Deep-Sea Hydrothermal Vent and Seep Habitats and Related Governance Issues

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Introduction

Deep-sea habitats are shaped by geological processes. Following formation by magmatic accretion, new seafloor exists for a few million years as a bare-rock volcanic terrain, followed by tens of millions of years as a sedimented abyssal plain before finally being subducted in the trenches. This paper will briefly consider abyssal plain and seamount habitats before concentrating on habitats at convergent and divergent plate boundaries. Some of the most unusual marine ecosystems are found at the tectonic plate boundaries in the deep sea where geological forces provide ecosystems with non-photosynthetic energy sources. These ecosystems occur at seafloor hydrothermal vents and cold seeps, which have become sites of intensive scientific research, some of which is related to future mineral resource exploitation. In order to understand the scientific value of vent and seep ecosystems, we first need to consider how ecosystems normally operate in the deep ocean.

The abyssal plain is the largest deep-sea habitat, covering nearly 60% of our planet's surface. Abyssal food chains are nourished by organic debris that sediments down from surface waters where phytoplankton carry out photosynthesis. Only a very small fraction (1% or less) of this surface productivity reaches the deep ocean floor. As a result, nutritional resources and animal life are very scarce. Deposit feeding and suspension feeding are the primary modes of nutrition among the abyssal fauna, along with predation and necrophagy. With the exception of manganese future nodule exploitation, there are few foreseeable threats to the abyssal plain ecosystem. Climate change will affect the distribution and intensity of surface productivity and thus the food supply to the deep sea. However, this is more likely to influence species distribution than survival. A more urgent concern is the need to document biodiversity in abyssal sediments, which as been estimated at up to 10 million species (Gage, 1996).

Seamounts and volcanic ridges offer a less common hard substratum to deep-sea animals, and because currents are often accelerated by these relief features, they can be heavily colonized by filter-feeding invertebrates. Strong currents also result in seamounts having fish populations distinctly different from the surrounding abyssal seafloor. Seamount fisheries are well developed worldwide and pose the most immediate threat to biodiversity in this habitat. Future dredging of cobalt-rich ferromanganese crusts that coat many seamounts in the Pacific could also have a widespread impact on the benthos.

Hydrothermal Vents

The 1977 discovery of luxuriant oases of giant tubeworms, clams and mussels clustering around hydrothermal vents >2000m deep came as a complete surprise to biologists who scrambled to identify the food source for this unusual ecosystem (Corliss *et al*., 1979). Vent faunal biomass can be 500 to 1000 times that of the surrounding deep sea, and rival values in the most productive marine ecosystems such as shellfish cultures. Biological productivity at hydrothermal vents is sustained not by photosynthetic products arriving from the sunlit surface ocean, but rather by the chemosynthesis of organic matter by vent microorganisms, using energy from chemical oxidations to produce organic matter from CO_2 and mineral nutrients (Tunnicliffe, 1991; Van Dover, 2000). Hydrogen sulphide and other reducing substances present in hydrothermal fluids provide the *fuel* for organic matter synthesis (Nelson and Fisher, 1995). Since hydrothermal fluids are formed by reaction of seawater with hot rock, researchers quickly realized that vent ecosystems were ultimately powered by heat from the earth's mantle. This was a startling conceptual challenge to the long held view that all of our planet's ecosystems require sunlight and photosynthesis to create new biomass and nourish animal food chains.

Another surprise to biologists was the novel nature of the vent organisms. Although the known global vent fauna numbers only around 500 species (Tunnicliffe *et al*., 1998), most were previously unknown to science and many exhibit unusual adaptations to the severe, potentially toxic nature of the hydrothermal fluids. High animal density and the presence of unusual species are now known to be common characteristics of deep-sea hydrothermal vents all over the globe, with the composition of the fauna varying between sites and regions. More than 100 vent fields have been documented along the 60,000km global mid-ocean ridge system. Species conservation and environmental stewardship are becoming issues of particular concern to hydrothermal vent scientists. Hydrothermal faunal communities occupy very small areas of the seafloor and many sites contain animal species found nowhere else. As vent sites become the focus of intensive research activity, ecotourism, mineral exploration and deep-sea mining, oversight organizations will need to develop mitigative measures to avoid significant loss of habitat or extinction of populations (Tunnicliffe, 1990).

Arguments for the conservation of vent species can be developed from the same sources that have led to the present global interest in the preservation of biodiversity. In addition, cutting edge biological science has become an important stakeholder in this resource and millions of research dollars are annually directed to laboratory and field studies of vent organisms. Vent biology, in its brief history, has made major contributions to the development of basic models of life processes. Most recent editions of university textbooks in biology and ecology now use examples from hydrothermal vents to illustrate points on symbiosis, detoxification, adaptation to extreme conditions and ecosystem function. The visually spectacular and extreme nature of vent communities also makes them popular subjects for the science media and science education sectors. Several of the world's leading natural history museums feature new exhibits on hydrothermal vents. While few of the novel animal species discovered at vents may be edible or of any immediate material value, there is considerable interest from the biotechnology industry in extreme vent microorganisms. Hydrothermal vents are sites colonized by hyperthermophilic Bacteria and Archaea. Enzymes from these microorganisms have a range of applications from molecular biology to the food processing, fabric and chemical industries. The "Taq" DNA polymerase enzyme, used worldwide in molecular biology, is produced from *Thermus aquaticus*, a thermophile first isolated from terrestrial hot springs. Today, the annual market for Taq polymerase is worth approximately $500 million per year. Several DNA polymerase enzymes from hydrothermal organisms are presently being marketed, including a "Vent polymerase" extracted from an organism first collected at shallow hydrothermal vents off Vulcano, Italy. We still know very little about the biodiversity of microbes at vents. As a result, their full biotechnological potential remains unquantifiable. There is a strong economic, as well as ecological, argument for preserving vent sites to safeguard this biodiversity and the genetic potential of both the prokaryotic and higher organisms.

Cold Seeps

Although hydrothermal vents have attracted most interest, animal assemblages at least partly dependent on chemoautotrophic production have also been found associated with a variety of "seeps" where fluids rich in methane and H_2S diffuse from the seafloor along continental margins (Tunnicliffe *et al*., 2003). Compared to hydrothermal vents, seep flow rates are usually slow and temperatures are only slightly different from the surrounding seawater. In deep waters, seep processes are related to geological phenomena such as subduction, petroleum or natural gas escape, artesian flow, and catastrophic erosion or submarine slope failures. Subduction zone seeps occur on geologically active (i.e. tectonic plate movement) continental margins. In this setting, the compression of oceanic sediments against the overriding continental plate creates deep overpressure zones where water within the sediment is forced out along faults. On passive continental margins, "salt tectonics" can create conduits for seeping fluids. For example, in the deep waters of the Gulf of Mexico, ancient salt deposits lie below sediments where hydrocarbons and methane have accumulated. Salt being lighter than compacting sediment, it tends to push upward as a salt dome, creating deep cracks in the sediments through which gasses and petroleum escape at the seafloor.

Seep fluids are rich in methane, produced by microbial or thermal degradation of organic matter in deep subsurface sediments. Migrating seep fluids can be enriched in hydrogen sulphide in near-surface sediments by microbial sulphate reduction coupled to methane oxidation (Martin *et al*., 1996). Seeps exhibit a fauna taxonomically similar to that of hydrothermal vents – vestimentiferan tubeworms, vesicomyid and mytilid bivalves, and there is evidence of their use of carbon from methane, through symbiotic bacteria (Gage and Tyler 1996).

Cold-seep areas that have so far been studied are at depths ranging from 400 to 6000 m in the Atlantic and the Eastern and Western Pacific and in the Mediterranean Sea; they occur in different geological systems, some on active and some on passive margins. Sibuet and Olu (1998) review the biogeography, biodiversity and fluid dependence of the communities at 24 deep cold seeps. The dominant cold-seep species are large bivalves (families Vesicomyidae and Mytilidae) but there are symbiont-containing species of other bivalve families, Pogonophoran worms, and sponges. Unlike hydrothermal vents, specialized carnivores have not been reported in high abundance. Most of the symbiont-containing cold seep species are new to science. A total of 211 species were listed by Sibuet and Olu (1998). Of these 147 are non-symbiont-containing species (and some of the symbiotic species retain functional digestive tracts, unlike some of their congeners from hydrothermal vents). Many appear to be opportunistic scavengers, capable of living away from seeps. From the data they reviewed, only 13 species occur at both cold seeps and hydrothermal vents. The species richness of cold seep communities decreases with depth, but at several seep sites there is high diversity compared with hydrothermal vents; this may be explained by the greater longevity of seep habitats. In some seep areas, deposits of gas hydrate (methane packed within the crystalline structure of ice) are exposed at the seafloor, and in one case a remarkable polychaete has been described living directly on gas hydrate in the Gulf of Mexico (Fisher *et al*., 2000).

Many deep-water seep environments are the site of significant reservoirs of petroleum and natural gas. In the Gulf of Mexico, offshore exploitation of oil and gas in proximity to seep communities has been occurring for decades. Effects on seep ecosystem function and biodiversity are not well documented. Exploratory drilling and the installation and operation of production platforms will produce localized and widely spaced disturbances. Depletion of subsurface oil and gas reservoirs may eventually affect the energy supply to seep communities, but this remains to be investigated. A more widespread impact may come from the exploitation of subsurface gas hydrate deposits. These reserves of methane ice occupy significant volumes within the seabed of continental margins worldwide. Recent global estimates of gas hydrate reserves greatly surpass total known world petroleum reserves. Although exploitation of subsea gas hydrates is probably many decades away, their extraction could involve large-scale disturbance of the seabed and consequent effects on seep communities.

A Hydrothermal Vent MPA

In early 2003, Canada became the first country to formally take measures to protect and conserve deep ocean hydrothermal vents. The Endeavour Hydrothermal Vents Marine Protected Area (MPA) is found in the northeast Pacific Ocean at 2200m depth, 200km southwest of Vancouver Island, Canada. Since their discovery in 1982, the Endeavour Hydrothermal Vents have been a focus of research by Canadian and international scientists. The 4 x 6 nautical mile (82 km^2) Endeavour MPA encompasses 5 vent fields that include features such as large hot black smoker chimneys and surrounding lower temperature vents. The fields span a wide range of hydrothermal venting conditions characterized by different water temperatures and salt content, mineral chimney morphology and animal abundance. Temperatures associated with the black smokers are typically in excess of 300˚C. Formation of the large, polymetallic chimneys takes place when dissolved minerals and metal ions carried upward by the hydrothermal fluids precipitate on contact with cold seawater. The flanks of the chimneys and the surrounding seawater support an abundant fauna that forms an unusual mosaic community whose composition is constantly changing in response to shifting temperature and chemical conditions. The Endeavour Hydrothermal Vents are home to at least 12 species found nowhere else.

The Endeavour MPA has been created to set the area aside for scientific research. Research activities are monitored by a Management Committee to mitigate use conflicts and environmental disturbance. Included in the present management plan are provisions such as zoning of sampling and 'observation only' areas, to ensure the pristine nature of the area and permit long-term observations of natural change and response to natural disturbances.

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