Rekawalagoon, Sri Lanka. (*e*) >30-m-tall *Rhizophora* spp. from Indonesia with a human reference point of 1.5 m, and (*f*) bottom-up perspective of *Rhizophora* spp. and (*g*) *Bruguiera* spp. in the same assemblage, all showing the mightiness of these mangrove trees. (*h*) Frontal *Sonneratia alba* mangrove fringe in Gazi Bay (Kenya), which are rather low (5–10 m) and sparse (29 trees 0.1 ha^{-1}) but very thick (D_{130} up to 100 cm). Imagine such a healthy mangrove greenbelt of just 500 m or even 250 m width separating a lagoon or bay from human settlements, and then picture a tsunami discharging its energy on this living dyke. This virtual image of how it could be and how it should be is in strong contrast with the December 26, 2004, media images showing huge waves discharging on "naked" beachfronts with tourist resorts and coconut trees. (*Parts a, e, f, g from Joe Garrison, Garrison Photographic, Cambodia. Part b from Norman C. Duke, University of Queensland, Australia. Part d from Farid Dahdouh-Guebas. Parts c and h from Nico Koedam, Vrije Universiteit Brussel.*)

a climate and pollution record, and they provide educational and scientific information from which we can learn. They also serve as a location for habitation and recreation for indigenous people, sustaining their livelihood as well as their cultural, spiritual, and artistic values.

Past human-mangrove interactions. The history of many mangrove sites in Latin America, Africa, Asia, and Oceania is characterized by detrimental human impacts such as deforestation, conversion to shrimp farms, mangrove land reclamation for tourist resorts, and fragmentation of mangrove populations by

Mangrove loss rates or estimates and the mangrove forest surface area for some select countries

Country or region	Time period	Mangrove loss, %	Mangrove forest surface area, km^2 (year)
Latin America			
Jamaica	xxxx*–1997	30	106 (1993)
Puerto Rico	xxxx–1979	75	92 (1997)
Mexico	1970–1992	65	5315 (1992)
Guatemala	1965–1997	31	161 (1997)
Ecuador	1969–1991	21	2469 (1997)
Peru	1943–1992	68	51 (1997)
Africa			
Gambia	1982–1995	17	497 (1995)
Guinea-Bissau	1973–1995	20	2484 (1995)
Asia			
India	1963–1977	50	6700 (1997)
Malaysia	1980–1990	12	6424 (1997)
Singapore	1822–1997	92	6 (1997)
Thailand	1961–1996	48	2641 (1997)
Vietnam	1943–1999	61	1560 (1999)
Philippines	1920–1990	97	1607 (1997)
Oceania			
Fiji	1869–1986	>9	385 (1993)

*Indicates that the time period during which the mangrove loss occurred is uncertain.
SOURCE: Based on data compiled from M. Jaffar, 1993; M. Spalding et al., 1997; C. D. Field, 2000; D. M. Alongi, 2002; E. Barbier and M. Cox, 2003.

urbanization. This has resulted in tremendous loss of mangrove forests in some countries (see **table**). It has been estimated that the total mangrove surface area has decreased from 198,090 km^2 in 1980 to 148,530 km^2 in 2000, a 25% loss. This impact has been documented through retrospective methods—such as sequential remote sensing, interviews with local people, and archive research—which all indicate that major mangrove functions have been lost (**Fig. 2**). In turn, this loss of natural functions considerably increases the sensitivity of the natural, as well as the human, environment to stochastic oceanic or climatic events such as cyclones and tsunamis.

South-East Asia tsunami. Until December 25, 2004, the most destructive tsunami that ever occurred in the Indian Ocean resulted from the eruption of the Krakatau (Krakatoa) volcano in 1883. The Krakatau explosion and resulting tsunami claimed around 36,000 human lives on Java, Sumatra, and smaller islands scattered over the Sunda Strait (Indonesia). But on December 26, the South-East Asia tsunami struck, resulting in tenfold more deaths, than the Krakatau volcanic eruption and leaving millions homeless. Near the Sumatran island of Nias, a seabed earthquake measuring 9 on the Richter scale generated a huge tsunami wave that spread in all directions, discharging its energy on thousands of kilometers of coast around the Indian Ocean. Waves up to 30 m (100 ft) high were reported to have stripped beaches with tourist resorts, local houses, roads, railways, and other human infrastructures and settlements up to several hundred meters or even several kilometers inland (**Fig. 3**). Recurrent high waves and the receding waves caused a massive flow of water and debris that ravaged the coastal zone. There were victims in Indonesia, Thailand, Burma, Malaysia, Bangladesh, India, Sri Lanka, Maldives, Seychelles, Somalia, Kenya, and Tanzania. The death toll for Indonesia and the Indian subcontinent alone amounted to about 170,000, and this figure does not account for deaths among tourists and other visitors from abroad. In total about 295,000 deaths and 130,000 injuries were recorded. The victims originated from 53 countries.

Fig. 2. Destroyed mangrove stand in Godavari delta, Andhra Pradesh, India. Fishing boats are shown searching for marine species that probably depend on the mangroves as nursery grounds. Apart from loss of function as nursery grounds, these mangroves have lost their ability to buffer oceanic influence on the land such as tidal activity, sea-level rise, and tsunamis. (*Courtesy of Nico Koedam, Vrije Universiteit Brussel, Belgium*)

Barrier function of mangroves. Unfortunately the role of mangroves as living barriers was underappreciated prior to the tsunami event of December 2004, and many mangrove forests had already been destroyed or damaged. This was the case for many mangrove sites in East Africa, Thailand, Indonesia (for example, Banda Aceh), India, and Sri Lanka (for example, the southwest coast)—areas badly affected by the tsunami tragedy. Scientists have repeatedly highlighted that mangrove forests provide goods and services to local communities; however, short-term economic gains have often been perceived to be more important. In Sri Lanka, for instance,

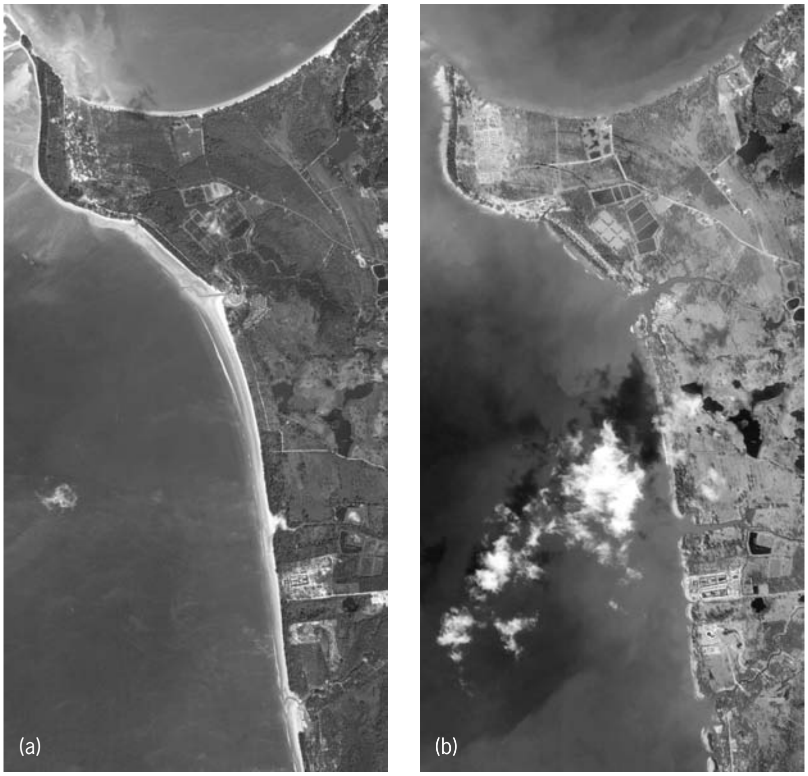

Fig. 3. Pre- and posttsunami coastline in Khao Lak, Thailand. (*a*)These reduced-resolution images were taken by Space Imaging's *IKONOS* satellite on January 13, 2003 (pretsunami), and (*b*) on December 29, 2004, just 3 days after the devastating tsunami hit the area. The images show that most of the lush vegetation, beaches, and resorts on the coast were destroyed by the tsunami. Breaches to the coastline are apparent, and new inlets have been carved into the shoreline. One resort near the newly carved inlet has virtually disappeared. Vegetation has been washed away, and there is standing water in low-lying areas. (*Courtesy of Space Imaging/CRISP-Singapore*)

despite existing regulations from the Forest Department and national and international recommendations for protection of selected mangrove areas, aquaculture ponds were created at the expense of mangrove forests. In addition, less drastic degradation has led to an increase in mangrove sensitivity to anthropogenic and natural hazards. For example, it has recently been reported that mangroves suffering from cryptic ecological degradation proved less resistant than unaltered mangroves during the recent tsunami. Cryptic ecological degradation is the introgression of nonmangrove vegetation into a true mangrove forest, which gives the false impression that the mangrove formation is rejuvenating in a healthy way. The fact that even such subtle changes in species composition (which do not necessarily result in a reduction in mangrove area) have had a profound impact on the damage the tsunami was able to inflict on the coastal zone, makes clear that the clearing of mangroves (or mangrove-shrimp farm conversions in other areas) will dramatically increase the vulnerability of shoreline areas.

Most evidence about the impact of the recent tsunami has come from media-interviewed witnesses who survived the natural catastrophe. Testimonies on the "power of mangroves" were reported from Indonesia, Thailand, Malaysia, Sri Lanka, and India, including the Andaman Islands, a low-lying area with extensive virtually pristine mangrove forests. Of the 418 villages hit by the tsunami along the Andaman coast, only 30, or 7%, were severely devastated. In areas where mangroves have been degraded by the aquaculture or the tourist industries, this percentage reaches an estimated 80 to 100%.

Future research. In addition to tsunamis, a healthy mangrove forest can offer protection against tidal erosion, sea-level rise, the El Niño Southern Oscillation, and associated heavy rains and tropical cyclones. However, the functions of mangrove forests during these extreme meteorologic events have not been investigated in detail. Determining whether mangrove forests play a protective role against these severe weather events requires the collection of data. The typology of the vegetation and of the geomorphologic settings in which mangroves thrive (for example, zoned forests fringing rivers or lagoons versus patchy basin forests), the species composition (that is, major species versus minor species versus associated mangrove species), and the spatial changes over time in the vegetation assemblages (for example, little change in zonation versus strong shifts in mosaic patches) can greatly differ between mangrove forests, as can the degree to which they are able to protect the coast. The assumed buffer function of mangroves has never been studied and compared across these many contexts. More research is necessary to understand the specific role of mangrove ecosystems (or similar vegetation types) in different environmental settings and under different impact types and intensities, information which would be of great value in planning human settlement and land management policy.

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For background information *see* ECOLOGICAL COMMUNITIES; FOREST MANAGEMENT; MANGROVE; TSUNAMI in the McGraw-Hill Encyclopedia of Science & Technology. F. Dahdouh-Guebas

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Mars Rovers

In June and July 2003, the National Aeronautics and Space Administration's Jet Propulsion Laboratory launched twin *Mars Exploration Rovers*, *Spirit* and *Opportunity*, on a 6-month journey to the Martian surface. Launched 3 weeks apart, both spacecraft successfully landed on Mars, *Spirit* on January 4, 2004, and *Opportunity* on January 25. *Spirit* has roamed a geological depression known as Gusev Crater, while *Opportunity* has explored an area known as Meridiani Planum, one of the flattest locations on Mars. At both landing sites, the twin rovers have made exciting scientific discoveries regarding a past and significant water history on the Martian surface. The *Mars Exploration Rovers* continue the NASA exploration strategy associated with understanding the Martian climate history and the possibility that Mars was once a warm and wet planet that could have been a habitat for life.

Entry, descent, and landing. During the cruise portion of the mission, each rover was contained within a spacecraft configuration that was first developed for the *Mars Pathfinder* mission that landed on July 4, 1997, and deployed the *Sojourner Rover*. For the *Mars Exploration Rovers*, the cruise configuration consisted of a cruise stage, a backshell, a tetrahedral lander structure which contained the rover, and an aeroshell that protected the lander and rover as the spacecraft descended through the Martian atmosphere. Both spacecraft traveled safely on their interplanetary journey from the Earth to Mars (over 450 million kilometers or 280 million miles) and arrived within an atmospheric entry corridor that was only 10 km (6 mi) wide.

Approximately 15 min prior to atmospheric entry, the cruise stage was jettisoned, leaving the lander and rover cocooned within the backshell and aeroshell (**Fig. 1**). Upon arrival at the top of the Martian atmosphere, the lander and rover navigated through what has been called the "6 minutes of terror" as the spacecraft slowed from a maximum speed of 5.4 km/s (12,000 mi/h) to a dead stop on the surface of Mars. During this descent, the thermal protection system on the aeroshell burned away and dissipated the majority of the spacecraft's kinetic energy. A subsonic parachute then opened to further slow the lander. The aeroshell was jettisoned, and the lander was lowered on a tether that separated it from the backshell. A radar sensor was used to determine the altitude of the lander as it continued the decent to the surface. The altitude solution then dictated the timing of the remaining landing events, including the opening of the lander's airbags, the firing of retro rockets to slow the lander to nearly zero velocity, and the cut of the tether that then released the lander to freely bounce on the surface until it came to a complete rest.

Once safely on the surface of Mars, the lander petals opened up revealing the rover stowed inside on what is known as the base petal of the lander. In the event that the lander came to rest on one of the side petals, the petals opened up in a specific order that allowed the lander to end up in a base-petal-down configuration. The *Spirit* lander came to rest in the base-petal-down position, while the *Opportunity* lander came to rest on one of its side panels prior to lander petal opening. A number of single-use mechanisms were then used to deploy the rover's solar panels, deploy the remote-sensing mast, lift the rover off of the lander base petal, and deploy the rocker-bogie mobility suspension hardware. Cable cutters were also used to sever a number of cable harnesses that connected the rover to the lander. These deployments took place over a number of sols (or solar days, whose duration is about 24 h 40 min) on the Martian surface. Finally, 11 sols after arrival, the *Spirit* rover drove off of its lander and onto the surface of Gusev Crater. For *Opportunity*, the egress of the rover occurred 8 sols after the initial landing event.

Instrumentation. The *Spirit* and *Opportunity* rovers (**Fig. 2**) carry identical scientific instrument suites. The remote-sensing instrument suite consists of the multispectral panoramic imaging system known as the Pancam and a miniature thermal emission spectrometer known as the mini-TES. These two instruments are located on a mast that stands approximately 1.3 m (4.3 ft) above the surface. The Pancam is configured as a stereo camera pair and achieves its multispectral capabilities through the use of a filter wheel which places one of eight narrow-band interference filters in front of a black-and-white charge-coupled-device (CCD) imager. The Pancam