A Method of Analysis of Biological Resource Use Systems Under the Convention on Biological Diversity

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Abstract. The 1992 Convention on Biological Diversity (CBD) establishes a new legal framework for the management of biological resource use, for example in fisheries. The signatory states to the CBD have agreed upon several major principles which become legally binding following ratification of the Convention by the national legislature. In terms of resource management, two of these principles are especially remarkable: 1. a concept of sustainability which includes distributional considerations; 2. an 'ecosystem approach' that calls for the integration of aspects of community ecology into management schemes. Unfortunately, current approaches to the management of biological resource use fall somewhat short of satisfying these two principles. I try to rectify this, developing a method of analysis that integrates neoclassical resource economics, property rights theory and community ecology into one theoretical concept which can be applied to such distinctive problems as overexploitation, negative impact on ecosystems by resource use, and conflicts among resource users. This method of analysis will make it possible to determine whether a specified biological resource use system and its accompanying management structures meet the requirements set out by the CBD.

Keywords: resource use system, Convention on Biological Diversity, sustainable use, ecosystem approach

1. INTRODUCTION

The Convention on Biological Diversity (CBD), which was signed at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992, establishes a new international legal framework in the field of biological resource use. The CBD becomes legally binding following ratification by the national legislature. Before this convention was signed, natural biological resources (i.e. wild species extracted from natural ecosystems) were internationally considered free goods of which any person could acquire exclusive legal ownership through acquisition. Differing rules established by the legal norms of the countries of origin and special regional agreements existed at the same time, as well as protective regulations which, however, were valid only for individual, clearly defined species or habitats (Klemm 1993).

The CBD, which has been signed by 170 states so far, grants all member states sovereign property rights to the natural biological resources they produce while at the same time declaring the conservation of biological diversity a "common concern of humankind". The Framework Convention on Climate Change, which was also signed in Rio in 1992, declared the climate a "common concern of humankind" as well. Thus, the signatory states to the CBD are obliged to exercise their property rights in accordance with the principles set out by the CBD, their respective sovereign property rights being limited accordingly.

Article one of the CBD defines three major principles as the main objectives of the Convention. They explain in detail how the political sustainability concept, which forms the basis of all documents signed in Rio and which was formulated by the *Brundtland Commission* (WCED, 1987) applies to biological resource use. These major principles are:

- **sustainable use of biological diversity**
- **conservation of biological diversity**
- **equitable sharing of benefits**.

Another achievement of the CBD is the **ecosystem approach,** although only formulated during the negotiations following the signing of the convention. It can be treated as a fourth major principle of the Convention. The ecosystem approach was discussed for the first time at the initial meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) of the Convention on Biological Diversity in 1995. In November of the same year, the second Conference of the Parties was held in Jakarta, which formally accepted the approach as a "primary framework of action to be taken under the Convention" by decision II/8 (UNEP/CBD/COP/2/19, decision II/8, paragraph 1). During the SBSTTA conferences that took place in 1996 and in 1997, as well as in January 1998 during a workshop in Malawi, which was organized especially for this purpose, the content of the ecosystem approach was defined more precisely. The ecosystem approach obliges all member states at all times and in all activities to handle ecosystems and regulate human involvement with ecosystems in a way which takes into account "the essential processes and interactions amongst organisms and their environment". This is to be achieved by the implementation of "appropriate scientific methodologies focused on levels of biological organization"

(UNEP/CBD/COP/4/Inf. 9).

2. THE RESOURCE USE SYSTEM AS THE OBJECT OF THE ANALYSIS

The requirements for resource use under the CBD, especially those implied by the ecosystem approach, are quite comprehensive. The CBD demands an integrative examination of ecological, economic, and socio-economic aspects of resource use at the same time.

From a scientific perspective, analyzing whether the extraction of a specified natural biological resource is in accordance with the CBD requires the examination of a relatively complex system. This system is not identical with the ecosystem. The ecosystem approach is connected with the political sustainability concept, which includes the anthropocentric concept of man involved in economic activities including resource use and provides a standard of justice for the structure of human society in general and for its institutional structure in particular. This connection shows that the system of resource use to be examined includes more elements and is therefore more comprehensive than the ecosystem, which merely represents a part of the system of resource use.

The complexity of the system of resource use is characterized by a great number of elements which are interrelated both directly and indirectly and interact with each other. These elements include:

- the individuals of the utilized resource;
- members of other plant and animal species, with which the utilized resource forms a community within a habitat;
- the inanimate environment;
- individual human actors or groups of these acting as resource users;
- institutions of human society which regulate access to the resource.

The complex and extensive system of resource use, on which the CBD's concept of sustainable use is based, will be referred to as **resource use system.**

For the purpose of a scientific analysis, it makes sense to identify individual sub-systems within the resource use system and to examine them separately with regard to their specific characteristics or their correlations with each other, as the number of elements is large and consequently, the resulting structure of interactions and repercussions in this system is quite complex. The way the system has been divided into sub-systems was selected for practical reasons. In order to be able to make use of available scientific knowledge as much as possible, the way scientific disciplines have traditionally been categorized was adopted for subdividing the system. For the purpose of analyzing the extraction of biological resources from natural ecosystems, the following types of sub-systems will be identified and their interrelations be examined:

1. The relevant **resource**. The resource is defined as the group of individuals of a utilized species. The group of individuals of a specific species within a habitat is referred to as *population* in ecology. The term *resource* emphasizes the anthropocentric point of view- the population is only of interest in its function as a resource that can be used within the economic system.

2. The **resource system**. It is defined as the community of biological species with which the utilized resource shares a habitat. This includes all aspects of the abiotic environment as well. The resource system is identical with the ecosystem. The normative term *resource system* is used deliberately to emphasize that the ecosystem is regarded from the perspective of humans involved in economic and resource-consuming actions.

3. The **use system**. It includes human actors that have direct access to biological resources (*users*), thus extracting them from nature and bringing them into the economic system. This also includes the systems of rules (*institutions*), on which the resource use is based. The term *actors* refers to individuals as well as to groups.

While the resource and the resource system are *ecological* sub-systems of the resource use system, the use system can also be regarded as a *socio-economic* sub-system. Figure 1 provides a model of the resource use system of natural biological resources with its sub-systems and explains this model, using the example of the anchovy fishery off the coast of Peru.

The Convention on Biological Diversity requires human utilization of natural biological resources to be viewed on the level of the resource use system. This forms the basis of the regulation of human involvement with ecosystems and therefore especially of resource use. What is most challenging about this is the fact that the scientific system analysis has to originate from this level as well.

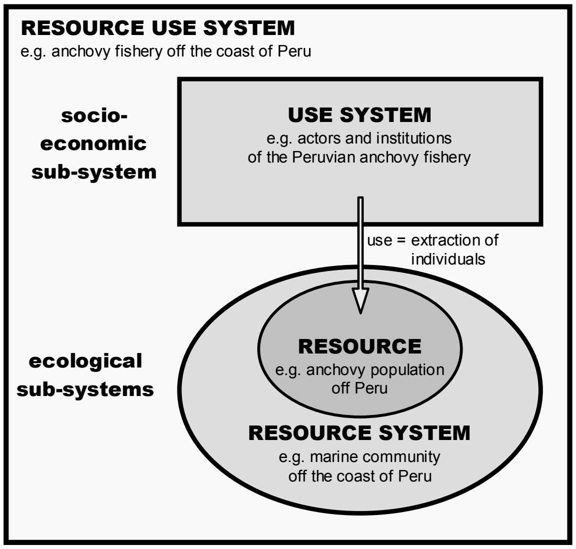

Figure 1: The resource use system

Thus, the examination of existing resource use systems in terms of their sustainability under the CBD's concept of sustainability presupposes the availability of a correspondingly integrative, interdisciplinary method of scientific analysis. The same holds true for sustainable structuring and managing of resource use systems. To date, the majority of analytical examinations of resource use and of sustainability (the criteria for sustainability being less strict than those in accordance with the CBD) have been limited to sub-systems of the resource use system. Therefore, analyses have generally been restricted to individual disciplines (ecology, economics, sociology). There have only been occasional integrative approaches that included two of the three above sub-systems of resource use systems (e.g., bio-economic modelling). The results found through this research can therefore not be globally applied.

I will present an integrative, interdisciplinary method of analysis of the use of natural biological resources in accordance with the Convention on Biological Diversity, illustrating up to a certain degree its advantages and applicability. The resource use system, which includes all relevant ecological and socio-economic aspects of resource use, will be the central focus of the examination. I have elaborated a comprehensive *method of analysis* based on this level, into which the theoretical knowledge of economics (resource economics, property rights theory) as well as of ecology (in particular community ecology) has been integrated. My task was essentially to :

Work out a *method of analysis* which integrates ecological and socio-economic aspects, and is also suitable for the examination of resource use systems of natural biological resources in order to determine their sustainability under the Convention on Biological Diversity, and which allows the management of resource use systems in accordance with the CBD's concept of sustainability.

3. SUSTAINABLE RESOURCE USE SYSTEMS OF NATURAL BIOLOGICAL RESOURCES

3.1 Requirements for Sustainable Resource Use Systems

Article 1 of the Convention on Biological Diversity obliges the signatory states by international law to ensure the sustainability of resource use systems of natural biological resources in accordance with the CBD. Under the condition that the CBD be ratified by the national legislature, the signatory states are obliged to regulate resource use systems of natural biological resources within their sovereign territories and to ensure the sustainability of these systems accordingly.

The sustainability concept of the Convention on Biological Diversity is based on:

- the political sustainability concept elaborated by the Brundtland Commission and the Rio Documents, especially Agenda 21 and the Rio Declaration;
- the 3 major principles of the CBD: sustainable use, conservation of biological diversity, and equitable share of benefits;
- the ecosystem approach, which can be considered the fourth CBD major principle.

With reference to the use of natural biological resources, the following requirements for the sub-systems of resource use systems can hence be developed (Figure 2):

- the use of the **resource** must be conducted in a way which ensures lasting conservation of the resource;
- the resource use must not endanger the conservation of the basic ecosystem functions of the **resource system**;
- the **use system** must ensure a lasting, fair distribution of benefits to all actors affected by and involved in the resource use.

3.2 A Model of the Use System

Upon closer examination of the scientific analysis of resource use systems of natural biological resources, one notices that scientific disciplines and sub-disciplines have conducted extensive research on population dynamics of resources, on interactions within resource systems, on the impacts of the extraction of resources on the ecological sub-systems, and on the search for optimized extraction strategies. Correspondingly, a great number of scientific works have been written on these topics. In contrast to this, only a few works dealing with the interaction among actors within use systems of natural biological resources have been published. In the field of economics, the only exception is property rights theory, which analyses CPR

(Common Pool Resource) use systems and is a part of the discipline of institutional economics. Apart from this, there are a number of sociological studies that deal with potential problems in connection with the extraction of natural biological resources within use systems (e.g., Finlayson 1994). However, I was able to find only very few works of this kind.

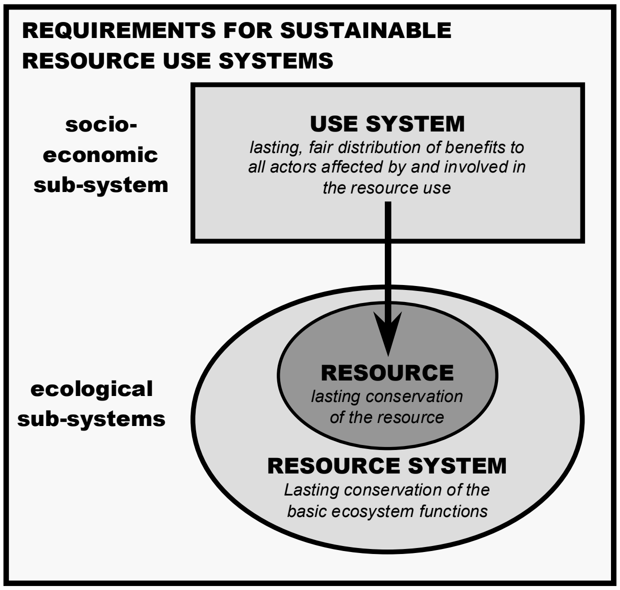

Figure 2: Requirements for sustainable resource use systems

Within use systems, the term *actors* is used to refer to individuals and organizations. Following North's categorization (1992), *organizations* are defined as groups of individuals united by a common purpose or a common goal. The interaction that takes place among the individuals within a specific organization is regulated by organization-specific institutions. Organizations include public bodies (political parties, governing bodies, authorities), legal entities of the economic world (companies, labor unions), education and research centers (universities, research institutes), and organized interest groups (associations, lobbies, citizens' action groups).

The complexity of the interaction that takes place among the actors of a use system, and of the structure of the use system, is not to be underrated. The users of natural biological resources are merely the last link in a complex chain of institutions and organizations which characterize a use system. In order to be able to determine the conditions under which an equitable distribution of benefits to all actors and those concerned in use systems of natural biological resources can be achieved in accordance with the sustainability concept set out by the CBD, it is therefore necessary to develop a model for the use system. The Institutional Analysis and Development (IAD) scheme will serve as a basis for the development of this model. The IAD scheme was worked out by Elinor Ostrom and a group of other researchers at Indiana University.

3.2.1 The Institutional Analysis and Development (IAD) Scheme (Ostrom et al., 1994)

Elinor Ostrom developed the IAD scheme over the course of many years during her studies of institutional economics. The development of the scheme was closely connected to the research she was doing on CPR use systems. It is against this backdrop that the scheme appears especially suitable for the analysis of resource use problems in use systems.

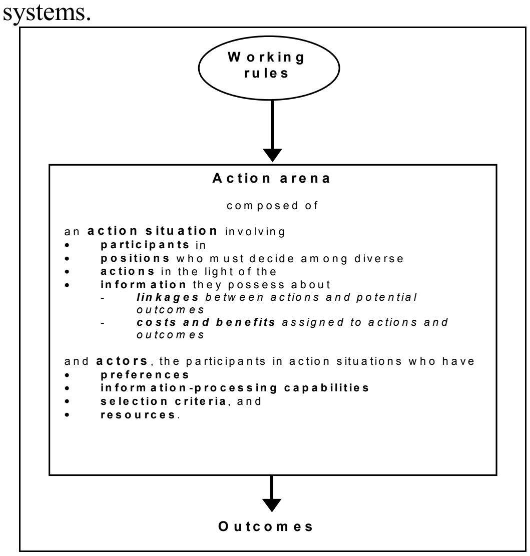

Figure 3: The action arena

The development of the IAD scheme is based on the idea that interactions which take place between actors on markets, within hierarchical organizations, and when making collective choices, are action arenas consisting of the same basic elements. The basic elements of an action arena characterize the action situation, and they also characterize the actors as participants in the action situation. Basic elements of the action situation include participants, positions and actions, as well as information on correlations between actions and results, and information on the net utility related to the actions and results. According to

Ostrom, Gardner, and Walker (1994), results of actions within action arenas depend on the *working rules*, which structure the actors' interactions within a specified action arena. *Working rules* are defined as the rules that are actually being complied with in an action arena, regardless of whether they are formal or informal (Figure 3).

According to the IAD Scheme developed within the framework of institutional analysis, interactions are structured by the working rules (i.e., institutions) and take place in various action arenas between individuals and organizations (as social actors). It is, however, not possible to observe individual action arenas separated from each other and from their social and physical environment (physical world). The reason for this is that on the one hand, the results of actions influence the action arenas as a result of their effects on the physical world and the social environment, and that on the other hand, the rules for specific action arenas are quite frequently the result of interactions between actors of higher-level action arenas. Ostrom, Gardner, and Walker (1994) refer to this phenomenon as the embedding of rules in other higher-level rules. The degree to which lower-level working rules are influenced by higher-level rules depends on how well the compliance with these rules within lower-level action arenas is monitored and on how strictly non-compliance is sanctioned by higher-level authorities.

This hierarchical system of rules is included in the IAD scheme as a framework of institutional analysis, as various hierarchical levels are included in this perspective (Figure 4). Ostrom (1990) holds the view that a sufficient analysis of all aspects of the interactions structured by the institutions, as well as their results, can be conducted on the basis of a three-level hierarchical system. These are the three levels Ostrom makes use of:

1. operational level
2. collective choice level
3. constitutional choice level

3.2.2 The Extended IAD Scheme

Upon closer examination of existing resource use systems of natural biological resources, however, as for instance in the case of fisheries, one cannot help noticing that Ostrom's IAD three-level scheme fails to provide a sufficient illustration.

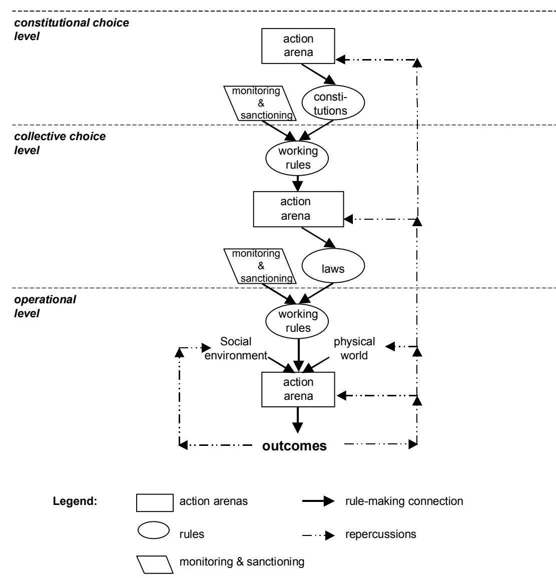

Figure 4: The IAD scheme (Ostrom et al., 1994)

In my opinion, the existence of a five-level hierarchy can be observed in existing resource use systems of natural biological resources consisting of:

1. the **resource use level**, which corresponds to the operational level in Ostrom's IAD Scheme;
2. the **management level**, on which the regulating authorities are situated;
3. the **national level,** on which national legislature enacts general laws concerning the use of natural biological resources and the appointment and responsibilities of the regulating authorities;
4. the **supranational level**, on which states reach agreements with a specified group of other states (for example, states within a specific region), in which they declare the renunciation of their legal sovereignty as far as the regulation and use of natural biological resources are concerned. In some cases, this is done with the help of supranational organizations with special competencies, such as NAFO, ICES, and ICCAT;
5. the **international level**, on which international regulations binding for a great number of member states and international organizations are created (e.g., UNCLOS, CBD, CITES).

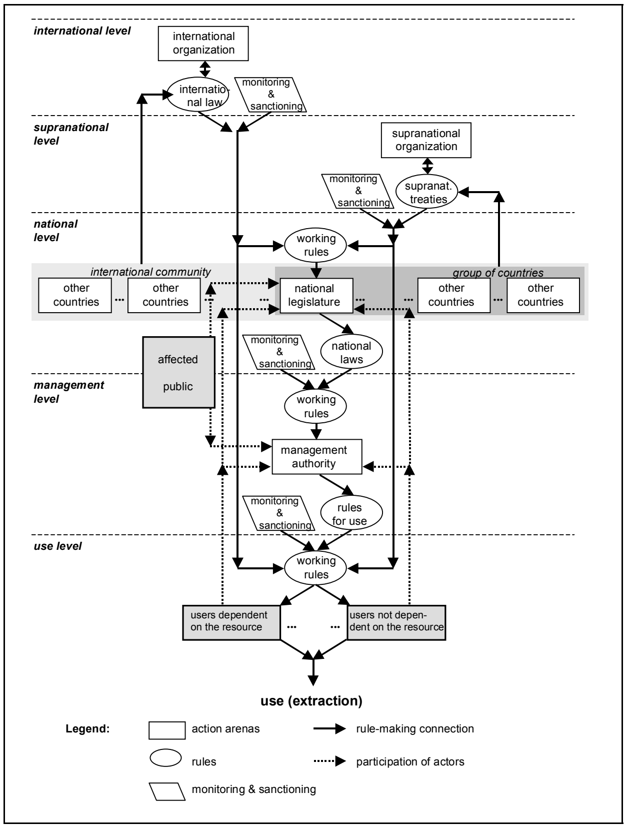

Figure 5: Extended IAD scheme

In addition, the CBD has raised the question of equitable distribution of the benefits to all actors and others involved within a use system. In order to be able to deal with this question, it makes sense to categorize the members of each group of users on the resource use level by the degree of their dependency on the resource. Other actors affected by the resource use should be included in the use system model as well.

Figure 5 shows an expanded version of the IAD scheme, which serves as a model use system within the resource use system.

3.3 Sustainable Use of Natural Biological Resources: *A Method of Analysis*

According to my argumentation so far, the normative requirements of the CBD with regard to the use of natural biological resources (sustainable use and the ecosystem approach) call for an innovative, interdisciplinary, integrative approach to the problems in connection with resource use.

A new *method of analysis* is therefore required. In my opinion, this new *method of analysis* should be focused on the examination of the use of natural biological resources on the basis of the resource use system model.

Another important element of a new *method of analysis* is the utilization of comprehensive, operational criteria, which allow an adequate assessment of the sustainability of existing resource use systems of natural biological resources under the Convention on Biological Diversity. The utilization of such criteria is necessary to ensure a successful regulation of resource use systems according to the guidelines set out by the CBD, for instance for successful fisheries management.

3.3.1 Sustainability Criteria for Resource Use Systems of Natural Biological Resources

In a comprehensive, interdisciplinary research project, I have committed a lot of time and effort to the problem of adequate criteria to determine the sustainability of subsystems of resource use systems under the CBD (Hummel 1998). The information available from the following disciplines has been used to create an overview as complete as possible:

- Ecology: population and community ecology Neoclassical resource economics: theoretical economics of renewable resources, fisheries economics, economics of forestry
- Institutional economics: property rights theory, theory of institutional change

The resulting sustainability criteria for resource use systems of natural biological resources are presented in Table 1.

The presence of a property rights regime based on the entire body of information available within a resource use system is essential. In terms of the interrelations existing in the ecological sub-systems of the resource use system, a general distinction must be made between *certainty or stochastic uncertainty* and *ignorance*. In case the body of available information at this time on the ecological subsystems is considered to be sufficient on the basis of a conservative estimation to produce a *deterministic or stochastic model* of satisfactory quality of population dynamics of the resource, as well as of the interactions in the resource system, *certainty or stochastic uncertainty* prevails. In this case, compliance with the sustainability criteria in ecological sub-systems of the resource use systems according to Table 1 can be satisfactorily checked.

In case the information available in a resource use system is, according to conservative estimation, insufficient for producing a satisfactory *deterministic or stochastic model* of the population dynamics of the resource and/or the interactions that take place within the resource system, *ignorance* prevails. *Ignorance* in a resource use system can be caused by insufficient research conducted to that point, or by certain characteristics of a specific ecosystem. With reference to research on resource use systems, it has to be said that the creation of deterministic or stochastic models require considerable financial and staffing resources. Frequently, the required resources are only available for research on economically important resource use systems, or in industrialized countries.

BASIC REQUIREMENT			
• Low opportunity cost of resource use			
EXTRACTED SPECIES			
• Cautious treatment of non-redundant species, highly cautious treatment of keystone species			
EXTRACTION TECHNOLOGY			
• Prevention of critical impacts on age structure and sex ratio; no extraction of individuals before the first reproduction cycle			
• Extraction technology adapted to the resource system in order to prevent negative impacts on biological diversity and/or non-redundant species or keystone species			
INTENSITY OF RESOURCE USE			
• Compliance with ecological sustainability concept: sustainable yield = natural regeneration dx/dt			
• Extraction only within the zone of stable biological equilibria of the regeneration function: $y < MSY,\ x > x_{MSY}$			
• Adaptation of intensity of resource use to the individual resource use system in order to prevent indirect impacts on biological diversity			
USE SYSTEM			
• In view of unpredictable impacts, general capability of gradually changing the institutions within the use system (participation of all actors in clearly-structured, democratic decision-making processes, no lock-in of the institutions with regard to distributional changes)			
• Institutionalized monitoring of the sustainability of the resource use system on a regular basis.			
• Conservation of existing functional CPR use systems.			
UNDER CERTAINTY OR STOCHASTIC UNCERTAINTY			**UNDER IGNORANCE**
Private ownership	or	**CPR use system** (Ostrom, 1990; Sethi & Somanathan, 1996)	**CPR use system** (Ostrom, 1990; Sethi & Somanathan, 1996)
• Adaptation of boundaries of the use system to distribution and migration of the resource species		• Compliance with requirements for functional CPR use systems (Ostrom, 1990)	• Compliance with requirements for functional CPR use systems (Ostrom, 1990)
• User discount rate below intrinsic rate of natural increase of the resource $\delta < r$ **or** • High economic value of unused stock $MRS\left[\frac{x}{y}\right] >> 0$		• Prevention of impacts which cause a strong increase of net utility of resource extraction or a decrease of the intensity of social sanctions	• Prevention of impacts which cause a strong increase of net utility of resource extraction or a decrease of the intensity of social sanctions
• Low negative externalities of the extraction affecting other goods or resources			
• Adaptation or insurance of the use system in case of predictable fluctuations of the abundance of the resource species			

Table 1: Sustainability criteria for resource use systems of natural biological resources

Great species diversity within an ecosystem, a large number of specific interrelations and structural features of the landscape, as well as the occurrence of apparently non-cyclic fluctuations are factors which make the research about resource use systems even more difficult. The more complex an ecosystem is, the more likely unpredictable repercussions, time-delayed effects, and effects of threshold values will occur in the case of human involvement with the system.

It has to be emphasized that the criteria included in Table 1 are based on the research carried out to date. However, there is not yet sufficient evidence for all aspects. There is still need for considerable research in the field of community ecology (with regard to the organization of the community), in the field of the property rights theory (with regard to the way CPR use systems should be structured), and in the field of institutional economics, in terms of the correlation between sustainability and institutional change within use systems.

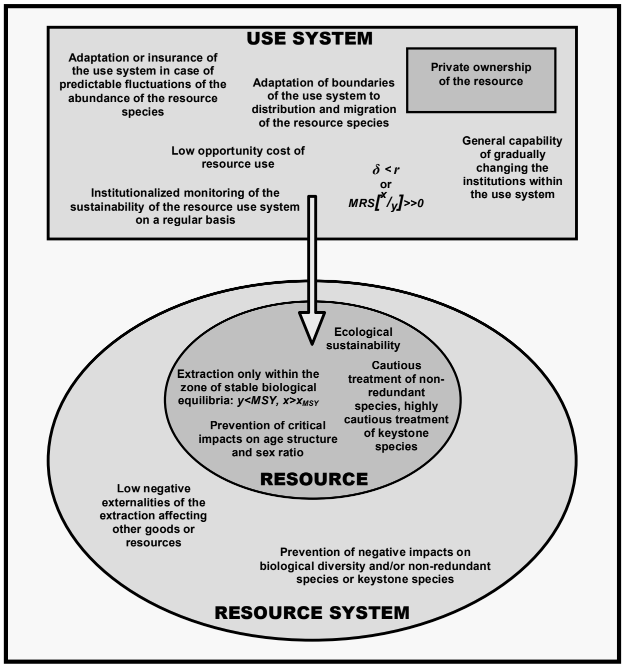

Figure 6: Sustainable use of natural biological resources under certainty or stochastic uncertainty and private ownership of the resource

3.3.2 Sustainable Use of Natural Biological Resources Under Certainty or Stochastic Uncertainty

In case of *certainty or stochastic uncertainty*, the sustainable use of natural biological resources can be achieved in the case of private ownership as well as in the case of CPR use if a number of frame conditions are met. Figure 6 illustrates the case of sustainable use of natural biological resources under *certainty or stochastic uncertainty* and private ownership of the resource. The sustainability criteria included in Table 1 have been assigned to the sub-systems of the resource use system of natural biological resources to which they directly relate. In this figure, no distinction is made between the effects of the extraction technology and of the intensity of resource use, so the relevant sustainability criteria included in Table 1 have been summarized.

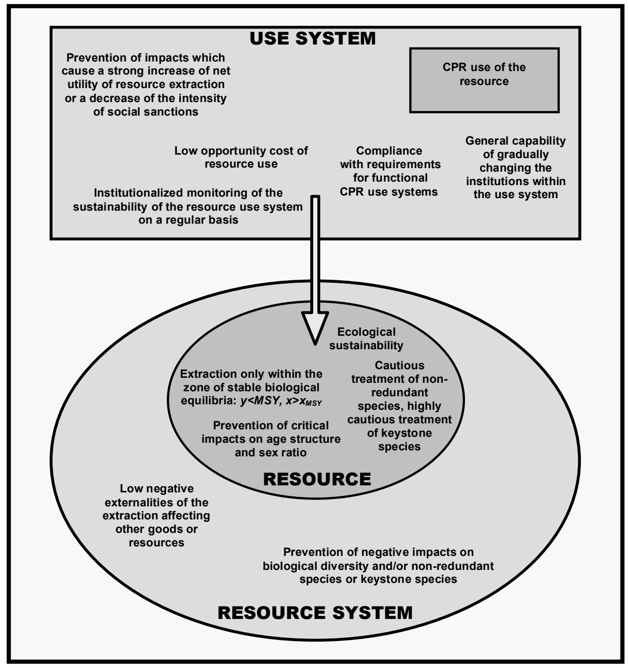

Figure 7: Sustainable use of natural biological resources under certainty or stochastic uncertainty and CPR use of the resource

Figure 7 illustrates the sustainable use of natural biological resources under *certainty or stochastic uncertainty* and CPR use of the resource. This case clearly shows that the sustainability criteria are closely connected. According to property rights theory, the presence of a functional CPR use system, the low opportunity cost of the resource use, and the prevention of strong external impacts on the net utility or the social sanction system automatically imply that all other criteria with regard to the resource or the resource system are met (Ostrom 1990). Similar connections between the sustainability criteria can be found under private ownership and *certainty or stochastic uncertainty*. In that case, the existence of adequate boundaries of the use system, low opportunity cost of the resource use, and the fulfillment of the condition $\delta<r$ automatically means, from a theoretical perspective, that the ecological sustainability concept is upheld. Diverse connections and interdependent relations can be found within the ecological sub-systems of resource use systems of natural biological resources as well. Non-compliance with ecological sustainability on a long-term basis can cause the resource stock to decrease and finally enter the zone of unstable biological equilibria of the regeneration function ($x<x_{MSY}$), which, in turn, will possibly affect the resource use system, and so on. The diverse connections that exist between the sustainability criteria suggest that non-compliance with a single criterion can trigger reaction chains which will affect all sub-systems of the resource use system and will lead to various repercussions.

3.3.3 Sustainable Use of Natural Biological Resources Under Ignorance

The immediate consequence of ignorance within a resource use system is the impossibility to determine the compliance with the sustainability criteria with regard to resources or the resource system in a satisfactory way. The information available on the resource and/or the resource system is insufficient, i.e. the body of information necessary for assessing the sustainability with regard to the resource or the resource system is too small.

The indications of the property rights theory suggests that there is a direct correlation between the compliance with the sustainability criteria related to the use system under CPR use (i.e., functional CPR use system, low opportunity cost of resource use use, prevention of strong external influences on the net utility or the social sanction system) and the compliance with the sustainability criteria related to the resource or the resource system. However, further research has to be conducted along these lines. Under ignorance, CPR use of a natural biological resource appears to ensure the sustainability of the resource use system as a whole if the relevant sustainability criteria are upheld (Figure 8).

4. CONCLUSION

The method of analysis presented in this paper represents an interdisciplinary, integrative approach to the problems related to resource use in accordance with the CBD. The resource use system model and comprehensive, operational sustainability criteria for resource use systems have been presented as central elements of the method of analysis. Diverse interactions take place between the sub-systems as well as within individual sub-systems of resource use systems of natural biological resources. Resource use systems are complex, dynamic systems, in which repercussions, time delays, and effects of threshold values can occur.
The sustainability criteria for resource use systems presented above are criteria which are supposed to maintain the dynamic equilibrium of sustainable resource use within this complex system on a long-term basis. In this case, maintaining a dynamic equilibrium means that although the system changes in the course of time, it is exclusively "natural" dynamic processes of change that take place in the resource system and in the use system. Thus, in spite of unexpected events or gradual changes of environmental factors, and in spite of the permanent change of the institutions within the use systems, the use of the resource is permanently conducted in accordance with the sustainability concept of the Convention on Biological Diversity. However, the dynamic equilibrium can only be maintained as long as all sustainability criteria are met.

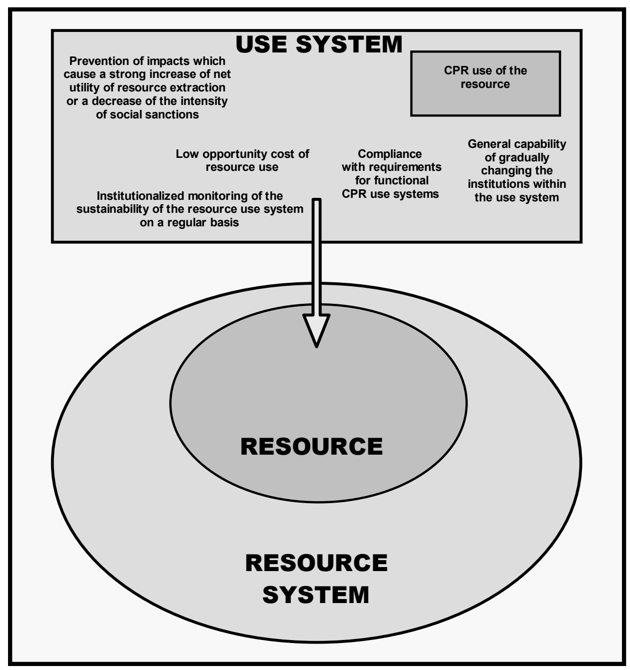

Figure 8: Sustainable use of natural biological resources under ignorance

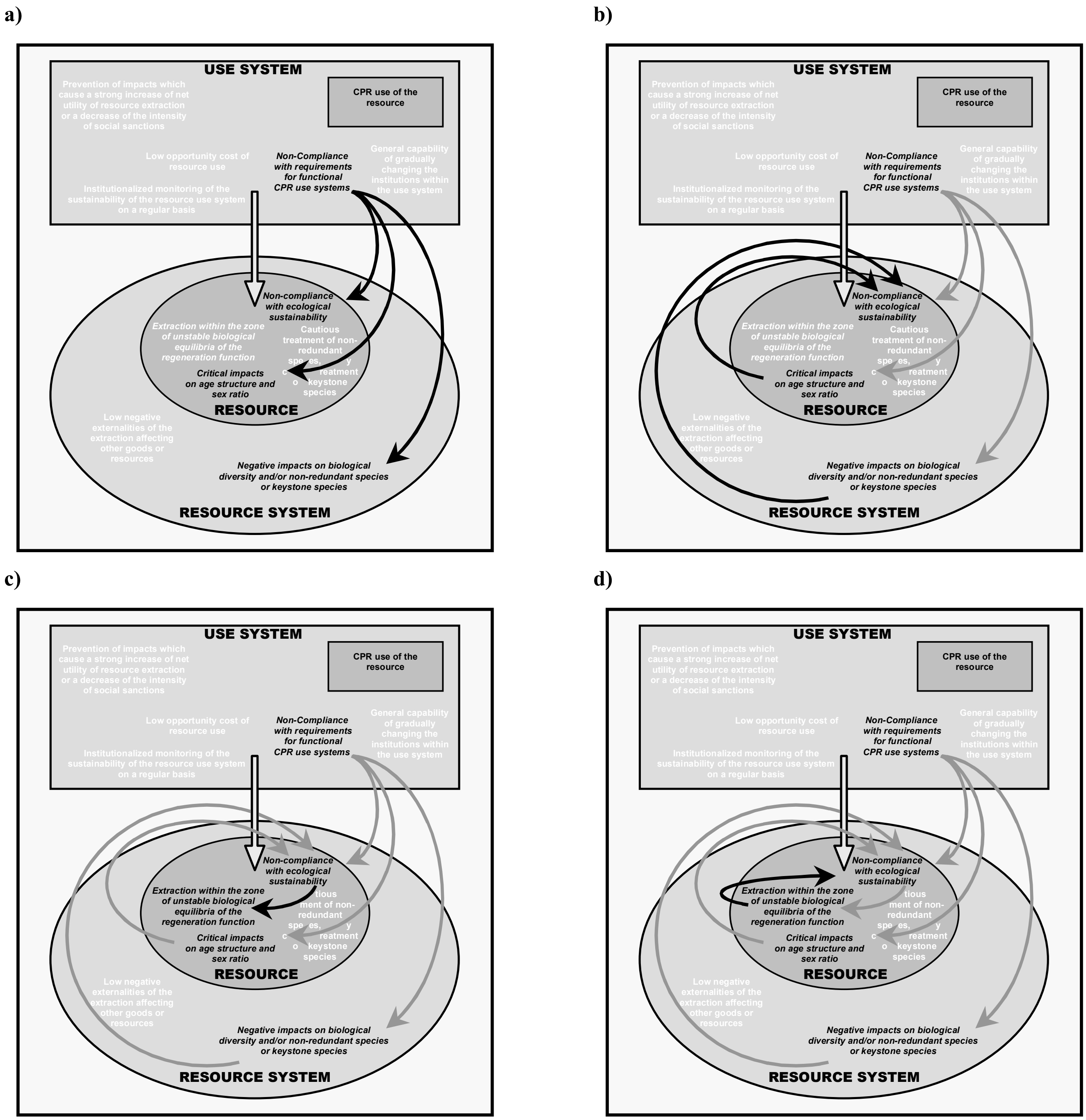

Figure 9: Possible reaction chains under open access use

Assuming that a diverse network of dependencies exists among the individual sustainability criteria, it can be concluded that non-compliance even with a single criterion can trigger chain reactions affecting all parts of the resource use system. The *method of analysis* deduced and expounded above, which integrates ecology and economics into its model view of resource use systems of natural biological resources, promotes a better understanding of similar complex chain reactions in existing, *non-sustainable use systems* of natural biological resources. The connections between the problems of **overexploitation, negative ecosystem effects** of resource use, and **conflicts** in use systems in particular are clarified through the examination of such chain reactions.

To illustrate this, I will use the example of the open access case, which has been extensively discussed in the social sciences. Within the framework of the *method of analysis* of resource use systems of natural biological resources, open access can be treated as a CPR use which *fails to meet the requirements of functional CPR use systems*. The open access situation can, for example, be caused by the impossibility to clearly define the boundaries of the resource, by an insufficient limitation of the group of users, or by the absence of inexpensive monitoring measures to control the users. This is considered the starting point of the reaction chains within the resource use system (Figure 9, a). The failure to meet the requirements of functional CPR use systems directly triggers **use conflicts** among the resource users. As long as the users are able to make an average profit, there is an incentive for them to increase their individual extraction. They try to achieve this by enhancing their effort. This results in a competitive race for the resource (e.g., the “race for fish”), which is accompanied by a competition for the use of increasingly productive technologies.

The *non-compliance with ecological sustainability,* that is, the **overexploitation** of the resource, is one of the consequences of this competition. The yield regularly exceeds the sustainable yield of the resource, resulting in a declining resource stock. In addition, extraction technologies may be implemented which have a *critical impact on the age structure and/or sex ratio of the population*. These technologies may also have an *immediate negative impact on biological diversity and/or non-redundant species or keystone species* in the resource system (i.e. **negative ecosystem effects**). Effects of such technologies will reinforce the reduction of the resource stock and promote *non-compliance with ecological sustainability*. This in turn may affect the resource stock, causing it to decrease even more (Figure 9, b).

In view of the growing scarcity of resources, users face continuously decreasing average profits, while the quantity of invested capital is steadily increasing. The users are under a growing pressure to further increase their effort to prevent economic loss, especially if the investments they have made are not completely reversible.

In case the open-access situation continues to exist, the decline of the resource stock, repeatedly accelerated by repercussions, will almost inevitably cause the stock to fall below x_{MSY} and as a consequence, it will finally result in the *extraction of the resource within the zone of unstable biological equilibria of the regeneration function* (Figure 9, c). Thus, *non-compliance with ecological sustainability* of the resource species is even more intensified (Figure 9, d). One can say that the resource use system will then have entered a vicious circle consisting of the **overexploitation** of the resource, **negative ecosystem effects** of the resource extraction and the related repercussions, and the continuously growing **use conflicts** among the resource users. If no regulating interference is made to interrupt the vicious circle of open access, it will only end when the resource is exterminated, or if economic breakdown without extermination of the resource occurs. In any case, the resource use system will cease to exist in its original form.

The presented method of analysis also provides an analytical perspective of complex chain reactions in general. However, it has to be kept in mind that the speeds of the individual processes within chain reactions may vary, and that time delays caused by natural effects of threshold values may occur.

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