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Short Communication

Auditing reforested watersheds on the loess plateau: Fangshan Shanxi

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ABSTRACT

Mapping watershed ecosystems, evaluating their ecological status and modelling land use futures are the aims of a project undertaken by an interdisciplinary team from Shanxi Forestry Academy and Watershed Systems Living Water Foundation. The project introduces geospatial methodologies and iGiS technologies for (a) mapping and modelling watersheds and (b) monitoring and evaluating rangeland restoration after reassigning collective forest lands to local farmers in accordance with land reform policies.

Two contemporary geospatial technologies were instrumental in the Fangshan project. These technologies are driving a paradigm shift in the way primary industries like mining, farming and forestry utilize GIS, engage in land evaluations, resource mapping, environmental assessments and product certification.

- Firstly, high resolution, true image 3D orthophoto mapping was produced as the iGiS map platform for the Fangshan project. The true colour orthophoto maps produced by the team proved very suitable, with the high resolution imagery achieving cartographic standards allowing draft mapping at 1:2000. Because unique *x*,*y*,*z* geocentroid coordinates are generated for each and every pixel in the orthophoto mapping process, detailed iGiS data bases with multiple attributes ranked parametrically were readily captured and recorded for every habitat and regolith.
- Secondly, the Shanxi Forest Academy team were trained in geospatial methodologies for mapping watershed ecosystems and modelling their habitat/regolith/energy relationships. Using GiS imaging technologies, these cartographic simulation methodologies enable ecological modelling of watersheds and their subterranean water systems, while providing a framework for monitoring and evaluating the environmental health of watersheds using permanent benchmarks and ecological indicators.

Habitat mapping and modelling of Fangshan watersheds revealed how ecological restoration is gradually occurring through strategic combinations of planned reforestation, traditional terrace farming systems and natural regeneration. These ecological strategies are shown to be beneficial land use partners in restoring the mountain rangelands, riparian ecostructures and ecosystem functions of degraded loess plateau watersheds.

1. Introduction

This paper outlines a heuristic method for auditing the ecological performance of rangeland watersheds and river floodplains using digital imagery and geographic information technologies. Trialled and tested successfully in trans-disciplinary R&D projects in Australia, New Zealand, India and China, geospatial toolkits combine well with heuristic research methods to generate unexpected research outcomes, while providing ecological indicators for evaluating the performance of watersheds. They are now ready to be introduced to a wider audience.

Increasingly in the modern world, digital imaging systems are preferred tools for medical, mining, environmental health and watershed R&D (Hall, 1992; Goodchild, 1996). Instead of reliance on statistical samples and topographic maps, up-to-date, true orthophoto imagery provides complete 3D coverage of the watershed in fine detail. This provides the GiS platform enabling accurate mapping and geospatial modelling. A case study of reforested rangelands in Fangshan County outlines how these new geospatial tools can be used in watershed R&D projects.

Since the 1990s, digital methods for mapping habitats and modelling watersheds have been added to the toolbox of professional practitioners in fields such as land evaluation, land use planning and watershed ecology. This paper is not a detailed review of these

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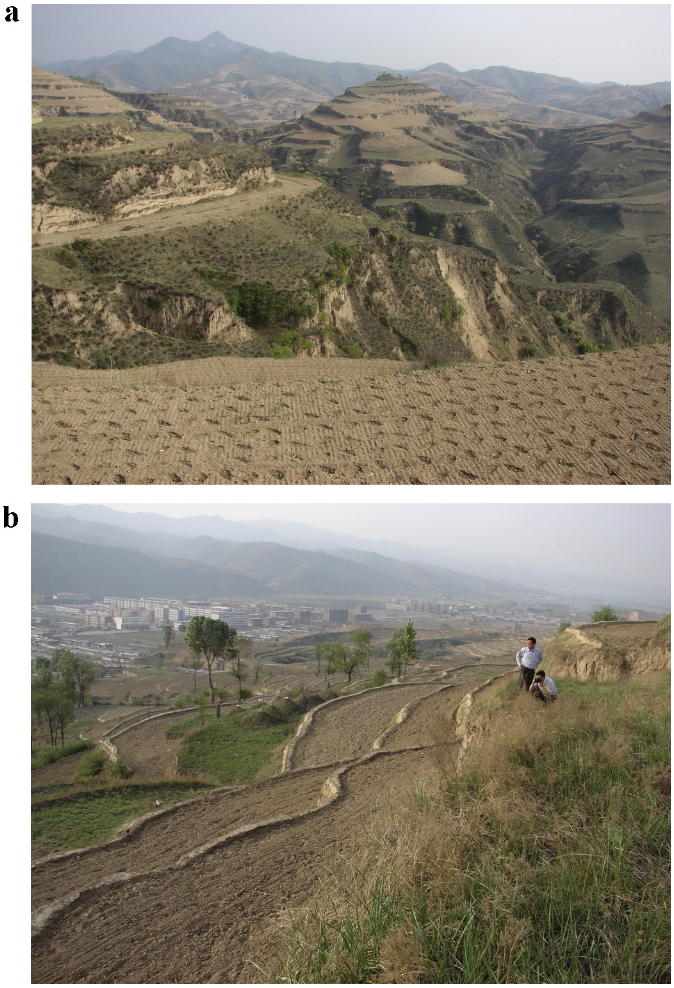

Fig. 1. Fangshan study area (photos Haikai Tane).

digital mapping methods. The objective is to show how to map watershed habitats and model spatial relationships with groundwater aquifers and atmospheric energy systems; to reveal the ecological status of watersheds.

1.1. Study area

In 2010, watershed audits of reforested rangelands in Fangshan County (111° E 38° N) began with field training programs at Shanxi Forestry Academy. By the end of 2012, habitat and regolith mapping were completed for partially reforested watersheds totalling 200 ha. Subsequently, indicators of atmospheric energies powering watershed ecosystems were developed and loaded in the Fangshan iGiS. Together, these ecological indicators enabled assessments of progress with restoration of rangeland watersheds on the loess plateau.

The Fangshan study area is shown in Fig. 1 with two perspectives of typical loess rangeland watersheds. The watersheds are located 1000 ± 100 m above sea level between the Yellow River Valley and Guandi Shan (2831 m). Fangshan County is a rural locality characterised by deep dissected loess hills, eroded mountains and narrow stream valleys. It is a settled area with an intricate patchwork of steep reforested gullies with terrace farmlands on rolling hills and valleys. Severe desertification is long standing and entrenched.

1.2. Paradigm shift in mapping watersheds

Until the 1990s, the most readily available maps were paper topographic maps with a two dimension matrix of Easting/Northing references representing latitudes and longitudes. Contour isopleths provided a surrogate measure of altitude. Land features were added using a range of cartographic icons and symbols. By and large, spot locations were relative, contours had low positional accuracy, site symbols were confusing and land resource assessments were overly subjective. This rendered the maps and spatial information derived from them, rather unreliable and less than useful for most researchers. Few people could read and understand these analogue paper maps or their “spaghetti” logic. Cartographic training and experience were necessary to read them (River Murray Mapping Task Force, 1995).

All this began changing in 1992 with the introduction of digital image mapping and global geocentroid (*x*,*y*,*z*) coordinates for global mapping and world navigation systems. By Year 2000, up-to-date, orthophoto maps with accurate digital terrain models (DTMs) were widely available. In many countries they are routinely used by farmers, foresters and mining corporations for mapping, modelling and monitoring their activities (River Murray Mapping Task Force, 1995). Producing true image 3D orthophoto mapping, at the desired scale and accuracy for auditing watersheds, requires image processing, spherical trigonometry, digital photogrammetry and geocentroid datum. Like driving a motor car, it is not necessary to be able to build the vehicle. Orthophoto mapping can be purchased over the internet at the required scale, accuracy and resolution, or constructed by cartographers with photogrammetry capabilities.

In digital orthophoto mapping, each pixel underpinning raster image maps has a unique *x*,*y*,*z* identity, allowing site specific data to be assigned to each polygon and pixel. Fangshan orthophotos are true image maps based on Shanxi’s surveyed 10 m DTM, making them more reliable and more easily understood than topographic maps at 1:10,000. Orthophoto maps are free of highly variable distortions that make aerial photos unreliable for mapping watersheds or evaluating their performance.

2. Methods of modelling river basins

There are two paradigms commonly used for mapping and modelling river floodplains and their river basins. For present purposes, it is sufficient to note the engineering “catchment drainage” paradigm has dominated Western science since Roman times (2000 ± Years BP). By comparison, the ecographic “watershed storage” paradigm has dominated Eastern and Oceanic cultures for at least 5000 years (Bardon, 1991; Tane, 1996). It is sometimes mistakenly assumed the two terms have similar meanings, resulting in cognitive dissonance and disputes. To avoid this problem, a glossary of technical terms and acronyms is provided in Appendix 1.

2.1. Catchments or watersheds?

The English word “catchment” originated as a technical engineering term for the surface drainage area of storm waters or sewage effluents. Since the 1950s, it has been extended to river, school and market catchments. In the catchment model, river basins are represented as closed confined surfaces draining water away. Land capability units provide spatial units for land evaluation. Land capability units are theoretical entities assumed to be spatially homogeneous. They are classified by grouping land areas with similar attributes and limitations in generic land capability classes. This approach was relatively common until the introduction of true image mapping, computer simulation and iGiS methodologies (River Murray Mapping Task Force, 1995).

Drainage catchments are best known for their closed systems engineering approach in which river basins and their infrastructure networks are modelled by “pipes and plumbing” analogues (Tane, 1996; Chen and Ouyang, 2005). Unfortunately, for a plethora of ecological reasons, engineering catchment methods render streams, rivers and floodplains incapable of cleansing and purifying water naturally. An ecological approach to modelling and managing watersheds is necessary to achieve these outcomes (Tane, 1996, 2004a,b, 2009).

By comparison, the watershed storage paradigm reflects the dynamic open systems approach which views habitats and regoliths as unique, heterogeneous units. Being dynamic open systems, subject to time lags, spatial discontinuities and ecological feedback controls, non-linear geospatial sciences provide better understanding of their complex ecological behaviour. This is the approach used in the new trans-disciplinary science of watershed ecology (Holling 1978; Deng et al., 1998; Chen and Ouyang, 2005). In watershed ecology, river basins are represented as open ecosystems with co-evolving suites of habitats and regoliths, gradually forming ecologically structured networks called ecostructures. In healthy watersheds, ecostructures store, cleanse and distribute aquifer water to surface habitats without the need for engineering infrastructure (Tane, 2009).

Without these ecosystem properties, springs, streams, rivers and watersheds would be unable to reverse the second principle of thermodynamics and prevent relentless decay. Before Nobel Prize winner Ilya Prigogine demonstrated that synergy was a common function of open (living) systems, Ferdinand von Bertalanffy revealed that bio-cybernetic feedback governors were normal attributes of healthy ecosystems. Consequently, in mapping and modelling watersheds, they are properly represented as interdependent co-evolving systems (Fig. 2). As a result of their unique spatial heterogeneity, stepped thresholds, time lags, and energy flux, watershed ecosystems are capable of becoming self-regulating and developing synergy (Hollings, 1978; Tane, 2009).

The tools and methods used in the Fangshan project for mapping watersheds habitats, regoliths and atmospheric energies belong to the second paradigm. Field tested extensively in watershed R&D projects in international programs (Tane and Dai, 1993; Tane, 1996, 2009; Tane and Wang, 2007) they have proven invaluable tools for

- researching mountain watersheds, river floodplains and their relationships;
- engaging in community development projects and participatory watershed programs; and
- tackling environmental restoration of degraded watersheds.

3. Theoretical framework

Through international programs, UNESCO reminds us “We all live in a watershed” where everything is connected. The critical thing to remember about watersheds is that the mountain tops and river floodplains, steep hills and gentle valleys, forests, farms, villages and towns are integral parts of the one watershed system (Curry, 1976). The living communities and shape of the terrain control the rate of energy expended by the water flowing through and over it. Links and relationships between habitats, regoliths, communities and aquifers are fundamental in regulating the local energy flux. Because all watershed elements interact with and modify the energy flow through the watershed, the performance of a watershed is a function of what lives there; from majestic mountains right down to diminutive algae/cryptogam communities (Priyardarshana et al., 2004).

Watershed ecology emerged simultaneously in several western countries, however it is in the Capital City of Australia, Canberra, designed by eco-architects Marion and Walter Burley Griffin (1911–20) that the first modern city was developed using watershed design principles. They employed detailed mapping and modelling of the Molonglo River floodplain to identify critical watershed habitats and riparian zones. To protect these habitats from the pressures of urban development, floodplains were made lakes and wetlands, and riparian zones assigned to ecologically compatible open space functions. The watershed approach was developed further by environmental planners during 1950–2000, for better managing floods, storm waters and urban effluents. These watershed principles are now used by ecological planners designing sustainable cities (Tane, 2009).

Watershed ecology is a geospatial science largely developed during the 1960s and 1970s by trans-disciplinary teams of geographers, ecologists and spatial information scientists using prototype GiS. To engage and integrate many different disciplines, a common platform is essential to integrate their disparate methods and information. Accurate, reliable and up-to-date orthophoto mapping proved to be the ideal platform. As computer capabilities grew large enough for image based GiS, dynamic simulation models like Adaptive Environmental Assessment and Management (AEAM) were adapted for investigating the ecological dynamics of waterways, floodplains, wetlands and watersheds (Holling, 1978; River Murray Mapping Task Force, 1995).

During the 1980s and 1990s AEAM was deployed around the globe in United Nations Environment Programs. During two decades of international applications, it was found that public acceptance and scientific reliability of AEAM spatial simulations often depended on recognition and reliability of the mapping units used. Originally, DTM grid squares provided the map units for AEAM simulation modelling; however, grids are abstract artifices which have little geographic or ecological meaning.

By the 1990s when computer capacity allowed gigabytes files to be manipulated quickly for the first time, DTM grid squares were replaced by discrete, unique polygons for each habitat with their own attribute database (Tane, 1994; River Murray Mapping Task Force, 1995). Successes achieved mapping river floodplains, wetlands and watersheds in Australia using digital imaging systems and GiS quickly attracted international attention. Subsequently applications were received from many researchers to join the 25th anniversary audit of the Waitaki Basin watershed in NZ (2001–2004). This program was followed by the “Water First Project” in Gujarat, India, established to map, model and restore dysfunctional watersheds in three Kheda villages. Successful outcomes achieved by these international trans-disciplinary team projects confirmed the clinical, empirical and diagnostic values of digital imagery and ecographic mapping for auditing watersheds, diagnosing dysfunctional ones, and developing watershed restorations strategies (Tane, 2009).

The watershed systems approach is based in part on earlier ecological land evaluation methods developed by CSIRO, FAO, UNESCO and other agencies working in the field of integrated resource assessments (River Murray Mapping Task Force, 1995; Rossiter, 2003). For the most part however, these older mapping methods represented land units as closed systems in stepped hierarchies. This is not the approach taken here. Cartographic simulation of watershed ecosystems requires all the area of interest to be mapped accurately using modern geospatial imaging systems with high positional accuracy. True image cartographic simulations of watersheds, rivers and wetlands have proven powerful research tools, ideally suited for participatory watershed programs (Tane and Wang, 2007).

To complete the watershed systems model, habitats and regoliths are spatially related through their aquifer recharge/discharge systems using the relational databases incorporated in the watershed iGiS. Cartographic theme maps of

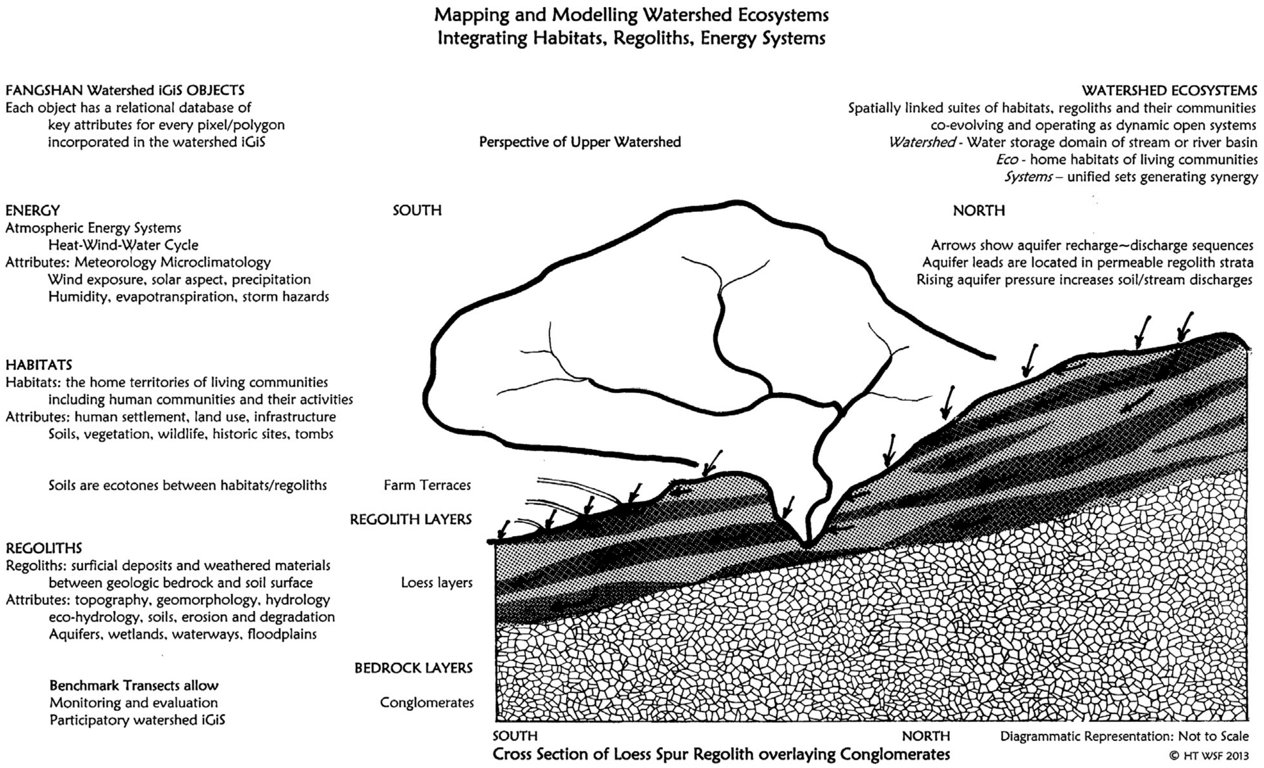

Fig. 2. Habitats are the home territories of living communities and the building blocks of watershed ecosystems providing the geospatial units for mapping and modelling watersheds. From above they are fuelled by solar, wind and water systems. From below they are fed from aquifer seeps and springs in the regolith. In traditional ecography they are mapped as unique areas with special relationships as shown in Old Mick Tjakamarra's Floodplain Dreaming (top left) and Huxian Folk Art of Dao natural farming (top right). Modern ecographic mapping of watershed habitats using GiS is more abstract and esoteric: for example, Tarwyn Park Australia showing habitats generated using true image iGiS – Tarwyn Park Bankers Trust R&D project (bottom).

habitat relationships identified and recorded in the field are generated for investigation. In addition, site specific indicators of sun–wind–water atmospheric energies are developed from meteorological records for each season. In previous approaches, aquifers and atmospheric energy systems were represented by generic indicators like ground water tables and annual rainfall. In reality, they are highly variable, dynamic processes, giving rise to aquifer suites and micro-climates influencing the co-evolution of watershed habitats and regoliths. Fig. 2 shows these complex interrelationships.

3.1. Watershed ecology and habitat ecography

Traditional methods for mapping habitats, rivers and their resources have an illustrious heritage stretching back many thousands of years in Oceana (Australia, New Guinea, New Zealand and South Pacific). Indigenous peoples in Oceana map their rivers and floodplains using traditional ecography and symbolic logic (Bardon, 1991; Tane 2005; Sveiby and Skuthorpe, 2006). Carved on teaching stones and painted using vibrant ochre, many examples of indigenous ecography are found in heritage and museum collections.

Intriguingly, traditional Aboriginal ecography (Fig. 3a) was instrumental in revealing the cultural intelligence and ecological science behind innovative watershed technologies developed by renowned Australian farmer, Peter Andrews. During the 1990s, his Tarwyn Park Bankers Trust R&D Syndicate engaged five Australian universities to participate in a $Aus5.5 million Natural Sequence Farming (NSF) project.

A key objective of the Tarwyn Park NSF project was mapping habitat/regolith processes and their relationships in graphic detail (Tane, 1996). To do this, networks of strategically located peizometers with electronic data recorders were installed on the Tarwyn Park floodplain to identify aquifers and model their water capture–store–seep–release processes. The groundwater data sets were added as regolith attributes and loaded into the Tarwyn Park iGiS for mapping water flows and modelling regolith links to habitats. The results confirmed the farmer's radical, cost-effective approach to restoring derelict floodplains to ecological functionality (Tane, 1996, 2009; Andrews, 2006). The farmer, Peter Andrews, was awarded Australia's highest honour for outstanding services to farming and conservation.

The integrated habitat/regolith map of Tarwyn Park shown in Fig. 3c is an example of modern ecography. For this landmark project, 1:2000 orthophoto mapping with 0.25 m pixels and 1 m contours was generated from high resolution imagery and 0.5 m geocentroid DTM. Using the Tarwyn Park iGiS, cartographic simulation of habitat/regolith relationships revealed the patterns of seasonal recharge–discharge cycles in stream and river floodplains (Tane, 1996; Andrews, 2006). The study confirmed ecological links connecting habitats and regoliths; revealing ecostructures for storing, purifying and distributing water throughout watersheds. A more accessible paper outlining the methodology can be found in the UNESCO Encyclopaedia of Life Support Systems EOLSS (Tane, 2009).

3.2. Mapping watershed habitats

The term "ecology" derives from the Greek word "oikos" meaning a home habitat: the place where communities live (Odum, 1971). Habitats are the key spatial units of ecosystems and the foundations of watershed ecology. Watershed ecology is the study of habitats and their communities, along with water flows sustaining them and atmospheric energies empowering them. By the time suites of habitats adapt and evolve ecosystem qualities, they have

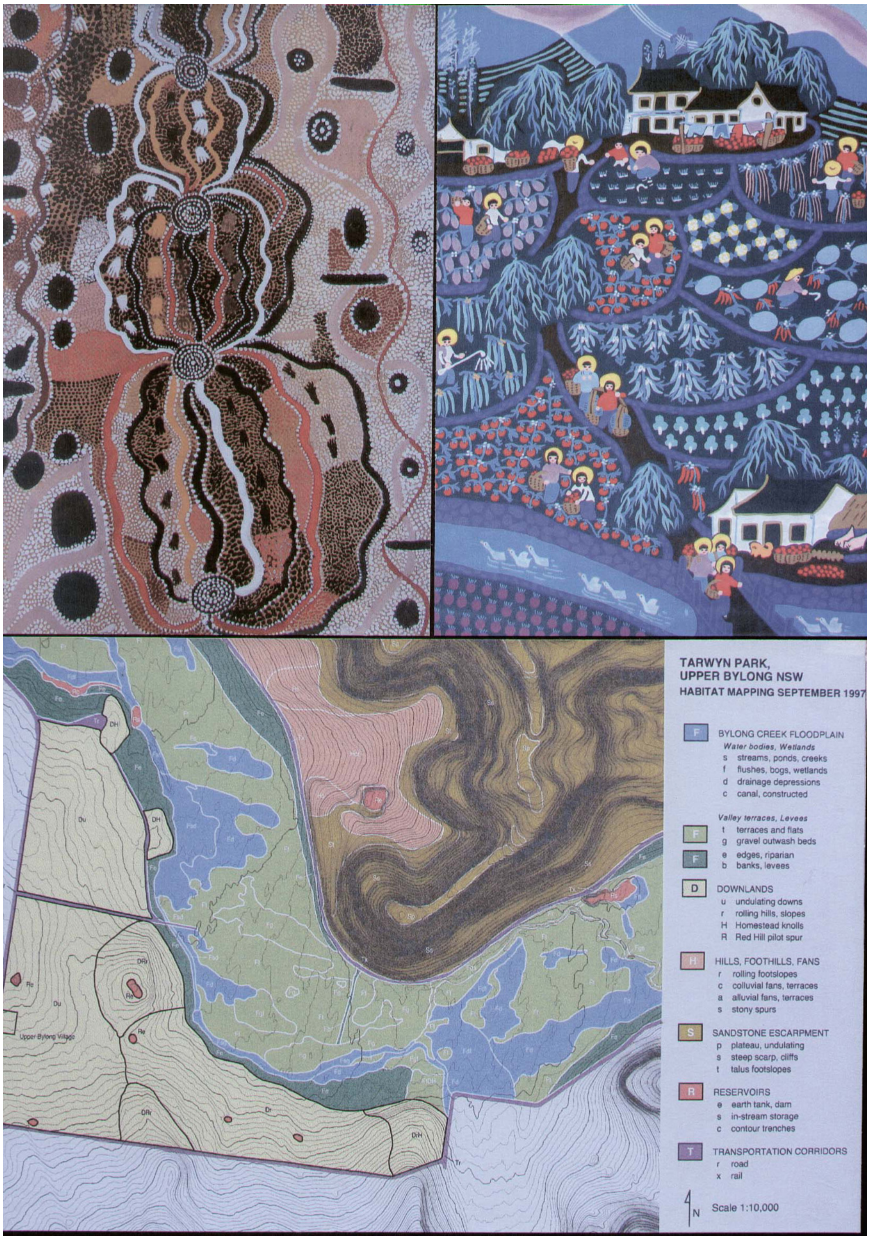

Fig. 3. Watersheds are dynamic open systems with linked suites of habitats and regoliths creating terraqueous ecostructures that store, clean and supply living water throughout the watershed. Habitats are the home territories of living communities. The regolith is the habitat's foundation, including soil material, ancestral landscapes and depositional materials down to geologic bedrock. The ecological performance of watersheds can be assessed to diagnose whether their habitats have been degraded or improved by human activities.

developed into watershed ecosystems with dynamic behaviour, non-linear qualities and cybernetic feedback linkages.

Mapping habitats and modelling ecosystems is the essence of ecological cartography, or ecography as it is now known (Tane, 1994). Traditionally, ecography employs empirical models showing where habitats are located and how their community resources are distributed. Subsequently, habitat/regolith relationships are modelled to show and explain watershed relationships. Traditional Chinese farming examples of land use/vegetation patterns are shown in Fig. 3b. Modern ecography mapping produced by the Tarwyn Park iGiS is illustrated by Fig. 3c. These watershed ecosystem mapping methods are more advanced than traditional land evaluation methods described by Rossiter (2003). They are more closely aligned with ecological cartography, AEAM and simulation gaming systems for watersheds (Holling, 1978; Tane and Nanninga, 1992).

Mapping Fangshan habitats involved identifying and distinguishing community patterns on true orthophoto imagery; patterns created by unique combinations of land use activities and vegetation cover. The first step involved studies of unique topological signatures characterising each habitat on laminated 3D orthophoto maps. Habitat boundaries were identified by separating pattern signatures distinguishing communities to produce draft habitat maps in hard copy formats. The habitat boundaries were then cross checked by other team members before being taken into the field for confirmation. During field confirmation, a third check was undertaken while record sheets were completed for each and every habitat. A copy of the habitat record sheet is provided in Appendix 2 showing the field data collected for attribute databases.

When field checking was completed, the habitats were captured on-screen; digitising the boundaries using the orthophoto imagery enlarged 4–5 times the final cartographic scale to maintain scale accuracy standards. During this process the GIS operator cross-checked consistency and reliability of the habitat units. When digitising was completed, data on the habitat field sheet data were loaded into the watershed iGiS, to create attributes tables for each habitat. Final drafts of the habitat maps were then produced and taken to the field for corroboration by local farmers and village officials. This five step quality assurance procedure illustrates how geospatial data in the Fangshan iGiS was validated.

3.3. Mapping watershed regoliths

The regolith is the matrix between geologic bedrock and soil surface. The regolith is where aquifer waters are stored in permeable layers before being restored, cleansed, replenished and redistributed to surface habitats. Fangshan regoliths were mapped from topography contours and landform patterns on greyscale photomaps with white contours. Regolith layers were corroborated from exposed cross sections in quarries, road cuttings and gullies; and from deep wells and borelog records. Key regolith attributes include geology, geomorphology, topography, eco-hydrography, wetlands, waterways, plus aquifer recharge and discharge sites. A regolith record sheet is included in Appendix 2.

Landforms and regoliths are distinguished by first separating different geologies and then delineating landforms on laminated orthophoto maps. Identifying topologies and topographies from image maps, using contour patterns and digital elevation models are essential skills for regolith mapping (Drury, 1987). It is also important to be able to recognise and differentiate natural geomorphologies from human constructions and cultural impacts.

Mapping regoliths requires expertise in fluvial geomorphology and physical geography with practical field skills in mapping landforms and surficial geology. Regolith mapping was undertaken separately from the habitat mapping to avoid confusion. Because watershed regoliths are key functional components of watershed systems, mapping them accurately enables reliable assessments of watershed storage, conditions and trends, natural hazards, nonconforming land uses, and sustainable development strategies.

In developing Watershed iGiS, objective inventories of habitat conditions and key attributes are essential before undertaking any assessments or evaluations. Only when cartographic processes and protocols are followed rigorously and systematically by the whole team, can inventory mapping of watersheds habitats and regoliths be completed accurately and reliably. This object oriented inventory approach to mapping watersheds is also an important modelling strategy for generating heuristic fertility, as Holling and Walters demonstrated in numerous worldwide applications of AEAM (Hollings, 1976; Walters and Holling, 1990). AEAM projects demonstrated that key drivers and dysfunction affecting watershed ecosystems are more readily revealed by engaging in spatial simulations with an open mind, free of restrictive aims or expectations.

3.4. Geospatial considerations

Trans-disciplinary R&D projects lke Fangshan integrate wide ranging disciplines on true image mapping called the GiS platform. GiS rules of engagement are necessary to ensure team members contribute and cooperate openly and fully. To ensure this happens, team training takes place for up to 3 months before mapping starts. During training, team members are routinely tested for spatial literacy skills. Those with poor spatial literacy are given alternate tasks or dropped from the team.

One of the tests is checking habitat boundaries. Different habitat pattern signatures are compared using remote sensing tools such as multi-spectral raster LUTs “look up tables” (Drury, 1987). Habitat “finger prints” (image topologies) are a function of all the biophysical activities and biota comprising the habitat community, including vegetation cover, land use activities and settlement infrastructure. When habitat mapping is completed, ecotonal boundaries of watersheds are identified by highlighting suites of habitats connecting adjacent watersheds, in much the same way as riparian ecotones connect aquatic and terrestrial habitats (Naiman and Décamps, 1990).

The trans-disciplinary composition of the team allows the watershed’s systems to be evaluated from multiple perspectives. By following the geospatial methods outlined, ecological processes underlying the performance of watersheds are gradually revealed and recorded during field surveys. Identification of ecological dysfunctions is also outcomes from field surveys, where they are recorded on field sheets (Appendix 2). They are openly discussed among the team until consensus is reached on their significance. Later, they are examined and assessed in the GiS laboratory using the relational databases to produce specific theme maps of land degradation and desertification (Fig. 5).

4. Outputs and results

The Fangshan project generated a range of maps and databases of habitat conditions provided in Figs. 4 and 5 and Appendix 2. These iGiS products were used for evaluating progress with reforestation, investigating the potential of sites, and exploring relationships between land use and watershed performance. In addition, the method’s heuristic fertility provided several unexpected results discussed in the following sections, by helping to

- identify and investigate habitat/regolith relationships;
- reveal the consequences of deforestation, burning and grazing;
- record key drivers of desertification and strategies for reversing it;
- expose the role of bioseals in regulating aquifer recharge/discharge systems;
- locate and confirm habitats suiting speciality crops, food forests and protection forestry;
- find habitats with micro-climates and recharge/discharge conditions suiting commercial nut trees such as walnut (*Juglans* sp.) chestnut (*Castanea* sp.) and hazel (*Corylus* sp.);
- identify underused facilities such as abandoned cave houses and vacant schools suitable for sedentary bee farming, rabbit farming and fungi farming.

The detailed scales used to map Fangshan habitats and regoliths (1:2500 and 1:5000 respectively) coupled with the object oriented development of the Fangshan iGiS, and the relational databases for each habitat and regolith, allowed high levels of oversight without loss of detail on site specifics. Theme maps produced by the Fangshan iGiS provide the status of watershed habitats and regoliths while revealing ecological dysfunctions. From this information permanent benchmark transects are identified for on-going monitoring and evaluation purposes. This step will be taken in the next stage of the project with Fangshan foresters and farmers.

4.1. Habitat/regolith relationships

In Fangshan County, precipitous gullies with exposed regoliths separate steep hills dominated by rolling spurs most of which are terraced for farming. The thick mantle of loess which covers much of the rangelands was deposited in layers over many thousands of years. In these deep loess terrains, regoliths of wind borne sediments are comprised of layered strata containing varying proportions of clay, silt and sand particles. Some layers are more porous than others allowing aquifer seeps to become storage strata. As aquifer pressure rises, water is gradually released through soil seeps and spring fed streams (Fig. 2).

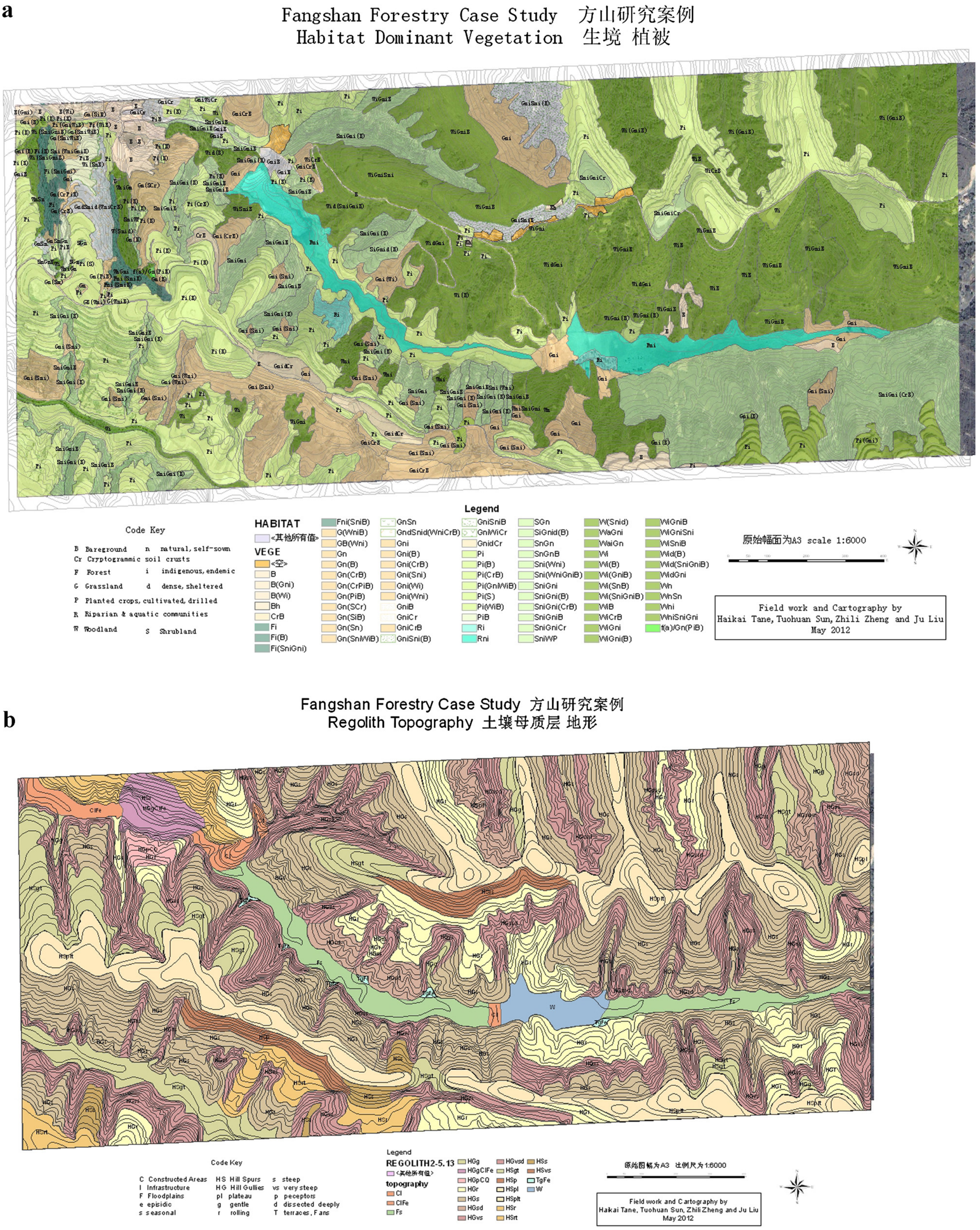

Fig. 4. Fangshan habitats and regoliths are functional mapping units identified on true image photo maps, defined by their spatial signature, described by their key attributes and then field checked. The main attributes recorded are topography, regolith geology, landform geomorphology, eco-hydrography, vegetation communities and land use systems.

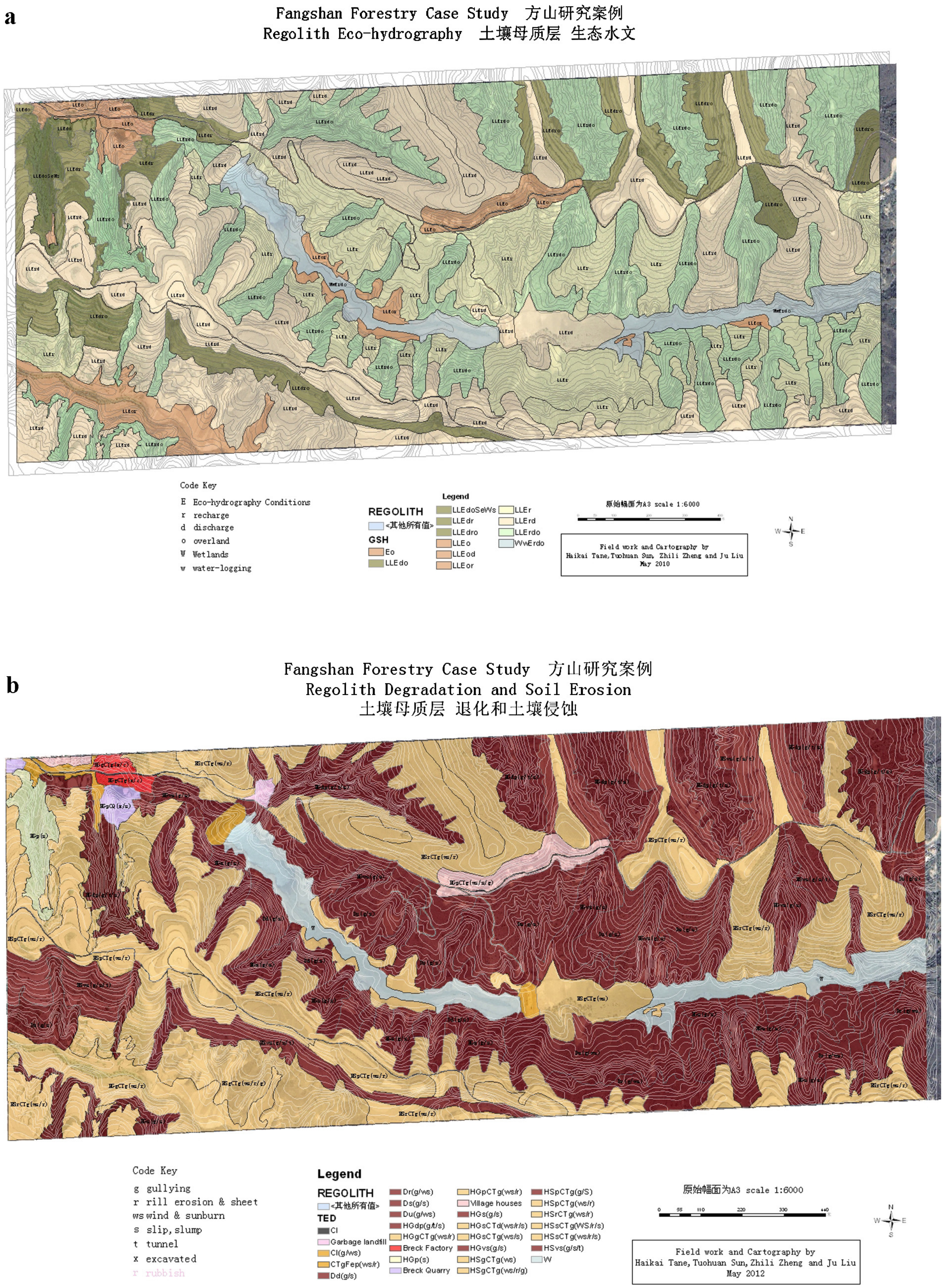

Fig. 5. Fangshan regoliths are deeply dissected in many places, accelerating the discharge flow rates from aquifers. Aquifer recharge–discharge cycles and watershed eco-hydrology are being compromised by non-conforming activities such a grazing and pugging by hard hoof animals and indiscriminate burning and vehicle tracking.

Beneath the deep loess layers, water rounded conglomerate gravels and boulders were found at a depth of 7–50 m. Conglomerates found at the bottom of a quarry contained calcite nodules in water worn indurated mudstones. In the areas mapped, these lower layers were not constraints on near surface aquifer systems and appear to have minor effects on habitat conditions.

To highlight geographic relationships and ecological connectivity, the Fangshan regolith map is shown below the habitat/vegetation map of the same area (Fig. 4). In watershed ecology, the structure and functions of land use systems and their vegetation communities; and how they relate to groundwater systems are more important for evaluating the performance of watershed ecosystems, than species taxonomy. If for other reasons taxonomy is important, species lists can be compiled in the field and included as habitat attributes in the watershed iGiS.

The physical connectivity of surface and groundwater has been studied for more than a century by hydro-geologists (Cherepansky and Vsevolozhsky, 2006). Even so, the complex ecological processes by which habitat communities stall and infiltrate surface water into the ground during wet cycles, and then discharge groundwater through surface seeps and springs during drier circles, are less well known (Tane, 1996, 2009). To address this situation, Fangshan regolith data sheets have an eco-hydrography section requiring the recharge/discharge status of each regolith to be recorded (Appendix 2). From this and other attribute data, the Fangshan iGiS generated the eco-hydrography map shown in Fig. 5.

When undertaking audits of rangeland watersheds, mapping and modelling the connectivity of surface habitats with regolith aquifers is fundamental. In ecologically functional watersheds, springs, streams and other surface waters are sustained more often than not by overflowing aquifers. In degraded, dysfunctional watersheds where only a small proportion of rainfall events and subsequent surface flows is taken into aquifer storage, most of the rainwater runs away overland or evaporates back into the atmosphere. In the Fangshan watersheds, restoration forestry and traditional terrace farming are slowly increasing rainfall recharge to groundwater. Where erosion is widespread, however; recharge–discharge relationships are compromised until erosion gullies and tunnels are remedied.

Depending on seasonal conditions and habitat status, both recharge and discharge processes were found to occur on some habitats at different times of the year. Traditional terrace farming incorporates design features making terraces more efficient in capturing and storing water in their subsoil aquifers, by stalling rainfall to reduce runoff. In these situations, both recharge and discharge processes are shown as regolith attributes.

4.2. Aquifers, ecostructures and bioseals

In healthy watersheds, this natural water distribution system operates as a stepped threshold spatial diffusion process, creating time lags and spatial discontinuities (Tane, 1996; Andrews, 2006). As a result of these intrinsic ecosystem functions, floodplains and watersheds are continually adapting, evolving and forging ecosystems through dynamic processes of ecosynthesis. As a result of dynamic uncertainty generated by these open system qualities, predictive and deterministic methods for modelling watersheds are inappropriate.

Ecographic mapping of the Fangshan watersheds allowed habitats and regoliths to be modelled as dynamic open systems. Attribute databases in the Fangshan iGiS allowed their functional relationships, dynamic processes and unique properties to be investigated. Spatial interactions between habitats and regoliths were shown to hold the key to the ecological performance of Fangshan watersheds. At the surface of the ground, where habitats and regoliths connect and overlap, micro-communities of algae, mosses, lichens and liverworts, called cryptogam communities, were flourishing in the absence of physical disturbances. These micro communities are relatively inconspicuous, however; their influences on ecological performance of watersheds are far greater than commonly appreciated. The health of these diminutive communities is crucial to the performance of habitats, riparian zones and watershed ecostructures (Tane, 2009).

Fig. 6. Algae interlaced cryptogram communities occur on the ground on and between soil particles and organic litter. They are primary colonisers stabilising loose particles in organic carpets grown by communities of algae, mosses, lichens and liverworts. In dry periods they appear as greyish stains or skins on bare soil. They are more easily studied with a magnifying lens. When wet their true colours are conspicuous, ranging from luminous green to bright orange. In the absence of soil disturbance by tracking, burning or grazing, algae and cryptogams form extensive communities capable of living for centuries (photos Haikai Tane).

Ecostructures operating within the regolith, store clean and distribute living water throughout the watershed in ways that are enhanced culturally by Fangshan farmers cooperating on a watershed basis. Most ecostructures are woven into the fabric of the terrain with few features recognisable above ground. Healthy riparian ecotones linking terrestrial habitats with aquatic habitats are signs that ecostructures are functioning (Tane, 2009).

Algae infused cryptogam communities co-exist to form biological bandages on bare ground and eroding soils (Fig. 6). Called soil crusts or skins, these cryptogam communities operate as primary stabilizers preventing erosion while regenerating habitats. They are not dependent on soil fertility; indeed they initiate soil fertility cycles by extracting essential minerals and nutrients from atmospheric moisture and storing it in biomass that eventually decays into seedbeds enabling plant succession and dynamic ecosynthesis (Eldridge and Tozer, 1997).

Cryptogam communities were found growing in carpets interwoven with algae biofilms through reforested areas and on stabilised slopes, however; only in habitats where there were no signs of burning or grazing. Cryptogam communities are known to act as bioseals regulating recharge and discharge flows, to and from aquifers (Tane, 2009). These bio-films regulate hydraulic pressure in aquifers and ecostructures only when their bioseals remain intact and unbroken. When communities of algae, mosses, lichens and liverworts develop undisturbed on bare ground, they blocked leaks, slowed down aquifer release rates, helped prevent soil erosion and initiated the growth of new topsoil.

Cryptogam carpets absorb dew, fog, mist, sleet, rain and snow, stalling and recharging ground water systems. Where aquifers surface again in seeps or springs, cryptogam communities can also regulate release rates by adaptive growth morphologies: sealing over completely in dry times; and bursting open under stronger pressure to release overflowing aquifers. Many sites at Fangshan provided evidence of the ecological role of cryptogams as pioneering communities sealing aquifer leakages. It was noted that terrace farmers traditionally maintained inclined terrace edges which are more easily covered with cryptogam carpets, herbs, flowers and vines. Scraping and reshaping terrace walls into more vertical alignments, to gain a little more crop space, destroys the bioseals with the result that aquifers within the terrace bleed dry, increasing soil droughts and seasonal water shortages.

4.3. *Degraded regoliths and desertification*

Severe sunburn and wind erosion, historic landslips and slumps, sheet and rill erosion, and gully and tunnel erosion are all widespread in the Fangshan watersheds. As well as massive degradation phases in recent centuries, several old cycles of degradation are evident in the landforms and regoliths, some possibly dating back to early periods of deforestation, burning and grazing during Neolithic times (8000–3000 Years BP). Degradation cycles have occurred several times since, gradually cutting precipitous gullies and gorges down to bedrock. When stable times returned, aggradation cycles partially refilled them again.

The degradation of regoliths in the Fangshan watersheds is severe to extreme (Fig. 5). Sunny and shady slopes are deeply dissected and extensively damaged. Mass movement of surface materials through tunnels, slips and slumps is common. In the gullies, erosion tunnels are channelling rainfall runoff into torrents that carve into the bed and banks with each large rainfall event. Repairing this level of damage is a major undertaking requiring stringent measures and strict controls on non-conforming activities such as burning, grazing and tracking. As a result of continuing non-conforming activities, aquifers with broken seals are draining at accelerated rates. Watersheds which leak and waste their aquifer waters, usually display levels of performance well below their ecological potential.

In loess landscapes with entrenched desertification like those at Fangshan, erosion gullies and vertical terrace banks heal very slowly. Field investigations revealed that as trees re-establish and stabilise slopes through interlocking root mats, their merging canopies also increase shade and shelter. Only with stability, shade and shelter has regeneration accelerated towards full ecological potential with soil deposits of loess, colluviums, alluviums and fluviums being completely capped by organic matter from maturing vegetation communities. Given the long history of desertification on the loess plateau, it is hardly surprising there is still a long way to go in restoring many sites in the Fangshan watersheds. There remain many eroding habitats lacking the key cryptogam communities and algal soil crusts needed to protect soils from erosion and seal aquifer discharge springs and seeps from leaking excessively.

4.4. *Drivers of deforestation and desertification*

As a rule of thumb, in healthy watersheds, more than two thirds of all precipitation is taken into aquifer storage or stored in biomass, while less than one third evaporates or flows away overland. In deforested and degraded watersheds, this ratio is reversed: two thirds of all precipitation evaporates or runs off overland, taking with it surface contaminants and nutrient laden soils (Tane, 1996, 2009; Andrews, 2006). The result is mineralised soils, less water stored in aquifers, diminished stream and river flows, polluted water and dead springs.

Desertification becomes serious when aquifers are disabled, watershed ecostructures are rendered dysfunctional, and the land dries out. Desertification is most common in predominantly pastoral countries like Australia, New Zealand, USA, Mexico, the Middle East and pastoral Africa (Ci, 2004). This situation is predictable because, hard hoof animals track and compact habitats, breaching bioseals, and drying out soils and wetlands.

The long shadow of pastoral livestock has been exposed by UN agencies as an ecological calamity affecting the whole planet (FAO, 2006; Tane, 2009). Tracking and treading, pugging and grazing by hard hoof animals are major drivers of riparian dysfunctions and wetlands disappearing. The consequences are aggravated floods and droughts with diminishing water supplies burdened with pathogens and pollutants. To allow even light grazing by hard hoof animals seriously compromises key algae and cryptogam communities regulating aquifer recharge and discharge processes. Because hard hoofs pierce bioseals that maintain aquifer water pressure, aquifers and springs drain at greatly accelerated rates, bleeding dry. The cumulative impact of these anthropocentric impacts is characterised as human induced desertification (Ci, 2004; Tane, 2009).

Cycles of deforestation and desertification are conspicuous features of Fangshan (Figs. 1–5). Foremost among the drivers of deforestation and desertification are human activities felling trees and burning rangelands, draining wetlands, disabling aquifers, destroying ecostructures and watershed systems.

The gradual drying out of loess plateau watersheds and the disruption this causes to the heat-water balance at the local and regional level destabilises meteorological processes and atmospheric energy regimes. While this situation is explained by a plethora of processes commonly summarised as human induced desertification, a scientific explanation is provided by Kravcik et al. (2007) in their scientific treatise on the ecological dynamics of watershed heat-water cycles. Applying this perspective to the Fangshan watersheds reveals serious problems that need addressing: notably the burning of regrowth, grazing ungulates and indiscriminate vehicle tracking.

4.5. *Reversing human induced desertification*

Reforestation is one of the most effective ways of reversing desertification. Interlocking tree root plates not only stabilise erosion prone terrain, they provide shade and shelter allowing understory communities to grow in more favourable conditions with fewer fatalities. Deeper rooting trees access aquifer leads bringing moisture back above ground to be stored in their biomass.

Transpiration from trees and forests converts excess solar radiation into latent heat of evapotranspiration, preventing the surface of the ground heating up, and soils and plants drying out and dying (Kravcik et al., 2007). Evapotranspiration leads to elevated atmospheric moisture levels which in turn increase the formation of dews, fogs and mists that can be absorbed by plant communities in mountain watersheds.

Atmospheric water redistribution is particularly important in Fangshan's drier rangelands, where rainfall may provide less than a third of the total water required by flora and fauna communities. In semi-arid mountain rangelands like those at Fangshan, it is not unusual for atmospheric fogs, mists and dews, subsoil seeps and springs to provide most of the water needed by habitats and their communities (Tane, 2009). These interactive watershed processes help provide an effective strategy for reversing desertification.

In healthy watersheds, more than 90% of all water is stored in layered networks of linked aquifers connected to suites of terraqueous habitats and riparian ecotones above ground. Over time they adapt and evolve into ecostructure networks distributing aquifer waters to surface habitats. This only occurs where the environmental health of a watershed allows habitats and ecosystems to function effectively. In this respect, reforestation and the elimination of open grazing by hard hoof animals have played key roles in reversing desertification and re-establishing terraqueous ecostructures in Fangshan's watersheds.

5. Discussion

In western science, the sophisticated ecological hydraulics of watershed ecostructures were first recognised and recorded in the 1990s, during practical and applied R&D projects for ecological restoration of river floodplains in Australia (Tane, 1996, 2004a,b, 2009). Mapping and modelling how this happens is not only important for understanding ecological processes sustaining habitats and their communities, it helps identify human activities undermining or enhancing the performance of watersheds.

Fangshan's reforested watersheds are typical of loess plateau areas suffering from entrenched desertification, massive gullying, widespread erosion and rural poverty. Mapping and modelling highlighted how and why burning regrowth, pastoral grazing and indiscriminate vehicle tracking compromise aquifer storage and surface springs, by disrupting aquifer recharge and discharge systems. These disruptive activities are renowned for their deleterious impacts on watershed systems; reducing watershed storage, reversing ecological recovery and inducing desertification.

When watershed systems are rendered dysfunctional, aquifers and springs can disappear completely, reducing groundwater storage, draining wetlands and depleting stream flows. Where ground is compacted from tracking and treading, rapid runoff occurs when it rains. The small amount of water actually recharging aquifers quickly passes through leaky regoliths at rates over 20 m/day, draining away in erosion gullies. Soon aquifers become so depleted they stop flowing altogether with the result that wetlands disappear, streams fail, and rivers they feed turn ephemeral. Soils dry out and mineralize, losing their organic nutrient and ecological functions. Before long, plant communities die from water deficit. Because there is insufficient atmospheric moisture to absorb solar radiation and not enough water stored in the biomass to maintain evapotranspiration rates, the land heats up more, drying it out even further (Kravcik et al., 2007). This environmental calamity is typical human induced desertification. It is most common in deforested watersheds grazed by hard hoof animals (Tane, 2009).

Typically, when watershed ecosystems are fully functional, ten times more water is stored in regolith aquifers than in watersheds with compact, eroded soils and degraded regoliths (Tane, 2009). In healthy watersheds, living water seeps and surges through aquifers in seasonal cycles, at rates of less than 1 m/day. This slow flow rate helps maintain extensive suites of terraqueous habitats, sustaining springs and wetlands throughout dry cycles. And in overflowing, aquifers help ensure perennial streams and rivers. Time lags and restricted flows ensure aquifer water releases reduce dependency on low, erratic rainfall, particularly in semi-arid rangelands.

5.1. Watershed farming systems

In Western cultures, it is common wisdom that farming systems are soil dependent. Soil based farming systems are called agriculture because "agri" means soil, and soils are seen to provide both the medium and nutrient for plant growth. Usually, land classification systems in Western cultures have a strong soil focus. By comparison, watershed farming systems in Asia and Oceana, such as tiered-terrace farming on the loess plateau are based on farming terraqueous habitats sustained by nutrient enriched aquifer water slowly seeping through near surface strata. These traditional watershed farming systems (traditional terraquaculture) are not to be found in western cultures and remain an enigma in western science (Geertz, 1971; Ruddle and Zong, 1988; Tane, 2009).

Traditional terrace and paddy farming systems in Asia-Oceana demonstrate a profound understanding of living water flowing within watersheds and the sealing functions of algae biofilms. Watershed farming focuses on expanding floodplain ecosystems, increasing aquifer storage and enhancing aquifer recharge through cooperative activities. On the loess plateau traditional Dao farming communities take great care with watershed activities, to achieve more efficient subterranean water distribution to surface crops, simply because they increase farm production levels without the need for irrigation infrastructure and agrochemical inputs. In these natural farming systems, nutrients for growing crops come from animal wastes and domestic effluents infused into near surface aquifers through aquifer recharge processes.

The benefits of traditional Eastern approaches to farming living water seeping and surging in seasonal sequences through watershed strata include elevated performance of aquifers and springs, ecostructures and ecosystems. Acting in concert, they eliminate the need for costly irrigation infrastructure by ensuring continuous aquifer seepage into surface soils at controlled rates; sustaining moisture for plant growth during dry summer periods. The process by which this occurs was revealed by mapping habitat/regolith relationships using watershed iGiS.

UNESCO's Hangzhou Declaration (2013) puts cultural intelligence at the heart of the sustainable development agenda. In this context, it is fortuitous that traditional ecography from Asia-Oceana is helping change Western perceptions of rivers, floodplains and watersheds, while fostering a revival of natural farming systems in the Asia-Pacific realm. The outstanding success of the Tarwyn Park Bankers Trust R&D Project in Australia has helped kindle academic interest in GiS disciplines and geospatial sciences. Mapping watersheds has not only revealed the power of traditional cultural intelligence from the Asia-Pacific realm, it has revealed how it is soundly based on symbolic logic, analogue models and traditional ecography.

Traditional farming systems such as paddy pond farming, food forests and tiered terrace farming like that at Fangshan may come closer to meeting the sustainable development and environmental protection principles of UN A21 than any other farming system worldwide. Because watershed farming systems do not constitute part of the western agricultural farming paradigm, it is not surprising they are widely misunderstood in the West where they are commonly misrepresented and often mislabelled as subsistence farming or peasant agriculture. Mapping and modelling Fangshan's mountain watersheds reveals how badly they have been maligned, and helps show why these natural farming systems are now being copied in Africa, Australia and New Zealand.

5.2. Restoring watershed ecosystems

Restoring watershed ecosystems and their ecostructure networks is not only essential for efficient water storage and distribution, it is also important for cleansing water of pathogens and pollutants. This is accomplished via slow in-situ filtration, through a stepped threshold diffusion process which spreads water flows far and wide for optimum recharge (Tane, 1996, 2009; Andrews, 2006). The Achilles heel of watershed storage and distribution systems is the physical fragility of their algal/cryptogam bioseals. They are easily broken by all sorts of physical impacts. While cryptogam mats are diminutive, primitive plant communities capable of withstanding climatic extremes, they are easily breached and broken by tracking and pugging activities rupturing the bioseals. Ecostructures with functioning bioseals maintain hydraulic pressure at a level allowing them to distribute water in all accessible directions including up through the soil to crops.

The importance of ecostructure hydraulics maintained by algae biofilms in cryptogam carpets cannot be over emphasised. In most temperate ecosystems, algal biofilms in cryptogam communities regulate aquifer recharge and discharge processes. These micro ecosystems are fundamental to the environmental health and ecological performance of rangeland watersheds. When the bioseals are breached and broken, watershed habitats are unable to regulate rainfall runoff, enhance aquifer recharge, or control rates of water discharge from them. Like broken brake lines in motor cars, when bioseals are breached and broken they no longer function. And like brakes with leaky hydraulic seals, when a watershed's bioseals are leaking badly, there are serious environmental consequences. In the case of the Fangshan watersheds, the consequences included a legacy of hazardous floods and droughts, gullying and soil erosion, severe soil sunburn, induced desertification, diminished farm productivity and widespread poverty.

6. Conclusion

When mapping complex dynamic ecosystems like watersheds, deterministic, predictive models that rely on prior theoretical knowledge tend to encourage preconceptions, when what is really needed is a clear, open mind. By comparison, descriptive spatial models help researchers explore ecological processes and investigate watershed relationships while revealing new insights. The heuristic fertility generated by these learning-by-doing research experiments is sometimes more important than the mapping outputs (Walters and Hollings, 1990).

The first stage of the Fangshan project demonstrates how mapping habitats, modelling spatial relationships and undertaking cartographic simulations of watersheds, achieve multiple objectives: from detailed maps, inventory databases and benchmark transects, to identifying ecological processes and watershed dysfunctions. This spatial methodology requires high resolution, up-to-date imaging systems and advanced GiS technologies. With the benefit of hindsight gained from over 20 years of field trials, the success of this approach depends on being able to recognise in the field how habitat, regolith and atmospheric energy systems are linked ecologically.

Team field work and theme maps generated by the Fangshan iGiS were important in helping identify and assess key ecological indicators for monitoring reforestation programs, identifying how terrace farming enhances aquifers, and evaluating the performance of Fangshan's watersheds. Outcomes and results from the project's first stage are now being used to design and adapt land use activities to match (and make better use of) seasonal energy flows and habitat sequences. This dynamic open systems approach marks a significant departure from previous land evaluation models viewing landscapes in closed system contexts, using generalised land units, broad climate indicators and statistical methods.

The understanding gained of Fangshan watersheds so far, remains an incomplete mosaic of ecographic patterns and ecological processes. A better understanding of historic/pre-historic phases of watershed aggradation and degradation is needed to complete the picture. Episodic events like historic invasions, wars and famines occurring over several millennia, have reduced many loess watersheds to huge erosion gullies that remain unstable. The situation is made even more complex by intervening cycles of partial rehabilitation and recovery. Even so the research outcomes of this project have provided invaluable lessons for protecting and restoring watersheds on the loess plateau.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2014.01.016.

References

Andrews, P., 2006. Back from the Brink. ABC Books, Sydney, Australia.

Bardon, G., 1991. *Papunya Tula: Art of the Western Desert*. Gecko Books, Marleston, South Australia.

Cherepansky, Vsevolozhsky, V.A., Zektser, I.S., 2006. Interconnection of surface and groundwater. In: Types and Properties of Water, UNESCO's Encyclopaedia of Life Support Systems. EOLSS Publishers, Oxford, UK http://www.eolss.net

Chen, Q.W., Ouyang, Z.Y., 2005. Watershed ecology and modelling system. Acta Ecologica Sinica 25 (May (5)).

Ci, L.J., 2004. Combating desertification. In: Regional Sustainable Development Review China, UNESCO Encyclopaedia of Life Support Systems. EOLSS Publishers, Oxford, UK, Retrieved from http://www.eolss.net

Curry, R.R., 1976. Watershed form and process: the elegant balance. Geology 400, 1–27.

Deng, Wang, Cai, 1998. Watershed ecology—new discipline, new idea and new approach. Chinese Journal of Applied Ecology 9 (4), 443–449.

Drury, S.A., 1987. Image Interpretation in Geology. Allen & Unwin, London, UK.

Eldridge, D., Tozer, M.E., 1997. Soil Lichens and Bryophytes of Australia's Dry Country, Dept. of Land and Water Conservation, Sydney, Australia.

FAO, 2006. Livestock's Long Shadow: Environmental Issues and Options. UN Food and Agriculture Organisation, Rome, Italy.

Geertz, C., 1971. Agricultural Involution: The Processes of Ecological Change in Indonesia, USA. University of California Press, Berkeley.

Goodchild, M.F., 1996. GIS and Environmental Modelling: Progress and Research Issues. GIS World Books, Fort Collins, USA.

Hall, S., 1992. Mapping the Next Millennium. Random House, New York.

Holling, C.S., 1978. Adaptive Environmental Assessment and Management. John Wiley & Sons, London, UK.

Kravcik, Pokorny, J., Kohutiar, J., Kovac, M., Toth, E., 2007. Water for the Recovery of Climate – A New Water Paradigm. People and Water NGO & Associations of Towns and Municipalities, Slovakia.

Odum, E.P., 1971. *Fundamentals of Ecology*, 3rd edition. WB Saunders Publishers, Toronto, Canada.

Naiman, R.J., Décamps, H., 1990. The Ecology and Management of Aquatic-Terrestrial Ecotones, vol. 4. UNESCO Paris and the Parthenon Publishing Group.

Priyardarshana, T., Asaeda, T., Manatunge, J., Fujino, T., Gamage, N., 2004. Dynamics, Threats, Responses and Recovery of Riverine-Riparian Flora. In: Oceans and Aquatic Ecosystems, UNESCO's Encyclopaedia of Life Support Systems. EOLSS Publishers, Oxford, UK http://www.eolss.net

River Murray Mapping Task Force, 1995. River Murray Mapping: Geographic information System for coordinating River Murray planning, development and management. Murray Darling Basin Commission, Canberra.

Rossiter, D.G., 2003. Biophysical Models in Land Evaluation. In: Land Use and Land Cover section, UNESCO's Digital Encyclopaedia of Life Support Systems. EOLSS Publishers, Oxford, UK http://www.eolss.net

Ruddle, K., Zong, 1988. Integrated Agriculture-Aquaculture in South Chin. Cambridge University Press, Cambridge, UK.

Sveiby, K.-E., Skuthorpe, 2006. Treading Lightly: The Hidden Wisdom of the Worlds Oldest People. Allen & Unwin, Crows Nest, NSW, Australia.

Tane, H., Nanninga, P.,1992. Mapping and modelling the river murray for ecologically sustainable development, in mapping for a green future. In: Proceedings of the 1st Australian Conference on Mapping and Charting. Australian Institute of Cartographers, State Print, South Australia, pp. 44–54.

Tane, H., Dai Xingzhao, 1993. Catchment planning and conservation strategies in the Murray Darling Basin. Australian Journal of Soil and Water Conservation 6 (3), 35–39.

Tane, H.,1994. Ecography: Mapping and Modelling Ecosystem. In: River Murray Mapping: the Geographic information System for coordinating, planning, development and management of the River Murray. Ecography Section, Murray Darling Basin Commission, Canberra, pp. 1–9.

Tane, H.,1996. The Case for Integrated River Catchment Management. In: Keynote address to an international conference on river catchments, Scotland, 11–13

September 1996. Multiple Land Use and Catchment Management, Macauley Land Use Research Institute, Aberdeen, Scotland, pp. 5–9 (Chapter 1).

Tane, H., 2004a. Infrastructures and ecostructures: environmental planning for sustainable settlement. NZ Planning Quarterly 54 (September), 10–13.

Tane, H., 2004b. Waters of Aotearoa: Alive or Dead? NZ Planning Quarterly 54 (September), 9–13.

Tane, 2005. Ruataniwha and Long-Feng Iconography. Watershed Systems Foundation, Twizel, NZ (Manuscript presented as invited lectures to members of the Chinese Academy of Sciences in Xian, Taiyuan and Lushan (2005–06) and on Maori Marae, in Aotearoa Oceana; Web copy: www.watershed.net.nz/cardo/paper1/htm).

Tane, H., Wang, X.J., 2007. Participatory GiS for Sustainable Development Projects. In: Whigham, P. (Ed.), Proceedings of the Spatial Information Research Centre's 19th Colloquium, Does Space Matter. Department of Information Science, Otago University, Dunedin, pp. 1–12.

Tane, H., 2009. Habitat and Riparian Management in Rangeland Ecosystems. Rangeland and Animal Sciences, Food and Agriculture Volume; UNESCO's digital Encyclopaedia of Life Support Systems, EOLSS Publishers, Oxford, UK http://www.eolss.net

Walters, C.J., Holling, C.S., 1990. Large scale experiments and learning by doing. Ecology 71 (6), 2060–2064.

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