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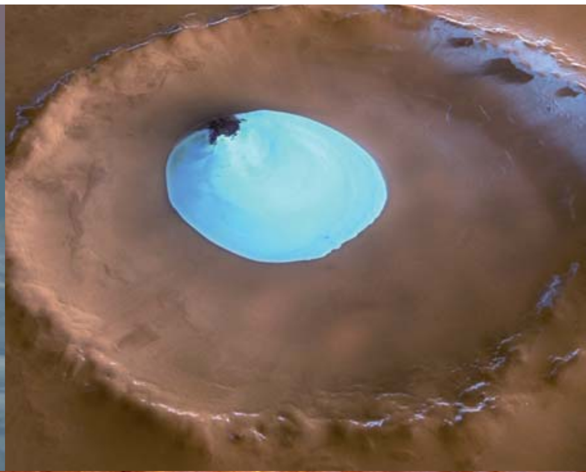
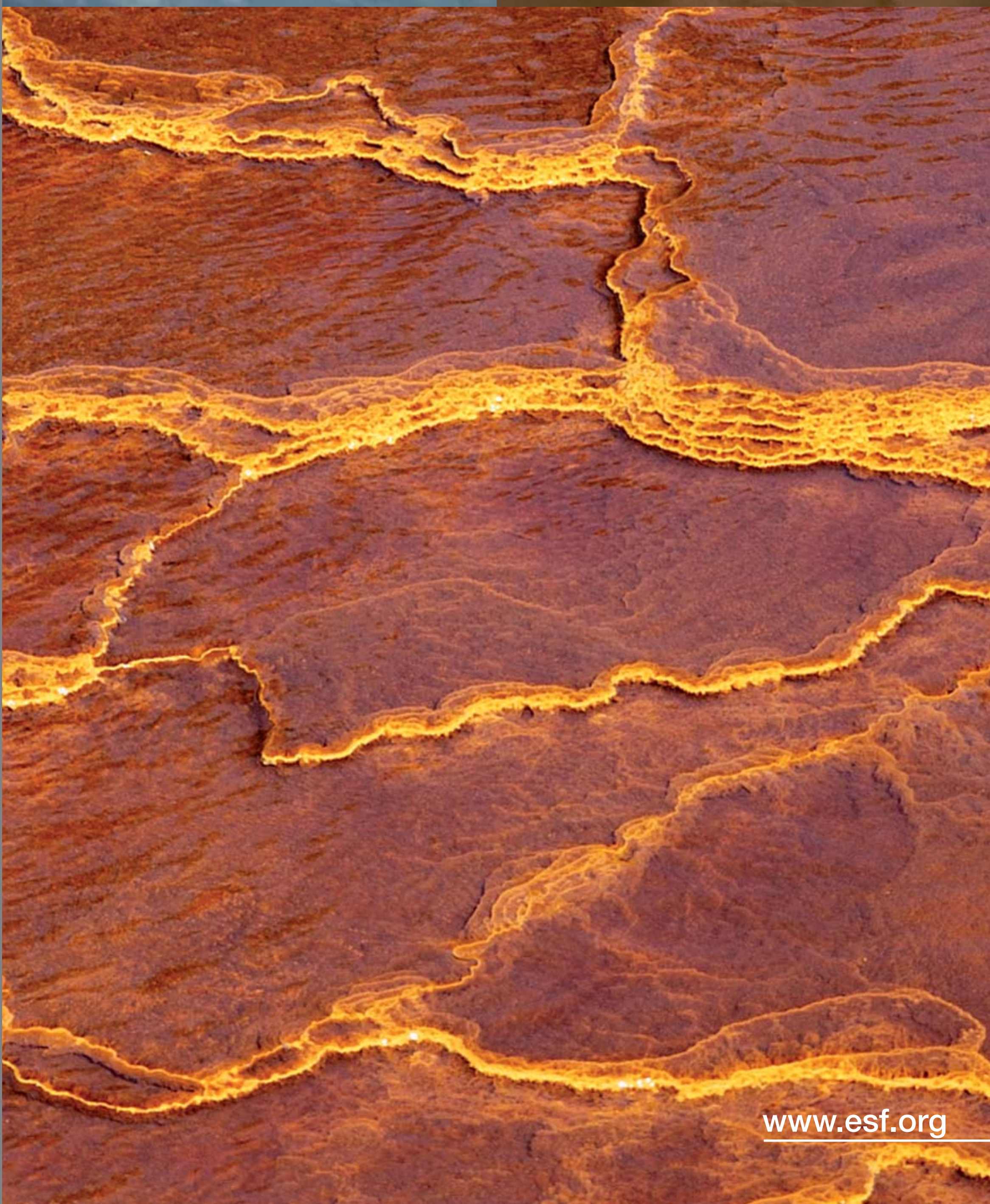
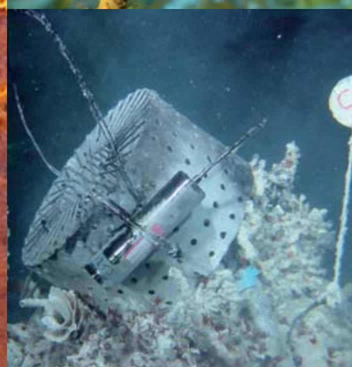
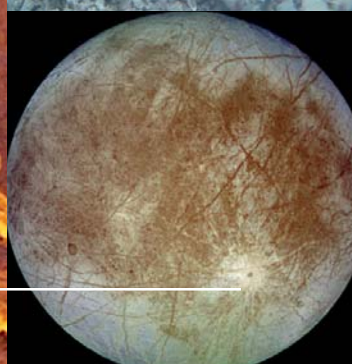
Investigating Life in Extreme Environments

A European Perspective



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Investigating Life in Extreme Environments • European Science Foundation

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Its activities include providing science policy advice (Science Strategy); stimulating co-operation between researchers and organisations to explore new directions (Science Synergy); and the administration of externally funded programmes (Science Management). These take place in the following areas: Physical and engineering sciences; Medical sciences; Life, earth and environmental sciences; Humanities; Social sciences; Polar; Marine; Space; Radio astronomy frequencies; Nuclear physics.

Headquartered in Strasbourg with offices in Brussels, the ESF's membership comprises 75 national funding agencies, research performing agencies and academies from 30 European nations.

The Foundation's independence allows the ESF to objectively represent the priorities of all these members. For more information see: http://www.esf.org

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European Medical Research Councils (EMRC)

Set up in 1971, the EMRC evolved into one of the five Standing Committees of the ESF in 1975. The EMRC membership is composed of delegates with a high scientific profile who are nominated by their ESF Member Organisations involved in biomedical sciences, together with observers from Canada, Israel, New Zealand, USA,, WHO-Europe, the European Commission and the ESF Standing Committee for Life, Earth and Environmental Sciences (LESC). Thirty-five representatives of 39 Member Organisations participate in the annual plenary meetings of the EMRC. An Executive Group composed of eight members is responsible for the follow-up of EMRC policies between annual meetings. For more information see: http://www.esf.org/emrc

ESF Standing Committee for the Humanities (SCH)

Established in 1978, SCH consists of representatives of ESF member research councils and academies, with subject specialists to complement ordinary membership. Observers attend from the ESF Standing Committee for the Social Sciences (SCSS), the COST Technical Committee (TC) in Social Sciences and Humanities, the European Commission, the US National Endowment for the Humanities, the Canadian Social Sciences and Humanities Research Council, and the Israel Academy of Sciences and Humanities. SCH has a policy of encouraging interdisciplinary work and sees its main task as the independent evaluation of collaborative research proposals emanating from the academic community. SCH also has a proactive function in the identification of priority research areas. For more information see: http://www.esf.org/sch

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European Polar Board (EPB)

EPB is one of ESF's expert boards focus on science policy and strategy. It is Europe's advisory body on science policy in the polar regions. It is concerned with major strategic priorities in the Arctic and Antarctic. EPB has 29 members from 19 countries. It acts to ensure high-level collaboration and coordination between European national funding agencies, national polar institutes, research organisations and the European Commission. For more information see: http://www.esf.org/epb

European Space Sciences Committee (ESSC)

Created in 1975, ESSC is one of ESF's expert boards focus on science policy and strategy. It deals with space research and covers all related aspects; i.e. space physical science, Earth observation, and life and physical sciences in space. ESSC investigates and presents the view of the scientific community in Europe on space research issues and provides an independent voice on European space science policy. For more information see: http://www.esf.org/essc

Context and background information on the activity

In February 2004, in the context of promoting interdisciplinary research on topics of common interest, the European Science Foundation's (ESF) Standing Committee for Life, Earth and Environmental Sciences (LESC) and three of ESF's Expert Committees, the Marine Board-ESF (MB-ESF), the European Space Science Committee (ESSC) and the European Polar Board (EPB), issued a common call for Expressions of Interest (EoI) on the topic 'Investigating Life in Extreme Environments'. ESF Standing Committee for the Humanities (SCH) and the European Medical Research Councils (EMRC) joined the initiative.

Subsequent to this call, 282 Expressions of Interest from 27 countries were received. The main contributors were from: Germany (18%), UK (16%), Italy (14%) and France (9%). There was also significant participation from the Russia (12 EoIs) and from eastern European countries (25 EoIs). Concerning the topics covered, 33% of the EoIs dealt with the marine environment, 22% with the polar environment and 16% with the space environment.

Given the EoIs received, and with the support of ESF and LESC, the Steering Committee of the initiative recommended that a large-scale workshop dealing with the topic Investigating Life in Extreme Environments (ILEE) be organised in order to debate and put forward research priorities and explore the recommendations of the community involved. The coordination was tasked to the Marine Board unit of ESF. This workshop, involving 128 participants, was held in November 2005 in Sant Feliu de Guixols (Spain). The workshop was chaired by **Daniel Prieur** (IUEM University of Brest, France) with **Ricardo Amils** (CBMSO Universidad Autónoma de Madrid and Centro de Astrobiología, Madrid, Spain) as rapporteur.

As a broad spectrum of the European scientific community expressed interest in the initiative, the workshop was organised around seven sessions (detailed below), three of which dealt with interdisciplinary issues:

1. Defining and characterising the boundary conditions of extreme environments - (cross-disciplinary)
2. Molecular adaptation and stability in extreme environments - (cross-disciplinary)
3. Microbial life in extreme environments
4. Life strategies of plants in extreme environments
5. Life strategies of animals in extreme environments
6. Human adaptation to extreme environments
7. Enabling technologies and applications - (cross-disciplinary)

In addition to the presentation sessions, working groups were established around five topics:

1. Microbial life in extreme environments
2. Life strategies of plants in extreme environments
3. Life strategies of animals in extreme environments
4. Human adaptation to extreme environments
5. Enabling technologies and applications

This report results from this workshop and a further one held in March 2006 in Strasbourg, the latter gathering the Steering Committee set up for this initiative as well as the sessions' chairpersons and rapporteurs. This report synthesises points of view regarding priorities and recommendations as expressed by the scientific community involved in this ESF initiative.

Investigating Life in Extreme Environments - A European Perspective
Editor: Nicolas Walter • **Contributors:** Ricardo Amils, Arnoldus Blix, Michael Danson, Christine Ebel, Cynan Ellis-Evans, Françoise Gaill, Helmut Hinghofer-Szalkay, Kai-Uwe Hinrichs, Francesco Loreto, Daniel Prieur, Farzam Ranjbaran, Klaus Valentin, Elisabeth Vestergaard, Nicolas Walter • **Acknowledgement:** The European Science Foundation would like to thank the following scientists who provided valuable comments and inputs on the present report: Stéphane Blanc, Charles Cockell, Terry Callaghan, Horst Felbeck, Claude Gharib, Yvon le Maho, Steven Scott.

Contents

Foreword

From the deepest seafloor to the highest mountain, from the hottest region to the cold Antarctic plateau, environments labelled as extreme are numerous on Earth and they present a wide variety of features and characteristics. The life processes occurring within these environments are equally diverse, not only depending on stress factors (e.g. temperature, pressure, pH and chemicals), but also on the type of life forms, ranging from microbes to higher species.

How is life limited by and adapted to extreme external biotic and abiotic factors? This key question summarises the deliberations raised by this exciting and fascinating research area. Addressing the challenge of answering this question would help to reveal new insights and refine theories concerning the origin and evolution of life on our planet, as well as life beyond Earth. Investigating life processes under extreme conditions can also provide new clues towards understanding and predicting ecosystems' responses to global change. Furthermore, this area of research has a wide application potential in the fields of (bio)technology, chemical and pharmaceutical industry, biomedicine and cosmetics.

Depending on the type of organism studied, addressing extreme environments presents different situations and issues to be considered. However, some transversal priorities stand out and have been identified in this report. The scientific community is calling for:

- **More consideration to be given to the ecosystem-based approach** when studying life in extreme environments;
- **The identification of model organisms in different phyla and for different extreme environments** to focus the research effort and provide a common framework for research activities;
- **The use of molecular structural biology and genomics tools**.

Looking at the European scientific landscape, the research community is aware of the benefits that would be derived from enhanced information flow between communities with different interests, as well as with the technological side of their research. It is apparent that an **interdisciplinary approach should be extensively promoted and supported** when it comes to examining life processes in extreme environments. It is also important to acknowledge that **scientific outcomes could benefit considerably from better networking and coordination among scientific communities involved in these areas of research.**

The European Science Foundation's (ESF) report *Investigating Life in Extreme Environments* is the result of a process that began in February 2004 with a call for Expressions of Interest addressed to the European scientific community. The high level of response convinced the ESF that the subject was an emerging interdisciplinary research domain that deserves attention.

In November 2005 a large-scale multidisciplinary workshop gathering 128 participants was organised in Sant Feliu de Guixols (Spain) to debate and put forward the scientific case and needs when considering Life in Extreme Environments in the broadest sense: from microbial life to human adaptation, from the depth of the oceans to outer space and planetary bodies. Since the marine and polar science communities expressed a strong interest from the early stages of the initiative, they were largely represented at the workshop and they were very active in providing their input and perspectives.

This report synthesises the findings expressed during the Sant Feliu de Guixols workshop. The content and recommendations presented here are not intended to be exhaustive, but are rather a first expression of integrated issues which can be considered among other priorities to be identified in future initiatives.

While the recommendations are developed in the context of extreme environments, many may be of relevance to other, more conventional research domains. Their application would provide a greater leverage effect on the scientific and technical achievements when considering specifically research on life processes in extreme environments.

These outcomes and findings advocate for the development of further knowledge in this area, and also for structuring the scientific landscape. This would catalyse scientific and technical achievements for the benefit of science and society. It is clear that additional steps and initiatives should be taken in the field of investigating life in extreme environments in Europe, furthering the efforts of this ESF initiative and broadening it to include areas yet to be addressed.

Bertil Andersson
CEO
European Science Foundation

Daniel Prieur
Chairman of the ESF
Investigating Life in Extreme Environments
workshop

Executive summary and summary of recommendations

General considerations

1. Coping with extreme conditions, microbes, plants and animals have demonstrated the ability to adapt and metabolise under high environmental stress. Relying on specific and complicated mechanisms, some organisms even require such conditions to live and evolve.

2. For most environmental parameters constraining life, specific limits have been established (but not definitely set) beyond which life, in its whole cycle, has never been described to date. **A given environment, where one or more parameters show values permanently close to lower or upper limits known for life, may be considered as an 'extreme environment'.**

3. When considering research activities and investigations on life in extreme environments, the overarching question is **'How is life limited by and has adapted to extreme external biotic and abiotic factors?'**

4. Certain physical and chemical conditions of some Earth-based extreme environments could be considered analogous to our planet's environment in its early stages of development and to other planetary bodies. Investigating life processes in these environments helps to consider questions of the origin of life on our planet and the presence of life beyond the Earth.

5. Earth is becoming increasingly exposed to severe environmental modifications because of anthropogenic activity. Changes on a global or regional scale are resulting in some environments becoming 'extreme' for the functioning of their existing ecosystems. It is also important to note that global change leads some extreme environments to become benign, with the risk of losing biodiversity of those species used to extreme conditions. Investigation of the metabolism and adaptation processes of some species accustomed to extreme and highly variable environments are relevant in trying to understand the foreseeable impacts of global change on ecosystems.

6. The study of humans evolving in extreme environments provides new keys and understanding of psychological, physiological, social and societal functioning of individuals, groups and populations.

Priorities of cross-cutting relevance

7. When considering research activities on microbes, plants, animals or humans evolving in extreme environments, several transversal scientific priorities arise for the scientific community. These priorities include: i) the identification of model organisms evolving in extreme environments, and the identification of model extreme environments; ii) the application of ecosystem-based approaches to scientific activities in extreme environments; and iii) developing investigation of life processes in extreme environments through molecular structural biology and genomics.

8. Model organisms and extreme environments - Recommendation:

- Identify and agree on i) model organisms in different phyla and for different extreme environments; and ii) model extreme environments, on which research activities across Europe would focus. Not only would these systems focus research activities in a concerted manner but they would bring a long-term perspective and an observatory component to the scene. Providing a common framework, they would also allow the development of comparative studies across domains and disciplines ***(Recommendation 1)***.

9. An ecosystem-based approach applied to extreme environments - Recommendations:

- Favour an ecosystem-based multidisciplinary approach when considering scientific activities in extreme environments. When dealing with the complex interplay of biotic and abiotic processes structuring ecosystems, emphasis should be given to describing the interface between biology and geochemistry ***(Recommendation 2)***.
- All environments have some degree of seasonal and spatial variability. Spatial and temporal variability, including long-term monitoring, need to be considered when planning and performing research activities in extreme environments ***(Recommendation 3)***.
- Evolution, dynamics and recovery of ecosystems in response to disturbances

should be investigated to further understand current and future factors influencing ecosystems' structure and functioning. This is of particular relevance when considering global change and anthropogenic pressures currently put on the Earth's environments ***(Recommendation 4)***.

10. **Molecular structural biology and genomics -** Recommendations:

    - Initiate efforts to integrate studies encompassing genomics, genetics, cellular and molecular biochemistry, biophysics and structural biology aimed at investigating life in extreme environments ***(Recommendation 5)***.
    - Compare genomes and proteomes and identify intracellular chemical and physical parameters for related organisms or cell communities adapted to different extreme environments ***(Recommendation 6)***.
    - Through functional and structural genomics, exploit the potential of the archaea and other microorganisms adapted to extremes as tractable models for difficult-to-study homologous human and pathogen macromolecular systems ***(Recommendation 7)***.

Scientific issues of specific interest

11. In addition to cross-cutting priorities and recommendations, several specific recommendations are expressed concerning: i) microbial life in extreme environments; ii) life strategies of plants in extreme environments; iii) life strategies of animals in extreme environments; and iv) human adaptation to extreme environments.

12. Recommendations on **microbial life in extreme environments** include:

    - Investigate further the molecular basis of the physiological adaptation of microbes to extreme environments, especially with regard to DNA, RNA and protection of cellular metabolites ***(Recommendation M1)***.
    - The deep subsurface (oceanic and continental) exhibits unique features in terms of temperature, pressure and availability of energy. Investigating the subsurface microbial processes further, especially with regard to cell division, would deepen the fundamental understanding of life and concepts of cell maintenance. Moreover, understanding the role of the subsurface in biogeochemical cycles is essential for an assessment of element budgets on a global scale ***(Recommendation M2)***.
    - Microbial extremophiles cover all three domains of microbial life, bacteria, archaea and eukaryotes. Comparative adaptation to different environmental stressors would provide a very useful insight into the nature and evolution of extremophilic organisms ***(Recommendation M3)***.

13. Recommendations on **life strategies of plants in extreme environments** include:

    - Give focus to boosting progress in molecular and biochemical studies and to unravelling the mechanistic basis of plant life under extreme conditions ***(Recommendation P1)***.
    - Study the strategies of adaptation (from the molecular to the ecosystem level) which allow plant life in extreme environments, as well as plants' strategies of reproduction and dissemination in their long-term efforts to avoid environments becoming hostile ***(Recommendation P2)***.
    - When considering studies on plant life in extreme environments, a particular attention should be given on fragile ecosystems, including ecosystems that are starting to be colonised by plants, or that are becoming unfavourable to plant life, especially as a consequence of global change and human-driven land use change. Study strategies of survival at this boundary that may be – or may become – of utmost importance for plant survival, for plant loss of diversity, and for the entire food-chain based on plant life ***(Recommendation P3)***.

14. Recommendations on **life strategies of animals in extreme environments** include:

    - Comparative studies are needed to determine the specificities of animals, communities and ecosystem responses to different types of environmental stress ***(Recommendation A1)***.
    - Favour characterisation studies on extreme environments and their interactions with animals; this would help in understanding adaptation processes ***(Recommendation A2)***.

- The analysis of the biodiversity dynamics of animal communities and ecosystems found in extreme environments, including palaeontological approaches, has to be promoted to understand the evolution of life in extreme environments ***(Recommendation A3)***.
- *In vivo* approaches simulating the natural environment are needed to help in the knowledge and prediction of the tolerance of animals to environmental changes ***(Recommendation A4)***.

15. Recommendations on **human adaptation in extreme environments include**:

- Bring together humanities, social sciences, psychology and medical sciences under the label of Human Sciences in studies on human adaptation to extreme environments ***(Recommendation H1)***.
- Issues of environmental monitoring and control have an important role both in artificial and confined environments as well as in natural environments. These aspects should be further investigated when considering humans, not only because the environment influences them, but also because there is an adaptive effect that humans impose upon the environment ***(Recommendation H2)***.
- When considering human species, favour cross-disciplinary dialogue and interactions while dealing with different levels of systems hierarchy at the same time. ***(Recommendation H3)***.
- Address systematically and carefully ethical issues when considering human adaptation to extreme environments ***(Recommendation H4)***.

Technological issues

16. Technology sees itself as a clear cross-cutting issue of major relevance and its barriers as one of the main limiting factors for the development of knowledge on life processes in extreme environments. Recommendations on **technological issues** include:

- Develop interdisciplinary initiatives to define environment-specific technological and technical requirements, their availability and a road-map for their development ***(Recommendation T1)***.
- Support the development of initiatives aiming to improve information exchange on available technologies and new developments throughout the scientific community involved in extreme environments ***(Recommendation T2)***.
- Develop and support mechanisms to facilitate access to and sharing of existing and future technical platforms and infrastructures to be used when accessing extreme environments ***(Recommendation T3)***.
- Consider further the enhancement of the European simulation capability in the field of extreme environments. Relevant simulation facilities (e.g. microcosms) should be developed ***(Recommendation T4)***.
- Develop *in situ* sampling, measurement and monitoring technologies (e.g. light-weight, low-power, and robust sensors) and capacity (e.g. in situ observatories and bio-logging). Categorisation and inventory of existing systems, technologies and techniques are also recommended. ***(Recommendation T5)***.

Economic and societal applications

17. Extremophilic species may have an important role to play in improving and creating some industrial processes. Furthermore, they potentially allow the development of new products.

18. Development of high-quality and robust facilities and technological capabilities developed for scientific activities in extreme environments brings together industries and research institutions. Through their involvement in such activities, they develop and gain knowledge, competencies and capabilities relevant to a wide range of industrial and economic sectors.

Policy aspects — the European arena

19. At the international level, Europe currently leads in areas such as polar research, biodiversity, and global change, although without a specific focus on extreme conditions. Polar and deep-sea research fields appear to be areas of excellence in Europe. In considering the type of organisms, the study of microbes, plants and animals are reasonably mature areas of research.

20. A strong benefit can be expected from international collaboration. This is of particular relevance in areas of global significance.

The need for further interdisciplinarity

21. Compartmentalisation between disciplines and their associated technological developments is seen as a major hurdle to greater efficiency in scientific activities, even if this statement applies to a whole range of scientific activities, it is of particular relevance when considering scientific and technological activities in extreme environments. Therefore, interdisciplinarity and multidisciplinarity between scientific domains and between the technological and scientific spheres is identified as a major source of potential increase in scientific achievements. When relevant, these aspects should be extensively promoted and supported as much as possible when considering life processes in extreme environments ***(Recommendation 8)***.

Networking and coordination

22. While high-level expertise and know-how have been developed at the European level, the fragmentation of this knowledge and the lack of coordination across initiatives are major constraints to the further development of a pan-European capacity. Therefore, it is recommended:

- To create as soon as possible an overarching interdisciplinary group of experts to define the necessary actions to build a critical European mass in the field of Investigating Life in Extreme Environments ***(Recommendation 9)***.
- That effort should be made to support and improve information exchange, coordination and networking of the European community involved in scientific activities in extreme environments. This could be achieved through a Coordination Action supported by the European Commission and include the development of a Web portal and associated developments (database of experts, dissemination of information). In this context, large-scale multidisciplinary events (e.g. conferences, fora and workshops) should be organised regularly in order to build and maintain momentum at the European level. This should be done in the context of the numerous specialised events that are already organised ***(Recommendation 10)***.

Programme issues

23. Overall, and especially because of their specificities and positioning at the frontier of science, research activities dealing with life processes in extreme environments raises issues such as: i) the long planning horizons that are necessary for field expeditions and the difficulty for the scientific community to become part of them; ii) the cost of carrying out scientific activities in such environments; and iii) the difficulty in accessing national research resources. It is recommended that:

- Extreme environments are integrated into national science strategy and clearly identified in national and European scientific calls and programmes ***(Recommendation 11)***.
- When considering scientific activities involving extreme environments, funding agencies should ensure that their assessment procedures can adequately review proposals involving a multidisciplinary approach as opposed to the more typical, strongly focused proposals ***(Recommendation 12)***.

Public outreach and education

24. It is important to inform the public on issues related to extreme environments, highlighting the exotic nature of these environments, their biota and their societal and economic potential.

25. It is fundamental to secure the transmission of extreme environments scientific knowledge to students and young scientists.

1. General considerations

1.1. Why investigating life in extreme environments is important

Life and extreme environments

To our present knowledge, the Earth seems to be the single habitable and inhabited planet within the solar system. The concept of habitability is often defined in terms of the requirements for human existence. However, that part of the Earth's biosphere permanently inhabited by human beings is rather small and most of the planet, its deep core or mantle, will clearly never see a living organism. In between these two zones (inhabited and uninhabited), a variety of environments exist where human beings cannot live permanently, or physically access, although other forms of life exist within them.

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Hydothermal vent — 2 ,630m deep

Coping with these latter environments, microbes, plants and animals have demonstrated the ability to adapt and metabolise under high environmental stress. Relying on specific and complicated mechanisms, some organisms even require such conditions to live and evolve.

From the bottom of the seas to the highest mountains, from the hottest regions to the cold Antarctic plateau, environments labelled as 'extreme' are numerous on Earth and they present a wide variety of features and characteristics. The life processes occurring within these environments are equally diverse, not only depending on stress factors but also on the type organisms, ranging from microbes to higher species.

Polar regions, outer space or deep-sea, these environments have always triggered human curiosity and their exploration has fascinated not only scientists but also the general public. However, they have been explored or sampled only very recently, mainly because of earlier technical limitations. This exploration is still in its infancy and novel organisms (e.g. extremophilic microbes), novel habitats (e.g. the deep subsurface, subglacial lakes or unexplored regions of the seafloor) and novel technological applications (e.g. bacteriorhodopsine for optical computers and information storage, acidophilic chemolithotrophic microorganisms for biomining and polymerase chain reaction) continue to be discovered.

Furthermore — and this is a key point about extreme environments — because of their particular characteristics and features, they provide a wide range of unique natural laboratories for the scientific community. Similarly unique are the multidisciplinary aspects of means and infrastructures that are utilised to conduct scientific activities within such environments. For example, polar stations are designed to facilitate a large spectrum of scientific activity, including biology, geology, atmospheric or medical research whilst underwater Remotely Operated Vehicles (ROVs) can be used for geological as well as biological surveys and sampling.

Credit : R. Amils

Rio Tinto (Spain)

1. General considerations

The relevance of studying life processes in extreme environments

Certain physical and chemical conditions of some Earth-based extreme environments could be considered analogous to our planet's environment in its early stages of development. Extending our knowledge of life processes in conditions broadly comparable to the paleo-environments of Earth would help reveal new insights and refine theories about the origin of life and how it has evolved over time on a constantly changing planet. In this context, attention should be given to fossil life forms such as microorganisms brought back to life from a state of deep sleep/dormancy for hundreds of thousands of years in ice (ice cores from Lake Vostock), a million years in permafrost, 25-40 million years in amber and an astounding 250 million years in salt crystals [1.1].

Furthermore, consideration should also be given to past extreme environments that resulted in mass extinctions and new evolution events (e.g. when oceans were anoxic, when there was darkness and low temperatures following the meteorite crash into the Gulf of Mexico, and when UV-B radiation was likely to be exceptionally high following massive volcanic activity of the Siberian plates). Much can be learned from these episodes.

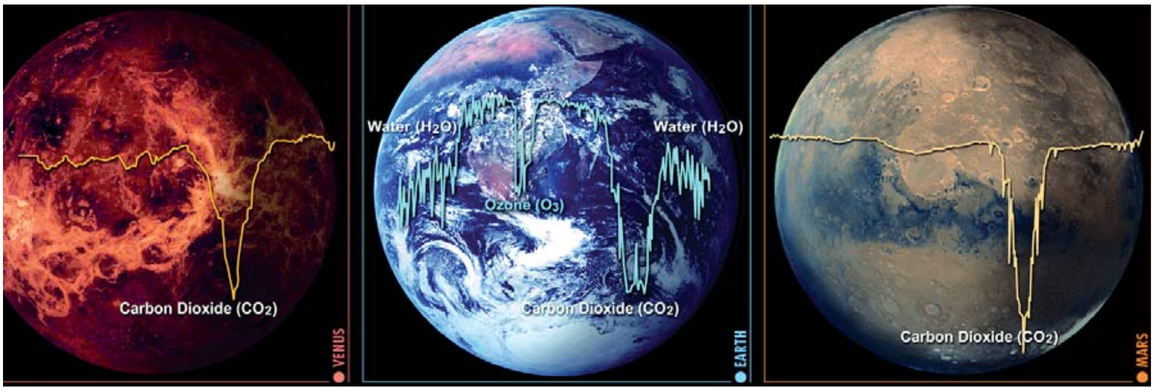
Not only are extreme environments thought to provide some analogy with those existing on the early Earth, but also some can be considered to show some similarities with other planetary bodies. One salient example of this is the analogy between Antarctica's subglacial lakes and the Jovian icy moon Europa [1.2], where a large amount of liquid water is thought to be present under a thick layer of ice. Investigating life processes in extreme environments may provide potential scenarios for possible extraterrestrial life, thus helping to consider that major question: *Is there life beyond the Earth?*

Credit : M. Danson

Mont Erebus Volcano in Antarctica

At present, planet Earth is increasingly exposed to severe environmental modifications, because of anthropogenic activities. Changes on a global or regional scale are resulting in some environments becoming 'extreme' for the functioning of their existing ecosystems; examples include acidification of the oceans and more frequent extreme climatic events such as severe droughts or flooding. It is also important to note that global change leads some extreme environments to become benign, with the risk of losing biodiversity of those species used to extreme conditions. In this context, investigation of the metabolism and adaptation processes of some species accustomed to extreme and highly variable environments are relevant in trying to understand the foreseeable impacts of global change on ecosystems.

The high stress level that can be induced in living organism by extreme conditions leads to the development of mechanisms that mitigate the potential negative effect of such environments. Depending on the stress factor, some mechanisms are fundamental for survival and are extremely developed and active. While in more conventional conditions they would be hardly noticeable, these physiological mechanisms are then much more visible and identifiable and can be better studied in extreme environments.



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Spectra from different Earth-like planets

The study of humans evolving in extreme environments provides new keys to the understanding of psychological, physiological, social and societal functioning of individuals and groups. The isolation and hazardousness of external environments are sources of major psychological stress; e.g. microgravity and the level of physical activities in confined areas have physiological impacts. Studying these aspects and their feedback mechanisms is fully relevant to scientific activities in extreme environments as they not only provide information about human functioning but also because scientific activities in harsh conditions are partially dependent on the human presence and its ability to perform research.

Indeed, other human groups than scientific personnel are evolving in environments that can be considered as extreme, arctic populations being an evident example. In this perspective, it is important to note that it is not only physico-chemical factors that can lead an environment to be extreme for its population, but also political, social and cultural factors. When considering populations evolving in such environments a particular feature is the high degree of transdisciplinarity and multidimensionality of the research involved. Understanding the mechanisms which make an impact on populations and individuals, studying their response and trying to develop mitigation means is extremely challenging and requires commitment from the social and human sciences communities.

On the applications side, industrial processes often induce conditions that are extreme in terms of pH, temperature and pressure. In these conditions, the development of extremophilic enzymes may have an important role to play in improving the efficiency of these processes and could even form the basis of new ones (e.g. for the textile or the food-processing industries). Furthermore, studies of extremophilic species and their properties have revealed features that potentially allow the development of new products in various fields such as cosmetics, food stabilisation, oil spill response, de-pollution or pharmaceutical applications.

Overall, extreme environments have features that are challenging for any research activity and their associated technological development. At the forefront of the technological challenges induced by extreme environments are issues of automation of sampling, monitoring and analysing equipment, miniaturisation of sensors and robotics. Industries and research institutions involved in generating such capabilities are developing competencies and know-how applicable to a whole range of high added-value activities.

It is important to foster and catalyse research activities on life processes in extreme environments, not only because they are applicable to some of the main scientific questions such as understanding the basics of life processes, the origin of life or the potential existence of extraterrestrial life, but also because the economic potential behind these activities is important. For all these reasons, 'investigating life in extreme environments' represents a major challenge for Earth's inhabitants at the beginning of the 21st century.

1.2 Defining the issue

Life, as we know it, is constrained by a series of environmental parameters (physical and chemical), whose values may vary according to space and time. Combinations of specific ranges for each of these parameters within a particular area define biotopes, or sets of environmental conditions, suitable for a given species. In its habitat, a given species carries out its complete life cycle.

For most environmental parameters constraining life, specific limits have been established (but not definitely set) beyond which life, in its whole cycle, has never been described to date (Table 1). For example, the highest temperature allowing the complete life cycle of an organism *(the archaeon Pyrolobus fumarii)* is 113°C, the lowest is -18°C. **A given environment, where one or more parameters show values permanently close to the lower or upper limits known for life may be considered as an 'extreme environment'.**

Credit: ESA/DLR/FU Berlin (G. Neukum)

Nanedi Valles valley system on Mars

1. General considerations

More generally, environments with parameters that put some particular species under threat (approaching its own limits), can be considered as 'extreme'. This is of particular relevance when considering global change issues, rapid environmental change such as drought or flooding and exceptional conditions; these issues are also considered in this report.

Extreme conditions are a requirement for some organisms to carry out their complete life cycle; some organisms have developed mechanisms to survive (without cell division or reproduction) for short or long (even very long) periods in extreme physico-chemical conditions, that mostly consist of dormancy stages. It is interesting to note that not only microorganisms, spores, seeds or cysts are able to go into a dormancy stage but also higher species such as tardigrades or nematodes – even the African lungfish can survive for years without water in dried up wadis of North Africa.

Overall, it is important to note that when considering extreme environments, *Homo sapiens*, represents a particular case as it has developed a variety of technologies to adapt more or less permanently to extreme conditions.

Table 1: Examples of parameters constraining life processes

Environmental parameters	Known lower limit for life	Known higher limit for life	Comments
Temperature	-18°C [1.3]	113°C [1.4]	Mean human body temperature 37°C
Pressure	10^{-14} Pa [1.5]	130 MPa [1.6]	Atmospheric pressure: 101 KPa
pH	Negative [1.7]	13.2 [1.8]	Neutral pH: 7
Salt concentration	None	5 M [1.6]	Human blood saltiness: 3.5 %
Water activity	0.7 [1.9]	1.0 [1.9]	
Light	Darkness	Variable	High light levels can cause photoinhibition and free radical formation
Highly energetic radiation	None	1.5 MRad [1.10]	1.5 MRad is 3,000 times the lethal level for humans

1.3. The Earth and beyond

A few typical extreme environments can be identified; the tables below (not exhaustive) describe them along with the environmental stressors that lead them to be considered as ‘extreme’.

Marine extreme environments

Deep-sea

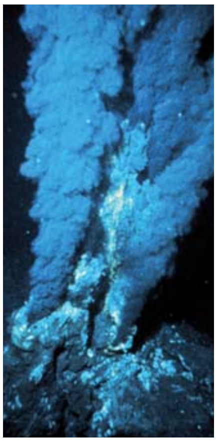
©Ifremer/Campagne - Biozaire 2 - 2001

Location:	Between 700 and 10,000m deep in seas and oceans
Environmental stressors:	
• Temperature	Low – between 2°C and 4°C
• Pressure	Very high – up to 1,000 MPa
• Light	Non-existent

Comments:

- *Broad gradients of parameters on a large spatial scale.*
- *World’s deepest seafloor is at 10,898 m below the ocean surface (Mariana trench).*
- *Bacteria [1.11] and eukaryotes [1.12] have been found in the deepest depths of the oceans.*

Hydrothermal vents



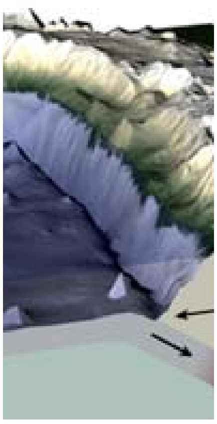
Credit:OAR/NURP/NOAA

Location:	Sparsely distributed on geoactive seafloors at different depths (Some vents are found in shallow water)
Environmental stressors:	
• Temperature	Very high at the vent chimney - up to 420°C while low in the surroundings
• Pressure	High to very high - depending on the vent’s depth
• Light	Low to non-existent
• Chemical stressors	High concentration of chemicals dissolved in the vent fluids, and low oxygen concentration
• pH	Low

Comments:

- *Steep gradients of parameters on a small spatial scale.*
- *High concentrations of potentially toxic chemicals.*
- *The most thermo-tolerant organism, the archaea Pyrolobus fumarii, was found in such environments. [1.4]*

Continental margins (active and passive)



Credit Robert Simmon - NASA GSFC

Location:	On the leading edge of a continental plate where it is colliding with an oceanic plate (e.g. western Pacific subduction zones) or on the trailing edge where continental crust is rifting (e.g. Atlantic passive margins).
Environmental stressors:	
• Temperature	High, because of tectonic activity in active margins Low in passive margins
• Pressure	High to very high - depending on the depth
• Light	Non-existent
• Chemical stressors	High concentration of chemicals, low oxygen, high salinity brines

Comments:

- *Hosts various types of geobiological features such as benthic ecosystems fuelled by cold seeps and/or mud volcanoes.*
- *Dynamic processes impacting the environment and disturbing the animal communities and more generally the existing ecosystems.*

1. General considerations

Marine and terrestrial extreme environments

Continental and seafloor subsurfaces

Credit: IODP-USIO

Location: Beneath the continental surface or seafloor

Environmental stressors:

- **Temperature** — Low to very high
- **Pressure** — High to very high
- **Light** — Non-existent
- **Chemical stressors** — Depending on the geological context

Comments:
- *Extremely low energy availability and long-term life processes.*
- *Bacteria found 3,200 m beneath surface. [1.13]*

Intertidal coastal areas

Credit: B. Casterline

Location: On the seashore, between low tide and high tide level, at the junction of sea, atmosphere and lithosphere

Environmental stressors:

- **Temperature** — High variability of temperature
- **Light** — High variability of exposure
- **Dryness** — High variability of the level of humidity

Comments:
- *Very dynamic environments, strong water flow.*

Hypersaline medium

Credit: R. Amils

Location: On the ground, in lakes or in the sea

Environmental stressors:

- **Chemical stressors** — High concentration of salt

Comments:
- *Different ions according to geological context.*
- *For terrestrial hypersaline media, intense evaporation, high UV and high temperatures because of their location.*

Terrestrial extreme environments

Polar regions

© IPEV – Alain Fornet

Location: Areas of the globe surrounding the poles, north of the Arctic circle, or south of the Antarctic circle.

Environmental stressors:

- **Temperature** — Very low – world's coldest record: -89.2°C in Vostok station in Antarctica
- **Dryness** — Very high in mainland - mean humidity 0.03% in Antarctica dry desert.
- **Light** — Non-existent during the 4-month winter in latitudes higher than the polar circles
- **High energetic radiations** — High due to the characteristics of the Earth magnetic field at these latitudes

Comments:
- *Relevant for human adaptation studies.*

Hot springs

Location: Sparsely distributed on the Earth's surface, usually in geoactive zone

Environmental stressors:

- **Temperature** High to very high
- **Chemical stressors** High concentration of chemicals

High altitude (and glaciers)

Location: In mountains, above 1,500m altitude, up to more that 8,800m

Environmental stressors:

- **Temperature** Low – decreasing with altitude
- **Atmospheric pressure** Low atmospheric pressure – decreasing with altitude
- **Dryness** High – increasing with altitude
- **High energetic radiations** High – increasing with altitude

Comment:
- *Relevant for human adaptation studies.*

Hot arid regions and deserts

Location: Sparsely distributed on the Earth's surface. For example the Sahara or Atacama deserts.

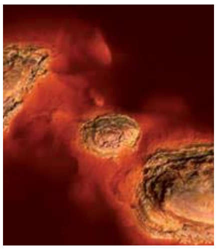
Environmental stressors:

- **Temperature** High and wide daily amplitude – 57.7°C measured at El Azizia in Libya
- **Dryness** High – constant lack of water
- **Light** High solar radiation pressure

Comment:
- *Relevant for human adaptation studies.*

Acidic environments

Credit: R. Amils



Location: Sparsely distributed on the Earth's surface, often following volcanic activities and metallic mining activities

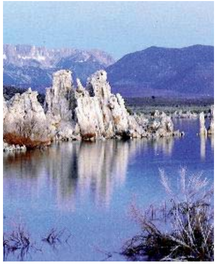
Environmental stressors:

- **Temperature** Moderate to high
- **Chemical stressors** High concentration of heavy metals
- **pH** Low (<7) to negative – Hyperacidic media have a ph<<1

Comment:
- *Some of these extreme environments are the product of microbial activity.*

1. General considerations

Alkaline environments



© Larry Fellows, Arizona - Geological Survey

Location:	Sparsely distributed on the Earth's surface. Soda lakes and soda deserts are typical examples
Environmental stressors:	
• **Temperature**	Depending on the location
• **Chemical stressors**	Usually high concentration of salt and sodium carbonate (a few alkaline lakes are non-saline)
• **pH**	High: between 7 and 14 – Hyperalkaline media have a pH>10

Comments:
- *Microbial life up to pH 13.2, some fish and shrimps evolve at pH 10.*

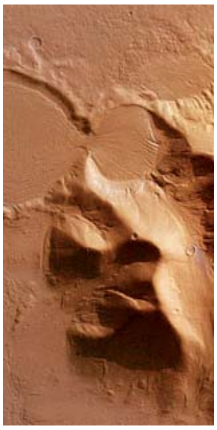
Environments strongly shaped by humans

Location:	Anywhere on Earth where human activity has induced major changes
Environmental stressors:	
• **Temperature**	Global warning induces increased temperatures
• **Light**	Enhanced UV-B radiation because of ozone layer depletion
• **Chemical stressors**	High concentration of polluting chemicals (heavy metals, hydrocarbons)

Comments:
- *Wide variety of disturbances, with local (e.g. mercury concentration in Amazonian rivers or acid mine drainage) and global (acidification of the oceans or global warming) impact, including over-exploited ecosystems.*

Outer space

Planetary bodies



Credits: ESA/DLR/FU - Berlin (G. Neukum)

Location:	In outer space, large celestial masses of rock, metal, or gas orbiting around a star.
Environmental stressors:	
• **Temperature**	All ranges of temperature from extremely low (less than -200°C) to extremely high (more than 300°C) – High variability because of rotation
• **Pressure**	From null to very high, depending on the atmosphere
• **Light**	From very low to very high exposure, depending on the position with regards to the star
• **High energetic radiations**	Typically very high, because of cosmic rays and central star's radiations

Comment:
- *Wide variety of environments, some include liquid water, as probably under the thick ice layer of the Jovian Moon Europa.*
- *Different level of gravity, depending on the mass.*

Space vessels/space environment

Credits: NASA

Location: In outer space, spacecraft, evolving in microgravity.

Environmental stressors:

- **Temperature** — All range of temperatures from extremely low to very high on external exposed facilities
- **Pressure** — Null on external exposed facilities
- **High energetic radiations** — From high in shielded areas to very high on external exposed facilities.

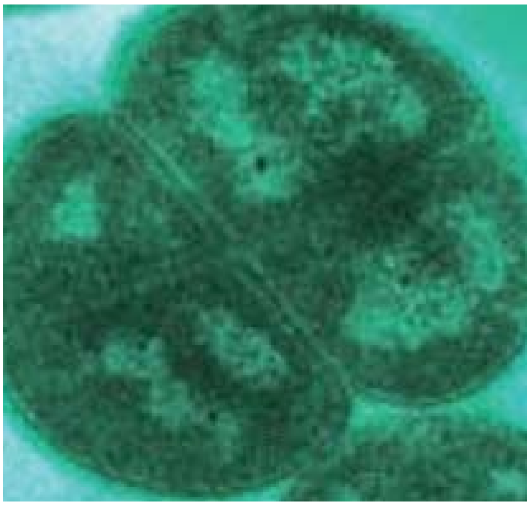
Comment:

- *Unique characteristic: Very low level of gravity (impossible to be simulated for a long period on Earth).*
- *Space vessels are confined and isolated environments – relevant for human adaptation studies.*
- *Bacillus subtilis can survive six years of exposure to the space environment (dormancy stage).*

1.4. Questions arising

When considering research activities and investigations on life in extreme environments, the overarching question is: ***'How is life limited by and how has it adapted to extreme external biotic and abiotic factors?'*** Considering this question and investigating this field involves developing new approaches, methods and tools as well as fostering those already in use; e.g. in accessing to extreme environments, sampling, in situ monitoring, laboratory simulation, or high performance analysis.

Credit: US-DoE



The polyextremophile Bacteria *Deinococcus radiodurans*

At a more detailed level, several fundamental questions arise that are relevant to any life forms from microbes to vertebrates.

What limits life on Earth in general?

This encompasses an understanding of what limits life under extreme conditions of e.g. temperature, salinity, pressure, pH, chemical composition of the environment or radiation (including light/darkness) and understanding how extremophilic organisms are different from conventional organisms.

What limits life with respect to certain groups or processes?

Considering this issue requires the use of disciplines such as molecular biology, ecology and physiology in order to understand how species colonise new environments or confront new stressors (e.g. high concentration of metals in soils and water, salinisation of soils and urban environment pollution).

All stages in the life cycle and the total life cycle as a whole need to be investigated to answer this question.

What limits individual species and to what extent can they usually acclimatise or adapt?

This encompasses the adaptation mechanisms associated with specific extreme environments: how have life forms been shaped by evolution to cope with hostile conditions? This question is of particular relevance when considering that global change leads some environments to become hostile for their living organisms (e.g. ocean acidification, enhanced UV radiation in polar regions, extension of deserts, pollution, reduction in sea ice and warming of the ocean). Investigating the capacity of species to face variations in their environmental conditions would allow a definition of the limits of these adaptive mechanisms and is a key to predicting future patterns of biodiversity loss or increase or ecosystem change. In this context it is important to consider not only adaptation to single stressors but also adaptation to multistressors because some environments provide a combination of environmental stressors.

What limits communities or ecosystems evolving in extreme environments; i.e. which parameters shape an ecosystem so that any change may drastically alter that ecosystem?

Some characteristic extremophilic species (e.g. resurrection plants of arid environments or acidophilic chemolithotrophs from acidic environments) have been investigated in some detail but little is known about interactions among species; e.g. multi-trophic relationships involved in life in extreme conditions. A multi-disciplinary effort is needed to characterise ecosystems in extreme environments. A particular issue would be to investigate how extremophiles shape their environment, another would be to compare the functions of ecosystems across a variety of extreme environments. (See also Section 2.1.2).

Credit: M. Danson

Santa Pola saltern (Spain)

© CNRS Photothèque/IPEV

King Penguin Colony

What happens to species facing a new environment?

This encompasses the study of the molecular and biochemical bases of response to conditions involving factors and stresses not yet experienced. A comprehensive understanding of the survival strategies of species through comparative genomics and proteomics would provide biological insights. These insights would not only involve new aspects of physiology and evolution that may be unique to extremophiles, but could also uncover some unknown adaptations required for life in stressful environments that may be shared across all domains of life. A special focus should be given to adaptations to absence of gravity, low temperature, low pressure, pollution and unusual radiation.

Besides these life process-focused issues, extreme environments also raise questions per se:

In what way are certain extreme environments analogues for ancient terrestrial and extra-terrestrial environments?

The study of current life forms adapted to extreme conditions will certainly bring insights to the early history of life on Earth and its potential analogues in the universe. First, it is recognised that hostile conditions (temperature, radiations and perhaps high salinity) prevailed while life emerged on Earth. Second, planetary exploration missions provided evidence for internal water, high salt conditions and low temperatures in the solar system, analogous to conditions found in certain areas on Earth; e.g. polar regions or the deep hypersaline ecosystems from the seafloor of the Mediterranean Sea. It is also important to mention that salt-adapted organisms display a remarkable ability to withstand dehydration, multiple stresses and to survive over geological time when trapped in salt crystals. Understanding the mechanisms responsible for this robustness may guide the search for traces of life on other planets.

What is the role of a particular extreme environment for regional/global ecology and element cycles?

So far, we do not understand the role of extreme environments in global biogeochemical cycles. For example, the contribution of the extreme marine environments to budgets of climatically relevant gasses (e.g. methane hydrates in continental margins) is largely unknown. Extreme environments can be sources of elements potentially hazardous to the hydrosphere and atmosphere, on the regional to global scale. Strong interactions between living organisms and inanimate matter, such as those that have shaped the Earth system over geological time, can play a fundamental role in buffering these emissions. These interactions also drive the functioning of unique ecosystems, sustaining energy transfer from the geosphere to the biosphere.

An additional consideration is:

What is the potential societal and economic value of extreme adaptation?

Organisms living in extreme environments must cope with higher levels of stressors and mutagenic agents than normal. Consequently, they are thought to have developed mechanisms that confer a high degree of resistance to damaging agents. Investigating these properties brings new potentialities of relevance to industrial processes including biotechnology, pharmaceutical applications or cosmetics that could be used for the benefit of human health, economic growth and sustainability. (See also Section 4)

© Ifremer/Campagne Phare 2002

2,630m deep: gills of giant worms Riftia, sea-anemones and gastropods

2. Scientific priorities

Life under extreme conditions is a reality for a whole range of life forms. When considering future research activities on microbes, plants, animals or humans evolving in extreme environments, several scientific priorities arise for the European community involved. Among the priorities identified by the participants to the ESF workshop, three are cross-cutting to the study of microbes, plants and animals (and to a lesser extent, humans). In addition, scientific priorities specific to each of them have also been identified. From priorities, recommendations have been developed.

2.1 Priorities of cross-cutting relevance

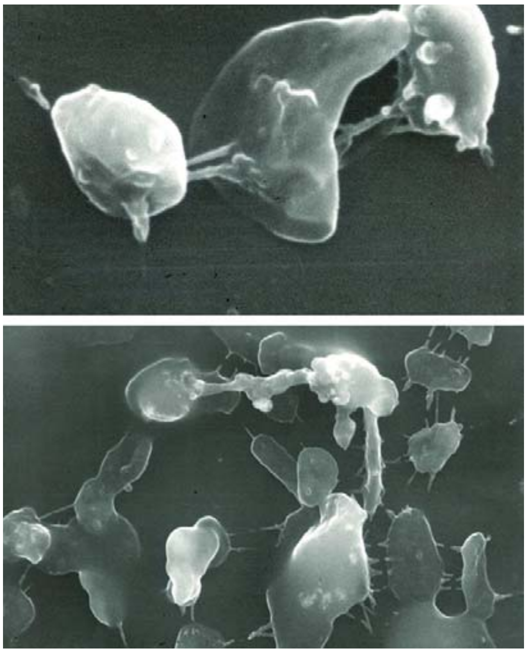
2.1.1. Focus on model organisms and model extreme environments

Since the beginning of the 20th century, the Drosophila fly has been workhorse of genetics and developmental biology research. This model organism is practical to study and work with and has allowed major scientific progress. A similar, while more detailed, approach should be adopted when considering life processes in extreme environments. Some species (microorganisms, animals or plants) are well adapted to their environment and may be considered as accurate representatives for understanding adaptation mechanisms and survival strategies in a given extreme environment.

Such species may encompass a wide range of characteristics, including the originality of molecular mechanisms, the specificity of some cell metabolism, the characteristics of various physiological responses, or the links between different stress responses and the regulation of the genomic activity. Focusing and converging research on such model species at different stages of their life cycle would reveal a large amount of knowledge on the mechanisms and strategies developed to cope with extreme environments.

Depending on the parameter considered, a number of model organisms are available. Considering high temperatures, examples could include the polychaete worm *Alvinella pompejana* from hydrothermal vents which is considered as the most thermotolerant metazoan known to science and which can survive in highly-pressurised aquariums [2.1], or the highly thermotolerant desert ant *Cataglyphis bicolour* (that is easier to collect). Other examples could include the archaeon *Haloferax volcanii*, which is adapted to high-salt conditions, or the extreme acidophilic archaea, *Ferroplasma acidophilum*, capable of growing at negative pH and that has been recently isolated from an acidic mine site. Even if this would raise inherent difficulties and require mobilisation of resources and expertise, there is a need for the community to agree on a set of model organisms to be further studied.

A similar assessment scheme can be established for specific types of extreme environments. This would allow some questions to be considered for a broad range of species; e.g. is the physiology of species inhabiting the polar regions similar in different geographical areas? What is the range of the metabolic response of polar organisms regarding a specific function (e.g. reproduction)? Is there a large diversity of responses depending on the species considered?



Credit: Prof. Ilan Rosenshine

Cells of *Haloferax volcanii*

Recommendation 1:
Identify and agree on i) model organisms in different phyla and for different extreme environments; and ii) model extreme environments, on which research activities across Europe would focus. Not only would these systems focus research activities in a concerted manner but they would bring a long-term perspective and an observatory component to the scene. Providing a common framework, they would also allow the development of comparative studies across domains and disciplines.

2.1.2. An ecosystem-based approach applied to extreme environments

Single-species studies have considerable merit but it is increasingly recognised that greater value will be obtained from research that acknowledges the ecosystems within extreme environments and the interdependence of the various ecosystem components. This is referred to as 'ecosystem-based research' applied to extreme environments. Though identified by the scientific community involved in the ESF initiative profiled here, there have been relatively few examples to-date of an ecosystem-based approach being applied to extreme environments [2.2]. This is in part because of the often considerable difficulties in accessing and researching these environments. Also, extreme environments have been subjected to more extensive studies only in relatively recent times.

In many cases, there is no detailed inventory of the biodiversity of extreme environments or full description of the temporal and spatial variability of their abiotic parameters. Nevertheless, it is recognised that understanding how various life forms survive at limits and interact with other organisms and their environment requires recognition of the ecosystem itself and where the target organisms fit into this system.

Marine life at 3,000m deep

It is also pertinent to mention that there is limited experience within funding agencies to effectively assess approach. Ecosystem-based research is by definition multidisciplinary and may also involve considerable technical and logistical resources, so funding bodies need to clearly identify these elements in programme calls for proposals so that reviewers are properly briefed (see also Section 5.2).

Recommendation 2:
Favour an ecosystem-based multidisciplinary approach when considering scientific activities in extreme environments. When dealing with the complex interplay of biotic and abiotic processes structuring ecosystems, emphasis should be placed on describing the interface between biology and geochemistry.

Recommendation 3:
All environments have some degree of seasonal and spatial variability. Spatial and temporal variability, including long-term monitoring, need to be considered when planning and performing research activities in extreme environments.

Recommendation 4:
Evolution, dynamics and recovery of ecosystems in response to disturbances should be investigated to further understand current and future factors influencing ecosystem structure and functioning. This is of particular relevance when considering global change and anthropogenic pressures currently put on the Earth's environments.

2.1.3. Molecular structural biology and genomics

The investigation of species and processes through molecular genetics, biochemistry, physiology, biophysics and structural biology has the potential to enlarge and deepen our knowledge of cellular and molecular adaptation processes. In this respect, the extremophile research can be divided into three broad areas: i) cellular adaptation to extreme conditions; ii) molecular adaptation to extreme conditions; and iii) extremophilic molecular systems as tractable models for complex homologous human and pathogen systems.

Another important aspect is tolerance. For example, to cope with low pH some cells have adapted to pump out H+ from the cell. However, some cellular structures can be just tolerant of, for example, high salt. Understanding the boundary between tolerance and adaptation in different organisms would be useful.

Mechanisms of cellular adaptation to extreme conditions

All cells protect themselves against stressors by inducing systems to rescue or eliminate damaged proteins (chaperones and proteases), to protect the genetic material (DNA repair systems), to eliminate unwanted molecules (transporters, detoxification systems) or to stabilise molecules and metabolites (compatible solutes etc.). Extremophiles are excellent models to identify novel protection systems and non-conventional metabolic pathways. For this purpose, genomes, proteomes, interactomes and metabolomes from organisms adapted to a wide range of environments should be compared at an integrated level. Expected outcomes are the characterisation of novel molecules and metabolic pathways that stabilise cellular macromolecules.

Understanding molecular adaptation to extreme conditions

Life under extreme conditions is limited primarily by the stability of macromolecules and their ability to exert their biochemical functions under non-conventional conditions that normally lead to the collapse of structures or to functional inactivation. Very little is known about the mechanisms involved in these processes. Interdisciplinary studies combining comparative genomics, enzymology, structural biology and biophysics should reveal the molecular strategy and the evolutionary processes that shaped macromolecules from the origin of life to present environmental constraints.

The expected outcomes include: i) an understanding of the structural and dynamic requirements of macromolecules for function; ii) a definition of the physicochemical limits for life; iii) a guide for research in astrobiology and origin-of-life studies; and iv) strategies for rational modifications of enzyme or pharmaceutical compounds in industrial processes.

Structural and functional genomics on extremophilic systems

Extremophilic organisms represent a unique resource characterising novel molecular systems. Those originating from extremophilic archaea are of special interest since they represent ancestral, simpler versions that can be models for homologous systems in eukaryotes (human) or bacterial pathogens. Archaeal genetic tools have recently been developed and we can expect the discovery of unknown interacting molecules and cellular processes for biotechnological and medical applications [2.3 and 2.4].

Recommendation 5:
Initiate efforts to integrate studies encompassing genomics, genetics, cellular and molecular biochemistry, biophysics and structural biology aimed at investigating life in extreme environments.

Recommendation 6:
Compare genomes and proteomes and identify intracellular chemical and physical parameters for related organisms or cell communities adapted to different extreme environments.

Recommendation 7:
Through functional and structural genomics, exploit the potential of the archaea and other microorganisms adapted to extremes as tractable models for difficult-to-study homologous human and pathogen macromolecular systems.

2.2. Issues of specific interest

2.2.1. Microbial life in extreme environments

Microbes living in extreme environments have a number of special features that provide fascinating insights into the nature of cellular and biochemical adaptation to extreme conditions, whilst being some of the most exploitable of extremophilic organisms for biotechnological processes. In addition, contemporary extreme environments are useful analogues of environments existing on early Earth and on other planetary bodies. The phylogenetically most deeply branching microbes on Earth proliferate in extreme environments. Studying these organisms and their habitats may thus provide a window of information on extinct organisms and early life on Earth.

Microbial extremophiles are the most extreme of all organisms: some can grow at temperatures as high as 113ºC [1.4], others at temperatures as low as -18 ºC [1.3], at negative pH [1.7] or at pH 13.2 [1.8], under extreme pressures of up to 130 MPa [1.6], in complete absence of oxygen [2.5], in salt brines [2.6], or even in conditions of nearly absolute energy starvation [2.7]. Particularly with respect to high temperatures, their cellular components have to be resistant to such conditions.

Whilst we have a partial understanding of proteins and enzymes with regards to extreme conditions, this is far less well developed for DNA and RNA, and we have little knowledge of how cellular metabolites are protected. Defining the molecular basis of these properties will make invaluable contributions to our understanding of the molecular and physiological adaptation to extreme environments. It will also allow us to define the limits of life on Earth, and hence of terrestrial-like life on other planetary bodies in our universe.

The vast, largely untapped subsurface of the continents and seafloor is one of the greatest realms of microbial life on Earth, both in terms of biomass and volume. Recently an international team of ocean scientists discovered that ethane and propane are being produced by microorganisms in deeply buried sediments [2.8]. The findings suggest that microbes below the seafloor carry out processes which are highly relevant to both the understanding of global cycles and the metabolic abilities of microbes. Investigating microbial processes in these environments needs to be explored further.

Extremes of temperature and pressure are met in such environments and in the subsurface, life under extremely low energy availability is not an exception but appears to be the rule [2.9]. Extremely slow growth rates suggested by geochemical turnover rates with estimated cell division times of the order of hundreds to thousands of years challenge our fundamental understanding of life and concepts of cell maintenance.

Finally, because microbial extremophiles cover all three domains of microbial life, bacteria, archaea and eukaryotes, comparative adaptation studies would provide a very useful insight into the nature and evolution of extremophilic organisms.

Credit Amaral-Zettler/micro*scope

Euglena mutabilis from the Acidic river Rio Tinto

Recommendation M1:
Investigate further the molecular basis of the physiological adaptation of microbes to extreme environments, especially with regard to DNA, RNA and protection of cellular metabolites.

Recommendation M2:
The deep subsurface (oceanic and continental) exhibits unique features in terms of temperature, pressure and availability of energy. Investigating the subsurface microbial processes further, especially with regard to cell division, would deepen the fundamental understanding of life and concepts of cell maintenance. Moreover, understanding the role of the subsurface in biogeochemical cycles is essential for an assessment of element budgets on a global scale.

Recommendation M3:
Microbial extremophiles cover all three domains of microbial life, bacteria, archaea and eukaryotes. Comparative adaptation to different environmental stressors and the results of gene arrays and proteomic studies would provide a very useful insight into the nature and evolution of extremophilic organisms (Recommendation M3).

2.2.2. Life strategies of plants in extreme environments

The most obvious difference between plants and other organisms is their ability to perform oxygenic photosynthesis using light and carbon dioxide (CO_2) in their chloroplasts. Photosystems make plants more susceptible to radiation and temperature when compared for example to bacteria. Because they are designed to accept light, they are inherently sensitive to radiation quality (especially UV) and quantity. As their thylakoid membrane system requires a certain degree of fluidity, they can tolerate only a limited temperature range and are restricted to areas that receive sunlight. Plants are less dependent on external resources and mainly need water, CO_2 and light. Investigating mechanisms of autotrophy have started at the molecular level and this transfer of knowledge is strongly needed for studies about plant life in extreme environments.

Espeletia timotensis on a semi-desert plateau at an altitude of 4,200m

Plants survive in extreme environments such as in anoxic conditions (e.g. the CO_2 springs), hypersaline soils and water, extreme temperatures, and also in extreme conditions caused by biotic stresses such as anthropic pollution and animal grazing. Many strategies allow autothropic carbon

Phytoremediation of a former gas-station in Rønnede (Denmark) using different species of Salix.

fixation and plant survival under extreme conditions, based on biochemical adaptation, molecular adaptation and acclimation mechanisms.

A second common characteristic for plants is that, when grown, their sessile life style does not allow active avoidance mechanisms as in motile (and/or mobile) organisms. Consequently, plants possess more protective mechanisms than mobile organisms. This applies in particular to juvenile or long-term survival stages; e.g. spores or seeds, which consequently deserve special attention. The peculiar strategies of adaptation developed by sessile plants need special studies, ranging from the mechanism level to the ecosystem level (e.g. its consequences for the plant-based life-chain pyramid). Exceptions to sessile life are found in the plant kingdom (e.g. clonal plants) and should be also investigated.

Finally, plants are extremely important elements in the Earth life-chain, because of their position as primary drivers, in many situations, of the trophic chain. They can also play a role as natural engineers producing environmental conditions suitable to life and as they can be extremely sensitive to environmental changes, they are useful as bio-indicators.

Recommendation P1:
Put the emphasis on boosting progress in molecular and biochemical studies and on unravelling the mechanistic basis of plant life under extreme conditions.

Recommendation P2:
Study the strategies of adaptation (from the molecular to the ecosystem level) which allow plant life in extreme environments, as well as plants' strategies of reproduction and dissemination in their long-term efforts to avoid environments becoming hostile (e.g. because of global change factors).

Recommendation P3:
When considering studies on plant life in extreme environments, a particular attention should be given on fragile ecosystems, including ecosystems that start to be colonised by plants, or that are becoming unfavourable to plant life, especially as a consequence of global change and human-driven land use change. Strategies of survival at this boundary that may be or may become of utmost importance for plant survival, for plant loss of diversity, and for the entire food-chain based on plant life.

2.2.3. Life strategies of animals in extreme environments

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Alvinella pompejana

The wide scope of this subject shows the complexity of the scientific community investigating life strategies of animals in extreme environments. This results from the diversity of animals and environments studied and, to a lesser extent, from the questions raised (ecology, evolution, physiology). Each subgroup is well organised and exhibits a high degree of maturity, but it seems clear that so far there are no links among these subgroups. There are several questions which cut across these subgroups (e.g. community responses, ecosystem functioning, hypoxia and thermal behaviour) and which require more coordination. The scientists concerned with the questions of life strategies of animals in extreme environments are numerous and highly diverse; e.g. groups working on polar animals or hydrothermal vents fauna.

Apart from the two environments generally studied (polar and deep-sea environments), more specific ones have also been studied, such as those that are under increased anthropogenic pressures; e.g. on coastal zones or polluted areas.

Within the research community a strong interest exists in the question of genomics and stress response. Another major point of interest is the need to develop comparative studies to identify the common characteristics and to determine the specificities of cells, animals, communities and ecosystem responses to environmental stress of various types including climate change.

There is also a consensus about the importance of characterising environments and their interactions with animals from the microscale (cellular) to the global scale (Earth), this is of particular relevance when considering animals evolving in extreme environments. Such approaches may help, for example, in understanding the establishment of symbiotic interactions as well as in their disappearance. Questions about variability of biodiversity are stressed by different subgroups of scientists. Approaches involving palaeontology may help the understanding of the evolution of life in extreme environments. In vivo approaches mimicking the natural environment would help in the understanding and prediction of the tolerance of animals to environmental changes.

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Onymacris unguicularis, fog-basking beetle of the Namib desert

Recommendation A1:
Comparative studies are needed to determine the specificities of animals, communities and ecosystem responses to different types of environmental stress.

Recommendation A2:
Favour characterisation studies on extreme environments and their interactions with animals; this would help in understanding adaptation processes.

Recommendation A3:
The analysis of the biodiversity dynamics of animal communities and ecosystems found in extreme environments, including palaeontological approaches, has to be promoted to understand the evolution of life in extreme environments.

Recommendation A4:
In vivo *approaches simulating the natural environment are needed to help in the knowledge and prediction of the tolerance of animals to environmental changes.*

2.2.4. Human adaptation in extreme environments

Human adaptations to extreme environments are of different types: they can be biomedical, physiological, psychological but also cultural, societal and technological. With this diversity of adaptation aspects, it seems important that scientists should collaborate in studying human adaptation to extreme environments under the label *Human Sciences*.

Humans adapt to extreme environments but there are also adaptive effects that they impose upon a given environment. Environmental monitoring and control have an important role both in artificial and confined environments (i.e. parts of the technosphere, ranging from spaceships to cities) as well as in natural environments.

In the context of scientific research conducted in extreme environments, studying human adaptation has a twofold aspect. First, it allows a better understanding of the mechanisms of human response to physiological and psychological stressors, paving the way for new therapies and applications in daily life. Second, with the development of countermeasures, it acts as an enabler aiming at optimising the well-being and security of the personnel involved in extreme environment research. This is of particular relevance when considering polar station crew, and astronauts performing research in microgravity. In these contexts, one can identify three major factors that would impact on human activity:

Isolation and confinement: crew in space vessels or polar stations are disconnected from their usual social environment and the hazardousness of the surroundings is a major source of stress for them. This psychological pressure impacts on the coherence of the group and its ability to perform research.

Level of activity: the low level of physical activity arising from confinement in space and polar stations may lead to hypokinesia (diminished movement of body musculature) with its associated impact on the human body. Understanding the impacts and associated mechanisms may help us to understand the role of physical inactivity on the aetiology of obesity and diabetes, bone osteoporosis and also muscle atrophy observed in the elderly.

Credit: ESA

ESA astronaut Ulf Merbold soon after leaving the Soyuz-TM 19 descent capsule

Reduced level of gravity (only for space missions): without gravity the complicated bone architecture or muscle organisation would not be necessary. The intricacies of the cardiovascular system are mainly organised to counteract continuous fluid transfer induced by gravity. The same evidence emerged from the organisation of the central nervous system given all the mechanisms developed to counteract gravity (e.g. the vestibular system). Studying human adaptation to microgravity therefore provides potentialities in a wide range of areas in fundamental sciences and also in pathology (i.e. ageing, cardiovascular dysfunctions, osteoporosis and muscle atrophy).

Finally, it can be observed that extreme environments are not necessarily disadvantageous, but may sometimes be favourable: there might be positive and negative impacts at the same time. This is one example where ethical issues enter the picture.

Recommendation H1:
Bring together humanities, social sciences, psychology and medical sciences under the label of Human Sciences in studies on human adaptation to extreme environments.

Recommendation H2:
Issues of environmental monitoring and control have an important role both in artificial and confined environments as well as in natural environments. These aspects should be further investigated when considering humans, not only because the environment influences them, but also because there is an adaptive effect that humans impose upon the environment.

Recommendation H3:
When considering human species, favour cross-disciplinary dialogue and interactions while dealing with different levels of systems hierarchy at the same time.

Recommendation H4:
Address ethical issues systematically and carefully when considering human adaptation to extreme environments.

3. Technological issues

3.1. Streamlining the issue

When considering scientific activities in extreme environments, technology sets itself as a clear and vital cross-cutting resource of major relevance. However, technological barriers are the main limiting factors for the development of new knowledge on life processes in extreme environments. Furthermore, technological developments are crucial elements that allow humans to cope with extreme environments. Without these, human beings would not be able to explore and evolve in some harsh conditions. Evident examples are space suits for planetary exploration and polar stations for the exploration of the polar regions.

Victor Remotely Operated Vehicle

Thus, it is important to develop a comprehensive characterisation of the barriers, technological needs and capabilities for investigation of life in extreme environments. It is also important to consider a common technology development plan to which different scientific communities (e.g. those studying microbes, plants, animals, humans) can contribute with their specific technology requirements, strengths and capabilities. Table 2 proposes a common functional grouping under various technology thrusts of relevance when considering investigation of life in extreme environments.

Furthermore, through the development of a road-mapping exercise on technology development, added benefit can be given to each of the diverse but connected research communities involved by bringing to them the existing tools and capabilities in use or under development by their neighbouring communities.

Harsh environments impose major constraints on the capabilities and sustainability of technologies that are required to undertake high quality research. Examination of the extremeness with respect to a chosen frame of reference requires measurement of the environmental parameters (physical, chemical and biological). Conducting scientific experiments accurately and robustly under extreme conditions requires technological tools with extreme capabilities needed during different phases of the scientific investigations such as discovery, access, measurement, analysis, acquisition and transmission of results or samples, life support systems, computer software etc. It is mainly through the enhancement and advancement of the technological capabilities that scientific experiments under extreme conditions can be further envisaged and enabled. In this context, selecting analogous sites to test technologies would be useful.

European ExoMars rover — artist's view

Recommendation T1:
Develop interdisciplinary initiatives to define environment-specific technological and technical requirements, their availability and a road-map for their development.

3. Technological issues

Table 2: Functional grouping of technologies under various technology thrusts

Technology thrust	Specialised systems, subsystems and tools	Important issues at the design stage
Exploration	Planetary and interplanetary access Terrestrial remote access Marine remote and/or deep access Polar remote, deep and subglacial access Local deployment, command and control Specialised deep drilling	Where to go? When to go? How to get there? How to navigate? How to communicate? What to look for? What to bring back? Environmental impacts Energy and life support sustainability
Identification	Sensing Recognition	Measurement of predefined physical, biological and environmental parameters. Recognition of targets and samples of interest
Monitoring	Sensing	Continuous and/or intermittent measurement of various parameters of interest on microbial, plants, animals and human subjects. Size, energy supply, communications
Acquisition	Containment Samples and/or data Retrieval	Isolation and insulations. Environmental control. Specialised sampling, capturing, retrieval and containment systems
Analysis	In situ Lab processing Data storage and communication	Autonomous or semi-autonomous mobile or stationary laboratories. Interfaces, communications, environmental control, energy, mobility, life support systems
Sample/species return	Samples/species monitoring Acquisition Contamination control, isolation and containment Life support systems Retrieval Transportation	Autonomous, remotely operated or manned vehicles. Life support systems, communications
Data acquisition, storage and transmission	Data acquisition and storage Data mining Data reduction and compression Communication	Power, data rate, volume, bandwidth

3.2. Crossing the borders

While some specific research and technology programmes have allowed significant progress, the fragmentation of scientific activities and strengths prevents spin-offs across disciplines. It is important that technology-related information exchange is facilitated between communities involved in research activities dealing with extreme environments. This is of particular relevance when considering, for instance, the effort put into the development of space technologies. The high quality, robustness and capabilities of light-weight and small-size sensors and instruments developed for space missions would surely have the potential to benefit terrestrial research in extreme environments.

Credit : DLR

Melting Probe technology of potential use for penetrating layers of ice.

Interactions between communities already exist; e.g. the Antarctica (subglacial) Lake Ellsworth exploration team (from the UK) involves scientists from the Beagle 2 Mars lander mission for the development of a robot exploration probe [3.1]. This use across domains would in turn benefit future planetary exploration systems through further advancements in the capabilities and operational knowledge and experiences gained. As another example, the European Space Agency (ESA) developed, together with the Italian national Antarctic research programme (PNRA) and French polar institute (IPEV), the water recycling system of the French-Italian Concordia Antarctic station [3.2]. These types of interactions and spin-offs should be encouraged.

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The AWI-operated German icebreaker Polarstern docked on the sea ice for unloading.

Regarding infrastructures, the ones that are used to reach and undertake scientific activities in extreme environments (e.g. icebreakers, polar stations or underwater vehicles), have very peculiar characteristics; they are typically rare (sometimes unique) complex systems, expensive to develop and operate. In order to maximise the scientific return on such investments at the European level, it is important to develop the mechanisms and tools necessary to facilitate access to and sharing of technical platforms and infrastructures (e.g. barter agreements, common programmes and international consortia).

Recommendation T2:
Support the development of initiatives aiming to improve information exchange on available technologies and new developments throughout the scientific community involved in extreme environments.

Recommendation T3:
Develop and support mechanisms to facilitate access to and sharing of existing and future technical platforms and infrastructures to be used when accessing extreme environments.

3.3. Collecting information – priorities

As already stated, access to extreme environments is time and resource limited. Laboratory simulation techniques and capabilities permit lowering the cost of investigations while allowing real-time long-term observation. An example of such a facility is the LabHorta in the Department of Oceanography and Fisheries of the University of the Azores (Portugal). LabHorta simulates the physical and chemical conditions found around deep-sea hydrothermal vents. This facility was developed and built to support and expand the capacity of research cruises together with experimental studies of the biology, physiology and behaviour of deep-sea hydrothermal vent fauna and taxa from other deep-sea environments [3.3]. Development of laboratory simulation techniques and facilities would stimulate and enhance the volume of research focused on extreme environments; they should be developed in Europe for relevant environments and made available to the European scientific community involved.

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The LabHorta facility designed for the simulation of deep sea hydrothermal vents' conditions

Besides the simulation issue, development of in situ measuring and monitoring capacity in harsh conditions is required. For example, this includes deep-sea observatories, polar observatories and Remotely Operated Vehicles (ROVs). Developing this capacity (quantitatively and qualitatively) means obtaining the highest quality information on the physical and chemical conditions as well as

Credit: NASA

The experimental Life on Ice: Robotic Antarctic Explorer (LORAX) autonomous rover

imaging. This also requires continuous development of, and access to, sensor, robotic and telemetry technology.

In this context, at the convergence of space-based infrastructure with global capacity, (GPS, telecommunication satellites), and new developments in microelectronics, on sensors, data storage and data transmitter technologies, bio-logging is a new field of activity that allows a large amount of information based on continuous measurements to be gathered remotely. This information can concern animal physiology (e.g. temperature or heart rate), behaviour (e.g. itinerary, speed, depth) but also the environment where the animal is located (e.g. ambient temperature, salinity or light). Any decrease in size, weight and cost of electronic components together with an increase in their capability enable bio-logging techniques to be very promising in scientific terms.

In addition to the development and use of in situ capabilities, there is a need to develop the use of remote measurement capability such as satellite remote sensing (e.g. for plants and algae monitoring on Earth-based environments or detections of gas resulting from biological activity on planetary bodies).

Recommendation T4:
Consider further the enhancement of the European simulation capability in the field of extreme environments. Relevant simulation facilities (e.g. microcosms) should be developed.

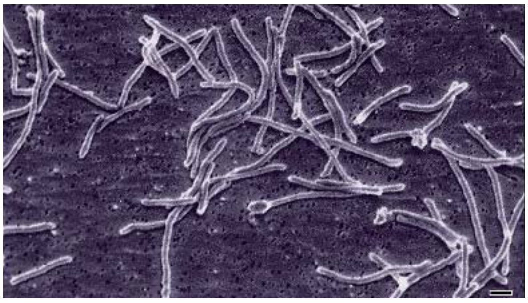
Recommendation T5:
Develop in situ *sampling, measurement and monitoring technologies (e.g. light-weight, low-power, and robust sensors) and capacity (e.g. in situ observatories and bio-logging). Categorisation and inventory of existing systems, technologies and techniques are also recommended.*

4. Economic and societal applications

Benefiting from extremophilic organisms

Organisms that live in extreme physico-chemical conditions, in high concentrations of deleterious substances or heavy metals, represent one of the most important frontiers for the development of new biotechnological applications. Actually, the biotechnological applications of extremophiles and their components (e.g. extremozymes) have been the main driving force for the research in this area [4.1].

Credit : Centre de recherche et de développement sur les aliments, Agriculture et Agroalimentaire Canada



Bacteria *Thermus aquaticus*

The most direct application of extremophiles in biotechnological processes involves the organisms themselves. Among the most established we can find biomining, in which microbial consortia that operate at acidic pH are used to extract metals from minerals [4.2]. Most applications involving extremophiles are based on their biomolecules (primarily enzymes, but also other components such as proteins, lipids or small molecules). The best-known example of a successful application of an extremophile product is *Taq* DNA polymerase from the bacteria *Thermus aquaticus* [1.6] which facilitated a revolution in molecular biology methodology, but also other commercialised products (e.g. ligases, proteases, phosphatases, cellulases or bacteriorhodopsin) have resulted from investigation of extremophiles isolated from different environments.

In order to develop biotechnological processes, it is important to isolate the organism. In addition, the use of new methodologies, such as comparative genomics is helping to sort out the genetic and molecular bases of adaptation to extreme conditions, facilitating the design of improved products by the introduction of appropriate modifications by protein engineering. This approach has been used not only for improving the thermostability of enzymes but to design cryo-enzymes for the food industry to operate at low temperatures.

Most microbial communities are complex and currently only a few components can be cultured. Sequence-based approaches to study the metabolism of microbial communities are being used to retrieve genomic information from the community of potential use in biotechnology (metagenomics). Strategies based on the generation of environmental genomic libraries have been developed to directly identify enzymes from the environment with the required specificity or the appropriate operational conditions.

Plants adapted to extreme environments also provide potential economic and societal applications. Extremophilic plants can survive under conditions toxic or harmful to crop plants. Therefore there is the potential to transfer, e.g. by molecular cloning, some of these abilities from extremophiles to crop plants with the aim of producing frost, salt, heavy metal or drought tolerance or enhanced UV stability.

Plants can also be useful to remediate polluted areas where life is made difficult or impossible. Phytoremediation is an innovative technology that uses the natural properties of plants in engineered systems to remediate hazardous waste sites. Within the phytoremediation technologies, phytoextraction (uptake and concentration of substances from the environment into plant biomass) and phytotransformation (chemical modification of environmental substances as a direct result of plant metabolism) are of applicative interest. Phytoremediation has been effectively used for the decontamination of soils and waters polluted by high concentrations of hazardous organic (e.g. pesticides) or inorganic (e.g. arsenic and mercury) substances. It is also a promising technology for the remediation of atmospheric pollutants (hydrocarbons, ozone) [4.3].

Biomedical applications of adaptive mechanisms of animals should also be thoroughly investigated. Such potentialities are real as illustrated by the subantarctic King penguin that has developed the ability to preserve fish in its stomach for three weeks at a temperature of 38°C [4.4]. With further developments, the antimicrobial and antifungal peptide involved in this conservation process might be used, for example, to fight some nosocomial infections.

4. Economic and societal applications

It is obvious that the combination of new methodologies to study extreme environments will provide important biotechnological breakthroughs.

Thus it is extremely important to support the development of this knowledge in Europe in order to be at the forefront of the new biotechnological advancements.

Benefiting from research activities

Conducting scientific activities in extreme environments requires high-quality and highly robust facilities and technological capabilities. In this context, efforts in sensor development and optimisation, miniaturisation of scientific devices, automation of processes, robotics, software development or material engineering are undertaken. This allows industries and research institutions involved in such activities to gain knowledge, competencies and capabilities relevant to a wide range of industrial and economic sectors.

5. Policy aspects – the European arena

5.1. European scientific landscape

The scope of research activities in extreme environments is very broad and the state of development of this area in Europe is very diverse, depending on: i) which extreme environment is studied and ii) which type of organism is considered.

Maturity

Historically in Europe, the consideration of extremophiles within funding programmes of the European Union Fourth (FP4) and Fifth (FP5) Framework Programmes has greatly contributed to establishing and structuring the European scientific community dealing with these topics. Currently, at the international level, Europe leads in areas such as polar research, biodiversity, and global change, although without a specific focus on extreme conditions.

Polar and deep-sea research fields, including associated technological developments, appear to be areas of excellence in Europe. In considering the type of organisms, the study of microbes, plants and animals are reasonably mature areas of research. However, gaps exist within each of the different fields (regarding species and environments) and there is a significant potential to investigate common questions (especially physiological and ecological ones) across various extreme environments. There is then a substantial potential to expand our functional knowledge of as yet relatively unexplored fields, exploiting recent advances in molecular and structural biology and developing new technologies and model organisms for extreme environments. These should include ecosystem approaches and in situ measurements.

A concerted European initiative could help considerably to achieve a visibility similar to current or past large-scale initiatives in the United States (e.g. the National Science Foundation/NASA Life in Extreme Environments Programme - LExEn) and to realise the field's full growth potential. Such an initiative should not only focus on organisms but also on the environments themselves, providing knowledge on interactions within ecosystems and an original integrated approach full of potentialities.

Existing initiatives

There is a general challenge across the topic areas of very different paradigms, methods and philosophies among the scientific disciplines involved. However, a patchwork of interdisciplinary projects and collaborative networks of interest already exists and is indicative of the dynamic nature of the research fields covered. These initiatives are spread across the European scientific landscape but are either dedicated to specific environments (e.g. European participation in the International Polar Year (2007-08), the European Polar Consortium, HERMES, ESO-NET and Mars Express), to specific geological contexts (e.g. European participation in IODP, InterRidge and EuroMARC), or focused on a thematic topic such as biodiversity (e.g. EuroCoML and MarBef). Connections with generalist networks are also important considering their advances in methodologies relevant to the field of investigating life in extreme environments (e.g. FP6 Network of Excellence Marine Genomics Europe).

© IPEV - Serge Drapeau

French-Italian Concordia Antarctic station: a platform for international cooperation

International collaboration

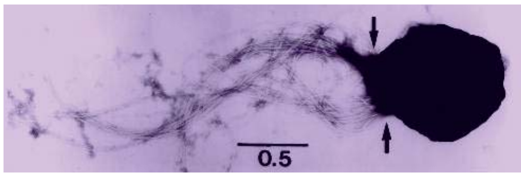
A strong benefit can be expected from international collaboration especially with Canada, China, India, Japan, Russia and the United States. This is of particular relevance in areas of global significance, e.g. desertification, pollution, and the effects of global change in polar regions and other fragile areas. International collaboration is indeed crucial both for large-scale initiatives such as the establishment of seafloor observatories, the use of large-scale (expensive) infrastructures, the planning and execution of space missions, and coordination of expeditions. Also, developing countries, where many of the as yet unexplored extreme environments exist, should be partners in cooperative ventures. Special attention should be paid to the education of local scientists and students on these topics; e.g. through the use of fellowships or organisation of joint investigation.

5.2. The need for further interdisciplinarity

Palmatogecko rangel in the Nabib desert

It is important to emphasise the unique opportunity that the interdisciplinary approach currently offers to investigations of life in extreme environments and that such an approach should be further developed. In order to deal with broader aspects of life in extreme environments in a scientific way and to secure access to sufficient future funding, appropriate mechanisms of peer review, adapted if necessary, and significantly increased openness would be needed.

Existing compartmentalisation between disciplines and their associated technological developments is seen as a major barrier to greater efficiency in scientific activities. Even if this statement applies to a whole range of scientific activities, it is of particular relevance when considering extreme environments because science and technology activities dealing with or relevant to extreme environments are widespread across the scientific landscape. Cross-over exists between disciplines, therefore others should be further studied or identified; e.g., using microbial and plant life processes in some particular conditions could lead to the development of better life-support systems in Antarctic or space stations. Interdisciplinary aspects should be considered as much as possible in any relevant scientific activity involving extreme environments, and especially when considering the study of ecosystems (see also Section 2.1.2). Larger and/or more frequent interdisciplinary initiatives should be developed to facilitate greater understanding of specific problems, ethical issues and even to develop a common scientific language. It is obvious that sharing common questions and techniques, developing the study of interfaces, undertaking comparative projects and integrating new tools and knowledge would definitely catalyse the development of scientific excellence for each area involved. Given Europe's academic history, tradition and capability, there is clearly potential to achieve truly remarkable results in this area.



The archea *Methanococcus jannaschiia* evolves in the area of hydrothermal vents

Alongside the knowledge-based approach, on a more practical side, interdisciplinary and multidisciplinary approaches are also necessary in remote research areas requiring expensive expeditions or space technology. A multitude of methods needs to be applied to maximise the scientific outcome samples that are expensive to collect. This also applies to the field of genomics of extreme model organisms where the generation of the data is fast but still expensive. Furthermore, the analysis of results would benefit tremendously from the synergistic effect of multidisciplinary expertise, ranging across ecophysiology to DNA bioinformatics. It is evident that, whenever such transdisciplinary research approaches are successful, the benefits are remarkable.

Recommendation 8:
Because of the transversal nature of science and technology activities in extreme environments, interdisciplinarity and multidisciplinarity between scientific domains and between the technological and scientific spheres is identified as a major source of potential increase in scientific achievement. When relevant, these aspects should be extensively promoted and supported as much as possible when considering life processes in extreme environments.

5.3. Networking and coordination

While high-level expertise and know-how have been developed at the European level, the fragmentation of this knowledge and the lack of coordination across initiatives are major constraints to the further development of a pan-European capacity.

Thus, there is a clear need to develop an efficient capability in networking and information exchange for the European scientific community involved in research on extreme environments. This networking should concern not only individual scientists but also existing and future collaborative initiatives. As stated above, it is important that such a capability is multidisciplinary and designed according to the requirements and expectations of the scientific community. This could include an Internet portal gathering and disseminating information on relevant programmes and projects, publications, funding opportunities and the use of infrastructures. To facilitate the networking of the community, it should also include a dynamic database of experts and specific scientific and technical expertises. An associated newsletter could also be considered in order to inform the scientific and technological communities and to promote interdisciplinary approaches in the field of extreme environments.

In addition, large-scale multidisciplinary events (conferences, workshops, fora) such as the ESF's Investigating Life in Extreme Environments (ILEE) workshop held in November 2005, should be organised regularly in order to build and maintain momentum at the European level and to shape initiatives and possibly develop relevant projects with a bottom-up approach. In this context, the competitive ESF Research Conferences scheme could be a very useful tool for the scientific community.

There is also a need to identify potential coordination (and possibly clustering) mechanisms to be initiated among existing networks and programmes as well as to investigate mechanisms for sharing costs associated with infrastructures (e.g. ROVs and ships) or national large-scale resources.

Credit: ESF

The ESF Investigating Life in Extreme Environments workshop, November 2005

The use of instruments such as the European Commission's Framework Programmes' Coordination Actions (CA) would be fully relevant to develop networking and coordination within the European research community involved in extreme environments.

These initiatives and undertakings need to be considered in detail and an overarching interdisciplinary group of experts should be established. This focal point, possibly set up under the auspices of ESF, would consider and steer the issues of coordination, networking and dissemination of activities. Furthermore, it could identify priorities and investigate new opportunities for Europe's scientific community. Theoretical and methodological approaches should also be discussed and defined to coordinate the various views of the community involved. It is important to note that acquiring a common language among the various fields considered is a prerequisite for this purpose.

Finally, reaching a critical mass, getting to know each other and identifying common research priorities through networking and cooperation would be the first steps towards the development of a European Research Area in the field of extreme environments and potential European-wide research projects and programmes.

Recommendation 9:
Create an overarching interdisciplinary group of experts to define the necessary actions to build a critical European mass in the field of Investigating Life in Extreme Environments.

Recommendation 10:
Efforts should be made to support and improve the information exchange, coordination and networking of the European community involved in scientific activities in extreme environments. This could be achieved through a Coordination Action in the European Union Seventh Framework Programme (FP7) and include the development of a Web portal and associated developments (database of experts, dissemination of information). In this context, large-scale multidisciplinary events (e.g. conferences, fora and workshops) should be organised regularly in order to build and maintain the momentum at the European level. This should be done in the context of the numerous specialised events that are already organised).

5.4. Programme issues

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Merged ice pancakes in Antarctica

Overall, and especially because of their specificities and positioning at the frontier of science, research activities dealing with life processes in extreme environments should adopt a bottom-up approach to be open and flexible in order to avoid any rigidity and possible obstruction of creativity, to take full advantage of current trends and possibilities, and to tap into the entire spectrum of European potential. In this context, the scientific community needs to continually generate new ideas and concepts.

A general difficulty from an operational point of view involves the long planning horizons of field expeditions to sample and monitor extreme environments that are often remote and hard to reach (e.g. oceanic sites, polar regions or planetary bodies). Because these expeditions (or missions) have a long planning interval relative to funding cycles, it is often difficult for the scientific community to take part in them.

The current level of coordination of European funding for investigating life in extreme environments is certainly viewed as a constraint that needs to be overcome. Carrying out scientific activities in such environments is often very expensive, because of the cost of facilities such as polar stations, research vessels, Remotely Operated Vehicles (ROVs) or interplanetary probes and landers. This represents a major constraint on scientific progress in these fields.

National research funding may be very difficult to access (deep-sea and high altitude research being particular examples). A strong European network could create stimuli for national research councils and funding organisations to commit themselves and include extreme environments as such in their national science strategy. A consideration at the European level of the funding needed for such initiatives, the tools and schemes to be implemented as well as the identification of potential synergies and scale effects would fall under the remit of the overarching interdisciplinary group of experts mentioned above. Furthermore, it would seem pertinent that extreme environments should be clearly identified in scientific calls and programmes. It is preferable to fund leading scientists in the field defining research goals rather than urging scientists to mould their research into existing funding schemes.

Finally, a new field needs new peer groups in order to avoid tunnel effects in scientific evaluation. Review and evaluation processes need to include a multidisciplinary aspect to be more open to external influences, and to embrace a broader view (systems biology being an example). Decision guidelines need to be appropriately flexible.

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Salar of Uyuni in Bolivia

Recommendation 11:
Extreme environments should be integrated into national science strategy and clearly identified in national and European scientific calls and programmes.

Recommendation 12:
When considering scientific activities involving extreme environments, funding agencies need to ensure that their assessment procedures can adequately review proposals involving a multidisciplinary approach as opposed to the more typical, strongly focused proposals.

5.5. Public outreach and education

Securing public awareness that science is exciting is crucial, especially as the general public is interested in seeing the outcome of investments in science. It is important to inform the public on issues related to extreme environments, highlighting the exotic nature of these environments and their biota. Extreme environments such as polar regions, deserts or outer space are exciting and easily communicated to the public because even the non-scientific audience intuitively sees that these environments impose a challenge for life. Moreover, observing and understanding life in extreme environments brings the public to question itself on very important issues such as the origin of life or potential life on other planetary bodies. Other extreme environments, such as intertidal sites, salt-water marshes or heavy metal polluted sites, may initially appear less attractive and exotic but are in practice more accessible to the general public and probably of greater relevance to daily life.

The popularity of television channels such as the Discovery Channel and National Geographic Channel in Europe and the USA suggests that the public is interested to learn how certain organisms survive and even thrive under extreme conditions. Raising public interest can be achieved by reports in the media detailing new findings such as the mysterious animals of the deep-sea, but also in reporting on expeditions to extreme environments on Earth or missions to outer space. Demonstrating applications of the data, e.g. how results from studies in extreme environments can influence crop production, would also be of importance.

Credit: UNIS

The Norwegian University Centre in Svalbard (UNIS) located at 78° North

It is also fundamental to secure the transmission of scientific knowledge to students and young scientists. This could be achieved through supporting PhDs and postdoctoral positions as well as involving students and young scientists in scientific events. The latter could be achieved, for example, through the organisation of interdisciplinary summer schools focused on life processes in extreme environments.

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Appendices

Appendix I: Contributors to the report

Name	Organisation	Town	Country
Dr Ricardo Amils	Universidad Autonoma de Madrid - Centro de Biología Molecular del CSIC	Madrid	Spain
Dr Arnoldus Blix	University of Tromso	Tromso	Norway
Dr Michael Danson	University of Bath - Centre for Extremophile Research	Bath	United Kingdom
Dr Christine Ebel	CEA-CNRS-UJF – Institut de Biologie Structurale	Grenoble	France
Dr Cynan Ellis-Evans	British Antarctic Survey	Cambridge	United Kingdom
Dr Françoise Gaill	University Pierre et Marie Curie - Laboratoire 'Systématique, adaptation, évolution'	Paris	France
Dr Helmut Hinghofer-Szalkay	Medical University Graz - Institute of Physiology, Center of Physiological Medicine; and IAP Institute Graz	Graz	Austria
Dr Kai-Uwe Hinrichs	Universität Bremen - Fachbereich Geowissenschaften	Bremen	Germany
Dr Francesco Loreto	CNR – Istituto di Biologia Agroambientale e Forestale (IBAF)	Rome	Italy
Dr Daniel Prieur	Université de Bretagne Occidentale - Laboratoire de Microbiologie des Environnements Extrêmes	Plouzane	France
Dr Farzam Ranjbaran	European Science Foundation	Strasbourg	France
Dr Klaus Valentin	Alfred-Wegener-Institut für Polar und Meeresforschung	Bremerhaven	Germany
Dr Elisabeth Vestergaard	Danish Institute for Studies in Research and Research Policy	Aarhus	Denmark
Mr. Nicolas Walter	European Science Foundation	Strasbourg	France

Appendix II: Steering Committee of the ILEE initiative

Name	Organisation	Town	Country
Dr Demir Altiner	Middle East Technical University	Ankara	Turkey
Dr Ricardo Amils	Universidad Autonoma de Madrid – Centro de Biología Molecular del CSIC	Madrid	Spain
Dr Fernando Barriga	Universidade de Lisboa	Lisbon	Portugal
Dr Cynan Ellis-Evans	British Antarctic Survey	Cambridge	United Kingdom
Dr Lucien Hoffmann	CRP Gabriel Lippmann	Belvaux	Luxembourg
Dr Jesus Martinez-Frias	CSIC/INTA – Centro de Astrobiologia	Torrejón de Ardoz	Spain
Dr Daniel Prieur	Université de Bretagne Occidentale - Laboratoire de Microbiologie des Environnements Extrêmes	Plouzane	France
Dr Zoltán Varga	Debrecen University	Debrecen	Hungary

Appendix III: ILEE Workshop Programme

(6-8 November 2005)

Saturday 5 November 2005

14.30	Registration at the hotel reception and ESF desk
18.00	Icebreaker
20.00	Dinner

Sunday 6 November 2005

08.30-08.45	Conference Opening Daniel Prieur – Chair of the Workshop
08.45-09.00	ESF Presentation Bertil Andersson (ESF Chief Executive)
09.00-09.20	Keynote Address Investigating Life in Extreme Environment – Challenges and Perspectives Jean-François Minster (CNRS, Paris, France – Marine Board Chairperson)
09.20-09.40	Keynote Address Extreme life at deep-sea hydrothermal vents from a geological perspective Steven Scott (University of Toronto, Canada)

Session 1
Defining and characterising the boundary conditions of 'extreme' environments
Session chair: Daniel Prieur
Rapporteur: Ricardo Amils

09.40-10.00	Biocatalysis under extreme conditions – harvesting the potential of extremophiles - Garo Antranikian
10.00-10.10	Discussion
10.10-10.30	Human adaptation – from the white to the red planet - Didier Schmitt
10.30-10.40	Discussion
10.40-11.10	*Coffee break*

Session 2
Molecular adaptation and stability in extreme environments

11.10-11.30	Peptides under extreme conditions: the foundation for the origin of life? Bernd Rode
11.30-11.40	Discussion
11.40-12.00	The interplay between metabolic programmes and stress-response programmes in hydrocarbon-degrading bacteria - Victor de Lorenzo
12.00-12.10	Discussion
12.30	*Lunch*
14.00-14.50	Round table discussion

15.00-17.30 Splinter Presentation Session

	Session 3	Session 4	Session 5	Session 6
	Microbial life in extreme environments Chair: **Michael Danson** Rapporteur: **Kaï-Uwe Hinrichs**	Life strategies of plants in extreme environments Chair: **Francesco Loreto** Rapporteur: **Klaus-Ulrich Valentin**	Life strategies of animals in extreme environments Chair: **Arnoldus Blix** Rapporteur: **Françoise Gail**	Human adaptation in extreme environments Co-Rapporteur : **Helmut Hinghofer-Szalkay** Co-Rapporteur : **Elisabeth Vestergaard**
15.00-15.15	General principles of microbial ecosystems in extreme environments **Helga Stan Lotter**	Life strategies and evolution of rock black fungi from Antarctic cold desert **Silvano Onofri**	The influence of high carbon dioxide atmosphere on marine organisms on a macro to micro scale **Henry Elderfield**	Human aspects of spaceflight and planetary exploration **Didier Schmitt**
15.15-15.20	Discussion	Discussion	Discussion	Discussion
15.20-15.35	Microorganisms in snow and ice **Roland Psenner**	Photosynthesis in Antarctic lichens in extreme environments: plant stress physiology approaches **Milos Bartak**	Metazoans living around deep-sea vents: evidence for avoidance mechanisms **David Dixon**	Vascular adaptations in extreme environments **Sergio Pillon**
15.35-15.40	Discussion	Discussion	Discussion	Discussion
15.40-15.55	Diversity of hyperthermophilic archaea and their viruses in extreme thermal environments **David Prangishvili**	Life strategies of seaweeds and ice-algae in polar waters **Christian Wiencke**	How polar birds cope with extreme temperatures **Yvon Le Maho**	Personnel in extreme environments: psychosocial challenges **Gro Sandal**
15.55-16.00	Discussion	Discussion	Discussion	Discussion
16.00-16.30		*Coffee Break*		

Appendix III: ILEE Workshop Programme

16.30-16.45	Terrestrial ecosystems in extreme environments **Yoseph Steinberger**	Role of the cell wall in the ability of the resurrection plant Craterostigma plantagineum to survive drying **Simon McQueen-Mason**	Ecophysiology of invertebrates living in periglacial habitat in ice-retaining stony debris. **Miroslav Zacharda**	
16.45-16.50	Discussion	Discussion	Discussion	
16.50-17.05	Microbial life and space environment **Gerda Horneck**	Plant growing in space **Franck Ditengou**	Food web structure and dynamics along a productive/latitude gradient in extreme environments at present and in the past **Erik Jeppesen**	Round table discussion Social aspects of human adaptation in extreme environments
17.05-17.10	Discussion	Discussion	Discussion	
17.10-17.25	Acidic environments under the control of iron **Ricardo Amils**	Adaptation of photosynthetic organisms to extreme ultraviolet conditions **Imre Vass**	The adaptive evolution of polar fishes: an exciting challenge for biology **Guido di Prisco**	
17.25-17.30	Discussion	Discussion	Discussion	
17.30-19.30	Poster session			

Monday 7 November 2005

Session 7
Enabling technologies and applications
Moderator: Farzam Ranjbaran

08.30-08.50	Subglacial waters - melting probe technology - **Stephan Ulamec**
08.50-09.00	Discussion
09.00-09.20	Technological challenges of planetary protection - **Gerhard Schwehm**
09.20-09.30	Discussion
09.30-09.50	The concept of LabHorta, the first land-based laboratory/experimental platform for conducting experimental studies on hydrothermal-vent organisms from the Mid-Atlantic Ridge - **Eniko Kadar**
09.50-10.00	Discussion
10.00-10.30	*Coffee break*
10.30-12.30	Flash presentations
12.30	*Lunch*
14.00-16.30	Working Group Discussions

WG1 Enabling technologies and applications	WG2 Microbial life in extreme environments	WG3 Life strategies of plants in extreme environments	WG4 Life strategies of animals in extreme environments	WG5 Human adaptation in extreme environments
Discussion	Discussion	Discussion	Discussion	Discussion

16.30-17.00	*Coffee break*
17.00-18.00	Report from the Working Groups
18.00-19.00	Round table discussion: Life in Extreme Environments at the European Level – ESF Boards and Committees Perspectives Niamh Connolly (Marine Board), Arja Kallio (LESC)
19.00-19.20	Conclusion of the Workshop
20.30	*Gala Dinner*

Tuesday 8 November 2005

Breakfast and departure

Closed Session

09.00-12.00	Wrap Up, Synthesis, Recommendations, Report Structure
12.00-13.30	*Lunch and departure*

Appendix III: ILEE Workshop Programme

ESF Joint Initiative
Investigation Life in Extreme Environment
Flash Presentations*

Monday 7 November 2005

10.30-12.30

1. **Proteins from Extremophiles as Probes for the Design of Advanced Nano-Sensors for Analyses of High Social Interests**
   Sabato D'Auria (Institute of Protein Biochemistry, Naples, Italy)

2. **Raman Spectroscopic Analysis of Biologically Modified Geological Substrates : Markers for the Astrobiological Exploration of Mars**
   Howell Edwards (Chemical and Forensic Sciences, School of Pharmacy, Univ. of Bradford, UK)

3. **Information and Communication Technologies for remote support in investigating life in extreme environments**
   Diego Liberati (CNR, Dipartimento di Elettronica e Informazione – Politecnico, Milano, Italy)

4. **Exploration of subglacial lakes**
   Martin Siegert (University of Bristol, Bristol Glaciology Centre, UK)

5. **Molecular Basis of Response Mechanisms to Environmental Stresses in Thermophiles**
   Simonetta Bartolucci (Dipartimento di Biologia Strutturale e Funzionale, Università degli Studi di Napoli Federico II, Italy)

6. **On the possible relevance of biotic control on the microbial food web in antarctic lakes**
   Antonio Camacho (Department of Microbiology and Ecology, University of Valencia, Spain)

7. **Microbial ecology and biotechnology of hydrothermal and sulphuric marine caves**
   Francesco Canganella (Dept. of Agrobiology and Agrochemistry, University of Tuscia, Viterbo, Italy)

8. **Death and longevity at the salinity limits of life**
   Terence McGenity (University of Essex, Department of Biological Sciences, Colchester, UK)

9. **Microbial life in extreme acidic aquatic environments**
   Christian Wilhelm (University of Leipzig, Department of Plant Physiology, Germany)

10. **Technical challenges for probing subglacial lakes in Antarctica**
    Jean Robert Petit (LGGE/CNRS, St Martin d'Hères, France)

11. **Molecular aspects of plant adaptation to continuous heavy metal exposure: Thlaspi caerulescens**
    Mark Aarts (Lab of Genetics, Wageningen University, Wageningen, The Netherlands)

12. **Effects of global environmental changes on terrestrial vegetation: Implications for extreme environments**
    Mauro Centritto (CNR - Istituto sull'Inquinamento Atmosferico, Monterotondo Scalo, Monterotondo Scalo, Italy)

13. **Cyanobacteria and algae polar ecology**
    Josef Elster (Academy of Sciences of the Czech Republic, Institute of Botany)

14. **Adaptive thermogenesis in cold acclimation and hibernation**
    Barbara Cannon (The Wenner-Gren Institute, Stockholm University, Sweden)

15. **Strategies of autotrophic organisms in extremely acidic waters to overcome limitations induced by acidity.**
    Dieter Lessmann (Department of Freshwater Conservation Brandenburg University of Technology, Germany)

16. **Evolution of zooplankton communities in extreme acidic environments**
    Rainer Deneke and Brigitte Nixdorf (Brandenburg University of Technology, Environmental Science and Process Engineering, Bad Saarow, Germany)

17. **Life shaped by Antarctic ice shelves: spatially explicit modelling can predict climate induced community shifts**
    Julian Gutt (Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany)

18. **How 'bioengineer' animals shape their extreme environment at deep-sea vents**
    Nadine Le Bris (IFREMER, Département Etude des Ecosystèmes Profonds, Plouzané, France)

19. **Vertebrates life in oxygen free environments**
    Gøran Nilsson (University of Oslo, Department of Molecular Biosciences, Norway)

** Each flash-presentation is of 5 minutes (including discussion)*

Appendix III: ILEE Workshop Programme

ESF Joint Initiative
Investigation Life in Extreme Environment
List of Posters

Poster Session 1: Life Strategies of animals in extreme environments

ANIM-01	**Adaptive thermogenesis in cold acclimation and hibernation** Barbara Cannon (The Wenner-Gren Institute, Stockholm University, Sweden)
ANIM-02	**Evolution of aquatic communities in extremely acidic environments (pH 0 - 4)** Rainer Deneke (Brandenburg University of Technology, Environmental Science and Process Engineering, Bad Saarow, Germany)
ANIM-03	**Anthropogenic Radionuclides in European Arctic Marine Habitats** Dirk Dethleff (Institute for Polar Ecology, Kiel University, Germany)
ANIM-04	**Life shaped by Antarctic ice shelves: spatially explicit modelling can predict climate induced community shifts** Julian Gutt (Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany)
ANIM-05	**Adaptation of terrestrial invertebrates to extreme cold environments** Ian Hodkinson (Liverpool John Moores University, dpt.of Biological and Earth Sciences, UK)
ANIM-06	**Industrial barrens: exploration of the novel extreme environment** Mikhail V. Kozlov (University of Turku, Section of Ecology, Finland)
ANIM-07	**How ‘bioengineer’ animals shape their extreme environment at deep-sea vents** Nadine Le Bris (IFREMER, Département Etude des Ecosystèmes Profonds, Plouzané, France)
ANIM-08	**Ecological peculiarities of the symbiosis between the scale-worm Branchipolynoe seepensis and the giant mussels Bathymodiolus spp. rom hydrothermal vents** Daniel Martin
ANIM-09	**Vertebrates life in oxygen free environments** Gøran Nilsson (University of Oslo, Department of Molecular Biosciences, Norway)
ANIM-10	**Living in a critical salinity zone – the physiology of the marine amphipod Gammarus oceanicus from the Baltic Sea** Monika Normant (University of Gdansk, Institute of Oceanography, Gdynia, Poland)
ANIM-11	**The different sensibility to temperature of fish and mammal metallothioneins is linked to the evolution of protein domains** Elio Parisi (CNR Institute of Protein Biochemistry, Napoli, Italy)
ANIM-12	**Colonisation of deep extreme environment: how to break the pressure barrier?** Florence Pradillon (Max-Planck Institute for Marine Microbiology, Molecular Ecology, Bremen, Germany)
ANIM-13	**Diversity, distribution and functioning of deep-water chemosynthetic ecosystems - ChEss, a Census of Marine Life pilot project** Eva Ramirez-Llodra (Institut de Ciències del Mar, CMIMA-CSIC, Barcelona, Spain)

ANIM-14	**Extreme Oxidative Threats in Deep-Sea Organisms** Jean-François Rees (Université de Louvain, Institut des Sciences de la Vie, Belgium)
ANIM-15	**Ecophysiology of invertebrates living in periglacial habitat in ice-retaining stony debris: Physiological questions** Vladimir Sustr (Academy of Sciences of the Czech Republic, Institute of Soil Biology, _eské Bud_jovice, Czech Republic) Miloslav Zacharda (Academy of Sciences of the Czech Republic, Institute of Systems Biology and Ecology, _eské Bud_jovice, Czech Republic)

Poster Session 2: Microbial life in extreme environments

MICR-01	**Molecular Basis of Response Mechanisms to Environmental Stresses in Thermophiles** Simonetta Bartolucci (Dipartimento di Biologia Strutturale e Funzionale, Università degli Studi di Napoli Federico II, Italy)
MICR-02	**On the possible relevance of biotic control on the microbial food web in antarctic lakes** Antonio Camacho (Department of Microbiology and Ecology, University of Valencia, Spain
MICR-03	**Microbial ecology and biotechnology of hydrothermal and sulphuric marine caves** Francesco Canganella (Dept. of Agrobiology and Agrochemistry, University of Tuscia, Viterbo, Italy)
MICR-04	**Anoxia in sulfide rich aquatic environments: microbial life under extremely low redox potentials** Emilio Casamayor (Centre d'Estudis Avançats de Blanes (CSIC), Blanes, Spain)
MICR-05	**Thioautotrophic symbiosis: towards a new step in eukaryote evolution?** Stéphane Hourdez (CNRS/UPMC - Station Biologique, Roscoff, France)
MICR-06	**Use of continuous culture to access the cultivable thermophilic microbial diversity from deep-sea hydrothermal vent** Anne Godfroy (IFREMER, Laboratoire de Microbiologie des Environnements Extrêmes , Plouzané, France)
MICR-07	**Halophilic fungi** Nina Gunde-Cimerman (University of Ljubljana, Slovenia)
MICR-08	**Life in sea ice** Johanna Ikävalko (University of Helsinki, Dept. of Biological and Ecological Sciences/Aquatic Sciences, Finland)
MICR-09	**Activity and diversity of methanogenic Archaea under extreme environmental conditions in Late Pleistocene permafrost sediments of the Lena Delta, Siberia** German Jurgens (University of Helsinki, Dept. of Applied Chemistry and Microbiology, Finland)

MICR-10	**Morphological diversity of hyperthermophilic viruses and virus-like particles in deep-sea hydrothermal vents** Marc Le Romancer (Université de Bretagne Occidentale, Institut Universitaire Européen de la Mer (IUEM), Plouzané, France)
MICR-12	**Translation in extremely thermophilic archaea: insights on the early evolution of the decoding machinery** Paola Londei (University of Bari, Dpt. DIBIFIM, Italy)
MICR-13	**Death and longevity at the salinity limits of life** Terence McGenity (University of Essex, Department of Biological Sciences, Colchester, UK)
MICR-17	**Search for extraterrestrial hereditable information** Wilfred F.M. Röling (Vrije Universiteit, Molecular Cell Physiology, FALW , Amsterdam, The Netherlands)
MICR-18	**Microbial diversity of snow collected from Himalayan peaks: a study system for stratospheric transfer of microorganisms and colonization of extremely cold environments** David Pearce (British Antarctic Survey, Cambridge, UK)
MICR-19	**Phenotypic and genotypic diversity of photosynthetic protists in microbial mats of Antarctic lakes** Koen Sabbe (Ghent University, Laboratory of Protistology & Aquatic Ecology, Ghent, Belgium)
MICR-20	**Microbial life in extreme acidic aquatic environments** Christian Wilhelm (University of Leipzig, Department of Plant Physiology, Germany)
MICR-21	**The Vostock Project (TBC)** Jean-Robert Petit (LGGE - Laboratoire de Glaciologie et Géophysique de l'Environnement, St Martin d'Hères, France)
MICRO-22	**Extremely acidophilic prokaryotes: new insights into their physiological and phylogenetic biodiversities** D. Barrie Johnson and Kevin B. Hallberg (School of Biological Sciences, University of Wales, Bangor, UK)

Poster Session 3: Life Strategies of plants in extreme environments

PLAN-01	**Molecular aspects of plant adaptation to continuous heavy metal exposure: Thlaspi caerulescens** Mark Aarts (Lab of Genetics, Wageningen University, Wageningen, The Netherlands)
PLAN-02	**Effects of global environmental changes on terrestrial vegetation: Implications for extreme environments** Mauro Centritto (CNR - Istituto sull'Inquinamento Atmosferico, Monterotondo Scalo, Monterotondo Scalo, Italy)

PLAN-03	**Preservation of extinct and extant forms of life under terrestrial magnetic anomalies** Cristina Dobrota (Babes-Bolyai University, Experimental Biology Dept., Cluj-Napoca, Romania)
PLAN-04	**Cyanobacteria and algae polar ecology** Josef Elster (Academy of Sciences of the Czech Republic, Institute of Botany)
PLAN-05	**Ecophysiological responses of halophytes to saline environements -Sustainable use, conservation and development** Hans-Werner Koyro (Justus-Liebig-University of Giessen, Institute for Plant Ecology, Germany) Vladimir Sustr (Academy of Sciences of the Czech Republic, Institute of Soil Biology)
PLAN-06	**Arabidopsis root growth in simulated microgravity conditions** Fernando Migliaccio (CNR, Institute of Agroenvironmental and Forest Biology, Monterotondo, Italy)
PLAN-07	**Life expansion in NE Sorkapp Land, Spitsbergen, under the contemporary climate warming** Wieslaw Ziaja (Jagiellonian University, Institute of Geography and Spatial Management, Krakow, Poland)
PLAN-08	**Adaptation of high plants or cyanobacteria to high visible light intensity or UVB** Lello Zolla (University of Tuscia, Dip. Environmental Science, Viterbo, Italy)
PLAN-09	**“United we stand”: The role of positive plant-plant interactions in the extreme environments** Elena Zvereva (University of Turku, Section of Ecology, Turku, Finland)

Poster Session 4: Enabling technologies and applications

TECH-01	**Proteins from Extremophiles as Probes for the Design of Advanced Nano-Sensors for Analyses of High Social Interests** Sabato D'Auria (Institute of Protein Biochemistry, Naples, Italy)
TECH-02	**Raman Spectroscopic Analysis of Biologically Modified Geological Substrates : Markers for the Astrobiological Exploration of Mars** Howell Edwards (Chemical and Forensic Sciences, School of Pharmacy, Univ. of Bradford, UK)
TECH-03	**Information and Communication Technologies for remote support in investigating life in extreme environments** Diego Liberati (CNR, Dipartimento di Elettronica e Informazione – Politecnico, Milano, Italy)
TECH-04	**Fluorescence in situ hybridisation coupled to ultra-small immunogold detection to identify prokaryotic cells on minerals by electron and X-ray microscopy** Bénédicte Menez (CNRS/Institut de Physique du Globe de Paris, France)

TECH-05	**Multiparametric cytometry and High-speed cell sorting to investigate Mechanisms of cold adaptation of psychrophilic microorganisms** Susann Müller (UFZ Centre for Environmental Research Leipzig-Halle, Department of Environmental Microbiology, Leipzig, Germany)
TECH-06	**'Sensory mechanisms in the deep sea and appropriate methods for observing deep sea animals** Julian Partridge (University of Bristol, School of Biological Sciences, UK)
TECH-07	**The exploration of Subglacial Lake Ellsworth, West Antarctica** Martin J. Siegert (Bristol Glaciology Centre, School of Geographical Sciences, University of Bristol, UK)

Poster Session 5: Human Adaptation to Extreme Environments

HUMA-01	**The Post-Tsunami crops through salt tolerant species** Adriana Galvani (Dipartimento di Scienze Economiche, Università di Bologna, Italy)
HUMA-02	**Phenogenotypic factors in the formation of non-specific human resistance and the level of biological aging under extreme environments** Eugene Kobyliansky (Tel-Aviv University, Israel)
HUMA-03	**Research needs related on human adaptation to global change for ahead in the northern most Europe** Juhani Hassi (Centre for Arctic Medicine, University of Oulu, Finland)
HUMA-04	**DADLE: a Challenge Towards Human "Hibernation"? (TBC)** Carlo Zancanaro (Department of Morphological & Biomedical Sciences, University of Verona, Italy)
HUMA-05	**Strategies of human adaptation to high altitude** Jean-Paul Richalet (Université Paris 13, France)

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EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

1 quai Lezay-Marnésia • BP 90015
67080 Strasbourg cedex • France
Tel: +33 (0)3 88 76 71 00 • Fax: +33 (0)3 88 37 05 32
www.esf.org