Application of scientific criteria for identifying hydrothermal ecosystems in need of protection

Appendix A. A collation of scientific evidence for describing/identifying hydrothermal ecosystems in need of conservation at 11 hydrothermal vent fields on the nMAR. This evidence includes information on i) initial discovery and explorations, ii) geological setting, iii) biological characterization, iv) ecological importance criteria assessment by other inter-governmental organizations and status, and v) scores regarding the relevance of each criterion. Where biomass-dominant species are shared across two or more fields, their characteristics for each criterion are repeated verbatim for each vent field in the assessment. The same repetitive procedure is used for ecosystem attributes associated with the active vent environment. Scientific evidence supporting a criterion that applies across all vent fields, is summarized in the main manuscript text.

A.1. Lost City vent field

<table>
<tr><td rowspan="2">LOST CITY</td><td>Latitude</td><td>Longitude</td><td>Depth (m)</td></tr>
<tr><td>30°07'N</td><td>42°07'W</td><td>720-850</td></tr>
<tr><td colspan="4">Initial Discovery and Explorations
The Lost City hydrothermal field was discovered in 2000 during a submersible dive to explore the Atlantis Massif, an Oceanic Core Complex [1, 2].</td></tr>
<tr><td colspan="4">Location and Geological Setting
Lost City is characterized by diffusely venting, low-temperature (max. 90°C) carbonate monoliths (30 to 60 m height) on a relatively shallow region of the Mid-Atlantic Ridge. It is located on a 1.5-Myr-old crust, nearly 15 km from the spreading axis, and has been hydrothermally active for at least 30,000 years [3]. Models suggest hydrothermal activity has persisted for >120,000 years [4]. Fluids emanating from the seabed are dominated by heat and products of exothermic serpentinization of peridotite (ultramafic rock) rather than seawater-basalt reactions. The fluids are alkaline (pH 9 to 11), hydrogen- and methane-rich, and devoid of dissolved metals [5].</td></tr>
<tr><td colspan="4">Biological Characterization
A description of the Lost City biological community was included in Kelley et al. [1], highlighting the low abundance and biomass of the invertebrate community, with “a few crabs, sea urchins, and abundant sponges and corals”. The microbial system is supported largely by methane (methane oxidizers) and hydrogen (sulfate reducers). Dissolved sulfide and sulfide oxidation play a role in this system in microbial sulfur cycling, but they do not have the same role in the foodweb as in black smoker ecosystems [6]. Details of the nematode fauna are reported in Tchesunov [7], including an account of a non-vent endemic species (Oncholaimus scanicus) that is abundant at Lost City, Lucky Strike, and Menez Gwen hydrothermal vents but is morphologically distinct at Lost City [7].
The fauna of the Lost City hydrothermal field is visually dominated by wreckfish (Polyprion americanus), cut-throat eels (Synaphobranchus kaupi), and large geryonid crabs [2]. Small gastropods and polychaetes are also reported [1, 8]. Vent-endemic taxa symbiotic with autotrophic bacteria that dominate the biomass at other known active hydrothermal vent fields on the Mid-Atlantic Ridge are mostly absent at Lost City. An amphipod Primno evansi is reported, Bathymodiolus azoricus mussels are “extremely rare”, and there is one other vent-</td></tr>
</table>

endemic taxon apparently not yet revealed [8]. The oldest, rounded and lithified structures are covered with epifauna [4].	
Classification Lost City is classified as an Ecologically and Biologically Significant Area by the Convention on Biological Diversity (report 2015, https://chm.cbd.int/pdf/documents/marineEbsa/204107/1). Lost City has also been recognized as a potential site of outstanding universal value in the high seas for many of its attributes, including the sculptural nature of its carbonate precipitates, their size and longevity and its role in understanding the diversity of hydrothermal processes on Earth and potentially in oceans of other planetary bodies [9].	

Scientific Information for Assessment of Lost City vent field for proposed criteria

Uniqueness and rarity	**SCORE: HIGH**
Vent fields host small, island-like ecosystems with distinctive biotic and abiotic features [10, 11]. Globally, the active vent habitat occupies an area less than that of the island of Manhattan (Van Dover et al. 2018). Free-living and autotrophic microorganisms dependent on reduced compounds in the hydrothermal fluids serve as the base of the chemosynthetic ecosystem [12, 13]. Juveniles and adults of vent-endemic (vent-obligate) taxa are adapted to the extreme chemical and physical conditions of the vent habitat and thrive in these specialized (unique) ecosystems [14]. Given the very small and discrete areas they inhabit, vent-endemic species are globally rare [15, 16]. • Lost City is a **discrete area** (10000 m^2, Ewan pers. comm) [1] that hosts **vent-endemic taxa**, including ***Bathymodiolus azoricus*** mussels which are "extremely rare" at Lost City [8]. • Lost City is a **singular site among hydrothermal systems**, distinct as a serpentinite end-member system with carbonate mineralogy and with alkaline fluids rich in H_2 and CH_4 resulting from serpentinization reactions. • Lost City hosts unique **microbial communities** that may represent an **extremely rare analogue for early Earth ecosystems** [17-20].	
Functional significance	**SCORE: HIGH**
All active hydrothermal vents support primary production by microorganisms, serve as discrete feeding area, and are essential for the growth, survival, reproduction, and persistence of vent endemic species [14, 21]. • **Vent-endemic taxa**, including ***Bathymodiolus azoricus*** mussels are "extremely rare" at Lost City [8] but may depend on the primary production of Lost City for their reproduction. • It is unknown if Lost City is a nursery ground or rearing area. • Lost City is exceptionally important for the **survival of microbes.** Hydrothermal fluid emissions at Lost City support the growth of sulfur-cycling and methane-oxidizing microorganisms adapted to the high pH and H_2- and CH_4-rich conditions [6, 17, 18].	
Fragility	**SCORE: HIGH**
All active vent fields are fragile ecosystems that are geographically isolated and discrete [11],	

hosting populations of benthic invertebrate species that rely on dispersal through pelagic larval stages [22] for maintenance of populations and genetic connectivity. Habitat degradation and fragmentation due to anthropogenic disturbance may result in local loss of biodiversity [23-25] and ecosystem services [26]. Connectivity among metapopulations of species is characterized by source-sink dynamics, making these systems sensitive to reduction or loss of source populations [27-29], with ecological consequences on the structure and function of metacommunities [21].

- **Lost City** may be susceptible to degradation by human activities especially considering that is a **singular isolated site** which harbours a pool of **microorganisms defined as a rare biosphere** [17].
- Vent-endemic *Bathymodiolus azoricus* mussels are "extremely rare" at Lost City [8].
- Because it is a carbonate system and metal-poor, it is not a direct target of the mining industry, but the structures and the biota may be indirectly impacted by mining activities through particle and bioavailable metal burdens.

Life-history traits of component species that make recovery difficult	**SCORE: HIGH**

Recovery dynamics of vent faunal communities on slow-spreading ridges, such as the Mid-Atlantic Ridge, are unknown. Because MAR vent fields are hydrothermally active for longer periods (thousands of years) than those on faster-spreading ridges (years to decades), they may have slower recovery trajectories [30, 31]. Some vent species are widespread on the MAR (e.g., *Rimicaris exoculata* shrimp; *Shinkailepas briandi* limpets) [32-34], others are not (e.g., *Bathymodiolus* sp. mussels) [29]. Source/sink and recruitment dynamics in vent ecosystems are poorly known if at all, and are likely to be unpredictable given that organisms disperse in the water column [22, 31]. While genetic connectivity observed for some species at vents on the nMAR depends on long-distance dispersal [29], population maintenance at a given site may depend primarily on self-recruitment (i.e., local sources and sinks ([35]. There is currently little data available on the autecology of smaller species (macrofauna & meiofauna). For example, some meiofauna have distinct life-history traits compared to the macrofauna, such as the lack of larval dispersal for nematodes [36], which may make recovery after disturbance difficult [37, 38].

- At Lost City, morphologically distinctive nematode species with no larval dispersal [7] and vent endemic *Bathymodiolus* mussel with **larval dispersal** [8] are reported.

Structural complexity	**SCORE: HIGH**

At all active hydrothermal fields, there are complex gradients of geological, geochemical, and thermal conditions that correlate with ecological zonation [14, 39]. Engineer (foundation) species modify physical and (or) chemical environments by altering fluid flow and chemistry [40], contributing to increased environmental heterogeneity. Through evolutionary processes, species at active hydrothermal vents have adapted to extreme environmental conditions, including tolerance to high temperature, low oxygen, and high metal concentrations [41].

- At Lost City, mineralogy, carbonate age, fluid flux, chemistry, and **associated microbiota differ within and between structures and stages of carbonate evolution** [6, 17]. The microbial system is supported largely by methane (methane oxidizers) and

hydrogen (sulfate reducers). Dissolved sulfide and sulfide oxidation play a role in this system in microbial sulfur cycling, but they do not have the same role in the food web as in black smoker ecosystems [6]. Carbonate structures at Lost City are classified into 4 stages of evolution: i) initial fluid flux, ii) nascent carbonate structures, iii) carbonate towers and flanges, iv) lithification from aragonite to calcite, with further lithification to rounded features colonized by epifauna [4, 42]. • **Adapted microrganisms** are present at Lost City [17]. • Vent-endemic *Bathymodiolus azoricus* are engineer species and present at Lost City [8], but they are very rare and not forming large aggregations as at other vent fields at MAR.	
Biological diversity	**SCORE: HIGH**
Biodiversity of microbial communities is very rich at hydrothermal vents [43, 44]. Vent-endemic animal species contribute novel diversity to the deep-sea fauna, often at taxonomic levels higher than genus and with radiations correlated with environmental attributes including ocean basin, depth, fluid chemistry, and temperature (e.g. polynoid scale worms, alvinocaridid shrimp, bathymodiolin mussels, bythograeid crabs). Habitat heterogeneity and structural complexity provide niches for diverse species [14]. Hydrothermal vent organisms are valued for their genetic diversity [15, 45]. • **Diverse microrganisms** are present at Lost City [2, 17]. • Lost City hosts **vent endemic** species • Flanges and spires are inhabited by numerous species of endemic polychaetes, nematodes, ostracods, stomatopods, and bivalves [2]. • Vent-endemic *Bathymodiolus azoricus* are engineer species and present at Lost City [8], but they are very rare and not forming large aggregations as at other vent fields at MAR.	
Biological productivity	**SCORE: HIGH**
Lost City is an exception, as it is a **serpertinite hosted vent system** (the only deep-one that is to date known). • The chemical energy for the synthesis of organic compounds is abundant at Lost City [46]	
Naturalness	**SCORE: HIGH**
Hydrothermal vents are relatively undisturbed [47]The only interventions to date are those of scientists and mineral resource explorers. An *Interridge Code of Conduct* guides scientific research and emphasizes avoidance of any scientific activity that would have a deleterious effect on the persistence of populations or that would lead to sustained alteration or visible degradation [48]. • Lost City is relatively undisturbed.	
Ecosystem services	**SCORE: HIGH**
Living resources from hydrothermal vent ecosystems provide or have high potential to provide	

provisioning services, including genetic resources, bioprospecting or bioinspired materials/processes [15]. They also harbour energetical and mineral resources not yet exploited. Hydrothermal vents contribute to regulating and supporting services including carbon sequestration by biological pump, or microbial oxidation of the greenhouse gas methane [49] and represent major source of iron, an essential trace element that controls marine productivity, in the global ocean [50]. Vents offer cultural services in the form of exceptional inspiration for arts, science, technology and our world [15]. Hydrothermal vents have been and continue to be fruitful areas for fundamental, interdisciplinary, scientific research. Discovery of hydrothermal vents [51] revolutionized our view of life in our oceans and the potential for life on other planetary bodies [14]. Hydrothermal vents are living libraries that open new paths for understanding the intersection of Life and Earth processes [15, 52]. Every studied vent field to date has increased the scientific knowledge, documented through the prolific and highly cited scientific literature [52]. They are used as experimental sites; they constitute a baseline for monitoring anthropogenic induced changes.

- As all active vent fields, Lost City, offers (potentially) rich provisioning, regulating, and supporting services [15, 49].
- Lost City is featured in the Disney 3-D IMAX film *Aliens of the Deep*. *["Astrobiologist Kevin Hand helps IMAX director film Aliens of the Deep". Stanford University. 14 January 2005. from Wikipedia 2020-6-10*]. The IMAX flange was unnamed prior to the documentary's release, but is extremely recognizable in the film and subsequently picked up the nickname of the video format played in theaters.
- Lost City is featured in episode 2 of the BBC's documentary *Blue Planet II ["Blue Planet II just showed us where life may have begun". The Independent. 2017-11-06. Retrieved 2019-04-11; from Wikipedia 2020-6-10].*
- Lost City was featured in a Clive Cussler novel by the same name, "The Lost City".
- Lost City has been and continues to be an important research site on the Mid-Atlantic Ridge.
- Lost City is globally distinctive with its carbonate chimneys forming through highly alkaline vent fluid and associated microbial communities, in contrast to acidic, sulfide- and metal-rich vent fluids at all other known vent fields along the northern Mid-Atlantic Ridge. Lost City hydrothermal vents discovered shifts in Archaea and bacteria communities over 1000-year time scales with changing environmental conditions [17]. Correlations between carbonate chimney ages and RNA sequences from the associated archaeal and bacterial communities suggest that 'rare' members of the microbial community can become dominant when environmental conditions change, on 1000-year timescales; the long history of chimney growth cycles at Lost City has resulted in numerous closely related microbial 'species', each pre-adapted to a particular set of recurring environmental conditions [17]. **The Lost City hydrothermal field is posited as a contemporary analogue for conditions where life on early Earth may have originated** [53, 54], where there is abiogenic production of organic carbon [46, 55], and where there are conditions similar to those that might support life within oceans of extra-terrestrial planetary bodies [19].
- Lost City may be used as a science or education example of particular geological, geophysical or biological attributes.

A.2. Broken Spur vent field

BROKEN SPUR	**Latitude**	**Longitude**	**Depth (m)**
	29 °10'N	43°10'W	3070-3110

Initial Discovery and Explorations

The presence of Broken Spur was initially suggested by water-column anomalies detected during a cruise on the R.R.S. "Charles Darwin" [56]. Geophysical imaging followed by the deployment of a camera system indicated seafloor hydrothermal activity. In June 1993, two *Alvin* dives confirmed the presence of an active hydrothermal field at the axial summit graben of the neovolcanic ridge at a depth of 3090 m [56]. The Broken Spur vent field was further explored in 1994 with the R.V. "Akademik Mstislav Keldysh" (BRAVEX/94 Scientific Team 1994).

Location and Geological Setting

The Broken Spur vent field is located at depths varying from 3070 to 3110 m [10]. The host seafloor is covered by pillow basalts occasionally collapsed, often covered by oxidised sulphide sediments. Broken Spur is a relatively low heat output system that is likely driven by magma, but it may be in a waning phase [57]. The estimated areal extent of seafloormassive sulfides is ~5000 m^2 [58]. In 1993, three active sites were located along with two weathered sulphide mounds emitting diffuse low-temperature fluids [56, 59, 60]. In 1994, more sites were discovered adding up to ten tall active sulphide structures, 7 of them harboring black smokers*: Mound `K', Judy's Tower*, Triple Chimney*, White Button, Dog's Head, Bogdanov Site*, The Spire*, Saracen's Head*, White Mushroom* and Wasp's Nest* [61]. The edifices range from a few meters to a few tens of meters in height and up to a few meters in diameter. In addition to the black-smoker chimney structures, the field also contains an actively-venting platform structure on top of a sulphide mound at White Button and sites of low temperature venting and inactive, weathered sulphide mounds. High temperature fluids from various edifices exhibited a temperature varying between 360-364°C [62]. Compared to other vent sites, the hydrothermal fluids are enriched in Li and have lower dissolved Mn and Sr concentrations [62]. Broken Spur contains an appreciable amount of noble metals (Au, Ag) compared to other vent fields on the MAR [63].

Biological Characterization

A description of the Broken Spur biological community was first provided by Murton et al. [56]. The field is characterized by the absence of the large shrimp swarms that are so characteristics of the Snake Pit and TAG vent fields [56]. These low-density populations appear to represent a climax feature of the field [61]. One exception is the Bogdanov site where large swarms of shrimp *Rimicaris exoculata* were observed. This site has a different topography than the other structures and may offer a better substrata and optimal habitat to allow shrimp colonization [61]. The total abundance of shrimps and mussels on the majority of structures in the Broken Spur hydrothermal field was considerably lower as compared with the corresponding biotopes of neighboring regions [64].

Broken Spur is a hybrid zone for the two *Bathymodiolus* species found on the MAR (*Bathymodiolus azoricus*/*B. puteoserpentis*) [29, 65, 66]. The most recent description of the Broken Spur vent ecosystem may be found in Ribakova & Galkin [67] and Galkin & Demina [68].

In addition to shrimp (*Rimicaris exoculata*, *Alvinocaris markensis*, *Mirocaris fortunata*) and mussels (*Bathymodiolus azoricus*, *B. puteoserpentis*, and hybrids of these), Broken Spur is colonized by brachyuran crabs (*Segonzacia mesatlantica*), galatheid squat lobsters (*Munidopsis sp*), gastropods including *Phymorhynchus moskalevi*, ophiuroids (*Ophioctenella acies*), ampharetid and chaetopterid polychaetes, and an actinian anemone [61, 69]. Two rare species of deep-sea fish are also reported at Broken Spur: *Haptenchelys texis* (Synaphobranchidae) and *Pachycara thermophilum* (Zoarcidae) [70]. Overall, alvinocaridid shrimp are present close to black smokers, high densities of ophiuroids are found on solid chimney surfaces and mounds, anemones peak at the base of sulphide mounds and highest densities of brachyuran crabs are found on platform structures [61].

Despite intensive sampling of this vent field for several decades, a new species of shrimp - *Keldyshicaris vavilovi* sp. nov., family Alvinocarididae, was discovered in 2005, highlighting our still fragmentary knowledge of hydrothermal vent biodiversity [71, 72].

Classification

Broken Spur was classified as an Ecologically and Biologically Significant Area by the Convention on Biodiversity (Report 2015, https://chm.cbd.int/pdf/documents/marineEbsa/204107/1).

Scientific Information for Assessment of Broken Spur vent field for proposed criteria

Uniqueness and rarity	**SCORE: HIGH**

Vent fields host small, island-like ecosystems with distinctive biotic and abiotic features [10, 11]. Globally, the active vent habitat occupies an area less than that of the island of Manhattan (Van Dover et al. 2018). Free-living and autotrophic microorganisms dependent on reduced compounds in the hydrothermal fluids serve as the base of the chemosynthetic ecosystem [12, 13]. Juveniles and adults of vent-endemic (vent-obligate) taxa are adapted to the extreme chemical and physical conditions of the vent habitat and thrive in these specialized (unique) ecosystems [14]. Given the very small and discrete areas they inhabit, vent-endemic species are globally rare [15, 16].

- Broken Spur vent field is a **discrete area** (5000 m^2) [10] that hosts **vent-endemic taxa**, including for example the shrimp (***Rimicaris exoculata***, *Alvinocaris markensis*, *Mirocaris fortunata)*, mussels (***Bathymodiolus azoricus*, *B. puteoserpentis***, and hybrids), crabs (*Segonzacia mesatlantica*), galatheid squat lobsters (*Munidopsis sp*), gastropods (*Phymorhynchus moskalevi)*, ophiuroids (*Ophioctenella acies*), ampharetid sp. and chaetopterid polychaetes, and actinian anemones [61, 69].
- Broken Spur is a unique area as it is a **hybrid zone** between the two mussel species *Bathymodiolus azoricus* and *B. puteoserpentis* [29, 65, 66]

Functional significance	**SCORE: HIGH**

All active hydrothermal vents support primary production by microorganisms, serve as discrete feeding area, and are essential for the growth, survival, reproduction, and persistence of vent endemic species [14, 21].

- Broken Spur is a discrete feeding area and essential for the survival, reproduction, spawning and recovery of **vent endemic** species including for example ***Rimicaris exoculata***, the two species of mussels ***Bathymodiolus azoricus*** and ***B. puteoserpensis*** and two species of deep-sea fish *Haptenchelys texis* and *Pachycara thermophilum* [56, 61, 65, 70, 73, 74].

- Broken Spur is a unique area as it is a **hybrid zone** between the two mussels *Bathymodiolus azoricus* and *B. puteoserpentis* [29, 65, 66]
- In 1995, late **zoeal and postlarvae of alvinocaridid shrimp** were widely dispersed in the water column in the vicinity of Broken Spur and extending into the next MAR segment and the Atlantis Fracture Zone beyond [75, 76].
- **Copepodid** stages 1-5 were found in plankton among adult dirivultid copepods and were the first report of early copepodid stages for dirivultids [77].
- Large populations of **peltospirid gastropods** were observed on a small active mound (J Sarrazin, video observation).

Fragility	**SCORE: HIGH**

All active vent fields are fragile ecosystems that are geographically isolated and discrete [11], hosting populations of benthic invertebrate species that rely on dispersal through pelagic larval stages [22] for maintenance of populations and genetic connectivity. Habitat degradation and fragmentation due to anthropogenic disturbance may result in local loss of biodiversity [23-25] and ecosystem services [26]. Connectivity among metapopulations of species is characterized by source-sink dynamics, making these systems sensitive to reduction or loss of source populations [27-29], with ecological consequences on the structure and function of metacommunities [21].

- Broken Spur is a **fragile ecosystem** that is geographically isolated and discrete [11], with many species (e.g. **vent endemic *Bathymodiolus azoricus* and *B. puteoserpensis, Rimicaris exuculata*)** dispersing only through **pelagic larval stages** [67, 68, 78, 79].
- *Rimicaris exoculata* shrimp have modified eyes that are poorly designed at the cellular level to recover from intense illumination [80, 81]. While there is no evidence that brief exposure to high intensity light from submersible assets has led to decline in population density [82], **long-term exposure to light** and loss of visual sensitivity have the potential to **alter the behavior and resilience of the shrimp populations.**

Life-history traits of component species that make recovery difficult	**SCORE: HIGH**

Recovery dynamics of vent faunal communities on slow-spreading ridges, such as the Mid-Atlantic Ridge, are unknown. Because MAR vent fields are hydrothermally active for longer periods (thousands of years) than those on faster-spreading ridges (years to decades), they may have slower recovery trajectories [30, 31]. Some vent species are widespread on the MAR (e.g., *Rimicaris exoculata* shrimp; *Shinkailepas briandi* limpets) [32-34], others are not (e.g., *Bathymodiolus* sp. mussels) [29]. Source/sink and recruitment dynamics in vent ecosystems are poorly known if at all, and are likely to be unpredictable given that organisms disperse in the water column [22, 31]. While genetic connectivity observed for some species at vents on the nMAR depends on long-distance dispersal [29], population maintenance at a given site may depend primarily on self-recruitment (i.e., local sources and sinks ([35]. There is currently little data available on the autecology of smaller species (macrofauna & meiofauna). For example, some meiofauna have distinct life-history traits compared to the macrofauna, such as the lack of larval dispersal for nematodes [36], which may make recovery after disturbance difficult [37, 38].

- At Broken Spur, many species (including engineer species) with **larval dispersal** are recorded (e.g. *Bathymodiolus* sp. mussels; *Rimicaris exoculata* shrimp [68, 78, 79, 83].

Structural complexity	**SCORE: HIGH**

At all active hydrothermal fields, there are complex gradients of geological, geochemical, and thermal conditions that correlate with ecological zonation [14, 39]. Engineer (foundation) species modify physical and (or) chemical environments by altering fluid flow and chemistry [40], contributing to increased environmental heterogeneity. Through evolutionary processes, species at active hydrothermal vents have adapted to extreme environmental conditions, including tolerance to high temperature, low oxygen, and high metal concentrations [41].

- Broken Spur harbors **several types of hydrothermal structures that have different morphologies and chemical and thermal conditions, with multiple and heterogeneous microhabitats**, that appear to significantly influence the distribution of vent species. Zonation of species is correlated with temperature and fluid chemistry, with *R. exoculata* shrimp in the warmest waters on surfaces of black smoker chimneys and other invertebrate taxa in cooler peripheral areas [61, 68]. Notably, only one of the 10 active edifices at Broken Spur has the large swarms of *R. exoculata* shrimp that dominate at Snake Pit and TAG vent fields [56, 61].
- ***Bathymodiolus*** mussels are the main **engineer species** at Broken Spur [61, 69], creating additional (and modified) areas for colonization.
- **Adaptation strategies** of the vent fauna, to the environment are exceedingly **rich** [41, 84-86].

Biological diversity	**SCORE: HIGH**

Biodiversity of microbial communities is very rich at hydrothermal vents [43, 44]. Vent-endemic animal species contribute novel diversity to the deep-sea fauna, often at taxonomic levels higher than genus and with radiations correlated with environmental attributes including ocean basin, depth, fluid chemistry, and temperature (e.g. polynoid scale worms, alvinocaridid shrimp, bathymodiolin mussels, bythograeid crabs). Habitat heterogeneity and structural complexity provide niches for diverse species [14]. Hydrothermal vent organisms are valued for their genetic diversity [15, 45].

- Broken Spur hosts **vent endemic species**.
- In addition to shrimp (*Rimicaris exoculata*, *Alvinocaris markensis*, *Mirocaris fortunata*) and mussels (*Bathymodiolus azoricus*, *B. puteoserpentis*, and hybrids of these), Broken Spur is colonized by brachyuran crabs (*Segonzacia mesatlantica*), galatheid squat lobsters (*Munidopsis sp*), gastropods including *Phymorhynchus moskalevi*, ophiuroids (*Ophioctenella acies*), ampharetid and chaetopterid polychaetes, and an actinian anemone [61, 69].
- Two rare species of deep-sea fish are also reported at Broken Spur: *Haptenchelys texis* (Synaphobranchidae) and *Pachycara thermophilum* (Zoarcidae) [70].
- Despite intensive sampling of this vent field for several decades, a new species of shrimp - *Keldyshicaris vavilovi* sp. nov., family Alvinocarididae, was discovered in

2005, highlighting our still fragmentary knowledge of hydrothermal vent biodiversity [71, 72].

Biological productivity	**SCORE: HIGH**

Chemoautotrophic microorganisms use the chemical energy of hydrothermal fluids to fix inorganic carbon and produce biomass [44]. High biological *in situ* productivity is found at most active hydrothermal vents [14]. Chemoautotrophic productivity occurs below the seafloor [87], on the seafloor as free-living microbes (attached or suspended), or living in symbiosis with large invertebrate species. This production is transferred to higher trophic levels [14, 88].

- Broken Spur is an active deep-sea hydrothermal vent [56], supporting ***in situ* primary productivity** [44].
- The fauna forms **biomass rich communities** at Broken Spur [61, 69].

Naturalness	**SCORE: HIGH**

Hydrothermal vents are relatively undisturbed [47]. The only interventions to date are those of scientists and mineral resource explorers. An *Interridge Code of Conduct* guides scientific research and emphasizes avoidance of any scientific activity that would have a deleterious effect on the persistence of populations or that would lead to sustained alteration or visible degradation [48].

- Broken Spur is relatively undisturbed.

Ecosystem services	**SCORE: HIGH**

Living resources from hydrothermal vent ecosystems provide or have high potential to provide provisioning services, including genetic resources, bioprospecting or bioinspired materials/processes [15]. They also harbour energetical and mineral resources not yet exploited. Hydrothermal vents contribute to regulating and supporting services including carbon sequestration by biological pump, or microbial oxidation of the greenhouse gas methane [49] and represent major source of iron, an essential trace element that controls marine productivity, in the global ocean [50]. Vents offer cultural services in the form of exceptional inspiration for arts, science, technology and our world [15]. Hydrothermal vents have been and continue to be fruitful areas for fundamental, interdisciplinary, scientific research. Discovery of hydrothermal vents [51] revolutionized our view of life in our oceans and the potential for life on other planetary bodies [14]. Hydrothermal vents are living libraries that open new paths for understanding the intersection of Life and Earth processes [15, 52]. Every studied vent field to date has increased the scientific knowledge, documented through the prolific and highly cited scientific literature [52]. They are used as experimental sites; they constitute a baseline for monitoring anthropogenic induced changes. As all active vent fields, Broken Spur, offers (potentially) rich provisioning, regulating, and supporting services [15, 49].

- Broken Spur has been and continues to be an important research site on the Mid-Atlantic Ridge, particularly as a hybrid zone for mussels [29].
- It is the type locality for the shrimp *Keldyshicaris vavilovi* sp. nov. [71, 72].
- Broken Spur may be used as a science or education example of particular geological, geophysical or biological attributes.

A.3. TAG vent field

TAG	Latitude	Longitude	Depth (m)
	26°08'N	44°49'W	3670

Initial Discovery and Explorations
Hydrothermal crusts, breccias, and anomalies were discovered at the Trans-Atlantic Geotraverse (TAG) Field in 1972 [89]. Low-temperature hydrothermal activity was confirmed in 1982 [90]. High-temperature black smokers were discovered in 1985 [91]. Localization of hydrothermal activity at TAG is tectonically (rather than magmatically) controlled [92], implicating deep, hot rock rather than a magma chamber as the heat source.

Location and Geological Setting
The basalt-hosted TAG active hydrothermal vent site is one of the largest known sulfide occurrences on the global mid-ocean ridge system [93, 94]. It is a complex environment, with high-temperature black smokers and a large sulfide apron with lower-temperature, diffuse flow. The site has supported hydrothermal activity for at least 150,000 years, with episodic high-temperature activity lasting 10s to 100s of years [95, 96]. In addition to the hydrothermally active TAG mound, there are numerous inactive sulfide mounds, recently mapped by [97].

Biological Characterization
Preliminary notes on biology at TAG were reported in [89] and included note of a "previously unknown benthic invertebrate", which has since been identified as the trace form of *Paledictyon nodosum* [98]. Galkin and Moskalev [99] provide the first details of biological zonation correlated with hydrothermal gradients at TAG.
Biomass at the active TAG site is dominated by dense aggregations of 'blind' shrimp (*Rimicaris exoculata*) on surfaces of high-temperature black smoker chimneys. There is a substantive literature on the feeding strategies of these shrimp [100-104], their derived eyes modified for detecting dim sources of light [80, 81, 105], their thermal tolerance [84], their reproductive biology [106-108], and their population connectivity [32, 33]. On the lower-temperature, sulfide apron, there are abundant shrimp-eating anemones (*Maractis rimicarivora*) and predatory gastropods (*Phymorhynchus* sp.) [109]. Bathymodiolin mussels are so far absent at the active TAG mound [99], though they are found at every other known active vent on the northern Mid-Atlantic Ridge. Chaetopterid polychaetes in stick-like mud tubes occur on the sulfide apron of TAG. An amphipod, *Dulichiopsis dianae*, is reported from basalt in the vicinity (minimal distance of 60 m) from active chimneys [110], but it is not considered to be vent endemic or vent obligate.

Classification
TAG is classified as an Ecologically and Biologically Significant Area by the Convention on Biological Diversity (report 2015, https://chm.cbd.int/pdf/documents/marineEbsa/204107/1).

Scientific Information for Assessment of TAG vent field for proposed criteria

Uniqueness and rarity	**SCORE: HIGH**
Vent fields host small, island-like ecosystems with distinctive biotic and abiotic features [10, 11] (Table 2). Globally, the active vent habitat occupies an area less than that of the island of Manhattan (Van Dover et al. 2018). Free-living and autotrophic microorganisms dependent on reduced compounds in the hydrothermal fluids serve as the base of the chemosynthetic ecosystem [12, 13]. Juveniles and adults of vent-endemic (vent-obligate) taxa are adapted to the extreme chemical and physical conditions of the vent habitat and thrive in these specialized (unique) ecosystems [14]. Given the very small and discrete areas they inhabit, vent-endemic species are globally rare [15, 16]. • TAG vent field is a **discrete area** (30000 m^2) [58] that hosts **vent-endemic taxa**, including for example *Rimicaris exoculata* and *R. chacei* and the shrimp-eating anemone *Maractis rimicarivora* [82].	
Functional significance	**SCORE: HIGH**
All active hydrothermal vents support primary production by microorganisms, serve as discrete feeding area, and are essential for the growth, survival, reproduction, and persistence of vent endemic species [14, 21]. • TAG serves as a discrete and essential **feeding area for its invertebrate populations** [82, 100, 103]. • TAG vent field is an important area for breeding and spawning for several species including for example the **shrimp *Rimicaris exuculata*** and the **shrimp-eating anemone *Maractis rimicarivora***, which are present in **large and stable populations at this discrete site** [82, 111]. • The biomass-dominant shrimp species *Rimicaris exoculata* is dependent on proximity to diffuse vent fluid [100, 103, 112], with autotrophic microbial epibionts and with microbial assemblages adapted to the stomach environment. Adult *R. exoculata* have a hypertrophied cephalothorax that hosts a dense epibiotic, autotrophic bacterial community. These bacteria colonize the outer exoskeleton of the mouthparts and carapace [113-115]. From a metabolic perspective, *R. exoculata*, which ingests mostly minerals, relies on its symbionts for nutrition [101]. At TAG and other hydrothermal vents on the northern Mid-Atlantic Ridge, populations of the shrimp *Rimicaris exoculata* are often segregated by size, with adults adjacent to [116] or above [82] juveniles. The adult and juvenile shrimp were initially described as different species, but molecular approaches soon revealed they were life-history stages [117, 118], indicating that TAG provides critical habitat for **both juvenile and adult shrimp**.	
Fragility	**SCORE: HIGH**
All active vent fields are fragile ecosystems that are geographically isolated and discrete [11], hosting populations of benthic invertebrate species that rely on dispersal through pelagic larval stages [22] for maintenance of populations and genetic connectivity. Habitat degradation and fragmentation due to anthropogenic disturbance may result in local loss of biodiversity [23-25] and ecosystem services [26]. Connectivity among metapopulations of species is characterized by source-sink dynamics, making these systems sensitive to reduction	

or loss of source populations [27-29], with ecological consequences on the structure and function of metacommunities [21].

- TAG is a **fragile ecosystem** that is **geographically isolated and discrete** (Beaulieu et al., 2015), with many species (e.g. *Rimicaris exuculata)* dispersing only through **pelagic larval stages** [22, 79]. Given the large population densities of shrimp, anemones, and other species at the active TAG site [82, 100], reduction or loss of TAG populations through human activities is likely to eliminate source populations that were both self-recruiting and served as an important supply of offspring to other sites on the MAR.
- *Rimicaris exoculata* shrimp at TAG have modified eyes that are poorly designed at the cellular level to recover from intense illumination [80, 81]. While there is no evidence that brief exposure to high intensity light from submersible assets has led to decline in population density [82]**, long-term exposure to light** and loss of visual sensitivity have the potential to **alter the behavior and resilience of the shrimp populations.**

Life-history traits of component species that make recovery difficult	**SCORE: HIGH**

Recovery dynamics of vent faunal communities on slow-spreading ridges, such as the Mid-Atlantic Ridge, are unknown. Because MAR vent fields are hydrothermally active for longer periods (thousands of years) than those on faster-spreading ridges (years to decades), they may have slower recovery trajectories [30, 31]. Some vent species are widespread on the MAR (e.g., *Rimicaris exoculata* shrimp; *Shinkailepas briandi* limpets) [32-34], others are not (e.g., *Bathymodiolus* sp. mussels) [29]. Source/sink and recruitment dynamics in vent ecosystems are poorly known if at all, and are likely to be unpredictable given that organisms disperse in the water column [22, 31]. While genetic connectivity observed for some species at vents on the nMAR depends on long-distance dispersal [29], population maintenance at a given site may depend primarily on self-recruitment (i.e., local sources and sinks ([35]. There is currently little data available on the autecology of smaller species (macrofauna & meiofauna). For example, some meiofauna have distinct life-history traits compared to the macrofauna, such as the lack of larval dispersal for nematodes [36], which may make recovery after disturbance difficult [37, 38].

- At TAG, **many species with larval dispersal** are recorded (e.g. *Rimicaris exoculata)* [79, 82, 109].
- Dirivultid copepods, which live in the gills of *Rimicaris exoculata* [119], have lecithotrophic larvae [120].
- At TAG, **fecundity of *Rimicaris exoculata* is relatively low** and ovigerous females are scarce during some sampling periods [106, 107, 121].

Structural complexity	**SCORE: HIGH**

At all active hydrothermal fields, there are complex gradients of geological, geochemical, and thermal conditions that correlate with ecological zonation [14, 39]. Engineer (foundation) species modify physical and (or) chemical environments by altering fluid flow and chemistry [40], contributing to increased environmental heterogeneity. This structural complexity within a field is illustrated by a photomontage of microhabitats at the Snake Pit vent field (Figure 3), including mussel beds (Fig. 3a), adult (Fig. 3b) and juvenile (Fig. 3c) shrimp swarms, and gastropod patches (Fig. 3d). Through evolutionary processes, species at active hydrothermal vents have adapted to extreme environmental conditions, including tolerance to high temperature, low oxygen, and high metal concentrations [41].

- TAG has **complex gradients of geological, geochemical, and thermal conditions, with multiple biological zones and microhabitats** [68]. Zonation of species is correlated with temperature and fluid chemistry, with *R. exoculata* shrimp in the warmest waters on surfaces of black smoker chimneys; anemones, chaetopterid polychaetes, and other taxa in cooler peripheral areas of the sulfide mound [99]. Patchiness in the distribution of adult and juvenile *Rimicaris exoculata* [82, 116] may be correlated by physico-chemical gradients of fluid chemistry, although a behavioral interaction between juvenile and adult shrimp cannot be ruled out. The diversity of TAG megafauna is low compared to the other sites on the Mid-Atlantic Ridge [14].
- **Adaptation strategies** of the vent fauna, to the environment are exceedingly **rich** [41, 84-86].

Biological diversity	**SCORE: HIGH**

Biodiversity of microbial communities is very rich at hydrothermal vents [43, 44]. Vent-endemic animal species contribute novel diversity to the deep-sea fauna, often at taxonomic levels higher than genus and with radiations correlated with environmental attributes including ocean basin, depth, fluid chemistry, and temperature (e.g. polynoid scale worms, alvinocaridid shrimp, bathymodiolin mussels, bythograeid crabs). Habitat heterogeneity and structural complexity provide niches for diverse species [14]. Hydrothermal vent organisms are valued for their genetic diversity [15, 45].

- TAG hosts **vent endemic species**. Animals include for example *Rimicaris exoculata* and *R. Chacei,* the shrimp-eating anemone *Maractis rimicarivora*, and predatory gastropods (*Phymorhynchus* sp.) [82, 109].
- *Paledictyon nodosum* is reported from TAG [98].

Biological productivity	**SCORE: HIGH**

Chemoautotrophic microorganisms use the chemical energy of hydrothermal fluids to fix inorganic carbon and produce biomass [44]. High biological *in situ* productivity is found at most active hydrothermal vents [14]. Chemoautotrophic productivity occurs below the seafloor [87], on the seafloor as free-living microbes (attached or suspended), or living in symbiosis with large invertebrate species. This production is transferred to higher trophic levels [14, 88].

- TAG is an active deep-sea hydrothermal vent [90, 91], supporting ***in situ* primary productivity** [44].
- The fauna forms **biomass rich communities** at TAG, such as *Rimicaris exoculata* shrimp populations [82, 111] and abundant shrimp-eating anemones (*Maractis rimicarivora*) and predatory gastropods (*Phymorhynchus* sp.) [109].

Naturalness	**SCORE: HIGH**

Hydrothermal vents are relatively undisturbed [47]. The only interventions to date are those of scientists and mineral resource explorers. An *Interridge Code of Conduct* guides scientific research and emphasizes avoidance of any scientific activity that would have a deleterious effect on the persistence of populations or that would lead to sustained alteration or visible degradation [48].

- TAG is relatively undisturbed.

Ecosystem services	**SCORE: HIGH**

Living resources from hydrothermal vent ecosystems provide or have high potential to provide provisioning services, including genetic resources, bioprospecting or bioinspired materials/processes [15]. They also harbour energetical and mineral resources not yet exploited. Hydrothermal vents contribute to regulating and supporting services including carbon sequestration by biological pump, or microbial oxidation of the greenhouse gas methane [49] and represent major source of iron, an essential trace element that controls marine productivity, in the global ocean [50]. Vents offer cultural services in the form of exceptional inspiration for arts, science, technology and our world [15]. Hydrothermal vents have been and continue to be fruitful areas for fundamental, interdisciplinary, scientific research. Discovery of hydrothermal vents [51] revolutionized our view of life in our oceans and the potential for life on other planetary bodies [14]. Hydrothermal vents are living libraries that open new paths for understanding the intersection of Life and Earth processes [15, 52]. Every studied vent field to date has increased the scientific knowledge, documented through the prolific and highly cited scientific literature [52]. They are used as experimental sites; they constitute a baseline for monitoring anthropogenic induced changes.

- As all active vent fields, TAG, offers (potentially) rich provisioning, regulating, and supporting services [15, 49].
- TAG was the first hydrothermal field to be discovered on a slow-spreading mid-ocean ridge [89], and it continues to be an important research site on the Mid-Atlantic Ridge. Since its discovery, the active TAG mound has been one of the most studied and visited sites by scientists on the Mid-Atlantic Ridge [97], including but not limited to geological, geophysical, geochemical, and ecological studies. It is also the locale of an ODP drilling program, with time-series studies of fluid chemistry [122] and studies of effects of drilling on the vent community [123]. There are two time-series studies of shrimp distribution and abundance [82, 124]. Samples from TAG active vents continue to be important in regional studies of microbial [113] and invertebrate [32] connectivity. TAG is the type locality for *Rimicaris exoculata* [125]. As it is part of the Ifremer exploration area for SMS, TAG was and continues to be the target of a series of cruises (Bicose 2014, Hermine 2017, Bicose 2 2018) to gain more knowledge on different aspects of the ecosystems, including active and inactive sites within the TAG vent field.
- TAG may be used as a science or education example of particular geological, geophysical or biological attributes.

A.4. Snake Pit vent field

SNAKE PIT	Latitude	Longitude	Depth (m)
	23° 22'N	44° 57'W	3350-3500

Initial Discovery and Explorations

The Snake Pit vent field was first discovered during a site-survey cruise of the Ocean Drilling Program (ODP) in 1985 [126] and was further explored by geologists during American [127] and French [128] submersible dive series.

Location and Geological Setting

The Snake Pit vent field is located on the flank of a volcanic cone, 25 km south of the Kane fracture zone; the host seafloor is fractured basalt [126]. It is the only known vent field in the study area at 3500 m, which may influence the nature of its fauna [129]. The vent field is relatively small compared to sites like Logatchev and TAG [58]. Active and inactive sulfide ecosystems are perched on top of a talus mound [130, 131]. High-temperature (366°C) fluids vent from black-smoker chimneys and low-temperature (226°C) fluids vent from sulfide domes [132]. The estimated areal extent of seafloormassive sulfides is ~3,000 m^2 [58]. The site covers a total area of ~45,000 m^2 (Ewan pers. com.) and comprises four known active sites: *Elan* (Moose), *Les Ruches* (Beehives), *Le Sapin* (Fir Tree), and *Le Clou* (Nail) plus a poorly characterized site, *La Falaise* (Cliff), and several low-temperature sites [130]. Major venting activity is found at *Les Ruches*. This mound harbors a complex of several active sulfide structures as well as inactive chimneys and is coalescent with *Le Sapin* and *Elan*. *Elan* is particularly distinctive with the presence of chimneys with vertical conduits as well as large beehives and flanges that resemble moose antlers; this type of structure is not reported anywhere else. The coalescent deposit of *Les Ruches, Elan,* and, *Le Clou* was drilled during ODP leg 106 (Ocean Drilling Program Leg 106 Scientific Party, 1986)[130], and the sulfides recovered were noted for their considerable geochemical and mineralogical diversity [130, 131, 133].

Biological Characterization

A description of the Snake Pit biological community was first provided by [134] and a quantitative study of biodiversity associated with Snake Pit mussel beds was reported by [135]. The most recent description of the Snake Pit vent ecosystem may be found in [68]. Like other active vent sites on the Mid-Atlantic Ridge, Snake Pit has been repeatedly visited by scientists, especially during the last 5 years due to its location within the French exploration contract area (Bicose cruises in 2014 & 2018, Hermine cruise in 2017).

Surfaces of high-temperature chimneys are occupied by dense populations of *Rimicaris exoculata* shrimp [134], occurring at temperatures up to 42°C (C Van Dover pers obs). Three other species of shrimp are also present (*Rimicaris chacei, Mirocaris fortunata, Alvinocaris markensis*). Shrimp nurseries as well as areas of gastropod egg layouts are reported at Snake Pit (J Sarrazin pers. obs.). Unlike TAG, Snake Pit hosts mussels (*Bathymodiolus puteoserpentis*). Dense assemblages of peltospirid gastropods can also be found in higher-temperature habitats (J Sarrazin et al. in prep). Gastropods in the genus *Phymorhynchus*, anemones, and ophiuroids colonize the less active (lower temperature) zones at the base of the high-temperature chimneys. Zoarcid fish (*Pachycara thermophilum*) are particularly abundant [134]. Recent biological studies include connectivity [29], physiological tolerances [84], microbial symbionts [104, 136], shrimp reproductive biology [107, 108] and trace metals

[137].
Classification Snake Pit was classified as an Ecologically and Biologically Significant Area by the Convention on Biodiversity (Report 2015, https://chm.cbd.int/pdf/documents/marineEbsa/204107/1).

Scientific Information for Assessment of Snake Pit vent field for proposed criteria

Uniqueness and rarity	**SCORE: HIGH**
Vent fields host small, island-like ecosystems with distinctive biotic and abiotic features [10, 11] (Table 2). Globally, the active vent habitat occupies an area less than that of the island of Manhattan (Van Dover et al. 2018). Free-living and autotrophic microorganisms dependent on reduced compounds in the hydrothermal fluids serve as the base of the chemosynthetic ecosystem [12, 13]. Juveniles and adults of vent-endemic (vent-obligate) taxa are adapted to the extreme chemical and physical conditions of the vent habitat and thrive in these specialized (unique) ecosystems [14]. Given the very small and discrete areas they inhabit, vent-endemic species are globally rare [15, 16]. • Snake Pit is a **discrete area** (3000 m^2) [58] that hosts **vent-endemic taxa**, including for example the shrimp *Rimicaris exoculata* and the mussel *Bathymodiolus puteoserpentis* [68]. • Snake Pit supports a unique **meiobenthic community**, including vent endemic dirivultid copepods [138].	
Functional significance	**SCORE: HIGH**
All active hydrothermal vents support primary production by microorganisms, serve as discrete feeding area, and are essential for the growth, survival, reproduction, and persistence of vent endemic species [14, 21]. • Snake Pit serves as a discrete and essential **feeding area for its invertebrate populations. Numerous vent-endemic taxa** (e.g. *Rimicaris exoculata*) **dependent on chemoautotrophically based food webs for their survival** [68, 135]. • The **cutthroat eel** (*Ilyophis saldanhai*; a deep-sea fish species found in the Atlantic and Pacific) is notably abundant at Snake Pit [134], likely feeding at/around Snake Pit. • Cutthroat eels are inferred to use Snake Pit possibly as breeding ground [127] • Snake Pit is an important area for **breeding and spawning for several vent endemic species**. **Egg capsules** of the predatory gastropod *Phymorhynchus* sp. and dense aggregations of **juvenile *Rimicaris exoculata*** are abundant on Snake Pit sulfides (J Sarrazin, video observations). • Snake Pit supports a **reproductive meiobenthic community** [138].	
Fragility	**SCORE: HIGH**
All active vent fields are fragile ecosystems that are geographically isolated and discrete [11], hosting populations of benthic invertebrate species that rely on dispersal through pelagic larval stages [22] for maintenance of populations and genetic connectivity. Habitat degradation and fragmentation due to anthropogenic disturbance may result in local loss of biodiversity [23-25] and ecosystem services [26]. Connectivity among metapopulations of species is characterized	

by source-sink dynamics, making these systems sensitive to reduction or loss of source populations [27-29], with ecological consequences on the structure and function of metacommunities [21].

- Snake Pit is a **fragile ecosystem** that is **geographically isolated and discrete** [11], with many vent endemic species (e.g. *Bathymodiolus puteoserpensis, Rimicaris exuculata)* [68, 134, 135] dispersing only through **pelagic larval stages** [78, 79]. Reduction or loss of populations through human activities is likely to eliminate source populations that were both self-recruiting and served as an important supply of offspring to other sites on the MAR.
- *Rimicaris exoculata* shrimp at Snake Pit have modified eyes that are poorly designed at the cellular level to recover from intense illumination [80, 81]. While there is no evidence that brief exposure to high intensity light from submersible assets has led to decline in population density [82], **long-term exposure to light** and loss of visual sensitivity have the potential to **alter the behavior and resilience of the shrimp populations**.

Life-history traits of component species that make recovery difficult	**SCORE: HIGH**

Recovery dynamics of vent faunal communities on slow-spreading ridges, such as the Mid-Atlantic Ridge, are unknown. Because MAR vent fields are hydrothermally active for longer periods (thousands of years) than those on faster-spreading ridges (years to decades), they may have slower recovery trajectories [30, 31]. Some vent species are widespread on the MAR (e.g., *Rimicaris exoculata* shrimp; *Shinkailepas briandi* limpets) [32-34], others are not (e.g., *Bathymodiolus* sp. mussels)[29]. Source/sink and recruitment dynamics in vent ecosystems are poorly known if at all, and are likely to be unpredictable given that organisms disperse in the water column [22, 31]. While genetic connectivity observed for some species at vents on the nMAR depends on long-distance dispersal [29], population maintenance at a given site may depend primarily on self-recruitment (i.e., local sources and sinks ([35]. There is currently little data available on the autecology of smaller species (macrofauna & meiofauna). For example, some meiofauna have distinct life-history traits compared to the macrofauna, such as the lack of larval dispersal for nematodes [36], which may make recovery after disturbance difficult [37, 38].

- At Snake Pit, many vent endemic species (e.g. *Bathymodiolus puteoserpensis, Rimicaris exuculata)* [68, 134, 135] disperse only through **pelagic larval stages** [78, 79].
- **Fecundity of *Rimicaris exoculata* can be relatively low** and ovigerous females are scarce during some sampling periods [106, 107, 121].
- Nematodes (e.g. *Thalassomonhystera vandoverae*), which lack pelagic larvae, are reported from Snake Pit [138, 139].

Structural complexity	**SCORE: HIGH**

At all active hydrothermal fields, there are complex gradients of geological, geochemical, and thermal conditions that correlate with ecological zonation [14, 39]. Engineer (foundation) species modify physical and (or) chemical environments by altering fluid flow and chemistry [40], contributing to increased environmental heterogeneity. Through evolutionary processes, species at active hydrothermal vents have adapted to extreme environmental conditions, including tolerance to high temperature, low oxygen, and high metal concentrations [41].

- The structural complexity of Snake Pit can be viewed at https://doi.org/10.17882/74349 . The video shows *Bathymodiolus puteoserpentis* mussel assemblages on the Elan edifice, *Rimicaris exoculata* (adult) shrimp swarms on Les Ruches, and *Peltospira smaragdina* gastropod assemblages surrounded by shrimp and mussels on Elan
- At Snake Pit, numerous microhabitats are documented for example at *Elan* (Moose) based on discrete aggregations of different species [68].
- At Snake Pit, surfaces of **high-temperature chimneys** are occupied by dense populations of *Rimicaris exoculata* **shrimp** [134], occurring at temperatures up to 42°C (C Van Dover pers obs). Three other species of shrimp are also present (*Rimicaris chacei, Mirocaris fortunata, Alvinocaris markensis*).
- Snake Pit hosts **mussels** (*Bathymodiolus puteoserpentis*), which are important **engineer species** creating additional (or modified) areas for colonization, increased environmental heterogeneity and may serve as refuges from predation, and can modify the physical or chemical environment by altering fluid flow and composition [83].
- Dense assemblages of **peltospirid gastropods** can be found in higher-temperature habitats (Sarrazin et al. in prep).
- **Gastropods** in the genus *Phymorhynchus*, **anemones**, and **ophiuroids colonize the less active (lower temperature) zones** at the base of the high-temperature chimneys. Zoarcid fish (*Pachycara thermophilum*) are particularly abundant [134].
- **Adaptation strategies** of the vent fauna, to the environment are exceedingly **rich** [41, 84-86].

Biological diversity	**SCORE: HIGH**

Biodiversity of microbial communities is very rich at hydrothermal vents [43, 44]. Vent-endemic animal species contribute novel diversity to the deep-sea fauna, often at taxonomic levels higher than genus and with radiations correlated with environmental attributes including ocean basin, depth, fluid chemistry, and temperature (e.g. polynoid scale worms, alvinocaridid shrimp, bathymodiolin mussels, bythograeid crabs). Habitat heterogeneity and structural complexity provide niches for diverse species [14]. Hydrothermal vent organisms are valued for their genetic diversity [15, 45].

- Snake Pit hosts **vent endemic species**. A quantitative study of biodiversity associated with Snake Pit mussel beds was reported by [135]. Animals include for example shrimp (*Rimicaris chacei, Mirocaris fortunata, Alvinocaris markensis*), mussels (*Bathymodiolus puteoserpentis*), peltosprirod gastropods, and many more. In the meiofaunal sizeclass 15 species were reported [138].

Biological productivity	**SCORE: HIGH**

Chemoautotrophic microorganisms use the chemical energy of hydrothermal fluids to fix inorganic carbon and produce biomass [44]. High biological *in situ* productivity is found at most active hydrothermal vents [14]. Chemoautotrophic productivity occurs below the seafloor [87], on the seafloor as free-living microbes (attached or suspended), or living in symbiosis with large invertebrate species. This production is transferred to higher trophic levels [14, 88].

- Snake Pit is an active deep-sea hydrothermal vent [132], supporting ***in situ* primary productivity** [44].
- The fauna forms **biomass rich communities** at Snake Pit, such as dense populations of *Rimicaris exoculata* shrimp [134] and *Bathymodiolus* mussel beds [135].

Naturalness	**SCORE: HIGH**

Hydrothermal vents are relatively undisturbed [47]. The only interventions to date are those of scientists and mineral resource explorers. An *Interridge Code of Conduct* guides scientific research and emphasizes avoidance of any scientific activity that would have a deleterious effect on the persistence of populations or that would lead to sustained alteration or visible degradation [48].

- Snake Pit is relatively undisturbed.

Ecosystem services	**SCORE: HIGH**

Living resources from hydrothermal vent ecosystems provide or have high potential to provide provisioning services, including genetic resources, bioprospecting or bioinspired materials/processes [15]. They also harbour energetical and mineral resources not yet exploited. Hydrothermal vents contribute to regulating and supporting services including carbon sequestration by biological pump, or microbial oxidation of the greenhouse gas methane [49] and represent major source of iron, an essential trace element that controls marine productivity, in the global ocean [50]. Vents offer cultural services in the form of exceptional inspiration for arts, science, technology and our world [15]. Hydrothermal vents have been and continue to be fruitful areas for fundamental, interdisciplinary, scientific research. Discovery of hydrothermal vents [51] revolutionized our view of life in our oceans and the potential for life on other planetary bodies [14]. Hydrothermal vents are living libraries that open new paths for understanding the intersection of Life and Earth processes [15, 52]. Every studied vent field to date has increased the scientific knowledge, documented through the prolific and highly cited scientific literature [52]. They are used as experimental sites; they constitute a baseline for monitoring anthropogenic induced changes.

- As all active vent fields, Snake Pit, offers (potentially) rich provisioning, regulating, and supporting services [15, 49].
- A Snake Pit biological community study was first provided by [134] and a quantitative study of biodiversity associated with Snake Pit mussel beds was reported by Turnipseed et al. [135]. Snake Pit is the type locality for *Segonzacia mesatlantica* [140], *Thalassomonhystera vandoverae* [139], the zoarcid fish *Pachychara thermophilum* [141] among others. Papers on biological themes published since 2015 and not cited above include for example studies of trace metals and biological accumulation [137], genetic introgression in mussels [142], iron-oxidizing microbes [143], nematodes [7], the microbial epibiome of vent shrimp [144], the biogeography of shrimp gut microbes [113], chemosensory organs of shrimp [145], and rhodalliid (siphonophore) occurrences [146]. As it is part of the Ifremer exploration area for SMS, Snake Pit was and continues to be the target of a series of cruises (Bicose 2014, Hermine 2017, Bicose 2 2018) to gain more knowledge on different aspects of the ecosystems including active and inactive sites.

- Snake Pit may be used as a science or education example of particular geological, geophysical or biological attributes.

A.5. Pobeda vent field

POBEDA	Latitude	Longitude	Depth (m)
	17°07'–17°08'N	46°25'-46°22'W	1950-3100

Initial Discovery and Explorations
The vent field Pobeda was discovered on the 37th Cruise of Professor Logatchev in 2014-2015 [147]. Initial studies included TV-profiling and sampling using TV-grab, dredge and gravity corer. There have been no further studies in this area.

Location and Geological Setting
Pobeda is the only active vent field on the MAR between 23°N (Snake Pit) and 14°N (Logatchev-1). Pobeda is described as an "ore node" by geologists, consisting of two hydrothermal fields, Pobeda-1 and Pobeda-2, and one ore body (inactive sulfide deposit) Pobeda-3 [147]. The complex is located at 17°07.45′–17°08.7′ on the eastern slope of the rift valley and is associated with gabbro-peridotites. Hydrothermal activity was confirmed at Pobeda-1 (2100-2450 m depth) and manifestations of hydrothermal activity (sulfides and turbidity) were recorded at Pobeda-2 (2800-3100 m). Pobeda-1 extends >2000 m from north-east to south-west with width varying from 100 to 500 m. Four discrete sulfide deposits can be distinguished within the field; black smokers were observed during video profiling at "Nr 2" (250-450 m across) [147]. Maximum age of SMS deposits at Pobeda was estimated as 177.5 ka [148].

Biological Characterization
Data on the biological community at Pobeda are fragmented. Molodtsova et al. [149] mention extensive fields of bivalve shells observed at TV profiles at Pobeda-1 (17°08.7′N, 46°23.44′W) and Pobeda-2 (17°07.45′N, 46°24.5′W). Samples of empty shells were taken at these sites and a nearby area. A thick layer of empty valves was found at the depth 10–15 cm below the surface, valves from a gravity core were identified as *Bathymodiolus puteoserpentis* and *Thyasira* sp. Poorly developed bacterial mats also were observed during TV profiling at Pobeda-1 [149]. Other representatives of typical MAR active vent fauna include snails (*Phymorhynchus ovatus)*, sea spiders *(Sericosura heteroscela)*, fragments of crabs (Bythograeidae gen. sp.) and tubes of chaetopterid polychaetes [149]. According to Gablina et al. [147], "shrimp and bivalves" were observed at Pobeda-1 in the area of black smokers.

Classification
None

Scientific Information for Assessment of Pobeda vent field for proposed criteria

Uniqueness and rarity	SCORE: HIGH
Vent fields host small, island-like ecosystems with distinctive biotic and abiotic features [10, 11] (Table 2). Globally, the active vent habitat occupies an area less than that of the island of Manhattan (Van Dover et al. 2018). Free-living and autotrophic microorganisms dependent on reduced compounds in the hydrothermal fluids serve as the base of the chemosynthetic ecosystem [12, 13]. Juveniles and adults of vent-endemic (vent-obligate) taxa are adapted to the extreme chemical and physical conditions of the vent habitat and thrive in these specialized (unique) ecosystems [14]. Given the very small and discrete areas they inhabit, vent-endemic species are globally rare [15, 16].	

- Pobeda is a **discrete area** (see Figure 1 in Gablina et al. [147]).
- At Pobeda, poorly developed bacterial mats were observed during TV profiling [149].
- **"Shrimp and bivalves" were observed at a black smoker** [147]. Expert knowledge as well as collected samples from *Bathymodiolus puteoserpentis* shells [149] suggest that these "shrimp and bivalves" are typical **vent endemic** species such as *Microcaris/Rimicaris/Chorocaris* and *Bathymodiolus*.
- Taxa at Pobeda that are known from other MAR sites include snails (*Phymorhynchus ovatus*), sea spiders (*Sericosura heteroscela*), fragments of crabs (Bythograeidae gen. sp.), and tubes of chaetopterid polychaetes [149].

Functional significance	**SCORE: HIGH**

All active hydrothermal vents support primary production by microorganisms, serve as discrete feeding area, and are essential for the growth, survival, reproduction, and persistence of vent endemic species [14, 21].

- Expert knowledge as well as collected samples from *Bathymodiolus puteoserpentis* shells [149] suggest that these "shrimp and bivalves" are typical **vent endemic** species such as *Microcaris/Rimicaris/Chorocaris* and *Bathymodiolus*. Bathymodiolus has symbionts and is **dependent on chemoautotrophically based food webs for their survival** [78]. Similarily, also vent shrimp typically have symbionts and depend **on chemoautotrophically based food webs for their survival** [103, 136].

Fragility	**SCORE: HIGH**

All active vent fields are fragile ecosystems that are geographically isolated and discrete [11], hosting populations of benthic invertebrate species that rely on dispersal through pelagic larval stages [22] for maintenance of populations and genetic connectivity. Habitat degradation and fragmentation due to anthropogenic disturbance may result in local loss of biodiversity [23-25] and ecosystem services [26]. Connectivity among metapopulations of species is characterized by source-sink dynamics, making these systems sensitive to reduction or loss of source populations [27-29], with ecological consequences on the structure and function of metacommunities [21].

- Pobeda is an **isolated and discrete vent field** where shrimp and bivalves were observed at a black smoker [147]. Expert knowledge as well as collected samples from *Bathymodiolus puteoserpentis* shells [149] suggest that these "shrimp and bivalves" are typical **vent endemic** species such as *Microcaris/Rimicaris/Chorocaris* and *Bathymodiolus*.

Life-history traits of component species that make recovery difficult	**SCORE: HIGH**

Recovery dynamics of vent faunal communities on slow-spreading ridges, such as the Mid-Atlantic Ridge, are unknown. Because MAR vent fields are hydrothermally active for longer periods (thousands of years) than those on faster-spreading ridges (years to decades), they may have slower recovery trajectories [30, 31]. Some vent species are widespread on the MAR (e.g., *Rimicaris exoculata* shrimp; *Shinkailepas briandi* limpets) [32-34], others are not (e.g., *Bathymodiolus* sp. mussels)[29]. Source/sink and recruitment dynamics in vent ecosystems are poorly known if at all, and are likely to be unpredictable given that organisms disperse in the

water column [22, 31]. While genetic connectivity observed for some species at vents on the nMAR depends on long-distance dispersal [29], population maintenance at a given site may depend primarily on self-recruitment (i.e., local sources and sinks ([35]. There is currently little data available on the autecology of smaller species (macrofauna & meiofauna). For example, some meiofauna have distinct life-history traits compared to the macrofauna, such as the lack of larval dispersal for nematodes [36], which may make recovery after disturbance difficult [37, 38]. • At Pobeda, "shrimp and bivalves" were observed at a black smoker [147]. Expert knowledge as well as collected samples from *Bathymodiolus puteoserpentis* shells [149] suggest that these "shrimp and bivalves" are typical vent endemic species such as *Microcaris/Rimicaris/Chorocaris* and *Bathymodiolus*. **Vent-endemic *Bathymodiolus*** mussels [78, 150] as well as shrimp disperse through **pelagic larval stages** making recovery unpredictable [79].	
Structural complexity	**SCORE: HIGH**
At all active hydrothermal fields, there are complex gradients of geological, geochemical, and thermal conditions that correlate with ecological zonation [14, 39]. Engineer (foundation) species modify physical and (or) chemical environments by altering fluid flow and chemistry [40], contributing to increased environmental heterogeneity. Through evolutionary processes, species at active hydrothermal vents have adapted to extreme environmental conditions, including tolerance to high temperature, low oxygen, and high metal concentrations [41]. • Pobeda is a structurally complex vent field [147]. • At Pobeda, **black smokers** as well as **thick layers of empty valves** were found at the depth 10–15 cm below the surface. The poorly developed **bacterial mats** represent microhabitats that could support distinctive faunas [147]. • "**Shrimp and bivalves**" were observed at a black smoker [147].	
Biological diversity	**SCORE: HIGH**
Biodiversity of microbial communities is very rich at hydrothermal vents [43, 44]. Vent-endemic animal species contribute novel diversity to the deep-sea fauna, often at taxonomic levels higher than genus and with radiations correlated with environmental attributes including ocean basin, depth, fluid chemistry, and temperature (e.g. polynoid scale worms, alvinocaridid shrimp, bathymodiolin mussels, bythograeid crabs). Habitat heterogeneity and structural complexity provide niches for diverse species [14]. Hydrothermal vent organisms are valued for their genetic diversity [15, 45]. • According to Gablina et al. [147], "shrimp and bivalves" and bacterial mats were observed at Pobeda-1 in the area of black smokers. Expert knowledge as well as collected samples from *Bathymodiolus puteoserpentis* shells [149] suggest that these "shrimp and bivalves" are typical **vent endemic** species such as *Microcaris/Rimicaris/Chorocaris* and *Bathymodiolus*, and that bactieral mats represent typically **diverse vent microbial communities**.	
Biological productivity	**SCORE: HIGH**
Chemoautotrophic microorganisms use the chemical energy of hydrothermal fluids to fix inorganic carbon and produce biomass [44]. High biological *in situ* productivity is found at most active hydrothermal vents [14]. Chemoautotrophic productivity occurs below the seafloor	

[87], on the seafloor as free-living microbes (attached or suspended), or living in symbiosis with large invertebrate species. This production is transferred to higher trophic levels [14, 88].

- Pobeda is an active deep-sea hydrothermal vent with black smokes [147], supporting *in situ* primary productivity [44].
- "Shrimp and bivalves" and bacterial mats were observed at Pobeda-1 in the area of black smokers [149]. This observation and expert knowledge suggest that these "shrimp and bivalves" can from biomass rich communities.

Naturalness	**SCORE: HIGH**

Hydrothermal vents are relatively undisturbed [47]. The only interventions to date are those of scientists and mineral resource explorers. An *Interridge Code of Conduct* guides scientific research and emphasizes avoidance of any scientific activity that would have a deleterious effect on the persistence of populations or that would lead to sustained alteration or visible degradation [48].

- Pobeda is relatively undisturbed.

Ecosystem services	**SCORE: HIGH**

Living resources from hydrothermal vent ecosystems provide or have high potential to provide provisioning services, including genetic resources, bioprospecting or bioinspired materials/processes [15]. They also harbour energetical and mineral resources not yet exploited. Hydrothermal vents contribute to regulating and supporting services including carbon sequestration by biological pump, or microbial oxidation of the greenhouse gas methane [49] and represent major source of iron, an essential trace element that controls marine productivity, in the global ocean [50]. Vents offer cultural services in the form of exceptional inspiration for arts, science, technology and our world [15]. Hydrothermal vents have been and continue to be fruitful areas for fundamental, interdisciplinary, scientific research. Discovery of hydrothermal vents [51] revolutionized our view of life in our oceans and the potential for life on other planetary bodies [14]. Hydrothermal vents are living libraries that open new paths for understanding the intersection of Life and Earth processes [15, 52]. Every studied vent field to date has increased the scientific knowledge, documented through the prolific and highly cited scientific literature [52]. They are used as experimental sites; they constitute a baseline for monitoring anthropogenic induced changes.

- As all active vent fields, Pobeda, offers (potentially) rich provisioning, regulating, and supporting services [15, 49].
- Only basic discovery observations of the active vent ecosystem have been made at Pobeda [147, 149], but more detailed scientific investigations remain to be undertaken. The preliminary observations indicate black smokers, bacterial mats, "shrimp and bivalves", and *Bathymodiolus* shells.
- Pobeda may be used as a science or education example of particular geological, geophysical or biological attributes.

A.6. Logatchev-1 vent field

LOGATCHEV-1	Latitude	Longitude	Depth (m)
	14°45'N	44°58'W	2925 - 3050

Initial Discovery and Explorations

The Logatchev-1, formerly known as “14-45”, was discovered in the years 1993-1994 during the 7th Cruise of the RV *Professor Logatchev* using a deep-towed photo-platform [151-153]. In 1995, this field was revisited with submersibles. Two “Mir” dives were made in February on the 35th Cruise of *Akademik Mstislav Keldysh*, followed by four *Nautile* dives during the *Microsmoke* Cruise in December [116, 154]. In July 1997, the field has been studied on three *Alvin* dives during the Cruise MAR’97 [155]. In the first decade of the 21st century, the field was re-visited several times: an *Atlantis* cruise [156], several German cruises (*Meteor* and *Maria S. Merian*) [157] and the *Serpentine* Cruise in 2007 onboard of *Pourquoi p*as? [116].

Location and Geological Setting

The Logatchev-1 hydrothermal field is located on the eastern slope of the rift valley, 35 miles south from the transform fault at 15°20’N [152]. The area is associated with ultramafic rocks and is located relatively high on the rift wall, 7.5 km from the ridge axis. The estimated seafloor massive sulfide deposit area is ~5,000 m^2 [58], the total estimated size of the vent field, including active and inactive structures is ~200,000 m^2 [155] The near-bottom water in this area contains high concentrations of methane: up to 182×10^{-4} ml l^{-1} exceeding the background value by four orders of magnitude [152]. The area extends over ~500 m from north-west to south-east and comprises at least nine hydrothermal sites of various size and type (listed up the slope): Quest, Anya (diffuse flow through the soft sediment), Irina-2 (high T chimney complex), Site F, Site B (“smoking crater”) , Irina-1 (“smoking craters”), Anna-Louise (“smoking crater”), “Smokey Strobe” (“smoking crater”) and Site A (Barad-Dur) (pillar-like chimney) [155, 157-159]. The sites with “smoking craters”, several to 15 m in diameter discharging black smoke spreading horizontally or even downslope owing to increased salinity of vent fluids (B, Irina I and Anna-Louise) occur on a large structure known as the “Main Mound”, 200x150 m across and 10-20 m high [155]. Hydrothermal deposits on the Main Mound are in particular enriched in Co, Ni, Cr and C_{org} whereas sulphide structures are enriched in Co, Cu, Zn and Ba [152]. The maximum age of SMS at Logatchev-1 was estimated as 58 ka [160].

Biological Characterization

The Logatchev-1 hydrothermal community was described in Gebruk et al. [155]. The peculiarity of the Logatchev-1 area is a high diversity of biotopes, including high temperature chimney complexes, single chimneys, smoking craters and sites with diffuse flow through the soft sediment. Black smoker chimneys are populated by shrimps *Rimicaris exoculata* forming dense swarms at some sites, as well as *R. chacei*, *Mirocaris fortunata* and several species of *Alvinocaris* shrimp. *Bathymodiolus puteoserpentis* mussels are common across the area. At the base of the chimney complex Irina-2, mussels form a thick bed up to 0.5 m with the highest biomass recorded for the MAR: over 70 kg m^{-2} (wet weight with shells). Associated with the mussel bed is the ophiuroid *Ophioctenella acies* forming a multilayer carpet with density reaching 80 ind. dm^{-2}. Also common on the mussels are gastropods of the genus *Phymorhynchus*: *P. moskalevi, P. ovatus* and *P. carinatus*. Overall Gebruk et al. [155] reported ~50 species from the Logatchev-1 vent field based on a series of three Alvin dives in 1997. Van Dover and Doerries [156] showed that macrofaunal diversity within the mussel-bed

habitat at Logatchev was lower than that at Snake Pit. Sharp numerical dominance by the ophiuroid *O. acies* results in very low measures of diversity (H'and J') and distinguishes Logatchev mussel beds from other studied mussel beds on the northern MAR. One of distinctive features of the Logatchev vent field is the occurrence of live vesicomyid clams. Gebruk et al. [155] reported from the site Anya's Garden populations of live clams identified later as *Abyssogena southwardae* [161]. Co-occurring with vesicomyids were mussels *B. puteoserpentis* and thyasirids *Thyasira southwardae [162]*. Logatchev-1 is the only known active vent with live vesicomyids north of equator on the MAR, with the exception of a record in the Vema transform fault [161]. High genetic connectivity between vesicomyid populations at Logatchev-1 and methane seep sites in the Gulf of Mexico and off Congo was demonstrated by Texeira et al. [163]. LaBella et al. [164] reported gene flow between *A. southwardae* populations at Logatchev-1 and Barbados and between the West Florida Escarpment and the Lobes of Congo. Active vent community dynamics over a decadal scale at Logatchev-1 was presented in Gebruk et al. [116]. Significant changes occurred between 1997 and 2007, with the most pronounced being the increase up to by order of magnitude in the population density of predatory gastropods *Phymorchynchus* spp. at the site Irina-2 and the disappearance of a live population of *Abyssogena southwardae* at Anya's Garden, perhaps as a result of a sediment slide . Other notable differences included the increase in abundance of mussels *B. puteoserpentis* and high abundance of gravid females of the shrimp *R. exoculata* at Irina-2. S Successional stages over a decadal scale were not observed [116].
Classification none

Scientific Information for Assessment of Logatchev-1 vent field for proposed criteria

Uniqueness and rarity	**SCORE: HIGH**
Vent fields host small, island-like ecosystems with distinctive biotic and abiotic features [10, 11] (Table 2). Globally, the active vent habitat occupies an area less than that of the island of Manhattan (Van Dover et al. 2018). Free-living and autotrophic microorganisms dependent on reduced compounds in the hydrothermal fluids serve as the base of the chemosynthetic ecosystem [12, 13]. Juveniles and adults of vent-endemic (vent-obligate) taxa are adapted to the extreme chemical and physical conditions of the vent habitat and thrive in these specialized (unique) ecosystems [14]. Given the very small and discrete areas they inhabit, vent-endemic species are globally rare [15, 16]. • Logatchev-1 is a **discrete area** (5000 m^2) [58] that hosts **vent-endemic taxa**, including shrimp (*R. chacei, Mirocaris fortunata, Alvinocaris* sp.), bathymodiolin mussels, and vesicomyid bivalves. • A very distinctive feature of the field is the occurrence of vesicomyids *Abyssogena southwardae* Logatchev-1 that remains the only known record of live vesicomyids at active hydrothermal vents north of the equator on the MAR [116, 155].	
Functional significance	**SCORE: HIGH**

All active hydrothermal vents support primary production by microorganisms, serve as discrete feeding area, and are essential for the growth, survival, reproduction, and persistence of vent endemic species [14, 21]. • Logatchev-1 is a discrete area that supports primary production by microorganisms and is **essential for feeding, the survival, reproduction, and recovery of vent endemic species** including for example ***Rimicaris*** *exoculata* and ***Bathymodiolus*** *puteoserpensis* [116, 155]. • High abundance of **gravid females of the shrimp *R. exoculata*** was observed at Irina-2 (site within Logatchev-1 vent field) [116].	
Fragility	**SCORE: HIGH**
All active vent fields are fragile ecosystems that are geographically isolated and discrete [11], hosting populations of benthic invertebrate species that rely on dispersal through pelagic larval stages [22] for maintenance of populations and genetic connectivity. Habitat degradation and fragmentation due to anthropogenic disturbance may result in local loss of biodiversity [23-25] and ecosystem services [26]. Connectivity among metapopulations of species is characterized by source-sink dynamics, making these systems sensitive to reduction or loss of source populations [27-29], with ecological consequences on the structure and function of metacommunities [21]. • Logachev-1 is a **fragile ecosystem** that is **geographically isolated and discrete** [11], with benthic invertebrate species such as *Rimicaris exoculata* or *Bathymodiolus puteoserpentis* [116, 155] that **disperse only through pelagic larval stages** [22, 79]. Given the large population densities of shrimp, anemones, and other species at the vent field, reduction or loss of populations through human activities is likely to eliminate source populations that were both self-recruiting and served as an important supply of offspring to other sites on the MAR. • *Rimicaris exoculata* shrimp have modified eyes that are poorly designed at the cellular level to recover from intense illumination [80, 81]. While there is no evidence that brief exposure to high intensity light from submersible assets has led to decline in population density [82], **long-term exposure to light** and loss of visual sensitivity have the potential to **alter the behavior and resilience of the shrimp populations.**	
Life-history traits of component species that make recovery difficult	**SCORE: HIGH**
Recovery dynamics of vent faunal communities on slow-spreading ridges, such as the Mid-Atlantic Ridge, are unknown. Because MAR vent fields are hydrothermally active for longer periods (thousands of years) than those on faster-spreading ridges (years to decades), they may have slower recovery trajectories [30, 31]. Some vent species are widespread on the MAR (e.g., *Rimicaris exoculata* shrimp; *Shinkailepas briandi* limpets) [32-34], others are not (e.g., *Bathymodiolus* sp. mussels)[29]. Source/sink and recruitment dynamics in vent ecosystems are poorly known if at all, and are likely to be unpredictable given that organisms disperse in the water column [22, 31]. While genetic connectivity observed for some species at vents on the nMAR depends on long-distance dispersal [29], population maintenance at a given site may depend primarily on self-recruitment (i.e., local sources and sinks ([35]. There is currently little data available on the autecology of smaller species (macrofauna & meiofauna). For example, some meiofauna have distinct life-history traits compared to the macrofauna, such as	

the lack of larval dispersal for nematodes [36], which may make recovery after disturbance difficult [37, 38].

- At Logatechev-1, **many vent-endemic species with larval dispersal** are recorded like for example *Rimicaris exoculata* shrimp, *Bathymodiolus puteoserpensis* mussels*, Abyssogena southwardae* clams [78, 79, 116, 155].

Structural complexity	**SCORE: HIGH**

At all active hydrothermal fields, there are complex gradients of geological, geochemical, and thermal conditions that correlate with ecological zonation [14, 39]. Engineer (foundation) species modify physical and (or) chemical environments by altering fluid flow and chemistry [40], contributing to increased environmental heterogeneity. Through evolutionary processes, species at active hydrothermal vents have adapted to extreme environmental conditions, including tolerance to high temperature, low oxygen, and high metal concentrations [41].

- Logatchev-1 area is **structurally complex, including high temperature chimney complexes, single chimneys, smoking craters and sites with diffuse flow through the soft sediment**. Black smoker chimneys are populated by engineer species like *Rimicaris exoculata* shrimps forming dense swarms at some sites, and *Bathymodiolus puteoserpentis* mussels forming thick beds [116, 155].
- At the base of the chimney complex Irina-2, **mussel beds reach thickness of up to 0.5 meters** [116, 155].
- **Adaptation strategies** of the vent fauna, to the environment are exceedingly **rich** [41, 84-86].

Biological diversity	**SCORE: HIGH**

Biodiversity of microbial communities is very rich at hydrothermal vents [43, 44]. Vent-endemic animal species contribute novel diversity to the deep-sea fauna, often at taxonomic levels higher than genus and with radiations correlated with environmental attributes including ocean basin, depth, fluid chemistry, and temperature (e.g. polynoid scale worms, alvinocaridid shrimp, bathymodiolin mussels, bythograeid crabs). Habitat heterogeneity and structural complexity provide niches for diverse species [14]. Hydrothermal vent organisms are valued for their genetic diversity [15, 45].

- Logatchev-1 hosts **vent endemic species**, such as for example *Rimicaris exoculata* shrimps or *Bathymodiolus puteoserpentis* mussels [116, 155].
- Overall Gebruk et al. [155] reported **~50 species from the Logatchev-1** vent field based on a series of three Alvin dives in 1997.

Biological productivity	**SCORE: HIGH**

Chemoautotrophic microorganisms use the chemical energy of hydrothermal fluids to fix inorganic carbon and produce biomass [44]. High biological *in situ* productivity is found at most active hydrothermal vents [14]. Chemoautotrophic productivity occurs below the seafloor [87], on the seafloor as free-living microbes (attached or suspended), or living in symbiosis with large invertebrate species. This production is transferred to higher trophic levels [14, 88].

- Logatchev-1 is an active deep-sea hydrothermal vent [116, 155], supporting ***in situ* primary productivity** [44].

- The fauna forms biomass rich communities at Logatchev-1. At the base of the chimney complex Irina-2, mussel beds reach thickness of up to 0.5 meters, representing the **highest biomass recorded for the MAR: over 70 kg m^{-2}** (wet weight with shells) [116, 155].

Naturalness	**SCORE: HIGH**

Hydrothermal vents are relatively undisturbed [47]. The only interventions to date are those of scientists and mineral resource explorers. An *Interridge Code of Conduct* guides scientific research and emphasizes avoidance of any scientific activity that would have a deleterious effect on the persistence of populations or that would lead to sustained alteration or visible degradation [48].

- Logatchev-1 is relatively undisturbed.

Ecosystem services	**SCORE: HIGH**

Living resources from hydrothermal vent ecosystems provide or have high potential to provide provisioning services, including genetic resources, bioprospecting or bioinspired materials/processes [15]. They also harbour energetical and mineral resources not yet exploited. Hydrothermal vents contribute to regulating and supporting services including carbon sequestration by biological pump, or microbial oxidation of the greenhouse gas methane [49] and represent major source of iron, an essential trace element that controls marine productivity, in the global ocean [50]. Vents offer cultural services in the form of exceptional inspiration for arts, science, technology and our world [15]. Hydrothermal vents have been and continue to be fruitful areas for fundamental, interdisciplinary, scientific research. Discovery of hydrothermal vents [51] revolutionized our view of life in our oceans and the potential for life on other planetary bodies [14]. Hydrothermal vents are living libraries that open new paths for understanding the intersection of Life and Earth processes [15, 52]. Every studied vent field to date has increased the scientific knowledge, documented through the prolific and highly cited scientific literature [52]. They are used as experimental sites; they constitute a baseline for monitoring anthropogenic induced changes.

- As all active vent fields, Logatchev-1, offers (potentially) rich provisioning, regulating, and supporting services [15, 49].
- Logatchev-1 is an important research area on the Mid-Atlantic Ridge**.** It is one of the few vent fields on the MAR with community dynamics studied over a decadal scale [116]. The “deep hydrothermal circulation system” (a key driving force of ultramafic-based hydrothermal flux) was first described for Logatchev-1 [152].
- Logatchev-1may be used as a science or education example of particular geological, geophysical or biological attributes.

A.7. Logatchev-2 vent field

LOGATCHEV-2	Latitude	Longitude	Depth (m)
	14°43'N	44°56'W	2640-2760

Initial Discovery and Explorations This field was discovered in 1993-1994 concurrent with Logatchev-1 (Batuyev et al., 1994). It was studied in detail (video imaging and sampling) between1996 and 1998 on the 16th and 17th cruises and in 2000 on the 19th cruise of Professor Logatchev [165]. In 2007, the field was visited during the Serpentine cruise onboard the R/V Pourquoi pas? with the ROV Victor 6000 [116].
Location and Geological Setting Logatchev-2 lies 5.5 km south-east of Logatchev-1, at a distance of 11.5 km from the ridge axis at depths varying from 2640 to 2760 m [151, 160]. The hosts rocks, as at Logatchev-1, are gabbro-peridotites. The slope steepness is 10-15° on the average reaching 55° in some places. Terraces 100-150 m wide separated by scarps are present in the lower and middle part of the field. Six sulphide mounds were identified at Logatchev-2 within a field ~550-200 m across [165]. The largest mound in the centre of the field is 160 m long, up to 80 m wide and reaches 12 m in height. Other mounds are smaller, from 20 to 60 m in diameter and 3 to 6 m high. The surface of the central mound is covered with 0.1-0.4 m thick crusts consisting mainly of manganese oxide, limonite-hematite and atacamite-limonite, with opal and barite associated with atacamite. The estimated areal extent of seafloormassive sulfides is ~1,000 m^2 [58]. The maximum age of SMS at Logatchev-2 was estimated as 7 ka [160]. Modern hydrothermal activity, though weak, was discovered on the central mound in 2007 on the Serpentine cruise [116, 166]. Fouquet et al. [166] noted that venting fluids (temperature 320°C) had unusually low salinity, and this was the first observation of the production of a condensed vapor phase for a mantle-based hydrothermal system.
Biological Characterization An extensive field (several tens of m across) of dead mussel shells (*B. puteoserpensis*) was found on the slope of the mound that had a weakly active chimney on top expelling shimmering water. The mussel shells still had their periostracum, indicating a recent catastrophic collapse of a large population and suggesting a rapid slowing down of the hydrothermal activity. Only a few live mussels, as well as shrimp *Rimicaris chacei* and *Mirocaris fortunata* were recorded on the single active chimney [116]. Cherkashev et al. [165] reported one TV-grab sample taken at Logatchev-2 (14°43.2N, 44°58.3'W, depth 2677 m) which brought an empty shell of *Phymorchynchus* sp. and the subfossil valves of two vesicomyids, one, ~220 mm long, identified later as *Abyssogena southwardae* and the second, 32.5 mm long, identified as *Vesicomya sp*. (Krylova E.M., pers. comm.).
Classification None

Scientific Information for Assessment of Logatchev-2 vent field for proposed criteria

Uniqueness and rarity	SCORE: HIGH
Vent fields host small, island-like ecosystems with distinctive biotic and abiotic features [10, 11] (Table 2). Globally, the active vent habitat occupies an area less than that of the island of Manhattan (Van Dover et al. 2018). Free-living and autotrophic microorganisms dependent on	

reduced compounds in the hydrothermal fluids serve as the base of the chemosynthetic ecosystem [12, 13]. Juveniles and adults of vent-endemic (vent-obligate) taxa are adapted to the extreme chemical and physical conditions of the vent habitat and thrive in these specialized (unique) ecosystems [14]. Given the very small and discrete areas they inhabit, vent-endemic species are globally rare [15, 16]. • Logatchev-2 is a **discrete area** (1000 m^2) [58] that hosts some **vent-endemic taxa**, including *Rimicaris chacei* and *Mirocaris fortunata* which were observed on a single active chimney [116]. • The hydrothermal community at Logatchev-2 is **unique** in that it is an example of a **senescent community** (with the presence of an extensive mussel shell field) on the MAR [116].	
Functional significance	**SCORE: ?**
All active hydrothermal vents form discrete areas that support primary production by microorganisms that is **essential for the survival, reproduction, and recovery of vent endemic species** and **is necessary for juvenile and adult life-history stages** [14, 21]. Given the very small and discrete areas they inhabit, vent-endemic species are globally **rare** [15, 16]. • Logatech-2 is a **senescent vent** on the northern Mid-Atlantic Ridge and is a special case about which very little is known. They are discrete areas that support primary and secondary production by microorganisms and likely represent a mosaic of microhabitats, some of which may support vent-endemic taxa living under low-flux conditions, others that may be recruiting species that can live only on inactive sulfides or may be found elsewhere in deep-sea environments. It is thus **not clear at this time to which extant Logatchev-2 is essential for the survival, reproduction, and recovery of vent endemic species.** • There are **no data on associated fauna** from the senescent Logatchev-2, but studies at the East Pacific Rise showed that nematodes, which lack larval phases, and harpacticoid copepods were thriving at senescent vents and may play an important role for the recovery of nematode communities at active vents [37, 38]. A predominantly juvenile macrofauna was present at senescent vents at the EPR [37].	
Fragility	**SCORE: HIGH**
All active vent fields are fragile ecosystems that are geographically isolated and discrete [11], hosting populations of benthic invertebrate species that rely on dispersal through pelagic larval stages [22] for maintenance of populations and genetic connectivity. Habitat degradation and fragmentation due to anthropogenic disturbance may result in local loss of biodiversity [23-25] and ecosystem services [26]. Connectivity among metapopulations of species is characterized by source-sink dynamics, making these systems sensitive to reduction or loss of source populations [27-29], with ecological consequences on the structure and function of metacommunities [21]. • Logatchev-2 is isolated and discrete [11]. • Logatchev-2 hosts some **vent-endemic taxa**, including *Rimicaris chacei* and *Mirocaris fortunata* which were observed on a single active chimney, that **disperse**	

only through pelagic larval stages [79, 116].

- *Rimicaris exoculata* shrimp have modified eyes that are poorly designed at the cellular level to recover from intense illumination [80, 81]. While there is no evidence that brief exposure to high intensity light from submersible assets has led to decline in population density [82], **long-term exposure to light** and loss of visual sensitivity have the potential to **alter the behavior and resilience of shrimp populations.**

Life-history traits of component species that make recovery difficult	**SCORE: ?**

Recovery dynamics of vent faunal communities on slow-spreading ridges, such as the Mid-Atlantic Ridge, are unknown. Because MAR vent fields are hydrothermally active for longer periods (thousands of years) than those on faster-spreading ridges (years to decades), they may have slower recovery trajectories [30, 31]. Some vent species are widespread on the MAR (e.g., *Rimicaris exoculata* shrimp; *Shinkailepas briandi* limpets) [32-34], others are not (e.g., *Bathymodiolus* sp. mussels)[29]. Source/sink and recruitment dynamics in vent ecosystems are poorly known if at all, and are likely to be unpredictable given that organisms disperse in the water column [22, 31]. While genetic connectivity observed for some species at vents on the nMAR depends on long-distance dispersal [29], population maintenance at a given site may depend primarily on self-recruitment (i.e., local sources and sinks ([35]. There is currently little data available on the autecology of smaller species (macrofauna & meiofauna). For example, some meiofauna have distinct life-history traits compared to the macrofauna, such as the lack of larval dispersal for nematodes [36], which may make recovery after disturbance difficult [37, 38].

- At Logatchev-2, a few *Rimicaris exoculata* shrimps, which are **vent-endemic species with larval dispersal,** are recorded [79, 116]. However, there are no data on other fauna or life-history traits of these faunae.

Structural complexity	**SCORE: HIGH**

At all active hydrothermal fields, there are complex gradients of geological, geochemical, and thermal conditions that correlate with ecological zonation [14, 39]. Engineer (foundation) species modify physical and (or) chemical environments by altering fluid flow and chemistry [40], contributing to increased environmental heterogeneity. Through evolutionary processes, species at active hydrothermal vents have adapted to extreme environmental conditions, including tolerance to high temperature, low oxygen, and high metal concentrations [41].

- Logatchev-2 is a **highly structured and largely senescent ven**t with mussel shells and a single active black smoker with some shrimp [116].
- At senescent Logatchev-2, **mussel shells provide a distinctive habitat** at this vent field [116].

Biological diversity	**SCORE: HIGH**

Biodiversity of microbial communities is very rich at hydrothermal vents [43, 44]. Vent-endemic animal species contribute novel diversity to the deep-sea fauna, often at taxonomic levels higher than genus and with radiations correlated with environmental attributes including ocean basin, depth, fluid chemistry, and temperature (e.g. polynoid scale worms, alvinocaridid shrimp, bathymodiolin mussels, bythograeid crabs). Habitat heterogeneity and structural complexity provide niches for diverse species [14].. Hydrothermal vent organisms are valued for their genetic diversity [15, 45].

- Logatchev-2 is a largely senescent vent with mussel shells and a single active black smoker with some **vent endemic *Rimicaris*** *exoculata* shrimp [116].
- At senescent Logatchev-2, mussel shells provide a distinctive habitat at this site [116], but organisms associated with this habitat are largely unknown.
- **Distinctive fauna and high diversity associated with senescent vent** sites have been described in the Pacific [37, 167, 168].

Biological productivity	**SCORE: ?**

Chemoautotrophic microorganisms use the chemical energy of hydrothermal fluids to fix inorganic carbon and produce biomass [44]. High biological *in situ* productivity is found at most active hydrothermal vents [14]. Chemoautotrophic productivity occurs below the seafloor [87], on the seafloor as free-living microbes (attached or suspended), or living in symbiosis with large invertebrate species. This production is transferred to higher trophic levels [14, 88].

- Logatchev-2 is a largely senescent vent with mussel shells and a single active black smoker with some vent endemic *Rimicaris exoculata* shrimp [116].
- The black smoer releases vent fluids, indicating that chemoautotrophic bacteria can use the chemical energy of the hydrothermal fluids to fix inorganic carbon and produce biomass [44].
- However, the role of senescent vents for productivity is unknown. There may be a functional significance of senescent vents with regard to productivity transfer to other deep-sea ecosystems [39].

Naturalness	**SCORE: HIGH**

Hydrothermal vents are relatively undisturbed [47]. The only interventions to date are those of scientists and mineral resource explorers. An *Interridge Code of Conduct* guides scientific research and emphasizes avoidance of any scientific activity that would have a deleterious effect on the persistence of populations or that would lead to sustained alteration or visible degradation [48].

- Logatchev-2 is relatively undisturbed.

Ecosystem services	**SCORE: HIGH**

Living resources from hydrothermal vent ecosystems provide or have high potential to provide provisioning services, including genetic resources, bioprospecting or bioinspired materials/processes [15]. They also harbour energetical and mineral resources not yet exploited. Hydrothermal vents contribute to regulating and supporting services including carbon sequestration by biological pump, or microbial oxidation of the greenhouse gas methane [49] and represent major source of iron, an essential trace element that controls marine productivity, in the global ocean [50]. Vents offer cultural services in the form of exceptional inspiration for arts, science, technology and our world [15]. Hydrothermal vents have been and continue to be fruitful areas for fundamental, interdisciplinary, scientific research. Discovery of hydrothermal vents [51] revolutionized our view of life in our oceans and the potential for life on other planetary bodies [14]. Hydrothermal vents are living libraries that open new paths for understanding the intersection of Life and Earth processes [15, 52]. Every studied vent field to date has increased the scientific knowledge, documented through the prolific and highly cited scientific literature [52]. They are used as experimental sites; they constitute a baseline for monitoring anthropogenic induced changes.

- Provisioning, regulating, and supporting services from senescent vents are not known to date.
- At Logatchev-2 there are little baseline historic data.
- Logatchev-2 is a very important site for understanding the structure and functioning of senescent hydrothermal-vent communities on the MAR [116]
- Logatchev-2 may be used as a science or education example of particular geological, geophysical or biological attributes.

A.8. Semyenov-2 vent field

SEMYENOV-2	Latitude	Longitude	Depth (m)
	13°31’N	44°58’W	2360-2580

Initial Discovery and Explorations

Semyenov-2 was discovered and surveyed on the 30th Cruise of RV Professor Logatchev in 2007 [169]. Active venting was first identified in 2007 and later explored with towed camera systems in 2009 during Russian cruises [148, 170]. In 2013, the field was explored by the ODEMAR French–German expedition aboard the RV Pourquoi Pas? using the AUV Abyss and ROV Victor 6000 [171].

Location and Geological Setting

The Semyenov area includes five vent fields, one of them, Semyenov-2, active [172]. The Semyenov vent fields are related to the latitudinally elongated, uplifted seamount-like massif of about 10 km length, 4.5 km width and 850 m elevation above the surrounding seafloor [172]. The seamount has a complex geological structure: serpentinized peridotites, gabbroids, basalts, metabasalts, and plagiogranites were recovered from its summit and slopes. Distance from the ridge axis varies from 0.5 km (Semyenov-4) to 10.5 km (Semyenov-1) [160]. The active field Semyenov-2 is located 8 km from the axis at the depth 2360-2580 m and is related to basalts. This vent field consists of two deposits (sulphide mounds and products of their disintegration). The dimensions of the deposits are 600 x 400 m and 200 x175 m respectively. The estimated areal extent of seafloormassive sulfides is ~3,000 m^2 [58]. Age estimations of this field vary from 3.1 to 76 ka years [160]. The ODEMAR expedition identified several hydrothermal mounds at Semyenov-2, three of them were actively venting: Michaelangelo, Ash Lighthouse and Yellow Submarine. Hydrothermal fluids were clear to whitish, with temperatures of ~316°C in the fragile anhydrite chimneys up to 2 m tall. Michaelangelo and Ash Lighthouse mounds harbor a single chimney structure with several vents, whereas Yellow Submarine has several chimneys aligned along a 10–20 m long ridge [171].

Biological Characterization

One TV-grab (St. 275) was taken at 13°30.82’N, 44°57.78’W, depth 2441 m. At least 12 taxa were preliminary identified in this sample, including the mussel *Bathymodiolus puteoserpentis*, the gastropod *Phymorhynchus ovatus*, polychaetes *Amathys lutzi* and *Levensteiniella* sp., the pycnogonid *Sericosura heteroscela*, shrimps *Alvinocaris markensis* and *Opaepele susannae*, the crab *Segonzacia mesatlantica* and the brittle-star *Ophioctenella acies* [172]. Of special interest is the record of the shrimp *O. susannae* (six specimens in the sample). This species has been described on the MAR from two locations south of Equator: Lilliput (9°32’S, 1500 m) and Sisters Peak (4°48’S, 2986 m) [173]. The new record of *O. susannae* north of the Equator is important for understanding relationships of hydrothermal vent fauna north and south of the Equator on the MAR. Other species known from both sides of the equator in the Atlantic include *Rimicaris exoculata* and *Bathymodiolus puteoserpentis* [174]. Such a pattern of distribution indicates that equatorial fracture zones in the Atlantic Ocean (Romanche and Chain) are not a major physical barrier for dispersal of (some) hydrothermal vent fauna along the MAR. Escartin et al. [171] reported extended mussel beds and associated bacterial mats at the Michelangelo mound at Semyenov-2, over an area of few tens of meters in diameter, with diffuse hydrothermal outflow and small vents distributed throughout. In contrast, there were no microbial mats nor macrofauna at the Ash Lighthouse and Yellow Submarine vent sites.

Classification
None

Scientific Information for Assessment of Semyenov-2 vent field for proposed criteria

Uniqueness and rarity	**SCORE: HIGH**
Vent fields host small, island-like ecosystems with distinctive biotic and abiotic features [10, 11] (Table 2). Globally, the active vent habitat occupies an area less than that of the island of Manhattan (Van Dover et al. 2018). Free-living and autotrophic microorganisms dependent on reduced compounds in the hydrothermal fluids serve as the base of the chemosynthetic ecosystem [12, 13]. Juveniles and adults of vent-endemic (vent-obligate) taxa are adapted to the extreme chemical and physical conditions of the vent habitat and thrive in these specialized (unique) ecosystems [14]. Given the very small and discrete areas they inhabit, vent-endemic species are globally rare [15, 16]. • Semyenov-2 is a **discrete area** (3000 m^2) [58] that hosts **vent-endemic taxa**, including mussels (***Bathymodiolus puteoserpentis***), shrimps (*Alvinocaris markensis*, *Opaepele susannae)*, crabs (*Segonzacia mesatlantica),* gastropods (*Phymorhynchus ovatus*), and polychaetes (*Aphisamytha lutzi* and *Levensteiniella* sp.); the pycnogonid *Sericosura heteroscela*, and the brittle-star *Ophioctenella acies* are also present [171, 172].	
Functional significance	**SCORE: HIGH**
All active hydrothermal vents support primary production by microorganisms, serve as discrete feeding area, and are essential for the growth, survival, reproduction, and persistence of vent endemic species [14, 21]. • Semyenov-2 is colonized by **vent-endemic taxa dependent on chemoautotrophically based food webs** [14, 78, 171, 172]. • Semyenov-2 hosts ***Bathymodiolus*** mussels which feed and breed at active vents [78]. • Given the presence of different size classes of individuals of *Bathymodiolus puteoserpentis* this site is a **nursery ground for vent-endemic fauna**. The Semenov-2 mussel populations contained animals of all sizes and in particular Ash Lighthouse mussels included many small juveniles of only a few millimeters length (pers. obs. N Dubelier and C Borowski).	
Fragility	**SCORE: HIGH**
All active vent fields are fragile ecosystems that are geographically isolated and discrete [11], hosting populations of benthic invertebrate species that rely on dispersal through pelagic larval stages [22] for maintenance of populations and genetic connectivity. Habitat degradation and fragmentation due to anthropogenic disturbance may result in local loss of biodiversity [23-25] and ecosystem services [26]. Connectivity among metapopulations of species is characterized by source-sink dynamics, making these systems sensitive to reduction or loss of source populations [27-29], with ecological consequences on the structure and function of metacommunities [21]. • Semyenov-2 is a isolated and discrete vent [11]. • At Semyenov-2, **vent-endemic species** (e.g. *Bathymodiolus puteoserpentis)* which disperse only through **pelagic larval stages** are present [78, 172].	

Life-history traits of component species that make recovery difficult	**SCORE: HIGH**

Recovery dynamics of vent faunal communities on slow-spreading ridges, such as the Mid-Atlantic Ridge, are unknown. Because MAR vent fields are hydrothermally active for longer periods (thousands of years) than those on faster-spreading ridges (years to decades), they may have slower recovery trajectories [30, 31]. Some vent species are widespread on the MAR (e.g., *Rimicaris exoculata* shrimp; *Shinkailepas briandi* limpets) [32-34], others are not (e.g., *Bathymodiolus* sp. mussels) [29]. Source/sink and recruitment dynamics in vent ecosystems are poorly known if at all, and are likely to be unpredictable given that organisms disperse in the water column [22, 31]. While genetic connectivity observed for some species at vents on the nMAR depends on long-distance dispersal [29], population maintenance at a given site may depend primarily on self-recruitment (i.e., local sources and sinks ([35]. There is currently little data available on the autecology of smaller species (macrofauna & meiofauna). For example, some meiofauna have distinct life-history traits compared to the macrofauna, such as the lack of larval dispersal for nematodes [36], which may make recovery after disturbance difficult [37, 38].

- At Semyenov-2, **vent-endemic species** (e.g. *Bathymodiolus puteoserpentis)* which disperse only through **pelagic larval stages** are present [78, 172].

Structural complexity	**SCORE: HIGH**

At all active hydrothermal fields, there are complex gradients of geological, geochemical, and thermal conditions that correlate with ecological zonation [14, 39]. Engineer (foundation) species modify physical and (or) chemical environments by altering fluid flow and chemistry [40], contributing to increased environmental heterogeneity. Through evolutionary processes, species at active hydrothermal vents have adapted to extreme environmental conditions, including tolerance to high temperature, low oxygen, and high metal concentrations [41].

- Semyenov-2 is characterized by **complex physical structures created by significant concentrations of biotic and abiotic features**. Escartin et al. [171] reported mussel beds and associated microbial mats at the Michelangelo mound at Semyenov-2, which extended over an area few tens of meters in diameter, with diffuse hydrothermal outflow and small vents distributed throughout.
- The vent mussel ***Bathymodiolus puteoserpentis*** is the main **engineer species** on the Michelangelo mound at Semyenov-2 [171], creating additional (or modified) areas for colonization [83]. In contrast, there were no microbial mats nor macrofauna at the Ash Lighthouse and Yellow Submarine vent sites [171].

Biological diversity	**SCORE: HIGH**

Biodiversity of microbial communities is very rich at hydrothermal vents [43, 44]. Vent-endemic animal species contribute novel diversity to the deep-sea fauna, often at taxonomic levels higher than genus and with radiations correlated with environmental attributes including ocean basin, depth, fluid chemistry, and temperature (e.g. polynoid scale worms, alvinocaridid shrimp, bathymodiolin mussels, bythograeid crabs). Habitat heterogeneity and structural complexity provide niches for diverse species [14]. Hydrothermal vent organisms are valued for their genetic diversity [15, 45].

- Semyenov-2 hosts **vent-endemic** taxa, including mussels (*Bathymodiolus puteoserpentis*), shrimps (*Alvinocaris markensis*, *Opaepele susannae)*, crabs

(*Segonzacia mesatlantica),* gastropods (*Phymorhynchus ovatus*), and polychaetes (*Aphisamytha lutzi* and *Levensteiniella* sp.); the pycnogonid *Sericosura heteroscela*, and the brittle-star *Ophioctenella acies* are also present [171, 172].

Biological productivity	**SCORE: HIGH**

Chemoautotrophic microorganisms use the chemical energy of hydrothermal fluids to fix inorganic carbon and produce biomass [44]. High biological *in situ* productivity is found at most active hydrothermal vents [14]. Chemoautotrophic productivity occurs below the seafloor [87], on the seafloor as free-living microbes (attached or suspended), or living in symbiosis with large invertebrate species. This production is transferred to higher trophic levels [14, 88].

- Semyenov-2 is an active deep-sea hydrothermal vent [172], supporting *in situ* primary productivity [44].
- Escartin et al. [171] reported bacterial mats.
- The fauna forms biomass rich communities at Semyenov-2. Escartin et al. [171] reported extended mussel beds.

Naturalness	**SCORE: HIGH**

Hydrothermal vents are relatively undisturbed [47]. The only interventions to date are those of scientists and mineral resource explorers. An *Interridge Code of Conduct* guides scientific research and emphasizes avoidance of any scientific activity that would have a deleterious effect on the persistence of populations or that would lead to sustained alteration or visible degradation [48].

- Semyenov-2 is relatively undisturbed.

Ecosystem services	**SCORE: HIGH**

Living resources from hydrothermal vent ecosystems provide or have high potential to provide provisioning services, including genetic resources, bioprospecting or bioinspired materials/processes [15]. They also harbour energetical and mineral resources not yet exploited. Hydrothermal vents contribute to regulating and supporting services including carbon sequestration by biological pump, or microbial oxidation of the greenhouse gas methane [49] and represent major source of iron, an essential trace element that controls marine productivity, in the global ocean [50]. Vents offer cultural services in the form of exceptional inspiration for arts, science, technology and our world [15]. Hydrothermal vents have been and continue to be fruitful areas for fundamental, interdisciplinary, scientific research. Discovery of hydrothermal vents [51] revolutionized our view of life in our oceans and the potential for life on other planetary bodies [14]. Hydrothermal vents are living libraries that open new paths for understanding the intersection of Life and Earth processes [15, 52]. Every studied vent field to date has increased the scientific knowledge, documented through the prolific and highly cited scientific literature [52]. They are used as experimental sites; they constitute a baseline for monitoring anthropogenic induced changes.

- As all active vent fields, Semyenov-2, offers (potentially) rich provisioning, regulating, and supporting services [15, 49].
- Semyenov-2 has little historic baseline data. Of special interest is the record of the shrimp *O. susannae* [172] that has been described on the MAR from two locations

south of Equator: Lilliput (9°32'S, 1500 m) and Sisters Peak (4°48'S, 2986 m) [173]. The record of *O. susannae* north of Equator is important for understanding relationships of hydrothermal vent fauna north and south of the Equator on the MAR.

- Semeynov-2 may be used as a science or education example of particular geological, geophysical or biological attributes.

A.9. Irinovskoe vent field

IRINOVSKOE	**Latitude**	**Longitude**	**Depth (m)**
	13°19'N	44°54'W	2700-2890 m

Initial Discovery and Explorations

The Irinovskoe hydrothermal field was first studied in 2011 on the 34th cruise of RV Professor Logachev [148, 175]. In 2013, the field was explored by the ODEMAR French–German expedition aboard the RV Pourquoi Pas? using the AUV Abyss and ROV Victor 6000 [171]. In 2016 the Meteor Cruise 126 worked at Irinovskoe using the ROV Quest [150].

Location and Geological Setting

This field is confined to the upper part of the south-eastern slope of the off-axial uplift located at 13°20′N at depths 2700–2890 m. The off-axial dome-shaped uplift with a peculiar corrugated surface is slightly elongated in the latitudinal direction and characterized by a relative height of approximately 1000 m [148]. The structure has a tectonic origin related to detachments and is largely composed of gabbro–peridotites. The field consists of two ore bodies 100 x 175 m and 100 x 125 m across and 3–5 m high. The hydrothermal deposits are represented by massive sulphide ores, disseminated ore mineralization in the host rocks and hydrothermal Fe hydroxide crusts [148]. The estimated areal extent of seafloormassive sulfides is ~10,000 m^2 [58]. Hydrothermal activity was not discovered during the initial study of the field. Active vents were identified in 2013 during the ODEMAR expedition at the summit of hydrothermal mounds marked as Active Pot and Pinnacle Ridge [171]. Both vents showed black smoker fluids venting at 365°C from 1 to 2 m high cauldron-shaped structures with large exit orifices (several dm in diameter). The nearby hydrothermal mounds showed both fallen and standing hydrothermal chimneys, up to 10 m in height [171].

Biological Characterization

Escartin et al. [171] reported microbial mats and diffuse lower-temperature outflows in the immediate vicinity of two active vents. N. Dubilier and C. Borowski (pers. obs.) found small mussel aggregations north of the Pinnacle Ridge vent at two chimneys that emitted shimmering water or faint streams of hot fluids. Mussel (*Bathymodiolus* sp.) collections at these sites contained predominantly large animals [150].

Classification

none

Scientific Information for Assessment of the Irinovskoe vent field for proposed criteria

Uniqueness and rarity	**SCORE: HIGH**

Vent fields host small, island-like ecosystems with distinctive biotic and abiotic features [10, 11] (Table 2). Globally, the active vent habitat occupies an area less than that of the island of Manhattan (Van Dover et al. 2018). Free-living and autotrophic microorganisms dependent on reduced compounds in the hydrothermal fluids serve as the base of the chemosynthetic ecosystem [12, 13]. Juveniles and adults of vent-endemic (vent-obligate) taxa are adapted to the extreme chemical and physical conditions of the vent habitat and thrive in these specialized (unique) ecosystems [14]. Given the very small and discrete areas they inhabit, vent-endemic species are globally rare [15, 16].

- Irinovskoe is a **discrete area** (10000 m^2) [58].

- **Microbial mats** are reported from Irinovskoe [171].
- **Vent-endemic *Bathymodiolus*** mussel collections at these sites contained predominantly large animals (pers. obs. N Dubilier and C. Borowski) [150].
- At Irinovkoe, vent associated fauna was collected but is not determined yet (pers. comm. S. Hourdez).

Functional significance	**SCORE: HIGH**

All active hydrothermal vents support primary production by microorganisms, serve as discrete feeding area, and are essential for the growth, survival, reproduction, and persistence of vent endemic species [14, 21].

- Irinovskoe is colonized by **vent-endemic *Bathymodiolus* mussels dependent on chemoautotrophically based food webs** (pers. obs. N Dubilier and C. Borowski) [150].
- At Irinovskoe, **mussels** were predominantly large/adults (pers. obs. N Dubilier and C. Borowski) [150].
- At Irinovkoe, vent associated fauna was collected but is not determined yet (pers. comm. S. Hourdez).

Fragility	**SCORE: HIGH**

All active vent fields are fragile ecosystems that are geographically isolated and discrete [11], hosting populations of benthic invertebrate species that rely on dispersal through pelagic larval stages [22] for maintenance of populations and genetic connectivity. Habitat degradation and fragmentation due to anthropogenic disturbance may result in local loss of biodiversity [23-25] and ecosystem services [26]. Connectivity among metapopulations of species is characterized by source-sink dynamics, making these systems sensitive to reduction or loss of source populations [27-29], with ecological consequences on the structure and function of metacommunities [21].

- Irinovskoe is a **isolated and discrete** vent [11].
- At Irinovskoe, **vent-endemic *Bathymodiolus*** museels which disperse only through **pelagic larval stages** are present (pers. obs. N. Dubilier and C. Borowski) [78, 150].

Life-history traits of component species that make recovery difficult	**SCORE: HIGH**

Recovery dynamics of vent faunal communities on slow-spreading ridges, such as the Mid-Atlantic Ridge, are unknown. Because MAR vent fields are hydrothermally active for longer periods (thousands of years) than those on faster-spreading ridges (years to decades), they may have slower recovery trajectories [30, 31]. Some vent species are widespread on the MAR (e.g., *Rimicaris exoculata* shrimp; *Shinkailepas briandi* limpets) [32-34], others are not (e.g., *Bathymodiolus* sp. mussels)[29]. Source/sink and recruitment dynamics in vent ecosystems are poorly known if at all, and are likely to be unpredictable given that organisms disperse in the water column [22, 31]. While genetic connectivity observed for some species at vents on the nMAR depends on long-distance dispersal [29], population maintenance at a given site may depend primarily on self-recruitment (i.e., local sources and sinks ([35]. There is currently little data available on the autecology of smaller species (macrofauna & meiofauna). For example, some meiofauna have distinct life-history traits compared to the macrofauna, such as the lack of larval dispersal for nematodes [36], which may make recovery after disturbance difficult [37, 38].

- At Irinovskoe, **vent-endemic *Bathymodiolus*** mussels which disperse only through **pelagic larval stages** are present (pers. obs. N Dubilier and C. Borowski) [78, 150].
- At Irinovkoe, vent associated fauna was collected but is not determined yet (pers. comm. S. Hourdez).

Structural complexity	**SCORE: HIGH**

At all active hydrothermal fields, there are complex gradients of geological, geochemical, and thermal conditions that correlate with ecological zonation [14, 39]. Engineer (foundation) species modify physical and (or) chemical environments by altering fluid flow and chemistry [40], contributing to increased environmental heterogeneity. Through evolutionary processes, species at active hydrothermal vents have adapted to extreme environmental conditions, including tolerance to high temperature, low oxygen, and high metal concentrations [41].

- Irinovskoe is characterized by **complex physical structures created by concentrations of biotic and abiotic features**. At the Active Pot and Pinnacle Ridge sites, black smoker fluids are venting from 1 to 2 m high cauldron-shaped structures with large exit orifices (several dms in diameter). Nearby hydrothermal mounds showed both fallen and standing hydrothermal chimneys, up to 10 m in height [171].
- The vent mussel ***Bathymodiolus*** acts as **engineer species** at Irinovskoe (pers. obs. N Dubilier and C. Borowski) [150], creating additional (or modified) areas for colonization [83]. In contrast, there were no microbial mats nor macrofauna at the Ash Lighthouse and Yellow Submarine vent sites [171].

Biological diversity	**SCORE: HIGH**

Biodiversity of microbial communities is very rich at hydrothermal vents [43, 44]. Vent-endemic animal species contribute novel diversity to the deep-sea fauna, often at taxonomic levels higher than genus and with radiations correlated with environmental attributes including ocean basin, depth, fluid chemistry, and temperature (e.g. polynoid scale worms, alvinocaridid shrimp, bathymodiolin mussels, bythograeid crabs). Habitat heterogeneity and structural complexity provide niches for diverse species [14]. Hydrothermal vent organisms are valued for their genetic diversity [15, 45].

- Irinovskoe hosts **vent-endemic** *Bathymodiolus* musssels [150].
- At Irinovkoe, vent associated fauna was collected but is not determined yet (pers. comm. S. Hourdez).

Biological productivity	**SCORE: HIGH**

Chemoautotrophic microorganisms use the chemical energy of hydrothermal fluids to fix inorganic carbon and produce biomass [44]. High biological *in situ* productivity is found at most active hydrothermal vents [14]. Chemoautotrophic productivity occurs below the seafloor [87], on the seafloor as free-living microbes (attached or suspended), or living in symbiosis with large invertebrate species. This production is transferred to higher trophic levels [14, 88].

- Irinovskoe is an active deep-sea hydrothermal vent [171], supporting ***in situ* primary productivity** [44].
- **Microbial mats** are reported from Irinovskoe [171].

- The fauna forms biomass rich communities. Mussel collections at Irinovskoe contained predominantly large animals [150].

Naturalness	**SCORE: HIGH**
Hydrothermal vents are relatively undisturbed [47]. The only interventions to date are those of scientists and mineral resource explorers. An *Interridge Code of Conduct* guides scientific research and emphasizes avoidance of any scientific activity that would have a deleterious effect on the persistence of populations or that would lead to sustained alteration or visible degradation [48]. • Irinovskoe is relatively undisturbed.	
Ecosystem services	**SCORE: HIGH**
Living resources from hydrothermal vent ecosystems provide or have high potential to provide provisioning services, including genetic resources, bioprospecting or bioinspired materials/processes [15]. They also harbour energetical and mineral resources not yet exploited. Hydrothermal vents contribute to regulating and supporting services including carbon sequestration by biological pump, or microbial oxidation of the greenhouse gas methane [49] and represent major source of iron, an essential trace element that controls marine productivity, in the global ocean [50]. Vents offer cultural services in the form of exceptional inspiration for arts, science, technology and our world [15]. Hydrothermal vents have been and continue to be fruitful areas for fundamental, interdisciplinary, scientific research. Discovery of hydrothermal vents [51] revolutionized our view of life in our oceans and the potential for life on other planetary bodies [14]. Hydrothermal vents are living libraries that open new paths for understanding the intersection of Life and Earth processes [15, 52]. Every studied vent field to date has increased the scientific knowledge, documented through the prolific and highly cited scientific literature [52]. They are used as experimental sites; they constitute a baseline for monitoring anthropogenic induced changes. • As all active vent fields, Irinovskoe, offers (potentially) rich provisioning, regulating, and supporting services [15, 49]. • There are no baseline historic data for Irinovskoe. Recent research expeditions have been undertaken and scientific studies are ongoing [150]. • Irinovskoe may be used as a science or education example of particular geological, geophysical or biological attributes.	

A.10. Ashadze-2 vent field

ASHADZE-2	Latitude	Longitude	Depth (m)
	12°59'N	44°54'W	3260-3300

Initial Discovery and Explorations

Indications of hydrothermal activity in the form of anomalies in the bottom water layer and hydrothermal minerals in bottom sediments at ~13°N on the MAR were registered during several Russian, French and US expeditions in 1990-2000s [148]. The field Ashadze-2 was identified by monitoring anomalies in the electric potential recorded by the deep-towed RIFT system during a 2003 cruise [166]. The field was visited on the Serpentine Cruise in 2007 with the ROV Victor 6000 [166, 176].

Location and Geological Setting

The Ashadze-2 field is located 7.6 km off axis on the western rift valley slope, 4.3 km west of the Ashadze-1 field at a depth of 3260-3300 m. The host rocks at Ashadze-2 are serpentinized peridotites with interspersed gabbroic bodies which are very common in the rift valley slopes in this segment of the MAR [166]. The high-resolution (up to 30 cm) topographic survey at Ashadze-2 revealed a chain of hydrothermal mounds and a crater-shaped structure 20–25 m in diameter and 1–3 m deep [166]. This constructional structure may indicate the sometimes-explosive nature of hydrothermal fluid emissions. Similar structures were previously documented at Logachev-1 [152]. Observations using ROV Victor 6000 revealed black smokers at the crater bottom . Black smokers at Ashadze-2 lie in a narrow (about 70 m), N-S trending graben-like trough bounded to the east by a faulted gabbroic body [166]. To the west, it is limited by a narrow N-S trending ridge, 20 to 50 m-high, that bears numerous extinct hydrothermal chimneys [160]. The estimated areal extent of seafloormassive sulfides is ~1,000 m^2 [58]. The mineralization is generally typical of massive sulphides associated with gabbro–peridotites, while being dominated by copper and copper–pyrite ores with elevated Cu, Au, and Co concentrations [148]. The maximum age of the ores at Ashadze-2 is 27.3 ± 1.8 ka [160].

Biological Characterization

Information on biota of Ashadze-2 is very limited, some remarks were made based on Victor 6000 dives during the Serpentine Cruise (Cruise Report, 2007) [166]. Active vents at the bottom of a crater and in a narrow graben-like trough could not be accessed with the ROV. However, shrimp resembling *Mirocaris fortunata* were observed through the shimmering water. At some distance from active vents, populations of Demospongia and cladorhyzid (carnivorous) sponges were reported. During the Meteor cruise in 2016 similar observations of a few vent organisms including a few shrimp were made by S. Hourdez (pers. com.).

Classification

None

Scientific Information for Assessment of the ASHADZE-2 vent field for proposed criteria

Uniqueness and rarity	SCORE: HIGH
Vent fields host small, island-like ecosystems with distinctive biotic and abiotic features [10, 11] (Table 2). Globally, the active vent habitat occupies an area less than that of the island of Manhattan (Van Dover et al. 2018). Free-living and autotrophic microorganisms dependent on reduced compounds in the hydrothermal fluids serve as the base of the chemosynthetic	

ecosystem [12, 13]. Juveniles and adults of vent-endemic (vent-obligate) taxa are adapted to the extreme chemical and physical conditions of the vent habitat and thrive in these specialized (unique) ecosystems [14]. Given the very small and discrete areas they inhabit, vent-endemic species are globally rare [15, 16].

- Ashadze-2 is a **discrete area** (1000 m^2) [58].
- At Ashadze-2, **shrimps resembling *Mirocaris fortunata*** (**vent endemic** species of the MAR) were observed through the shimmering water. At some distance from active vents, populations of Demospongia and cladorhyzid (carnivorous) sponges were reported, together with anemones [166].

Functional significance — **SCORE: HIGH**

All active hydrothermal vents support primary production by microorganisms, serve as discrete feeding area, and are essential for the growth, survival, reproduction, and persistence of vent endemic species [14, 21].

- At Ashadze-2, shrimps resembling *Mirocaris fortunata* (vent endemic species of the MAR) were observed through the shimmering water [166].
- Vent shrimp have symbionts and depend **on chemoautotrophically based food webs for their survival** [103, 136].

Fragility — **SCORE: HIGH**

All active vent fields are fragile ecosystems that are geographically isolated and discrete [11], hosting populations of benthic invertebrate species that rely on dispersal through pelagic larval stages [22] for maintenance of populations and genetic connectivity. Habitat degradation and fragmentation due to anthropogenic disturbance may result in local loss of biodiversity [23-25] and ecosystem services [26]. Connectivity among metapopulations of species is characterized by source-sink dynamics, making these systems sensitive to reduction or loss of source populations [27-29], with ecological consequences on the structure and function of metacommunities [21].

- Ashadze-2 is geographically isolated and discrete [11].
- At Ashadze-2, shrimps resembling *Mirocaris fortunata* (considered as vent endemic at other MAR vents) were observed through the shimmering water (Serpentine 2007) [166].
- Vent shrimp rely on dispersal through pelagic stages [79].

Life-history traits of component species that make recovery difficult — **SCORE: HIGH**

Recovery dynamics of vent faunal communities on slow-spreading ridges, such as the Mid-Atlantic Ridge, are unknown. Because MAR vent fields are hydrothermally active for longer periods (thousands of years) than those on faster-spreading ridges (years to decades), they may have slower recovery trajectories [30, 31]. Some vent species are widespread on the MAR (e.g., *Rimicaris exoculata* shrimp; *Shinkailepas briandi* limpets) [32-34], others are not (e.g., *Bathymodiolus* sp. mussels)[29]. Source/sink and recruitment dynamics in vent ecosystems are poorly known if at all, and are likely to be unpredictable given that organisms disperse in the water column [22, 31]. While genetic connectivity observed for some species at vents on the nMAR depends on long-distance dispersal [29], population maintenance at a given site may depend primarily on self-recruitment (i.e., local sources and sinks ([35]. There is currently little data available on the autecology of smaller species (macrofauna & meiofauna). For example, some meiofauna have distinct life-history traits compared to the macrofauna, such as the lack of larval dispersal for nematodes [36], which may make recovery after disturbance difficult [37, 38].

- At Ashadze-2, shrimps resembling *Mirocaris fortunata* were observed (Serpentine 2007) [166]. These shrimp disperse in the water column [79], making recruitment unpredictable.

Structural complexity	**SCORE: HIGH**

At all active hydrothermal fields, there are complex gradients of geological, geochemical, and thermal conditions that correlate with ecological zonation [14, 39]. Engineer (foundation) species modify physical and (or) chemical environments by altering fluid flow and chemistry [40], contributing to increased environmental heterogeneity. Through evolutionary processes, species at active hydrothermal vents have adapted to extreme environmental conditions, including tolerance to high temperature, low oxygen, and high metal concentrations [41].

- Ashadze-2 vent field is **geologically and geochemically complex** and contains a chain of hydrothermal mounds and a crater shaped structure 20–25 m in diameter and 1–3 m deep [166]. The subsequent visual observations revealed back smokers at the crater bottom, thus indicating recent hydrothermal activity.
- At Ashadze-2, shrimps resembling *Mirocaris fortunata* (considered as vent endemic at other vent sites) were observed through the shimmering water (Serpentine 2007) [166].

Biological diversity	**SCORE: HIGH**

Biodiversity of microbial communities is very rich at hydrothermal vents [43, 44]. Vent-endemic animal species contribute novel diversity to the deep-sea fauna, often at taxonomic levels higher than genus and with radiations correlated with environmental attributes including ocean basin, depth, fluid chemistry, and temperature (e.g. polynoid scale worms, alvinocaridid shrimp, bathymodiolin mussels, bythograeid crabs). Habitat heterogeneity and structural complexity provide niches for diverse species [14]. Hydrothermal vent organisms are valued for their genetic diversity [15, 45].

- At Ashadze-2, shrimps resembling *Mirocaris fortunata* (considered as **vent endemic** at other MAR vents) were observed through the shimmering water (Serpentine 2007) [166].
- Observations of a few vent organisms including a few shrimp were made by S. Hourdez (pers. com.).
- Expert knowledge based on these direct observations and scientific inference suggest that more vent-endemic species may be encountered in the future.

Biological productivity	**SCORE: HIGH**

Chemoautotrophic microorganisms use the chemical energy of hydrothermal fluids to fix inorganic carbon and produce biomass [44]. High biological *in situ* productivity is found at most active hydrothermal vents [14]. Chemoautotrophic productivity occurs below the seafloor [87], on the seafloor as free-living microbes (attached or suspended), or living in symbiosis with large invertebrate species. This production is transferred to higher trophic levels [14, 88].

- Observations of back smokers [166], suggest that Ashadze-2 is an active deep-sea hydrothermal vent, supporting ***in situ* primary productivity** [44].

• A few vent organisms including a few shrimp were observed (S. Hourdez, pers. com.).	
Naturalness	**SCORE: HIGH**
Hydrothermal vents are relatively undisturbed [47]. The only interventions to date are those of scientists and mineral resource explorers. An *Interridge Code of Conduct* guides scientific research and emphasizes avoidance of any scientific activity that would have a deleterious effect on the persistence of populations or that would lead to sustained alteration or visible degradation [48]. • Ashadze-2 is relatively undisturbed.	
Ecosystem services	**SCORE: HIGH**
Living resources from hydrothermal vent ecosystems provide or have high potential to provide provisioning services, including genetic resources, bioprospecting or bioinspired materials/processes [15]. They also harbour energetical and mineral resources not yet exploited. Hydrothermal vents contribute to regulating and supporting services including carbon sequestration by biological pump, or microbial oxidation of the greenhouse gas methane [49] and represent major source of iron, an essential trace element that controls marine productivity, in the global ocean [50]. Vents offer cultural services in the form of exceptional inspiration for arts, science, technology and our world [15]. Hydrothermal vents have been and continue to be fruitful areas for fundamental, interdisciplinary, scientific research. Discovery of hydrothermal vents [51] revolutionized our view of life in our oceans and the potential for life on other planetary bodies [14]. Hydrothermal vents are living libraries that open new paths for understanding the intersection of Life and Earth processes [15, 52]. Every studied vent field to date has increased the scientific knowledge, documented through the prolific and highly cited scientific literature [52]. They are used as experimental sites; they constitute a baseline for monitoring anthropogenic induced changes. • As all active vent fields, Ashadze-2, offers (potentially) rich provisioning, regulating, and supporting services [15, 49]. • There are no baseline historic data. Ashadze-2 and Ashadze-1 are geographically very close (a few km), but differ dramatically in depth (~3300 m, and 4200 m respectively), providing a unique opportunity to study bathymetric influence on communities. • Ashadze-2 may be used as a science or education example of particular geological, geophysical or biological attributes.	

A.11. Ashadze-1 vent field

ASHADZE-1	Latitude	Longitude	Depth (m)
	12°58'N	44°51'W	4080-4200

Initial Discovery and Explorations

The Ashadze-1 hydrothermal field was discovered in 2003 [177] and was revisited in 2005 and 2007 during cruises of RV Professor Logatchev. The field was detected by turbidity anomalies in the near-bottom waters and hydrothermal minerals in the bottom sediments. The field was also visited on the Serpentine Cruise in 2007 with the ROV Victor 6000 [166].

Location and Geological Setting

The Ashadze-1 field lies on the western slope of the rift valley 3.7 km away from the ridge axis at the depth of 4100 m. The host rocks at Ashadze-1, as at Ashadze-2, are serpentinized peridotites with interspersed gabbroic bodies which are very common in the rift valley slopes in this segment of the MAR [166]. The estimated seafloor massive sulfide deposit area is ~5000 m^2 [58]. The vent field is ~50 x 300 m in size. Active vents at Ashadze-1 are distributed over an area about 150-m long, along an EW-trending south-facing scarp [166]. Morphologically, the deposits are represented not only by typical mound-, crust and blanket-like structures topped by chimneys, but also by unusual ‘‘forest-like’’ chimney accumulations (up to ten 30–40 cm high chimneys per 1 m^2) [178]. The average chemical composition of the Ashadze SMS is characterized by the enrichment of copper, gold and cobalt, which is typical for ultramafic-hosted deposits. The maximum ages of the ores at Ashadze-1 is 7.2 ± 1.8 ka [160]. The Ashadze-1 hydrothermal field is organized around a group of three very active black vents [179]. The 2-m high ‘Long chimney’ with a fluid temperature of352°C is located at the top of a small mound. The ‘Big Black smokers’ are five big apertures that expel black fluids at temperatures up to 353°C. The ‘Twin chimneys’ are two thin black smokers 50 cm high, with fluid temperatures of 347°C. North of the active centre is located the site “Anemone Garden” with a group of small chimneys that expel a fluid reaching 112°C.

Biological Characterization

There is a high diversity of micro-habitats, with a complex of sulphide structures, high fluid flow/diffuse-flow areas that provide essential temperature/fluid/substrata gradients for hydrothermal vent faunal communities [179]. The vent community is dominated by two species: the anemone *Maractis rimicarivora* (reaching densities of 32 ind.m^{-2}) and the chaetopterid polychaete *Phyllochatopterus polus*. These species form large populations on different substrata, such as on the walls of active and old chimneys, fragments of fallen chimneys and hydrothermal sediments. The shrimp *Mirocaris fortunata* is notable on walls of active and old chimneys. Fabri et al. [179] listed 43 species in the Ashadze-1 community. Mussels typical of most vent communities (*Bathymodiolus* spp.) on the MAR were absent. Some typical MAR vent species, like the shrimp *Rimicaris exoculata*, were present in single numbers, while others such as the shrimp *Rimicaris chacei* and *Mirocaris fortunata*, were common. Four species of *Phymorchynchus* were reported: *P. carinatus*, *P. ovatus*, *P. moskalevi* and *P.* aff. *carinatus*. Common at the vent field were the gastropods *Peltospira smaragdina*, *P. thorvaldssoni*, *Shinkailepas briandi* and *Pseudorimula midatlantica*. Other typical gastropods included *Sutilizona pterodon* (in high numbers at some sites), *Lepetodrilus atlanticus*, *Lirapex costellatus* and *Lirapex* sp.. At the surface of oxidized chimneys tubes of chaetopterid polychaete *Phyllochaetopterus polus* [180] were present in high numbers. Other

polychaete species in this community included *Archinome* sp., ampharetids *Amathys lutzi* and *Glyphanostomum*. sp. nov. and the spionid *Prionospio* sp., the latter particularly abundant at the South-East 2 site [179]. Typical representatives of MAR vent communities included the crab *Segonzacia mesatlantica*, the ophiuroid *Ophioctenella acies* and the zoarcid fish *Pachycara thermophilum*. The ophiuroid *Ophioctenella acies* and the scavenger pycnogonid *Sericosura heteroscela* commonly occur at the base of chimneys in a temperature zone around 3.5°C. Galatheid crabs *Munidopsis exuta* were common at the periphery. Predators include the crab *Segonzacia mesatlantica* and the zoarcid fish *Pachycara thermophilum.* Benthic communities were most diverse and abundant at the site 'Anemone garden' [179].
Classification None

Scientific Information for Assessment of the Ashadze-1 vent field for proposed criteria

Uniqueness and rarity	**SCORE: HIGH**
Vent fields host small, island-like ecosystems with distinctive biotic and abiotic features [10, 11] (Table 2). Globally, the active vent habitat occupies an area less than that of the island of Manhattan (Van Dover et al. 2018). Free-living and autotrophic microorganisms dependent on reduced compounds in the hydrothermal fluids serve as the base of the chemosynthetic ecosystem [12, 13]. Juveniles and adults of vent-endemic (vent-obligate) taxa are adapted to the extreme chemical and physical conditions of the vent habitat and thrive in these specialized (unique) ecosystems [14]. Given the very small and discrete areas they inhabit, vent-endemic species are globally rare [15, 16]. • Ashadze-1 is a **discrete area** (~5000 m^2) [58] that hosts **vent-endemic taxa** including for example ***Rimicaris exoculata,*** *Segonzacia mesatlantica* and *Pachycara thermophilum* [179]. • The Ashadze-1 community is dominated by the **sessile anemone *Maractis rimicarivora*** and the chaetopterid *Phyllochatopterus polus*, both species are often common at the periphery of vent communities on the MAR. Some scavengers such as *Phymorhynchus* spp., *Ophioctenella acies* and *Munidopsis exuta* colonize substrata in the active zone [179].	
Functional significance	**SCORE: HIGH**
All active hydrothermal vents support primary production by microorganisms, serve as discrete feeding area, and are essential for the growth, survival, reproduction, and persistence of vent endemic species [14, 21]. • Ashadze-1 is a discrete area that is colonized by vent-endemic taxa who depend on chemoautotrophically based food webs [179]. Isotope studies demonstrated a **chemosynthesis based food-web** [179]. • Whilst there is no direct observation for particular life history stages at Azhadze-1, the presence of vent-endemic fauna [179] suggests that it is likely a nursery ground for the vent-endemic fauna.	
Fragility	**SCORE: HIGH**

All active vent fields are fragile ecosystems that are geographically isolated and discrete [11], hosting populations of benthic invertebrate species that rely on dispersal through pelagic larval stages [22] for maintenance of populations and genetic connectivity. Habitat degradation and fragmentation due to anthropogenic disturbance may result in local loss of biodiversity [23-25] and ecosystem services [26]. Connectivity among metapopulations of species is characterized by source-sink dynamics, making these systems sensitive to reduction or loss of source populations [27-29], with ecological consequences on the structure and function of metacommunities [21]. • Ashadze-1 is geographically isolated and discrete [11]. • Ashadze-1 is a **discrete area** (5000 m^2) that is colonized by **vent-endemic taxa**, such as for example *Rimicaris exoculata*, *Segonzacia mesatlantica* and *Pachycara thermophilum* [179]. Reduction or loss of populations through human activities is likely to eliminate source populations that were both self-recruiting and served as an important supply of offspring to other sites on the MAR. • *Rimicaris exoculata* shrimp have modified eyes that are poorly designed at the cellular level to recover from intense illumination [80, 81]. While there is no evidence that brief exposure to high intensity light from submersible assets has led to decline in population density [82], **long-term exposure to light** and loss of visual sensitivity have the potential to **alter the behavior and resilience of the shrimp populations**.	
Life-history traits of component species that make recovery difficult	**SCORE: HIGH**
Recovery dynamics of vent faunal communities on slow-spreading ridges, such as the Mid-Atlantic Ridge, are unknown. Because MAR vent fields are hydrothermally active for longer periods (thousands of years) than those on faster-spreading ridges (years to decades), they may have slower recovery trajectories [30, 31]. Some vent species are widespread on the MAR (e.g., *Rimicaris exoculata* shrimp; *Shinkailepas briandi* limpets) [32-34], others are not (e.g., *Bathymodiolus* sp. mussels)[29]. Source/sink and recruitment dynamics in vent ecosystems are poorly known if at all, and are likely to be unpredictable given that organisms disperse in the water column [22, 31]. While genetic connectivity observed for some species at vents on the nMAR depends on long-distance dispersal [29], population maintenance at a given site may depend primarily on self-recruitment (i.e., local sources and sinks ([35]. There is currently little data available on the autecology of smaller species (macrofauna & meiofauna). For example, some meiofauna have distinct life-history traits compared to the macrofauna, such as the lack of larval dispersal for nematodes [36], which may make recovery after disturbance difficult [37, 38]. • At Ashadze-1 many species, like for example *Rimicaris exoculata, Maractis rimicarivora* or peltospirid gastropods, disperse only via the water column [79, 179], which makes recruitment unpredictable.	
Structural complexity	**SCORE: HIGH**
At all active hydrothermal fields, there are complex gradients of geological, geochemical, and thermal conditions that correlate with ecological zonation [14, 39]. Engineer (foundation) species modify physical and (or) chemical environments by altering fluid flow and chemistry [40], contributing to increased environmental heterogeneity. Through evolutionary processes, species at active hydrothermal vents have adapted to extreme environmental conditions, including tolerance to high temperature, low oxygen, and high metal concentrations [41].	

- Ashadze-1 is characterized by **complex physical structures created by significant concentrations of biotic and abiotic features**. Physically, the deposits are represented not only by typical mound-, crust and blanket-like structures topped by chimneys, but also by unusual ''forest-like'' chimney accumulations (up to ten 30–40 cm high chimneys per 1 m^2) [178].
- There is a **high diversity of microhabitats**, with a complex of sulphide structures, high fluid flow/diffuse-flow areas that provide essential temperature/fluid/substrata gradients for hydrothermal vent faunal communities [179].
- The vent community is dominated by two species: the anemone *Maractis rimicarivora* reaching high densities of 32 ind. m^{-2}, and the chaetopterid polychaete *Phyllochatopterus polus* [179].

Biological diversity	**SCORE: HIGH**

Biodiversity of microbial communities is very rich at hydrothermal vents [43, 44]. Vent-endemic animal species contribute novel diversity to the deep-sea fauna, often at taxonomic levels higher than genus and with radiations correlated with environmental attributes including ocean basin, depth, fluid chemistry, and temperature (e.g. polynoid scale worms, alvinocaridid shrimp, bathymodiolin mussels, bythograeid crabs). Habitat heterogeneity and structural complexity provide niches for diverse species [14]. Hydrothermal vent organisms are valued for their genetic diversity [15, 45].

- Ashadze-1 hosts **vent-endemic fauna** such as such as for example *Rimicaris exoculata*, *Segonzacia mesatlantica* and *Pachycara thermophilum* [179].
- Fabri et al. [179] listed 43 species in the Ashadze-1 community.

Biological productivity	**SCORE: HIGH**

Chemoautotrophic microorganisms use the chemical energy of hydrothermal fluids to fix inorganic carbon and produce biomass [44]. High biological *in situ* productivity is found at most active hydrothermal vents [14]. Chemoautotrophic productivity occurs below the seafloor [87], on the seafloor as free-living microbes (attached or suspended), or living in symbiosis with large invertebrate species. This production is transferred to higher trophic levels [14, 88].

- Ashadze-1 is an active deep-sea hydrothermal vent [179], supporting ***in situ* primary productivity** [44].
- The fauna forms **biomass rich communities**. The anemone *Maractis rimicarivora* reaches densities of 32 ind.m^{-2} [179].

Naturalness	**SCORE: HIGH**

Hydrothermal vents are relatively undisturbed [47]. The only interventions to date are those of scientists and mineral resource explorers. An *Interridge Code of Conduct* guides scientific research and emphasizes avoidance of any scientific activity that would have a deleterious effect on the persistence of populations or that would lead to sustained alteration or visible degradation [48].

- Ashadze-1 is relatively undisturbed.

Ecosystem services	**SCORE: HIGH**

Living resources from hydrothermal vent ecosystems provide or have high potential to provide provisioning services, including genetic resources, bioprospecting or bioinspired materials/processes [15]. They also harbour energetical and mineral resources not yet exploited. Hydrothermal vents contribute to regulating and supporting services including carbon sequestration by biological pump, or microbial oxidation of the greenhouse gas methane [49] and represent major source of iron, an essential trace element that controls marine productivity, in the global ocean [50]. Vents offer cultural services in the form of exceptional inspiration for arts, science, technology and our world [15]. Hydrothermal vents have been and continue to be fruitful areas for fundamental, interdisciplinary, scientific research. Discovery of hydrothermal vents [51] revolutionized our view of life in our oceans and the potential for life on other planetary bodies [14]. Hydrothermal vents are living libraries that open new paths for understanding the intersection of Life and Earth processes [15, 52]. Every studied vent field to date has increased the scientific knowledge, documented through the prolific and highly cited scientific literature [52]. They are used as experimental sites; they constitute a baseline for monitoring anthropogenic induced changes.

- As all active vent fields, Ashadze-1, offers (potentially) rich provisioning, regulating, and supporting services [15, 49].
- Ashadze-1 and Ashadze-2 present a unique opportunity for studies of bathymetric patterns. Fabri et al. [179] suggested that (1) symbiotrophic species might have existed in this community but disappeared (owing to decline in the vent activity or other reasons), or (2) symbiotrophic species are lacking due to the great depth. The type of hot vent community with (almost) lack of symbiotrophic species is a unique feature of Ashadze-1.
- Ashadze-1 is the type locality of a *Phyllochaetopterus* species [180].
- Ashadze-1 may be used as a science or education example of particular geological, geophysical or biological attributes.

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