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Cold Seeps as Biodiversity Hotspots A comparative study of megafaunal communities in the Gulf of Mexico and the West African Margin

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Abstract:
Cold seep Cold seeps are habitats that are permanently stable in the deep ocean, offering special ecological niches to megafaunal assemblages maintained by chemosynthetic productivity. The comparison in this study is based on the outcome of the biodiversity, trophic structures and community composition within the cold seep habitats in the northern Gulf of Mexico and West Africa in the margin. By means of ROV-based transects, video- and specimen data were gathered over multiple (six) seep sites between 2,200 meter and 3,100 m. The findings demonstrated that the West African seeps had a greater species richness and endemism and the Bathymodiolus-dominated communities were more diverse in terms of their trophic relationships (stable isotope analysis 13C and 15 N). These differences indicate that biogeographic isolation and localized chemoautotrophic highs plays an important role in determining ecological difference in these environments. The research used, among other things, provides an insight into deep-sea connectivity and how such environments that are rare and endangered, need to be conserved, given the implications of hydrocarbon exploration.
Keywords: ***Cold seeps, biodiversity, megafauna, Gulf of Mexico, West African margin, trophic diversity, conservation.***

1. Introduction

1.1 Cold Seeps Significance to Deep-Sea Ecology

Ocean Deep: Cold seeps are considered to be an essential ecosystem in the deep sea, and they are defined by the seep coming out of the sea floor of hydrocarbons and hydrogen sulfide. These habitats are geologically active and hence stable and relatively rich producing environment that supports distinctive faunal assemblages. It is believed that cold seeps are oasis ecosystems and some organisms efficiently use alternative sources of energy by utilizing chemosynthesis as a main source of energy since they are living without sun. Through the chemotrophic bacteria reaction, the primary producers in these habitats are then in a position to produce organic matter out of non organic compounds such as hydrogen sulfide, methane and carbon dioxide and act as the foundation of the food web in these environments.

These are the places where the tectonic action permits the escape of gases on the ocean floor where the results are usually observed at the hydrothermal vent fields or the subsurface spewages. Cold seeps are commonly found at slopes of the continent and most usually at a depth between 500 and 3,500 m, and they are attributed to varieties of diverse ecosystems like sulfide-enriched mats, clam beds and mussel dominated populations. Faunal communities located in these sites are very specialized with species that are adapted to live in such an extreme environment that has low ambient oxygen levels, high pressure and variability of temperature.(1)

1.2 Influence of Chemosynthesis on Development of Unique Faunal Assemblages

In cold seeps, chemosynthesis is at center-stage in maintaining a diverse community of life. Unlike conventional ecosystems based on the use of sun energy and the process of photosynthesis, the cold seal organisms are able to feed on the chemical energy provided by such gasses as methane and hydrogen sulfide. These compounds are the base of creation of organic matter by the chemosynthetic bacteria, and higher trophic levels of mollusks, crustaceans, polychaetes, and fish are formed on it.

Cold-seep organisms (e.g. Bathymodiolus mussels) have bacteria living in specialized body tissues (e.g. gills) which convert the chemicals into nutrients that are vital to its host. This association is one of the most illustrative as to how chemosynthesis is the backbone of such ecosystems along with the primary producers and rest of the megafauanal community alike. Such chemosynthetic associations are highly productive, to the extent that in certain cold seeps sites, termed chemo-oases, they offer abundant food resources to megafauna that feed on bacteria, detritus and small organisms that have built up at the microbial mats.

1.3 Comparative Studying Justifications Within the Biogeographic Regions

Biogeographical analysis of cold seeps is a very important issue that allows determining ecological diversity of such habitats. There are two cold seep environments that have been examined; The Gulf of Mexico and the West African margin. These cold seeps are different because of their geological histories, hydrocarbon seepages and oceanography. Findings of the comparison between these regions give a chance to explore the impact of regional factors on megafaunal communities structure and composition.(2)

The Gulf of Mexico has been synonymous with large inventory of cold seep habitats, with a great diversity of chemosynthetic organisms, many of which are endemic to the gulf. The West African margin, in turn, is a relatively poorly known (and even more poorly sampled) but equally fascinating system, with comparatively poorly known cold seeps and a remarkably diverse deep-sea ecosystem that could provide novel information on biogeographic connectivity and development of chemosynthetic ecosystems. An insight into the contribution of geographic isolation and regional environmental conditions to species richness, endemism and trophic diversity is also essential in making an appraisal of the global significance of the cold seeps habitats in sustaining biodiversity in the marine realm.

1.4 The aim of the studies was devoted to the megafaunal diversity and trophic stratification

This paper seeks to compare the megafaunal biodiversity as well as the structure of trophic assemblage among the cold environments in the West African margin and the northern Gulf of Mexico. In particular, this paper covers two major goals of the study, namely: (1) evaluating the species richness and endemism of the megafaunal assemblages in the two areas and (2) investigating food webs at the community level in both regions with stable isotope analysis (delta 13C and delta 15N) to learn about the energy distribution and trophic position of key species. Using the comparison of such cold seep ecosystems, the research tries to explain the causes of variability in the ecology and how the observed changes in biodiversity occur in various locations. The latter among others also seeks to illuminate the importance of chemoautotrophic productivity as an important process that influences community composition and trophic diversity in these extreme ecosystems.(3)

2. Study Regions and Descriptions of the Seep Sites

2.1 Cold Seep Distribution in Gulf of Mexico and off Western Africa

Cold seeps are common in continental margins where geological actions including tectonic activity and seepage of hydrocarbons establish an invariable resource-rich environment in the deep seas. The two main areas that are crucial and contain cold seep environment in this work are Gulf of Mexico (GOM) and West Africa margin (WAM).

Gulf of Mexico has long been reported as a hot spot of hydrocarbon seepage with numerous cold seep sites observed along the gulf continental slope and deepwater regions. These seafloors spread out by 1000 to more than 3000m and are distinguished by large-scale methane hydrate, sulfide-endowed sediment and diverse chemosynthetic life forms. The high organic productivity and enhanced methane release combined with the oceanographic conditions in the Gulf has resulted in the choice of the area as the study site of chemosynthetic communities.(4)

On the other hand, the margin of West Africa lacks well-documented seep sites, therefore, it is a potential region of comparative studies. The West African margin extends between Senegal and Angola and has a diversity of deep-sea habitats that comprise cold seep areas and hydrothermal vents fields. Most seep sites that were also surveyed in this research paper are found at Atlantic Ocean, along Gabon and Equatorial Guinea coasts with a range of 2,200 meters to 3,100 meters. The regions are considerably unexplored as compared to the Gulf of Mexico hence an opportunity to examine a possibly different ecosystem that can be characterized by difference in compositions of species and ecological functions.

2.2 Geochemical Settings and Depth Profiles of the Surveyed sites

The sites of cold seeps in question in both regions have a variety of depths, which enables comparing the species diversity and trophic framework at different environmental levels.(5)

Gulf of Mexico: The depth of the survey sites was between 2,200 meters and 3,100 meters, the sites had sulfide-rich strata of sediments with considerable amount of methane originating at the seabed. In these locations, geochemical environment is characterized by the high concentration of hydrogen sulfide and methane as the main energy supply to chemosynthetic communities. The tidal mixing and seasonal currents also affect the Gulf of

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Mexico seeps because the influences can be directed to the distribution of nutrients and the availability of the chemosynthetic sources of energy.

West African Margin: During the survey in West African margin, the surveyed sites consisted of similar depths that ranged between 2,200 meters and 3,100 meters. The intensity of methane and hydrogen sulfide emissions is also high in such sites, although there is a minor difference in their geochemical capabilities, with a few sites demonstrating a more powerful impact by the deepwater currents, and subsurface fluid flow. It is believed that the deeper locations along West African margin are exposed to seafloor spreading processes in which the condition to liberate hydrocarbon reservoirs is periodic, and thus chemosynthesis in the Gulf of Mexico locations is not as sustained.

2.3 Access Matters: Exploration and Explains Faunal Presence

The two regions are rich in exploration history with a number of cold seep locations explored in the past few decades using the ROVs and submersibles. The gulf of Mexico contains large seep communities, and the fauna in the deep sea including Bathymodiolus mussels, siboglinid polychaetes and chemosynthetic bacteria, have long been studied scientifically. The fauna in the Gulf is so adapted through methane and hydrogen sulfide and hence their ecosystem is highly diversified with many endemics.

Conversely the west African margin is a newer area of research and much of the faunal information of these cold seep areas is incomplete. Initial investigations have shown conclusively that Bathymodiolus mussels and vestimentiferan tubeworms are among the crucial species, whereas the level of species richness and endemism remains to be probed. The scarcer data available on West African margin demonstrates the necessity of additional investigation, and this work is focused on filling some of the existing gaps in knowledge by comparing the trophic structure and faunal diversity of the mentioned two regions.(6)

3. Faunal Documentation and Survey techniques

3.1 Visual and Sample Collecting Deployment and Operation of ROVs

In this investigation, remotely operated vehicles (ROVs) were used to do deep sea survey on the cold seeps at the Gulf of Mexico and the West African margin. ROVs will prove excellently suitabled in such environments due to the opportunity to maintain close control in real time by the sampling activities and deliver hi- def video records of deep-sea life in the depths of 2,200 to 3,100 meters. The ROVs deployed during this research were fitted with high-resolution cameras, light systems and sample collection devices which enabled visual survey as well as collection of specimens.

ROV activities were conducted in the least disturbing manner to the cold seep sensitive environments. The cars were removed into the research ship and on the ocean floor, their movements followed along preset transects to obtain an all-inclusive footage of the megafaunal communities and acquire biological samples. Our visual surveys (ROV-based surveys) allowed us to obtain both visual evidence of life (video images) as well as physical evidence (specimen) of the megafauna that are present in the cold seep sites.(7)

3.2 Species identification approach and video Transect Protocols

Video transect was carried out at all the cold seep sites during the ROV surveys and a uniform protocol was used to carry out the transects consistently so as to get consistent data across the sites. Each transect used to last a span of about 30 to 60 minutes and with a width of about 50 meters. The ROV followed the transect route, obtaining the continuous video records of the bottom and the benthic communities living there.

The author has documented the video that is shot at high definition resolution (1080p), and features clear sighting of the large scale megafauna, such as mussels, worms, and shrimp, in addition to the less noticeable species. The ROV used during the transects remained at a constant speed (roughly 0.1 meters per second and the details of the behavior of species, their interactions, and the characteristics of the environment could be observed carefully. The camera systems had wide lens capabilities to cover the whole area of the habitat and fauna in the environment and there was focused lighting to support the illumination of the specimens sufficiently.

Once the video footage was obtained, the identification of the species was carried out through viewing the recorded material to compare it to the known taxonomic sources. Identification of the existing species was done based on morphological characteristics, e.g., body shape, size and unique body anatomy. To identify it more accurately, the comparison to the previous documentation of cold seep fauna and consultations with taxonomic experts were used.(8)

Along with visual identification, the stable isotope data was measured (13 C and 15 N) in order to learn the trophic structure of the communities and, thereby, get information on the feeding strategies and consequences of different species identified.

3.3 Storage and Taxonomy of Specimens Collected

Specimens of major species of the megafaunal were then picked in form of samples to be analyzed further after visual identification. The respective sample collection arm has been used to collect samples of individual organisms, which in turn is used to protect the immediate environment. All the specimens were fitted in labeled containers with preserved solution (usually, formalin or ethanol) which assisted in preservation of tissue to aid in taxonomic classification at a later date.

The specimens which were brought back in good health were put in the laboratory. Taxonomic sorting of species was carried out diligently where special interest was focused on either defining endemic species and identifying novel taxa using set taxonomic guidelines. The specimens were classified by the use of a taxonomic key, but also consulted by experts to identify the species. Specimen accessions were made and specimens preserved to be used in the future and added to an already growing collections of cold seep species that will ultimately help in the distribution of different species, endemism, and the biogeographic relationships between the various seep locations.

These combined approaches of visual data, species collection and using stable isotopes offer an in-depth portrait of faunal diversity and trophic structures of cold seeps based upon taxonomically distinct sites in two biogeographically diverse locales.(9)

4. Stable isotope sampling and Trophic Analysis

4.1 Tissue Preparation and Tissue Sampling to Isotopic Measurements

In order to determine the trophic structure of the cold seep communities, stable isotope analysis (SIA) was used i.e. carbon (delta-13 carbon) and nitrogen (delta-15 nitrogen). Such isotopes are widely applied to ecological studies to assess energy flow in the food web and establishment of trophic positions, as well as sources of carbon. The other important megafaunal species that was carefully sampled with the tissue samples to analyse the stable isotopes are Bathymodiolus mussels, vestimentiferan tubeworms, and chemosynthetic bacteria, which are the central components of the food webs of the cold seeps.

In case of each species, a soft tissue (the major source used was the guts, gills, or muscle tissues) had been dissected with sterilized instruments in such a way that the tissue samples did not contaminate any other sample. The retrieved tissues were quenched immediately in pre-labeled vials then stored at liquid nitrogen temperature to maintain isotopic integrity. The samples were later sealed in bags and dispatched to the laboratory to be freeze-dried to eliminate any water content since water has the propensity of diluting the concentration of isotopes hence, affecting accurate measurements.

The dried tissues were then ground into fine powder with the help of a mortar and pestle making sure to get a uniform sample. Each specimen was analyzed by taking a subsample of about 1-2 mg powder, any contact with foreign materials (e.g. plastics or metals) was avoided. These subsamples were further taken to a specialized was supported laboratory such that further analysis was carried out.(10)

4.2 Inference of Trophic Levels and Carbon Source through Measurement of 13 C and 15 N Stable Isotopes

The sample analysis of stable isotopes was carried out by mass-spectrometry method which made it possible to measure any 8 reflectance value with high accuracy. The 13 C ratio is used to give an understanding of carbon sources used by organisms so that it is able to differentiate organisms which chemosynthesize either using methane or hydrogen sulfide or synthesize using photosynthetic primary producers. Cold seep environments In cold seep environments, the variation of carbon source is an important factor to consider in explanations of how organisms within these environments accommodate their chemosynthetic microbial symbionts and whether or not they utilize either (detritus or chemosynthetically-derived) fixed carbon.

Ratios of 15N aid in ascertainment of trophic position of every species. An increase in the 015N value will tend to point towards increase in the trophic level because the organisms at higher trophic level will tend to become enriched with nitrogen isotopes as a result of trophic transfer. Comparing 15N values among the species in each cold seep site, one is able to determine a feeding relationship and energy flow within the food web of that site. Similar 815N values will indicate similar food web provision and large differences in 813C and 815N value indicate different dietary source or ecological niche.(11)

4.3 Comparative interpretation of food web structure over sites

The findings in stable isotope were to compare the trophic structure of both the cold seep communities in the gulf in Mexico and in the West Africa margin. One of the important results of the analysis was that the trophic diversity at the communities dominated by Bathymodiolus in the West African margin revealed a wider variety of trophic positions thus a more complex food web. These locations had a higher dependence pattern of chemosynthetic bacteria as the main source of carbon and allowed a larger number of consumers that related to distinct levels of the food web.

On the contrary, the Gulf of Mexico sites showed a greater number of monotypic communities, a more detridivorous reliance, and a reduced number of trophic interactions. These sites had more locally confined trophic spectrum in the species, possibly appearing less variation n space in the carbon resources or trophic diversities overall than the west African margin.(12)

Combining 3 data on 4 species in each region and 2 data on 8 species in the total of 2 regions allowed us to understand more on carbon flow and trophic activity of the cold seep ecosystems. This results in the differences in the biogeographic patterns of food web complexity and the trophic diversity indicating the role of localized ecological factors and chemoautotrophic productivity concerning the structure of deep-sea communities.

5. Results

5.1 Megafaunal Diversity, populations and Community structure

Observations made in the two areas with surveys carried out in the Gulf of Mexico (GOM) and the West African margin (WAM) showed the two regions to have a great difference in the richness, abundance and composition of their oceanic Megafaunal communities. A total of 15 megafaunal species was identified over the six surveyed cold seep sites (between 2,200 to 3,100 meters deep), 12 species were identified at the Gulf of Mexico and 10 species at the West African margin.

Gulf of Mexico: The Gulf of Mexico was a heterogeneous megafauna community with Bathymodiolus mussel dominating the Gulf megafauna community. Mussels tended to harbor small crustaceans and polychaetes, however species richness was on the whole lower than the West African margin. Bathymodiolus species thrive well in such environments and they dominated the Gulf of Mexico cold seeps forming the foundation of the local chemosynthetic food web.(13)

The more diverse community composition, in which there were a greater number of endemic species, was found in West African Margin which had a contrast. Besides the Bathymodiolus mussels, the West African seeps also had large stands of Lamellibrachia tubeworms that is a major staple species involved in chemosynthesis in the area. The trophic diversity was also reasonably greater and the number of consumers was broader which encompassed shrimp, bivalves, and crustaceans. These sites generally had high species richness and abundance reflecting the importance of localized chemosynthetic productivity supporting higher complexity food webs.

5.2 Habitat associations of Dominant taxa (e.g., Bathymodiolus, Lamellibrachia)

Community composition as well as the examination of the dominant taxa and the relating associations was found with subdued associations within the environmental contexts of the cold seep habitats.

Bathymodiolus Mussels: the presence of the Bathymodiolus mussels, which is a key species in cold seep habitats, occurred in both regions. These mussels were located mainly in sulfide-laden sediments in the gulf of Mexico and were usually in dense mats of mussels which were linked with exaggerated methane and hydrogen sulfide leaks. Likewise, in the West African margin, Bathymodiolus species had also been found at methane seep but with a greater diversity of other chemosynthetic life.

Lamellibrachia Tubeworms: Lamellibrachia tubeworms were also a prominent characteristic in much of the West African margin seep deposits. These are the species that are famous to be in symbiosis with bacteria chemosynthetic bacteria that enable them to live in an environment where there is a lot of hydrogen sulfide and methane. In contrast to the Gulf of Mexico where Lamellibrachia-dominated communities were less common (79), the Lamellibrachia-dominated communities were more dominant in the West African margin than Bathymodiolus dominated communities, indicating that chemoautotrophic productivity in the area could contribute more faunal associations.(14)

5.3 Regional Diversities of Trophic and endemism

Comparison of regional and interregional trophic diversity showed that there was a large regional disparity:

Trophic Diversity within the Gulf of Mexico: Disparities of trophic diversity within the gulf were relatively small, as the chemosynthetic organisms Interior within the Gulf and particularly within the gulf as the base of the food web, encompassing Bathymodiolus and tubeworms among others. According to Eckmann and Aldridge, the higher trophic levels included mainly detritivores and predators that included polychaetes and crustaceans. The trophic structure was not that complex since there were fewer species holding the high-ranking trophic position.

Trophic Diversity in the West African Margin: Unlike the rest of them, the West Africa margin exhibited a higher level of trophic complexity. The food web became more complex due to the presence of Lamellibrachia tubeworms as well as increased variety of shrimp, crustaceans and bivalves. These creatures could take advantage of the chemosynthetic energy of methane and overwhelm sulfide and develop a wider trophic interactions.

5.4 Localized occurrence of Isotopic Evidence of Localized Chemosynthetic Productivity

The 6 18O and 13 18N analysis (i.e., stable isotopes of nitrogen and carbon) gave a good idea about the carbon sources and the processes of energy flow in the two regions. It was found out that:

Most of the megafaunal species acquired the detritus and chemosynthetically derived carbon through methane and hydrogen sulfide in the Gulf of Mexico, which was marked by the 6 values, which were comparatively low (showing a sulfide-based food web). This evidence gives credence to the thought that seep communities in the Gulf of Mexico are a lot more reliant on the detrital addition and possess fairly basic trophic interactions.

The δ 13C and δ 15 values in West African margin showed higher trophic diversity and higher rate of trophic level feeding and chemosynthetic carbon food utilization. Food webs that had a wider variety of trophic interactions were produced by the presence of Lamellibrachia and other chemosynthetic organisms in the sites. Variation in the isotopic signatures was increased, because of regional differences in chemosynthetic productivity and food availability.(15)

6. Conclusion

6.1 Cold Seeps as Hotspots of Biodiversity with Faunal Signatures That are Specific to Regions

As this study has confirmed, the cold seeps serve as key biodiversity hotspots of deep-sea megafaunal assemblages. The two margins of the Gulf of Mexico and West Africa are two unique cold seep ecosystems that though having similar processes of chemosynthesis have different faunal patterns due to the geochemical and biogeographic conditions in the two areas. In the Gulf of Mexico there is a simpler trophic structure (with the large Bathymodiolus mussel and related fauna) and lower species richness than in the more complex communities seen in the West African margin. The latter accommodates greater variety of species including Lamellibrachia tubeworms as well as variability in trophic structure. Such difference in faunal composition demonstrates the importance of cold seeps as the biodiversity hotspots and the role of the local environmental conditions in the evolution of these ecosystems.

Species, endemism and trophic complexity seen on the West African margin poses the idea of a West African treasure trove that may be a part of special evolutionary adaptations that can prove to be a significant to the study of deep-sea ecology. By contrast, the Gulf of Mexico, which has more monotypic communities, sheds light on the consequences of ecological lifestyles of long-term stability in seep habitats.

6.2 The effect of Biogeographic and Geochemical factors on Community Structure

This investigation finds out that biogeography factors and geochemistry are core players in the community structure of the cold seep ecosystems. The chemistry in the Gulf of Mexico is a continuous source of methane and hydrogen sulfide emissions which act as fuel to the communities dominated by Bathymodiolus. By contrast, the West African margin has a more heterogeneous geochemical regime, with seep sites being episodically dominated by methane and with more diverse hydrocarbon seep processes, reflecting more diverse fauna as well. Lamellibrachia tubeworms and other species which are dependent on chemosynthesis have a high prevalence in this area, which suggests that the local geochemical conditions (e.g. hydrogen sulfide and methane availability) are key drivers of benthic faunal assemblage diversity.

Besides the geochemical examples, biogeographic isolation forms part of the regional variation of species endemism. There are also more endemic species along the West African margin, something that indicates that isolated condition in the past has enabled establishment of novel chemosynthetic systems that differ with those found in the Gulf of Mexico. This means that the aspects of geochemical productivity in combination with geographic factors works to generate region specific ecosystems and this implies that various communities live within similar ecological niches which survive under different conditions.

6.3 Conservation Impliciations With Deep-Sea Exploration of Hydrocarbons

The results of this research have significant conservation effects in view of the increased hydrocarbon exploration of deep-sea. The high levels of species specialization and the complex food web in cold seep ecosystem make them sensitive to various effects of hydrocarbon production, such as chemical pollution, habitat loss, and sedimentation. The possible effects of such kind of activities to biodiversity and the ecosystem functionality are severe particularly in highly endangered regions such as the West African margin where distinct species might face the threat of extinction.

Considering these results, the actual need is the monitoring and conservation of the habitats of cold seeps to preserve their biodiversity and guarantee that they may be able to proceed to supply the essential ecosystem services within the deep ocean. These environments need to be acknowledged to have ecological importance, and their weak position, which can only be achieved by adopting policies that are in their long term protection.

6.4 The recommendations to monitor and protect vulnerable seep habitats have been listed.

With reference to the findings of the study, the following recommendations will assist in improving the safety and long-term management of cold seep ecosystems:

Long-term monitoring: Develop comprehensive monitoring programs based on the use of ROVs and non-invasive methods to monitor the effects of alteration in species composition, trophic structure, and geochemical regimes of the sites of cold seeps especially areas within the hydrocarbon exploration.

Establishment of Marine Protected Areas Creation of marine protected areas (MPAs) to cover hotspot locations of important cold seep habitat, particularly the high endemism and biodiversity locations at West African margin and Gulf of Mexico.

Control Deep-Sea Exploration: Start issuing more strict rules to the exploration of hydrocarbons in the deep-sea areas indeed with the less effect that should be an operation where seep areas are not destroyed so that they can be left to the next generation of species.

International Cooperation: Facilitate international cooperation in the safeguarding of these ecologically important systems with particular focus on international collaborations across national territories in such examples as the Gulf of Mexico and West African margin, which are subjected to comparable ecological stressors.

To sum up, cold seeps are one of the most significant habitats that harbor distinct biodiversity and provide important ecosystem services. This paper highlights the urgency to take some actions to make sure such environments are not endangered due to human activity and meet their sustainability in the long-term perspective.

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Conflicts of interest

The authors have no conflicts of interest to declare

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