Chapter 46. Hydrothermal vents and cold seeps

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Abstract

Hydrothermal vents and cold seeps constitute energy hotspots on the seafloor that sustain some of the most remarkable ecosystems on earth. In response to increasing demands for raw materials and the development of new technologies for exploration and exploitation, deep-sea hydrothermal vent and cold seep ecosystems are facing increasing pressures. Chemosynthetic communities are functionally distinct from other marine communities, with many open questions about their distribution, diversity, functioning and environmental features. Nevertheless, their unique biodiversity constitutes a vast genomic repository of great value for humanity, for the provision of new biomaterials, medicines and genetic resources. Because of their significant potential, it is critical to protect vent and seep biodiversity. However, insufficient knowledge of the drivers of ecosystem and community dynamics at vents and seeps makes anticipating any trends in their ecological status problematic. In this context, action has taken place at national and international levels through the development of protection plans or codes of conduct, and formal protection measures under State or international law are progressing, in parallel to research efforts.

1. Inventory

Hydrothermal vents and cold seeps constitute energy hotspots on the seafloor that sustain some of the most remarkable ecosystems on earth. Occurring in diverse geological settings, these environments share high concentrations of reduced chemicals (e.g., methane, sulphide, hydrogen, iron II) that drive primary production by chemosynthetic microbes. Their biota are characterized by a high level of endemism with common specific lineages at the family, genus and even species level, as well as by the prevalence of symbioses between invertebrates and bacteria (Dubilier et al., 2008).

Hydrothermal vents are located at mid-ocean ridges, volcanic arcs and back-arc spreading centers or on volcanic hotspots (e.g., Hawaiian archipelago), where magmatic heat sources drive the hydrothermal circulation. 245 of the 521 vent fields known as of 2009 are visually confirmed (Beaulieu et al., 2013) (Figure 1).

Cold seeps are found on sediments of both passive continental margins and subduction zones, in links with subsurface hydrocarbon reservoirs. The migration of hydrocarbon-rich seep fluids is driven by a variety of geophysical processes, such as plate subduction, salt diapirism, gravity compression or the dissociation of methane hydrates. The systematic survey of continental margins has revealed an increasing number of cold seeps worldwide (Foucher et al., 2009; Talukder, 2012). However, no recent global inventory of cold seeps is available.
Both vent and seep ecosystems are made up of a mosaic of habitats covering wide physico-
chemical ranges (e.g., in temperature, salinity, pH, and oxygen, CO₂, hydrocarbon and metal 
contents) (Fisher et al., 2007; Levin and Sibuet, 2012; Takai and Nakamura, 2010). Some 
regions (e.g., Mariana Arc or Costa Rica margin) host both types of ecosystems, forming a 
continuum of habitats that supports species with affinities for vents or seeps (Watanabe, 2010; 
Levin et al., 2012). Habitats indirectly related to hydrothermal venting include inactive 
sulphide deposits and hydrothermal sediments (German and Von Damm, 2004). Seep-related 
habits are also formed by cold-water corals growing on the carbonate precipitated from the 
microbial oxidation of methane (Cordes et al., 2008; Wheeler and Stadnitskaya, 2011).

Figure 1. Global map from InterRidge database (http://vents-data.interridge.org/maps) 
displaying visually confirmed and inferred hydrothermal vents fields. Updated from S. 
Beaulieu, K. Joyce, and S.A. Soule (WHOI), 2010.

2. Features of trends in extent or quality

Chemosynthetic ecosystems were discovered only about 40 years ago from seafloor 
geological surveys with manned submersibles; hydrothermal vents in 1977, on the Galapagos 
Spreading Center, and cold seeps at the base of the Florida escarpment in the Gulf of Mexico 
in 1984. In the last decade, high-resolution seafloor mapping technologies using remotely 
operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) have enhanced 
capacity to explore the deep seabed.

Since the last global compilation (Baker and German, 2004), the known number of active 
hydrothermal vent fields has almost doubled, with an increasing proportion of new 
discoveries being in arc and back-arc settings, as a result of increasing exploration efforts 
(Beaulieu et al., 2013). Furthermore, new types of chemosynthetic ecosystems are still being 
discovered, such as serpentinite-hosted ecosystems found on continental margins, ridges and 
trenches (Ohara et al., 2011; Kelley et al., 2005).

Currently, vent fauna constitute between 7 and 11 biogeographic provinces, including new 
discoveries in the Arctic and Southern Oceans (Bachraty et al., 2009; Rogers et al., 2012). 
Each new vent field or cold seep area comes with a series of unknown species, and these 
biogeographic patterns should be considered as preliminary. Although recent global efforts 
have addressed this knowledge gap (e.g., the international Census of Marine Life projects,
Few sites have repeated observations over more than ten years from which temporal trends can be described (Glover et al., 2010). Recolonization within few years has been investigated over a couple of vent fields affected by volcanic eruptions on fast-spreading ridges. The resilience of most vent communities to major disturbance, however, remains unknown and cannot be directly extrapolated from observations on these naturally unstable environments. Succession at cold seeps, including later stages of deep-water coral colonization, may proceed over centuries to millennia with slow-growing and long-lived species that should be considered particularly vulnerable to disturbance (Cordes et al., 2009).

Nonetheless, life histories of key species and their links with resource and habitat variability have just started to be described (Ramirez Llodra et al., 2010). Important biodiversity components supporting ecosystem functions also remain under-studied. In particular, only several studies deal with meiofaunal organisms from vent and seep sites (Vanreusel et al., 2010). Insufficient knowledge of the drivers of ecosystem and community dynamics at vent and seeps makes anticipating any trends in their ecological status problematic.

3. Major pressures linked to the trends

The deep sea is being seen as a new frontier for oil and mineral extraction, in response to increasing demands for raw materials for industrialization development and new technologies. As a consequence, vent and seep ecosystems, so far preserved from direct impacts of human activities, are facing increasing pressures (Ramirez Llodra et al., 2011; Santos et al., 2012). Offshore oil extraction now occurs mostly in deep waters, as deep as 3000 m. Seafloor installations can directly affect cold seep communities in their direct neighborhood, if visual surveys and Environmental Impact Assessments (EIAs) are not completed prior to drilling. In addition, an increasing threat exists of large-scale impacts from accidental spills, such as the 2010 Deepwater Horizon blowout in the Gulf of Mexico, which was the largest accidental release of oil into the ocean in human history (Montagna et al., 2013).

Further pressures on cold seep communities may arise from the increasing demand and technology progress for the exploitation of new types of energetic resources, as exemplified by the world’s first marine methane hydrate production test in the Nankai Trough in 2013. Sequestration of CO₂ in deep-sea sedimentary disposal sites should also be considered a potential threat specific to these communities (IPCC, 2005).

The increased demand for metals is promoting deep-sea mineral resource exploration both within Exclusive Economic Zones (EEZs) and in the Area, raising the issue of potential impacts on vent ecosystems (Van Dover, 2012). In 2011, the granting of a mining lease to exploit sulphide minerals for gold, copper and zinc in the EEZ of Papua New Guinea turned the deep-sea mining industry into a reality. Additionally, in the last five years, the ISA has granted two new exploration permits for polymetallic sulphide deposits and two others are about to be signed on the Atlantic and Indian mid-ocean ridges (http://www.isa.org.jm/en/scientific/exploration/contractors). Significant threats are anticipated on the largely unknown communities associated with inactive hydrothermal deposits and typical vent communities within these areas (ISA, 2011).

Indirect pressures on vent and seep ecosystems resulting from global change are not well constrained. They are less sensitive to changes in photosynthetic primary production than
other deep-sea ecosystems, but potential threats also exist. Changes in water-mass circulation could affect larval dispersal, potentially reducing the capacity for species' populations to maintain themselves across fragmented habitats (Adams et al., 2011). The extension of hypoxia or anoxia on continental margins and in semi-enclosed seas could also profoundly alter the functioning of these ecosystems because of the high oxygen demand of chemosynthetic activity. Warming is already affecting the deep ocean waters, especially at high latitudes (e.g., Arctic) and in enclosed seas (e.g., Mediterranean). Cold seep ecosystems could be affected, through direct impacts on the activity of fauna and the microbial consortia or major disturbances, such as land-slides and gas extrusion caused by hydrate destabilization. These ecosystems occupy fairly small areas of the seabed (typically km-scale) and may be more vulnerable to non-specific pressures such as deep-sea fishing or waste dumping. Even activities such as scientific research or bioprospecting can pose a threat to the integrity of these unique communities and their endemic species (Baker et al., 2010).

4. Implications for services to ecosystems and humanity

Chemosynthetic communities are functionally distinct from other marine communities, with many open questions about their distribution, diversity, functioning and environmental features that limit the ability to estimate ecosystem services (Armstrong et al., 2012). Nevertheless, deep-sea vents and seeps represent one of the most physically and chemically diverse biomes on Earth and have a strong potential for new species discoveries in all branches of the tree of life (Takai and Nakamura, 2011). Their specialized phyla are adapted to a range of environmental constraints. Archaea that live at extremes in pressure, temperature and pH are particularly attractive to industrial sectors (UNU-IA, 2005). In the animal kingdom, unique extremophilic traits are also displayed (Le Bris and Gaill, 2007). This makes these ecosystems a vast genomic repository of unique value to screen for highly specific metabolic pathways and processes. The vent and seep biota thus constitute a unique pool for the provision of new biomaterials, medicines and genetic resources that has already led to a number of patents (Gerde, 2006; Arrieta et al., 2010). This great potential value to humankind is accounted for in the public awareness of potential threats and acceptability of deep-sea conservation programmes (Jobstvogt et al., 2014).

Chemosynthetic ecosystems are linked with adjacent deep-sea ecosystems through surrounding deep-sea corals and other filter-feeding communities, but the quantitative importance of their chemosynthetic production at the regional scale still remains to be appraised. At the global scale, a significant role of seep ecosystems is recognized in the regulation of methane fluxes, oxygen consumption and carbon storage from anaerobic methane oxidation by microbial consortia in sediments (Boetius and Wenzhöfer, 2013). Recent evidence shows that hydrothermal vent plumes sustain microbial communities with potential connections to zooplankton communities and biogeochemical fluxes in the deep ocean (Dick et al., 2013). The biological stabilization of metal (e.g., iron, copper) from hydrothermal vents under dissolved or colloidal organic complexes for long-range export in the water column has been documented recently (Wu et al., 2011; Hawkes et al., 2013). Recent assessments of these iron sources indicate their significance for deep-water budgets at oceanic scales and underscore the possibility for fertilizing surface waters through vertical mixing in particular regional settings (Tagliabue et al., 2010).
Because of their significant potential, it is critical to protect vent and seep biodiversity from adverse impacts caused by human activities. Furthermore, beyond the requirement to maintain biodiversity for future generations, cultural ecosystem services like scientific and inspirational values of the deep-sea ecosystem, and tourism, have to be recognized in an assessment of their economic value (Jobstvogt et al., 2014).

5. Conservation responses

Action has taken place at national and international levels through the development of informal or voluntary protection plans or codes of conduct and formal protection measures under State or international law. An example of informal measures is the adoption by the scientific community of the InterRidge Statement of Commitment to Responsible Research Practices (Devey, 2007). The marine mining industry has also produced the International Marine Minerals Society Code for Environmental Management of Marine Mining (IMMS, 2011), which outlines principles and best practice for use by industry, regulatory agencies, scientists and other interested parties (Boschen et al., 2013). Under the OSPAR Convention, “Oceanic Ridges with Hydrothermal Vents” are classified as priority habitats in need of conservation (OSPAR 2010).

Formal protection measures for hydrothermal vent ecosystems have been undertaken mainly within the EEZ of States (Table 1). An exception is the Rainbow hydrothermal vent field that was proposed to be included in the Azores Marine Park by the Portuguese Government, even though it lies outside the EEZ, at the Oslo-Paris Convention (OSPAR) (Ribeiro, 2010; Calado et al., 2011). Portugal proceeded with this area as a Marine Protected Area on the understanding that it is located on the extended continental shelf. It is also notable that some areas protected from bottom fishing also contain chemosynthetic ecosystems (e.g., the Kermadec Ridge and the South Georgia and South Sandwich Islands Maritime Zone), although these protections do not apply to other activities, such as mining.

The Convention on Biological Diversity (CBD) and its commitment to protect 10 per cent of the oceans is driving the process of identifying Ecologically and Biologically Significant Areas (EBSAs) in the high seas (Dunn et al., 2014). Scientists have additionally outlined the need to develop a cohesive network of such protected areas in the context of management of marine mining activities (Boschen et al., 2013; Van Dover et al., 2012). Implementation of such measures would require coordination of actions within and outside of EEZs by States and by the International Seabed Authority (ISA), which is charged with regulating mining activities in the Area. At present, however, no formal legal framework exists for establishment of protected areas on the high seas outside the frame of deep-sea mining under the ISA, whose jurisdiction is limited to the deep seabed. The Ad Hoc Open-ended Informal Working Group established in 2004 relating to the conservation and sustainable use of marine biological diversity in Areas Beyond National Jurisdiction has not yet fully identified gaps and ways forward for an effective legal framework of relevance to hydrothermal vent and cold seeps, among other deep-sea environments.
### Table 1: Summary of vent ecosystems protected to date under national or international law

(Santos et al., 2012; Calado et al., 2011; ISA, 2011; USFWS, 2012)

<table>
<thead>
<tr>
<th>Ocean region</th>
<th>Name of site</th>
<th>Type of chemosynthetic ecosystem</th>
<th>Depth &amp; location</th>
<th>Legal framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>North East Pacific</td>
<td>Endeavour hydrothermal vents MPA</td>
<td>Five vent fields including black smokers</td>
<td>2250m depth, 250km SW of Vancouver Island in Canadian EEZ.</td>
<td>Protected under the Canadian Government’s Ocean Act.</td>
</tr>
<tr>
<td>North East Pacific</td>
<td>Guaymas Basin Hydrothermal Vents Sanctuary</td>
<td>Hydrothermal vents located in a sedimented seabed.</td>
<td>Gulf of California, depth of ~2500m, Within Mexican EEZ.</td>
<td>Protected under Mexican State Law.</td>
</tr>
<tr>
<td>North East Pacific</td>
<td>Eastern Pacific Rise Hydrothermal Vents Sanctuary</td>
<td>Hydrothermal vents located on the East Pacific Rise</td>
<td>East Pacific Rise, depth of ~2800m, in Mexican EEZ.</td>
<td>Protected under Mexican State Law.</td>
</tr>
<tr>
<td>North West Pacific</td>
<td>Mariana Trench National Monument</td>
<td>Hydrothermal vents, CO$_2$ vents, sulphur lake.</td>
<td>Located around three northernmost Mariana Islands &amp; Mariana Trench 10m - 1650m depth.</td>
<td>Protected under US Law following Presidential Proclamation.</td>
</tr>
<tr>
<td>North Atlantic</td>
<td>The Azores Hydrothermal Vent MPA</td>
<td>Seven hydrothermal vent fields including Lucky Strike, Menez Gwen, Rainbow and Banco Dom João de Castro. Except for Rainbow they are all Natura 2000 SAC (special areas of conservation under the EU habitats directive)</td>
<td>Amongst or to the south west of Azores Islands, N. Atlantic. 40m - 2300m depth.</td>
<td>Protected under Portuguese national &amp; EU Habitats Directive, Rainbow is the first protected vent site located outside of an EEZ. It is included in the Azores Marine Park.</td>
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References


