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SUSTAINABLE MANAGEMENT OF RIVER OASES ALONG THE TARIM RIVER (P.R. CHINA) AND THE ECOSYSTEM SERVICES APPROACH

ABSTRACT. In north-western China, the endorheic Tarim River is running along the northern rim of the Taklamakan desert. It is the solely water source for the oases in the region as precipitation is low. The river is mainly fed from water of snow and glacier melt, causing floods in the summer months. Due to global climate change the annual water discharge is increasing. However, not sufficient water flows downstream, as the region is the main production area of cotton in China, and much water is needed for irrigation. A conflict arises between water users of the upper reaches and water users of the lower reaches of the Tarim River as well as with the natural vegetation. The central question of the Sino-German SuMaRiO project (Sustainable Management of River Oases) is how to manage land use, i.e. irrigation agriculture and utilization of the natural ecosystems, and water use in a very water-scarce region, with changing water availability due to climate change, such that ecosystem services and economic benefits are maintained in the best balance for a sustainable development. The overall goal of the project is to support oasis management along the Tarim River under conditions of climatic and societal changes by: i) developing methods for analyzing ecosystem functions/ecosystem services, and integrating them into land and water management of oases and riparian forests; ii) Involving stakeholders in the research process to integrate their knowledge and problem perceptions into the scientific process; iii) Developing tools (Decision support system) with Chinese decision makers that demonstrate the ecological and socio-economic consequences of their decisions in a changing world.

KEY WORDS: China, Tarim Basin, Sustainable Management, Ecosystem Services

INTRODUCTION, STUDY AREA AND PROBLEM DESCRIPTION

The Tarim River is located in the northern rim of the Taklamakan Desert in the Xinjiang Uyghur Autonomous Region in the Northwest of P.R. China (see Fig. 1). The basin is bounded by the Tian Shan in the North (up to 7000 m asl.), by the Kunlun Shan in the South (up to 6000 m asl.), by the Pamir Mountains in the West (up to 7000 m asl.) and is at an altitude of 1000 Meters above sea level in average. The Taklamakan Desert dominates the basin. The Tarim River is the longest endorheic river in China flowing eastward ending in the Taitema Lake. The Tarim River forms at Aksu City through the confluence of the Yarkant River from the West, Hotan River from the South and Aksu River from the North. The latter river contributes about 70% to the Tarim River's discharge.

The climate in the Tarim River Basin is continental and arid [Kottek et al., 2006] with monthly average temperatures of –7°C in January and 26°C in July and

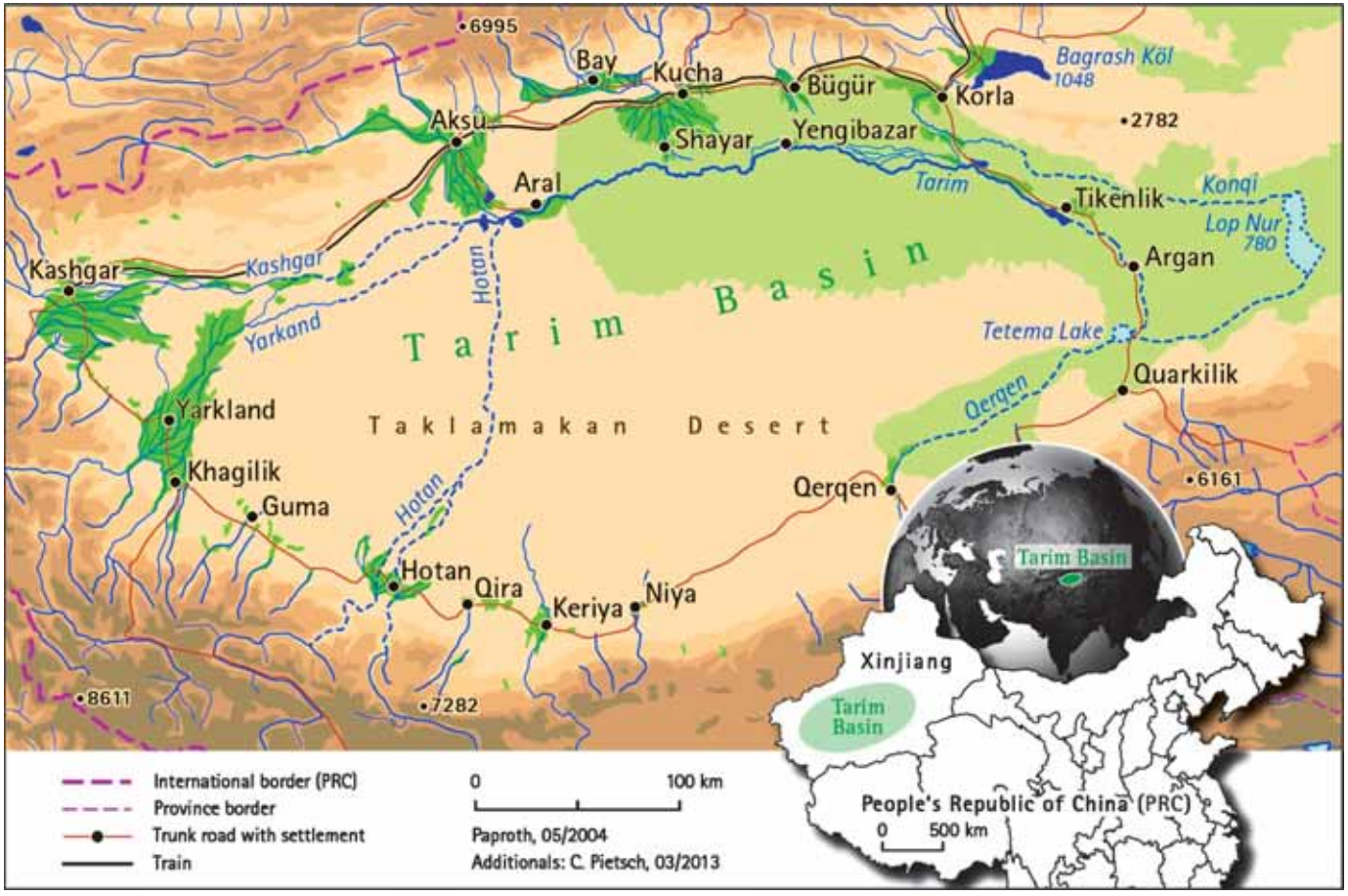

Fig. 1. The study area

50 mm precipitation in average per year. In the surrounding mountains the average precipitation is 400 mm. The average potential evaporation rate for the entire basin is about 1600 mm per year. Additionally, the region has a high duration of sunshine per year (2500 hours).

Southern Xinjiang is rich in various ecosystems. Especially there are desert and semi-desert ecosystems as well as the riparian vegetation along the rivers called 'Tugai'. The Tugai ecosystem consists mainly of Euphrat Poplar (*Populus euphratica*), Tamarix species (e.g. *Tamarix ramosissima*), reed (e.g. *Phragmites australis*) [Halik et al., 2011] and shrubs as well as special adapted plants. In the oases agriculture plays the dominant role with cotton and orchards, but there is also peri-urban and urban vegetation. These ecosystems provide various ecosystem services.

Xinjiang's primary sector (natural resources) has a share of 16%, whereas the secondary sector (industry) has a share of 50% on the provincial's gross domestic product. Farming, besides forestry and fishing, had a share of 67% of the agricultural production in 2008 [China Statistic Press, 2009]. The main agricultural product is cotton. In Xinjiang 40% of the total Chinese cotton is produced [Chadhuri, 2005], that is about 15% of the worldwide produced cotton. In 2011 the cotton production area was 1 129 700 ha. Cotton production is very water intensive. In China 3000 to 5000 cubic meters of water are used per hectare.

Human activities have taken place in the Tarim River Basin since several thousand years, and the region is permanently inhabited since several hundreds of years. The Tarim River provided a corridor for the ancient Silk Road along which settlements were founded in the oases. The Silk Road made it a centre of exchange and commerce in those days.

Starting in the 1950's, a rapid development of the region puts growing pressure to the land and water resources of the Basin. During these times the Chinese government promotes the development of the western provinces of China and encourages people to move to the "West". The on-going settlement in this region is causing conflicts between human needs and nature. The water supply in this region is solely depending on river water. Thus, water management is crucial to keep human and nature needs in balance. Most of the water is used by agriculture, especially the water intensive production of cotton. Additionally, it uses most of the agricultural land. Due to the overuse of fertilizers and pesticides, water and land are prone to salinization. This leads to land grabbing and desertification.

In Fig. 2 the regional problem is sketched. Due to the low precipitation and the high evaporation rates, the region's water supply depends solely on the river water. Fresh water flows mainly in summer into the Tarim River. This glacier and snow melt water causes floods and fills the reservoirs and channels. In the last five decades the annual average temperature rose by 0,4°C. The global climate models predict a continuation of this trend in the next fifty years, probably causing a surplus of water and thus the expansion of cotton fields in the upper reaches in the next years.

In the study region, two major conflicts do exist: First, the conflict of water use between human needs and natural vegetation; second, the conflict of land use between cotton production and unspoiled land. The effects of these conflicts are land degradation and desertification.

In the scope of SuMaRiO project research on climate change, agricultural impacts on the environment, ecosystem services and socio-economics in the region has been carried out. The results of the project will be used to set up a decision support system. This decision support system will support a sustainable water and land use management in the region. On an international level the Convention of Biodiversity and the Convention to Combat Desertification are implemented by the project.

Besides irrigation, the water is used for industrial production, households and is needed by the natural Tugai vegetation. However, the biggest water user is the agriculture. The Chinese

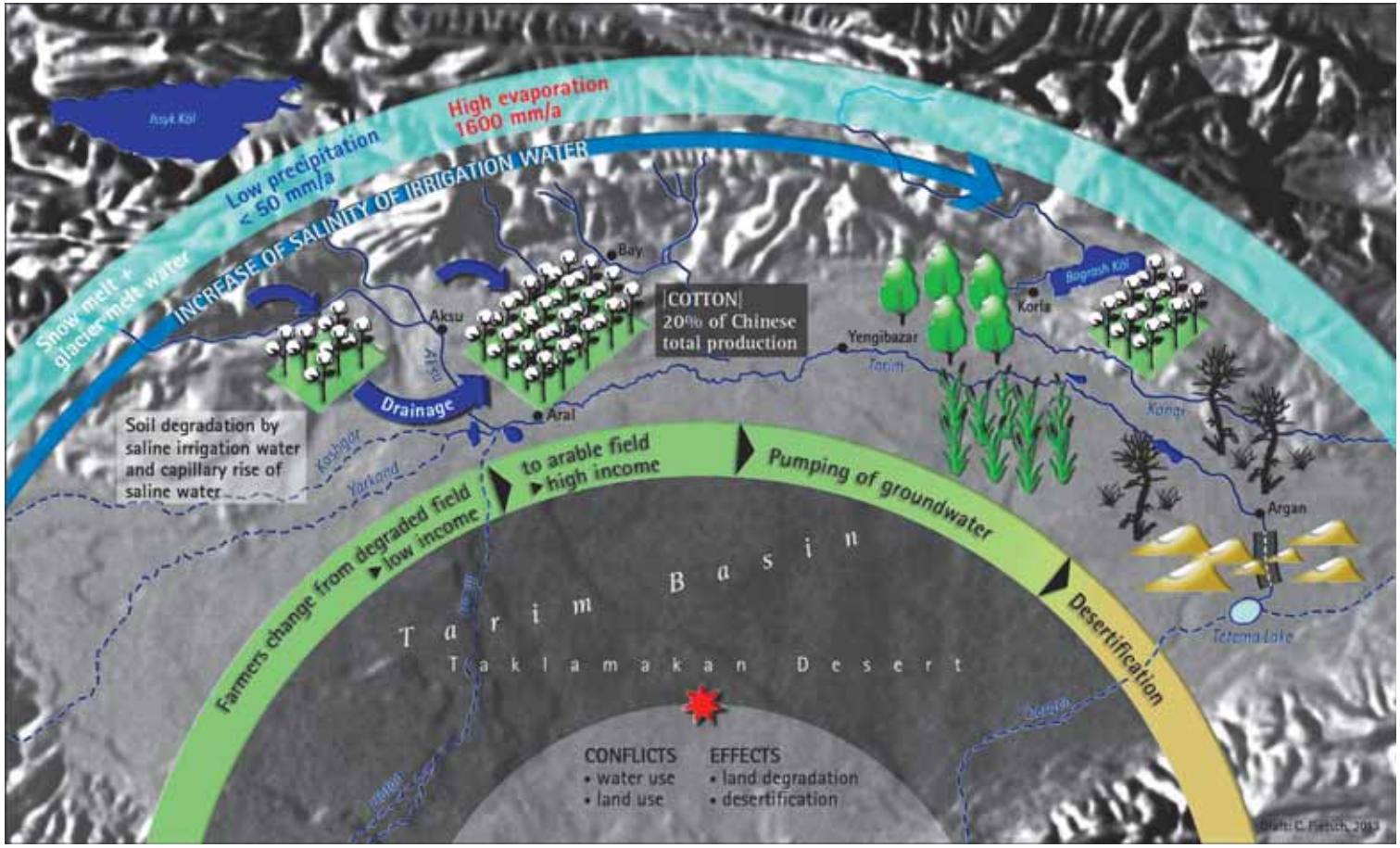

Fig. 2. Sketch of the regional problem on land and water management

government promoted cotton production in Xinjiang starting in the 1980's. The dry climate and the high duration of sunshine hours make the region potentially suitable to produce cotton with high quality. But the cotton in Xinjiang requires an average of 4,000 cubic meters of water per hectare. High yields can only be reached on the poor silty soil with a high input of fertilizers and pesticides. The fertilizer and pesticide residues are washed deeper into the soil by the irrigation water. On a field with an existing drainage system, the polluted water is drained into the drainage channel. This highly saline water is led back into the Tarim River causing an increase of salinity of the river water towards the lower reaches of the Tarim River. The salinization of the Tarim River water is increasing even more, as the already saline water is used along the Tarim River again for irrigation and thus more and more fertilizer residues are added to the water. The biggest area of cotton production along the Tarim River is on the upper reaches, with the freshest water, using and storing most of the water coming from the Aksu River. The lower reaches are falling dry in winter and spring. Farmers in that region are pumping groundwater to produce cotton or to irrigate their orchards. This causes the drop of the groundwater level on which the natural vegetation is depending.

The cotton production helps the farmers to increase their income and their standard of living in the rural areas. Smallholders who do not have installed a drainage system in their fields leave the saline fields behind and utilize new land for their cotton production to secure their livelihood. In fields with no drainage system, the groundwater table is rising due to heavily irrigation. With capillary rise of the shallow groundwater, salt is transported to the soil surface making the field unsuitable for further cotton production. This causes a vicious cycle of land grabbing, and expansion of the desert which is threatening the ecosystems and the livelihoods of the farmers.

THE SUMARIO PROJECT

The SuMaRiO project is funded by the Federal Ministry of Education and Research of Germany in the Sustainable Land management funding measure. The project consortium comprises eleven German and nine Chinese Universities and Research Institutions and various Chinese Stakeholders. The project started in March 2011 and has duration of five years.

The central question is how to manage land use, i.e. irrigation agriculture and utilization of the natural ecosystems, and water use in a very water-scarce region, with changing water availability due to climate change, such that ecosystem services and economic benefits are maintained in the best balance for a sustainable development. The overall goal of SuMaRiO is to support oasis management along the Tarim River under conditions of climatic and societal changes by:

- Developing methods for analyzing ecosystem functions/ecosystem services, and integrating them into land and water management of oases areas and floodplain forests;
- Involving stakeholders in the research process to integrate their knowledge and problem perceptions into the scientific process;
- Developing tools with Chinese decision makers that demonstrate the ecological and socio-economic consequences of their decisions in a changing world;
- Jointly identifying options for optimizing economic, ecological, and societal utilities.

PROJECT STRUCTURE, ECOSYSTEMS AND ECOSYSTEM SERVICES

The project comprises five work blocks (see Fig. 3). Work Block 1 is organizing and coordinating the project. Work Block 2 is dealing with the regional climate change and the discharge of Tarim tributaries. This work block includes the modelling and monitoring of glaciers and snow melt.

Work Block 3 is working on sustainable water and land use management from plot scale

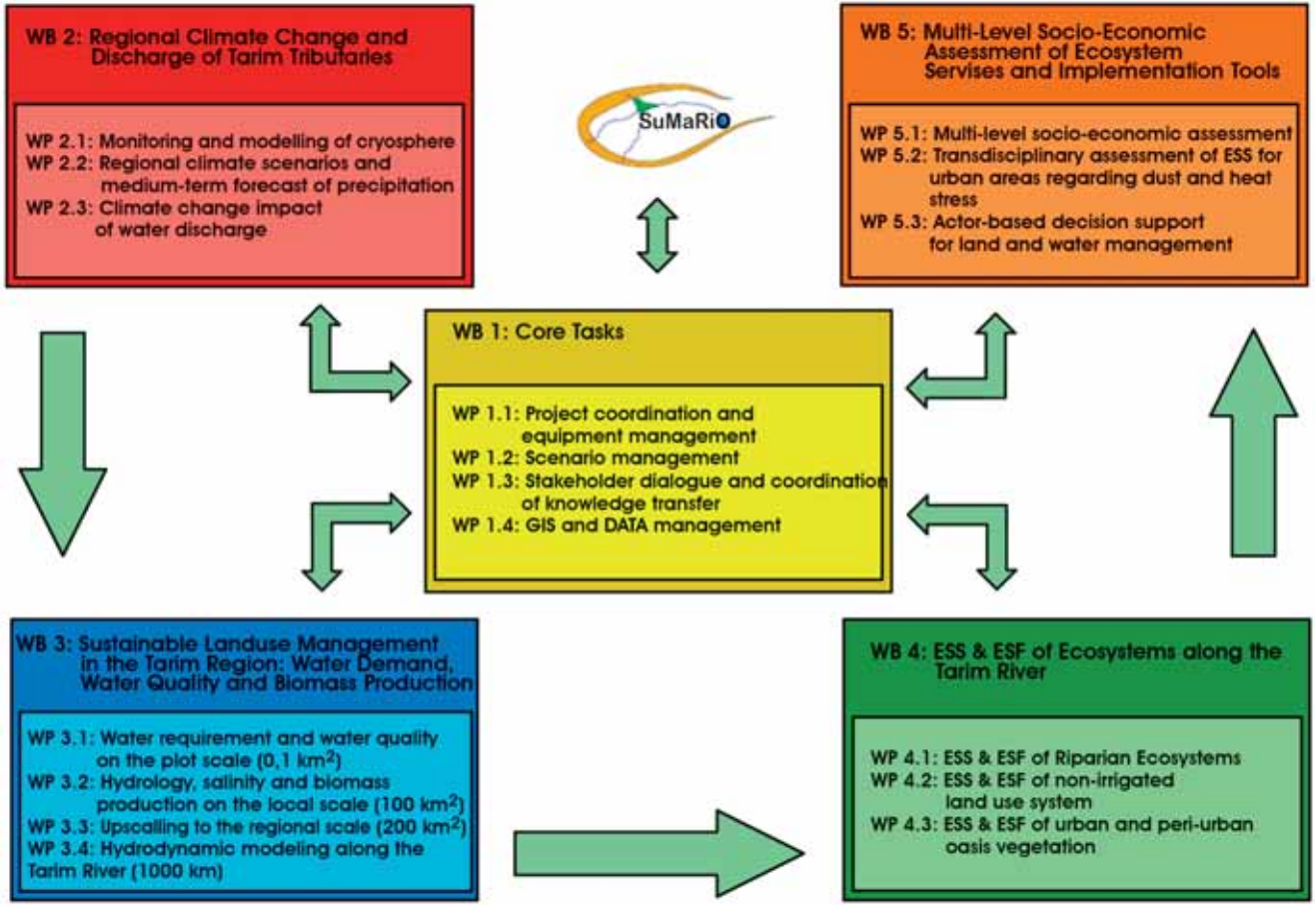

Fig. 3. SuMaRiO project structure

(farmer's field) via farm scale to regional scale (Tarim Basin) on agricultural ecosystems. On plot scale studies on water use and evaporation of cotton plant is carried out. On the regional scale plant parameters like biomass and leaf area index is taken from satellite images. Along the length of the Tarim River a model with water users is set up.

Work Block 4 is studying the ecosystem services and ecosystem functions in the following ecosystems: i) riparian ecosystem (Tugai vegetation), ii) non-irrigated land use systems, iii) urban and peri-urban ecosystems. The mainly investigated ecosystem services in the project are: a) provisioning services with water supply, food and fodder, fibre and raw material and natural medicine; b) regulating services with water purification, soil fertility, air quality and local climate; c) supporting services with genetic resources, biomass production, nutrient cycling and water cycling; d) cultural services with recreation, aesthetic appreciation and scientific discovery.

Work Block 5 assesses on several levels the socio-economic situation of the region. With contingent valuation method the social value of a more sustainable water management program (willingness to pay) and thus water pricing is assessed. Family farms, large scale farms and farms of the Xinjiang Production and Construction Corps (state farms) are analyzed. The utilization potential of native plants, like *Apocynum pictum* and *Phragmites australis* (reed) is estimated. A transdisciplinary assessment is conducted of the ecosystem services for urban areas regarding dust and heat stress.

OUTCOME OF THE PROJECT – A DECISION SUPPORT SYSTEM

The outcome of the project will be a decision support system. This tool will enable the stakeholders to see the consequences of their actions in terms of water and land management.

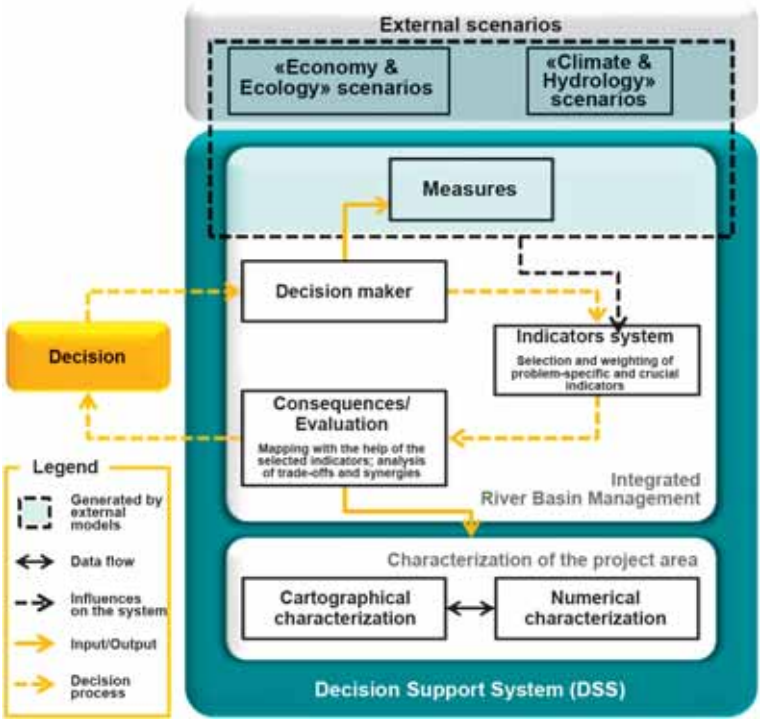

Fig. 4. Outline of the decision support system of the SuMaRiO project. Source: Marie Hinnenthal, Universitaet der Bundeswehr, Muenchen

On the way to develop the decision support system, the multi-level stakeholder dialogue is an important tool for the implementation of the project results. The dialogue involves the local farmers earning their livelihood mainly from agriculture. There are family farmers from the Uyghur minority and from the Han Chinese being interviewed on their livelihoods. Stakeholders on county level, city level and provincial level are being interviewed. The feedback on the scientific work in SuMaRiO and the needs from the different stakeholder levels will provide input to the decision support system.

The decision support system (Fig. 4) will combine the Integrated River Basin Management and ecosystem services. The decision support system is based on two external scenarios. There will be a scenario dealing with the regional economy and ecology. In this scenario "business as usual" and "regional sustainable management" with its consequences on the ecosystems will be implemented. The scenario on climate and hydrology will comprise the trends in climate change in the region and their impact on the hydrology in the region.

The step "Alternatives" will give the user the possibility to implement measures (e.g. policy measures), other options or the combination of several measures. In the Step "Consequences/ Effects" first the status quo is indicated. The changes based on the observations of past and future scenarios (e.g. climate change) according to the prompted measures will be illustrated. According to the results of the decision support system the user can see the consequences of her/his action, for example an implemented policy measure.

IMPLEMENTED GOALS OF THE CONVENTION OF BIOLOGICAL DIVERSITY, THE CHINESE NATIONAL BIODIVERSITY STRATEGY AND ACTION PLAN AND THE CONVENTION TO COMBAT DESERTIFICATION

On an international level the SuMaRiO project implements goals stated in the Convention of Biological Diversity and the Convention to Combat Desertification. Under the Convention on Biological Diversity the international community adopted the Strategic Plan of the Convention on Biological Diversity (CBD) or the so called Aichi Targets in 2010. The Aichi targets are 20 headline targets, organized under five strategic goals that address the underlying causes of biodiversity loss, reduce pressure on biodiversity, safeguard biodiversity at all levels, enhance the benefits provided by biodiversity, and provide for capacity building [Secretary of CBD, 2010].

Under the strategic goal to address the causes of biodiversity loss by mainstreaming biodiversity across government and society, the SuMaRiO-project contributes to the Aichi targets 2, 3 and 4 by reaching out to stakeholders at all levels and taking steps to implement sustainable production and to integrate ecosystem services into planning in the region. The reduction of the direct pressures on biodiversity and promotion of sustainable use is the second strategic goal of the Convention of Biological Diversity and is implemented by the SuMaRiO-project under the Aichi targets 5, 7 and 8. The project is assessing the status quo of natural habitats, especially forests, agriculture and studies the impact of land use on degradation (soil salinization) and vice versa. The third goal of the CBD is to improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity. Under the Aichi Target 11, the study along the Tarim River assesses the extinction risk of the Tugai vegetation and evaluates the ecosystem services and benefits from protected areas. The benefits from biodiversity and ecosystem services to all should be enhanced, as stated in the fourth strategic goal of the CBD. SuMaRiO evaluates ecosystem services which are related to water, health (dust transport), well-being and the function of the urban vegetation. It also analyzes ecosystems supporting livelihoods and the well-being of local communities and will provide a tool to manage natural resources conflicts. These tasks are under the Aichi Targets 14 and 15. In the project the implementation

through participatory planning, knowledge management and capacity building, the fifth strategic goal of the CBD, is a major part. With the stakeholder dialogue, representatives from all levels are involved in the creation of the decision support system. The projects' decision support system will meet the postulation of Aichi Target 19.

To implement the Convention on Biological Diversity, each country has its own National Biodiversity Strategy and Action Plan (NBSAP). The Chinese NBSAP promotes large-scale projects on biodiversity with international capital and to strengthen the international exchanges and cooperation with the focus on capacity building in biodiversity. The project, furthermore, promotes the harmony between man and nature and has the strategy to strengthen the ecosystems. The SuMaRiO project, having a focus on land use, is carried out in the national priority area 2 (the northwestern ecologically fragile territories) a typical desert ecosystem. The impact of climate change on biodiversity is assessed and the conservation of biodiversity and wetlands is integrated into sectoral and regional planning. The project investigates, assesses and monitors biodiversity in different ecosystems in the region (action field 3) and aims to improve sustainable use policies (action field 1). In the stakeholder dialogue the project encourages stakeholders to actively participate in biodiversity conservation and sustainable use to improve the implementation capacity.

Objectives of the Convention to Combat Desertification (CCD) are also implemented by SuMaRiO. The project aims to improve the living conditions of the local populations by assessing the socio-economic and environmental vulnerability to climate change. The focus of SuMaRiO is sustainable land management and the sustainable use of biodiversity which generates a global benefit via the production of sustainable produced cotton. Awareness raising on land degradation and education is promoted in the stakeholder dialogues and the exchange with students. In the process of developing a decision support system, policy, institutional and socio-economic drivers of land degradation and barriers to sustainable land management are assessed. With the help of the decision support system recommendations to remove these barriers are developed. The results of the project will improve knowledge of interactions between climate change adaption and restoration of degraded land in an ecological fragile area.

In the SuMaRiO project the Convention of Biological Diversity and the Convention to Combat Desertification are considered in one large region. The project's results will contribute to the Convention of Biological Diversity and the Convention to Combat Desertification and the Chinese national biodiversity strategy and action plan. The recommendations are found in a rational discussion between various stakeholders. The decision support system is a crucial tool for finding quantifiable results of the planned measures and supports the stakeholder's discussion. The implemented policies are described in point 3 of this extended abstract.

ECOSYSTEM SERVICES

The concept of EcoSystem Services (ESS) was first used in the 1960's and has been formalized and brought to a general public by the United Nations Millenium Ecosystem Assessment program, launched in 2001. In the Millenium Ecosystem Assessment Report (MA) Ecosystem Services are defined as *"the benefits people obtain from ecosystems"* [MA, 2003]. This definition refers to the definitions given by Costanza et al. [1997] and Daily et al. [1997]. It takes natural as well as man-made or man-modified ecosystems into account and refers to material as well as intangible benefits [MA, 2003].

Usually Ecoystem Services are classified to four categories [according to MA, 2003, Mace et al., 2011] (see also Fig. 5):

- **Provisioning Services**: Products obtained from ecosystems. E.g.: Food, Fresh Water, Fiber, Genetic resources

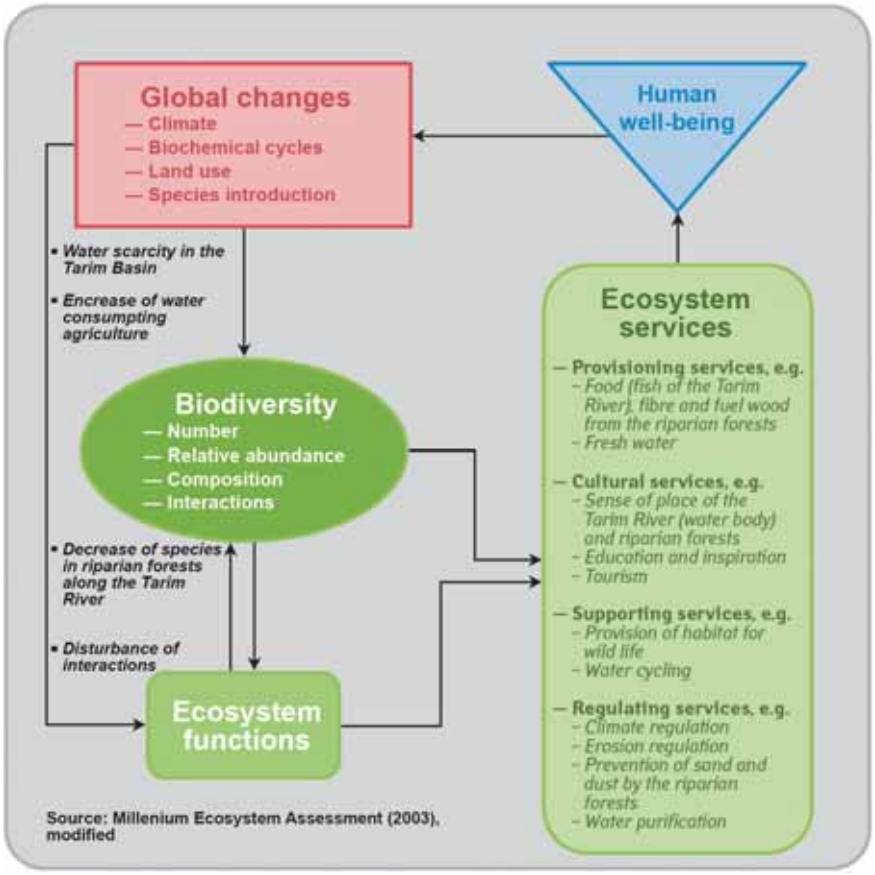

Fig. 5. Ecosystem Functions and Ecosystem Services as discussed in the SuMaRiO framework

- **Regulating Services**: Benefits obtained from ecosystem processes. E.g.: Climate regulation, Water purification, Disease Regulation

- **Cultural services**: Intangible benefits obtained from ecosystems. E.g.: Recreation, Tourism, Aesthetic, Educational

- **Supporting Services**: Necessary for production of all other services. E.g.: Soil formation, Nutrient cycling, Primary Production.

The concept of ecosystem services, as introduced, is a very holistic approach aiming to maintain or improve human well-being. Human well-being is strongly dependent on functioning ecosystems that satisfy fundamental human needs like fresh air, drinking water and food to name only some. Ecosystems and their ability to deliver ecosystem services are affected by human impacts as well as natural environmental change. The aim of the Ecosysem Service concept is *"to enhance the contribution of ecosystems to human well-being without affecting their long-term capacity to provide services"* [MA, 2003]. It propagates a sustainable use of natural resources. Ecosystem services are underpinned by biodiversity. In most cases a stable delivery of ecosystem services increases with biodiversity [Norris et al., 2011].

Ecosystem services can be seen as a tool for integrating ecosystems into decisions of all kind (especially landuse decisions) and conduct them towards a sustainable direction. Daily et al. [2009] give a framework on how ecosystems and their services are

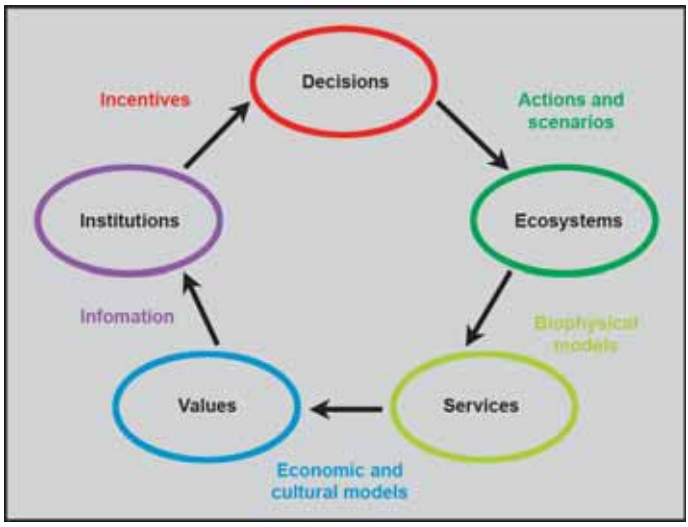

Fig. 6. Linkage between ecosystems and decisions. Source: Daily et al., 2009 (altered)

linked to decision making and figures out the transdisciplinarity of the concept, which is introduced in the Fig. 6.

An ecosystem consists of certain structures and functions, which are interacting. The United Nations Convention on Biological Diversity defines an ecosystem as '*a dynamic complex of plant, animal and micro-organism communities and their nonliving environment interacting as a functional unit*' [United Nations, 1992]. These functions and structures have to be assessed and modeled using natural science methods. In cooperation with local stakeholders (e.g. administration, local population) the services delivered by an ecosystem are identified. The importance of each service is dependent and differing on the stakeholders' point of view and the particular scale that a project is dealing with. Using economic and cultural models the provided services are valued. A valuation can be achieved using several methods. For example the travel-cost method, where people are asked, how much they would be willing to pay to visit the reviewed ecosystem [European Environment Agency, 2010].

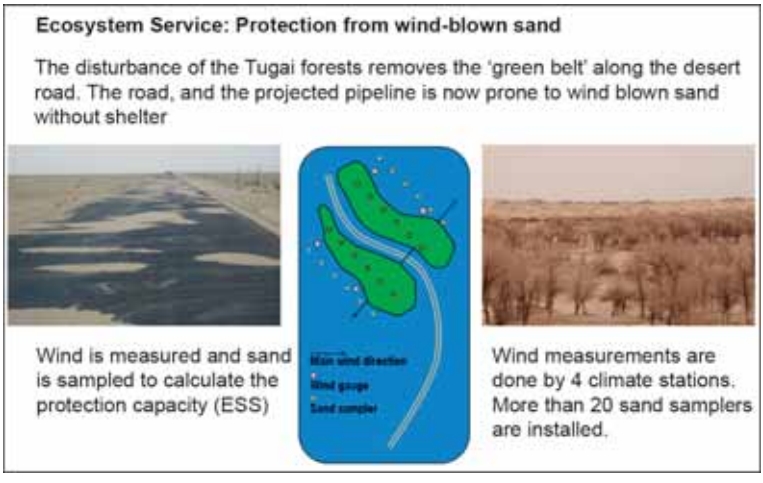

Fig. 7. Research scheme for the potential of Tugai forests regarding "sand fixation"

Amongst others within SuMaRiO a cost-benefit analysis used to valuate the ecosystem service 'sand fixation', provided by the Tugai vegetation at the lower reaches of Tarim River. Since there is a national highway accompanied by the vegetation belt this protective function can be valuated by comparing the costs of road maintenance at sections with and sections without natural vegetation, respectively the costs for artificial lining. Figure 7 shows the research scheme which is applied in the SuMaRiO project to make research on the ESS 'sand fixation' of Tugai forests.

The depicted values are to be embedded in institutions. This can happen in form of pilot projects, demonstrating the usefulness of sustainable decisions. It is important to try to strengthen representative existing institutions and provide information on the merits of certain decisions.

The step from institutions to decisions mainly is about financial incentives. The question is how decision makers can be motivated to decisions taking the ecosystem values into account. Especially within the SuMaRiO research area a merge of modern techniques and knowledge and traditional management approaches has a high potential to create a conservation approach.

The circle is fulfilled with the step from decisions to ecosystems. Here is examined how made-decisions are feed backed by the ecosystem. This deals with the retrospective as well as a projection to the future, using different scenarios. The scientific task lays in the developing of these scenarios and monitoring the effects of decisions on ecosystem structures and functions.

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Christian Rumbaur graduated from the Technical University Freiberg and obtained Diploma of Geology in 2002. After his studies he participated in several Chinese and Sino-German research projects at the Hohenheim University in cooperation with the China Agricultural University in Beijing with extensive field experience in the North China Plain. In 2004 he got a Scholarship from the German Research Foundation (DFG) and the Chinese Ministry of Education. In 2009, he received his PhD in soil science from the Technical University Freiberg in cooperation with the Hohenheim University and the China Agricultural University in Beijing. Since 2011 he is scientific assistant at the Technical University of Munich at the professorship for Hydrology and River Basin Management coordinating the Sino-German SuMaRiO-project.

Martin Kuba is scientific assistant at the Catholic University of Eichstaett-Ingolstadt, chair of Applied Physical Geography and at the Floodplain Research Institute Neuburg. He studied physical geography, environmental psychology and (eco-) climatology at the Catholic University of Eichstaett-Ingolstadt and TU Munich and graduated with a diploma thesis about avalanche hazards in the Bavarian Alps. His current research focus is on measurement and modelling of soil moisture and its relation to ecosystem function and ecosystem services within the SuMaRiO-project at the Tarim River in Xinjiang/China and on the Danube floodplain in Bavaria.

Markus Disse is professor for Hydrology and River Basin Management and the Technical University of Munich (Technische Universität München, TUM). He worked at the Institute of Hydrology and Water Management, Karlsruhe University, since his PhD in 1995. Until 2003 he was employed at the German Federal Institute of Hydrology (BfG) in Koblenz where he conducted research on the morphology of water bodies and flood modelling. From 2003 until 2013 he held the position of a professor of Water Management and Resources Protection at the University of the German Federal Armed Forces in Munich. His research interests focus on three different areas: process-based hydrological modelling of river basins, flood risk management and the sustainable management of water resources. His experimental research concentrates on hydrological processes in steep drainage basins with the main emphasis on runoff generation and concentration as well as snow measurement and modelling. He is the leader of the SuMaRiO-project.