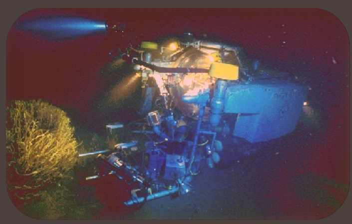
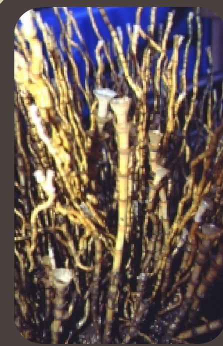
Gulf of Mexico

Chemosynthetic Communities

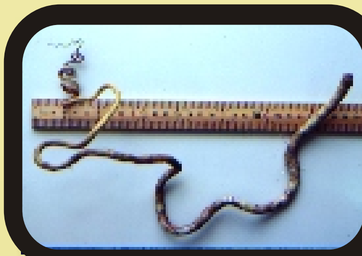
A Teacher's Companion!









MMS
U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

Johnson Sea Link **Submersible**

B.

Giant Isopod

A.

Chemosynthetic Mussels and Predatory Starfish

B.

Researchers Working on Tube Worms

A.

Tube Worms and Crab

B.

Tube Worms

A.

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A. Greg Boland - MMS

B. Jonathan Blair - National Geographic Society

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Tension Leg Platform

A.

Gaper/Anglerfish

B.

Gas Hydrates

C.

Tube Worm on Deck

A.

Gulf of Mexico

Chemosynthetic Communities

A Teacher's Companion

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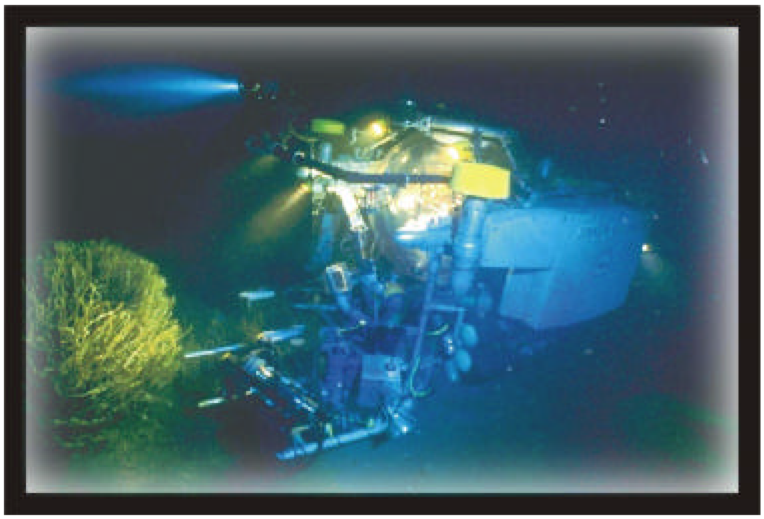
Chemosynthetic Communities of the Gulf of Mexico
A Teacher's Companion

Introduction

This *Teacher's Companion* accompanies the Minerals Management Service's educational poster "Chemosynthetic Communities of the Gulf of Mexico." Its purpose is to assist teachers in introducing the topic of chemosynthetic communities and other ecological concepts to students at the middle and high school levels.



Research Submersibles

Manned submersibles are the principal tools used by scientists to study chemosynthetic communities. The depth of the shallowest known community at 1,000 ft is far beyond the limits of scuba diving. Photo by J. Blair, National Geographic.

Chemosynthetic communities are remarkable in that they use a carbon source independent of photosynthesis and the sun-dependent photosynthetic food chain that supports all other life on earth. Although now thought to be relatively common where the proper conditions exist in the deep Gulf of Mexico, these unique communities of animals were only discovered in the Gulf of Mexico in 1984.

This packet contains information on some of the Government's involvement in deep-sea science. It describes the two known forms of primary production (photosynthesis and chemosynthesis) and the makeup of the unusual chemosynthetic communities. It further discusses the importance of the multidisciplinary approach to the marine sciences (or oceanography) and how the marine environment changes with increasing depth. It describes the ecology of chemosynthetic animals, the bacterial populations upon which they depend, and other forms harbored within the communities. It compares them with similar communities around the world, describes their significance, and relates MMS actions to ensure community protection.

We have attempted to define and explain basic ecological principles. Technical terms found in bold type are further contained in the glossary. Scientific ("Latin") names have been avoided, as these are not necessary for the understanding of ecological concepts. However, we do use common names of the higher taxa, which the student may want to understand further.

The Minerals Management Service (MMS), a Federal agency created by Secretarial Order 3071 on January 19, 1982, shoulders significant responsibilities in managing the natural and economic resources of America. The MMS manages more than a billion offshore acres and collects billions of dollars in mineral revenues annually. While the Gulf is one of our Nation's greatest natural resources, it also is an important source of the Nation's energy. Thousands of oil and gas production platforms located on the U.S. continental shelf of the Gulf of Mexico make up the largest artificial island and reef system in the world, and an entire generation of Gulf Coast citizens now depends on them for energy, food, and recreation. These facilities must be managed prudently to prevent significant environmental impact. The existing management relationship is the result of a longstanding partnership between the oil and gas industry and the Federal Government to develop our marine resources in an environmentally safe and responsible manner.

Tension Leg Platform Near Bush Hill

The Conoco tension leg platform is located only about 1/2 mi from the lush chemosynthetic community known as Bush Hill. This platform, installed at a depth of 1,720 ft, was the first Tension Leg Platform (TLP) in the Gulf of Mexico and held the record for the deepest production platform between 1989 and 1994. TLP's are held to a bottom template by numerous large cables. Many other chemosynthetic communities are closely associated with major oil-field discoveries. Photo by G.S. Boland/MMS.

The MMS runs the Federal Government's program for managing mineral resources on the Outer Continental Shelf (OCS). Since 1953 more than 12 billion barrels of domestic oil and 131 trillion cubic feet of gas have been extracted from under the ocean floor. These resources have brought nearly $100 billion into the U.S. economy since 1982. These funds are among the largest Federal revenue sources outside the U.S. Treasury Department. They, in turn, are distributed to Native American tribes and allocated to States, the Land and Water Conservation Fund, the Historic Preservation Fund, and the general U.S. Treasury.

Royalty management, MMS's other major mission, has collected and distributed more than $98 billion in bonuses, rents, and royalties from companies that lease and produce minerals from Federal lands, both onshore and offshore, and from American Indian lands since 1982. The MMS is a major source of revenue to the U.S. Treasury, providing over $61 billion over the same period. In 1998, about $6 billion was distributed to States, American Indian tribes, and their allottees.

We trust that this effort provides you with a new educational opportunity and we welcome comments and suggestions.

For more information contact us at:

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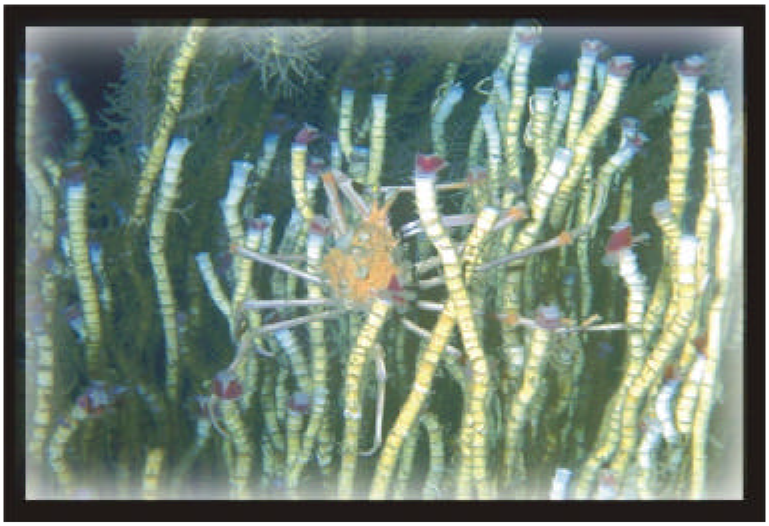
What are Primary Production, Photosynthesis, and Chemosynthesis?

These short definitions and discussions are offered to explain, at the most basic level, the great significance of chemosynthetic communities. The biochemical process known as chemosynthesis is a distinctly different (yet common) form of primary productivity, as opposed to photosynthesis.

Primary production is the conversion of carbon dioxide (CO_2) into simple sugar. The sugar is ultimately made into all other important molecules necessary for life (e.g., fats, complex carbohydrates, and proteins), whether on land or in the water. This is the very base level of the food chain everywhere. Carbon compounds from those molecules of “fixed” CO_2 eventually find their way throughout the whole biosphere of the earth from lowly, tiny organisms like bacteria through the largest predators. The carbon compounds are ultimately remineralized (metabolized and oxidized back to CO_2), and the cycle is repeated.

Overwhelmingly, the most important and common form of primary production is **photosynthesis**. Believed to be the only energy source (photons of light) for any organism other than bacteria until 1977, photosynthesis is almost always accomplished through the capture of light by a green pigment (chlorophyll) in a living plant. A photosynthetic plant might take any form, from algae to seagrasses, lichens, mosses, ferns, and trees. In any case, an elegant intercellular set of chemical reactions using light energy converts CO_2 in the air or water into food, usually a six-carbon sugar, glucose. Organisms that are capable of producing their own food in this way are also called **autotrophs** or autotrophic. Virtually all animals are **heterotrophic**; that is, they eat living or dead organic matter. In the oceans, these include filter (suspension) feeders, deposit feeders, scavengers, and predators. But ultimately, the food of a heterotroph originated from primary production at the very base of the food chain.



Tube Worm "Forests"

Tube worm colonies often form large "bushes" and particularly lush concentrations of bushes give the impression of an exotic kind of forest. Individual tube worms can reach 3 m in length and could be up to 400 years old! A deep-sea crab is shown here, possibly grazing on small animals along the stalks of the tube worms. Photo by J. Blair, National Geographic.

In 1977, an amazing discovery was made in the deep waters of the Pacific Ocean. Using the research submersible *Alvin*, scientists discovered an oasis of densely packed animals, where none were expected, near a spreading tectonic ridge in the Pacific Ocean at a depth of over 8,500 feet! It was later realized that these large and numerous animals were getting their food from a source not related to photosynthesis. Hydrogen sulfide (H_2S) was coming out of the earth through hot **hydrothermal vents** at ridges in the earth's spreading crustal rocks. At such ridges, new rock is being exposed at "spreading centers." Surprisingly, bacteria in the water around the vents were using CO_2 in the presence of other dissolved gasses, oxygen and hydrogen sulfide (H_2S), to fuel the manufacture of sugar. But what was remarkable was that the bacteria were found not only in the water and **benthic** (bottom) films or mats, but living symbiotically in the tissues of the numerous newly discovered animals found around the vents. A new form of productivity for any animal larger than bacteria –**chemosynthesis** (called one of the major biological discoveries of the century)– had been discovered in the total absence of sunlight. This **symbiosis** is critical to the existence of all **chemosynthetic animals** and **chemosynthetic communities**. More recently, in places like the Gulf of Mexico, similar forms have been found at **cold seeps**, places where H_2S and hydrocarbons (mostly methane, CH_4) seep from the bottom.

What are the Characteristics of Chemosynthetic Communities?

In addition to the different biochemical strategies and other unique requirements chemosynthetic bacteria need to live, there are some other important contrasts between chemosynthetic and more typical deep-sea communities:

- As we have seen, chemosynthetic animals are those animals that are able to live on dissolved gasses through a symbiotic association with chemosynthetic bacteria living in their tissues (**endosymbionts**). Major groups of chemosynthetic animals in the Gulf of Mexico consist of species of tube worms and several types of mussels and clams. In return for their food source, the animals give their symbiotic bacteria a secure home. They also attract other heterotrophic animals such as snails, fishes, worms, seastars, and crustaceans, much as a reef does. Taken together, all of these animals (and the microbes) are part of the chemosynthetic **community**, a functional assemblage of animals in deepwater that do not depend on the fall of scarce foodstuffs from the surface far above. They vary in depths from about 400 m to at least 3,000 m (probably much more). By virtue of the ample nutrient source (the gasses and symbiotic bacteria), they have a much greater average physical size than the usual small deepwater animals. There are large numbers of several dominant species, as opposed to small numbers of very many species.

Mussels and Tube Worms

A view from the submersible showing a mixture of both methanotrophic mussels and tube worms. Photo by J. Blair, National Geographic.

- Wherever these animals occur around the world, they typically form dense clusters around the seep or vent sites that provide their nutrition. The great biomass found at these deep sites is usually hundreds or even thousands of times larger than the biomass of animals living on the surrounding seafloor. This is an example of the principle that nutrition is a major limiting factor to the abundance of most animals in the deep sea.

- Chemosynthetic communities are islands of high biomass and productivity in an otherwise monotonous deepwater world, an oasis in a desert. They are analogous to other communities in shallow water such as mangrove forests and seagrass beds (very productive), coral reefs, oil platforms, rocky ledges, and pinnacles (structural in origin, attracting other animals).

- Chemosynthetic communities are wonderful natural laboratories and places to test ecological hypotheses to determine their effects on the surrounding neighborhood. Considered as a special location, they can be viewed as centers of larval dispersal and settlement, isolated communities with evolutionary and genetic potential worthy of controlled studies of ecological change with time.

- It has only recently been demonstrated that simple forms, including chemosynthetic bacteria and other simple, primitive forms (*e.g.*, the Archaea), live in the most hostile environments on earth, even under the extreme conditions around thermal vents, in hot mineral springs, deep into rocks and in the coldest Antarctic settings. Recent evidence of liquid water on Europa, a moon of Jupiter, evidence of water inside a meteorite older than our solar system, and the suggestion of possible fossilized cells in a Martian meteorite cause one to ponder whether similar forms of life might have evolved independently somewhere else in the universe. Many scientists believe Archaea bacteria were the first forms of life on earth.

What is the General Character of Deep-Sea Animals and Communities?

To understand the significance of the discovery of chemosynthesis and chemosynthetic forms, one must first understand the usual character of deepwater habitats and the makeup of animal communities.

As one proceeds across the seafloor of the ocean from the shore out to the deep sea, the character of the benthic community changes dramatically. On the continental shelf from the beach to about 200 m deep, surface and benthic photosynthetic productivity provides abundant food into the shallow food web. Nutrients from estuarine and river systems (and sometimes upwelling) further fertilize the photosynthetic plants. These include several types of phytoplankton, benthic algae, and seagrasses. Depending on water clarity and resulting sunlight penetration, the depth at which photosynthetic production can occur will vary from almost nothing to 60-80 m.

As one proceeds outward across the steeper continental slope, there are typically reductions in available organic nutrients. Much of the food that is produced in the surface waters is used and recycled in the water column through the pelagic food web. What little food escapes the swimming animals (the "**nekton**") and larger **planktonic** animals sinks to the bottom. When the food finally reaches the seafloor, it has a decreased nutritional value, and only bacteria can use some of the remaining organic matter. With increasing depth, the sediments become finer; the temperature, lower; and the hydrostatic pressure, higher.

Chemosynthetic Tube Worms

This is a vertical view looking down from the submersible on a tube worm bush at Bush Hill from about 2 m above. A symbiotic clam is seen attached to the end of an individual tube worm. This interesting association is still not fully understood. Photo by G.S. Boland for LGL Ecological Research Associates/MMS.

So the deep bottom animals live under conditions of total darkness (except for a tiny amount of bioluminescence), crushing pressure, generally very weak currents, little food, cold, and on a featureless, fine mud bottom except for the occasional animal track or burrow. The animals are mostly small and fragile and are anatomically and physiologically adapted for these severe conditions. As one approaches the true **deep sea** (the lower slope and the **abyss**, 1,000 m or more), the structure of the bottom-dwelling community has virtually nothing in common with a **continental shelf** community. Conditions have now become very stable in terms of water temperature, oxygen, and saltiness (salinity). The deeper one goes down the **continental slope** and across the continental rise and **abyssal plain**, the lower the living **biomass** becomes. The bulk of the animals here eat by filtering the water, sweeping or eating the sediment surface, or scavenging on the occasional dead fish, whale, or kitchen refuse that falls to the bottom. Interestingly, diversity increases as the depth increases; that is, there are more and more different species represented by very few, widely-spaced individuals.

What Do We Know about Gulf of Mexico Chemosynthetic Communities?

The first chemosynthetic community found in the Gulf of Mexico as a whole was discovered by accident at the base of the Florida escarpment by scientists using the *Alvin* submersible in March 1984. Later that year, two other serendipitous discoveries first found hydrocarbon seep-type communities on the soft bottom of the Central Gulf. In early November 1984, just a few months after the Eastern Gulf discovery and only seven years after the initial discovery of chemosynthetic communities at the Galapagos Rift in the Pacific Ocean, large clams similar to those around hydrothermal vents in the Pacific were photographed at a depth of 940 m by a Texas consulting company, LGL Ecological Research Associates, working on a deep-sea project for MMS. Later that same month on a different research cruise, Texas A&M University researchers unexpectedly collected chemosynthetic species in dredge and trawl tows from an area known to have sediments containing oil, gas hydrates, and hydrogen sulfide. Carbon isotopic analyses of the samples collected by trawling confirmed that the tube worms and molluscs lived via a chemosynthetic strategy. To the scientific community this was a remarkable finding. Later that year, photographs also taken during the LGL November 1984 cruise for MMS revealed, for the first time, tube worms living on the Central Gulf of Mexico seabed at a depth of 635 m.

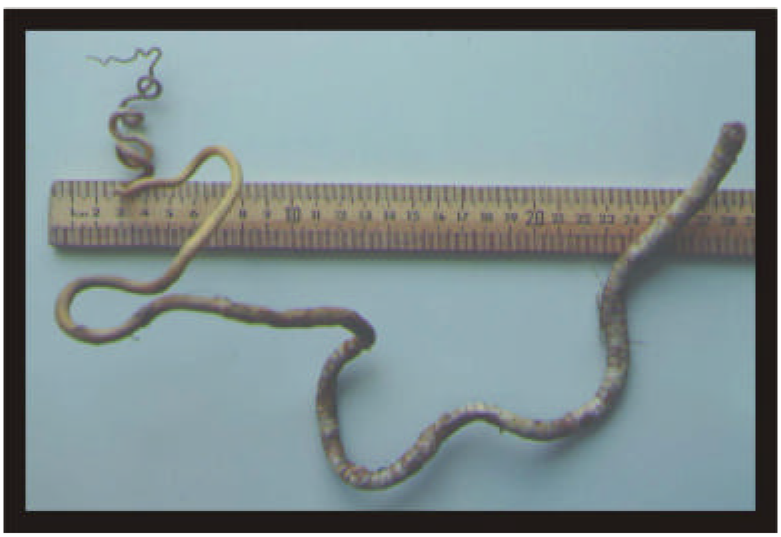
Tube Worms

Cluster of tube worms on deck collected as a complete colony by the Johnson Sea Link *Submersible. Photo by G.S. Boland/MMS.*

The Minerals Management Service responded by providing additional funding to LGL and Texas A&M University for the initial surveys and analyses using a Johnson Sea Link research submersible from the Harbor Branch Oceanographic Institution. Six successful dives revealed the magnitude of the communities, their faunal composition, spatial variability, and relationships among the fauna, bacterial mats, seeps, and unusual geological formations. These faunal assemblages quickly revealed striking parallels to other distant chemosynthetic communities. While there are no hydrothermal vents in the Gulf, the local geology obviously provided habitats with quite adequate hydrogen sulfide and methane seepage capable of supporting prolific chemosynthetic communities.

Gulf of Mexico chemosynthetic communities have been described by four general community types. These are communities dominated by tube worms, mussels, large clams living on the surface, and other smaller clams that live under the surface of the mud. These animal groups tend to display distinctive characteristics in terms of how they aggregate, the size of aggregations, the geological and chemical properties of the habitats in which they occur and, to some degree, the heterotrophic fauna that occur with them. Many of the species found at these cold seep communities in the Gulf are new to science and remain undescribed. As an example, at least six different species of seep mussels have been collected but none are yet described. The structures of chemosynthetic communities worldwide are parallel. (That is, they have major type species in common.) Biologists have yet to work out the **zoogeographic** relationships and evolutionary histories.

The following information has been learned about the various chemosynthetic animals in the Gulf of Mexico:



Tube Worm on Deck

This is an individual tube worm, the longer of the two species living in the Gulf of Mexico. While this one might stretch to about 1 m long, some tube worms reach 2 and even 3 m in length. The complicated curls of the smaller end or "root" of the tube worms is normally buried in the sediment. It is now known that this root area is the major site of diffusion where the worm obtains its sulfide nutrition. Photos by G.S. Boland/MMS.

Tube Worms

- All of the Gulf chemosynthetic species studied to date have a very slow growth rate, interestingly, about the same growth as a coral head (7 mm/year), although tube worms grow slower as they grow older, unlike corals. Some of the larger tube worms reach a length of 3 m and may be hundreds of years old (based on recent measurements of tube worm growth). This contrasts with some other tube worms in the Pacific, which are among the fastest growing deep-sea animals!

Mussels

Chemosynthetic mussels have been found living on the surface of hydrocarbon-saturated sediments as well as along the edge of a high salinity “lake” of sea water saturated with methane, also called **brine pool**.

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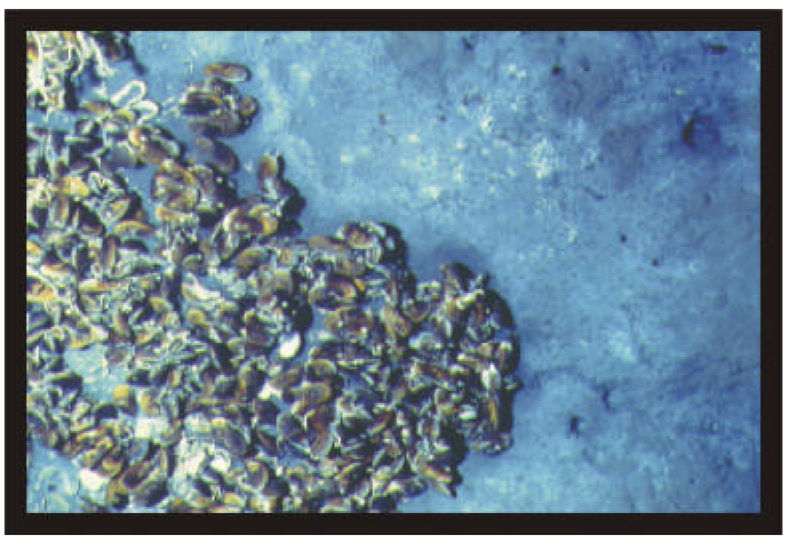
- Mussel communities can be short lived. Dissolution studies show that accumulations of dead shells are no older than 15-20 years old.
- Growth rates of chemosynthetic mussels have been found to be surprisingly high for a deep-sea animal and similar to mussels from a shoreline environment at the same temperature.
- The discovery of seep mussels represented the first animals known to use methane as a food source (with their bacterial endosymbionts).

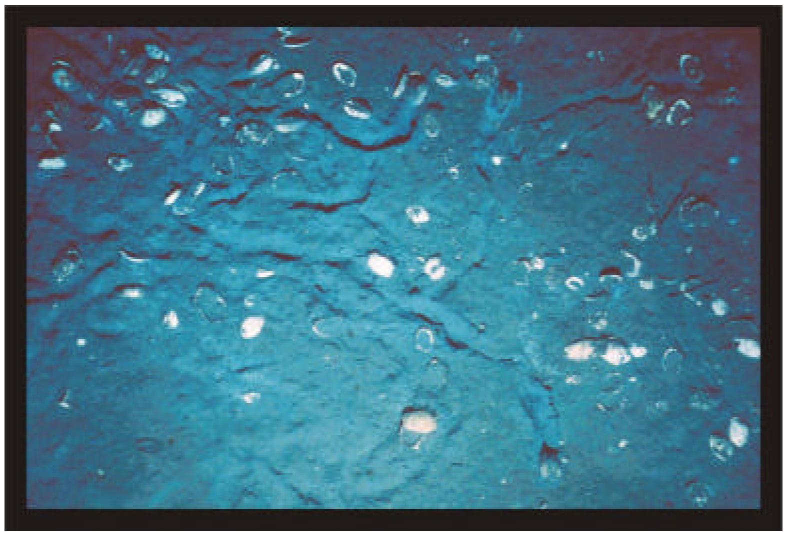


Mussels

These mussels use methane as a food source. They have a narrow range of where they can live balancing the anoxic environment where methane can be used with the oxygenated water necessary for normal respiration. Layers of living mussels are often seen piled on each other in areas that meet both kinds of environmental conditions. Photo by G.S. Boland for LGL Ecological Research Associates/MMS.

Clams

Two species of large chemosynthetic clams have often been observed on the surface of the mud bottom near cold seeps, leaving behind extensive trails in the mud. This is probably an active adaptive behavior allowing the clams to reach higher sulfide concentrations in the sediment, a unique behavior not shown by similar species at Pacific hydrothermal vents where stationary clams can face periodic loss of their nutrient supply.



Clams

Several living chemosynthetic clams are seen here plowing through the sediment at a depth of 980 m. Individual clams are about 50 mm long. This was one of several photos taken on November 14, 1984, that first recorded chemosynthetic animals from the Central Gulf of Mexico. Photo by G.S. Boland for LGL Ecological Research Associates/MMS.

General

- When communities are disturbed, for example, buried and suffocated by natural turbidity flows or slumps, the same type of community grows back, given the same local chemical conditions.
- Chemosynthetic communities are localized, highly productive habitats. But it is not yet known how much carbon in the chemosynthetic system supports the surrounding heterotrophic (nonchemosynthetic) food chain.
- Anoxic brine pools, which fuel surrounding mussel beds with gas, have been discovered. Mussels and other animals that fall into the pool soon die from suffocation. The pools are far saltier than ambient water and some are significantly warmer.

Mussel Community

Several non-chemosynthetic animals are also seen here taking advantage of this mussel bed oasis. A predatory starfish lies across the dense bed of methanotrophic mussels. Numerous small crabs can also be seen clinging to the sides of mussel shells. Photo by J. Blair, National Geographic.

Ice Worms

A new species of segmented worm (a polychaete) actually inhabits depressions on the surface of exposed blocks of solid methane hydrate. It is not known how the depressions are formed, possibly by the feeding activities of the worm grazing on bacteria from the methane ice surface. These "ice worms" are the only seep animals known to inhabit this niche anywhere in the world. Main photo by C. Fisher, Pennsylvania State University; Inset photo of individual ice worm by G.S. Boland/MMS.

- The number of known chemosynthetic communities in the Gulf of Mexico now exceeds 50. These communities range in depth from a few hundred meters to one found at 3,000 m. Scientists believe that there are likely to be many, many more, especially in deepwater. Natural oil slicks seen at the water's surface in the deep Gulf further support this view.

- No two communities are exactly the same. They reflect locally distinct geochemical microhabitats. Communities can change rapidly over distances of only a few meters.

- The level of natural oil and gas seepage in the Gulf is surprising! Estimates obtained using photographs taken from space indicate that approximately 10 million gallons of oil seep naturally from the bottom of the Gulf every year. Many surface slicks coincide well with known positions of chemosynthetic communities.

- The types of acoustic signals received during geophysical surveys are strongly correlated with the geological and geochemical conditions that might support the growth of chemosynthetic communities. Geophysical records obtained by lease operators are the principal tool used for the initial search for the location of communities, as well as their protection.

Do Chemosynthetic Communities Have Any Value?

Yes and no. It depends on one's perspective. There are many precedents for one to find "value" in anything. Value might be based on aesthetics, financial worth, productivity, rarity, or any number of other criteria.

To many scientists, the chemosynthetic communities have substantial aesthetic value. But to the average citizen who has no access to the deep ocean as they might have to a colorful, shallow coral reef or the Grand Canyon, they may have little aesthetic attraction. We know that chemosynthetic communities form natural deepwater "reefs" and attract crabs, fishes, snails, and a myriad of smaller animals as a refuge and possibly a place to eat. To these animals, of course, the community has "value." But so far as we humans are concerned, none of these species have value as a commercial or recreational fishery. Even if they had food value, their depth, distance from shore, and isolation make them nearly inaccessible.

Ecologically, the communities certainly increase local productivity. But compared to all of the green plant productivity in the shallow ocean, the overall effect is nil. The Government has afforded no special legal status to either the communities or the individual species, as is given to marine mammals under the Marine Mammal Protection Act and to many other species under the Endangered Species Act. However, the MMS does require that operators exploring for oil and gas in the Gulf of Mexico avoid areas that could support chemosynthetic communities.

In another way, their unique biochemical (chemosynthetic) metabolism and the unusual places they inhabit define their "value." Anything rare, unusual, or unique has some inherent value, whether it's an old Grecian vase, a Spanish doubloon, the Old Faithful geyser, or an Atlantic right whale. And the chemosynthetic communities are extremely valuable as natural laboratories for many types of scientific study. Even after 125 years of scientists studying life in the oceans, these communities have been known for only two decades. There is still very much left to learn. Numerous species collected from chemosynthetic communities are new to science, and these species have intellectual value to taxonomists and zoogeographers.

The MMS studies have suggested that the communities or at least a few species might be fragile and vulnerable to the physical effects of the oil and gas industry. For this reason, MMS intends to continue to protect and conserve them under its legal mandates.

How Do Scientists Study Chemosynthetic Communities?

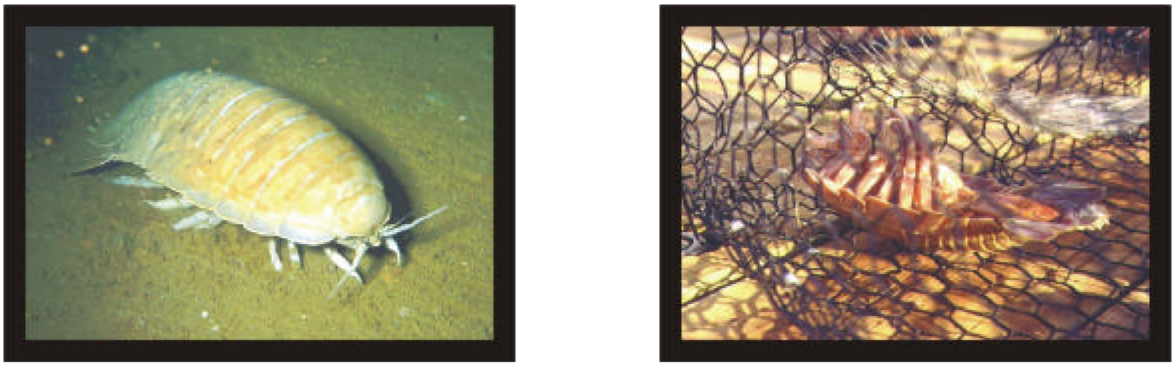
The small spatial extent and rapid environmental and community changes over short distances at these remarkable sites pose a considerable challenge to the scientific investigator who needs to sample and observe the communities. With the notable exception of acoustic geophysical studies that require surface ships to tow recording instruments, all of the effective studies in the Gulf of Mexico and elsewhere have been conducted with manned submersibles and unmanned, remotely operated vehicles or "ROVs" (mostly the former).

Research Submersibles

A swimmer stands on top of the Johnson Sea Link *just after surfacing from a dive. He will insert a large lifting rope into the top of the sub, which will allow it to be lifted back onto the deck of the research vessel. Photo by G.S. Boland/MMS.*

Here, all technical stops are pulled. Scientists and design engineers have invented many devices and instruments to collect samples and to measure, probe, and image environmental features. Many are quite innovative. Operations have included high-precision sampling of animals, water, rocks, sediments, and gas hydrates. Laser beams are used to estimate object size. Scientists have invented and deployed in situ instruments and camera systems on the seafloor and left them there to record various events over time. Some of these experimental packages have measured currents, temperature, gas bubble-stream volume, and provided time-lapse photographic records. Individual experiments have been generally successful in determining growth rates of selected animals, changes in animal density over time, and changes in gas hydrates. Scientists have discovered several species new to science and they have set out baited traps to capture large, motile animals associated with the communities.

Samples, photographs, and data obtained from these ship and submersible operations require many months of analysis and interpretation prior to the writing of scientific reports and journal publications.



Deep-sea Isopod

The deep-sea isopod is shown on the bottom and in a trap that was deployed near a seep community. These and other unusual animals are studied to determine their relationship with the high productivity found at the chemosynthetic communities. Photos (left) by J. Blair, National Geographic Society; (right) by G.S. Boland/MMS.

Ecology, Biochemistry, Geochemistry, Biogeochemistry, and Geophysics: Scientists Needed!

Ecology is the study of living organisms and their interrelations with each other and their chemical and physical environment. In other words, ecology is necessarily a multidisciplinary field. In the study of chemosynthetic communities, we recognize the importance of understanding both the animals and the conditions necessary for their distribution, abundance, and continued survival. Therefore, we must enlist help from scientists in a number of different specialized disciplines to gain a real understanding of chemosynthetic community ecology. For most scientific studies there is the need for all sorts of interrelated expertise:

- ***Biochemists*** have specialized experience with the chemistry of cellular function and its relationship with external chemistry.

- ***Geochemists*** study the chemical content of the rocks and sediments with an eye on the origin, formation, fate, and seepage of gasses. One area of interest here is the formation of **gas hydrate**, an ice-like solid made up of methane and water (and other hydrocarbons) that forms under certain conditions of gas seepage, low temperature, and high pressure.

- ***Biogeochemists*** investigate complex biological, geological, and chemical processes that define the origin and function of an ecosystem. In the case of chemosynthetic communities, one looks at the formation of carbonate rocks by bacteria, the fate and use of environmental gasses, and the entire range of the effects of the environment on the biota and the reverse. One application is the determination of ratios of isotopes of carbon, nitrogen, and sulfur to understand chemical pathways in the rocks, gasses, and animals.

- ***Geophysicists*** study subsurface geological structure using acoustic technology. This is done to understand the formation of sediments, rock layers, salt domes, and faults, and the subsequent trapping and release of gasses, brines, and oil to the surface. These studies assist in the understanding of animal distribution and abundance, and the records are used for the regulatory conservation of the communities.

Still other types of scientists such as biologists and ecologists study the anatomy, physiology, growth rates, **zoogeography,** and systematic position (**taxonomy**) of the respective species. (It is not uncommon to find species new to science in deepwater.)

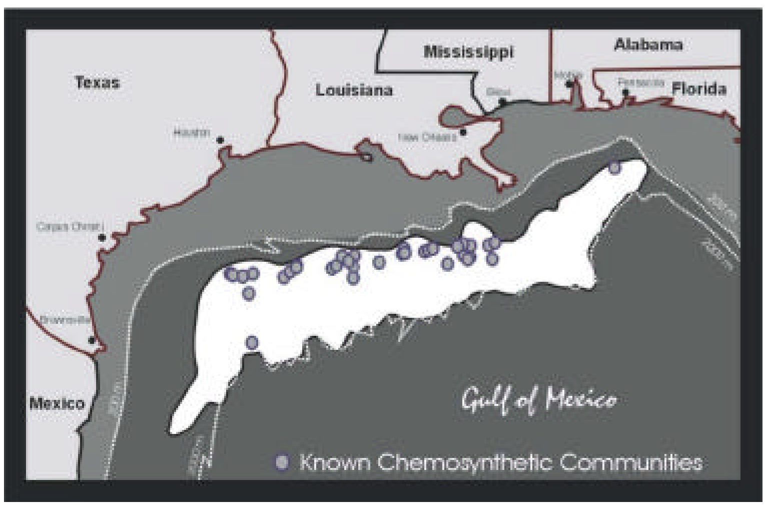
Gas Hydrates

Gas hydrates are ice-like substances of hydrocarbons and other chemicals held in place by "cages" of water molecules. When methane hydrates form near the surface of the seabed, they play a major role in the formation of lush chemosynthetic communities through the utilization of this energy source by bacteria. The exposed portions of the "ice" shown above are brightly colored yellow and orange. Photo by R. Sassen, Texas A&M University.

Why is the Minerals Management Service Involved in Deep-Sea Science?

Worldwide, there are approximately 6,500 oil and gas production platforms on the continental shelves of 53 countries. Approximately 3,800 of these occur offshore in the U.S. Gulf of Mexico, where they supply nearly 27 percent and 20 percent of the U.S. production of natural gas and oil, respectively. We use these petroleum products primarily for fuel to drive our cars and heat our homes, but also to make the plastics used in safety helmets, medical instruments, dinnerware, and countless other items we use or come into contact with each day.

The MMS, a bureau within the U.S. Department of the Interior, pursues research on the marine environment as part of its responsibility to manage the mineral resources, such as natural gas and oil deposits, on the Outer Continental Shelf (OCS) in an environmentally sound and safe manner. Various Federal laws and regulations protect the environment; the National Environmental Policy Act and the Outer Continental Shelf Lands Act cover most activities in the marine environment. The MMS funds studies looking at the possible effects of human activities on environmental aspects of the marine ecosystem. This information, combined with data that continue to be collected, helps MMS make decisions that safeguard the environment.



Map of the Gulf

Locations of known chemosynthetic communities on the continental slope of the Gulf of Mexico.

The MMS has seen a trend for petroleum exploration and development in deeper and deeper water over the last several years in the Gulf of Mexico. In spite of the great cost involved, the industry has been successful in developing and extracting oil and gas from deep reservoirs, largely as a result of new and exciting technology, engineering accomplishments, and financial relief. In anticipation of these developments, MMS has supported deepwater studies to meet its environmental responsibilities. The MMS has supported two major studies of chemosynthetic communities, known informally as CHEMO I and II. Related research has been supported by the National Oceanic and Atmospheric Administration's National Undersea Research Program

(NOAA/NURP), the National Science Foundation (NSF), the Naval Research Laboratory (NRL), and the Department of Energy (DOE). In addition to the direct support of environmental studies, the MMS has cooperated with other agencies such as NOAA and the Environmental Protection Agency (EPA) in regulations relating to community conservation and protection.

Laws, Regulations, Studies, and Community Protection

The Laws

The MMS has responsibilities for the regulation and permitting of most offshore oil and gas activities and the collection of leasing and royalty monies due to the Government on the United States OCS. Although it also includes the continental slope and abyssal areas as well as the shelf, the legal definition of "Outer Continental Shelf" is the submerged land seaward of bottom acreage under the states' jurisdictions. The Gulf of Mexico OCS extends into abyssal depths greater than 3,000 m. The Gulf of Mexico OCS occupies about 2.2 million statute miles, over a third of which is under lease.

Legal mandates guiding the MMS are found in the OCS Lands Act of 1978 as amended (OCSLAA), the National Environmental Policy Act of 1969 (NEPA), and many other laws. The NEPA promotes efforts that will prevent or eliminate damage to the environment and requires that Federal agencies prepare environmental impact statements (EIS's) for their actions. The OCSLAA gave responsibility to the Secretary of the Interior for the management of minerals extraction on the OCS and required the establishment of the MMS Environmental Studies Program to support management decisions. The Studies Program, established in 1973, supports the collection and analysis of information for the MMS leasing program. Its objectives are to provide relevant environmental information to decisionmakers on possible impacts of petroleum activities.

The Studies

In recent years, the oil and gas industry has leased tracts in depths greater than 3,000 m and has developed tracts in depths to nearly 2,000 m. This has placed chemosynthetic communities within the range of potentially adverse environmental effects of this industry. These effects might include physical disturbance from facility emplacement, for example. Following the discovery of the Gulf of Mexico chemosynthetic communities, the MMS recognized their importance and funded two major studies of them under the lead of Texas A&M University. Most of the above information on the Gulf communities resulted from the MMS-funded work. This information is used extensively in EIS's and other documents, and often results in the publication of peer-reviewed papers in scientific journals.

The Protection

But even before the studies could begin, the MMS moved to provide adequate protection for the Gulf chemosynthetic communities. The MMS has at its disposal many regulatory measures for the protection of valued resources and the marine environment in general, and issues a variety of rules affecting virtually every aspect of the petroleum and related industries. Among these measures are published regulations sent to all offshore operators; called Notices to Lessees (NTL's), the measures are a type of postlease administrative action.

In December 1988, the MMS issued NTL 88-11 (now 98-11), which became effective on February 1, 1989. It required avoidance or protection of chemosynthetic communities. In 1999, the NTL was revised to more specifically define measures operators must take to avoid and protect chemosynthetic communities. In depths greater than 400 m, operators must supply geophysical data and maps to MMS to determine the possibility of the existence of local chemosynthetic communities. Prior to approval of plans to drill exploratory wells (Exploration Plans or EP’s), plans for conducting development activities (called Development Operations Coordination Documents or DOCD’s), or pipeline applications, operators must delineate all seafloor areas to be disturbed, as well as provide geophysical data and maps that depict characteristics of the sea bottom that could support chemosynthetic communities. Potential areas where chemosynthetic communities could be present must be avoided by 1,000 feet for the platform itself and by at least 250 feet for other disturbing activities, such as anchoring.

If the MMS review suggests that chemosynthetic communities could be harmed, the operator must (1) modify the application to relocate the operation, (2) modify the application to provide additional photographic or videotape information to determine the presence or absence of communities, or (3) otherwise ensure that the operation does not impact a community (*e.g.*, through the precision placement of anchors).

To date, it appears that these protective measures have been effective. Several chemosynthetic communities have been studied on a regular basis for many years and no detectable degradation has occurred that could be attributed to man’s activities. Research is continuing on how best to predict where new communities will occur in water depths than cannot be easily visited. One interesting avenue of investigation will be the observation of oil seeps on the surface of the Gulf by satellites in space. Many known communities are directly associated with active oil seeps. There are probably many hundreds of undiscovered chemosynthetic communities throughout the geologically complex Gulf of Mexico continental slope. As these new and deeper communities are discovered and explored, they will probably reveal many new species and new secrets about life in the deep sea.

Glossary

Abyss *n*. (abyssal *adj.*) With reference to the greatest depths of the ocean and defined differently by different authors, but generally greater than 2,000 m.

Abyssal plain *n.* Called by many the flattest places on earth, these "plains" are the *benthic* environments farthest from land in the large ocean basins of the world.

Autotroph *n*. (autotrophic *adj.*) Organism that only requires the inorganic compound CO_2 as a carbon source. It does not depend on eating any other organism for food.

Benthic *adj.* (benthos *n.*) Making reference to the seafloor environment or the animals and communities (the benthos) that live on and in the ocean bottom. As opposed to *plankton* and free-swimming pelagic forms.

Biomass *n.* A term referring to the total mass of biota living in a defined area or volume. It can refer to the total mass or a defined group or size of animals and/or plants.

Brine pool *n.* A pool of highly salty, anoxic seep water that collects in a bottom depression. The methane seeping up through the pool feeds a unique assemblage of seep mussels.

Chemosynthesis *n*. (chemosynthetic *adj.*) A form of primary productivity that fixes inorganic carbon into living animal tissues. Specialized bacteria are required. This chemical process does not require sunlight as does photosynthesis (see below). See also *chemosynthetic animal* below.

Chemosynthetic animal An individual animal or species that gets its nutrition with the energetic assistance of endosymbiotic bacteria. The host provides the bacteria with oxygen, a chemical (gas) energy source, and a source of carbon (CO_2) to produce energy and living tissue.

Chemosynthetic community An assemblage of animals made up in part by one or more community species of dominant *chemosynthetic animals*.

Cold seep *n*. A seepage of fluids from the ocean bottom into the overlying waters. Seeps of dissolved gasses such as methane (CH_4) and hydrogen sulfide (H_2S) fuel chemosynthetic animals and communities in the Gulf of Mexico. (As opposed to heated "*hydrothermal vents*" at mid-ocean tectonic spreading centers, which also support other chemosynthetic communities.)

Community Any assemblage of animals and/or plants in a defined area and physical environment (often local or regional, zoogeographically) that interact together in many complex ways. Marine examples include coral reef communities, rocky intertidal communities, soft-bottom communities, mangrove forests, and kelp forests.

Continental shelf — The slowly deepening continental margin from the shore to the point (shelf-slope break) where the continental slope deepens more rapidly seaward, typically at a nominal depth of about 200 m.

Continental slope — The continental margin seaward of the continental shelf which deepens rapidly into the deep sea to the abyssal rise and plain.

Deep sea — Variously defined, the "deep sea" refers to the ocean seaward of the continental shelf. It is sometimes used synonymously with the term "abyss"; however, to most scientists, it includes the continental slope.

Endosymbiont — A symbiont that lives within an animal, some in the actual tissues and cells of the animal (the case with chemosynthesis). Other types live in the gut cavity of, say, a cow or termite to aid in the breakdown of otherwise indigestible foods.

Gas hydrate *n.* — A solid matrix composed of water and methane (with traces of other low molecular weight hydrocarbons) and that is stable at adequately low temperatures and high pressures. Hydrates in the seafloor are sometimes exposed at the sediment-water interface. Methane hydrates might someday become a major source of energy.

Heterotrophic *adj.* — Deriving energy and sustenance through the ingestion and metabolism of organic matter. As opposed to autotrophic, which forms usable food compounds from simple CO_2. See *chemoautotrophic* and *chemosynthetic*.

Hydrothermal vent — Vents in the seabed through which flow volumes of heated water containing hydrogen sulfide and various minerals from the rocks below. Found in certain zones (*e.g.*, mid-oceanic ridges), the vents lie in areas associated with seafloor spreading, seismic activity, and sometimes lava. These support some *chemosynthetic communities* as do Gulf of Mexico *cold seeps*.

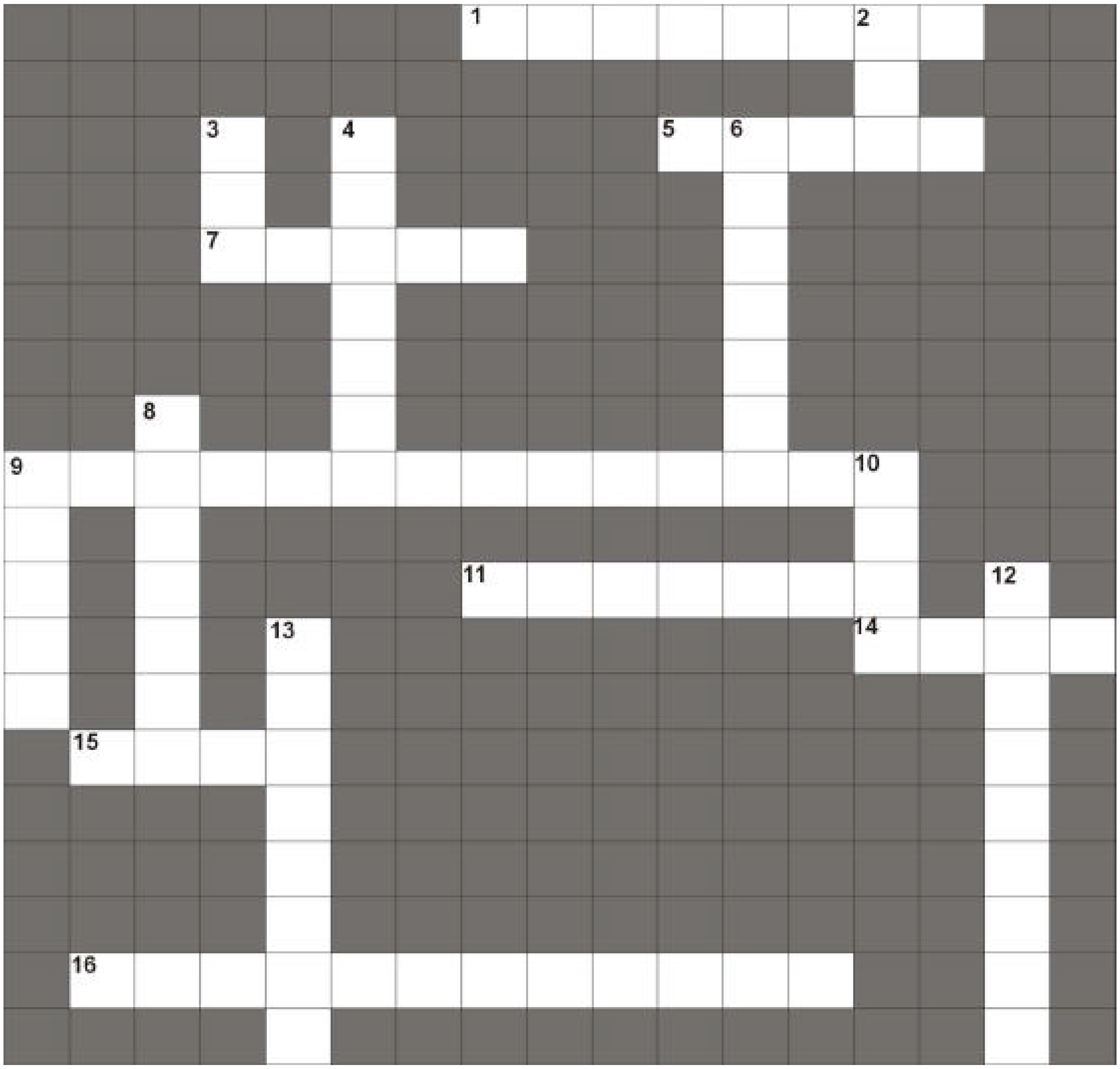
Nekton *n.* — Free-swimming organisms in aquatic ecosystems. Unlike *plankton*, they are able to navigate at will, for example, fishes.

Photosynthesis *n.* — The intracellular biochemical reactions within chlorophyll (photosynthetic adj.) containing (generally green) plants that use light energy to convert ambient CO_2 into sugar.

Plankton *n.* (planktonic *adj.*) — Several types of small plants (phytoplankton) and animals (zooplankton) that drift more or less passively with the ocean currents. Phytoplankton are responsible for a large part of marine *primary productivity.*

Primary production	Either of two sets of biochemical reactions that require an external energy source to produce a sugar molecule from ambient CO_2. See *chemosynthesis* and *photosynthesis*.
Symbiosis *n.* **(symbiotic *adj.*)**	A type of close relationship wherein two or more organisms live in close association that is mutually beneficial and sometimes obligatory.
Taxonomy	The science or process of systematically ordering biological organisms into established categories (e.g., phylum, class, order, family, genus, and species) indicating relationships and suggesting evolutionary history.
Zoogeography *n.* **(zoogeographic *adj.)***	The study of the geographical distribution of animals at different taxonomic levels. Emphasis is given to the explanation of distinctive patterns in terms of past or present environmental factors.

Crossword Puzzle **(answers on page 24)**



ACROSS

1. The science of systematically ordering biological organisms into established categories.
5. Greatest depths of the ocean, generally greater than 2,000 m.
7. The continental ________, which is seaward of the continental slope.
9. A form of primary production (not photosynthesis).
11. A solid ice-like matrix composed of water and methane gas (and traces of other hydrocarbons) that is stable at adequately low temperatures and pressures.
14. Brine ________, where salty water collects in a bottom depression.
15. The National Environmental Policy Act (abbrv.).
16. A living form (usually bacterium) that lives within an animal and performs a useful service to its host.

DOWN

2. The Minerals Management Service (abbrv.).
3. The Outer Continental Shelf; under law, the submerged land seaward of states' waters.
4. The amount (weight) of animals and/or plants living in an area of sea bottom.
6. Animals living in or on the ocean bottom.
8. The most common and simplest hydrocarbon.
9. The informal term for the MMS's chemosynthetic community investigations in the Gulf of Mexico.
10. A "leaking" of fluids from the ocean floor into surrounding waters.
12. An assemblage of animals and/or plants in a defined area and physical environment.
13. Several types of small plants and animals that drift more or less passively with ocean currents.

Further Reading

The bulk of scientific information on the Gulf of Mexico chemosynthetic communities is found in scholarly papers prepared for publications in scientific journals. These are not generally accessible to the average student and tend to be overly technical. There are a few notable exceptions found in the popular literature:

MacDonald, Ian and Charles Fisher. 1996 (Oct.). "Life Without Light." National Geographic Magazine. 190(4): 8697.

MacDonald, I.R. 1998. "Natural Oil Spills." Scientific American 279(5): 30-35.

Fredrickson, J.K. and T.C. Onstott. 1996. "Microbes Deep Inside the Earth." Scientific American 276 October 1996.

Internet Sites

MMS
http://www.gomr.mms.gov/homepg/regulate/environ/chemo/chemo.html

TAMU
http://www.ocean.tamu.edu/NR1/home.html

Penn State
http://www.bio.psu.edu//cold_seeps/index.html

Puzzle Answers