DEEP-OCEAN STEWARDSHIP INITIATIVE

DOSI

POLICY BRIEF

NOVEMBER 2021

Redefining the Influence of Chemosynthetic Ecosystems for Effective Management

Key Messages:

1. Chemosynthetic ecosystems can influence the function and health of our ocean.
2. It is necessary to broaden the definition of chemosynthetic ecosystems (hydrothermal vents and hydrocarbon seeps) to include their zone of influence and expand perception of these systems as broad habitat areas rather than isolated islands in the deep sea.
3. Chemosynthetic ecosystems can be impacted by deep-water fishing, offshore oil and gas extraction, and deep-sea mining.
4. Standardized methodological approaches for baseline surveys, monitoring, and impact assessments can inform spatial management of these ecosystems.

New Scientific Understanding:

Some organisms gain their energy from chemicals as opposed to sunlight. In **chemosynthetic ecosystems**, microbes use chemical energy to create biomass which in turn feeds animals. Examples of chemosynthetic ecosystems are **hydrothermal vents** (Fig. 1) and **methane seeps** (Fig. 2), both of which contribute significantly to the function and health of our ocean. Recent evidence suggests that these habitats influence a large **transition zone** (Fig. 3) including non-chemosynthetic regions (background); these influenced regions also need to be considered during management planning. The transition zones harbor a mixture of vent or seep fauna, as well as species from the surrounding deep sea that are utilizing the resources generated at these sites (Fig. 4). These resources include unique substrate, fluxes of nutrients and **chemosynthetic productivity**. These zones also include unexpected biological interactions, for example recently discovered animal taxa that are supported by **methane-dependent symbiotic bacteria**. The spatial scale of this influence varies across sites and among regions globally as a function of physical, chemical, and geological processes. These zones are also not stable. Warming oceans will increase the amounts of methane released from buried reservoirs favoring spatial expansion of methane seepage. As climate change affects photosynthetic food quality, timing and magnitude, benthic organisms reliant on photosynthetic-based source of energy may be able to increasingly use chemosynthetic ecosystems as temporary bridges. These chemosynthetic ecosystems influence on the greater ocean can affect the way climate change impact resilience and potential extinction driven by modifications of dispersal and even evolution of species.

The role of chemosynthetic ecosystems and their transition zones is key for preservation of marine ecosystems and evolutionary processes. The width of the transition zone should be determined during preliminary impact assessments for anthropogenic activities. **Climate-smart management plans** for human activities affecting vent and seep habitats, including deep-sea mining and oil and gas extraction, should incorporate these transition zones and recognize **diffuse interactions** with species from background deep sea communities. This will ensure the most appropriate data are considered when making decisions regarding the resilience, climate adaptation, conservation and use of these ecosystems.

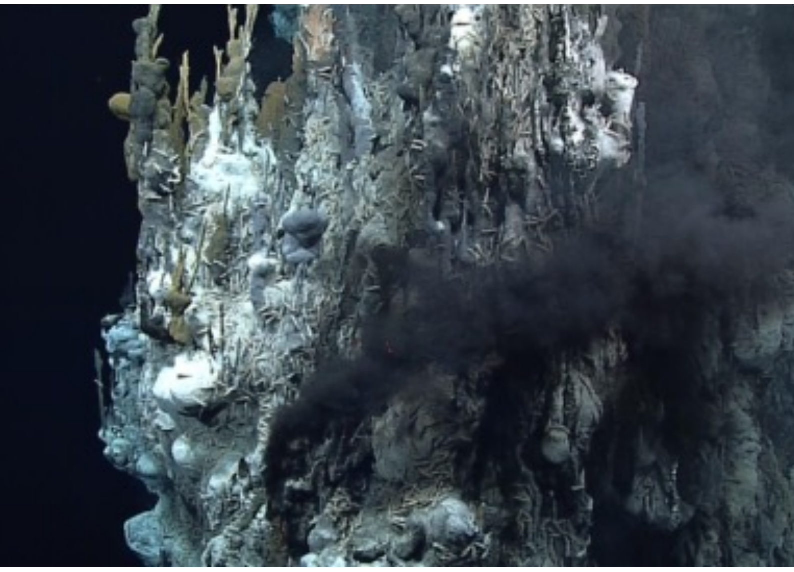

Fig 1. An active "black smoker" hydrothermal vent chimney with small vent shrimp. Image courtesy of NOAA Office of Ocean Exploration and Research, 2016 Deepwater Exploration of the Marianas.

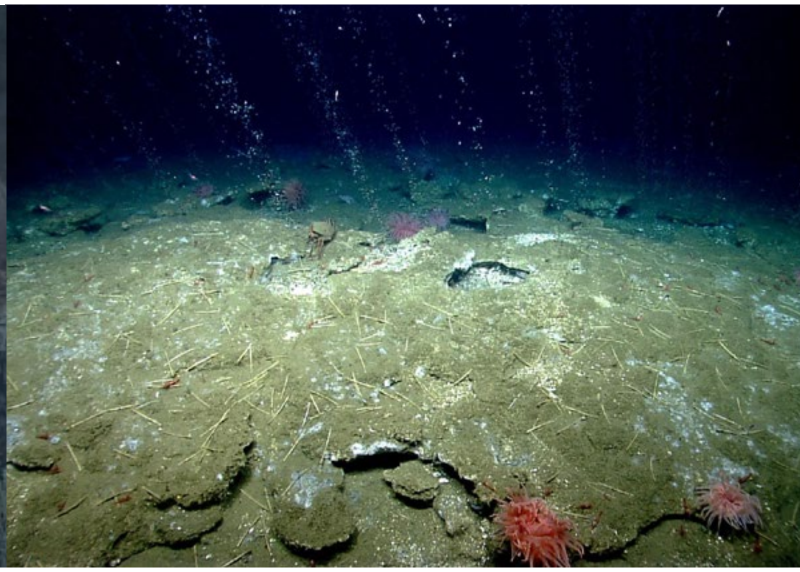

Fig 2. Methane bubbles seep with quill worms, anemones, and patches of microbial mats along the periphery of the seepage area, offshore Virginia north of Washington Canyon. Image courtesy of the NOAA Office of Ocean Exploration and Research, 2013 ROV Shakedown and Field Trials in the U.S. Atlantic Canyons.

The Problem:

Human interests and extractive industries are progressively moving into deeper waters and interacting with hydrothermal vents and cold seeps. At hydrothermal vents, a major threat is future mining of **seafloor massive sulfide deposits (SMS)**. Cold seeps can be impacted by commercial fishing, oil and gas exploration and exploitation, and in the future, gas hydrate & phosphorite extraction or offshore energy installations. All of these ecosystems are also impacted by climate change and rising levels of contamination.

Approaches to identify chemosynthetic habitats do not adequately identify the extent of influence these habitats have on marine systems. Surveys used to locate these habitats typically include a mapping component, using a combination of acoustic data. These data allow location of the areas of highest fluid flux activity and aggregations of chemosynthetic animals with calcified bodies. For a more detailed analysis of the engineering characteristics of the environment prior to the start of industrial activities, remotely operated vehicles (ROV) or autonomous underwater vehicles (AUV) are often used. These allow the acquisition of video or photographic transects.

Remote sensing and visual surveys do not allow the identification of inconspicuous chemosynthetic ecosystem components. These ecosystems are linked to those from the surrounding area by a **sphere of influence** rather than possessing a sharp boundary. These links are only detectable by direct measurements, physically sampling sediments, water and living organisms associated with them. Hydrothermal vents influence trace-metal inputs to the global ocean, regionally influence distribution of nutrients and plankton, and locally influence food abundance through enhanced microbial primary and secondary productivity. Methane seeps provide habitat (hard substrates, microbial mats) and elevated microbial production that can locally alter food webs over hundreds of meters to kilometers of the surrounding seafloor and the overlying water column. A wide range of water and seafloor organisms are known to live, feed, and/or reproduce within or at the periphery of vents and seeps (Fig. 5). The biological and chemical influence of hydrocarbon seeps in the water column may be enhanced by methane bubble plumes and, in some settings, upwelling associated with crater-like topographic seabed features (**pockmarks**).

The Concepts of Transition Zones and "Chemotones":

Chemosynthetic habitats of the deep seabed do not possess sharp boundaries with the vast deep ocean water column as is commonly suggested. Instead, continuous transition zones extend from the local source of energy to background communities of the deep sea both horizontally and vertically. Transition zones are **ecotones**, generated by the overlapping of physical, chemical, and biological components of chemosynthetic ecosystems with those inherent to background ecosystems. The exact size and shape of these transition zones varies among regions and is related to the amount of chemosynthetic productivity, the specific interaction of microbes and fauna from both adjacent ecosystems, as well as to the local geological and oceanographic conditions. The largest transition zones are found where there exists high chemosynthetic production that is frequently used by background deep-sea species, as well as where geomorphological features, such as ridges and mounds, associated with seeps and vents influence local current patterns.

Areas where chemosynthetic production from chemosynthetic ecosystems overlap with photosynthetic-based communities are known as '**chemotones**'. Where food supply from surface photosynthetic productivity is low or lacks consistency, the influence of food supply from chemosynthetic production can be significant over a wide area. The size of the transition zone will also vary with the relative strength and nature of the connections with the background fauna. These connections, in turn, will depend on the diversity and frequency of visits

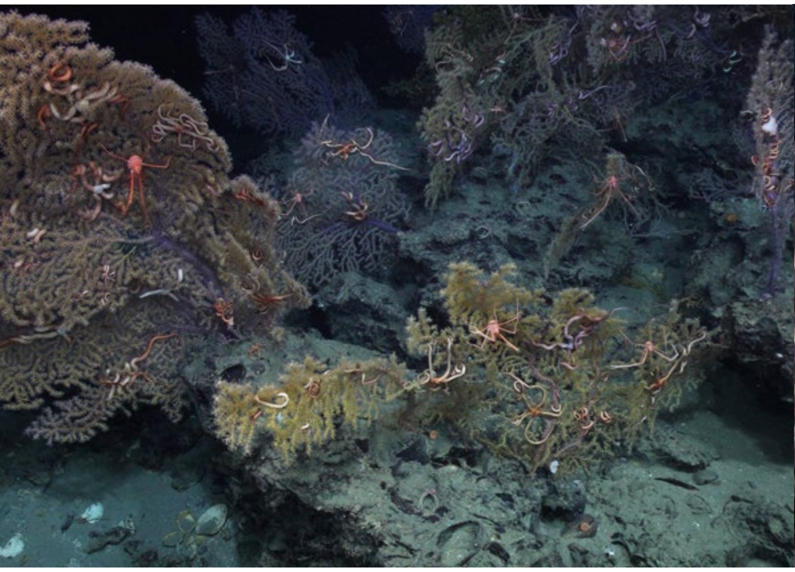

Fig 3A. Seep transition zone with paramuricea coral fans (like those impacted by the Deepwater Horizon oil spill) using substrate provided by seep-related carbonate rocks with embedded chemosynthetic clam shells. Image courtesy of Erik Cordes, ECOGIG consortium, and the Ocean Exploration Trust.

*Fig 3B. A methane seep transition zone offshore North Carolina, USA. White bacterial mats indicate areas of active seepage, while the fish (*Brama sp.*) and seastars are background deep-sea species visiting the seeps to take advantage of the chemosynthetic productivity. Image courtesy of Ivan Hürzeler, DEEP SEARCH project, and copyright Woods Hole Oceanographic Institution.*

from large, mobile, benthic and demersal predators and scavengers, as well as the daily vertical migrator fauna. Many vent and seep species also release planktonic larvae that develop in near surface waters. Methane advected away from seeps and vents may be oxidized by microbes associated with mixotrophic animals that can use a mix of photosynthetic and chemosynthetic food sources. While the harnessing of chemical energy is foundation to these habitats, they in turn affect turnover of nutrients, the sequestration of carbon and removal of contaminants within the chemotones.

The release of chemicals from chemosynthetic environments can be highly variable in time and space, driven by physical factors, geological setting, and oceanographic conditions that together dictate the area covered by transition zones. Seeps are often related to seismic activity and can act as surficial indicators of deep fluid deposits and fault systems controlling them, which can cover wide areas below the seafloor. Seeps are dynamic and can behave as chemosynthetic ecosystems even without active bubbling. Methane bubbles that remain trapped in low permeable fine sediments are only detectable using high resolution seismic records, and direct geochemical measures.

Application to Spatial Management:

The way in which the boundaries of chemosynthetic ecosystems are outlined and defined has broad implications for defining the management unit. A soft boundary that includes a transition zone implies that each site exerts its influence over some inherent distance. This distance needs to be empirically measured and cannot be generalized among sites with different attributes and in different regional settings. The buffers or set-back distances established around each site to provide protection must also protect the zone of influence by extending from the edges of transition zones.

Improved methods for baseline surveys, monitoring, and impact assessment should be developed to determine the distance over which this transition from the chemosynthetic to background deep-sea habitat occurs. These methods cannot simply rely on remote sensing and visual indicators of habitat type, since many relevant processes cannot be measured from these data, such as energy flow, nutrient and habitat provision, biogeochemical cycling, species interactions and the subsurface biological community. Seismic, mapping, and visual surveys must be supplemented by direct samples of the surrounding sedimented habitats and the overlying water column. These should be analyzed for indication of chemosynthetic inputs obtained through chemical measurements, organic carbon availability, and stable isotopes of the organic matter and fauna. Additional functions should be explored based on biological trait analysis of vent and seep communities. Molecular barcoding of fauna as well as assessment of the presence of chemosynthetic microbial symbionts should be conducted in order to establish genetic connectivity and extent of reliance on chemosynthesis. Surveys and sampling, before, during, and after industrial activity, need to extend beyond the visually obvious edge of the habitat to define the transition zone. The exact distance should

*Fig 4. Red rock-fish (*Sebastes sp.*) and spotted wolffish (*Anarhichas minor*) using carbonates from methane seeps at the Prins Karls Forland shelf (Åström et al. 2020).*

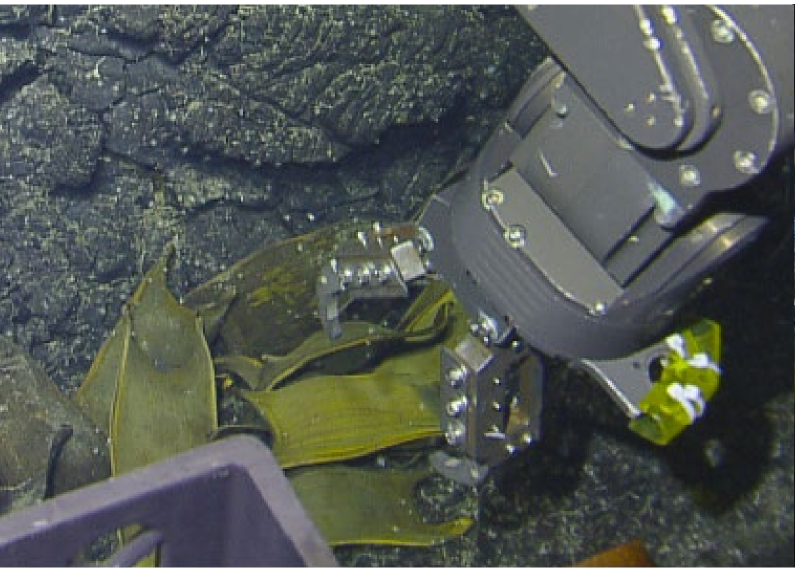

Fig 5A. Groups of skate egg cases of Bathyraja spinosissima *near vents from northwest of the Galapagos Islands. Image courtesy of OCEAN EXPLORATION TRUST/NOAA.*

*Fig 5B. Extensive aggregations of brooding female octopuses (*Muusoctopus robustus*), "octopus garden", associated with vents from Monterey Bay National Marine Sanctuary. Image courtesy of OCEAN EXPLORATION TRUST/NOAA.*

be determined by baseline surveys as part of the Environmental Impact Assessment (EIA) process, and these areas should be operationalized and included in the required management process of each of the individual sites.

We recommend that chemosynthetic ecosystems be considered as habitats with broad transition zones rather than sharp boundaries in the context of spatial management. Their use by surrounding deep-sea biota, including commercially valuable fish and shellfish, has gained recognition for methane seeps as essential fish habitat by the United States of America Pacific Fisheries Management Council. In different exclusive economic zones, and in areas beyond national jurisdiction, vents and methane seep habitats could be classified as vulnerable marine ecosystems (VME) as defined in Food and Agriculture Organization (FAO) Regional Fisheries Management Organization (RFMO) Guidelines and fall under one or more spatial management regimes. The high degree of connectivity among these habitats and the background deep sea requires a revision of management policies and procedures. It is only through the conceptualization of these sites as having strong links to background deep-sea ecosystems, that the ecosystem services they provide may be effectively preserved and the overall health and function of our oceans maintained.

Suggested Priority Actions for States:

1. Spatial management plans, including monitoring and conservation set-asides, need to include the transition zone around seeps and vents.
2. These management plans should be developed and implemented any time deep-sea human activities; including fishing, energy development, or mining; may intersect with hydrothermal vent or hydrocarbon seep sites.
3. The areal extent of the transition zone can only be determined by using a combination of remote sensing (multibeam echosounder bathymetry and sub-seabed high resolution seismic profile) in conjunction with visual surveys and sampling of sediments, fluids, and fauna carried out by deep-sea submersibles (human-occupied, remotely operated, or autonomous) (See Box 1).

Recommendations for EIA terms of reference

BOX 1

When assessing chemosynthetic ecosystems through the EIA process, its connectivity with surrounding areas should be addressed as following:

1) Habitat

- How do the physical substratum (shear stress), sediment type, environmental parameters (e.g., depth, pressure, salinity, oxygen, methane, sulfide, particle concentration, currents), and microbial and animal communities change?
- Over what distances do changes occur?

2) Communities

- Are there overlaps in the distributions of species?
- How much genetic similarity is there?
- Do the same species disperse across the two habitat types? Over what time scales?
- To what extent do the same species colonize the habitats?
- Is there interaction (feeding, refuge, competence) between species?
- Are there differences in animal behavior (feeding, reproduction, directional movement)?
- Where do animals feed and what is the origin of food in their gut and tissues? Do they house chemosynthetic symbiotic bacteria?

3) Environment

- What are the concentrations of elements such as iron, manganese, and trace elements? How do the concentrations change?
- What are the concentrations of pollutant elements such as heavy metals and plastics? How do the concentrations change?
- What is the flux of carbon and nutrients? How does it change?

4) Productivity

- What is the productivity and how does it change?

Further reading

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ABOUT DOSI

The Deep-Ocean Stewardship Initiative seeks to integrate science, technology, policy, law and economics to advise on ecosystem-based management of resource use in the deep ocean and strategies to maintain the integrity of deep-ocean ecosystems within and beyond national jurisdiction.

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