Syndromes of Global Change

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Abstract A novel transdisciplinary description of the mega-process called "Global Change" in terms of functional patterns ("Syndromes") is presented. This approach to environmental analysis is inspired by medical sciences, where syndromes are perceived as typical combinations of pertinent co-factors. Sixteen main syndromes are identified as the sub-dynamics generating the world-wide environment and development process with all its negative aspects and impacts. The analysis relies on a specific semi-qualitative methodology, which brings together elements from complex systems theory, fuzzy logic and expert-judgment evaluations. The concept is illustrated by in-depth treatment and comparison of the syndromes Sahel" and "Green Revolution". As a corollary of the syndrome approach, a simple operational definition of "Sustainable Development" is suggested. Keywords: Earth System analysis, sustainable development, vulnerability, expert system, marginal agriculture

1 Introduction: The Changing Globe

"Global Change" is all around us: in the five decades since the end of Second World War numerous activities have transformed the (sur)face of our planet in an unprecedented way [1]. This mega-process concludes the triumphal march of the bourgeois-industrial revolution which started in England some two hundred years ago in a final and all-embracing manner. The ultimate driving forces of change have been natural sciences and fossil fuels, that is, an explosive combination of rather disparate gifts to humankind by history. Some of the consequences of this success story, however, are irritating, if not terrifying. We name just a few of them:

- modification of the physico-chemical composition of the atmosphere;
- soil degradation of all types;
- reduction of natural ecosystems by area and quality, implying significant loss of biodiversity;
- pollution of freshwater resources and coastal zones;
- global dissemination of allochthonous species, pests and disease vectors;
- population growth triggering transboundary migration and crowding in ill-managed mega-cities;
- amplification of world-wide disparities regarding affluence, sanitation and education - not to speak of imponderableslike human dignity.

All this is very real, even though the intensity and criticality of each single phenomenon listed above might be debated. In its totality, however, Global Change is clearly about to *transform the operational mode of the planetary ecosystem*, thereby generating cascades of significant (and possible irreversible) impacts on a majority of individuals in present and future generations [2]. About two decades ago the sciences, the political arena and the media began to recognize the significance of this spectrum of problems. With the fanfare announcing the discovery of the hole in the ozone layer over Antarctica [3], world opinion was finally shaken awake and pushed into a condition of hyperactivity which reached its spectacular peak in the Rio Conference on Environment and Development [4]. Today, 5 years after Rio, concern about the condition of the "patient Earth" has considerably declined, but not because the problems have actually become less acute. The reason is that, particularly in the industrialized countries, the worries about unemployment, criminality or the costs of social security systems are again generally being discussed as purely social and often national problems - essentially divorced from the global problems of the civilization-environment interface. The view towards the long-term dangers thus threatens to become almost completely blocked.

The basic questions concerning the possibilities for a "sustainable development" [5] of the planetary partnership of nature and civilization nonetheless remain: where is the Earth System heading, how can it be steered around all hazardous zones and finally be assured a "soft landing"? Competent answers have seldom been given to these fundamental questions. The main reason for this is that a successful "Earth System Management" as defined by *Agenda 21* [4] presupposes in the first place a solid "Earth System Analysis" which maintains the right balance between detailed knowledge and generalization and between a quantitative and a qualitative description [6].

Up to now, scientists have tried to approach an understanding of the coupled dynamics of ecosphere and anthroposphere mainly along two clearly separate paths:

On the one hand there are the rather traditional disciplinary-sectoral approaches, which in a very competent way endeavor to determine quantitatively single *facets of Global Change* in their global manifestation. Examples of these are the high-tech measurement campaigns to determine fluoride and bromide-containing components in the stratosphere, or the large-scale mapping of the integral and differential effects of wind erosion on soil resources. The results of this research are impressive and are an essential basis for any sort of systematic view of the overall spectrum of problems [7]. The simple accumulation of such results *per se*, however, cannot reflect the complex character of the system under investigation.

In contrast to the – in the best sense – "reductionist" approach just mentioned, the so-called "world models" do not push the individual (dimensional, sectoral, disciplinary, etc.) determinants of the system to the center of analysis, but rather the *"wiring" of the segments*. This "holistic" approach to Earth System analysis makes use of the simulation of more or less sophisticated copies of the planet in the laboratory of a virtual reality and owes its existence largely to the advent of electronic computers. Prominent representatives of the adolescent school of "integrated modeling" are WORLD3 [8], IMAGE2.0 [9], and TARGETS1.0 [10]. The protagonists of this school hope that with progressing geographical explicitness and process connectivity the digital copies will ever better be able to mimic the dynamic character of the original. This hope may possibly prove deceptive, since the chosen approach of *analogous modeling* by reproduction of the quantitative actual structure of the system may gain forecasting and hindcasting power only when the degree of sophistication becomes excessive (in analogy to Eco's logic this would correspond to a map with scale 1 : 1 [11]). In this case the simulation model completely loses its character as a heuristic instrument, as its dynamics are no easier to understand than those of its original!

Moreover, it appears completely illusory that the dimensions of individual and collective human behavior could be even approximately integrated into these models through differential equations to generate, ultimately, "history machines".

We are thus of the opinion that a *combination of both approaches* can help us on the way to Earth System analysis. This will require to sacrifice quantitative rigor significantly – but not drastically – by favor of *qualitative, intuitive* and *typifying* aspects. The basic idea here is that the overall phenomenon "Global Change" should not be divided into regions, sectors or processes but be understood as a *co-evolution of dynamic partial patterns* of unmistakable character. These patterns are bundles of interactive processes which appear repeatedly and widely spread in typical combinations - the "*syndromes of Global Change*" (compare [12, 7, 13]). The term syndrome is used here in a double sense: on the one hand neutrally, in the sense of the literal, ancient Greek meaning as a "flowing together of many factors", on the other hand normative, in the sense of medical terminology as "a complex clinical picture". The group of syndromes is thus limited to evident mis-developments in the recent history of civilization-nature relations, which in their totality and linkage make up the complex of problems outlined above. An important example here is the "SAHEL Syndrome" detailed below, which reflects the over-exploitation of marginal land. The aims of this article are to explain the main characteristics of the syndrome concept, to introduce the methodology of syndrome diagnosis and syndrome taxonomy, and to illustrate the formal analysis by means of more detailed examples.

2 The Syndrome Concept

Before we begin with the formal description of our approach, let us try to prevent possible misinterpretations of the syndrome concept by the following remarks.

Firstly it must be borne in mind that we do not interpret syndromes simply as complexes of causes and effects, but as patterns of interactions, frequently possessing clear feedback character. Such interpretations have proved very valuable in the physical theory of complex systems, particularly for the description of "emerging co-operative phenomena" in dissipative systems far from equilibrium [14, 15].

Furthermore, it must be clearly pointed out that an exact separation of the syndromes from each other – say through a mathematical algorithm in the sense of matrix diagonalization – is neither possible nor sensible. In spite of this, the syndromes possess an unmistakable qualitative identity, similar to the way in which the colors of the spectrum are recognizable to us without the help of wavelength-measurement equipment. While our example of color is an extremely simple allegory, the meaning of systems analysis based on qualitative patterns becomes much more easily grasped when we illustrate our approach with the phenomenon "culture" which is determined by ethnic, linguistic, or political factors.

Although it is hardly possible to characterize adequately and to separate from each other, say, the Italian and Chinese cultures by means of primitive lists of ingredients in the style

- "pasta, red wine, opera (Milano), the Mafia, fashion, improvisational talent, Renaissance" versus
- "spring roll, plum wine, opera (Beijing), Kung Fu, water-color painting, industry, Ming Dynasty",

these two cultures nonetheless possess their own clearly recognizable identities. These reproduce themselves continually from more subtle constituent elements than the above-mentioned ingredients, that is, language, family structure, work ethos, artisanal and art tradition, social and environmental behavior, etc.. The reality of cultures as persistent civilizational patterns will be evident to anyone who wanders through the cultural mosaic landscape of Los Angeles or New York City with their eyes and ears open.

Within the framework of this example we now might turn our attention to a single sectoral aspect and ask, for instance, what contribution individual cultures have made to the development of painting. These contributions may be understood only in the respective cultural context, and a hypothetical planned sponsorship of talent would have to take the respective context into account.

In a similar way, our analysis of Global Change must take into account the syndrome context of a specific global environmental trend – for example a particular form of soil degradation – if this trend is to be understood and, if necessary, countered. The SAHEL and GREEN REVOLUTION Syndromes described in greater detail below contribute to no small degree to soil degradation, *but in differing ways as an expression of quite different complexes of interactions.*

The "soft identity" of the syndromes of Global Change and their transdisciplinary composition demands specific and sometimes innovative methods of investigation such as

(1) decomposition of complex functional networks,
(2) qualitative reasoning concepts,
(3) modeling of fuzziness and uncertainty,
(4) knowledge acquisition strategies,
(5) set-value analysis.

We can obtain a geographically explicit overall view of Global Change if we determine which syndromes are currently operating for all regions of the Earth. This overall picture may be produced as a superposition of all mosaic structures that show the spatial distribution of the single syndromes. It must be remembered though that the maps so produced do not display a static pattern but rather the active zones of problematic environmental and development processes.

2.1 The Basic Vocabulary I: Symptoms of Global Change

The disciplinary concepts and notions needed for Global Change analysis are usually not easily understood by scientists from other disciplines. Sometimes the same terminology is used for different concepts in different sectors. Therefore, the syndrome approach needs its own highly aggregated "vocabulary". On the one hand this is necessary to simplify the interactions between different disciplines and between different syndromes, and on the other hand to have well-defined concepts for modeling.

The basic units for the description of the Earth System and its syndromes are the *symptoms of Global Change* as proposed by the German Advisory Council on Global Change (WBGU) [2]. They define the most relevant aspects of the global dynamics closely related to the civilization-nature interface. We are currently operating with about 80 symptoms, including, for example, the following:

- urban sprawl,
- increasing significance of NGOs,
- terrestrial run-off changes,
- deposition and accumulation of waste,
- increasing mobility,
- tropospheric pollution,
- increasing consumption of energy and resources.

The names of the symptoms have to be understood more as guiding headlines than as definitions. These symptoms, taken from different spheres (atmosphere, biosphere, anthroposphere, and so forth), focus on qualitative and quantitative changes of the Earth System, and include usually the states and the rate of change of the quality or quantity concerned. Sometimes even the qualities analogous to higher derivatives will be included if they contribute to Global Change. In the case of a symptom refering to a quantity X it can be written as a tupel $(X, \dot{X}, \ddot{X}, \dots)$. Unlike the usual elements of analysis, symptoms are not designed to be easily indexed. For many of them quantitative data are not available and only qualitative information, obtainable as expert knowledge, can be used. A good example for such a case is the symptom called *emancipation of women*, which demonstrates that the lack of data and knowledge is a fundamental one and not only due to limited efforts in statistics. Additionally, it demonstrates that the term "symptom", although analogous to medicine, does not explicitly refer to a value judgment: symptoms are not necessarily "good" or "bad", they can be either or both.

For a quality or quantity to be usable as a symptom, it has to be possible that it can change significantly on a medium-term temporal scale, that is, years and decades. In order to perform the analysis of Global Change, variables that fluctuate on small (< 1 year) time scales cannot be described as symptoms. It is furthermore required that symptoms are defined as disjunct entities.

For Global Change analysis the simple identification of symptoms is not sufficient. Their interactions are also crucial. Such interactions have one target symptom and one or more source symptoms representing the causal connections between the symptoms involved. The form of an interaction is broadly described by its type. In graphical representations of symptoms and interactions as in Fig. 1, the induction of a monotonic increase in the target symptom by an increase in the source symptom is expressed through the symbol "$\longrightarrow$". Contrary, an attenuation effect is expressed by the symbol "—•". The combined influence of two or more symptoms on others might occur as well and is represented by the symbol "$\}\!\longrightarrow$". Finally, one has to take into consideration and symbolize cases of more complex, that is, non-monotonic, interactions or cases where the knowledge base is uncertain, for example if experts judge the interaction of symptoms differently, or if no research has been done so far. This is symbolized by a question mark in the graphs. Interactions are also stated in cases where they appear not under all circumstances, but in a very relevant number of cases. It has to be kept in mind, however, that the states and their rates of change are not completely determined by interactions and other symptoms, but some fraction of them and their rates of change are external to our analysis, so that even symptoms that are not strengthened through interactions can increase. As displayed in Fig. 1, the symptoms provide a dynamic and transdisciplinary language to describe Global Change phenomena. They indicate possible critical shifts towards non-sustainability. As Global Change today mainly refers to "anthropogenic" processes, symptoms are either direct expressions of human actions (for example, change of consumption patterns) or indirectly induced by it (for example, anthropogenic climate change). The former are aggregations of social actions forced by individuals, or in other words macro-results of micro-level processes. Thus, the operation with macro-level symptoms does not exclude

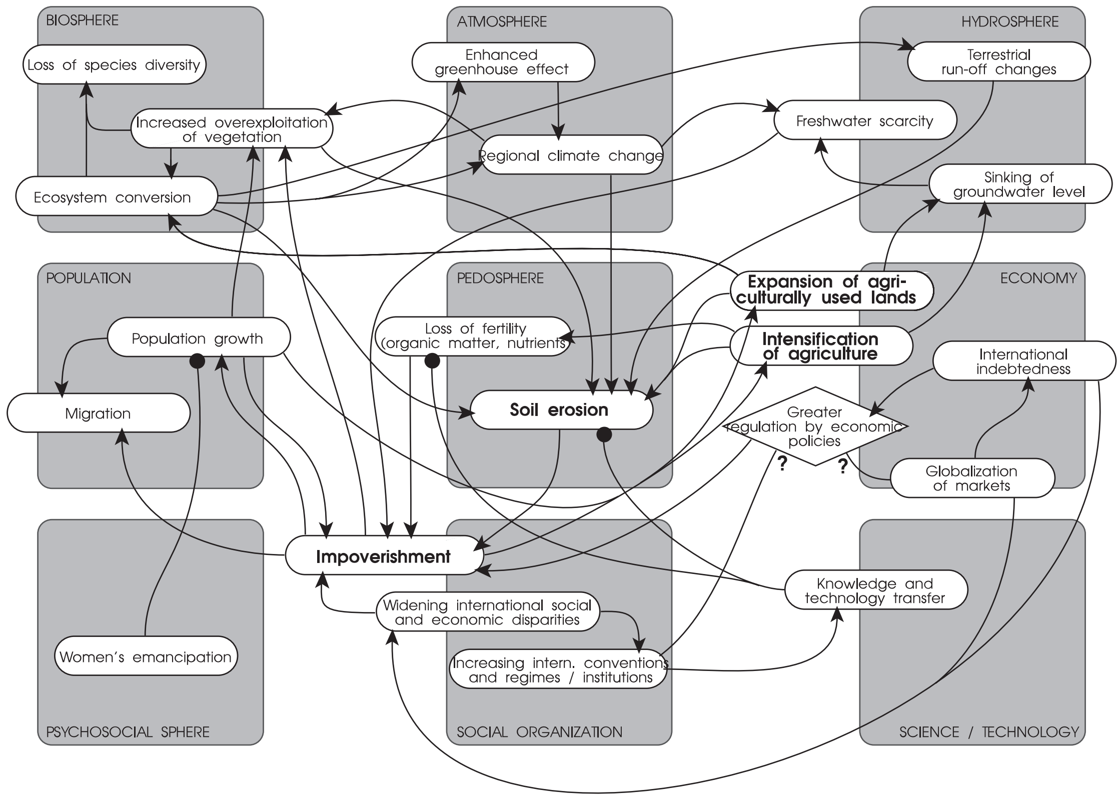

Figure 1. SAHEL Syndrome specific network of interrelations. This network describes the complex interactions between symptoms of different Earth System spheres that make up the typical pattern of overuse of agriculturally marginal land. The core symptoms, denoted by bold lettering, outline the vicious circle characteristics of the SAHEL Syndrome.

the identification of individuals or group actors, which would be very disadvantageous concerning support for Earth System management. The syndrome approach is, on the contrary, strongly connected with social science debates about explanation of human action [16] within the framework of the dialectical relation between action and structure [17].

The Earth System is not only a functional unit, it is a *geographical* one as well. Using symptoms and interactions without taking into account their spatial occurence may lead to oversimplifying an examined problem complex and result in logical inconsistencies. Interactions that are never active at the same location would seem to be active simultaneously when neglecting space. This could lead to significant errors in the qualitative analysis, for example, the false identification of feedback loops.

Our analysis is therefore spatially dependent, that is to say, syndromes have different intensities and varieties at different locations, symptoms have different values, and interactions exist in or between some locations and not between others. However, the plain geographical space as describable, for example, through latitude and longitude seems not to be sufficient to specify all the important aspects determining the existence of interactions. These can be also natural or socio-economic. Although some of these factors can be determined by their geographical location this is not possible in every case (for example, for the difference between rural artisans and rural farmers), without making the geographical resolution higher than the minimal scale for many of the symptoms. We therefore introduce the concept of the "functional space" which differentiates between all factors important for the definition of syndromes, interactions and symptoms. Examples for functional locations can be, for instance, sectoral, including financial markets, agriculture, and heavy industries, or socioeconomic, for instance, poor people or wealthy people or politically (un)stable regions, or natural, for instance, slope of cropland. For each interaction, the domains are defined in which it is active in geographical and functional space.

Taking into account the minimum sensible scales for many symptoms (for example, *Industrialization* or *Globalization* do not happen below a regional scale) and the limited possible complexity of any analysis, the geographical and the functional space have to be discretized. Also there are some criteria in functional space that are inherently discrete, such as the question of gender. The crucial choice of the resolution of this discretization can vary from interaction to interaction and from symptom to symptom; also the geographical discretization can depend on the functional one and vice versa, so that there is every possibility for multi-scale analysis or modeling.

The realization of the concepts described above is obviously a huge task, although every method of reducing it that can be agreed upon will be applied. This and especially the transdisciplinary nature of the pro-

Utilization Syndromes	
SAHEL **Syndrome**	Overuse of marginal land
OVEREXPLOITATION **Syndrome**	Overexploitation of natural ecosystems
RURAL EXODUS **Syndrome**	Degradation through abandonment of traditional agricultural practices
DUST BOWL **Syndrome**	Non-sustainable agro-industrial use of soils and bodies of water
KATANGA **Syndrome**	Degradation through depletion of non-renewable resources
MASS TOURISM **Syndrome**	Development and destruction of nature for recreational ends
SCORCHED EARTH **Syndrome**	Environmental destruction through war and military action
Development Syndromes	
ARAL SEA **Syndrome**	Damage of landscapes as a result of large-scale projects
GREEN REVOLUTION **Syndrome**	Degradation through the transfer and introduction of inappropriate farming methods
ASIAN TIGER **Syndrome**	Disregard for environmental standards in the course of rapid economic growth
FAVELA **Syndrome**	Socio-ecological degradation through uncontrolled urban growth
URBAN SPRAWL **Syndrome**	Destruction of landscapes through planned expansion of urban infrastructures
DISASTER **Syndrome**	Singular anthropogenic environmental disasters with long-term impacts
Sink Syndromes	
SMOKESTACK **Syndrome**	Environmental degradation through large-scale diffusion of long-lived substances
WASTE DUMPING **Syndrome**	Environmental degradation through controlled and uncontrolled disposal of waste
CONTAMINATED LAND **Syndrome**	Local contamination of environmental assets at industrial locations

Table 1. Global Change phenomena like soil degradation, climate change or worldwide development disparities can be structured as symptoms and their mutual reinforcement, resulting in so-called syndromes of Global Change. These patterns of non-sustainable development can be grouped according to basic human usage of nature: as a source for production, as a medium for socio-economic development, as a sink for civilizational outputs.

ject, which does not use only traditional, well-defined disciplinary concepts, requires an iterative approach: firstly a rather coarse version of the set of syndromes, symptoms and interactions is described and then modifications are made iteratively to enhance its details and consistency in an ongoing discourse process. The openness of the approach also ensures the possibility of including future research results into the syndrome concept. This iterative process of analysing Global Change shows some analogies to the hermeneutic method of understanding common in parts of the humanities [18]. In order to understand a piece of art or a text we operate with a contextual pre-knowledge, structuring the large amount of information. This structured manifold subsequently serves as a hypothesis about the object and might be corrected according to unexplained elements or new information about it leading to a better understanding in the third step.

2.2 The Basic Vocabulary II: Syndromes

Once one realizes the huge complexity of the network of interrelations for all symptoms and their interactions, the necessity for an analytical tool to brake this global network into conceivable units becomes evident.

The philosophy of the syndrome concept rests on the assumption that Global Change phenomena cannot be resolved into isolated changes, occurring in single Earth System spheres, such as the hydro-, atmo- or anthroposphere. Analysis based upon sectoral information alone commonly fails. The interactions of processes in all spheres, especially the social driving forces, their direct or indirect effects across sectoral borders and the feedback loops that "re-import" anthropogenic changes have to be taken into account. In order to integrate these relevant aspects and to structure the huge amount of sectoral information we focus on specific syndromes of Global Change. They are defined as *archetypical pat-*

terns of civilization-nature-interactions, which can be understood from the methodological point of view also as *sub-dynamics of Global Change.* Humans use natural systems and functions throughout the globe in very different ways. Nevertheless one can find quite similar "failures" or problematic co-evolutions. Analogously to medicine, the term syndrome refers to a typical cooccurence of different symptoms, like a cough or fever in the case of a cold. Each of these symptoms could be observed as a single phenomenon or in combination with others.

The list of intuitively formulated syndromes presented in Table 1 supplies an overview of the 16 species we are currently working on. The names of the syndromes refer to functional patterns found worldwide, not to specific places or events. The functional structure of each syndrome, including human driving forces and natural systems reactions are indicated by the short descriptions. In Section 3 selected syndromes (SAHEL, GREEN REVOLUTION) are described in more detail. Syndromes can be further typologized by regarding the way in which humans and social systems use and misuse nature. This leads to three major types: *utilization syndromes, development syndromes and sink syndromes.*

Analyzing syndromes allows not only for an evaluation of the general effect of human systems on the natural environment, but also for the reconstruction of archetypical pathways in which this happens. So we get information not only about the dynamics of the Earth System, expressed by the contribution of single syndromes to the key problems of Global Change, but also elementary knowledge about social driving forces, actor groups and their location.

2.3 Concepts of Syndrome Diagnosis

So far we have discussed the major structural elements of syndromes. In this section we will discuss some appropriate methods of data analysis and interpretation in order to "measure" syndromes. These concepts have to start from the syndrome-specific network of interrelations explained above. The question arises whether the proposed network is actually active to a globally relevant extent – only that makes it a syndrome of the currently ongoing Global Change. From the considerations on interactions and their dependence on geographical and functional location, it is obvious that it is also necessary to determine the regions where the conditions for the syndrome-specific interactions are present and therefore a breakout of the syndrome is possible. The concepts to operationalize these measures are called "*intensity* of" and "*disposition* towards a syndrome", respectively. The transition from a prone region, that is, with a significant disposition, to an actually infected region, that is with a significant intensity, is triggered by the *exposition* factors. Before explaining these concepts in more detail, some words have to be said on the methods of qualitative systems analysis used for syndrome diagnosis.

2.3.1 Methods of Qualitative Syndrome Diagnosis.

Suppose that it is necessary to solve a transdisciplinary problem. If one is a non-generalist, one would like to aggregate knowledge from experts or databases in order to make mostly confident decisions. However, databases are often characterized by incomplete knowledge, and also for experts it is more or less difficult to formulate their knowledge in a symbolic way. Therefore it is necessary to establish knowledge accumulation and structuring systems which are capable of processing uncertainty and may lead to formalization of qualitative indicators for the examination of a problem. Such qualitative knowledge is the major basis for deeper insight into an underlying problem. Obviously, syndromes are also trans-sectoral phenomena, which can be only examined by including the evaluations of experts from many different disciplines. The role of the syndrome analyst is to compile the expert knowledge in a formalized framework which exactly fits the claims of an expert system. Then the question arises of what this framework has to look like in order to fit the needs formulated in the introductory remarks.

One important tool which has promoted the progress of expert systems is fuzzy logic [19, 20]. In contrast to classical boolean logic, fuzzy logic makes use of continuous truth values between 0 and 1 which somehow reflect fuzzy evaluations. These continuous truth values either reveal the usage of fuzzy evaluation categories (warm, cloudy, high, etc.) and/or the availability of blunt or uncertain knowledge. The basic idea is that on a basis of as much available information as possible, the different contributions are evaluated in terms of fuzzy categories, which then are compiled in the form of a logical evaluation tree to obtain one single, yet fuzzy, measure for the overall evaluation (for an example regarding the disposition towards the SAHEL Syndrome, see Fig. 2). Using

generalized logical connectives (fuzzified AND, OR, NOT) these trees reflect the decision criteria of the syndrome analyst on how to combine the different contributions. There are, however, other qualitative methods which can be made use of, for instance, qualitative differential equations [21], which are useful for a qualitative modeling of the dynamics. A further important property of the framework has to reflect the regional dependence of symptoms, their interactions, and syndromes. This is especially difficult if interactions are spatially active, for instance, if migration is relevant both for the region where people are emigrating from and for the regions they are heading towards. Another example involves the accessibility of regions: the major part of the deforestation process in Russia is taking place along roads and railways and not in the outback (OVEREXPLOITATION Syndrome). Therefore the formal, qualitative models building up the framework have to be supplemented by a GIS (Geographic Information System), which allows the spatial peculiarities described to be included.

2.3.2 Disposition: Geographically Explicit Proneness.

The disposition refers to the process of identifying the proneness of entire regions towards specific syndromes. Within the disposition analysis a number of questions

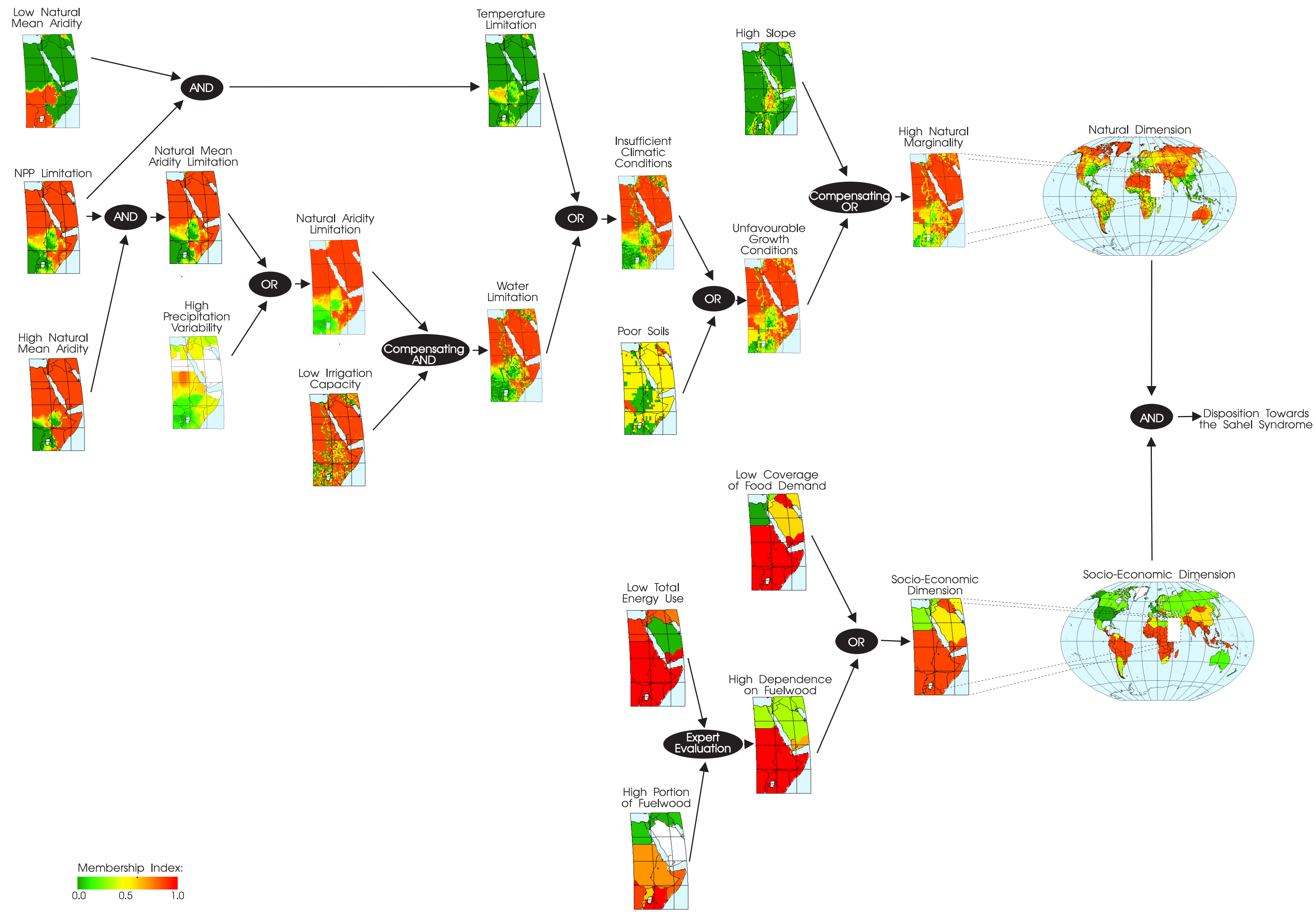

Figure 2. Decision tree for the disposition towards the Sahel Syndrome. The tree is evaluated stepwise by the application of different fuzzy logic operators indicated by the black ellipses. As an example for the global evaluation of the natural and the socio-economic dimension for the Sahel Syndrome disposition, the map boxes display the stepwise results of the algorithm for an area in north-eastern Africa (lat/long: $5°S - 35°N/25°E - 52°E$). Each original data set is fuzzyfied by a membership function which maps the data to the degree of inclusion to the logical clause "high/low X". Green denotes a low membership index to the logical clause and red denotes a high membership [22, 23].

have to be addressed: why do we have a rapid economic growth connected with the disregard of environmental standards (Asian Tiger Syndrome) in South-East Asia but not in Africa? What is the reason for the environmental degradation due to the overuse of marginal land in the Sahel? What are the socio-economic and natural prerequisites for the development and destruction of nature for recreational ends? The disposition is determined by structural peculiarities of the region which persist over medium and long-term time scales. Described in terms of interacting symptoms, the disposition towards a syndrome is determined by the ensemble of conditions for the existence of the interactions in the syndrome specific *kernel*. This kernel is defined as that part of the syndrome-specific network of interrelations which is necessary for the existence of the syndrome, irrespective of the variety of the syndrome (see Section 2.3.4). These conditions can be either natural (climate, orography, soil properties, etc.) or socio-economic (political system, traditions, culture, etc.). The different contributions have to be assessed on the basis of available information, that is quantitative and qualitative, which then is systematically interpreted with regard to the specific mechanism behind the interaction to be indicated. Combining these geographically explicit contributions into an evaluation tree yields the geographically explicit overall disposition measure (see Fig. 2).

This measure is not only relevant for the analysis of currently ongoing Global Change, but is even more important concerning the future. Regions which are prone to one or even more syndromes, but are not yet affected, have to be considered as particularly endangered. Therefore, politics concerning these regions (either local, regional, or even global politics) have to focus with special emphasis on either the prevention of exposition factors which can trigger the syndrome or on measures suited to reduce the disposition itself. From our point of view the latter goal is superior: to prevent marginal land from overuse, it is probably best to reduce the dependence of the local people on these marginal resources or to improve the productivity and reduce the vulnerability of the land by appropriate agricultural practices.

2.3.3 Exposition: the Triggers.
The disposition of a region towards a syndrome does not imply that the region will automatically be affected by the syndrome mechanism. Just as in medicine, where a pathogenic germ induces an infectious disease if the immunity system is too weak, single events or other rather short-term factors can actuate a syndrome if the corresponding disposition is high. These factors are called exposition factors which can be distinguished as:

(a) *endogenous*, that is, they are captured within our approach. Examples are other syndromes (compare Section 2.4) acting as triggering factors. Often this is connected with certain stages of the actuating syndrome, for example, the construction of a dam within the Aral Sea Syndrome itself can lead to the Sahel Syndrome via the changes in land use and property rights. This has to be contrasted with the later phase of the Aral Sea Syndrome, that is, the dam has been already operating for some time with all the effects involved in the syndrome. Yet, this stage does not any longer infect the Sahel Syndrome.

(b) *exogenous*, that is, the factors are not described by symptoms or syndromes. These factors can be further classified as:

- natural catastrophes like volcanic eruptions, earthquakes, etc. which might lead, for example, to migration movements possibly strengthening or triggering the Favela Syndrome;
- extreme events within the realm of natural variability, like floods and droughts. As an example, consider the drought in the Sahel region which has reinforced the vicious circle between poverty and overuse;
- political events like the collapse of the socialist countries in central and eastern Europe. Syndromes which might have been activated in this way include the Overexploitation Syndrome which can be observed in Siberia;
- short-term economic events, like price changes or changes in currency exchange rates. These might lead to benefits from the exploitation of resources which are rather difficult to access (Overexploitation and Katanga Syndrome).

This list of exposition factors is still preliminary. As one can see, however, there are factors which are singular (volcanoes, price changes, etc.), as well as processes with a longer time scale (migrations, droughts, etc.). If a suitable exposition factor hits a disposed region, the syndrome mechanism is activated and the environmental degradation processes develop according to the syndrome dynamics. If this assumption is correct, there should be some way to indicate not only disposition and exposition, but also the syndrome *intensity*. If this is done independently, there is a way for a consistency check of the analysis: only those regions can be indicated as affected, where the disposition is high and corresponding exposition factors have occurred.

2.3.4 Intensity and Variety of a Syndrome.
The difficult task of measuring a syndrome is that it is not a static fact which has to be proven, but rather the entire dynamics of the syndrome kernel has to be grasped. Therefore one has to specify the syndrome kernel not only by the schematic network of interrelations but also by some qualitative or semi-quantitative model. The model should be (a) as general as possible, that is, without assuming over-special functions for the interdependencies and (b) be based on available information. The proposed, knowledge-based model should then allow a necessary condition for the syndrome to be derived in terms of actually available data. The extent to which this condition is fulfilled can serve as a simple systematic and aggregated indicator for the syndrome reflecting the presence of the mechanism of the kernel. Being based on geographically explicit data and information, a map results that indicates those regions which are currently affected by the syndrome.

As an example consider the vicious circle of the Sahel Syndrome. Without going into all the details (see Section 3.1.4) a model is needed which reflects the mutual amplification of rural poverty, soil degradation, and extension of agricultural farm land [24]. It turns out that is necessary to use rates of change over some period of time rather than pure absolute numbers. This hints at the probably major difficulty in intensity measurement: the limited availability of time series for most data.

So far we have focused on the measurement of the kernel of the syndrome. Yet, it is clear that the type of overuse is slightly different when comparing the Sahel region with Brazil, even though the overall mechanisms are similar. These differences are caught by the concept of *variety*, which is intended to grasp those peculiarities which are important for some type of curative or preventive measures. In case of the SAHEL Syndrome the type of the syndrome is mainly determined by the causes of marginality: there are regions with marginal land due to a semi-arid climate, and there are regions where marginality results from limited soil fertility [25]. This exactly constitutes the stated difference between the Sahel region itself and Brazil. This implies that different varieties in terms of disposition are constituted by different contributions of single factors in the overall disposition. In order to measure the actual variety of the syndrome in a region which might have been detected as affected in terms of the intensity measure, it is necessary to extend the data analysis beyond the pure kernel of the syndrome.

Finally, some words should be said on the validation of the different measurements. It has turned out (see [22]) that the best cross-check for the analysis is the usage of (a) one's own educated guesses and (b) different case-studies from those regions where these guesses might be contradictory to the measurement. For most regions the global measurement cannot be as good as the often large number of detailed field-studies. The strength of our approach is its general overview on all aspects of Global Change and the identification of hot spots from a global perspective.

2.4 Taxonomy of Syndrome Coupling

So far we have considered syndromes as isolated patterns of Global Change. As outlined in the last subsections, an essential part of the dynamics of Global Change is expected to be well described in terms of intra-syndrome dynamics. Even so, major elements of the dynamics cannot be recapitulated by this scheme. Nevertheless, the decomposition of Global Change into archetypical patterns not only allows the analysis of each single syndrome, but is equally appropriate as a framework to characterize and classify couplings between different sub-dynamics of the Earth System. These couplings are understood as couplings between syndromes and can be observed in one or more of the following forms:

➤ *Coincidence*
The weakest form in which syndromes interact is when they occur simultaneously in a country or region, but without one acting as a driving force for the other. A country like Australia, for example, may be affected by the KATANGA Syndrome, the DUST BOWL Syndrome and the MASS TOURISM Syndrome at the same time, without any significant mutual reinforcement occurring between them. Such "weak" links can be important when assessing the general vulnerability of a country in order to identify hot spots of Global Change.

➤ *Coupling through common symptoms*
A stronger form of syndrome linkage is when two syndromes have one or several common key symptoms. If, as in the case of the SAHEL and the RURAL EXODUS Syndrome, the symptom of *social and economic marginalization* is part of the core mechanism, the parallel occurrence of the two syndromes in space and time will be regarded as more than pure coincidence especially if the global trend of marginalization is explained by them to a large extent.

➤ *Infection*
A syndrome already active may trigger another syndrome in a certain region. Deliberate reshaping of the natural environment through large scale projects (ARAL SEA Syndrome), for instance, may lead to changes in people-environment interactions in the region concerned and cause the RURAL EXODUS Syndrome and/or the SAHEL Syndrome to emerge, even though these degradation patterns did not exist there previously.

➤ *Reinforcement*
Symptoms can have a reinforcing effect on each other, but so can entire syndromes. In this case they do not trigger other syndromes through common symptoms but through the total force of their characteristic pattern. An example of this is the driving force exerted by the Sahel Syndrome on the FAVELA Syndrome. The simultaneous incidence of phenomena such as soil erosion, marginalization of the rural population and growth of urban agglomerations which can be observed in newly industrializing and developing countries, in particular, is not a mere spatial coincidence, but reflects a syndrome-reinforcing linkage of high global relevance.

➤ *Attenuation*
Syndromes may also be linked through attenuation. An example of this is the impact that the SCORCHED EARTH Syndrome has on the MASS TOURISM Syndrome; whenever wars and civil wars involve deliberate destruction of civilizational infrastructures and the natural environment, recreational tourism depending on the latter declines immediately as a result. Former Yugoslavia is the most recent example of this phenomenon. The converse example is the death strip along the former intra-German border, where nature was able to develop relatively undisturbed for many years, thus escaping the potential damage caused by the URBAN SPRAWL Syndrome or the DUST BOWL Syndrome, for instance.

➤ *Succession*
Syndromes are, of course, a part of the historical development of the civilization-nature interface. The syndrome approach provides sufficient material for retrospectively analyzing the history of human induced damages of nature. It is possible to identify not only past occurrences of individual syndromes (the ironworks of Saxony induced the SMOKESTACK

Syndrome in the early 19th century, for example), but also typical succession patterns of syndromes. The sequence of development stages through which civilization progresses is evidently linked to very specific syndromes, for instance, SAHEL, GREEN REVOLUTION or ASIAN TIGER Syndrome, which can thus be used, at least in an exploratory way, to assess the future development of the Earth System.

3 Analysing Global Change by Syndromes: Exemplary Results

In this chapter, two exemplary syndromes will be discussed focusing on the core problem "soil degradation", in order to highlight the results obtainable by taking into account respective mechanisms, dispositions and intensities. The geographic regions infected by the two syndromes are superimposed on a map of human-induced soil degradation [26].

3.1 The SAHEL Syndrome

The key characteristic of the Sahel Syndrome is described as the overuse of agriculturally marginal land by a poor or impoverished rural population living in a context of action offering little or no alternative livelihood opportunities – thus leading to the further degradation of their environment. This syndrome typically occurs in countries on a low level of socio-economic development and in regions vulnerable to human impacts due to relatively weak agricultural production potential. This production potential can either be limited due to aridity limitations, temperature limitations or due to limiting soil-fertility conditions. The main driving forces and effects are inherent in all forms of the SAHEL Syndrome, regardless of the types of production limitations given by natural environmental conditions. This enhances the explanatory force of the model and ameliorates its regional fitting – including poverty-driven agricultural overuse practices in areas usually not associated with the term "Sahel", such as the Amazonian basin or the rainforest areas of some African countries. The core mechanism or kernel of this syndrome consists of a vicious circle, relating the trends *impoverishment, intensification/expansion of agriculture and soil erosion* – the latter leading to productivity losses and subsequently more poverty. Case studies of peasant agro-ecosystems in poor countries show that this basic mechanism describes the situation of many people in the "Third World", caught in a typical socio-ecological trap [27].

3.1.1 The Disposition Towards the SAHEL Syndrome.
Disposition towards a syndrome, as defined in Section 2.3.2, usually depends on natural environmental and socio-economical characteristics which are assumed to change slowly in time compared with the typical time scales of the syndrome dynamics. The initial consideration is that not all countries or regions will be equally susceptible to the trend interaction pattern labeled the SAHEL Syndrome. In an analogy to human physiology, the task was to find some key features of the Earth System that would define its proneness towards the SAHEL Syndrome. As the syndrome essentially describes the overuse of agricultural marginal sites, the task of finding regions prone to the syndrome can be transformed into the search for characteristic aspects of such sites.

Speaking analytically, agricultural production can be decomposed into the more natural environmental elements and the more social aspects which contribute to it. This analytical decomposition represents the first bifurcation of a decision tree for agricultural marginality. The entire decision tree, which claims to include all relevant elements and features of the disposition space of the SAHEL Syndrome, is presented in Fig. 2. Besides the different qualities entering the tree, the logical connectives used in the analysis are also shown. The different data sets employed are discussed in more detail below.

An appropriate way to formalize this decision tree has to reflect the mostly qualitative nature of the syndrome mechanism's description which also implies the use of qualitative knowledge in the identification of disposed regions. Up to now, the fuzzy logic concept has proved to be most fruitful in this context. In the case of the disposition towards the SAHEL Syndrome, one has to identify conditions for the following central interactions: (a) poverty-driven low capital input intensification and expansion of agriculture causes soil degradation and (b) yield decline forces the poor rural population to further land use changes due to the absence of economic alternatives. Interaction (a) becomes probable if the considered region is fragile with respect to its natural environmental conditions for agriculture ("natural dimension"), while (b) becomes probable if there is a high proportion of subsistence farming in an economy oriented towards the primary sector ("socio-economic dimension"). These conditions are estimated on the basis of available global data sets which include for the natural dimension, the net primary productivity of natural vegetation (NPP) as a basic indicator for general growth conditions and the orography as an indicator for erosion risk, while for the socio-economic dimension data on the energy use characteristics and market statistics for food products were used. In the sense of a fuzzy logic formalization all linguistic categories indicated by map boxes in Fig. 2 are characterized by membership indices between 0 (the category does not apply to the region at all) and 1 (the category applies fully to the region). Accordingly the ellipses depict appropriate fuzzy connectives, (for details see [22]).

3.1.2 Natural Components of the Disposition.
To assess the natural marginality of agricultural areas with respect to farming or pastoral use, we have to analyze the interplay between the different limiting factors for agricultural production. Most models concerned with agricultural productivity put special emphasis on the mean climatic variables and soil properties, which certainly represent the most dominating factors. Further aspects which have to be taken into account are the interannual variability of seasonal precipitation patterns and temperature, which cause uncertainty in agricultural planning, and perturbations in output. The

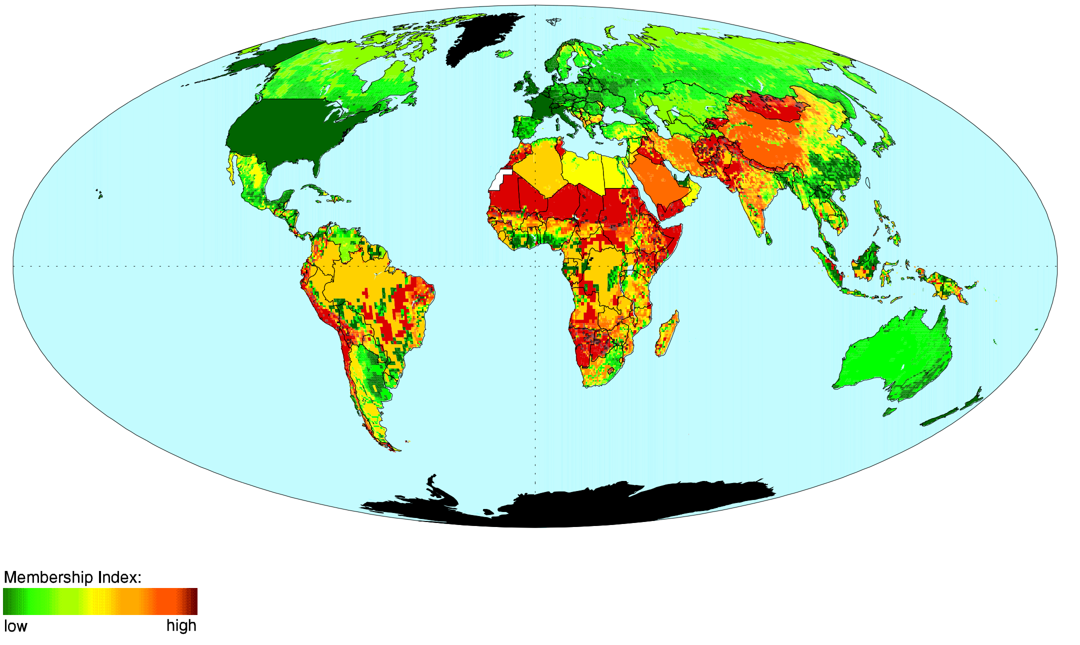

Figure 3. Global distribution of SAHEL Syndrome Disposition. The red areas are prone to being infected by the overuse of agriculturally marginal land, or in other words, these areas have a high disposition towards the SAHEL [7] Syndrome.

compensation of dry conditions by direct irrigation at the plant site is another additional factor. Although this aspect actually has to be considered as an anthropogenic issue, it crucially depends on natural conditions, for instance, the availability of surface or ground water. The topographical suitability for agricultural production of an area has to be considered due to the increasing risk of erosion. Finally, it is important to take into account the possibility of pastoral land use.

3.1.3 Socio-economic Components of the Disposition.

Agriculture as a very specific interaction between civilization and its natural environment is equally determined by social and economic features, which may aggravate or compensate the limiting natural factors mentioned above. The first component of the socio-economic dimension of the disposition space was derived from the consideration that societies with a high dependency on agricultural production and at the same time a high proportion of subsistence farming are very likely to impose high pressure on marginal natural resources such as soils and vegetation [23]. In contrast, societies with higher proportions of industry, services and a high degree of industrialized agriculture put much less pressure on these resources. The latter societies are rather prone to the DUST BOWL Syndrome [28]. As the measurement and even the definition of subsistence agriculture is quite difficult, an indirect way of measuring this type of cultivation was chosen. By balancing domestic food supply (including production, ex- and import) and food demand, an indicator for the probability of subsistence production can be derived. The necessary data came from FAO food statistics [29].

As a second indicator for subsistence production, the consumption of fuelwood, which is a characteristic feature of most agricultural productions in developing countries, where commercial use of oil, gas or electricity is widely restricted for economic and technical reasons, was taken into account. A measure was developed accounting for both the absolute level of energy consumption and the share of fuelwood in national energy consumption.

It is clear that it is an enormous endeavor to develop a quantitative model which sufficiently considers all of the aspects mentioned so far. Nevertheless there is a huge amount of qualitative expert knowledge on the interdependencies involved. We have therefore formulated a qualitative and synoptic model which allows for the evaluation of the disposition towards the SAHEL Syndrome. The two aspects, the natural and the socio-economic dimension, have been combined using fuzzy logic. The right hand side of Fig. 2 shows the corresponding decision tree and the operators used in the analysis of the social dimension of marginality. The resulting global distribution of the SAHEL Syndrome disposition is shown in Fig. 3. It can be seen that even highly fragile regions in industrialized countries (for example, the western USA) are not prone to the syndrome because of the missing socio-economic conditions while, for example, in the Sahel region, in parts of western Africa, the North-East of Brazil, the west coast of South America, Mongolia and the west of the Indian sub-continent both the social and the natural dimension apply, resulting in a high disposition. Those regions are either endangered by the outbreak of the syndrome or the syndrome is already active, which has to be decided by the investigation of the intensity (or, more qualitatively, the presence) of the syndrome, which is described next.

3.1.4 An Indicator for SAHEL Syndrome Intensity.

The condition for the presence or intensity of a syndrome in a specified region is the validity of the most important trends and mechanisms (interrelations), which are represented in the syndrome kernel (marked in bold in Fig. 1). In the case of the SAHEL Syndrome this kernel is dynamically dominated by a vicious circle consisting of soil degradation, leading to increasing poverty by yield decline and, as a reaction, land use changes which result in turn in an overuse of the land.

To detect this mechanism, we assumed that for a given region at a given time t there is a measure $A(t)$ for poverty near the subsistence level, a measure $N(t)$ which denotes the extent and intensity of agriculture, and a measure $B(t)$ for the state of soil degradation. We may now describe the mechanism formulated above in a more formal way:

1. Poverty near the subsistence level (A) causes an increase in extent (expansion) and intensity (intensification) of agriculture (dN/dt),
2. agricultural activity (N) causes an increase in soil degradation (dB/dt) and
3. an increase in soil degradation (dB/dt) causes an increase in poverty (dA/dt).

It is very difficult, or even impossible, to determine the exact functional dependence of, for example, dN/dt on A, especially because the specific form would depend on the kind of measures chosen for N and A. Therefore we only rewrite the *qualitative relations* 1-3 together with the reasonable assumption of monotony (which means, for example, that higher levels of A lead to higher dN/dt values) in a system of differential equations. Fortunately it is possible to mathematically deduce some general properties of this system without determining the explicit form. We will refer here to one result which is not the most general one but allows for evaluation on the basis of available global data sets. The following relation holds in the case of linearized functions and a value for t that is not too small:

$$\frac{dN/dt}{N} = \frac{dB/dt}{B} = \frac{dA/dt}{A} = const. \qquad (1)$$

This means that in the case of the validity of *qualitative* relations 1-3 representing the causal structure of the mechanisms under consideration the relative temporal changes of N ,B and A are (a) equal and (b) constant in time.

To check whether condition (a) is fulfilled one needs at least data for (N, B, A) at two times distinct $(t1, t2)$ to calculate the time derivative numerically, while for condition (b) at least three times would be necessary. The latter requirement exceeds the present global data availability. As a measure for poverty in the range of the subsistence level, A, we used the head count index which gives the number of people with an income below a poverty line defined by basic needs with respect to nutrition and non-food consumption (for the difficulties in defining such basic needs see [30]). We had to rely on the data collection of Ref. [31] which provides country-wide rural poverty head-count indices for the eighties and for the year 1992 and on the data set of Ref. [32] covering the same times. Both data sets concentrate on developing countries. For 96 countries with available data we calculated the mean relative change $(dA/dt)/A$ for the time interval from 1985 to 1992.

In the case of the soil degradation data we used the GLASOD database [26], which i.a. contains information about the severity of anthropogenic soil degradation (state of soil degradation B) and the present rate of anthropogenic soil degradation (dB/dt). The data was collected during the 1980s and is therefore commensurable with the poverty data sets. The spatial units of the data set are the polygons of the FAO soil-type map which usually implies a sub-country resolution. To obtain the relative change of soil degradation, the estimated rate from the GLASOD data set had to be scaled to the unit of severity by a factor f which we obtained from comparisons with estimations reported in Ref. [33].

We developed subsequently a combined measure for the intensity and the extent of agricultural use N in a country based on the indicators livestock and arable land. With respect to the livestock we considered the number of camels, cattle, sheep and goats. To make these numbers comparable, they were weighted according to the livestock unit [34]. To include the arable land in the measure we compared the mean production of one livestock unit (meat, milk) with the mean millet yield of one hectare [35] in terms of energy content. Using the data sets (country-wide) of Ref. [36] we calculated the mean relative change in agricultural intensity and extent $(dN/dt)/N$ for the time interval from 1985 to 1992.

To evaluate the necessary condition for the existence of the qualitative relations between poverty, land use change and soil degradation according to the above condition we define, for the case that all relative changes in a considered region are greater than 0, the following measure for the degree of deviation:

$$T = \left| \frac{dN/dt}{N} - \frac{dB/dt}{B} \right| + \left| \frac{dN/dt}{N} - \frac{dA/dt}{A} \right| + \left| \frac{dA/dt}{A} - \frac{dB/dt}{B} \right| \qquad (2)$$

which yields 0 for the case of exact equality of all three relative changes and increasing positive values for increasing deviation. The method and result of this evaluation is explained in more detail in [24]. A country-wide evaluation of the presence of the SAHEL Syndrome is displayed as an overlay on the map of human induced soil degradation in Fig. 6.

3.2 The GREEN REVOLUTION Syndrome

The degradation of the natural conditions for agricultural production and the degradation of the social structure as a consequence of the large scale, officially planned, and rapid modernization of the agricultural sector of developing countries with imported non-appropriate techniques to cover the growing domestic demand for food is characterized as the GREEN REVOLUTION Syndrome. We do not declare every form of agricultural productivity gains by "revolutionary" methods as syndromatic. We only focus on negative symptoms contributing to Global Change and affecting other spheres or types of civilization-nature interactions.

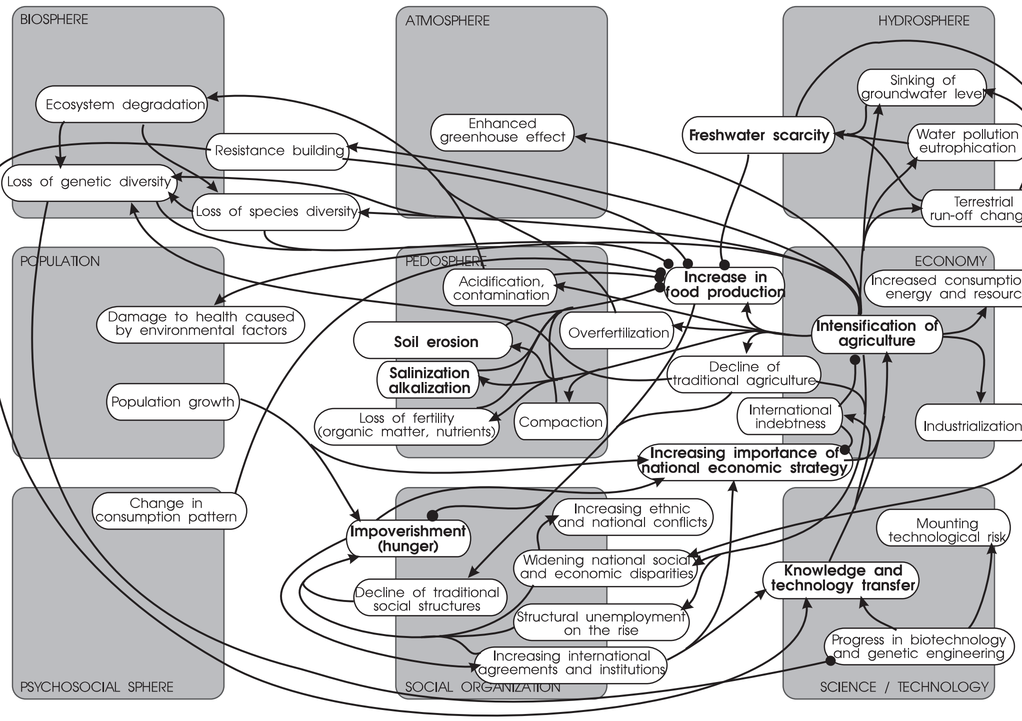

Figure 4. Network of interrelations specific to the Green Revolution Syndrome. This network describes the complex interactions between symptoms of different spheres that make up the typical pattern of environmental and social degradation by the transfer and introduction of inappropriate farming methods. The core symptoms of the Green Revolution Syndrome are denoted by bold lettering. These symptoms were used for the syndrome intensity measurement [39].

In the early 1960s a growing demand for food in the developing countries was recognized, especially in countries with overproportionally (with respect to food production growth rates) growing population like India, where hunger and famines had occured. To prevent a "Malthusian crisis" (and in some cases to prevent a "red" revolution, which loomed in some Asian and Latin American countries in these years) many developing countries decided to improve their food output by some new methods in the field of agriculture. At the same time the agroindustrial complex in the industrialized world was about to expand significantly – both in economic and scientific terms. The production of fertilizers, pesticides, and new high yielding varieties (Hyv) became less expensive and the belief in technical solutions based on cheap energy and resource input was also on the advance. Early criticism of this development as in the famous book Silent Spring [37] was simply not taken seriously by mainstream opinion of that period. Given the geopolitical situation of these years - the West preferred transfering western technology into developing countries over letting them become or remain dependent for their food supply on the Eastern bloc - and the technical progress then taking place, the development politics took care to encourage the enhancement of the agricultural sector in the developing countries. In parallel, a number of international institutions were founded which support the technology transfer into the Green Revolution countries and important technical progress was made. The Hyv developed then were only suitable on good soils and had a high demand on water. Therefore the first Green Revolution only occurred in regions with sufficient rain or on irrigated land. 50-60 % of the productivity increase in the Green Revolution countries was due to irrigation [38].

Today the problematic consequences of the Green Revolution are widely recognized. Under the impression of a still-growing world population and its changing consumption patterns a further rise in world food production is necessary. The "Second" Green Revolution, proposed by the main research institutes and development politicians, promises to take the negative consequences of the first one into account. It intends, for example, also to take into account the needs of the semi-arid regions which have been so far widely neglected.

3.2.1 The Green Revolution-Specific Network of Interrelations.

The growing *population* and the *impoverishment* that exists for various reasons in developing countries leads - driven by *national economic strategies* and under the assistance of *knowledge and technology transfer* – to an *intensification of agriculture* and hence to an increase in food production (Fig. 4). This pattern of symptoms is referred to as Green Revolution. Based on the development of high yielding varieties, especially rice, wheat, and maize, the Green Revolution primarily occurred in tropical and subtropical countries with a high input of irrigation water. This input often led and leads to a number of natural degradations: *salinization, erosion/morphological changes, loss of fertility, lowering of groundwater level.* Further effects on the environment are the *contamination of the soil, water pollution/eutrophication, overfertilization*, the *increasing resistance of pests* to the enhanced usage of fertilizers and pesticides, and finally *compaction* by using modern agromachines. On the other hand we also experience a social degradation: the imported techniques are expensive, they are often only effective on large farms, former common goods like groundwater became only available for "rich" farmers. Therefore a *decline of traditional agriculture* and of *traditional social structures* and an *widening of national disparities* can be recognized. The bias towards certain regions may also enhance the possibility of *ethnic and national conflicts*. The dependence on imported agricultural requisits and technology can increase the *international indebtedness*. In summary, one can conclude that the degradation of natural resources has negative effects on the increase of *food production* and that the social degradation increases the *impoverishment*. These negative effects are what we refer to as the syndrome character of the Green Revolution.

3.2.2 The Intensity of the Green Revolution Syndrome.

To get an global overview of the regions affected by Green Revolution Syndrome we first have to identify the regions which experienced the Green Revolution as such (syndromatic or non-syndromatic). Based on national economic factors gathered for the period between 1960 and 1990, the countries are identified which have undergone such a development [39]. The core mechanism mentioned above leads to the following four necessary conditions that have to be fulfilled:

- There was a strong increase in the areal productivity of cereals.
- At the beginning of the period there was a deficit in food production/supply.
- The cereal production delivers a significant contribution to the nations nutrition.
- There was an increase in the national cereal production which had not been exported.

The validity of the above conditions is checked with the help of the following indicators, based on data from FAO [29] and WRI [36]:

- Absolute increase in areal productivity of cereals between 1960 and 1990.
- Averaged malnutrition in 1961 measured as nutritional energy supply per capita.
- Cereal production per capita in 1991.
- Relative non-exported increase in cereal production measured as the difference of increase in cereal production and increase in cereal exports related to the cereal production in 1961.

The four conditions have to be satisfied simultaneously. To evaluate whether a country is a Green Revolution country or not, the membership indices of these indicators are combined by a fuzzy-logic-extended And. If the resulting membership index is 0 the considered country is certainly not a Green Revolution country; if it is 1 the country is certainly a Green Revolution country [39].

If a country is identified as a Green Revolution country, one has to determine whether a natural or a social degradation or both have occured. To identify natural degradation the rate of soil degradation in areas of cereal production [22, 26, 29, 33] is used.

The social degradation can be determined by the increase of rural poverty, an indicator also used to determine the intensity of the Sahel Syndrome, and the fraction of export profits to serve the international debts of a country. To obtain the indicator for the existence of the Green Revolution Syndrome in a country, the indicators of social degradation and natural degradation are added and compared to the indicator of the existence of the Green Revolution as such. If the Green Revolution is not important in a country, the observed degradations are also less important - with respect to the Green Revolution Syndrome. The above evaluation yields the membership index for presence of the Green Revolution Syndrome for every nation which is displayed in Fig. 5. This will be discussed in the next section.

3.3 Anthropogenic Soil Degradation and its Syndromatic Causes

Figure 6 compares the Sahel Syndrome and the Green Revolution Syndrome regarding their anthropogenic soil degradation. Evidently there are regions in which only one, two or none of both syndromes are present. A short evaluation of the result is necessary. The African Sub-Saharan countries are still in the grip of the social and economic marginalization of large parts of their rural population. Possible reasons for the absence of the Green Revolution Syndrome here are the low presence of cereals for which Hyvs have been developed, the fact that there are mainly not very fertile, lateritic soils present [40] and the fact that most governments in this region were for various reasons not able to make a strong long-lasting commitment to a Green Revolution. In the politically more stable, mostly centralized, South and East Asian countries the Green Revolution was initialized to deal with the problems in food production. In fact, the syndromatic consequences can clearly be detected there. The simultaneous occurrence of both syndromes in countries like India, Pakistan, Algeria and Columbia can be interpreted as an indicator of the widening internal social disparities.

The socio-economic indicators used for the previously described intensity measurements for the Sahel Syndrome and the Green Revolution Syndrome result from about the same time period as the evaluation of human-induced soil degradation (mainly the 80s). Therefore it is possible to compare the results directly in an superposition of the syndrome intensities as the causes for the observed soil degradation. Since we examined only two of the main syndromatic causes for soil degradation in this example, not all the degraded regions in Fig. 6 can be explained completely by our assessment. The two syndromes introduced in this contribution deal mainly with agriculturally induced problems in developing countries. Hence, the soil degradation in the developed countries cannot be explained by these syndromes. It must be explained by other syndromes such as the Dust Bowl Syndrome which is the main cause for agriculturally induced soil degradation in North America, South

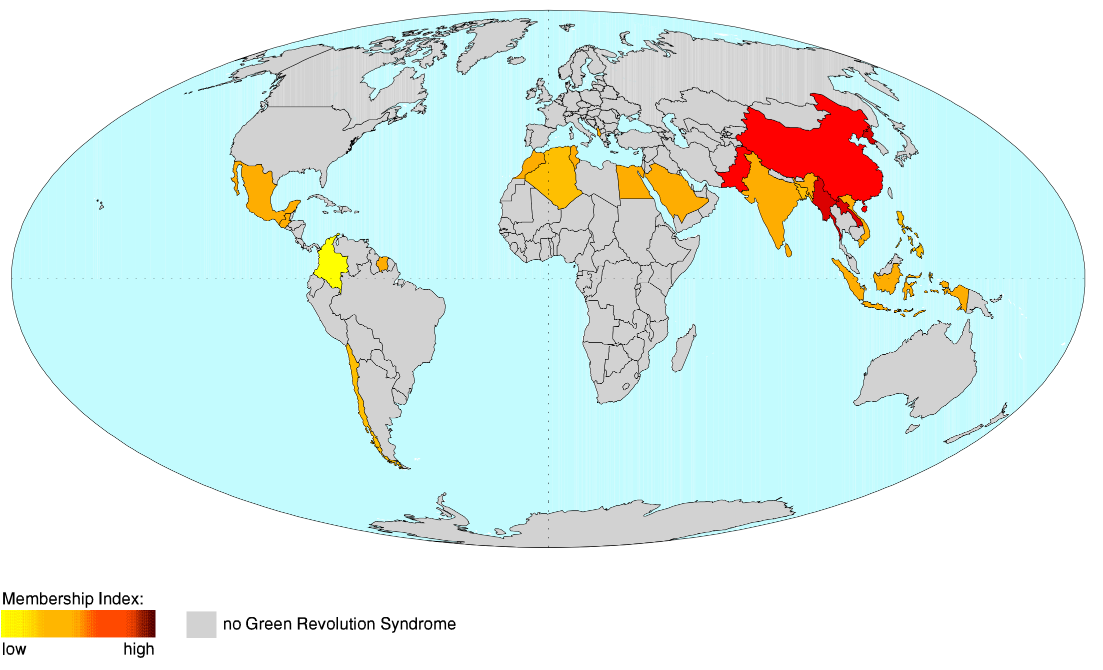

Figure 5. Country-specific membership index for the intensity of the Green Revolution Syndrome. (Note, that unintuitively the red colour stands for the Green, not for the Red, Revolution which to avoid was one intention for starting it.).

Africa, Europe and the southwestern parts of the Commonwealth of Independent States (Cis). However, even the soil degradation in the developing countries cannot be exclusively attributed to the Sahel and the Green Revolution Syndrome. Some of the degraded areas in these countries are influenced by other syndromes, especially the Dust Bowl Syndrome, the Overexploitation Syndrome, the Rural Exodus Syndrome and the Scorched Earth Syndrome.

The seeming inconsistency of the presence of a syndrome and mild soil degradation seen in Fig. 6 can frequently be explained by the following effects: (a) There are problems arising from the low resolution of the syndrome intensity data (which are only country-sharp due to the use of socio-economic indicators) and higher resolution for the rate of soil degradation data. (b) There are problems with the comparability of soil degradation data in desert countries with a low percentage of farmland (for example, Saudi Arabia). Although this explanation of a core problem of Global Change through syndrome intensities is not complete, we hope that we were able to demonstrate the main idea of our approach Of course, this excercise has to be finished by taking into account all syndromes contributing to soil degradation.

4 Conclusions and Outlook

In this contribution we have tried to present a genuinely transdisciplinary approach to scientific reasoning about Global Change in a sufficiently self-contained way. The most important novel aspect of our approach is the decision to employ dynamic patterns as the primary units of analysis, as such patterns seem to match best the heuristic granularity of the issues dealt with. This decision has a number of crucial implications.

First of all, we have to realize the fact that a mature methodology for treating dynamic patterns in a well-defined formal way is clearly still lacking. There is no such thing as a "pattern calculus" as compared to Newton's and Leibniz's calculus. We may resort, however, to ad hoc combinations of elements from symbolic dynamics, qualitative modeling, artificial intelligence, fuzzy logic etc., and look forward to pertinent methodological breakthroughs in years to come. The theory of complex systems is certainly a fertile soil for progress in that direction.

We have to accept, on the other hand, that our everyday perception of entangled situations is undoubtedly organized into patterns, which are identified, processed and stored in a more or less intuitive manner. *To make this intuition gradually more and more educated*, in order to help us along the way towards a better understanding of Global Change, appears to be a most valuable goal. This strategy even seems to be the most promising way of keeping science safely away from the Scylla of "Reductionism" and the Charybdis of "Analoguism", as outlined in the introduction.

Moreover, having made our epistemological decisions, we must ask whether the induced decomposition of the global environment and development process into typical patterns is unique. With reference to the cultures allegory mentioned above, we claim that the syndromes of Global Change introduced in this paper are *sufficiently* unique, in the sense of soft identity, for the practical purposes of Earth System analysis.

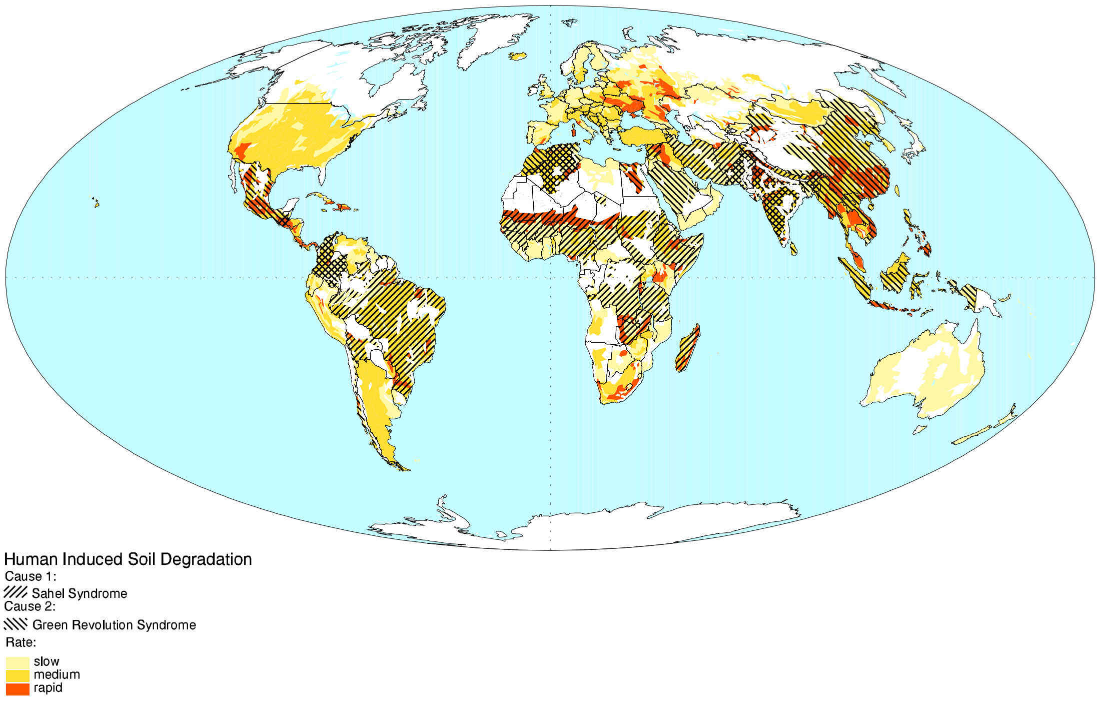

Figure 6. Global distribution of the Global Change core problem "soil degradation" and its decomposition into Syndromes. Here, the rate of anthropogenic soil degradation [26] is used as an indicator for the Global Change core problem "soil degradation". The indicator is superimposed with the presence of the SAHEL Syndrome (left to right hatching) and the GREEN REVOLUTION Syndrome (right to left hatching) as two important explanatory mechanisms. Areas with both syndromes present are denoted by the cross hatching. Areas with anthropogenic soil degradation and no hatches, are infected by other syndromes. So are the large areas in Europe and North America, indicated as being exposed to human-induced soil degradation, mainly infected by the DUST BOWL Syndrome which is not included in this example. White areas are either not infected by anthropogenic soil degradation or no data is available [24, 13].

This does not mean that the list of syndromes as it stands now is correct or even complete: all the material presented here is only the beginning of a scientific enterprise, which *by construction* is doomed to fail without ample cooperation and interaction within the relevant research community. As a matter of fact, the authors of this paper plan eventually to produce a "Syndrome Atlas" of Global Change in collaboration with the German Advisory Council on Global Change (WBGU) and other institutions. The quality of such a product depends heavily on a perpetual broad-scale discussion of the objectives, methods, data and judgments involved. A powerful instrument for promoting this discussion is our web-interfaced data base, where the definitions of symptoms and syndromes are stored and updated.

Before concluding, let us make a short comment on a potential operationalization of the chameleonic notion "Sustainable Development" via the syndrome concept. Rather than defining sustainable development in a positive manner by listing the various desiderata, it may be more practical and useful to qualify, in a negative way, *non-sustainable development* (for a detailed discussion, see [6]). The approach described in this article may offer a concrete, but non-trivial scheme for doing so.

Our speculation is based on the idea that many syndromes as specified above might accompany humankind for many decades without causing intolerable damage or even disturbing the operational mode of the entire Earth System.

Under certain circumstances, however, these syndromes may become quite dangerous if left unattended and uncontrolled – that is to say, an individual syndrome may enter a em critical stage. By "critical" we mean that either the syndrome has devastating effects on the region infected, or the syndrome triggers the crossing of critical thresholds for global dynamics (like, for example, the shut-down of the North Atlantic deep-water formation [41]). In analogy to medical science we might say that critical syndromes have become *malignant*. Note, however, that many critical developments occur rather insidiously than catastrophically.

So the necessary condition for steering the planet Earth along a sustainable path is to follow the instruction bluntly summarized as follows: "Do whatever you like, including, for instance, industrializing of the developing countries, but beware of causing or not preventing malignant syndrome evolution!" We certainly do not contend that an instruction of the type just given resolves all the problems associated with the sustainable development paradigm and its implementation, but the underlying message should be taken seriously. Quite generally, we are well aware of the fact that one cannot manage the Earth System in the same way as, for example, a greenhouse with tomatoes, where the wise gardener may rather easily re-direct the system's path, for example by allocating more water, fertilizer or energy. On a global scale, we lack not only the wise gardener but also the stupid tomatoes. Earth System management is more like complex self-organization of tomatoes than controlling a system by some parameters from the outside. Therefore, eventual hints for management resulting from the syndrome concept have to be specified for different actor levels – from the individual via local government and NGOs to the UN level.

In summary, much more research is needed, but we hold that the presented methodology opens a promising road towards the understanding of the intrinsic processes of Global Change, and supplies a valuable tool for risk assessments in regions prone to non-sustainable developments. We invite the scientific community to participate in these research efforts.

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