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EVOLUTION AND BIODIVERSITY IN THE ANTARCTIC - THE RESPONSE OF LIFE TO CHANGE (EBA): ROLE AND LEGACY

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ABSTRACT

The international, multi- and cross-disciplinary programme Evolution and Biodiversity in the Antarctic: the Response of Life to Change (EBA), launched by the Scientific Committee for Antarctic Research (SCAR) in 2004, covers most of Antarctic biological research in the marine, terrestrial and freshwater realms, assembling almost one hundred research teams. It liaises with physical, geological and historical disciplines, because of the intimate connection between the living and abiotic environments. Cross-linkages are being established with SCAR Programmes in other disciplines. The cooperative and cross-disciplinary research of EBA is a long-term legacy, in particular for evolutionary and biodiversity information. EBA has direct relevance to Global Change, because it addresses the impacts of the latter on biodiversity, evolutionary adaptations and community dynamics. It has been a Lead Project of the International Polar Year (IPY, 2007-9), envisaging links with the Arctic. This is undergoing rapid climate change with progressive and fast decrease of sea and land ice. The responses of cold-adapted polar organisms provide information to analyse the effect of changes in general and foresee their impact at lower latitudes. EBA was approved by SCAR in 2004 and shall run until 2013. In 2009, the EBA community began planning its future. Cross-disciplinary science must be retained, but the EBA wide umbrella must be replaced by a more focussed approach. Antarctic research is expensive, and must be excellent, relevant, multi-national and well planned. The Peninsula and the sub-Antarctic islands are very important areas, and the relationship between South America and Antarctica, and their mutual influence must be considered. Climate change and its effects on biological systems and biodiversity in a changing environment are two major multi-disciplinary themes that may develop into new SCAR programmes. At the 2010 SCAR Meeting, the proposal of two distinct but complementary Science Programmes was brought to the attention of National Delegates, who agreed on further action along these research lines.
Keywords: EBA; adaptive evolution; biodiversity; climate change; polar amplification.

RESUMO

EVOLUÇÃO E BIODIVERSIDADE NA ANTARTICA - A RESPOSTA DA VIDA À MUDANÇA (EBA): PAPEL E LEGADO. O programa interdisciplinar internacional Evolução e Biodiversidade na Antártica: a Resposta da Vida à Mudança (EBA) lançado pelo Comitê Científico para Pesquisa Antártica (SCAR) em 2004 ampara a maioria das pesquisas biológicas nos ecossistemas Antárticos marinho, de água doce e terrestre, agregando quase uma centena de grupos de pesquisa. Devido a ligação íntima entre os ambientes bióticos e abióticos, o SCAR faz a união entre disciplinas físicas, geológicas e históricas. Ligações adicionais estão sendo estabelecidas com programas SCAR em outras disciplinas. A pesquisa cooperativa e interdisciplinar do EBA é um legado de longo prazo, principalmente com o que diz respeito a informação evolutiva e da biodiversidade. O EBA tem relevância direta com Mudança Global porque ele aborda os impactos das mudanças climáticas na biodiversidade, adaptação evolutiva e dinâmica de comunidades. O programa EBA tem sido um Projeto Líder

do Ano Internacional Polar (IPY, 2007-9), ponderando uma ligação com o Ártico. Este está sofrendo rápida mudança climática com rápida e progressiva redução de gelo marinho e terrestre. As respostas de organismos polares adaptados ao frio fornece informações para a análise do efeito das mudanças em geral e para a previsão de impactos em latitudes menores. O EBA foi aprovado pelo SCAR em 2004 e deve durar até 2013. Em 2009, a comunidade do EBA começou a planejar seu futuro. A ciência interdisciplinar deve continuar, mas a grande cobertura do EBA deve ser substituída por uma abordagem mais focada. A pesquisa Antártica é dispendiosa e, portanto, deve ser de excelente qualidade, relevante, multinacional e bem planejada. A península Antártica e as ilhas subantárticas são áreas muito importantes e a relação entre a América do Sul e a Antártica e suas influências mútuas devem ser consideradas. A mudança climática e seus efeitos em sistemas biológicos e na biodiversidade em um ambiente heterogêneo são dois principais temas interdisciplinares que podem se tornar novos programas SCAR. No encontro do SCAR em 2010, a proposta de dois Programas Científicos distintos, porém complementares foi trazida à atenção dos Delegados Nacionais, que por sua vez, concordaram com mais ações ao longo destas linhas de pesquisa.
Palavras-chave: EBA; evolução adaptativa; biodiversidade; mudança climática; amplificação polar.

RESUMEN

EVOLUCIÓN Y BIODIVERSIDAD EN LA ANTARTIDA: ESTUDIO DE LA RESPUESTA DE LOS SERES VIVOS AL CAMBIO (EBA); ROL Y LEGADO. El programa internacional multi e inter disciplinario Evolución y Biodiversidad en la Antártida: Estudio de la Respuesta de los Seres Vivos al Cambio (EBA) lanzado por el Comité Científico de Investigación Antártica (SCAR) el año 2004, incluye gran parte de la investigación biológica Antártica de los ámbitos marino, terrestre y de agua dulce, reuniendo a un centenar de equipos de investigación. Este programa estuvo relacionado con disciplinas físicas, geológicas e históricas, debido a la conexión íntima que existe entre los ambientes vivos y abióticos. Interrelaciones están siendo establecidas con los programas de SCAR en otras disciplinas. La investigación interdisciplinaria y cooperativa de EBA es un legado a largo plazo, en especial para la información evolutiva y de biodiversidad. EBA tiene una relevancia directa en el Cambio Global, debido a que trata sobre los impactos a la biodiversidad, a las adaptaciones evolutivas y a las dinámicas comunitarias. Ha sido un proyecto líder del Año Polar Internacional (IPY, 2007-09), concibiendo vínculos con el Ártico. Esta zona está sometida a un rápido cambio climático con una disminución progresiva y rápida de hielo marino y terrestre. Las respuestas de los organismos polares adaptados al frío proveen de información para analizar el efecto de los cambios de manera general y aplicar este conocimiento para prever el impacto del cambio también a bajas latitudes. EBA fue aprobado por SCAR el año 2004 y se mantendrá activo hasta el año 2013. El año 2009, la comunidad EBA empezó a planificar su futuro. La ciencia interdisciplinaria debe ser mantenida, pero el marco EBA debe ser reemplazado por una concepción mas focalizada. La investigación antártica es cara y debe ser excelente, relevante, multinacional y bien planificada. La Península y las islas sub antárticas son áreas muy importantes y la relación entre Sudamérica y la Antártida y su mutua influencia debe ser considerada. El cambio climático y sus efectos sobre los sistemas biológicos y la biodiversidad en un ambiente cambiante, son los dos principales temas multidisciplinarios que pueden desarrollarse dentro de los nuevos programas SCAR. En la reunión de SCAR del año 2010, la propuesta de dos Programas Científicos distintos pero complementarios llamó la atención de los Delegados Nacionales que acordaron realizar acciones futuras de estas líneas de investigación.
Palabras clave: EBA; evolución adaptativa; diversidad biológica; cambio climático; amplificación polar.

Describe the past, understand the present and predict the future

THREATS BY CURRENT CLIMATE CHANGE

SUSTAINABLE WORLD AND BIODIVERSITY

One of the largest challenges facing humankind is the management of the Earth System to ensure a sustainable human future. Understanding the Earth System functioning in the context of natural and anthropogenic changes is thus essential. The 'health' of the Earth and its living creatures are tightly linked, hence dependence on the environment and its changes is very high.

The concept of 'sustainable world' is strongly linked to the concept of 'biodiversity'. All life becomes possible because biodiversity makes the planet what it is. Biodiversity depends on many factors, which include diversity of genes, individuals, species, and habitats on Earth, as well as - above all - their interconnections and relationships (Pimm 2009).

Evaluating the impacts of Climate Change is a demanding challenge with implications for the Earth System, because the impacts of current changes on marine and terrestrial systems will negatively affect biodiversity. All regions are undergoing changes, due to the combined effects of natural change and human activity. The anthropogenic impact is crucial in causing and/or accelerating environmental change. This awareness is steadily spreading within the world public opinion, despite resistance and attempts to disseminate scepticism staged by commercial interests.

In general, patterns of biodiversity and distribution are generated by factors and processes which work on both evolutionary and ecological timescales (Pörtner & Farrell 2008). Environmental changes are able to modify and drive these factors and processes. For instance global warming produces effects on the physiology and ecology of many species, and appears to be the master driver of changes (Rosenzweig *et al*. 2008). Climate change can affect every aspect of an organism's biology, from cellular biochemistry to food web and habitat. All organisms are vulnerable to environmental change because it affects the physiology and, thereby, the ecology of species (Walther *et al*. 2002, Pörtner & Knust 2007). Even though warming is more evident in the air than the sea, marine polar species are particularly vulnerable because of their stenothermal nature, which allows a small window of tolerable temperatures (Pörtner *et al.* 2007).

Understanding the impact of past, current and predicted environmental change on biodiversity and the consequences for polar-ecosystem adaptation and function is a research priority for polar scientists. The critical examination of polar ecosystems undergoing change provides a major contribution to the understanding of evolutionary processes of relevance to life on Earth.

THE 'POLAR AMPLIFICATION'

We need to improve our knowledge of the ways in which life has evolved and in which it is likely to change. Compared to temperate and tropical latitudes, the polar regions are undergoing rapid environmental changes. The urge to investigate biodiversity at high latitudes is increasing, because organisms living in the polar regions are exposed to strong biological constraints and increasing threats of loss of their diversity. Warming is having stronger impacts in the Arctic, where the sea ice is predicted to disappear in a few decades (Walsh & Timlin 2003, Johannessen *et al*. 2004, Overpeck *et al*. 2006). The Arctic (together with the Sub-Antarctic) is less extreme than Antarctica. Its climate exhibits significant spatial and temporal variability, leading to regional climates with different features, intermediate between polar and temperate latitudes and bearing ecological and socio-economical consequences.

Antarctica, known to have a decisive role in driving the world's climatic features, has not been spared either. The general trends are contradictory, but the western side of the Antarctic Peninsula is currently undergoing one of the fastest rates of change on the planet with significant biological consequences (Clarke *et al.* 2007). Large reduction of annual sea ice causes migration of key fish species of the Antarctic trophic web (whose reproduction processes, being closely associated to sea ice, are upset), introduction of species from lower latitudes (such as myctophids) and altered assemblages of primary producers (Moline *et al*. 2008). Wholesale extinctions of fish species will require many concomitant synergistic events, but

species may become geographically or ecologically segregated marginalised (Anisimov *et al*. 2007). Thus, in both polar environments, changes have complex and interacting effects. In fact, an impact on the lowest or highest level of a food web could indirectly propagate further affecting other taxa from other levels of the web. For example, the progressive disappearance of sea ice in the Arctic will eventually hit the top predators such as the polar bears, which are in risk of extinction.

A 'polar amplification' of the climate warming due to anthropogenic effects has been predicted and it is supported by retreat acceleration of glaciers, sea-ice thinning and permafrost degradation. The vulnerability of species to recent and past climate change does raise the possibility that human influence may cause a major extinction event in the near future, and detailed analyses have led to the alarming conclusion that many species could be driven to extinction over the next 50 years. Debates are under way to urgently launch new policies aimed at identifying and reducing the impacts of human activities. The latter are mainly related to accelerated global warming, increased UVB levels, uncontrolled fishing, and introduction of alien species.

Global warming has indeed prompted scientists and governments to seriously consider the consequences of its rapid progress. Only resorting to concerted international efforts to conjugate political and economical factors based on increasing scientific evidence shall provide the best conditions to minimise the negative effects of human activities on Earth. The scientific evidence must be sought independently, and multidisciplinary, international programmes are needed to understand life processes, structure and functioning of living systems, evolution and adaptations. The aim is to protect polar biodiversity and life from the dangers, which are becoming more and more threatening.

THE SEARCH FOR EFFICIENT STRATEGIES

EVOLUTION AND BIODIVERSITY IN THE ANTARCTIC - THE RESPONSE OF LIFE TO CHANGE

SCAR has three Standing Scientific Groups (SSGs), and have endorsed five Scientific Research Programmes since 2004, namely Evolution and Biodiversity in Antarctica (EBA, Life Sciences-SSG), Antarctica and the Global Climate System (AGCS; Physical Sciences-SSG), Antarctic Climate Evolution (ACE; GeoSciences-SSG), Subglacial Antarctic Lake Environments (SALE; cross-disciplinary), and Interhemispheric Conjugacy Effects in Solar-Terrestrial and Aeronomy Research (ICESTAR; Physical Sciences-SSG). These projects are coming to an end in the near future, but SCAR is holding workshops on identifying cross-linkages among the three SSGs in order to progress their work through a multidisciplinary pathway. In addition, SCAR has established an Action Group on Prediction of Changes in the Physical and Biological Environments of the Antarctic, also active through several workshops.

It was the search for an efficient strategy that led to the birth of EBA. In 2004 the Scientific Committee on Antarctic Research (SCAR), fully aware of the global environmental problems, launched this vast programme, which virtually assembles all 36 countries participating in SCAR, is co-chaired by G di Prisco (IBP-CNR) and P Convey (BAS, UK), and is expected to end in 2013. EBA inherited the tasks and legacy of many successful SCAR marine and terrestrial initiatives of previous years, such as Ecology of the Antarctic Sea-Ice Zone (EASIZ), Evolution of Antarctic Organisms (EVOLANTA), Regional Sensitivity to Climate Change in Antarctic Terrestrial Ecosystems (RiSCC).

EBA aims at gaining knowledge of the ways in which evolution has driven and is driving life, and how life is likely to change. It is the only programme with this major goal, and is endowed with the relevant human resources, expertise, and capability. The top priority is to neutralise threats to biodiversity, in particular, before they become hopelessly irreversible, those driven by anthropogenic contributions. EBA's outputs include a roadmap for research on life in extreme environments. It consolidates the community, and establishes linkages and dialogue with funding agencies and other stakeholders, including industry, companies, science associations and other projects/ programmes.

Some key questions are: how is the polar biota geographically structured and related to those elsewhere? How well are polar organisms able to cope with daily, seasonal and longer-term environmental

changes? Will climate change result in relaxation of selection pressure on genomes, or tighter constraints and ultimately extinction of populations and species? *Vis-à-vis* of changing environments, how do we apply findings to development of conservation policies and patterns of human use?

Besides the need to address these questions in all biological disciplines (for example, molecular biology, ecophysiology, microbiology, taxonomy, biology), the study of biotic history is linked intimately to tectonic, climatic and palaeobiological studies and biogeography. Strong integration with programmes investigating climate and tectonic history are an essential feature of the work because intimate feedback between the living and abiotic environments have modulated both.

In summary, EBA integrates fields from functional genomics and molecular systematics, to ecosystem science and modelling, and draws on and contributes information to climate modelling and tectonics. It provides a platform for interactions amongst disciplines essential to understand the role of biodiversity in the Earth System and its responses to change by highlighting the Antarctic context, establishing crosslinks with the Arctic, enhancing our ability to achieve a sustainable future for all life. The polar environments indeed offer an immensely valuable, regionally focussed approach. Polar ecosystems allow studies on their responses to change induced by natural and anthropogenic processes, and the ways in which these responses feed back to influence the processes. EBA provides the best platform to combine findings from different nations, and accordingly gather the best estimates on the consequences of continued environmental changes in Antarctica EBA stimulates community networking through newsletters, promotional leaflets, scientific publications and an interactive web portal (www.eba.aq). Encompassing some 620 scientists, it was selected by ICSU/WMO as one of the Lead Projects for the International Polar Year (IPY 2007-2009). IPY took place half a century after the 3rd IPY, the International Geophysical Year (IGY), to which we owe countless milestones of Polar Science.

EBA is an overarching umbrella that provides advice to other main Antarctic institutions, such as the Antarctic Treaty Consultative Meetings (ATCM) and the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). It assembles international SCAR, Arctic and IPY programmes, for ex. Census of Antarctic Marine Life (CAML), Antarctic Benthic DEEP-Sea Biodiversity - System Coupling (ANDEEP-SYSTCO), International Collaborative Expedition to Collect & Study Fish Indigenous to Sub-Antarctic Habitats (ICEFISH), Marine Biodiversity Information Network (MarBIN, now renamed Antarctic Biodiversity Facility, ANTABIF), Microbiological and Ecological Responses to Global Environmental Changes in Polar Regions (MERGE), Marine Fishes of North East Greenland (TUNU-MAFIG).

THE FIVE WORK PACKAGES OF EBA

Among the ecological factors controlling distribution patterns and biodiversity of the modern Antarctic biota, the most important are temperature, water availability in the terrestrial ecosystems, ice cover, oxygen, light, UVB and wind in the marine systems. These factors are not constant, and all of them vary over a time range from daily to seasonal (annually and interannually). Interannual variability is of fundamental importance to ecosystem dynamics, e.g., subdecadal variations associated with El Niño-Southern Oscillation (ENSO) (Harangozo 2000, Kwok & Comiso 2002, Meredith *et al*. 2004). The ensemble of factors may be disrupted if the pattern of environmental variability changes. The Antarctic environment may vary on even longer timescales. Huge variability sets a significant challenge to ecologists attempting to determine the effects of long-term environmental change. By investigating all of these aspects, EBA is a source of information on the resistance and recoverability of Antarctic communities under current environmental conditions. The evolution of Antarctic organisms has taken millions of years to develop adaptations suitable to allow survival and reproduction during gradual establishment of extreme cold. Insights on the ability of cold-adapted organisms and communities to cope with changes is likely to provide useful information for analysing changes at lower latitudes.

EBA is structured in five Work Packages, which envisage the strong need of increasing synergy between molecular techniques and ecophysiology:

1. Evolutionary history of the Antarctic biota

Interaction with earth scientists is envisaged to clarify the geological and physical history of the Antarctic, and modern molecular techniques will advance our understanding of how evolutionary processes are related to the physical setting.

2. Evolutionary adaptation to the Antarctic environment

When investigating cold adaptation, studies on the survival strategies developed by organisms living at the extremes are central for understanding how life adapts to its environment. Adaptations allow organisms to survive in the Antarctic; the ecological and biochemical examination of response(s) to environmental changes imply the exploration of limits of organismal performance.

3. Gene flow and population dynamics

Isolation is a driving force of evolution in the Antarctic. This Work Package intends to understand the extent of isolation of populations, by examining (i) population structure and dynamics, (ii) dispersal to and around the Antarctic, (iii) genetic make-up and gene flow.

4. Patterns and diversity of organisms and ecosystems in the Antarctic

This Work Package is centred on examining biodiversity, for example, by investigating spatial and temporal variation, latitudinal and environmental gradients, unexplored areas, relationships with global patterns.

5. Impact of past, current and future environmental change on biodiversity and ecosystem function

Examination of how environmental changes are driving evolution will help in the prediction of future outcomes.

A GLIMPSE INTO THE FUTURE

If we consider the extent of environmental changes occurring at these latitudes and the key role of the poles in shaping global climate, the importance of monitoring and protecting polar environments becomes even more urgent. Disturbance due to warming may well affect climate at lower latitudes. For instance, if melting of Arctic ice has an impact on the Gulf Stream and modifies its course, Arctic conditions may hit large areas of northern Europe. With parts of the Antarctic currently undergoing the most rapid rates of warming seen on the planet, their terrestrial and marine ecosystems provide important indicators or early warning systems that may help us to predict and understand the sort of changes that are likely to impact lower latitudes in future.

It is important to keep investigating the relationships and the mutual influence that exist between the Antarctic continent (with special attention to the Antarctic Peninsula, where warming is occurring very rapidly) and many relevant areas, for example adjacent South America, the sub-Antarctic islands, the Arctic.

EBA's umbrella is very wide, and is far more than an individual research programme. EBA is successfully fulfilling the role of providing advice to ATCM and CCAMLR, and of coordinating large international polar and IPY programmes. But, it is now time for EBA to develop into more focussed SCAR projects. The essential synergy of disciplines is a long-lasting legacy of EBA, and we need to continue highlighting multi-national and cross-disciplinary initiatives by (i) encouraging integration of biochemistry/molecular biology, physiology, molecular genetics, morphology, taxonomy, biogeography, ecology, ethology, and other biological disciplines; (ii) upgrading synergy with physical sciences, modelling, palaeoscience, geophysics, glaciology, oceanography, climatology, statistics, to establish links between evolution and tectonics, climate evolution, glacial processes; (iii) maintaining the links with the Intergovernmental Panel on Climate Change (IPCC 2007) and the Committee for Environmental Protection (CEP).

The EBA community is expected to have a key role in outlining the next generation of SCAR Life Sciences programmes. But indeed, it would be impossible to try and cover all biological sciences by a single programme. In 2009, scientists began discussing the future of EBA at the SCAR Biology Symposium in Sapporo (Japan), and continued in May 2010 in a workshop in Tuscany (Castiglioncello, Italy). Topics included (i) identification of gaps to be filled in biodiversity information, (ii) physiological adaptations and molecular evolution, (iii) human impacts and biological invasion, (iv) Outreach &

Education. Information sources must be placed into a publicly accessible and comprehensible format, connecting the research actors with the public and decision makers' domains, including all educational sectors, but building on existing (although often inaccessible) information. We will encourage training of PhD students and postgraduates, and promote web sites, media coverage, publications, conference proceedings, input to databases. Dissemination encourages involvement of the public opinion by establishing an interface to the public and private sectors to enable understanding and acceptance of Antarctic science.

In the SCAR LS-SSG and Delegates Meetings (Buenos Aires, July-August 2010) we proposed to lead the EBA structure towards two Science Programmes, focussed on distinct but complementary aspects of Polar Biology. The SCAR Delegates favourably considered this proposal, and encouraged us to proceed along these lines. Both programmes refer to marine, freshwater and terrestrial organisms, and are briefly summarised below:

1. ANTARCTIC ECOSYSTEM THRESHOLDS AND RESILIENCE (AntETR)

AntETR is strongly characterised by 'omics' approaches, and will examine biological processes (intra-cellular/inter-cellular → organism → community → ecosystem) to define their tolerance limits and determine resistance and resilience to change.

Some Key Questions are:

- How does genetic variation underlie the life history and physiological adaptation of polar organisms?

- Will invasive species have catastrophic impacts?

- How do species traits impact on community interactions and stability (nutrient cycles, productivity)?

2. STATE OF THE ANTARCTIC ECOSYSTEM (AntEco)

Biodiversity dictates how ecosystems function and underpins the life-support system of our planet. The aims are to focus on patterns of biodiversity within the Antarctic, sub-Antarctic and Southern Ocean regions, and to provide the scientific foundation for biodiversity conservation and management.

Some Key Questions are:

- How has Antarctic biology responded to past change and what does this tell us about the capacity to respond to future change?

- How do we explain the origin, current distribution and abundance of biodiversity?

- What are the threats and what are the implications for the maintenance of biodiversity and ecosystem services?

ANTARCTIC CLIMATE CHANGE AND THE ENVIRONMENT

The publication of the 'Antarctic Climate Change and the Environment' (ACCE) report by SCAR (Turner *et al*. 2009; it can be purchased from SCAR or downloaded from www.scar.org) is a pivotal event in Antarctic environmental research. The Antarctic climate system is closely coupled to other parts of the global climate system. The report presents the latest research, identifies areas for future research, and addresses the urgent questions that policy makers have about Antarctic ice melting, sea-level rise and biodiversity. Over 100 world-leading scientists contributed to the review, which puts Antarctic climate change into context and reveals the impact on the rest of the planet. It focuses on the impact and consequences of rapid warming of the Antarctic Peninsula and the Southern Ocean, ice loss in parts of Antarctica and increase in sea ice around the continent, impact of climate change on Antarctic organisms, unprecedented increase in carbon dioxide levels, connections between human-induced global change and natural variability, and the extraordinary finding that the ozone hole, an anthropogenic environmental impact, has shielded most of Antarctica from another, global warming. This review illustrates how human activity is driving rapid climate change. Integration into a single source will help scientists and policy makers to understand the distinction between environmental changes linked to the Earth's natural cycles, and those that are human induced. It provides an essential Southern Hemisphere companion to the Arctic Climate Impact Assessment (2005). Convey et al. (2009) provide an overview of the major elements and conclusions of the ACCE report.

EBA and the new proposed programmes directly address the top issues of ACCE and will constantly feed annual updates into the report.

However, funding is a huge challenge. Scientists are funded individually at national levels, with different timescales and priorities. But EBA's success requires a long-term multidisciplinary and multinational commitment. Without this, no credible progress can be made. We do hope National Committees are fully aware of the urge of supporting EBA and its legacy.

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