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Assessment of river health in the Gui River

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This report is the result of work undertaken as part of the River Health and Environmental Flow in China Project, that was funded under the Australia-China Environment Development Partnership, an Australian Government AusAID initiative.

This pilot study was also supported by the Chinese government via a grant under the Commonwealth Scientific Research Foundation (No. 201001021) and as a "948" project (N0. 201007).

Partners

Executive summary

This report describes a river health assessment undertaken in the Gui River catchment, located in the Pearl River Basin in China's south-east. The objective of the project was to establish a method for selecting suitable indicators of river health and to make an initial assessment of river health in the catchment.

Rivers provide a range of goods and services that communities depend on. River health assessments try to assess the ecological condition of rivers and their capacity to continue to provide these valuable goods and services. A science-based assessment can help identify rivers in poor health and the likely causes of the decline in their ecological condition. This information can be used to help prioritise government actions and funding aimed at improving river health. River health assessments can also be used to indicate the effectiveness of earlier management interventions. Reducing pollution to improve water quality and river health is currently a high priority for the Chinese government. Studies such as this one are intended to support these priorities by providing methods for better assessing and understanding the current ecological state of China's rivers and the different factors that are affecting them.

1.1 Methodology

Twenty-five sites across the Gui River catchment were sampled in April 2010 for water quality, benthic macroinvertebrates, fish, algae, and aquatic and riparian vegetation. For each of these indicator groups, a range of different indicators was assessed to determine whether indicator values changed in a predictable way with changes in levels of disturbance in the catchment and whether they were suitable for reflecting changes in river health.

To test indicators against levels of catchment disturbance, a primary 'disturbance gradient' was generated by assessing land use and land cover upstream of each sampling site. Potential indicators were assessed to see how they varied with changes in levels of disturbance. A secondary water quality disturbance gradient was also used to test the response of biological indicators. This process identified eight water quality indicators and 10 biological indicators as potentially suitable. A simple classification of the catchment based on stream order was used to differentiate between 1st, 2nd and 3rd+ order streams (principally highlands, midlands and lowlands). Reference values for some of the indicators were then determined for the three river classes.

Reference values are indicator values that are associated with 'good' or 'bad' river health scores. Different values are selected for different indicators and these may vary depending on river class. For the Gui River assessment, reference values were set based on existing Chinese standards (e.g. national water quality guidelines), data collected during fieldwork, and various international standards and studies. For each site, the results for each indicator were scaled to produce a score from 0–1, using the reference values for the appropriate river class as benchmarks. These scores were aggregated to produce scores for different indicator groups and sites. Based on these scores, each site was graded on a scale of river health from critical to excellent. In addition to this detailed technical report, a separate 'report card' was produced to summarise the study and its results in an easy-to-read format.

In addition to the more comprehensive river health assessment based on ecology and water quality, catchment hydrology was used to assess health of a subset of reaches in the main stem of the Gui River. Several methods were trialled, including two existing rapid methods for assessing hydrological alteration and a new method (the Index of Flow Deviation or IFD), developed as part of the project, which used monthly gauged data to assess health based on changes in eight flow parameters.

1.2 Results of the river health assessment

The results of the study suggest that the health of the Gui River is compromised in areas with intensive urban and agricultural development, but most sites were deemed to be in relatively good ecological condition. Water quality was generally found to be good, although there were clear trends towards increasing concentrations of nitrogen in agricultural and urban areas, as expected, because river health generally declines from the highlands to the lowlands.

The biological indicator groups suggested a poorer level of health than the water quality indicators. In particular, algae, invertebrates and fish indicators suggested some sites were in poor to critical condition. This difference may reflect that biological indicators integrate ecosystem condition and stress over time. The difference also highlights the importance of not relying solely on water quality to assess aquatic ecosystem health.

Values of the biological indicators varied depending on local- and catchment-scale land use practices, thought the results were not always consistent. Local land use refers to land use practices in adjacent riparian buffer strips, i.e. strips of land along each side of the river. With only a small sample size, it is difficult to draw firm conclusions about the relative influence of land use at these two scales. At the local scale, however, indicators of riparian condition did reflect the condition of riparian zones (e.g. width and degree of fragmentation). The condition of riparian zones will influence the in-stream river health scores, largely because it controls the degree the riparian zone buffers neighbouring land use.

Analysis of monthly hydrological data suggests that stream flow patterns have not been substantially affected by reservoir construction. However, anecdotal evidence suggests that low flows during the dry season have been an issue in recent years. More detailed studies could determine if these periods of extreme low flow are too short to be observed in monthly data and what their potential impacts may be. Local and river-scale effects were also evident from the assessment of physical form, primarily through longitudinal fragmentation and alteration of hydraulic habitats above and below hydroelectric dams.

While not well reflected in the limited data collected, longer-term declines in fish diversity throughout the catchment raise questions about factors relating to the health of fish assemblages. As well as potential water quality issues, the effects of barriers and fishing pressure warrant further consideration.

1.3 Recommendations

Robust conclusions on river condition can rarely be made on the basis of a single investigation. Values of river health indicators vary naturally in both space and time. Distinguishing natural variation from actual increases or decreases in river health is difficult, especially when limited data is available, which presents a challenge for river health assessments. Lack of data can also impede identification of suitable reference values. When a new river health assessment program is being developed and implemented, reference values are likely to include considerable uncertainty because little data is available in the early stages of investigation. As more data becomes available over time, understanding of local aquatic conditions will increase and reference values can be refined. As a result, the reliability of river health assessments will increase. Establishing a central repository of ecological data that is collected as part of river health assessments would provide an excellent basis for developing reference values that are appropriate for Chinese rivers.

However, the real benefit of a river health assessment system in guiding management actions will only be realised with further monitoring and an improved understanding of the basin's ecosystems. A mature monitoring program may provide more specific information on the state of the river basin and specific causes of poor health, allowing more targeted responses.

Further work is needed to refine the methods used during the pilot study to improve the quality of the results. This work should include confirming initial results and refining the set of recommended indicators by repeating some of the work. A larger data set that covers a longer period of time will provide greater confidence in the results. The existing water quality guidelines, including development of Chinese standards for total nitrogen (TN) in rivers and streams, and other river health reference values also need to be refined.

Care should be taken when using hydrological data to assess river health. Rapid desktop approaches that rely on basic indicators linked to a limited number of flow parameters are attractive. However, desk methods often are not closely correlated to the flow requirements of a river ecosystem and do not recognise the natural variation in flow pattern across different river types and the importance of a different flow components for river health. The IFD appears to be an ecologically relevant indicator of hydrological alteration. By not requiring huge amounts of data, it provides a suitable approach for use in river health assessments where the availability of hydrologic data is often limited.

A shift towards a routine monitoring program requires significant investment of time and resources to develop the necessary systems and human capacity. A considered approach to these issues is important to ensure the program will be effective and sustainable over the long-term. Ideally, the program should use an adaptive approach that integrates scientific knowledge and research, policy and management, and effective stakeholder engagement.

The results of the pilot study demonstrate a clear link between human disturbance and river health. The preliminary nature of the study makes it difficult to identify specific management responses to address poor river health in the catchment. It is reasonable to assume that river health will be improved by targeting urban and industrial pollution, improving land management practices, and revegetating riparian land.

Comparing the results for different indicators against various disturbance gradients identified a number of indicators that appear to respond to changes in catchment disturbance. These indicators are strong candidates for inclusion in a river health assessment program for the Gui River Basin.

The approach undertaken in this project is underpinned by the understanding that indicators should respond predictably to changes in the catchment and reflect changes in river health. However, it cannot automatically be assumed that indicators that are suitable for one river basin will necessarily be suitable in another location – different local conditions can affect the response and the suitability of different indicators. Indicators should ideally be tested for their responsiveness within different settings.

Reference values will also vary significantly between different rivers and regions within China. Water quality parameters can also show significant natural variation. Reference values will therefore need to be established for different river types. The development of a national river classification system may be of benefit in supporting this process.

Common objectives for national governments in developing national river health assessment programs is to be able to compare the relative health of different rivers, to help establish priorities for funding and to assess the success of restoration activities. Attempting to meet these objectives can result in pressure to adopt common indicators and reference values across a country. However, often, this is not a scientifically sound approach because the health of different types of river ecosystems (e.g. from tropical to arid zone environments) may be best assessed using different indicators.

It is possible, and arguably more relevant, to establish a common reporting framework, where the results for different indicators from different rivers can be compared against. If results are scaled in the same way – so that a ‘good’ score or a ‘poor’ score is equivalent – it should not matter if different indicators or indicator groups are used to calculate river health scores: the scores can still be compared with one another. As such, in implementing a national river health assessment program, a balance is needed between avoiding prescriptive guidelines on indicators and reference values, while at the same time ensuring that the methods for data collection and analysis are sufficiently consistent to allow results from different rivers and regions to be compared.

Contents

Acronyms

ACEDP	Australia–China Environment Development Partnership
AusAID	Australian Agency for International Development
BI	Biotic Index
CLC	Corine Land Cover
CSR	Catchment Sediment Risk sub-indicator
DEM	Digital Elevation Model
DO	Dissolved Oxygen
EHMP	Ecosystem Health Monitoring Program
EPT	Ephemeroptera, Plecoptera and Trichoptera
FARWH	(Australian) Framework for the Assessment of River and Wetland Health
FFI	Free-flow Interruption Sub-indicator
HFV	High-Flow Volume
HMF	Highest Monthly Flow
IBD	Biological Diatom Index
IFD	Index of Flow Deviation
IPS	Specific Pollution Sensitivity Index
LoCB	Longitudinal-continuity barrier sub-indicator
LFV	Low-Flow Volume
LMF	Lowest Monthly Flow
LULC	Land Use and Land Cover
PCA	Principle Components Analysis
PFS	Physical Form Stressor Index
PHF	Persistently Higher Flow
PLF	Persistently Lower Flow
PRWRPB	Pearl River Water Resources Protection Bureau
PVL	Persistently Very Low
RMB	Renminbi
SFS	Seasonality Flow Shift
STI	Sediment Transport Interruption sub-indicator
TDS	Total Dissolved Solids
TN	Total Nitrogen
TP	Total Phosphorous
WQ	Water quality
YRCC	Yellow River Conservancy Commission

Key concepts

River health: A 'healthy' river is one that has retained its biodiversity and ecosystem integrity. The health of a river depends on its ability to maintain its structure and function; to recover after disturbance; to support local biota (including human communities) and to maintain key processes like sediment transport, nutrient cycling and energy exchange. River health incorporates both ecological and human values.

River health assessment: A river health assessment is the process of comparing the condition of a river's ecosystem to a set of reference values that are based on river health. The results of river health assessments are used to identify rivers in poor health, to identify causes of poor river health, to help prioritise river restoration and management interventions and to evaluate the effectiveness of management actions.

River health indicators: Indicators of river health can be physical, chemical or biological measures that respond in a positive or negative way to a given level of disturbance or pressure and, therefore, are assumed to reflect changes in river health. There are many possible indicators that can be used to assess the health of a river. In this report, **'indicator group'** refers to a collection of indicators that relate to a particular aspect of the river ecosystem: indicator groups considered in the project included water quality, macroinvertebrates, diatoms, fish, riparian and in-stream vegetation and hydrology. Indicators represent quantitative descriptors of each indicator group. For example, fish species richness was used to represent 'fish'. The selection of appropriate indicators that are sensitive to the threats, disturbances or management actions being monitored is critical to the success of a river health monitoring program.

Disturbance gradient: A disturbance gradient is a range (from low to high) of human impact or pressure (for example the percentage of cleared riparian vegetation or urban development) used to assess the response of potential indicators. A disturbance gradient is often used to derive indicator reference values for river health scores where undisturbed reference sites are not available.

Reference value: A reference value is value or guideline derived for each river health indicator based on a given benchmark (reference condition) or level of disturbance. For example, a given reference condition for a healthy river ecosystem may be based on a system that has been minimally disturbed by human activity.

Report card: Report cards are a way of communicating the results of a river health assessment in an easy-to-read format. They are designed to be easily understood and interpreted by all stakeholders, including the general public.

Team structure

The pilot study has been undertaken by a team of Chinese experts from the Pearl River Water Resources Protection Bureau together with Australian experts under the banner of the International WaterCentre and experts from a number of Universities and Research Organisations in China.

Chinese Pearl River pilot project team

Advisor	Position
Wu Yadi	Vice Director, Pearl River Water Resources Protection Bureau
Liu Xin Yuan	General Engineer, General Engineer of Pearl river water resources protection Bureau
Liu Wei	Senior Engineer, Pearl River Water Resources Monitoring Centre
Wen Pin	General Engineer, Pearl River Water Resources Protection Scientific Research Institute
Li Xue Ling	Director, Pearl River Water Resources Protection Scientific Research Institute
Wu Shiliang	Vice-Director, Pearl River Water Resources Protection Scientific Research Institute
Weng Shichuang	Engineer, Pearl River Water Resources Protection Scientific Research Institute

Australian project team

Advisor	Role
Nick Bond, Griffith University	Pilot study leader, River health expert
Robert Speed, Independent consultant	Project director
Stuart Bunn, Griffith University	Technical director
Chris Gippel, Fluvial Systems Pty Ltd	River health expert, hydrology and physical form
Catherine Leigh, Griffith University	River health expert
Peter Hanington, University of Queensland	River health expert
Jane Catford, University of Melbourne	River health expert, aquatic and riparian vegetation
Paul Close, University of Western Australia	River health expert, aquatic fauna
Dajun Shen, IWHR	Water resources management specialist
Fiona Chandler, International WaterCentre	Project manager; communications and capacity building
Todd Zeng, International WaterCentre	Logistics and administration
Kate Hodge, Hodge Environmental	Report card design

Project supervisory and support team

Advisor	Position/Organisation
Shi Qiuchi	Division Chief, Division of Water Resources Protection, Chinese Ministry of Water Resources
Zhu Jiang	Deputy-Director, International Economic & Technical Cooperation and Exchange Center, Chinese Ministry of Water Resources
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Committee member	Organisation
Liu Zhiguang	Deputy Director General, Department of International Cooperation, Science and Technology, Chinese Ministry of Water Resources
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Tanja Cvijanovic	Australian Department of Sustainability, Environment, Water, Population and Communities
Martin Cosier	Australian Agency for International Development
Gunther Mau	Australia–China Environment Development Partnership

1. Introduction

1.1 The importance of river health

River health is a concept that incorporates both ecological and human values. The health of a river depends on its ability to maintain its structure and function, to recover after disturbance, to support local biota (including human communities), and to maintain key processes, such as sediment transport, nutrient cycling, assimilation of waste products, and energy exchange. In broad terms, a healthy river is one that can sustain its ecological integrity.

River health is important. Healthy rivers provide water for drinking, for agriculture and for industry; fish and other produce for consumption; buffers against flooding; electricity generation; and transport and recreational opportunities. As rivers become unhealthy, they lose their capacity to provide these valuable goods and services.

Maintaining and improving river health requires an accurate assessment of the current ecological state of river ecosystems. Ideally, this process should involve monitoring and assessment that can:

- identify rivers that are in poor health, or at risk of poor health
- identify the likely causes of poor health, such as sources of pollution
- help prioritise funding for river restoration, including catchments that are most in need, and guide effective and efficient management actions
- assess the effectiveness of management actions, which can be particularly important where there is significant investment of public funds in improving river health
- allow for reporting on river health, to improve awareness within both government and the broader community of the current condition of a waterway

River health monitoring can involve consideration of all elements of a river ecosystem that respond at different spatial and temporal scales. These elements include water quality, the structure, abundance and condition of aquatic flora and fauna; hydrology; levels of catchment disturbance; and the physical form of the channel system. Importantly, no single variable can indicate ecological condition unequivocally and a suite of complementary variables is typically required to provide an accurate picture of river health. Over time, water quality monitoring programs alone may prove to be inadequate in providing a thorough understanding of the condition of a river.

In recognition of the importance of healthy waterways, the Chinese government has committed to programs that will involve the investment of billions of dollars over the coming decades to reduce pollution and to improve water quality and overall river health. A comprehensive program for river health monitoring and assessment has the potential to provide valuable guidance to these investments through identifying priority regions for intervention, establishing effective and efficient management actions and strategies and, by allowing for ongoing evaluation of the effectiveness of management, including pollution abatement and river rehabilitation actions.

The need for such a river health monitoring and assessment program is recognised in the ongoing efforts by various Chinese ministries and their agencies to improve the scope, quality and utility of information that is currently collected about river health. This report forms part of a project designed to contribute to that goal.

1.2 Background to the project

This report documents a pilot study (the Gui River pilot project) undertaken as part of the River Health and Environment Flow in China Project (the project). The project is one of a number of projects being completed under the ACEDP, an initiative of the Australian and Chinese governments, and funded through the AusAID. This pilot study was also supported by the Chinese government through grants under the Commonwealth Scientific Research Foundation (No. 201001021) and under a ‘948’ project (N0. 201007).

The project’s objective is to strengthen China’s approaches to improving river conditions through developing and applying advanced methods for monitoring river health, estimating environmental flows and translating that to policy approaches. The broader aim of the project is to develop a consistent national approach to river health assessment. The project involved trialling international approaches to river health and environmental flow assessment as part of the three pilot studies conducted in the Pearl, Liao and Yellow River Basins.

River health assessments were undertaken in all of the three pilot basins. The assessment methodologies applied in the three studies were similar, but not identical. The assessments analysed and interpreted newly collected and existing data sources relevant to the ecological health of the pilot sites. Based on the results of this work, the project was able to comment on the current health of the pilot rivers, and make recommendations for future monitoring programs and other management actions. The final stage of the project will involve making recommendations about the options for developing and implementing a river health monitoring program for wider use in China, based on the results of the three pilot studies.

This report focuses on the work in the Pearl River Basin, undertaken in the Gui River sub-catchment over the period from February 2010 to April 2011. This report is the final report for the pilot project. It is one of a number of project reports related to the pilot study. Other relevant project reports that provide context and background to this report, include:

- *Technical Report 1: River Health Monitoring, Assessment and Applications* (Gippel 2010). This report documents approaches to river health monitoring and assessment and outlines the key steps and issues involved in developing a river health-monitoring program.
- *Report on data and information on River Health in the Pearl River Basin (Gui Catchment)* (PRWRPB 2010). This report includes detailed background information for the Gui River pilot project.
- *River Health Assessment in China: development and comparison of indicators of hydrological health* (Gippel et al. 2011a). This report summarises various approaches to assessing hydrological alteration. Elements of that report are included in this (current) report in summary form.
- *River health assessment in China: development of physical form indicators* (Gippel et al. 2011b). This report describes options for using channel form as an indicator of river health and elements are summarised in this (current) report document. [1]

1.3 Objectives of the Pearl River pilot project

The objectives of the Pearl River pilot project were to:

- develop and demonstrate a method for assessing river health, suitable for Chinese conditions
- assess the ecological condition of the Gui River catchment
- comment on the factors likely to be influencing river health and suitable policy responses
- demonstrate the use of a river health report card format to summarise rivers' ecological condition and convey that information in a clear and simple way
- assess the suitability of the assessment methodology for application in China
- make recommendations on the development of a river health-monitoring program for wider application within China.

Experience internationally shows that the process of developing a river health-monitoring program can take up to a decade and cost tens of millions of dollars. The work undertaken in this study is a small, preliminary, and important step in that process.

Making robust conclusions on river condition on the basis of an initial investigation is challenging. River health assessments make inferences about river health based on what might be expected of a healthy river – such as the number of fish or macroinvertebrates, or the values of water quality parameters. The natural variation (in time and space) of these river health indicators represents an important constraint on river health assessments, especially when the assessments are based on preliminary data sets, or on data sets with limited spatial and temporal resolution. Establishing suitable reference values is difficult when first implementing a monitoring program. Reference values typically need to be adapted from other regions. Refining them to accurately reflect the local conditions generally depends on the accumulation of additional data and an understanding of how they naturally vary. As a result, setting initial reference values for river health indicators is inherently difficult, and in the early stages of investigation, reference values are likely to include a level of uncertainty.

Therefore, the focus of this study, and its most significant outcome, was to establish a method for identifying suitable river health indicators and applying them, as well as starting the process of building a base of knowledge of the ecosystems in the region. The conclusions about the actual health of the river and recommended management responses that are made in this report are based on a limited, preliminary assessment, and the limitations of the study should be carefully considered when these results are relied upon. Over time, the outcomes of future river health assessments will improve as larger data sets become available, the local aquatic conditions are better understood, and as reference values are refined.

1.4 Overview of the methodology and rationale

A major goal of river health monitoring is to assess the current condition of an aquatic ecosystem so it can be maintained or returned to an acceptable level of health. Assessing the condition of aquatic ecosystems typically involves developing health assessment indicators that reflect anthropogenic impacts. These indicators can then be used to set minimum targets, which, if not met, are indicative of the need for some form of management action. While river

1 These and other project reports are available at www.watercentre.org

health monitoring programs are somewhat unique to particular regions, based on local taxonomic and environmental characteristics, most have been developed around a similar conceptual foundation (see Gippel 2010), which involves identifying of a suite of indicators that describe the physical and biotic environment in ways that show a predictable response to anthropogenic drivers such as agricultural development and urbanisation.

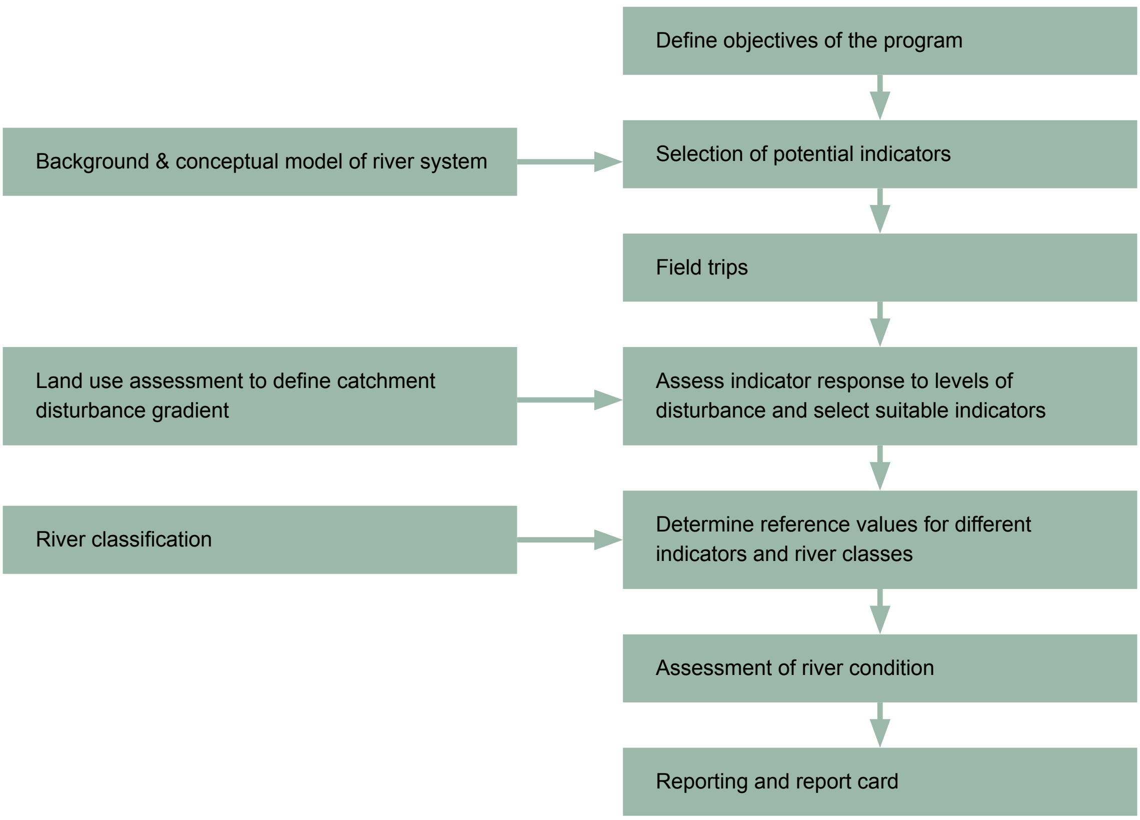
Indicators are typically used to assess river condition by making comparisons against a reference condition. The reference condition is often the value an indicator is expected to have in the absence of any form of human disturbance. By comparing scores for different rivers against a reference condition, it is possible to rank locations by their overall health. These rankings, together with a specified minimum acceptable level of health, can be used to guide and prioritise investment to improve river health.

The Gui River Pilot Project trialled approaches to river health monitoring and assessment, including testing of indicators of ecosystem health against a disturbance gradient. This pilot project involved both desktop and field study components, drawing on prior experience from within the project team, together with specific information provided in a background report compiled before the field program started (PRWRPB 2010).

In general, these components were based on the successful and well-documented approach of the freshwater ecosystem health monitoring program (EHMP) in South East Queensland, Australia (Bunn et al. 2010). The approach used in South East Queensland focuses on using conceptual models and objectives, and quantitative testing of potential indicators against a known disturbance gradient. The approach involves eight distinct steps, which were applied in the pilot study, and were also used to structure this report. The following section provides a brief conceptual overview of each step and describes the actual work program.

The approach taken in the pilot project was designed to identify suitable indicators and reference values to incorporate into a routine monitoring program. When a monitoring program is established, these steps should not need to be repeated annually. However, elements of the program, particularly reference values, should be regularly reviewed and refined as part of a cycle of adaptive management.

Figure 1. Steps in developing an ecosystem health monitoring and assessment program.



1.5 Key steps in developing a monitoring program

1.5.1 Step 1: Defining objectives of the program

Objectives of river health monitoring programs can vary from place to place, based on the types of human disturbances impacting on the river, and also based on the values and uses for the river system. While most river health monitoring programs share the objective of assessing if rivers are at an acceptable level of health, in some regions the focus can be on measuring impacts of particular threats, such as hydrologic alteration and water use or pollution. A monitoring program can also focus on particular assets or values of importance, such as highly valued or iconic species or sites.

In many instances, a common set of indicators that are capable of assessing a range of threats to different aspects of river health (e.g. water quality, fish communities etc.) will be widely monitored. This range of indicators can also be supported by additional indicators for more targeted monitoring.

River health monitoring can also assess the outcomes of management interventions aimed at improving river health (Gippel 2010). Experience suggests that the impacts of local management interventions are not always detected by routine assessment programs. Therefore, more intensive monitoring, such as with additional indicators or additional sampling sites, is often justified. More intensive monitoring is particularly justified where interventions are costly or can be refined over time based on further monitoring results (e.g. environmental flow releases).

1.5.2 Step 2: Develop conceptual models linking a range of drivers to potential impacts

Conceptual models are important for developing a river health monitoring and assessment program because they can be demonstrate how human disturbances are likely to affect river health. Conceptual models also help to identify, and provide a clear understanding of, the processes that help maintain healthy ecosystems, and how these processes might change as ecosystem health declines. Therefore, conceptual models can help determine the aspects of river health that should be monitored, which helps to guide indicator selection and interpretation. Developing conceptual models can also help to identify any areas of disagreement the importance of processes and identify any major gaps in knowledge. Finally, conceptual models are valuable communication tools. Graphical conceptual models are particularly helpful for communicating with a non-technical audience. Graphical conceptual models were developed for this pilot study and incorporated into the river health report card that summarises the results of the assessment for a non-technical and semi-technical audience.

1.5.3 Step 3: Selection of appropriate indicators

Indicators are central to river health assessments. Indicators are variables that provide a concise measure of the condition of different aspects of river health. In most river health assessment programs, a suite of indicators are used to characterise different aspects of the ecosystem (for example water quality, fish, plants), and are tied to different parts of the system that are important or at risk from disturbance identified in step 2.

A large number of indicators have been used in river health monitoring programs around the world. For this pilot project, the selected indicators related to key elements of the river's ecosystem, including water quality, macroinvertebrates, diatoms, fish, riparian and in-stream vegetation and hydrology. This report refers to these elements as 'indicator groups'.

Indicators are quantitative descriptors of each indicator group. For example, fish species richness was used to represent 'fish', and 'hydrology' was quantitatively measured using eight separate indicators describing different components of the river flow regime. Selecting appropriate indicators that are sensitive to the threats, disturbances or management actions is critical to the success of river health monitoring programs.

1.5.4 Step 4: Conduct a trial sampling program and refine the selected indicators

Perhaps the most critical step in the developing a river health assessment process is testing the sensitivity of indicators to relevant disturbance gradients. This assessment can be based on existing data sets if they are available, or the assessment may require additional field collection of data. In general, the aim of this step is to identify a suite of indicators associated with each indicator group that respond in a predictable way to stressors, such as an environmental disturbance gradient.

Data sets appropriate for testing the sensitivity of indicators should include a variety of information relevant to potential stressors or disturbances in the study area. Describing the disturbance gradients is likely to rely on a variety of available data sets, which may include:

- land use information (using remote sensing or aerial photography and GIS) to quantify catchment disturbance
- water resource use information to quantify a flow disturbance gradient
- point source pollution (for example from industrial sources) to properly capture stressor gradients.

After disturbance gradient is described, data on potential indicators is required across the range of disturbance to assess the sensitivity of the indicator to the change in disturbance. This assessment can be based on existing data, or on field collection of new data; however, it is important that the data reflects a consistent sampling methodology. Appropriate timing of collection should also be considered. Sites should be sampled over the same period and sampling techniques among sites should be consistent.

The data is then analysed to select indicators that respond in a predictable way to the specific measures of disturbance. Indicators may respond to a disturbance gradient in many ways: in a linear or curvilinear way, showing no response; or in a random, non-predictable way. Generally, only those indicators that respond in a predictable way should be considered for inclusion in a river health monitoring and assessment program. Indicators that are too variable or show no clear trend along the disturbance gradient are generally rejected. Some indicators may respond in a similar way to others, so including them may provide little additional information. Redundant indicators can be discarded to reduce costs.

A range of approaches can be used to considering the response of indicators to disturbance gradients. In many cases, there may be multiple disturbance gradients (e.g. land use alteration, water extraction, pollution), making analysis more complicated. Four possible approaches for considering how indicators respond to disturbance gradients include:

- simple linear regression models
- non-linear regression approaches
- data reduction approaches to reduce complex gradients into simple metrics (e.g. via principal components analysis (PCA))
- more complex modelling approaches (e.g. multiple regression)

Multiple regression modelling is often chosen because it can identify which disturbance gradients account for the variability in each of the indicators; the scale at which the disturbance gradient is acting (e.g. whole of catchment); and quantify the proportion of variation for by each disturbance measure and then model the disturbances as a whole. The simplest multiple regression model is often a simple linear regression (e.g. see Smith and Storey 2001).

1.5.5 Step 5: River classification to identify homogenous 'river types'

Classifying similar types of rivers together is an important step in river health assessment and river management more generally. River classification ensures that comparisons are only made between similar types of systems. Classification helps to set thresholds for determining what is 'good' river health and what is not.

Recognise the differences in river types is important when developing a monitoring program because:

- different types of rivers (and other freshwaters) will not look and behave the same even when they are healthy
- the types of indicators that might be appropriate in one type of river may not be appropriate for another
- the methods used to sample in one type may not be possible or relevant in another
- even where the same indicator can be used in different river types, the thresholds or targets are likely to differ.

1.5.6 Step 6: Select suitable reference values for ecological indicators

When the list of indicators of ecosystem health has been chosen, a scoring system must be devised to assess ecosystem health. There are several aspects to developing this scoring system: determining reference values, determining scores to reflect varying levels of health, and standardising across indicators so they can be combined for an overall measure of health. Standardising across indicators is generally straightforward. However, developing different score for individual indicators is quite challenging.

The traditional approach to setting reference values relies on reference sites, which are free of anthropogenic disturbances, to guide setting values for target indicators. However, these sites often do not exist, and this approach cannot indicate what the minimum values should be before concerns are expressed about the health of a river. A range of approaches has been developed in the literature to assist in setting suitable scoring systems. Options for scoring are discussed in Section 9.

1.5.7 Step 7: Assess river health and report and communicate results

Despite its technical nature, it is important that the findings on river health assessment can be communicated simply and effectively to different groups, including government officials with different levels of technical training, other scientists, and also the wider community who often have an interest in the health of the rivers they live around. Effectively communicating to diverse groups may require several different reporting techniques. Typically, a detailed technical report describing the details of the methods and results of a river health assessment is prepared, together with a simple, non-technical summary report. The detailed technical report ensures that consistent approaches are adopted in different locations, and that future assessments can follow the same procedures and approaches to site selection, classification and sampling, even if a different group of technical experts undertake or oversee the work.

For communicating with a wider audience, an example of a simple report card was prepared as part of the pilot project. These simple reports rely on aggregating scores for different indicators, sites and regions to give a single measure of health. In aggregating scores for a single site or region, a number of different approaches can be taken. Approaches include averaging scores, or giving the same importance to each indicator, or weighting scores, giving one indicator a greater value in calculating the overall site score because of the importance of the indicator, or because it is a more accurate measure of health.

1.5.8 Step 8: Implement management actions and address priority areas or threats

While one use of river health monitoring programs is to simply audit and report on the condition of ecosystems, the results can also guide investment in river health improvement. Decisions about whether to invest in management actions, and if so, which ones and where, are not strictly scientific. Rather, investment decisions are guided by the desired state of the river based on the intended uses. For example, in areas where rivers provide water for human consumption, a strong focus may be directed towards ensuring water quality is sufficient to protect human health, although it is also important to recognise that humans depend on healthy rivers in complex ways – not just in terms of water quality (see section 1.1).

There are also different ways to prioritise investments to improve river health. For example, investment may be directed toward the worst sites to ensure that all rivers achieve a minimum standard of overall condition. In other cases, funds may be focused on conserving the highest value (best) river reaches to ensure they do not decline in condition in the future. These decisions all reflect the types of values placed on rivers, and the condition or level of health required to achieve those objectives.

2. Background on the pilot study region

2.1 Overview of the region

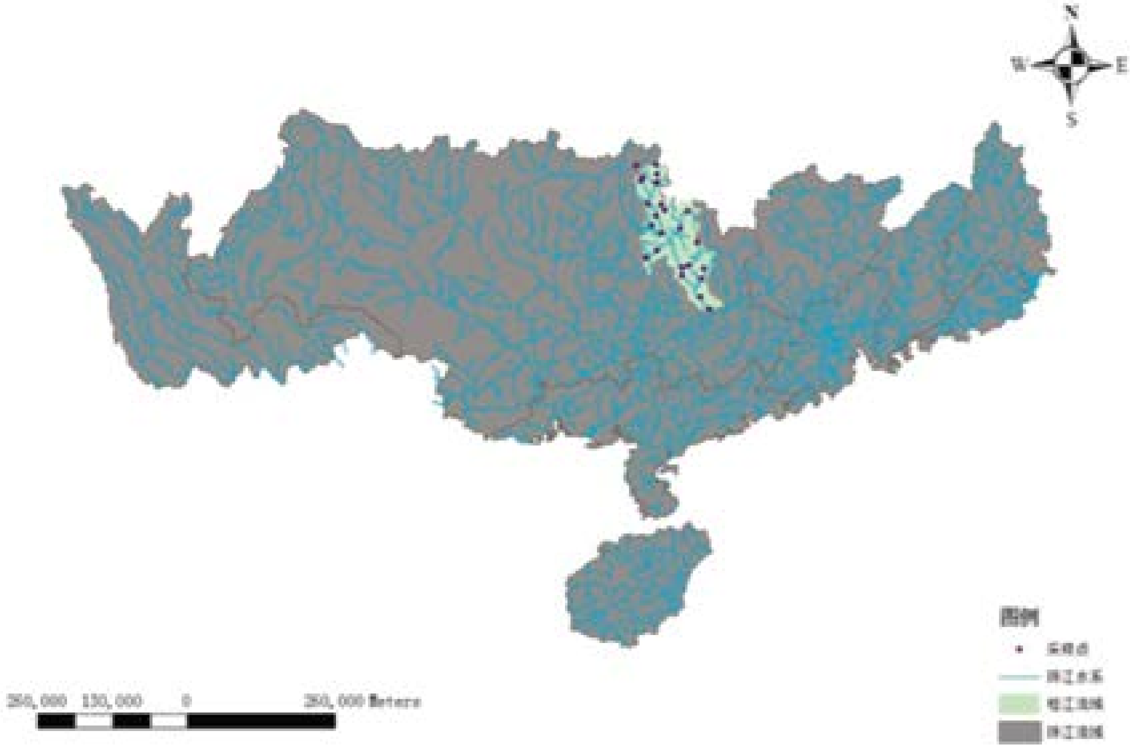
The Pearl River Basin is located in in southern China and crosses five provinces – Guangdong, Guangxi, Yunnan, Guizhou, Jiangxi – as well as northeast Vietnam (Figure 2). The basin has a total area of approximately 400,000km^2 and consists of three main tributaries, the Xi Jiang (West River), the Bei Jiang (North River), and the Dong Jiang (East River). The river is about 2,200 km long from the start of the Xi Jiang to the delta, making it China's third longest river in length, and the second largest by volume with an average discharge of 9500 m^3/s.

Figure 2. Map showing the location of the Pearl River Basin, which extends inland from the south-east coastline.

2.2 Gui River

The pilot project work in the Pearl River was conducted on the Gui River (Gui Jiang), a northern tributary of the Pearl River with a drainage area of approximately 18,790 km^2 (Figure 3). Although small compared to other tributaries of the Pearl River, the river drains a unique karst landscape and is a famous tourist destination. A detailed background document (PRWRPB 2010) has been compiled on the Gui River Basin, describing its physical, chemical, biological, social and economic attributes. Key aspects of the region described in the background report are detailed below, along with new information on hydrology, physical form and vegetation in the region.

Figure 3. Map of the Pearl River Basin showing the location of the Gui River Pilot sub-catchment.



The Gui River originates from the south of Laoshanjie in the east slope of Mao'er Mountain in Huajiang village, Xing'an County, Guangxi Zhuang Autonomous Region, and flows into the Lingqu Canal in the township of Darongjiang. In these upper reaches, the river is known as the Li Jiang. According to historical records, the Lingqu Canal was dug in 219 BC with an overall length of 34 kilometres, to divert water from the Xiang Jiang into Li Jiang (whose name literally means diverting away some of the water of Xiang River). The Li River flows through a number of cities and counties – Guilin, Yangshuo and Pingle – and then flows into Gongcheng River and becomes the Gui River. After flowing through Zhaoping and Cangwu, it merges with Xun River into the Xi River in Wuzhou City (Figure 4).

Figure 4. Figure showing LANDSAT image of the Gui catchment highlighting the river network and major (dots) and minor (stars) towns.

2.2.1 Climate and Hydrology of the Gui catchment

The Gui River Basin has a subtropical monsoon climate, with abundant but spatially and seasonally variable rainfall across the basin, ranging from an annual average of 2000~2400 mm to the north, to an average of 1500~1600 mm in the mid to lower reaches. Rainfall during the wet season (March–August) accounts for more than 75 per cent of the yearly rainfall, with less than 25 per cent occurring during the dry season (September–February).

In the upper most parts of the catchment there is occasional snow during winter. Temperatures however are generally high, with an average annual temperature of 18.8 °C, a maximum monthly average of 28 °C (July) and minimum of 7.9 °C (January). Daily temperatures range between -5.1–38.5 °C. In the lower reaches the average temperature is about 19.7 °C, with the highest average month temperature of 28.8 °C in July, the lowest of about 9.2 °C in January, and extremes ranging between -4.1–40.0 °C.

The humidity in the Gui River Basin is also high, averaging between 70–80 per cent during the wet season and 6–13 per cent in the dry season. Potential evaporation ranges from 1592 mm to the north to 1078 mm. The Gui River Basin has high annual runoff (MAF~ 597 m^3/s), but high seasonal variation, with more than 80 per cent of runoff occurring from March–August. Large floods can occur with the biggest flood in the Gui River occurring in 1908 with the peak discharge of 20,000 m^3/s at the Ma River hydrometric station.

2.2.2 Geology

The catchment of the Gui River includes large areas of limestone, which give rise to a unique Karst landscape. In the upper catchment substrates include, laterite, latosolic red soil, red earth, yellow-brown soils. Altitude ranges from roughly 2000 m in the north to 50 m above see level in the south, although mountainous areas extend along the eastern and western edges of the catchment also (Figure 5). In lowland and terraced areas aeolian sandy soil, marine solonchak and paddy soils are more common. The sediment concentration of Gui River is low with the annual average of only 0.134 kg/m^3, although during the flood season it can be up to 0.315 kg/m^3, with a total annual sediment discharge of 2.65 million tons. Below Pingle, most of the Gui River Basin is arenaceous rocks while limestone dominates Li River sections.

2.2.3 Riparian and aquatic vegetation

The catchment of the Gui River is still heavily forested, with most areas being covered by green broad-leaved forest. Some coniferous forest also occurs in some parts of the catchment (Figure 5). The mountainous nature of the catchment, and high aesthetic values, has also meant that much of the native forest cover is still protected. Compared to many other rivers in China, and elsewhere in the world, the Gui catchment still has a very high level of cover of native forest. This has presumably increased since the 1990s when a reafforestation program began. Anecdotally, while the upland vegetation is largely protected, there has been a substantial loss of floodplain wetlands in sections of the Li River floodplain due to agricultural development (Liu Wei, pers. comm.). There is also some concern relating to the effects on riparian vegetation from changes in river flows to maintain navigation for tourist boats on Li River during the dry season (Ye et al. 2010).

Figure 5. Digital Elevation Model for the Gui River Basin showing elevation above sea level in meters.

Note: Sampling sites are also marked, including one site, which fell outside the Gui Catchment.

2.2.4 Population and land use

The total population within the Gui River basin in 2008 was about 5,072,700, with 3,247,000 people located in rural areas. Of the ~18,700 km² total catchment area, most is still covered in natural vegetation; ~48 per cent forest and 36 per cent grassland. Modified land includes around 13 per cent agricultural land (~2,285 km²), and of this, approximately 1700 km² is irrigated. Less than 1 per cent of the catchment is urbanised (Figure 6).

Figure 6. Land use and land cover map of Gui River.

2.3 Key ecological assets and values

Environmental assets in the Gui River basin include tracts of land and natural vegetation that are protected as a source of drinking water, nature reserves, water conservation forest reserves, wetland protected areas and river based tourism (sightseeing). Rivers are also a very important source of protein for many locals living within the catchment, and maintaining healthy fish populations, and the environmental conditions they depend on, are critical aspects of river health from a social perspective. More information on the ecological and social values of the Gui River catchment is provided in the background report (PRWRC 2010). The basin does not include any specific areas of international importance, such as Ramsar-listed wetlands.

2.4 Threats

2.4.1 Pollutants (including sewage)

There are only low levels of industrial development in the Gui River Basin. A survey conducted in 2005 by the Pearl River Water Resources Protection Bureau found a total of 95 industrial and mixed sewage outlets (PRWRPB 2010). The main sources of water pollution are non-point source sewage discharge and agricultural and urban runoff. Most of the larger towns now have sewage treatment plants in operation. Specifically, there are four such plants in operation in Guilin and one in Wuzhou. The middle reach of the Gui River still has no sewage treatment plants, although Zhaoping was due to have a treatment plant completed in June 2010. While sewage treatment plants are now in operation in many of the larger towns and cities, there are also many localised sources of sewage discharge from smaller villages and settlements that will continue to have an impact on both the tributaries and main channel of the Gui River. Sampling sites were intentionally selected to make sure these smaller streams were included because the cumulative impacts from small discharge sources are easily overlooked, but can be significant.

2.4.2 Sand and gravel extraction

Over 30 gravel extraction plants along the Li River have been closed down in recent years, although 52 plants are still granted gravel extraction rights along 6 rivers, including the Gui River in Pingle County, the Xiang River across Quanzhou County and Xi'an County and the Zi River in Ziyuan County. Administration regulations and planning of river sand extraction have been developed in most cities and counties, which clearly identifies river course and areas available for sand extraction, as well as areas prohibited for extraction. As well as extraction of gravel for building requirements, illegal dredging for gold is also a common activity, with a recent *China Daily* report suggesting that over 400 illegal boats are active in the Gui River catchment, mainly located in Zhaoping and Cangwu reaches.

2.4.3 Invasive animal and plant species

The most notable invasive alien species in the Gui River include Apple Snail (*Pomacea a*), Red-eared Sliders (*Trachemys scripta*), which are a type of turtle, and Canadian Goldenrod (*Salidago canadensis*), which is a highly invasive plant. Apple Snails and Red-eared Sliders were introduced to Guilin as food, but they have since been thought to have caused some ecological damage, although this is not well documented. Native to North America, Canadian Goldenrod was introduced to Shanghai as an ornamental plant in 1935 (Dong et al. 2006). It has since escaped into natural environments and has spread rapidly. Canadian Goldenrod is especially abundant in eastern China where it outcompetes native plants and has altered ecosystem function (Dong et al. 2006). In addition to terrestrial invasive plants like Canadian Goldenrod, there are at least two free-floating invasive plant species in the Gui River, both of which are native to South America. Water hyacinth (*Eichhornia crassipes*) is listed as alien and invasive in China (Chu et al. 2006), and water lettuce (*Pistia stratioides*) is also invasive, though its native/alien status in China is unknown (http://www.issg.org). These species have the potential to form dense mats across the surface of water, blocking out light and creating habitat suitable for mosquito breeding – a problem for human health. This is particularly likely in the warmer, sunnier months and in rivers that have high nutrient loads.

2.4.4 Lack of environmental flows below storages

The Gui River catchment includes three large cities: Guilin, Hezhou and Wuzhou These cities extract water from the river for a variety of uses. In 2008, water abstraction from the river totalled 4.026 billion m^3, among which Guilin extracted 2.274 billion m^3, Wuzhou extracted 167 million m^3 and Hezhou extracted 1.585 billion m^3.

There are a number of large storages in the Gui River Basin, including Qingshitan Reservoir, Fuzi Mouth Reservoir, Xiaorong River Reservoir and the Chuan River Reservoir, which focus on replenishing water in the Li River during the dry season, on flood prevention during the wet season, as well as localised power generation.

Despite high annual runoff totals, high seasonality in rainfall leads to a large gap between the runoff amounts in the flood season and the dry season. Lasting from September to February in the following year, the dry season only accounts for 18.9 per cent of the annual runoff. The actual measured average of lowest runoff months is only 5.9 m^3/s, 4.5 per cent of the average annual runoff. Insufficient adjustment capacity of upper-reach water storage projects means that during dry season, serious water shortage problems occur. Noted impacts of this water shortage include periodic drying of the Li River, decreasing water quality, and the loss of navigation for tourism operators.

2.4.5 Fishing pressure and river fragmentation

Large numbers of fish are stocked annually into the Gui River (400,000–600,000), but there are no direct fish passage facilities on existing hydroelectric dams, limiting the ability for fish to disperse up and down stream. This has almost certainly caused the loss of migratory species from the Gui River. There is also substantial fishing pressure in these rivers, primarily subsistence fishing in the upper reaches. In the broader Pearl River Basin, the impacts of overexploitation of fish stocks on fish population viability is increasingly recognised, and there are extended fishing bans put in place each year during the spawning season. While overfishing may not appear to reflect an ecosystem in poor health, it can lead to declines in health if not carefully managed, and indicators of fish population health are therefore a valuable inclusion in river health assessment.

3. Pilot study methodology

3.1 Overview

The Gui River pilot study was conducted to trial approaches to river health monitoring and assessment, including the testing of indicators of ecosystem health against a disturbance gradient. The study generally followed the steps outlined in Section 1.5. This study relies largely on data from fieldwork conducted in April 2010. Data from that work was used to test a number of potential indicators (physical, chemical and biological) by assessing their suitability and sensitivity to measured disturbance gradients.

Field surveys were distributed across three river regions in the basin. All measures and collection of samples (that were later used as indicators or to calculate indicators) were completed within a short time span so that temporal variability in environmental conditions was relatively controlled. For the purposes of this report, indicators were then analysed against the disturbance gradients and indicators were primarily selected based on their sensitivity (i.e. response to the disturbance gradients) (Bunn et al. 2010).

A broad suite of indicators were calculated and tested. The use of multiple indicators that represent all aspects of river ecosystems (physical, chemical and biological) follows successful and well-documented river health monitoring programs elsewhere (see Flotemersch et al. 2006; Bunn et al. 2010). Surface-water-quality indicators included physical and chemical parameters (e.g. electrical conductivity and measures of oxygen demand) and nutrients (e.g. total nitrogen concentration). Four major groups of biological indicators were also tested: benthic algae, benthic macroinvertebrates, fish and riparian vegetation, and included both single indicators (e.g. biotic abundances) and multi-metric indicators (e.g. indices of biotic integrity). This approach is also considered to be a holistic method of river health monitoring and assessment (Gippel 2010a).

This chapter describes the objectives of the monitoring program (step 1, see section 1.5.1). Steps 2–6 (sections 1.5.2–1.5.6) are then described, detailing the conceptual models for the study region, the river classification method, the indicators considered and trialled in this pilot study, the disturbance gradients used and the methods of data analysis. Steps 7 and 8 (sections 1.5.7 and 1.5.8) are discussed in more detail in Chapter 6. Chapters 3 and 4 discuss the indicators tested for different indicator groups in more detail and the results of this assessment.

3.2 Defining objectives for the program

River health monitoring programs must take account of overall objectives for the program. The objectives should go beyond simply assessing the condition of the waterways in a basin. A program may be designed to monitor the condition of certain high-value assets (e.g. particular fish species, or certain wetlands). Alternatively, or in addition, a program may be designed to identify threats to river health, or to assess the effectiveness of management interventions. These objectives need to be developed in close consultation with a range of stakeholders, ideally including stakeholders responsible for managing the catchment, as well as stakeholders who rely on its resources.

It was not possible to undertake this type of consultation for the pilot study. Instead, a desktop review and internal discussions were used to identify key human disturbances within the catchment and management actions that might be implemented to address these disturbances (Table 1).

The pilot study was then undertaken to identify indicators suitable for assessing the impact of these types of disturbances. However, any future monitoring program should build on this list of threats and priorities, together with the key assets discussed in section 2.3. These threats and priorities should be evaluated by a broader group of stakeholders to ensure that any monitoring program meets their needs in providing information on the condition of the basin.

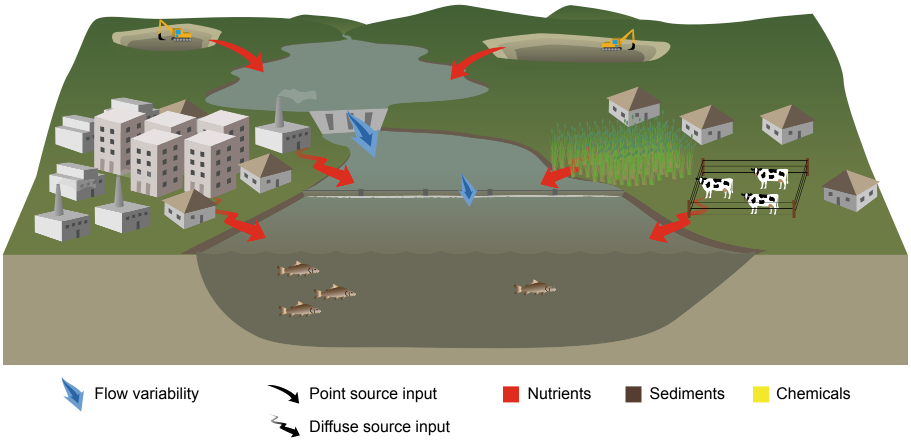
Table 1: **Key human disturbances and priorities for management identified from background reports**

Human disturbances	Priorities for management
Flow alteration due to dams In-stream sand mining Urbanisation Diffuse pollution from farmland	Evaluate impacts of barriers and water extraction Evaluate impacts of fishing Manage direct impacts from gravel extraction Reduce nutrient loads

3.3 Conceptual model of river health

Conceptual models can be used to show how human disturbances are likely to affect river health. The main conceptual model for the Gui River pilot project was developed to show how biological attributes of the river ecosystem respond to disturbance associated with land use activities in the region, and which biological indicators may best reflect these responses. Conceptual models can range from simple diagrammatic representations of threats to the ecosystem and the attributes of interest, to expressing more complex cause–effect relationships. A very simple graphical model highlighting potential threats to stream health in the Gui catchment is shown in Figure 7. In the Gui River, the main disturbances consist of agricultural land use (primarily horticulture), urbanisation, gravel extraction and hydrologic alteration from hydropower generation and water extraction. These are fairly typical drivers of declining river condition throughout China and the rest of the world.

Figure 7. A simple conceptual model showing potential human impacts on the Gui River.



3.4 Classification of Gui River Catchment

As rivers vary in size and form from one region to another based on climate, topography and other factors, many of the indicators that are routinely monitored in river health programs can also show considerable levels of natural variation. This has important implications for condition assessment as natural variation in indicator values associated with changes in climate, geology and river type can become confounded with anthropogenic effects. Good examples of this include the general increases in conductivity and turbidity as streams move from bedrock controlled to more alluvial channels. These physical changes are met with corresponding changes in the biota that must be taken into account to avoid inadvertently labelling sites as in poor condition, when indicator scores are naturally lower in a particular area.

There are three broad strategies that are employed in river health monitoring programs to address this issue. The first is to select indicators that are relatively invariant across natural gradients while still being sensitive to anthropogenic stressors. While a potentially important aspect of indicator selection, this alone will generally only partly address the issue. The second approach is to use predictive models that explicitly incorporate local environmental conditions to predict the species that would be expected at a site in the absence of any human disturbance. Such approaches are often referred to as multivariate approaches in the river health literature. Examples include AUSRIVAS and RIVPACS. The third approach adopted by multi-metric assessments, such as the assessment being applied here, is to 'a priori' divide sites or catchments up into groups that differ systematically from one another, and which would be expected to have different indicator values between groups even under pristine or reference conditions. Having divided rivers up in this way, a decision is then made to either i) develop entirely different indicator sets for each of those regions, or ii) to adopt distinct targets (reference points) for more widely used indicators. The most appropriate method depends on the geographic scale and extent of variation in river type that is encompassed within a particular assessment program.

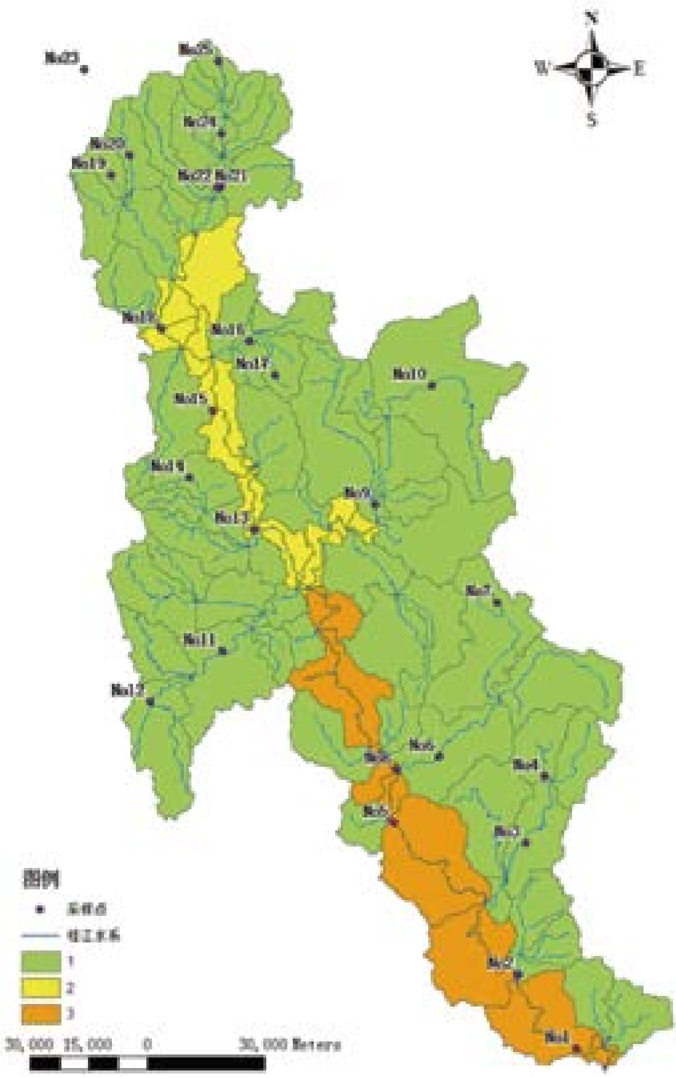
River classification is often undertaken using statistical approaches. One important caveat on using statistical classification methods is that these methods will almost always divide the sites or rivers being compared into different classes, even when, from a physical or biological perspective, scientists might regard those rivers as being quite similar. As an analogy, if fruit were classified into different types, a classification only of apples may distinguish between different varieties. However, if the initial set also included bananas and oranges, all varieties of apples may be grouped together. Hierarchical classification techniques are one way of dealing with this issue, but they still require an explicit decision about the level in the hierarchy at which groups should be regarded as the same.

This analogy has important implications for the Gui River pilot, because (picking just two potentially important environmental gradients) most sites fall in a similar climatic zone, and even sites in the most downstream reaches still consist of relatively coarse bed material. Early in the pilot work, a classification of the catchment was undertaken based on climate and physiographic variables including geology, temperature, rainfall, altitude and slope, all of which are known to affect water quality and biological characteristics of rivers. The classification was done using SPSS and initially identified classes, which could broadly be regarded as upland, main-trunk and lowland tributary (Figure 9). These classes also accord, to a large degree, with a classification based on the Strahler stream order (Strahler 1952), which is also sometimes used as a simple way to distinguish rivers based on size and position.

The merit of using stream order to classify streams has been widely debated (Paller et al. 1994; *Gerritsen et al.* 2000; Van Sickle and Hughes 2000; Smith and Kraft 2005). Within small geographic regions, stream order is a convenient descriptor of the relative position of sites or streams within the catchment that can relate to biological attributes. Over larger spatial scales, however, using stream order as a classification tool is misleading. Therefore, this very simple approach should not automatically be transferred to other regions. In most cases, an alternative classification scheme (for example based on altitude or climate etc.) would be more useful and appropriate.

Having identified homogenous classes of rivers or sites across the catchment, these classes were used for evaluating targets and reporting results in the associated scorecard. However, because only 25 sites were surveyed, the sites have not been divided into separate classes to describe in detail the relationships between the indicators and anthropogenic stress as might have been done with a larger dataset.

Figure 8. Classification of sub-catchments across the Gui River Basin together with locations of field sampling sites.



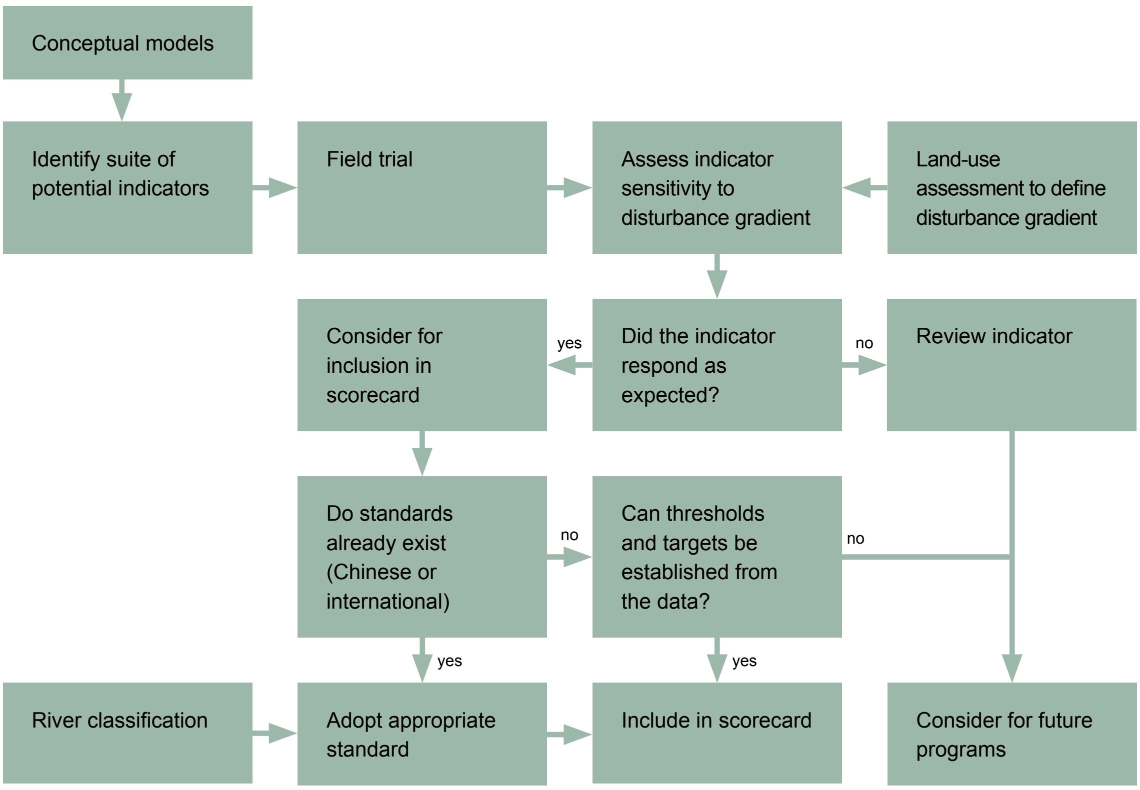
3.5 Approach to indicator selection and trialling

Following the holistic approaches to river health monitoring discussed by Gippel (2010a) and used in many other successful river health monitoring programs elsewhere in the world (Flotemersch et al. 2006), field data collection incorporated a range of ecosystem components, including water quality, riparian land use, geomorphology, and fish, benthic algae and benthic macroinvertebrate assemblages. For this report, a suite of indicators were derived from this dataset and then analysed against land-use disturbance gradients calculated using GIS-derived measures of catchment disturbance – particularly agriculture and urbanisation. A subset of indicators was then selected based on their effectiveness (i.e. response to the disturbance gradients) (e.g. see Smith and Storey 2001) for inclusion in a report on the health of the Gui River catchment. A broad suite of indicators were derived and tested during the process.

As outlined in section 1.5, there are a number of key steps to identify appropriate indicators and set targets that are consistent with the river health objectives for the sites or region under investigation. This section of the report details the GIS and statistical analysis of a suite of indicators evaluated during the trial. When establishing a field trial, indicators proven in previous river health monitoring programs are usually included and then tested against a known disturbance gradient. Other indicators believed to show promise (based on expert opinion, experience, local knowledge, scientific literature) may also be considered for the disturbance gradient analysis. Skills of personnel and practicalities about what can be collected in the field, as well as what can be analysed in the laboratory, also determine the indicators that may or may not be included in a field trial. The relevant steps, and decisions to be made at each step in the process outlined in section 1.5, are presented graphically in Figure 9.

Details on each of the indicators tested for the Gui River pilot project and the rationale for their inclusion are provided in sections 3.8–3.14. Testing the indicators involved either direct measurement (e.g. water conductivity) or sampling of biota from which indicators could be calculated (e.g. family-level richness of macroinvertebrate communities).

Figure 9. More detailed flowchart showing the steps involved in the trialling and selection of indicators for inclusion in the Gui River pilot scorecard./



3.6 Site selection

The analyses on site selection are based on data collected from the Gui River Basin in April 2010 as part of the pilot project. Field sampling was conducted by staff from PRWRPB and members of the Australian team, and involved collecting data from 25 sites over a seven-day period. Sites were distributed throughout the Gui River catchment with the aim of incorporating a mix of relatively undisturbed and modified sites across a range of river sizes and classes. Often, as part of pilot studies such as this, GIS analysis is conducted first to help ensure that sites are selected across the full range of environmental conditions or types and extent of land-use change. In this case, sites were selected first, although retrospective analysis suggests the sites covered a sufficiently large gradient for the purposes of the assessment.

While site selection for pilot studies is often based on a prior assessment, when selecting sites for inclusion in actual assessment programs, it is critical that every effort is made to avoid introducing bias into the site selection process. If bias is introduced, the results of the assessment may not be considered ‘representative’ of the condition of the catchment, which can lead to difficulty in accepting the results. Ideally, site coordinates within a given part of the catchment could be drawn randomly to prevent biases, for instance. Without a formal process for site selection, there is often a tendency to select sites that represent the best or worst conditions of a region or to actively exclude these sites. Both scenarios are problematic for assessing overall catchment health.

Another important consideration for assessment is the definition of a site. To assess physical form and streamside zone condition, a ‘site’ may range from approximately 100–400m in length (although ideally measured over an even greater section of the river to avoid very localised disturbances biasing the results). Fish sampling might be spread over a slightly smaller area and water quality sampling should be undertaken in a mixed section of the river where it is assumed that the samples integrate water quality in the river as a whole, rather than, for example, immediately below a drain. Also, road crossings may provide easy access, but roads often create an obvious localised area of disturbance, particularly downstream. They can also experience heavy traffic, which can be a problem if sampling requires any equipment to be left in place overnight.

3.7 Land-use disturbance gradient

Land-use change has long been recognised as a major human-induced disturbance on river health (Vitousek 1992; Sala et al. 2000; Allan 2004; Dudgeon et al. 2006), and is the primary anthropogenic driver thought to be affecting stream health in the Gui River catchment. Change in land use was, therefore, used as the primary disturbance gradient to test the indicators of river health for the Gui River pilot project.

Land use and land cover (LULC) compositions of the catchment upstream of each of the sampling sites were extracted from the land use and land cover map interpreted from Landsat TM and + ETM imageries from 2007 using ArcGIS 8.7 Desktop GIS software. Land use was classified according to Level 1 of the Corine Land Cover (CLC) classification scheme (Table 2), which is widely used around the world to summarise land-use data. The percentage cover of each of the different land-use categories was calculated within the entire catchment area upstream from each site, and within a 1 km buffer area (500 m either side) extending upstream from the sampling site to a point 5 km upstream of each sampling location. These two scales of land use are referred to as catchment and buffer scales. At a local scale, riparian condition was further assessed by measuring average width and longitudinal connectivity of the riparian buffer zone. These local scale measures were assessed over a roughly 1.5 km length of the river, and ultimately were also included as indicators of riparian condition.

Table 2. Corine Land Cover classification scheme.

Level 1	Level 2	Level 3
1. Artificial surfaces	1.1 Urban fabric	1.1.1 Continuous urban fabric
		1.1.2 Discontinuous urban fabric
	1.2 Industrial, commercial and transport units	1.2.1 Industrial and commercial units
		1.2.2 Road and rail networks and associated land
		1.2.3 Port areas
		1.2.4 Airports
	1.3 Mine, dump and construction sites	1.3.1 Mineral extraction sites
		1.3.2 Dump sites
		1.3.3 Construction sites
	1.4 Artificial, non-agricultural vegetated areas	1.4.1 Green Urban areas
		1.4.2 Sport and leisure facilities
2. Agricultural areas	2.1 Arable land	2.1.1 Non-irrigated arable land
		2.1.2 Permanently irrigated land
		2.1.3 Rice fields
	2.2 Permanent crops	2.2.1 Vineyards
		2.2.2 Fruit trees and berry plantations
		2.2.3 Olive groves
	2.3 Pastures	2.3.1 Pastures
	2.4 Heterogeneous agricultural areas	2.4.1 Annual crops associated with permanent crops
		2.4.2 Complex cultivation patterns
		2.4.3 Land principally occupied by agriculture with significant areas of natural vegetation
		2.4.4 Agro-forestry areas
3. Forests and semi-natural areas	3.1 Forests	3.1.1 Broad-leaved forest
		3.1.2 Coniferous forest
		3.1.3 Mixed forest
	3.2 Shrub or herbaceous vegetation associations	3.2.1 Natural grassland
		3.2.2 Moors and heathland
		3.2.3 Sclerophyllous vegetation
		3.2.4 Transitional woodland scrub
	3.3 Open spaces with little or no vegetation	3.3.1 Beaches, dunes, sand plains
		3.3.2 Bare rock
		3.3.3 Sparsely vegetated areas
		3.3.4 Burnt areas
		3.3.5 Glaciers and perpetual snow
4. Wetlands	4.1 Inland wetlands	4.1.1 Inland marshes
		4.1.2 Peat bogs
	4.2 Coastal wetlands	4.2.1 Salt marshes
		4.2.2 Salines
		4.2.3 Intertidal flats
5. Water bodies	5.1 Continental waters	5.1.1 Water courses
		5.1.2 Water bodies
	5.2 Marine waters	5.2.1 Coastal lagoons
		5.2.2 Estuaries
		5.2.3 Sea and Ocean

Level 1 classes were used for land use description in the gradient analysis.

3.8 Water quality

3.8.1 Rationale for inclusion

Water quality is the key component of aquatic ecosystem condition. As such, measures of the physical and chemical condition of the water column are often included in ecosystem health monitoring and assessment programs. They may also act as stressors on aquatic biota. Water quality is already widely monitored in China. Therefore, in addition to inclusion of water quality in new initiatives to assess river health, analysing existing datasets in evaluating water quality problems is recommended. Analytical approaches for examining existing water-quality time-series data based around Chinese Water Quality Standards are presented in Gippel (2010b).

The key aspects of water quality measured included the physico-chemical properties of the water (temperature, pH, conductivity, turbidity, DO), nutrient concentrations, and the presence of toxicants, such as heavy metals. These indicators are typically included in river health surveys and relate to a range of potential sources, including agricultural, domestic and industrial point-source pollution, as well as diffuse inputs associated with runoff from the broader catchment. The relative concentrations of nutrients and pollutants can generally provide a clear indication of the likely sources in the catchment, and by having a relatively comprehensive spatial monitoring program, the spatial patterns of water quality decline (and decline in other indicators) can help identify critical areas to be addressed by management actions.

One of the advantages of a suite of water quality indicators is that there are often externally prescribed standards for different uses, e.g. indicators based on drinking water, reducing the need to rely on 'reference condition' targets in setting objectives for each of the metrics. However, there may still be cases when, even under natural conditions, some aspects of water quality may reach values often thought of as being related to degradation. However, because water quality data exists for so many systems around the world, the range of values that different water quality parameters might take, for example, in tropical versus desert streams, is relatively well documented (e.g. see Wetzel 2001).

A critical problem with monitoring water quality is that most parameters vary over a very large range according to the current and recent runoff history. For example, immediately following a dry period, flushing material from stream banks, drains and other areas can elevate loads substantially, but only during the initial flush of water. Given the strong condition gradients likely to arise in China, there is still value in snapshot sampling of water quality.

3.8.2 Methods (sampling and laboratory analyses)

At each sampling site, a range of physical and chemical variables was measured. Water temperature (°C); dissolved oxygen (DO mg/L); conductivity (µS/cm); and total dissolved solids (TDS, mg/L); were measured *in situ* with a handheld YSI multi-parameter instrument (professional plus); pH was measured using a pen style YSI pH tester instrument (YSI Incorporated, Yellow Springs, Ohio, USA). The sensors were calibrated before the measurements were taken.

Water samples for analyses of other parameters were collected in polyethylene plastic bottles rinsed three times with distilled water and kept at 4 °C for laboratory analysis. For nutrient analyses, the water samples were filtrated through 0.45 µm pore sized Millipore nitrocellulose membrane filters. Ammonia-nitrogen (NH3-N); nitrite-nitrogen (NO2-N); nitrate-nitrogen (NO3-N); and TN (mg/L) water samples were acidified to $pH<2$ by sulfuric acid, while samples for PO4-P and total phosphorus (TP) (mg/L) analysis were acidified to $pH \leq 1$ with nitric acid. The concentration of NH3-N was measured with Nessler's reagent, NO3-N and TN determined by the alkaline potassium persulfate oxidation–UV spectrophotometric method, respectively. TP was analysed by digestion and a colorimetric method (ammonium molybdenum blue method/ascorbic acid method) after the samples were digested with concentrated nitric and sulfuric acid to convert all the phosphates into the orthophosphate form (NEPB, 2002). Orthophosphate (PO4-P) was measured by the same analytical method as TP, but the samples were not digested (NEPB, 2002).

The dissolved metals of Pb, Cr, Al, Zn, Cu, Hg and As were determined by using atomic absorption spectrophotometer (APHA 2005).

Table 3. Summary of water quality parameters and associated methods

WQ component	Indicator	Unit	References/instruments
Physical	pH		YSI multi-parameter instrument
	DO	mg/L	YSI multi-parameter instrument
	EC	μs/cm	YSI multi-parameter instrument
	SS	mg/L	YSI multi-parameter instrument
	TDS	mg/L	YSI multi-parameter instrument
Nutrients	NH_3-N	mg/L	Nessler's reagent – NEPB 2002
	TN	mg/L	UV spectrophotometric method – NEPB 2002
	NO_2-N	mg/L	Chinese Standard Methods for Examination of Water & Wastewater (GB3838-2002)
	NO_3-N	mg/L	UV spectrophotometric method – NEPB 2002
	PO_4^{3-}	mg/L	Ascorbic acid method – NEPB 2002
	TP	mg/L	Ascorbic acid method – NEPB 2002
Heavy metals	Pb	mg/L	Atomic absorption spectrophotometer – APHA 2005
	Cd	mg/L	Atomic absorption spectrophotometer – APHA 2005
	Cr	mg/L	Atomic absorption spectrophotometer – APHA 2005
	Al	mg/L	Atomic absorption spectrophotometer – APHA 2005
	Zn	mg/L	Atomic absorption spectrophotometer – APHA 2005
	Cu	mg/L	Atomic absorption spectrophotometer – APHA 2005
	Hg	mg/L	Atomic absorption spectrophotometer – APHA 2005
	As	mg/L	Atomic absorption spectrophotometer – APHA 2005

3.9 Benthic Algae

3.9.1 Rationale for inclusion

Benthic algae are useful ecological indicators because they are abundant in most streams, they respond rapidly to changed conditions, are relatively easy to sample, and their tolerance to environmental conditions is known for many species due to the cosmopolitan distribution of many taxa. Univariate measures such as abundance (measured as chlorophyll concentration or weight loss on ashing) can provide an indication of high abundances, which may indicate eutrophication. Compositional indicators, especially of diatoms, are also widely used, particularly in Europe, where numerous indices have been developed that reflect changes in community composition along disturbance gradients with declining water quality (Żelazna-Wieczorek and Ziulkiewicz ; Griffith *et al.* 2005; Johnson *et al.* 2005; Torrisi *et al.* 2010). Two of the more widely used indicators were included in the pilot study: the Biological Diatom Index (IBD;Lenoir and Coste 1996), and Specific Pollution Sensitivity index (IPS; Coste in CEMAGREPH 1982), both of which take into account the tolerance of different taxa to declines in water quality. While the sensitivity of these metrics is well established, they require relatively high levels of taxonomic expertise to identify specimens, and considerable lab work to process samples. In addition, it is important to recognise that sensitivity can vary regionally even within the same species, as with the sensitivity metrics based on macroinvertebrates. Therefore, applying these indices in China requires further evaluation to revise existing sensitivity grades. In particular, for example, it has been shown that some diatom-based indices do not perform as expected in limestone streams subjected to low levels of human disturbance (Eloranta and Soininen 2002). This is an observation of particular relevance to the Gui River and its tributaries.

Indicators derived from sampling algae are not restricted to measures of community structure, and therefore, together with species richness, it is possible to use measures of algal abundance (chlorophyll concentration) and isotopic signatures (N15 ratios) to detect nutrient enrichment and nutrient sources, with N15 ratios frequently being enriched by sewage discharge (Bergfur et al. 2009).

Periphyton have been widely used as bio-indicators in Europe. Some phytoplankton and periphytic algae have been shown to have very narrow tolerance ranges of pH, and diatoms have been used to indicate acidification in rivers (Coste et al. 1991).

3.9.2 Methods (sampling and laboratory analyses)

Periphyton samples were scrubbed by toothbrush from at least six rocks or cobbles, which were big enough to resist the water flow. These samples can represent the local water quality and environment. The samples were preserved with 4 per cent formaldehyde and taken to the laboratory for diatom analysis. Each sample was prepared by H_2O_2 (30 per cent) and HCl (10 per cent). Permanent slides were mounted using Naphrax (r.i. 1.74). Up to 400 valves were counted and identified in each sample with a light microscope using Nomarski differential interference contrast optics at a magnification of 1000. They were mainly identified following Krammer (1985) and Lange-Bertalot (1991). Water column chlorophyll concentrations were estimates from a 50 ml alequate of a 1 litre water sample taken from the river, which was placed on ice in the dark before being filtered through a Whatman GF/C filter, within 4-6 hrs. Chlorophyll concentrations were determined spectrophotometrically after acetone extraction in the laboratory.

3.10 Benthic macroinvertebrates

3.10.1 Rationale for inclusion

Globally stream macroinvertebrates are probably one of the most commonly used biological measures of stream health. For example, in Europe there are more than one hundred different bio-assessment methods in use, and two thirds of them are based on macroinvertebrates (Rosenberg and Resh 1993; Verdonschot et al. 2000). Macroinvertebrates are popular because they are found in most habitats, they have generally limited mobility, they are quite easy to collect with well established sampling techniques, and there is a diversity of forms that ensures a wide range of sensitivities to changes in both water quality (of virtually any nature) and habitats (Hellawell).

After collecting benthic invertebrate samples, it is relatively straightforward to calculate a large number of different indices. Previous studies suggest these indices are frequently correlated with each another, and a subset is generally appropriate for capturing the range of possible response patterns along gradients of disturbance (Bunn et al. 2010). The subset of indices calculated in this study is described in the following sections. These indices used are just a subset of the available indices and they demonstrate that rather, than focusing on quantity (there are too many to include all), the emphasis in adopting a final set of invertebrate indicators should be on selecting ones that show both predictable and consistent responses to the disturbance gradients, and that have a sound mechanistic explanation for such trends. A small number of reliable indicators with these properties will be far more effective than a longer list of less reliable or less defensible ones.

3.10.2 Methods (sampling and laboratory analyses)

Benthic macroinvertebrates were collected using a D-frame dip net (15 cm radius, 500 μm mesh) in April 2010. All 25 sites sampled were sufficiently wadeable to allow a sample to be collected, although in some sites the wadeable area was restricted to the stream margins. Samples were collected by taking replicate kick samples from multiple locations to cover a total length of 10 m of the streambed. The contents of the 10 m equivalent sweep were then emptied into a white sorting tray before live-picking individuals for a period of 30 minutes. In all cases, live picking was conducted by two staff, at least one with prior experience in identifying stream macroinvertebrates. Live-picked animals were stored in labelled jars in 70 per cent ethanol.

In the laboratory samples were rinsed through a sieve (500 μm mesh). The retained invertebrates were sorted and preserved in 70 per cent alcohol. Macroinvertebrates were identified generally to the genus level. While Chironomidae were only identified to subfamily level, and Nematoda were not identified. The Oligochaeta was identified as either *Branchiura sowerbyi* or other Oligochaeta.

Widely used indicators that were calculated included total density (D), taxa richness (S), Ephemeroptera, Plecoptera and Trichoptera (EPT) richness and EPT ratio (i.e. the proportion of total species richness comprised of EPT taxa), Berger-Parker Dominance (Dominance), percentage of clingers (Clingers) and Shannon index. Most of these indices are well known and the necessary formulae are widely available.

In addition, two tolerance metrics were calculated: the Biotic Index (BI; Lenat 1993), and weighted and unweighted SIGNAL II (OCP) Scores (based on Order/Class/Phylum sensitivity grades; Chessman 2003). These metrics reflect the overall tolerance of the assemblage (similar to IBD and IPS), and broadly assume that only more tolerant taxa will persist in more polluted environments. The order/class/phylum version of SIGNAL 2 is regarded as being well suited to use by technicians with lower levels of training relative to metrics requiring family level data. However, it is critical to recognise that these metrics have been calculated and included only as a demonstration. Reliable tolerance metrics assume the presence of a large database that can be used to define the tolerance values for each taxa, and taxa from different regions would be expected to have different tolerance values. Therefore, while the approach is readily transferrable to China, the actual tolerance values may not be.

Unweighted SIGNAL scores are simply the average of the signal sensitivity grades (Table 4) for those taxa collected (see Chessman 2003). Weighted scores represent the average of the product of the SIGNAL sensitivity grade multiplied by the weighting scores in Table 5. Note that these weightings are arbitrary and could be modified to suite different sampling effort, which may tend to yield higher or lower abundances on average. BI scores were calculated based on tolerance values in Lenat (Lenat and Crawford 1994).

Table 4. SIGNAL OCP grade scores system for macroinvertebrates (Chessman 2003).

Taxon	Sensitivity Grade (1–10)	Standard Error of Grade
Acarina	6	0.3
Amphipoda	3	0.6
Anaspidacea	6	0.2
Anostraca	1	0.5
Bivalvia	3	0.6
Branchiura	1	3.0
Bryozoa	4	5.2
Coleoptera	5	0.4
Collembola	1	0.6
Conchostraca	1	0.6
Decapoda	4	0.5
Diplopoda	4	1.5
Diptera	3	0.3
Ephemeroptera	9	0.3
Gastropoda	1	0.5
Hemiptera	2	0.5
Hirudinea	1	0.7
Hydrozoa	1	0.7
Isopoda	2	0.7
Lepidoptera	2	0.5
Mecoptera	10	0.7
Megaloptera	8	0.6
Nematoda	3	0.8
Nemertea	3	0.9
Neuroptera	6	0.8
Nematomorpha	6	0.7
Notostraca	1	0.4
Odonata	3	0.4
Oligochaeta	2	0.4
Plecoptera	10	0.3
Porifera	4	1.3
Trichoptera	8	0.3
Turbellaria	2	0.3

The SE of grade reflects the degree of consistency in the sensitivity of taxa within each taxonomic unit.

Table 5. Abundance weightings used in calculating the weighted SIGNAL scores.

Abundance	Weighting
>20	5
>10	4
>5	3
>3	2
1,2	1

3.11 Fish

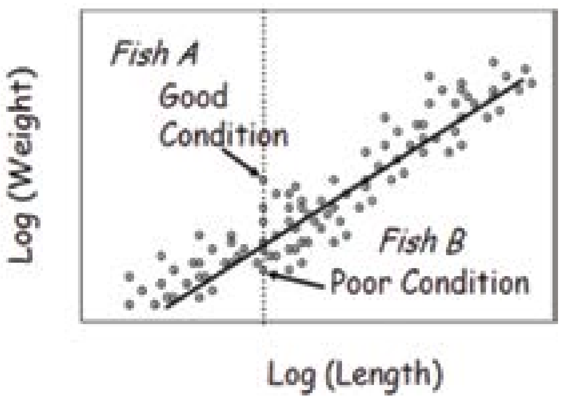
3.11.1 Rationale for inclusion

Fish have valuable properties as an indicator group. As well as having a range of sensitivities to water quality and habitat deterioration, they are relatively easy to sample and identify in the field, and they tend to integrate effects of lower trophic levels. Fish assemblage structure is reflective of integrated environmental health (Barbour et al. 1999; Kennard et al. 2001). As they typically move over larger spatial scales and are comparatively long-lived, they are also suited to assessing macro habitat and regional differences, and integrate the effects of long-term changes in stream health (Kennard et al. 2001). Fish are also highly valued socially and economically, and there is often pressure to incorporate them into river health assessment programs. However, there are specific challenges for sampling fish compared to invertebrates and diatoms. Because of their small size and limited movement, it is possible to sample invertebrates and diatoms easily in the field in a way that provides consistent and repeatable results with relatively little sampling effort. Both invertebrates and diatoms generally require additional laboratory work to finalise identifications.

While fish are easily identified in the field, typically, a greater sampling effort is required to provide consistent measures of abundance and community composition (e.g. Kennard et al. 2001). In addition to the greater effort required, differences in stream size also requires different sampling approaches. These issues can be problematic for calculating indices based on abundance, biomass or species richness, all of which are sensitive to sampling effort. A number of alternative indicator types have been applied to fish assemblages, such as the proportion of introduced or migratory species, changes in the relative number of pollution sensitive taxa (e.g. fish IBIBarbour *et al.* 1999). However, with the exception of exotic species, these indictors depend on developing expected 'reference' values that may be difficult to develop unless historical data can be accessed. There are historical species lists for the Gui River, and these lists suggest an overall downward trend in species richness since the 1970s. Further work is required to determine whether species losses reflect the loss of migratory species through dam construction, or some other change.

While most river health indicators reflect properties of biological assemblages, indicators that assess individual condition (or health) are frequently applied to fish. As with other taxa, as fish grow and age, there are generally predictable changes in both their length and weight. This general relationship can, however, change depending on the condition or relative health of the individual. Conceptually, healthier fish are expected to weigh relatively more for a given length than fish in poor condition (Figure 10). This general rule is complicated by potential sexual dimorphism and also changes in weight associated with spawning; however, assuming sampling times do not coincide with spawning period, then fish condition has been shown to relate well to some forms of stream degradation.

Figure 10. Hypothetical length-weight relationship for a given species, with residuals around a common regression line being used to indicate fish in relatively good or poor condition.



As well as changes in weight-based condition, fish in poor health are often more prone to infection by parasites and disease. Lesions and the presence of parasites are another example of an easily measured indictor of potential poor health, particularly when considered in terms of the proportion of individuals caught at a site that suffer from these problems.

Finally, at a sub-individual level tissue samples can be used to test for the presence of heavy metals, both as a measure of exposure of the organism to these stressors in the environment but also as a measure of the risks posed to humans who may rely on the fish as a source of protein.

3.11.2 Methods (sampling and laboratory analyses)

Fish assemblages were sampled using a range of approaches including boat and backpack electrofishing, seine nets and gill nets. At each site where fish samples were collected an average of ~30–60 minutes was spent sampling fish over a length of stream typically spanning 150 m from downstream to upstream at each site. All fish caught were placed in a plastic bucket before being photographed measured and weighed. Fish length estimates were based on standard length, which is measured from the tip of the snout to the base of the caudal fin. Fish were weighed to the nearest 0.1 g. All fish where then frozen for return the laboratory and later identification. Numbered photographs associated with each fish were then used to link field identifications with those confirmed in the lab.

3.12 Physical form (riparian and channel condition)

3.12.1 Rationale for inclusion

Physical form is included in many modern river health assessment programs (Gippel 2010a), for example, the EU Water Framework Directive (Kallis 2001) and the Australian Framework for the Assessment of River and Wetland Health (FARWH) (Norris et al. 2007). In this context, 'physical form' encompasses fluvial geomorphological process and form, or the interaction of sediment, flowing water, and organic factors (growing and dead vegetation) to shape river channels and floodplains. Physical form is included because, together with chemical processes (water quality); radiation (energy from the sun); hydrological processes (river flow regime); and geomorphological processes provide the template on which ecological processes proceed.

Geomorphological condition is defined as the balance of sediment supply, transport capacity and resistance to erosion, which gives rise to a distribution of physical forms at a range of scales. Good or desirable physical form is a state that does not limit the achievement of good or desirable ecological condition.

Data collected from bioassessment surveys (e.g. fish, diatoms, and invertebrates) are often difficult to interpret without the aid of contextual information concerning physical form. For example, a stream with a mud bed would have a different invertebrate community compared to a stream with a cobble bed, even though both streams might be of a similar size and found in similar parts of a catchment. Similarly, some measured aspects of the flora and fauna are scale-dependent, so it is preferable to have basic information describing the physical setting of the surveyed site. Some geomorphological data can be useful for developing a physical form indicator in its own right, while other data might be used only as contextual information to help interpretation of biological indicator data.

There are, however, significant challenges in using physical form as part of a river health assessment program. These challenges include:

- a lack of people formally trained in fluvial geomorphology
- the complex, and often poorly understood relationship between physical form and ecosystem health or ecological variables
- physical form can respond in a number of different ways to the same type of disturbance
- physical form and process are highly variable in time and space, and this variability is normal in healthy rivers
- the physical form of rivers is highly scale-dependent
- the physical form of rivers varies markedly between the headwaters, mid-reaches and lowland reaches
- and most lowland rivers in the world are highly disturbed in physical form, which creates a lack of reference sites.

These issues have been addressed in a variety of ways, and there is no accepted standard method for the assessment of physical form.

3.12.2 Potential approaches to assessment of physical form as a component of river health

Approaches to assessing physical form as a component of river health include considerations of:

- physical form as it relates to habitat for biota
- relative stability of physical form
- sediment transport processes
- variability of physical form
- physical form and connectivity
- direct alteration and management of physical form.

These options, and issues associated with each, are discussed in more detail in the companion report to this one, 'River health assessment in China: development of physical form indicators' (Gippel et al. 2011b). The physical form of most rivers in China has been modified for a long time, so it is generally not possible to characterise the natural geomorphological attributes, and their natural rates of change through time, that are associated with good river health. The inability to define reference conditions for natural physical form attributes means that in this regulation, physical form is indicated by attributes of selected stressors of physical form. This approach assumes that the presence and intensity of the selected stressors on physical form impairs river health, while a river without these stressors present is in reference condition. In reality, a river without the selected stressors present may not have the same characteristics of physical form as a river totally undisturbed by human activity, but this is considered unknowable.

The physical form indicator category covers stressors that impact the characteristics of the bed and banks, and the continuity of the river in the longitudinal (upstream and downstream) and lateral (river channel to floodplain, if present) directions.

Of the human activities that disturb physical form, construction of weirs, dams and dikes are highly significant because of their impact on connectivity; hard-lining river banks is significant because of its impact on reducing channel dynamism; and, gold mining and extracting sand and gravel is important because it directly modifies physical habitat and generates turbidity. But there is no sufficient data for these two stressors in Gui River. So the lateral-continuity and bed disturbance are not included in the physical form indicator category.

Weirs and dams also indirectly impact the channel hydraulic habitat quality by creating deeper lentic (ponded) conditions upstream. Weirs and dams with hydropower stations create unnaturally high variability of water levels (and thus hydraulic habitat conditions) at the daily time scale (which is not captured by the hydrology indicator).

Bank stability can be reduced through human disturbance of riparian vegetation, but this stressor is not included in the physical form indicator category because it is captured by the riverine vegetation indicator.

3.12.3 Index and Sub-indicators

The physical form stressor index (PFS) is based on several stressor sub-indicators: free-flow interruption sub-indicator (FFI), catchment sediment risk sub-indicator (CSR); sediment transport interruption sub-indicator (STI), longitudinal-continuity barrier sub-indicator (LoCB). The FFI is measured primarily in the field (Table 6) and the others are desktop-measured using maps, aerial photography and other records (Table 6). The field-measured physical form stressor sub-indicators are only sampled in spring (i.e. not included in the autumn field sampling). The desktop measured sub-indicators are measured once per year, at a convenient time, using information collected over the sampling year.

The field-measured sub-indicators (Figure 11, Figure 12 and Figure 13) are assessed over a sample zone, the length of which is approximated by estimating the mean bankfull channel width and then multiplying this width by 10. The minimum sample zone length is 150 m, which applies to rivers with channels less than, or equal to, 15 m average width. The maximum sample zone length, set for the practical reason of constraining the time it would take to undergo the sampling, is 1000 m, which applies to rivers with channels equal to or wider than 100 m.

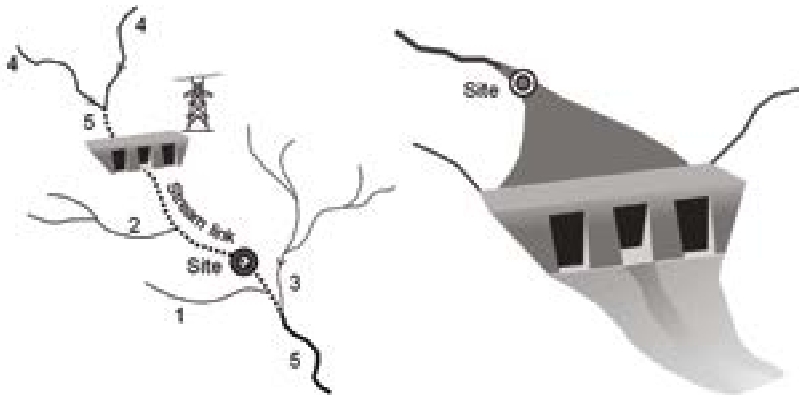
The CSR sub-indicator requires analysis of spatial data using GIS. For each sampling site, the total sub-catchment (S-c) that drains to that point is delineated. Within these sub-catchments, the areas of Forest (Fo), Grassland (Gr), Farmland (Fa), Paddy (Pa), Urban (Ur), and Reservoir (Re) land cover types are measured. The combined area of Fa, Pa and Ur land cover are expressed as a proportion (P) of the total sub-catchment area, such that $P = Area_{(Fa + Pa + Ur)} / Area_{S\text{-}c}$.

Table 6. The four sub-indicators of the physical form stressor index

Sub-Indicator	Score
Free-flow interruption (FFI) Observed in the field, with assistance from maps/aerial photographs and local knowledge, as necessary.	
The site is in a stream link* containing a hydropower station upstream of the site (Figure 11) The site is in the backwater of dam or weir (Figure 11) The site is in a free-flowing section of river	3 3 0
Sub-total Sub-indicator score	/6 1 – (Sub-total/6)
Sediment transport interruption (STI) Observed in the field, with assistance from maps/aerial photographs and local knowledge, as necessary.	
The site is in stream link* that (containing a hydropower station upstream of the site Contains an upstream major-sized dam ≥ 15 m high Contains an upstream moderate-sized dam 10 m ≤ height < 15 m Contains an upstream small-sized dam or weir 2 m ≤ height < 10 m Does not contain an upstream dam or weir higher than 2 m	3 2 1 0
Sub-total Sub-indicator score	/3 1 – (Sub-total/3)
Longitudinal-continuity barrier (LoCB) N = number of intact in-stream structures (weirs or dams) that span the river width, located between the site and the mouth, and lacking a dedicated fishway; measured from a map or aerial photograph (Dams with dedicated fish passage are not counted. Figure 13)	
N ≥ 10 10 > N ≥ 5 5 > N ≥ 3 3 > N ≥ 2 N = 1 N = 0	3 2.5 2 1.5 1 0
Sub-total Sub-indicator score	/3 1 – (Sub-total/3)
Catchment sediment risk (CSR) P = proportion of the upstream catchment area that is Farmland, Paddy, and Urban land cover (combined areas); measured using GIS	
P > 0.5	3
0.25 < P ≤ 0.5	2
0.1 < P ≤ 0.25	1
< 0.1	0
Sub-total Sub-indicator score	/3 1 – (Sub-total/3)

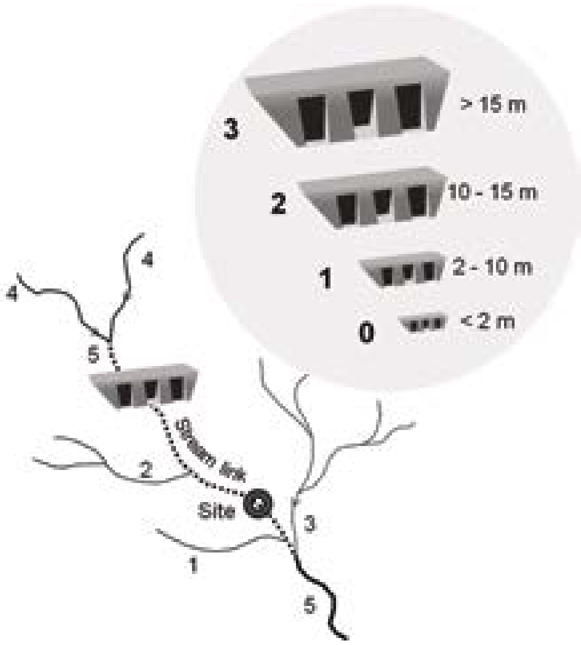
* In this context, a stream link is a continuous reach of river interrupted by entry of a tributary that is of equal or higher Strahler stream order, or of third order or higher.

Figure 11. Illustration depicting the two cases of site location where the free-flow interruption sub-indicator score is 3.



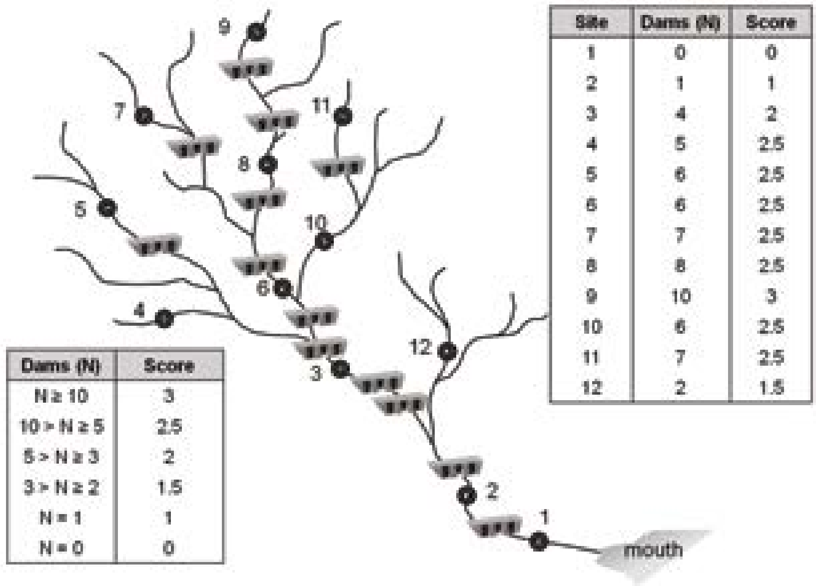
Note: The numbered streams indicate an example of how Strahler stream order is used to define a stream link (dashed line).

Figure 12. Illustration depicting how scores are assigned for the sediment transport interruption sub-indicator according to dam height.



Note: The numbered streams indicate an example of how Strahler stream order is used to define a stream link (dashed line).

Figure 13. Illustration depicting how scores are assigned for the longitudinal-continuity barrier.



Dams with dedicated fish passage are not counted.

All sub-indicators except FFI can take a maximum value (S_{max}) of 3, while FFI can take a maximum value of 6 (Table 6 and Table 7). The sub-indicator scores (S) are standardized to a score that ranges between 0 and 1 by the equation 1 – (S / S_{max}) (Table 6 and Table 7). These sub-indicator scores then fall into one of the five grades of river health specified in this Regulation.

The physical form stressor combined index (PFS) value is the sum of the sub-indicator values (S_{sum}), and it can take a maximum value of 15. The combined index total is standardised to a score that ranges between 0 and 1 by the equation 1 – (S_{sum} / 15). The physical form stressor index score (PFS) then falls into one of the five grades of river health specified in this Regulation.

3.13 Riparian and in-stream vegetation

3.13.1 Rationale for inclusion

Riverine vegetation refers to plants in the river channels and riparian zone, which includes river banks, the floodplain and its wetlands, and other fluvial landforms inundated by bank-full discharge (Hupp and Osterkamp 1996). Reflecting the broad range of environmental conditions (Richardson et al. 2007), riverine flora is typically very diverse (Hughes 1997; Naiman and Décamps 1997). Whether herbs, shrubs or trees, all riverine vegetation provides an important role for both the structure and function of river ecosystems (Barling and Moore 1994; Naiman and Décamps 1997; Pen 1999; Hood and Naiman 2000; Richardson et al. 2007). The services that riverine plants provide are crucial for ecosystem health and are highly valuable to humans. These include:

- **Habitat:** Living and dead vegetation provides habitat for other biota. For example, it acts as a substrate for algae and invertebrates, and it can create pools and backwaters of low velocity, suitable for fish and turtles.
- **Source of energy and nutrients:** In-stream and riparian vegetation provide a source of carbon, nutrients and energy, and helps to form the basis of aquatic (and terrestrial) food webs.
- **Water filtration:** Riparian vegetation provides a buffer zone that filters sediments and controls nutrients. In-stream vegetation acts like a sewage treatment plant by filtering water and improving its quality.
- **Channel and riverbank stabilisation:** Shoots and particularly roots of riverine vegetation stabilise stream channels and banks.
- **Dispersal corridors:** Intact strips of riparian vegetation provide a corridor for the movement of animals.
- **Moderation of stream temperature:** Vegetation can moderate stream water temperature through evapotranspiration and shading.

The health of riverine vegetation is threatened by numerous processes that occur both inside and outside of the actual river (for examples see: Robertson 1997; Carpenter et al. 1998; Hood and Naiman 2000; Ogden 2000; Jansen and Robertson 2001; Richardson et al. 2007; Merritt et al. 2010; Quinn et al. 2010; Catford et al. 2011). Threats to riverine vegetation include:

- hydrological modification
- water pollution and disturbance caused by recreation and navigation along the river
- catchment land use practices that lead to vegetation clearing
- livestock grazing and trampling
- water pollution (including eutrophication)
- increased sediment deposition
- invasion by alien plants, which can reduce native plant cover and diversity and alter the structure and function of riparian plant communities.

Riparian vegetation provides numerous ecosystem services and functions, so disturbance and loss of riparian vegetation can impede river health. Assessing the condition of riparian vegetation can indicate the extent of human modification and disturbance that a riverine ecosystem has experienced, but it also indicates when a riparian ecosystem is in good condition or not. A dense, continuous, wide strip of riparian vegetation indicates good riparian condition. Large, mature trees usually indicate a lack of disturbance in the last few decades, and high numbers of young trees (saplings) indicate successful reproduction and suggest continued health of the riparian vegetation.

3.13.2 Methods

A sampling site consisted of a 500–1000 m reach with three sections of 50 m within that reach. All measurements and estimates were made for the three 50 m sections, and averaged across the reach to give a single value for the site.

At each of the three sections, the width of the riparian vegetation was measured with a range finder. The longitudinal extent or continuity (i.e. the inverse of fragmentation) of the riparian vegetation was scored from 0–5:

- 0 = no vegetation
- 1 = isolated or scattered vegetation
- 2 = regularly spaced vegetation
- 3 = occasional clumps of vegetation
- 4 = semi-continuous vegetation
- 5 = continuous vegetation.

The cover abundance of trees, shrubs and herbs was estimated. Values for these measures and estimates were recorded for both the left and right banks, and together they indicate the condition of the riparian zone including its capacity to filter inflowing water, and provide habitat, shelter and food for other organisms. In addition, the average and maximum tree height, and number of saplings (young trees) were recorded at each section. The name of the dominant tree species and a general site description were also recorded.

The cover abundance of in-stream vegetation (macrophytes) was estimated in each 50 m section.

3.14 Hydrologic alteration

3.14.1 Rationale for inclusion

Hydrologic alteration is one of the major drivers of ecological change in aquatic ecosystems, and should be a key component of a river health assessment program. Assessments of hydrologic alteration are often based around the natural flow paradigm (Lytle and Poff 2004), which emphasises evolutionary links between patterns of flow variability (timing, frequency and magnitude of different flows) and morphological, behavioural and life-history adaptations of the biota. Increasing levels of flow alteration are expected to increase the risk that these evolutionary linkages will be disrupted (Bunn and Arthington 2002). While there is much complexity and by no means perfect links between hydrologic alteration and ecological change, measures of hydrologic alteration provide a simple means of assessing potential risk. There is also a need to better understand the links between flow regime characteristics and ecological patterns and processes in particular regions to help inform this risk assessment process. The hydrology indicator values might be used as part of a multi-metric index, or they might be used to inform the narrative associated with the report card.

3.14.2 Methods

There are a number of methods for assessing hydrologic alteration currently in use in China. Many of these are derived from the Tennant method (Tennant 1976), which specifies nothing more than seasonal baseflows, and is probably not well suited to assessing rivers in China; rivers in China differ both in river type and the nature of flow alteration patterns from rivers in the central US where the Tennant method was originally developed. The range of methods that may be suitable for assessing hydrologic alteration in China are thoroughly reviewed in (Gippel *et al.* 2011)). Gippell et al. (2011) outlines the problems with many of the methods for assessing hydrologic alteration. In addition to reviewing existing methods, Gippel et al. (2011) propose two new metrics: the IFD and the IFH. As with most existing metrics used in river health assessments, the IFD assesses whether general hydrological parameters, thought to be either universally important or universally undesirable for maintaining good river health, have characteristics that are different to those of the reference (natural or unimpaired) flow regime. In contrast, the IFH examines whether specific hydrological parameters, identified as either locally important or locally undesirable for maintaining river health to an agreed standard, occur in the current flow regime. The IFH complements more detailed assessments of environmental flow requirements (Gippel et al. 2011). This study applied the IFD.

The IFD was designed to work with monthly historical flow data. It comprises eight indicators, with each one having conceptual relevance to ecosystem health. The eight indicators comprise:

- high-flow volume (HFV)
- highest monthly flow (HMF)
- low-flow volume
- lowest monthly flow (LMF)
- persistently higher flow (PHF)
- persistently lower flow (PLF)
- persistently very low (PVL)
- seasonality flow shift (SFS).

The IFD focuses on highlighting deviations of flow parameters beyond a reasonable range of natural variability, proving to be adequate as a river health index (Gippel et al. 2011). The IFD highlights impacts of flow regulation, and also highlights years of naturally lower than usual flows, both of which are important determinants of ambient ecological health, as measured using bioassessment methods. At the very least, the IFD provides a simple way of establishing the relative hydrological health of rivers at the national and regional scales for gauging stations that have pre-regulation flow data available.

An important consideration in evaluating hydrologic alteration is the high likelihood for a temporal trend in runoff that is independent of water resources development. For example, climate signals are present in runoff records of the Yangtze and Yellow Rivers. The headwater forests were also gradually cleared from the 1950s to 1990s, probably increasing baseflows. A major re-afforestation program was implemented in the 1990s in the Gui Jiang catchment, which will also have introduced trends into the time series.

It is important to take these temporal trends into account when defining the impacts of dams on flow. Ideally, the impacts are taken into account by comparing hydrologic regimes over similar time series by comparing modelled natural flows (i.e. without water resource development (extractions, diversions etc.)) with modelled actual flows. This approach addresses the issues of temporal trends, but also requires modelled data, which are not always available. The alternative is to define an early period as the benchmark period, and then compare all flows against that period. In this case, the deviation of flow indices could be due to a number of causes (climate change, dam, or land use change), which cannot be easily disentangled.

3.15 Overall summary of indicators selected for the trial

Summarising the previous sections of this chapter, indicators fall into a number groups that represent different measures of pressure on the ecosystem (e.g. land use, hydrology) and response (invertebrates, diatoms, fish, physical form). These groups are widely used together, but are reported on separately in river health monitoring programs. While collectively they can provide a summary of overall river health, treated separately they provide information on the potential priority threats that might need to be addressed to improve river health. Links between the health as determined by different indicator groups and the pressures acting on the ecosystem are drawn through the use of the conceptual models as discussed in section 1.5.

The indicators that were calculated across each of the main groups from the April 2010 dataset are summarised in Table 7. The following section of the report summarises the observed relationships between measures of land use change (the major pressure on rivers in the Gui River catchment) and the various river health indicators. As discussed in section 1.5, testing these links as part of the development of a river health monitoring program helps refine the set of indicators that are reported on and provides an evidence base on which to justify their inclusion. This becomes critical if contention arises from the results of future assessments.

Table 7. List of potential ecological health indicators for the Gui River Pilot Project and their expected response to environmental degradation.

Class	Variable	Units	Details	Expected response
Land use	Agriculture	%	% land use type in the upstream catchment	
	Urbanisation	%		
	Buffer Agriculture	%	% land use type in a 500 m buffer upstream of the site	
	Buffer Urbanisation	%		
Riparian condition	Riparian Width	m	Width of riparian vegetation strip	
	Riparian continuity	1-5	Ranking (1-5) of continuity of riparian vegetation along a 1km strip upstream of each site.	
Water quality	pH		pH	↑↓
	Chl-a		Chlorophyll concentration	↑
	DO	$mg.l^{-1}$		↑
	Turbidity	NTU	Nephelometric turbidity units	↑
	N02-N	$mg.l^{-1}$	Nitrites	↑
	NH4-N	$mg.l^{-1}$	Ammonia	↑
	NO3	$mg.l^{-1}$	Nitrate concentration	↑
	TN	$mg.l^{-1}$	Total Nitrogen concentration	↑
	TP	$mg.l^{-1}$	Total Phosphorous concentration	↑
	Cu	$mg.l^{-1}$	Copper	↑
	Cd	$mg.l^{-1}$	Cadmium	↑
	Pb	$mg.l^{-1}$	Lead	↑
	Cr	$mg.l^{-1}$	Chromium	↑
	Zn	$mg.l^{-1}$	Zinc	↑
	As	$mg.l^{-1}$	Arsenic	↑
	Hg	$mg.l^{-1}$	Mercury	↑
Algae	δ15N		δ15N enrichment	↑
	Filamentous algae cover	%	% cover of streambed in sampling area	↑
	IBD			↓
	IPS			↓
Invertebrates	Total abundance		Total macroinvertebrate abundance	↓
	Trichop Richness		Number of trichoptera species	↓
	EPT		Number of taxa from Ephemeroptera, Plecoptera & Trichoptera	↓
	RatioHepEph		Ratio Heptegonids/Ephemeroptera	↓
	Biotic index		Sensitivity score of invertebrate families	↑
	Dominance ratio		Ratio of abundance of 5 most common taxa to all others.	↑
	Dominance ratio 2		Ratio of most common taxa to all others.	↑
	Percentage Clingers			↓
	Taxon richness		Number of invertebrate taxa	↓
	Insect richness		Number of insect taxa	↓
	Dominant abundance		Abundance of most dominant taxa	↑
	Shannon Index		Shannon-Weiner diversity index	↑
	SIGNAL		Sensitivity score	↓

Class	Variable	Units	Details	Expected response
Fish	Fish Biomass		Biomass of fish caught during in field surveys	↓
	Fish Species Richness		Number of taxa caught at each site	↓
	Fish abundance		Number of individuals caught during surveys	↓
	Fish residual weight		Average residuals for each site based on pooled (log-log) length-weight regression	↓
	Fish tolerance index		To be developed in the future.	
Physical form	Free flow interruption		Extent of *local* hydrualic disruption due to upstream or downstream dam or weir	↓
	Sediment transport interruption		Presence and size of upstream dams and weirs	↓
	Longitudinal-continuity barrier		Number of intact in-stream structures (weirs or dams) that span the river width, located between the site and the mouth, and lacking a dedicated fishway	↓
	Catchment Sediment Risk		Proportion agriculture and ubranisation in the catchment	↓
Riparian vegetation	Width		Average width of riparian vegetation (isolating urban or agriculture or other land uses)	↓
	Fragmentation		Degree of longitudinal fragmentation of riparian vegetation	↓
	In-stream macrophyte cover		Percentage of cover of in-stream macrophytes	↑
Hydrology	Index of Flow Deviation (IFD)		Measures annual deviation in ecologically relevant flow metrics relative to modelled or pre-regulation monthly data.	↓

Details of the different indicator groups are discussed in the text.

4. Analyses of indicator response

Outline of statistical approach

This section summarises the statistical testing of potential indicators. Analyses were essentially conducted in two steps. First, correlations between catchment disturbance and water quality parameters were examined. Secondly, relationships between both water quality and land use and the biological indicator groups were examined. These two steps were separated because pressures acting on the aquatic ecosystem, such as land use change, hydrological alteration and riparian condition, often affect water quality parameters (e.g. nutrient concentrations, DO), which in turn affect biota (e.g. fish, macroinvertebrates and algae). Therefore, water quality parameters can act as both disturbance gradients and river health indicators. In the Gui River pilot project, water quality parameters were used as the secondary disturbance gradient for testing the effectiveness of biological indicators along with the primary land use gradient. Physical-form indicators were not included in the analyses as they measure the drivers or pressures directly.

There are a number of analytical approaches that can be used to examine trends in river health indicators, and the decision about which approach is most appropriate is generally guided by the size of the dataset and the number of indicators being examined. In this study, a very simple approach was adopted based on examining simple pairwise (Pearson) correlations between each of the measures of disturbance (catchment land use) and the various river health indices. Tests for correlations were supported by examining scatterplots to identify outliers and to determine where transformations were required. This also helped identify potential non-linear relationships among variables that would not be picked up by simple linear correlations.

To reduce the number of independent predictor variables being examined, a similar approach to Bunn et al. (2010) and Smith and Storey (2001) has been adopted, and used axis-scores from Principle Components Analysis (PCA) as a means of summarising some of the water quality indicators used as measures of secondary disturbance. Specifically, concentrations of six heavy metals were treated in this way; being reduced to just two PCA axis scores PC1 and PC2 for each site. While heavy metal concentrations were all low, the two PCA axes were strongly correlated with concentrations of Cd and Zn (PC1) and Cu, Pb and Cr (PC2) (Table 8). Correlations between biological indicators and the PCA axis scores would thus be indicative of correlations also with these respective groups of metals. These correlations are examined below.

Table 8. Factor loadings between PCA axes and each of the metals sampled.

Metal	PC1	PC2
Cu	0.27	-0.63
CD	-0.67	-0.03
Pb	-0.09	-0.70
Cr	-0.06	-0.32
Zn	-0.67	-0.08
As	0.16	0.07

Note: Axis 1 and 2 explained 60 per cent of the total variance.

4.2 Summary of land use disturbance gradient

Forest and grassland (natural vegetation cover) were the dominant land use types upstream of most sites surveyed, with median percentage cover in the three classes (first order, second order, third order and above) ranging from 45–70 per cent. Across individual sites, native vegetation cover ranged between 9 and 97 per cent. Agricultural land use ranged from 0–33 per cent of total land use, but in streamside buffer zones approach 70 per cent, indicating a tendency for agriculture to be located close to streams. Urban land use overall was also minimal (0–3 per cent) but covered a much larger range (0–69 per cent) in buffer areas. Of the three catchment classes, 2nd and 3rd+ order streams, on average, had higher levels of catchment disturbance, but 1st order streams were the most variable, including the most disturbed and least disturbed sites in terms of agriculture (Table 9). Urbanisation occupied 100 per cent of the buffer-zone land use at one site in the 3rd class.

Table 9. Summary of land use above each site.

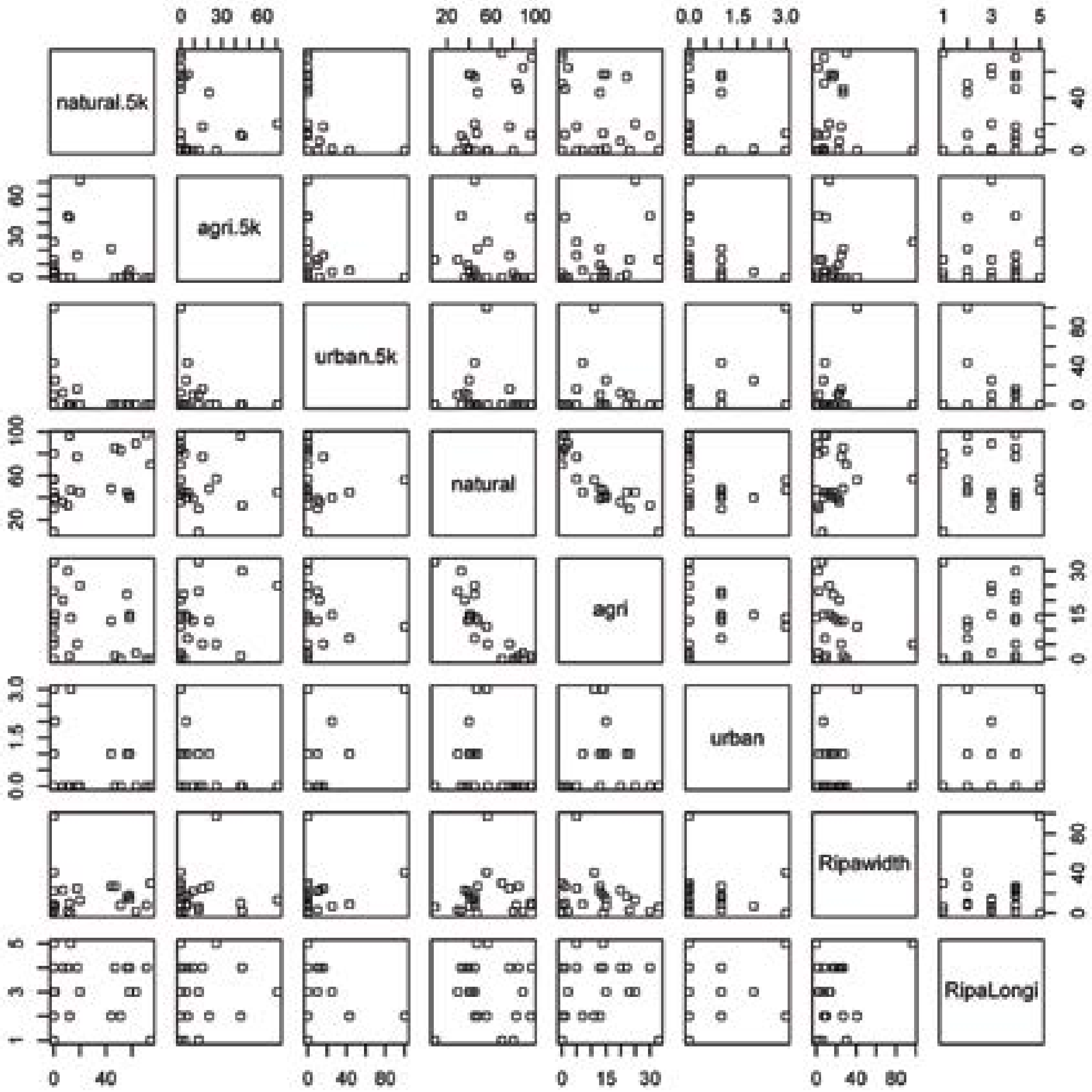
Class	stat	n	forest.5k	agri.5k	urban.5k	forest	agri	urban	Ripawidth	RipaLongi
1	median	8	49	0	0	77	2	0	8	3
	min		0	0	0	9	0	0	2	1
	max		74	13	12	97	33	1	30	4
	se		11	2	2	12	5	0	4	0
2	median	6	6	21	0	51	6	0	11	4
	min		0	3	0	33	0	0	2	1
	max		20	71	43	80	30	1	97	5
	se		4	11	7	8	5	0	15	1
3	median	9	13	4	0	45	14	1	17	3
	min		0	0	0	39	1	0	0	2
	max		58	44	100	96	22	3	41	5
	se		9	5	11	6	2	0	4	0

Numbers refer to percentages in the whole upstream catchment or streamside buffer respectively. Width and longitudinal statistics relate to the width (m) and fragmentation (scaled 0–5) along a 1 km reach at each site.

Overall, while much of the Gui River catchment is dominated by natural vegetation classes (forest and grassland), land cover is much more altered in close proximity to rivers. This reflects the dependence of humans (and agriculture) on water, and the tendency for population centres to be located near rivers.

Because of the relatively small number of sites included in the pilot study, and also the relatively high level of similarity of catchment characteristics, a completely independent analysis around each of the three catchment classes has not been attempted. Instead, sites from the three classes have been combined to examine the impacts of direct and indirect disturbance gradients. However, the different catchment classes will be revisited in evaluating targets and thresholds for applying the indicator scores to condition assessment. To differentiate the potential impacts of different forms of land use, a common problem in simple correlative studies is covariance among the different variables being examined (Allan 2004). Figure 1 shows a correlation plot, comparing the different land use descriptors against one another for sites in the Gui River catchment. It shows that the variables of interest (notably agriculture and urbanisation) are poorly correlated with one another. This addresses the risk that the impacts of agriculture will be confounded with the impacts of urbanisation, but does not rule out the potential correlation of either of these land use types with other natural physical gradients.

Figure 14. Scatterplot showing correlations between individual pairs of land use descriptors for the 23 sub-catchments being examined.



The 0.5k post-script refers to land use in the buffer zone 5 km upstream and 500 m either side of the river from the point of sampling.

4.3 Indicator responses to disturbance gradients

4.3.1 Water quality

Water quality results

Water quality was broken into three additional groups: physicochemical, nutrients, and metals, which were ultimately represented by two PCA axis scores. While a proper assessment of the 'condition' scores is presented in 5, overall, the water quality in the Gui River catchment was good, with all parameters within typical ranges that do not immediately indicate any major concerns (Table 10). When the disturbance indicators were examined, some clear trends were evident among a number of the indicators (Table 11). The strongest trends were for increasing pH and conductivity in agricultural areas; increasing nutrient concentrations (NH4, NO3, TN); and decreasing oxygen concentrations associated with urbanisation at both catchment wide and buffer-scales (Table 11). Figures showing pairwise relationships are presented in the section 8.1.

Table 10. Summary of water quality characteristics at the 25 sites sampled.

	Physicochemical Indicators				Nutrients				
	pH	Cond	DO	NTU	NO2-N	NH4-N	NO3	TN	TP
median	7.87	155	8.255	2.75	0.0175	0.115	1.155	1.31	0.04
sd	0.4	70.9	0.4	4.4	0.0	0.1	0.5	0.6	0.0
min	6.79	22	7.39	1.2	0.013	0.015	0.42	0.58	0.02
max	8.74	258	9.17	15.1	0.19	0.356	2.86	3.16	0.12

	Metal concentrations						
	Cu	CD	Pb	Cr	Zn	As	Hg
median	82	17	0	1.5	0	32.5	49.5
sd	21.6	13.5	0.4	8.0	1.1	29.2	28.7
min	30	3	0	0	0	0	0
max	97	47	1	23	3	71	94

Table 11. Correlations between water quality indicators and the primary disturbance indicators.

	Physicochemical Indicators				Nutrients					Metal PCA Axes	
WQ	pH	Cond	DO	NTU	NO2.N	NH4.N	NO3	TN	TP	PC1	PC2
agri	0.69	0.6	-0.04	-0.09	-0.19	0.16	0.37	0.36	-0.23	0.23	0.04
urban	-0.26	0.23	-0.54	0.37	0.04	0.8	0.58	0.6	0.31	0.22	0.03
agri.5k	0.07	0.36	0.17	0.06	0.36	-0.33	-0.22	-0.22	-0.2	0.18	0.07
urban.5k	-0.3	0.08	-0.5	0.33	-0.01	0.73	0.33	0.33	0.22	0.12	0.29
Ripawidth	-0.13	-0.22	-0.02	0.17	-0.07	0.02	0.02	-0.02	-0.23	0.17	0.04
RipaLongi	0.2	-0.05	-0.24	-0.42	-0.19	-0.01	0.25	0.22	-0.12	0.14	-0.09

Correlations in bold have r > ±0.4 and p<0.05.

Water quality recommendations

Historically, water quality measurements have formed the basis of most river health assessment programs both in China and elsewhere. In this assessment, there were predictable relationships between urbanisation and nutrients, for example, and between increasing conductivity and agriculture in the upstream catchment. Not surprisingly, nitrogen was the major nutrient responding to urbanisation gradients, and urbanisation was associated with increased concentrations of several forms of nitrogen (NH4, NO3 and TN), which were also correlated with each another. While transformation between different forms of nitrogen will occur due to natural processes within the stream, they potentially may be derived from different sources (e.g. sewage, agriculture). Therefore, it appears to be beneficial to continue to include these separate measurements in water quality assessments, rather than simply TN for example.

In addition to the observed trends, there is still considerable potential for human activities to influence the variables that showed no trends, such as heavy metal concentrations. Most of these parameters showed very little variation and it is not surprising that no relationships were observed. Metal concentrations are more likely to vary in response to industrial or mining activities. As isolated point sources of pollution, these disturbances may not be easily picked up by the disturbance metrics used in this analysis. It is recommended heavy metal concentrations are still included in the reporting (Table 12); however, the drivers of change in these indicators are absent in the Gui catchment. The final screening process relates to setting appropriate targets and benchmarks, discussed in Section 5.

Due to the wide use of water quality monitoring, it is recommended to incorporate all the measured parameters into future monitoring programs.

Table 12. List of WQ indicators recommended for potential inclusion in the report card.

Indicator group	Indicators showing expected response	Provisional indicators showing limited variation in the Gui
WQ	pH	Turbidity
	Cond	Metal Concentrations
	DO	TP
	NH4	FRP
	NO3	
	TN	

4.3.2 Algae

Algae results

A total of five algal indicators were examined: two (Chl.a and fil.algae) measured algal abundance, two (IBD and IPS) reflect environmental tolerances of extant taxa, and one (δ15N) provides an indication of the likely sources of Nitrogen fuelling algal growth. Most indicators showed considerable variation among the sites sampled (Table 13). All indicators showed trends in response to urbanisation or agriculture with the exception of fil.algae, which showed no clear relationships (Table 14). δ15N values increased with proportion of agriculture in the catchment, while Chl.a concentrations indicated higher algal abundances in urban catchments. IBD and IPS were both strongly negatively correlated with urbanisation (Table 14). IPS was negatively correlated with measures of N enrichment also (NH4.N and TN). A negative correlation between DO and Chl.a (and IBD) may reflect covariance in DO or possibly excessive algal respiration at some urbanised sites. Figures showing pairwise relationships are presented in section 8.2.

Table 13. Summary of algal indicators from the 25 sites sampled.

	Chl.a	δ15N	fil.algae	IBD	IPS
median	1.6	5.8	2.2	16.9	17.1
sd	1.1	2.3	31.8	2.0	2.8
min	0.5	3.1	0.0	12.1	12.3
max	4.9	12.8	88.0	19.4	19.9

Table 14. Correlations between algal indicators and land use and water quality stressors.

	Chl.a	δ15N	fil.algae	IBD	IPS
agri	0.04	0.54	0.05	0.03	0
urban	0.58	0.16	-0.03	-0.58	-0.75
agri.5k	-0.14	0.47	-0.13	0.12	0.12
urban.5k	0.64	-0.09	-0.06	-0.32	-0.44
Ripawidth	0.13	-0.24	0.25	-0.08	-0.03
RipaLongi	-0.02	0.14	-0.07	-0.12	0.05
pH	-0.23	0.26	0.16	0.29	0.3
Cond	0.38	0.74	0.04	-0.32	-0.35
DO	-0.58	0.15	0.45	0.51	0.47
NTU	0.29	-0.15	-0.41	-0.29	-0.36
NO2.N	0.27	-0.01	-0.23	-0.31	-0.37
NH4.N	0.52	0.3	0.19	-0.47	-0.52
NO3	0.4	0.29	-0.19	-0.36	-0.41
TN	0.42	0.35	-0.15	-0.42	-0.47
TP	0.02	0.18	0.07	-0.22	-0.28
PC1	0.56	0.07	0.17	-0.1	-0.2
PC2	-0.3	-0.44	-0.45	0.28	0.36

Correlations in bold have r > ±0.4 and $p<0.05$.

Algae recommendations

Chlorophyll concentrations, IBD, IPS were clearly associated with the impacts of urbanisation, and it is recommended that these indicators are considered for future monitoring programs. Careful thought needs to be given to the differences between IBD and IPS. The scoring system for these two indices may also need to be revised for Chinese river systems, not just in Gui Jiang, but more generally. δ15N also showed clear response to agriculture, indicating possible agricultural runoff even though overall nutrient concentrations were not particularly high. δ15N is therefore a potentially sensitive indicator of enrichment. The final subset of potential algal indicators is summarised in Table 15.

Table 15. Summary of algal indicators considered for potential inclusion in the report card.

Indicator group	Indicators showing expected response	Provisional indicators showing limited variation in the Gui
Algae	Chl-a	
	δ15N	
	IBD	
	IPS	

4.3.3 Invertebrates

Invertebrate results

Relative to other indicator groups, a large number of invertebrate indicators were examined. This was primarily because of the large number of indices that have been developed around invertebrates and the ease with which these indicators can be calculated after assemblage data has been gathered. As with other indicator groups, most invertebrate indicators showed substantial variation across the 25 sites surveyed (Table 16).

Of the 14 indicators examined, 12 showed a strong and statistically significant relationship with the urbanisation gradient (Table 16). Relationships between agriculture and riparian buffer land use showed similar patterns in terms of direction, but were typically of lower magnitude. This was a surprising result given the low levels of urbanisation within the catchments overall, and the frequent association of urbanisation with riparian regions (Section 3.7).

Other disturbance gradient indices that invertebrate metrics showed positive or negative significant and strong relationships to included conductivity (8 indicators); ammonium (NH4; 7 indicators); NO3, TN, TP; and PC1 and PC2 (5 or fewer indicators showing a relationship each) (; setion 8.3). As with algae, correlations with secondary (WQ) disturbance indices probably reflect a mix of direct causal relationships and associations arising from covariance patterns. A large number of pairwise comparisons were undertaken in this analysis leading to the potential for *p*-values to become somewhat misleading. For example, by adopting a *p*-value of 0.05 means that 1 test in 20, in this case ~10 tests, may show a significant *p*-value by chance alone. While the correlations along suggest that many of the indicators examined have potential to be included in a broader river health assessment, there are other additional factors relating to causal models, likely transferability, and ease of explanation that need to be considered in selecting a final subset. These issues are discussed in more detail in the recommendations section below as well as in chapter relating to targets and thresholds.

Table 16. Summary of invertebrate indicator values at the 25 sites sampled.

	Total abundance	Trichop species	EPT	EPT ratio	Ratio HepEph	Biot	Ratio five
median	153.5	0.0	4.5	0.3	4.5	5.4	90.3
sd	90.9	1.3	4.2	0.2	29.5	1.8	12.7
min	9.0	0.0	0.0	0.0	0.0	2.6	60.5
max	310.0	6.0	16.0	0.6	98.5	8.9	100.0
	Clingers	**Total richness**	**Insect richness**	**Dominant abund**	**Shannon**	**SIGNAL**	**SIGNAL weighted**
median	26.9	12.0	9.0	49.5	2.5	4.6	4.7
sd	36.8	7.3	7.7	47.0	1.1	1.7	1.9
min	0.0	2.0	0.0	7.0	0.2	1.5	1.0
max	93.3	29.0	28.0	216.0	3.9	6.7	7.9

Table 17. Correlations between invertebrate indicators and land use and water quality stressors.

	Total abundance	Trichop species	EPT	EPT ratio	Ratio HepEph	Biotic Index	Ratio five	clingers	taxarich	Insect richness	Dominant abundance	Shannon	SIGNAL	SIGNAL weighted
agri	0.09	-0.34	-0.25	-0.15	-0.13	0.32	0.11	**-0.45**	-0.05	-0.27	0.04	0.04	-0.21	-0.23
urban	**-0.53**	-0.31	-0.61	**-0.63**	-0.5	**0.64**	0.5	**-0.68**	**-0.58**	**-0.63**	-0.06	-0.57	-0.66	-0.62
agri.5k	0.1	-0.21	0.02	0.22	0.21	0.11	-0.03	0.04	0.15	0.05	0.02	0.12	0.22	0.22
urban.5k	-0.29	-0.19	-0.39	**-0.44**	-0.33	**0.65**	0.29	**-0.42**	-0.32	-0.38	-0.03	-0.31	-0.45	-0.4
Ripawidth	0.05	-0.18	0.01	-0.04	0.14	-0.09	-0.22	0.03	0.14	0.14	-0.05	0.19	0.03	0.06
RipaLongi	**0.41**	0	0.24	-0.06	0.1	-0.15	-0.43	0.03	0.41	0.33	0.19	0.29	0.02	0.12
pH	0.19	-0.14	-0.02	-0.03	-0.09	-0.01	-0.11	-0.18	0.1	-0.04	-0.02	0.18	-0.06	-0.16
Cond	-0.14	**-0.52**	-0.58	**-0.43**	**-0.6**	**0.52**	0.37	**-0.73**	-0.36	**-0.55**	0.25	-0.36	-0.52	-0.6
DO	0.11	0	0.03	0.09	0.26	-0.14	0.05	0.2	0	0.09	0.02	0.01	0.16	0.08
NTU	-0.24	-0.23	-0.18	0.09	-0.41	0.09	0.22	-0.29	-0.19	-0.18	-0.08	-0.17	0.03	-0.09
NO2.N	-0.34	-0.23	-0.07	0.33	-0.19	-0.02	0.26	0.15	-0.24	-0.19	-0.09	-0.29	0.27	0.25
NH4.N	-0.35	-0.22	**-0.58**	**-0.76**	**-0.43**	**0.77**	0.35	**-0.67**	**-0.46**	**-0.54**	0.03	-0.45	-0.77	-0.7
NO3	-0.19	-0.15	-0.31	-0.4	-0.47	0.38	-0.03	**-0.69**	-0.11	-0.28	-0.02	-0.1	-0.45	-0.51
TN	-0.24	-0.17	-0.36	-0.43	-0.5	**0.43**	0.03	**-0.72**	-0.18	-0.34	-0.01	-0.18	-0.5	-0.55
TP	-0.28	-0.12	-0.29	-0.23	-0.29	**0.52**	0.34	-0.29	-0.38	-0.3	0.04	**-0.49**	-0.23	-0.23
PC1	-0.1	**-0.86**	**-0.53**	-0.38	**-0.62**	0.15	0.42	-0.37	-0.38	**-0.51**	0.27	-0.39	-0.41	-0.36
PC2	0.1	0.32	**0.45**	0.4	0.31	0.3	**-0.45**	0.16	0.46	**0.44**	**-0.51**	**0.54**	0.41	0.36

Correlations in bold have r > ±0.4 and p<0.05.

Invertebrate Recommendations

Some general observations are, of those indices calculated, some (such as percentage of clingers), are much less widely used than others and may be inappropriate in many stream types. Also, the Shannon index has little conceptual basis for use in river health assessments, and its use in ecology has been criticised more generally due to the lack of a mechanistic basis for trends in the index (Hurlbert 1971).

Another important point is that the two grade-based sensitivity indices (the Biotic Index and SIGNAL score) were developed in very different regions to those being assessed here. A strength of the order-class-phylum version of the SIGNAL scoring system is its assessment of sensitivity at a very coarse taxonomic level, which is likely to increase its generality. However, irrespective of the apparent effectiveness of these indices in reflecting observed disturbance gradients in the Gui River Pilot study, any wider adoption of sensitivity-based metrics would require specifications to be revised based on expert knowledge of Chinese taxa – a point stressed in previous studies (e.g. Morse et al. 1991). This also applies to sensitivity indices for fish and diatoms. Setting thresholds should be considered in selecting a final subset of indicators. Indicators that seem to have the most validity include those presented in Table 18.

Table 18. Subset of invertebrate indictors recommended for inclusion or exclusion in the scorecard for the Gui River

Indicator group	Indicators showing expected response	Provisional indicators included or excluded based on additional factors
Invertebrates	EPT taxa	Trichop Species*
	EPT ratio	Ratio HepEph*
	Biotic Index	Clingers*
	Ratio Five	Insect richness*
	SIGNAL	Taxa Richness*
	SIGNAL weighted	Dominant abundance*
		Shannon*

* Excluded based on factors other than the presence/absence of a strong correlation.

4.3.4 Fish

Fish results

In contrast to macroinvertebrates, a relatively small number of fish-based indicators were examined. This reflects the fact that greater regional differences in broad taxonomic groups and in the life history of individual taxa, coupled with greater challenges of sampling, have resulted in many fewer indicators being developed for fish that could be easily trialled. The indicators examined focussed on abundance, biomass, diversity and individual condition. However, despite considerable variation in biomass, abundance and individual condition among the 25 sites (Table 19), there were few significant relationships (Table 20). The exceptions were the relationships between conductivity and abundance, and residual weights and agriculture land use, turbidity, and conductivity. The overall length weight relationships (Figure 15) showed the predicted relationship, and indeed the analyses of correlation scores suggest that negative residuals were associated with agricultural sites.

Table 19. Summary of fish indicator characteristics across the 25 sites surveyed.

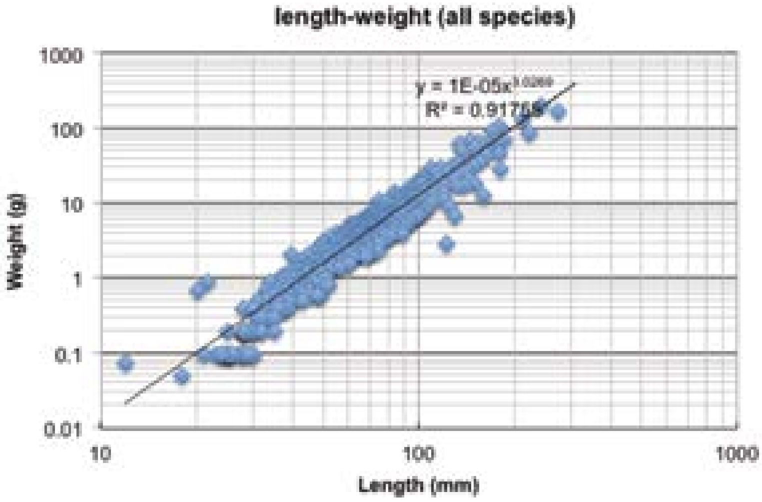
	fish_biomas	fish_richness	fish_abund	fish_resid
median	253.4	6	48	-0.002
sd	320.3	3.5	50.6	0.3
min	5.4	2	6	-0.572
max	1244.5	13	230	0.493

Table 20. Correlations between fish indicators and land use and wq stressors.

	fish_biomas	fish_richness	fish_abund	fish_resid
agri	-0.15	-0.1	-0.32	-0.31
urban	0.01	-0.21	-0.28	0.04
agri.5k	-0.32	0.14	0.17	**-0.57**
urban.5k	0.06	-0.13	-0.13	0.16
Ripawidth	0.15	0.38	0.01	-0.17
RipaLongi	-0.04	-0.07	-0.11	-0.08
pH	-0.06	-0.01	-0.32	-0.21
Cond	**0.36**	0.22	0.11	**-0.59**
DO	0.12	0.1	-0.21	-0.17
NTU	-0.11	-0.13	0.07	-0.49
NO2.N	-0.17	0.34	**0.71**	-0.29
NH4.N	0.33	-0.03	-0.21	0.18
NO3	0.22	-0.18	-0.12	-0.07
TN	0.26	-0.14	-0.09	-0.08
TP	**0.43**	0.1	0.24	0.06
PC1	0.27	**0.45**	0.38	-0.44
PC2	-0.24	-0.21	0	0.18

Correlations in bold have $r > \pm 0.4$ and $p<0.05$.

Figure 15. Plot showing length-weight relationship (note log-log axes) examined across all species of fish.



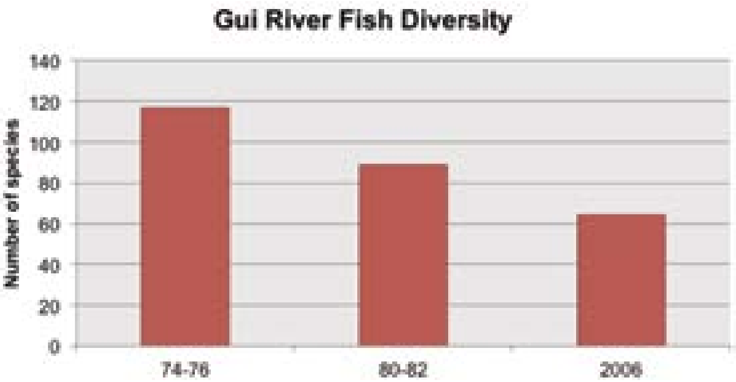
Fish recommendations

There is considerable interest in incorporating fish into river health monitoring programs, but it brings considerable challenges, particularly for adequate sampling and taxonomic generality. This assessment tested only a small range of possible fish-based indicators, and while their were significant relationships with salinity and turbidity, we doubt there being a causal link between these variables given that water quality was generally good.

From fisheries surveys conducted over several decades, it is clear that the number of fish species in the Gui River catchment is declining markedly (Figure 16). This decline poses considerable challenges for assessing 'present day' disturbance gradients because large-scale changes in assemblages throughout the catchment may already have occurred. This 'ghost of land use past' has been documented elsewhere, such as in invertebrate assemblages in previously cleared and now reforested catchments in the USA (Harding et al. 1998). In addition, the construction of numerous barriers along the Gui River may also act as a migration barrier, and may have contributed to overall species decline. The assessment approach adopted in this study is poorly suited to capturing these impacts, and would require the inclusion of largely unregulated catchments as a point of comparison. This may be possible in future assessments.

Overall, the results of the pilot project point to the need for substantial work to revise and improve indicators of fish assemblage health, coupled with an assessment of appropriate sampling strategies before fish indicators are recommended to be included in report cards (Table 21).

Figure 16. Trends in fish species richness in the Gui River catchment since the 1970s.



Data from PRWRPB (2010).

Table 21. Summary of fish indicators considered for potential inclusion in the report card.

Indicator group	Indicators showing expected response	Provisional indicators showing limited variation in the Gui
Fish		Fish richness
		Fish abundance
	Residual weight*	

Note that these indicators all require further development before being more widely adopted.

4.3.5 Physical form

Physical form results

Information on land use and on-stream barriers was compiled from several sources. Data for FFI was collected from the field surveys, whereas data for STI, LoCB and CSR came from Google Earth satellite imagery and pre-existing GIS layers of water infrastructure. Details of individual dams are summarised in Table 22, and calculations of individual physical form sub-indices are in Tables 23–25. Final results are provided in Table 26.

Table 22. Details of the barriers on the Gui River

No	Name	Address	Installed Capacity (MW)	Basin Area (km2)	Mean Annual Discharge (m^3/s)	Dam height (m)	Pool Level (m)	Fishway	Water System
A	Fuzikou Hydropower Station	Yao autonomous township, Xingan county, Guangxi	15.0	325	18.2	76	270	No	Ludong River
B	Shuangtan Hydropower Station	Shuangtan village, Lingchuan county, Guilin, Guangxi	69.0	1260	-	-	-		Li river
C	Bajiangkou Hydropower Station	Dafa Yao autonomous township, Pingle county, Guangxi	78.0	12,621	67.8	52	97.6		Gui River
D	Zhaoping Hydropower Station	Zhaoping town, Zhaoping county, Guangxi	63.0	13,170	430		72		
E	Xiafu Hydropower Station	Fuyu village, Zhaoping town, Zhaoping county, Guangxi	45.0	15,200	483	30	54		
F	Jinniuping Hydropower Station	Xiongbu village, Majiang town, Zhaoping county, Guangxi	48.0	15,748	500	32	42		
G	Jingnan Hydropower Station	Jingnan township, Cangwu county, Guangxi	69.0	17,388	551	34	30		
H	Wangcun Hydropower Station	Wang village, Changzhou district, Wuzhou, Guangxi	40.0	18,261	590	48	17		
I	Shankou Hydropower Station	Dongchang town, Lipu County, Guangxi	0.8	1925	-	57	-		Lipu River
J	Jiangkou Hydropower Station	Pingle town, Pingle county, Guangxi	0.8	1950	51.51	139	-		

- data missing

Table 23. The calculation of FFI and LoCB

No.	Name	Nearest barrier upstream (name)	Nearest barrier downstream (name)	Distance upstream to barrier (km)	Distance downstream to barrier (km)	Total barriers upstream	Total barriers downstream (to the mouth)	Backwater	Downstream of a hydropower station	FFI	LoCB
No.1	Wangcun	G	H	44	3	7	1	✔		3	1
No.5	Xiafu Hydropower Station	E	F	2	34	5	3		✔	3	2
No.8	Zhaoping Hydropower Station	D	E	2	18	4	4		✔	3	2
No.11	Lipu Hydropower Station	-	J/I	-	20/32	-	8				2.5
No.12	Niancun	-	J/I	-	49/61	-	8			0	2.5
No.13	Yangshuo hydrologic station	B	C	104	70	2	6		✔	3	2.5
No.15	Guanyan	B	C	54	120	2	6		✔	3	2.5
No.18	Guilin hydrologic station	B	C	22	152	2	6		✔	3	2.5
No.22	Darongjiang	A	B	15	28	1	7		✔	3	2.5
No.24	Ludonghe	-	A	-	3	-	8		✔	3	2.5
No.25	Wuguihe	-	A	-	28	-	8			0	2.5
No.2	Longjiang	All these sites locate in other tributaries without barriers.					1			0	1
No.3	Fuqun River						1.5				
No.4	Huangyao						1.5				
No.6	Siqin River27#						2				
No.9	Gongcheng hydrologic station						2.5				
No.10	Gongcheng River						2.5				
No.14	Yulong River						2.5				
No.16	Chaotian River						2.5				
No.17	Xinzai						2.5				
No.19	Lantian						2.5				
No.20	Dongjiang River						2.5				
No.21	Lingqu						2.5				

Table 24. The calculation of STI

No.	Name	Nearest barrier upstream (name)	Dam height (m)
No.1	Wangcun	G	34
No.5	Xiafu Hydropower Station	E	30
No.8	Zhaoping Hydropower Station	D	-
No.13	Yangshuo Hydrologic Station	B	-
No.15	Guanyan	B	-
No.18	Guilin HydrologicSstation	B	-
No.22	Darongjiang	A	76

*Even the dam height of the two hydropower station (B&D) is unknown. However, it is assumed to be higher than 15 m.

Table 25. The calculation of CSR

	Subbasine area (m^2)	agrarian area (m^2)*	urban area (m^2)	P	CSR
No.01	18,225,844,984	2,413,137,450	189,162,934	14%	1
No.02	366,812,244	2,214,158	0	1%	0
No.03	635,168,244	154,917,284	19,853,620	28%	2
No.04	220,456,373	61,110,772	16,384,772	35%	2
No.05	15,165,435,225	2,198,659,305	169,309,313	16%	1
No.06	1,590,208,573	353,158,267	8,709,023	23%	1
No.07	82,809,525	0	8,413,802	10%	1
No.08	13,165,090,708	1,833,913,609	146,060,650	15%	1
No.09	2,604,514,542	341,201,812	10,480,350	14%	1
No.10	972,901,207	190,491,429	2,730,795	20%	1
No.11	989,285,979	71,812,538	11,587,429	8%	0
No.12	358,767,468	1,771,327	2,287,964	1%	0
No.13	5,552,592,665	824,404,983	123,992,871	17%	1
No.14	83,547,577	26,865,122	0	32%	2
No.15	4,252,512,650	599,815,514	120,154,997	17%	1
No.16	352,272,604	16,458,578	0	5%	0
No.17	36,090,782	0	0	0%	0
No.18	2,906,894,776	317,362,706	93,732,706	14%	1
No.19	49,080,512	1,107,079	0	2%	0
No.20	106,870,046	0	0	0%	0
No.21	236,619,729	54,542,102	1,549,911	24%	1
No.22	721,225,201	37,862,109	590,442	5%	0
No.24	306,513,330	3,764,069	0	1%	0
No.25	33,802,818	369,026	0	1%	0

*: agrarian area = farmland and paddy

Table 26. The score of physical form stressor index (PFS)

No.	Name	FFI	STI	LoCB	CSR	PFS
No.1	Wangcun	3	3	1	1	0.47
No.2	Longjiang	0	0	1	0	0.93
No.3	Fuqun River	0	0	1.5	2	0.77
No.4	Huangyao	0	0	1.5	2	0.77
No.5	Xiafu Hydropower Station	3	3	2	1	0.40
No.6	Siqin River27#	0	0	2	1	0.80
No.7	Siqin River26#	0	0	2	1	0.80
No.8	Zhaoping Hydropower Station	3	3	2	1	0.40
No.9	Gongcheng hydrologic station	0	0	2.5	1	0.77
No.10	Gongcheng River	0	0	2.5	1	0.77
No.11	Lipu Hydropower Station	0	0	2.5	0	0.83
No.12	Niancun	0	0	2.5	0	0.83
No.13	Yangshuo hydrologic station	3	3	2.5	1	0.37
No.14	Yulong River	0	0	2.5	2	0.70
No.15	Guanyan	3	3	2.5	1	0.37
No.16	Chaotian River	0	0	2.5	0	0.83
No.17	Xinzai	0	0	2.5	0	0.83
No.18	Guilin hydrologic station	3	3	2.5	1	0.37
No.19	Lantian	0	0	2.5	0	0.83
No.20	Dongjiang River	0	0	2.5	0	0.83
No.21	Lingqu	0	0	2.5	1	0.77
No.22	Darongjiang	3	3	2.5	0	0.43
No.24	Ludonghe	3	0	2.5	0	0.63
No.25	Wuguihe	0	0	2.5	0	0.83

A low PFS score indicates a heavy stress on the physical form at a site. Those sites immediately downstream of a barrier received consistently lower scores (Table 26). Low scores also indicate that most of the barriers in Gui River are high dams (mostly more than 30 meters in height), and lack fishways.

4.3.6 Riparian and in-stream vegetation

Vegetation results

Riparian buffer width and continuity both varied considerable between sites (Table 27) and with stream order. Because riparian width is generally, (although not always; Mac Nally *et al.* 2007) assumed to scale with stream order (Naiman and Décamps 1997), it is not surprising to see a general trend of increasing median and maximum riparian width at larger sites. Maximum riparian width often reflected the transition to non-riparian vegetation, which can make it difficult to identify in some forest types (Mac Nally *et al.* 2007). Across all stream orders, observed minimum buffer widths were less than 1 m, and fragmentation was high. Observations at a number of field sites showed that agriculture, including rice-paddy farming, can extend right up to the stream margins (The absence of a riparian buffer coupled with nutrient additions and the high volumes of water involved in paddy farming will lead to high levels of nutrients leaking into rivers from such locations.).

Table 27. Summary statistics for riparian width and continuity recorded at each site.

Summary Statistic	Stream Order	Riparian Width (m)	Longitudinal Continuity (0-5)
Median	1	7.7	3.0
	2	12.8	4.0
	3+	16.7	3.0
Min	1	1.5	1.0
	2	1.5	1.0
	3+	0.1	2.0
Max	1	30.0	4.0
	2	96.7	5.0
	3+	41.3	5.0
Std Deviation	1	11.5	1.3
	2	33.3	1.4
	3+	12.0	1.1

The absence of a riparian buffer coupled with nutrient additions and the high volumes of water involved in paddy farming will lead to high levels of nutrients leaking into rivers from such locations.

Figure 17. Example of paddy farming extending to the stream margin.

Vegetation recommendations

While assessments of vegetation condition often involve more detailed data collection incorporating structural complexity, diversity, recruitment and the presence of invasive species (e.g. the habitat hectares approach Parkes et al. 2003), it was not practical to incorporate these indicators into the present data collection process due to limited time and lack of sufficient expertise and training throughout the whole project team. Instead, two much simpler measures that relate specifically to the likely buffer capacity of riparian zones became the focus. While the influence of buffer width and continuity varies greatly depending on the ecological process of interest (Naiman and Décamps 1997; Hansen et al. 2010), it still seems appropriate to use measures of buffer width to identify sites where buffers are very narrow or completely absent, as in The absence of a riparian buffer coupled with nutrient additions and the high volumes of water involved in paddy farming will lead to high levels of nutrients leaking into rivers from such locations. An additional advantage of the measures used is they can be assessed directly in the field or via remote sensing. For remote sensing, it would make sense to undertake the assessment over a slightly larger scale. At present, Google Maps imagery, which is generally widely available, does not provide sufficient resolution in all regions (e.g. see Figure 18) for a Google Earth image of the location shown in Figure 17), but other sources of imagery will often be available.

Figure 18. Image showing the stream reach where Figure 17 was taken.

While evidence of agriculture can be clearly seen in the image, it is difficult to ascertain the boundaries of land under cultivation.

One aspect of vegetation that was not considered further in this study was in-stream macrophytes. This indicator proved too unreliable due to surveys being done at a time of year when macrophyte cover is at a minimum. Nuisance levels of aquatic macrophytes are, however, often associated with high nutrients levels. Many of the more common floating macrophytes in China are invasive (e.g. Eichhornia crassipes, Pistia stratioides) and can:

- pose a threat to native species diversity
- alter the structure and function of river ecosystems
- clog irrigation channels and ponds
- impede navigation
- provide habitat (stagnant patches of water) that is suitable for breeding of disease vectors, like mosquitoes and flies (Chu et al. 2006; Lu et al. 2007; Weber et al. 2008).

An increase in the abundance of disease-carrying mosquitoes and flies poses a serious threat to human health (e.g. transmission of malaria). As already noted, the issue with in-stream macrophytes as an indicator is the substantial variation in abundance through the year, with proliferations of macrophytes generally occurring during the warmer months. This has important implication for sampling. While the pilot project was not able to demonstrate techniques for assessing in-stream macrophytes, they should not be ruled out for incorporation into future assessments.

Table 28. Suggested indices to rapidly assess riverine vegetation condition, including quantification methods and references for example schemes.

Indicator group	Indicators showing expected response	Provisional indicators showing limited variation in the Gui
Riparian vegetation	Vegetated buffer width	
	Vegetation buffer continuity	
In-stream vegetation		Cover of free-floating nuisance/invasive taxa*

* Not assessed in this study.

4.3.7 Hydrology

Hydrology results

The IFD indicators were derived for each year in the available historical monthly flow time series (1957–2010) for three gauges on the Gui River system: Guilin (Li River); Gongcheng (Gongcheng River); and Majiang (Gui River). The reference statistics for the indicators were derived from modelled reference data, available for the period 1957–2000. Further detail of the three gauges is provided in Gippel et al. (2011).

The annual IFD index score calculated over the time series for the three Gui River system stations indicated a degree of inter-annual variability, which reflected natural variability in hydrological conditions and resulted in some years having very high levels of flow deviation (Figure 19). The scores at Guilin and Majiang showed no general decline when Qingshitan Dam began operation from 1964 in the headwaters of the Li River. At Gongcheng, the index scores followed a similar pattern through time as the Gui and Li river stations (Figure 19). There is no trend apparent in the IFD scores for the three gauges on the Gui River system.

The most recent three years of flow records in the Gui River systems were 2008–2010, which also showed a low level of flow deviation, consistent with the longer period (1957–2010) (Figure 20).

Figure 19. Time series of IFD indicator scores in 5 classes of deviation for the three Gui River gauges.

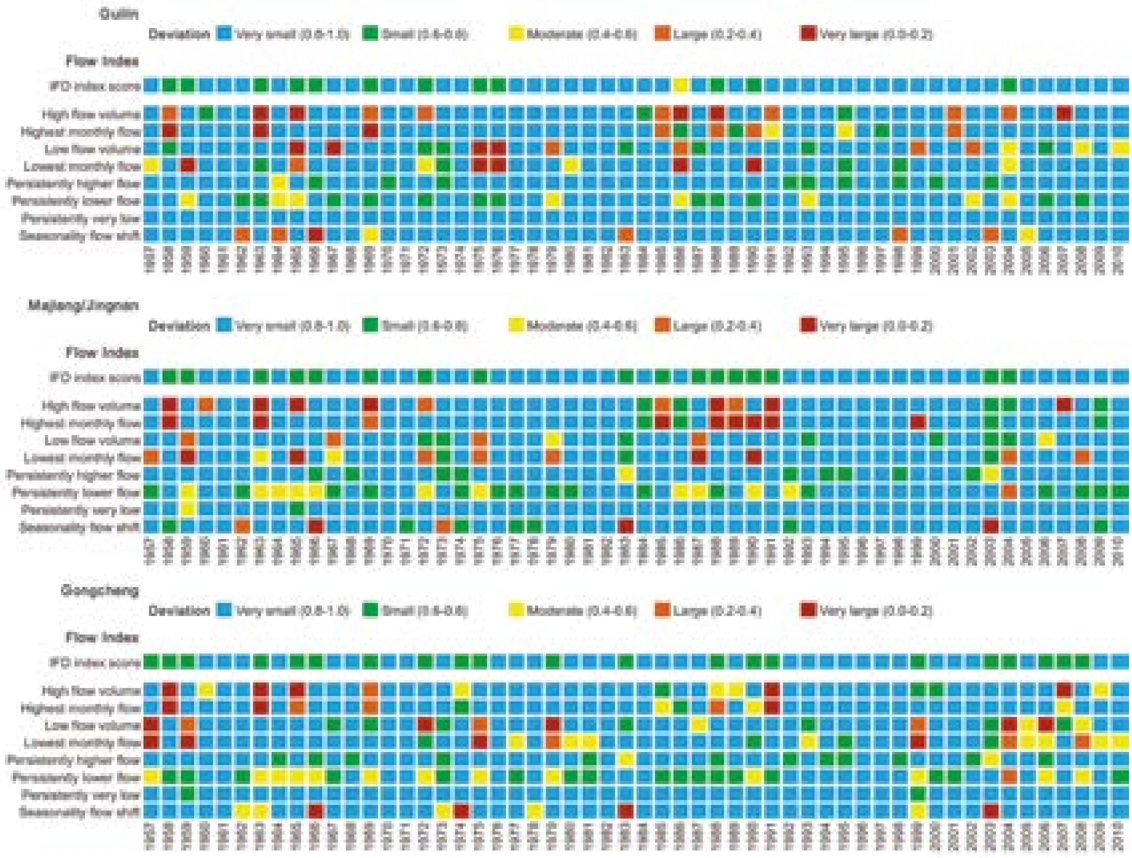
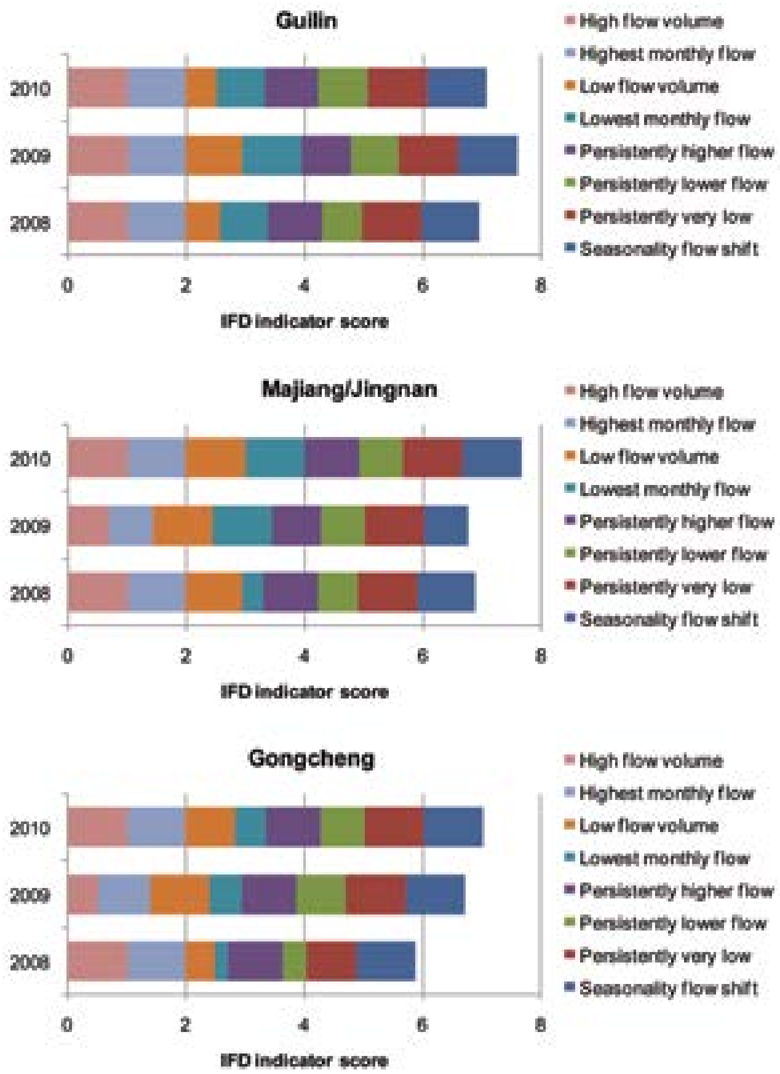


Figure 20. Detailed IFD indicator scores for Gui River system stations for the last three years of available record.



Hydrology recommendations

As discussed in Gippel et al. (2011), the IFD was developed to measure flow alteration based on a comparison with pre-regulation monthly flow data, and to overcome some of the limitations recognised in alternative indicators currently in use in China and elsewhere. The IFD was designed to work with monthly historical flow data, which is more commonly available than daily and modelled reference data (although the later can be used where available). It comprises eight indicators, with each one having conceptual relevance to ecosystem health. The IFD, with its focus on highlighting deviations of flow parameters beyond a reasonable range of natural variability, proved to be adequate as a river health index. The IFD highlights impacts of flow regulation, and also highlights years of naturally lower than usual flows, both of which are important determinants of ambient ecological health, as measured using bioassessment methods. At the very least, the IFD provides a simple way of establishing the relative hydrological health of rivers at the national and regional scales for gauging stations that have pre-regulation flow data available.

4.4 Summary of potential indicators

A summary of the indicators selected for potential inclusion in the report card is presented in Table 29. As outlined in Section 1.5 and Figure 9, the next step is to set appropriate targets and benchmarks to allow these indicators to be incorporated into a score of river health. This step may lead to a certain indicators being excluded from the program if appropriate reference points for scoring cannot be established. This step is discussed in Section 5.

Table 29. Summary of the indicators selected for potential inclusion in the report card.

Indicator group	Indicators showing expected response
WQ	pH
	Cond
	DO
	NH4
	NO3
	TN
Algae	Chl-a
	δ15N
	IBD
	IPS
Invertebrates	EPT taxa
	EPT ratio
	Biotic Index
	Ratio Five
	SIGNAL
	SIGNAL weighted
Fish	Fish richness
	Fish abundance
	Residual weight*
Macrophytes	Riparian Width
	Riparian connectivity
Physical form	Free Flow Interruption
	Sediment Transport Interruption
	Longitudinal-continuity barrier
	Catchment Sediment Risk
Hydrology	Index of Flow Deviation (IFD)

5. Ecosystem Health Reference Values, Scoring Options and Results

5.1 Introduction

To report on river health, it is important to set threshold or target values (referred to here as 'reference values') for each of the indicators that reflect different levels of ecosystem health. Most importantly, it is necessary to agree on levels that distinguish between 'good' (reference) and 'bad' (unacceptable) condition in a particular river, based on:

- river type (based on a classification process)
- management objectives for the river.

For example, different trigger values for water quality parameters are routinely set for different uses or values (e.g. aquatic biodiversity, drinking water, recreational contact, industrial use), which can be used to set thresholds of concern. While the process of establishing targets and thresholds of concern (values for an indicator that are considered to reflect poor condition) can be guided by scientific knowledge, this process is a subjective one. Therefore targets and thresholds may evolve over time as well as varying from place to place. Different interest groups (e.g. tour operators, farmers, industry) may have different beliefs about what is acceptable. Thus, the final targets and thresholds may require an iterative process involving some negotiation and assessment of different objectives.

5.2 Setting reference values

There are a number of approaches that can be used to set ecosystem health targets. Probably the most widely used approach is to use the values indicators would take if the site or catchment was undisturbed by human activity (i.e. in a state of biological integrity). However, in practice these sites will not exist for many stream types. The use of 'reference sites' is therefore common as a concept, but rare in practice. Alternatives for reference values include:

- best attainable condition, i.e. the expected condition if best management practices were in use, for a given use of the river or catchment
- established criteria or standards (often applied to water quality)
- standards required for designated use (swimming, fishing, industry, agriculture, drinking, e.g. China River Categories I–V)
- comparison with values derived from indicator-disturbance relationship equations.

5.3 Options for reference values for the Gui River Pilot Project

Setting indicator targets is one of the more difficult aspects of establishing a river health-monitoring program. This is because, while conceptual approaches to river health assessment and the sampling methods used are relatively easily transferred from one region to another, it is much more difficult to transfer expectations about target and threshold values for indicators.

There are several approaches for setting targets, and the following section outlines these approaches in some detail. However, it is worth stating that the relatively small number of sites surveyed in the Gui River catchment limited the options for setting thresholds and targets.

The broad approaches for setting targets can be grouped into the following categories:

1. targets and thresholds based on pre-defined standards
2. targets and thresholds drawn from reference site values
3. targets and thresholds based on statistical summary of observed data
4. extrapolation of observed relations.

Examples of each approach are discussed below.

5.3.1 Targets and thresholds based on pre-defined standards

The first approach based around pre-defined standards is widely applied to water quality data. For example, in China, State of the Environment reporting for river health is based on the National Surface Water Quality Standard (GB3838-2002), which classifies chemical water quality into five water use categories for a range of indices (MEP 2008). A number of water quality indicators are used to define these standards, with each parameter having a numerical limit for each category (Ma and Ortolano 2000). Under these standards (Table 30), functional river categories I, II and III would provide some protection for aquatic ecosystem health. In particular, categories I and II would be most applicable, because category III also applies to aquaculture, trade waters and swimming areas. Standards for category III and above rivers could therefore have potential for use as thresholds values to indicate when the aquatic ecosystem is in an unacceptable state of health. These standards are applied independently of the data collected in any particular sampling period, although actual data may be used to refine standards over time.

Table 30. China surface water quality standards for each river category for relevant, potential indicators of aquatic ecosystem health.

River categories	Phenols mg/L	DO mg/L	BOD5 mg/L	CODMn mg/L	NH3-N mg/L	TN mg/L	TP mg/L
	≤	≥	≤	≤	≤	≤	≤
I	0.002	7.5	3	2	0.15	0.2	0.02
II	0.002	6	3	4	0.5	0.5	0.1
III	0.005	5	4	6	1	1	0.2
IV	0.01	3	6	10	1.5	1.5	0.3
V	0.1	2	10	15	2	2	0.4

5.3.2 Targets and thresholds drawn from reference site values

Historically, the concept of reference sites has underpinned most scoring systems. However, in practice these sites are difficult to find. Where it is possible, a set of reference sites should be identified before sampling begins, usually based on the assessment of land use and other pressures on river health. Reference sites are selected based on the absence of significant human influences in the upstream catchment. In the Gui River catchment, the upland sites were relatively undisturbed compared to lowland sites; but the river classification in this study highlights the potential bias associated with adopting data from these sites as a reference for sites in the rest of the catchment. The bias would be based on the different characteristics of these sites compared to others, such as stream size, altitude, slope etc. This is a common problem.

While the small dataset and limited number of potential reference sites makes applying this approach difficult in the Gui, it is worth noting that some of the indicators that were successful in the trial (such as IBD, IPS, Biotic Index and SIGNAL) all draw on the perceived tolerance of different taxa to declining water quality or habitat conditions to some degree. Implicit in these indices is an expectation that 'sensitive' taxa are more likely to occur at reference sites. Therefore, the reference condition concept comes into play in developing these metrics, but often via the input of expert opinion.

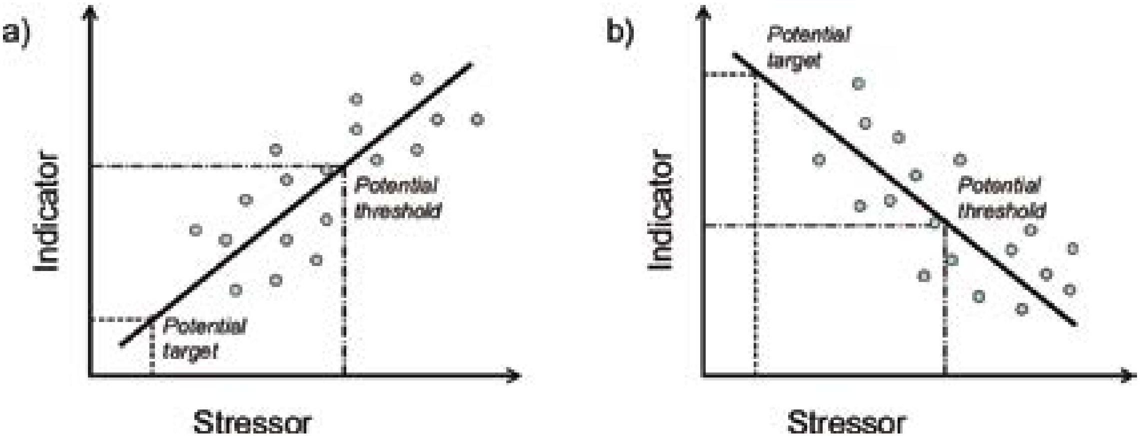
5.3.3 Targets and thresholds based on statistical summary of observed data

Alternatively, in situations where no sites are in 'reference condition' or there are very few minimally disturbed sites (such as in the Gui River Pilot Project) it must be considered likely that most sites will be in a relatively disturbed condition. Threshold values that indicate when an aquatic ecosystem is in an unacceptable state of health can be derived from observed data.

The logic behind this approach is that a random sample of sites will contain a mix of good and bad conditions – the best sites may be used to indicate targets, while the worst sites may be used to set thresholds of concern. For example, values higher than the median or mean (depending on if the data was normally distributed or not) could represent the threshold to separate sites experiencing different levels of stress (Figure 21). In Australia, the ANZECC guidelines recommend the use of the 95th percentile of observed values for indices that respond in a positive direction to a disturbance gradient or the 5th percentile of observed values for indices that respond in a negative direction to a disturbance gradient, as indication of unacceptable ecosystem health (ANZECC 2000) (see also Figure 22). This approach could also be used to set potential target values if no other guidelines are available and in the absence of true reference condition sites, as indication of 'good' ecosystem health (US EPA 2000; Stoddard et al. 2006).

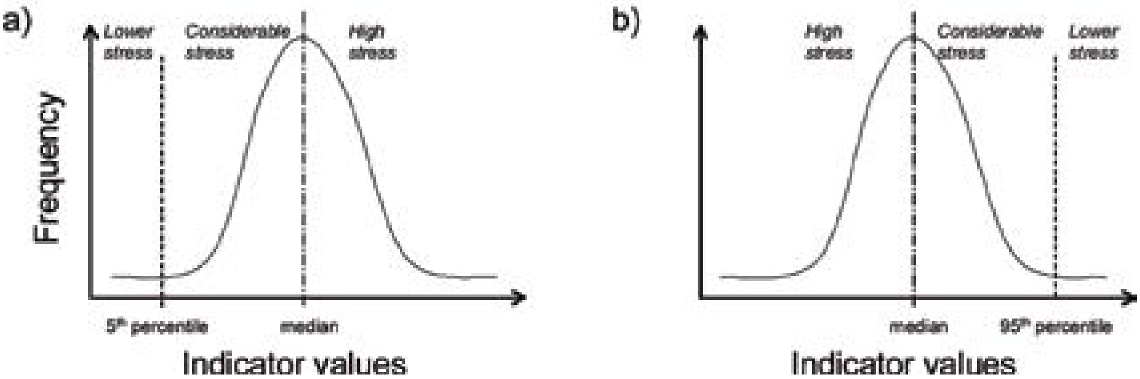
Broadly, this approach has some merit, but is extremely risky if applied to small datasets because the best and the worst sites may not captured in the data. Therefore, this approach may be useful in a future assessment program, but is probably not suitable for the Gui River dataset. By way of example, if this approach was applied to data on metal concentrations, for example, some sites in the Gui River would be deemed to be above the threshold of concern, while, in practice, it is known that all sites had low metal concentrations. While the existence of Chinese Water Quality Standards makes this a trivial example, it highlights the risk of applying this approach. However, if a bigger set of sites was surveyed, it would be more likely that the sample included sites that truly did contain elevated metal concentrations.

Figure 21. Theoretical relationships between an indicator of aquatic ecosystem health and an environmental disturbance (stressor) to which the indicator shows a) a positive response, or b) a negative response.



Potential target values for the indicator would correspond with the environmental disturbance value considered to represent a minimal or acceptable level of stress. For (a) this would be a low indicator value, and for (b) a high indicator value. Potential threshold value for the indicator would correspond with the environmental disturbance value considered to represent a high or unacceptable level of stress. For (a) this would be a medium to high indicator value, and for (b) a low to medium value. Blue circles represent observed data where there are no minimally disturbed sites.

Figure 22. Observed values of an indicator may be used to inform decisions about target and threshold values for aquatic ecosystem health.



When no (or very few) minimally disturbed sites exist, it may be expected that a small percentage of sites (e.g. 5 per cent) are under comparatively low levels of environmental stress – potential target values could therefore be derived from (a) the 5th percentile of observed values for each indicator that responds in a positive way to environmental disturbance; or (b) the 95th percentile of observed values for indicators that respond in a negative way to disturbance. For these same directions of response, indicator values at sites that are under unacceptably high levels of environmental stress may be expected to be (a) higher than the median observed value for all sites; or (b) lower than the median observed value for all sites.

5.3.4 Extrapolation of observed relations

Another less widely used approach is to use empirical models (e.g. indicator–disturbance gradient regression models) to extrapolate target and threshold values (Stoddard et al. 2006). In the case of regression models, a target value may be inferred for an indicator by setting the coefficient for the disturbance gradient variable to a value indicative of minimal human disturbance (e.g. zero percentage urban land cover). A threshold value may also be inferred by setting the same disturbance gradient variable to a value indicative of an unacceptable level of human disturbance. There are two issues associated with this approach, however. First, caution must always be applied when extrapolating from a regression curve as the estimates will be outside the range of observed data from which the model was derived (Stoddard et al. 2006). Second, the values of the disturbance gradient variables chosen to represent states of minimal and unacceptable levels of human disturbance will be subjective. These risks mean that for the time being, this approach is not advocated.

5.3.5 Decision framework for setting targets and thresholds

In cases where no, or very few, minimally disturbed sites exist within river monitoring and assessment regions, the following decision tree may be used to derive target and threshold indicator values to score sites for aquatic ecosystem health.

1. Does an established and appropriate guideline value exist for the indicator that could be used as a target or threshold value?
   a) Yes: Choose the most conservative or most appropriate value for the indicator and region of interest, based on local knowledge, expert opinion, type of river system and region, the temporal and spatial scale of relevance of the guideline, the current and future management and land use practices in the region
   b) No: go to (2).
2. For the region of interest, can target and threshold values be estimated (extrapolated) from the relationships modelled between the observed indicator data and the disturbance gradients (in this case the regression models that conformed to selection criteria) by setting the coefficient for the disturbance gradient variable to a value indicative of minimal human disturbance (to estimate the target indicator value) or unacceptable levels of human disturbance (to estimate the threshold indicator value)?
   a) Yes: Follow the same process outlined for (1a), substituting 'established' for 'extrapolated'.
   b) No: go to (3).
3. Use the distribution of observed data for the indicator and region of interest to derive target and threshold indicator values, considering local knowledge, expert opinion, type of river system and region, the temporal and spatial scale of relevance of the data, the current and future management and land use practices in the region.
   a) For indicators that respond in a positive way to environmental stress, choose the target value as the 5th percentile of observed indicator values in the region of interest, and the threshold value as the median.
   b) For indicators that respond in a negative way to environmental stress, choose the target value as the 95th percentile of observed indicator values in the region of interest, and the threshold value as the median.
4. These values should be reviewed and, if necessary, be revised based on results of successive monitoring and assessment rounds; any changes to the program's objectives and spatial or temporal scale of relevance; management actions that affect aquatic ecosystems. In particular, if the number of minimally disturbed sites within any reporting region increases substantively in the future, the use of 5th median and 95th percentiles of observed data in the decision tree should be re-considered.

Note that in the Gui River the first branch of the decision tree has been relied on – the use of established guidelines or those drawn from expert opinion. As already discussed above, braches 2 and 3 are dependent on more comprehensive datasets in order to be applied with any level of reliability.

5.4 Potential target and threshold values for the Gui River Basin

Based on the decision framework, and the results of the April 2010 field trial analyses, the tables below present potential target and threshold values for the reduced list of physical, chemical and biotic indicators for the Gui River Basin (see section 4.4).

5.4.1 Water Quality

To maintain consistency with existing water quality standards, the following table scores indicators on the scale of I–V although these were rescaled between 0 and 1 for calculating site scores. Water quality standards are presented in Table 31.

Table 31. Water Quality standards associated with different river class zones in China.

Class	pH	Cond	DO	NTU*
I	6–9	-	7.5	1
II	6–9	-	6	1
III	6–9	-	5	1
IV	6–9	-	3	1
V	6–9	-	2	1

Class	pH	Cond	DO	NTU*
I	6–9	-	7.5	1
II	6–9	-	6	1
III	6–9	-	5	1
IV	6–9	-	3	1
V	6–9	-	2	1

* Drinking water standard

Class	Cu	CD	Pb	Cr	Zn	As	Hg
I	0.01	0.001	0.01	0.01	0.05	0.05	0.00005
II	1	0.005	0.01	0.05	1	0.05	0.00005
III	1	0.005	0.05	0.05	1	0.05	0.0001
IV	1	0.005	0.05	0.05	2	0.1	0.001
V	1	0.01	0.1	0.1	2	0.1	0.001

5.4.2 Algae

Unlike water quality, there were no existing Chinese standards for the algal indicators that could be drawn on. The same situation was also true for invertebrates and fish. Tables 27–29 indicate the source of the scoring system in its original form and, where necessary, any conversions that were applied to create the categories for reporting on a similar scale to water quality. In the case of IPS and IBD, indicator scores were drawn from published studies (Eloranta and Soininen 2002) (Table 32). Values for Chlorophyll, a concentration, and δ15N were drawn from work in South East Queensland (Smith and Storey 2001); however, in South East Queensland, only target and threshold values were available (Table 33). These values were converted to a scale of I–V by splitting the intermediate values into equal bins (Table 34).

Table 32. Values for IPS for different river health categories in Finland.

IPS and IBD Index Score	Water Quality	Trophic Status
>17	High	Oligotrophy
15–17	Good	Oligo-mesotrophy
12–15	Moderate	Mesotrophy
9–12	Poor	Meso-eutrophy
<9	Bad	Eutrophy

Source: Eloranta and Soininen (2002).

Table 33. Target (class I) and threshold (class V) indicator values for δ15N and Chl-a concentrations from the ANZECC guidelines and SEQ Healthy Waterways monitoring program.

Class	Equivalent class	δ15N$	Chl.a(mg/m3)*
Upland guide	I	5	
Upland WCS	V	10	
Lowland guide	I	5	12
Lowland WCS	V	10	19

$ANZECC standards
*EHMP standards
Note: Chl-a is not used as an indicator in upland streams and were excluded from the Gui River analysis.

Table 34. δ15N values divided into 5 categories (Class I-V) based on uniform divisions between the target and threshold values from ANZECC Guidelines (Table 33).

Class	Equivalent class	δ15N	Chl.a(mg/m3)*
Upland guide	I	5	Not applied
	II	7	
	III	8	
	IV	9	
Upland WCS	V	10	

Note: Chlorophyll concentrations were not included in the Gui River reporting.

5.4.3 Invertebrates

As with algae, target and threshold values for selected macroinvertebrate indicators were drawn from existing programs and from the literature, largely to demonstrate the approach and provide a demonstration report card. However, these scoring systems should not be adopted in their present form. Decisions about appropriate scores require further analysis of a much larger set of samples to decide on appropriate scoring systems. This is true even where the scoring systems appear to be consistent with expectations.

EPT taxa richness is widely used as an indicator; however, there are also likely to be regional differences in species richness, and also the number of species collected will vary with sampling effort. Therefore, it was not appropriate to apply straight EPT taxa richness values to the Gui River samples. Instead, previously published EPT and total taxa richness values associated with different condition scores (Lenat 1988) were used, which are reproduced in Table 35, and were converted into percentages (Table 36) on the basis that percentages would be slightly more general than absolute values. **Again, however, this is a bold assumption adopted for the purposes of demonstrating the trial report card and generally values based on local data should be used for future assessments**. Values for the Biotic Index were also taken from Lenat (1988) (Table 37).

Table 35. Taxa richness criteria for assigning water quality classification to free-flowing, shallow North Carolina streams and rivers, July-September.

	EPT Taxa Richness			Total Taxa Richness		
class	Mountain	Piedmont	Coastal	Mountain	Piedmont	Coastal
Excellent	>41	>31	>27	>91	>91	>83
Good	32–41	24–31	21–27	77–91	77–91	68–83
Good-fair	22–31	16–23	14–20	61–76	61–76	52–67
Fair	12–21	8–15	7–13	46–60	46–60	36–51
Poor	0–11	0–7	0–6	0–45	0–45	0–35

Source: Lenat (1988).

Table 36. Values of EPT ratios derived from data in Lenat (1988) and Table 35.

		EPT Taxa Ratio	
class	Mountain	Piedmont	Coastal
I	>0.45	>0.34	>0.33
II	0.42–0.45	0.31–0.34	0.31–0.33
III	0.36–0.41	0.26–0.30	0.27–0.30
IV	0.26–0.35	0.17–0.25	0.19–0.25
V	0.0–0.25	0.0–0.16	0.0–0.18

Table 37. Values of the Biotic Index from Lenat (1988) for streams in different condition in North Carolina.

	Ecoregion	
water quality classification	**Mountains**	**Hill Country and Coastal Plain**
Excellent	<4.18	<5.24
Good	4.19–5.09	5.25–5.95
Good-Fair	5.10–5.91	5.96–6.67
Fair	5.92–7.05	6.68–7.70
Poor	>7.05	>7.71

Note: These values are adopted here for demonstration purposes and should be not adopted for future reporting.

Finally, a similar approach was adopted in deriving a scoring system for SIGNAL values, which are presented in Table 38.

Table 38. Values for the SIGNAL index associated with different measures of ecosystem condition in south-east Australian streams where the SIGNAL index was developed.

Class	SIGNAL 2 Score	Habitat quality
I	>6	Healthy habitat
II	5–6	Mild pollution
III	4–5	Moderate pollution
IV	<4	Severe pollution
V	<3	Very severe pollution

5.4.4 Fish

In contrast with water quality, algae and invertebrate indicators, there were no existing schemas that could be adopted to associate different indicator scores with measures of stream health based on fish. The values presented in Table 39 reflect a mix of local expert opinion and scores based on a statistical assessment of condition data, noting that, overall, there appear to have been long-term declines in fish diversity in the Gui River catchment. The premise behind the fish condition indicator is that sites where the average residual weight scores (after fitting a length-weight regression) are negative, are home to fish in poorer condition than the average. Conversely, above-average residual weights indicate fish in relatively good condition. A simple scoring system based on distance from the average residual weight (±1 or ±2 standard deviations) was applied to this indicator (Table 39).

Table 39. Values of three fish indicators used in the trial report card.

upland	fish_richness	fish_abund	fish_resid weight
I	3	20	μ+1sd
II	3	16	>μ
III	2	12	<μ
IV	2	8	<μ-1sd
V	1	4	<μ-2sd
lowland	**fish_richness**	**fish_abund**	**fish_resid weight**
I	8	>20	μ+1sd
II	6	>16	>μ
III	4	>12	<μ
IV	2	>8	<μ-1sd
V	1	>4	<μ-2sd

5.4.5 Physical form

The physical form index presented in Section 3.12.1 includes a scoring system that standardises the index scores for use in a multi-metric index. The details of the index are not repeated here and the reader is referred back to section 3.12.3 for more details.

5.4.6 Vegetation

Riparian buffer width influences a large range of ecological processes, and the ecological values provided by different buffer widths vary greatly (Naiman et al. 2005; Hansen et al. 2010). For example, while a 5 m buffer may provide shade for small streams and protect bank stability, much wider buffers (30+ m) may be required to filter soluble nutrients from adjacent agriculture, and much wider zones to provide terrestrial biodiversity benefits (Naiman et al. 2005; Hansen et al. 2010). The information from these reviews was applied, as well as information from the field data to score riparian width and continuity data. These criteria could be refined depending on the types of value being sought from riparian buffers (e.g. bank stability, nutrient interception, terrestrial biodiversity etc.).

Table 40. Values for the 2 riparian indicators used in the trial report card

Class	Width (m)	Continuity (0–5)
I	50	5
II	30	4
III	20	3
IV	10	2
V	5	1

5.4.7 Hydrologic alteration

As for physical form, the hydrologic alteration an approach to assessing hydrologic alteration was developed for this project that includes a scoring system that standardises the index scores for use in a multi-metric index. The details of the index are not repeated here and the reader is referred back to section 3.14.2 for more details.

5.5 Scoring River Health

While the tables in section 5.4 associate condition with category measures ranging between I–V, for statistically summarising different indicators, it is preferred to adopt a numerical scoring system. The categories detailed in Section 5.4 were converted into numerical values as shown in Table 41. This step could also be avoided by relating the original indicator values to a numerical scoring system at the beginning of the assessment. A key feature of the scoring system is that all indicators are expressed on a common scale. The formulae for undertaking this type of conversion are relatively simple, but differ depending on whether the indicator increases or decreases with a relative decline in the observed condition.

Table 41. Conversion of categorical indicator classes into numerical indicator scores.

Class	Numerical score	Description
I	1	Excellent
II	0.8	Good
III	0.6	Fair
IV	0.4	Poor
V	0.2	Very poor

5.6 Aggregation and reporting of indicator scores

A final step in preparing a scorecard is aggregating the results for simplified reporting. This aggregation is often done by averaging the scores for indices within each indicator group, although it may also be preferred to include some measure of the variability or worst and best performing indicators within each group. For example, if any of the individual indices is particularly detrimental to overall ecosystem health (e.g. excessively high heavy metal concentrations), it may be more appropriate to take the minimum score for any one indicator within an indicator group as the overall score for the group.

Scores can also be aggregated across sites to provide an overall score for each of the river regions. This can be done by averaging the indicator group scores across sites within each river region, which is the method used by the EHMP in Australia.

Another step may be required to set the levels at which scores are considered to be 'acceptable' or 'of concern' for ecosystem health. For example, is a score of 0.5 considered to pass or fail in terms of ecosystem health? The chosen as the acceptable cut-off may also depend on the ecosystem health objectives or the management actions applicable to the site, river section or reporting region. For example, a score of 0.2 may be considered acceptable for a site in a designated industrial zone where little or no ecosystem health management is expected. These options and their implications for ecosystem health and management must be considered carefully (see Gippel 2010a for more information).

Potential scores for the Gui River Basin, based on the sampling and analyses of the April 2010 data, are presented in Section 6. These scores are provided as an example only, based on the processes outlined in this document. Revision should be considered based on future monitoring and assessment rounds and expert opinion and local knowledge of what may be expected for aquatic ecosystem health in the river regions of the catchment.

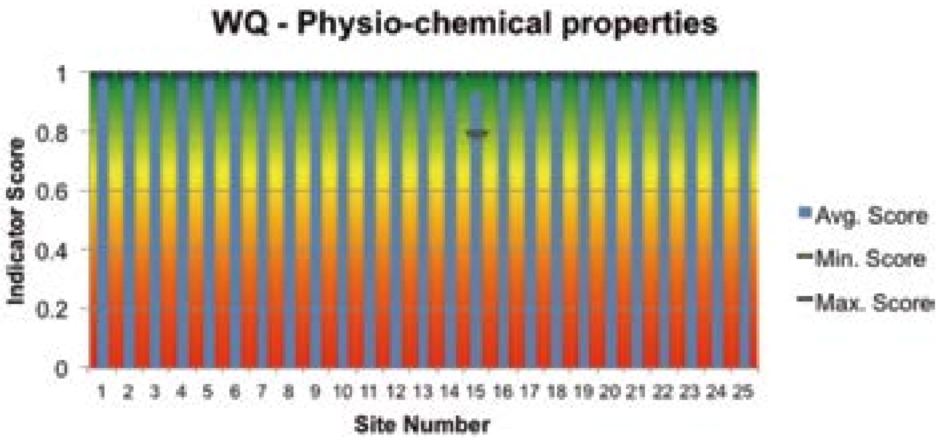
5.7 Assessment of river health based on the pilot data

Previous sections of the report have outlined a general approach to river health assessment (section 1), discussed the selection of and trialling of indicators (section 3 and section 4), and the conversion of data into an appropriate scoring system based on targets and thresholds (Section 5.4). This section provides a brief summary of the findings from the pilot sampling program for river health in the Gui River catchment.

5.7.1 Water quality

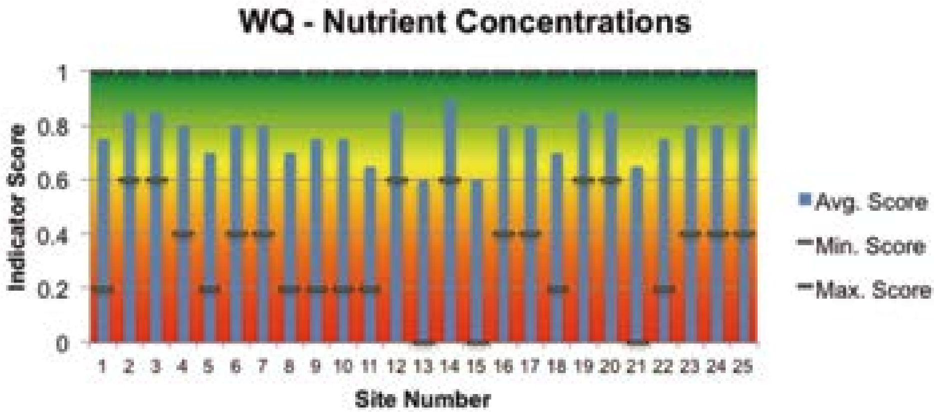
In general, physio-chemical parameters were very good (Figure 23), while nutrient concentrations were elevated at a number of sites (Note: Bar heights represent average values for the sub indicators, and the horizontal lines the maximum and minimum sub-indicator scores at each site.) leading to only moderate condition scores with respect to this indicator. This is largely the result of elevated NH_4 and NO_3 concentrations, particularly in more urbanised reaches. Heavy metal concentrations were low at all sites (Figure 24), and this does not appear to be a problematic aspect of river health in the catchment. Such a finding is not unexpected given the low levels of industry, although ongoing gold dredging and mercury extraction may still lead to sediment contamination, which will not be picked up the sampling undertaken in the pilot.

Figure 23. Summary of physico-chemical water quality indicators for the 25 sites surveyed.



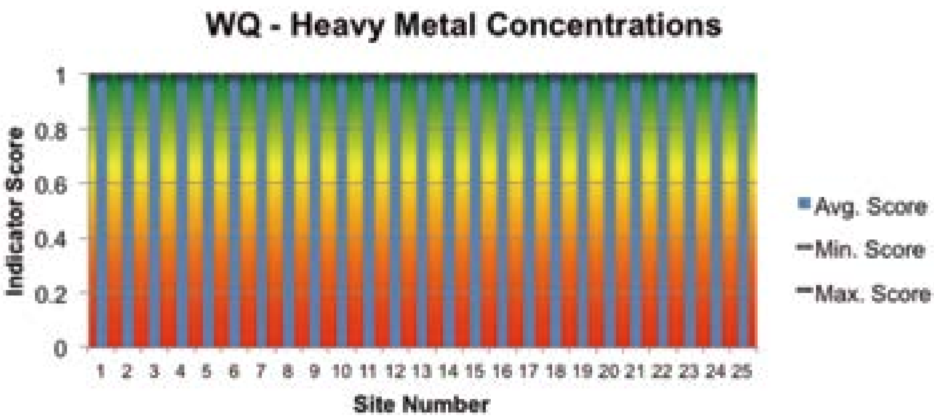
Note: Bar heights represent average values for the sub indicators, and the horizontal lines the maximum and minimum sub-indicator scores at each site.

Figure 24. Summary of nutrient indicators for the 25 sites surveyed.



Note: Bar heights represent average values for the sub indicators, and the horizontal lines the maximum and minimum sub-indicator scores at each site.

Figure 25. Summary of heavy metal indicators for the 25 sites surveyed.

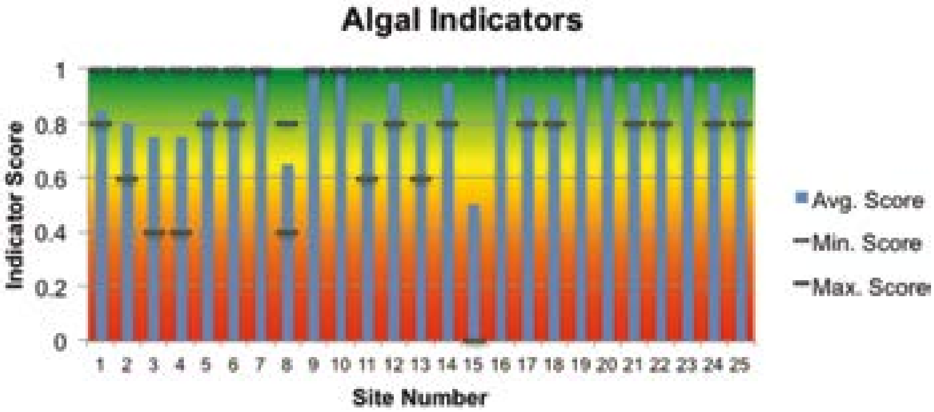


Note: Bar heights represent average values for the sub indicators, and the horizontal lines the maximum and minimum sub-indicator scores at each site.

5.7.2 Algae

Given the elevated nutrient concentrations, algal indicators also scored poorly at many sites (Figure 26). Poor score were recorded for both measures of community structure (IBD and IPS) and elevated δ15N levels in algal tissue samples, which supports the role of humans in increasing nitrogen enrichment. It is expected that efforts to reduce nutrient loads, through decreased urban and agricultural runoff, would lead to an overall improvement in this indicator group.

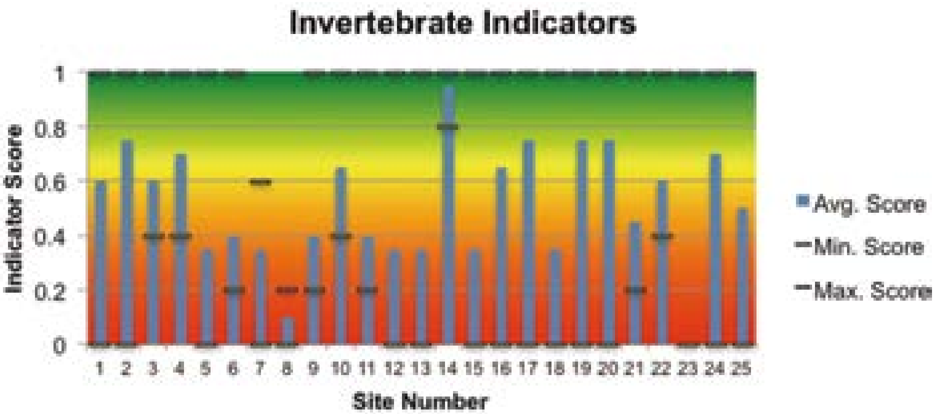
Figure 26. Summary of algal indicators for the 25 sites surveyed. Invertebrates



Note: Bar heights represent average values for the sub indicators, and the horizontal lines the maximum and minimum sub-indicator scores at each site.

Invertebrate indicators gave a less impressive picture of river health, with few sites being considered in good condition based on the targets and thresholds set in the previous section of the report (Note: Bar heights represent average values for the sub indicators, and the horizontal lines the maximum and minimum sub-indicator scores at each site.). As was noted, the scoring systems adopted for the macroinvertebrate indicators are largely based on existing overseas systems, which have been developed over many years in specific relation to local taxonomy and tolerance patterns of individual taxa. Thus, the overall poor scores may to some degree reflect the need to develop proper scoring systems for Chinese taxa based on local knowledge and a wider assessment of distributional patterns. Nevertheless, there was still considerable variation in the invertebrate indicator scores across the 25 sites (Figure 27). There was also a consistent trend towards lower scores in the more lowland sites (class 3 sites; Figure 27). This is an expected pattern with these sites generally having higher levels of catchment disturbance. There was also some consistency between the algal and invertebrate scores at specific sites, with sites 8, 11, 13 and 15 performing poorly for both indicator groups, as well as for nutrients.

Figure 27. Summary of invertebrate indicators for the 25 sites surveyed.

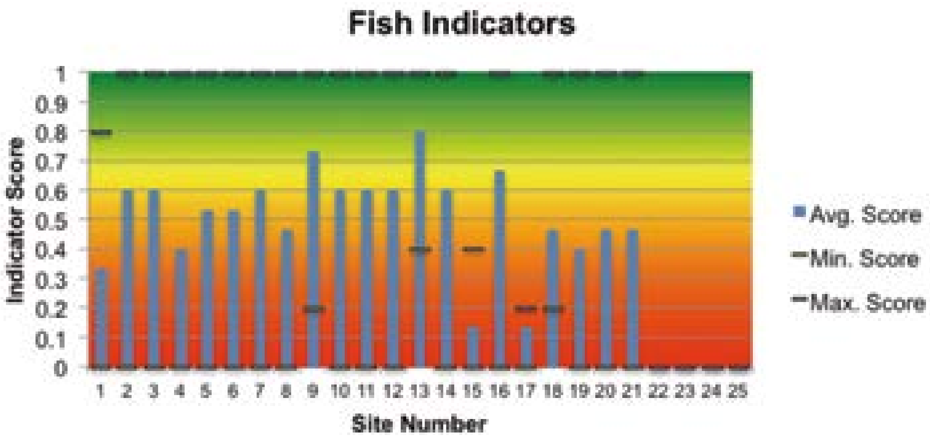


Note: Bar heights represent average values for the sub indicators, and the horizontal lines the maximum and minimum sub-indicator scores at each site.

5.7.3 Fish

The fish indicator group proved problematic to develop and requires further work. It was not possible to conduct an assessment at all sites due to a lack of data. However, among the sites that could be assessed, there was considerable variation in the indicator scores; some sites that scored low for the fish indictors also scored poorly for other indicator groups (e.g. site 15). In contrast to the nutrient, algae and macroinvertebrate indicators, fish indicators showed an improvement across the three stream classes (Figure 28), which is contrary to expectations, given these sites were generally more disturbed. Across all of the indicator groups examined, fish are probably the most sensitive to stream size, which, by definition, increases across the three stream categories. This sensitivity calls into question whether the pattern reflects differing levels of river health or simply a change in a covariate across the three groups. Unfortunately, based on the indices presented here, fish appear to remain an unreliable indicator, and further work is required.

Figure 28. Summary of fish indicators for the 25 sites surveyed.

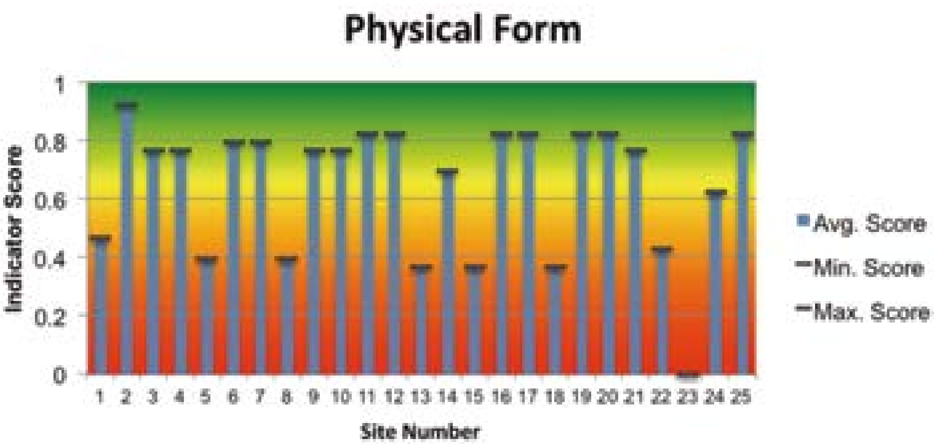


Note: Bar heights represent average values for the sub indicators, and the horizontal lines the maximum and minimum sub-indicator scores at each site.

5.7.4 Physical form

The physical form sub-index provides a measure of physical threats to the river channel rather than a measure of actual changes in physical form. Sites immediately above, or below, impoundments and those on the main-stem of the river showed notably higher levels of impact associated with longitudinal fragmentation and the impacts of hydroelectric dams on local hydraulic conditions (i.e. ponded and tailrace areas immediately above or below the dam) (Figure 29).

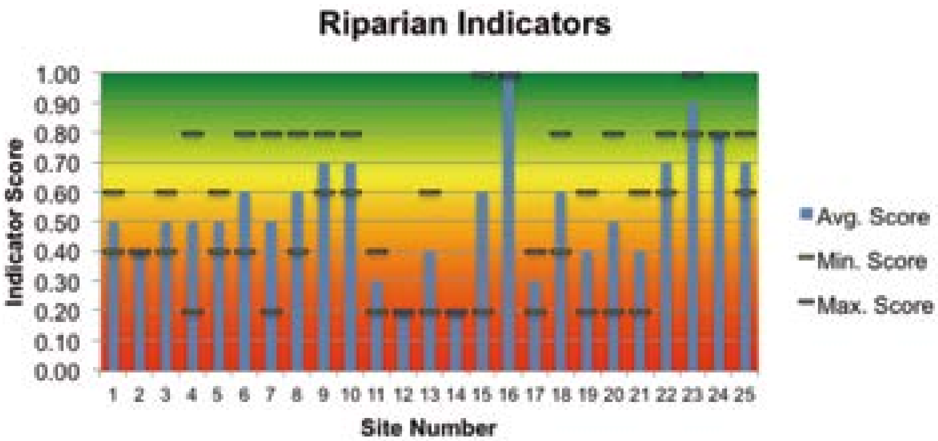
Figure 29. Summary of the physical form index (PFS) for the 25 sites surveyed.



5.7.5 Riparian vegetation

Riparian vegetation was assessed using very simple measures that reflect the direct impacts of land use on buffer width and continuity. As evidenced by photos and the results in section 6, buffers were frequently absent or very narrow, resulting in quite low scores for a number of sites (Figure 30). The loss of riparian buffers from streamside zones is a global problem, and yet also a very easy one to address through appropriate management actions, such as restricting the proximity of paddy fields to streams, and implementing revegetation programs. This need not be to the exclusion of human use, and may instead involve cultivation of useful timber species that help provide a buffer from surrounding land use (e.g. see Naiman et al. 2005).

Figure 30. Summary of riparian indicators for the 25 sites surveyed.



Note: Bar heights represent average values for the sub indicators, and the horizontal lines the maximum and minimum sub-indicator scores at each site.

5.7.6 Hydrology

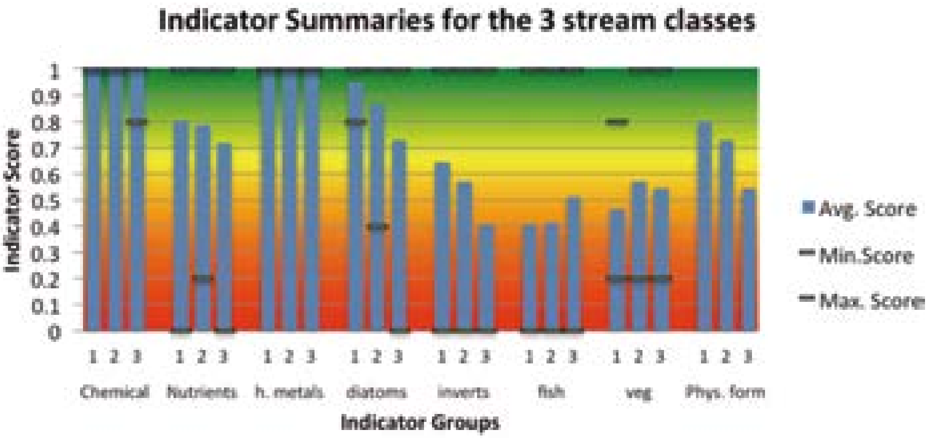
Because hydrologic data was only available for a subset of sites, a detailed assessment is not presented here. See section 7 for more details.

5.7.7 Overall summary.

The eight indicator groups present a mixed result for the health of rivers in the Gui catchment. While some aspects of water quality are very good, nutrient concentrations were elevated at a number of sites, and this was linked with declines in algal and macroinvertebrate indicators (Figure 31). Fish indicator scores increased in larger streams, perhaps reflecting a relationship with stream size, but this group may also benefit from increased nutrient concentrations through greater food availability. Riparian vegetation also was often in relatively poor condition, with only narrow and fragmented buffers. It is worth noting that some sites in each of the three groups (orders 1,2,3+) scored highly across all indicators.

Several indicator groups require more analysis before they can be more widely adopted in China. For example, while algae and macroinvertebrate indicators showed the predicted patterns, more widespread adoption would need the development of scoring systems based on local data, rather than data adopted from overseas schemes for the purposes of this demonstration. These issues form a component of the recommendations for future work included in the final section of the report.

Figure 31. Summary of the 8 indicator groups (three water quality and four biological) across the three stream classes (first order, second order and third/fourth order).



Note: Bar heights represent average values for each indicator group averaging across sites. The horizontal lines represent the average maximum and minimum sub-indicator scores observed for any single indicator at any single site.

6. Conclusions and Recommendations

6.1 River health in the Gui River Basin

The pilot study used a suite of indicators to assess the aquatic ecosystem health of streams and rivers in the Gui River Basin. The indicators were grouped into water quality indicators (physical/chemical, nutrient and heavy metal indicator groups); biotic indicators (algae, macroinvertebrates, fish and riparian condition indicator groups); and physical form and hydrology indicators. The indicators within each group were chosen based on a robust method of testing their response to a disturbance gradient and scores were derived for each indicator to assess river health. Hydrologic alteration was assessed at only a subset of locations on the main stem of the river.

The results of the study suggest that the health of the Gui River is compromised in areas with intensive urban and agricultural development, but most sites visited were deemed to be in relatively good ecological condition. Water quality was generally found to be good. However, as would be expected, there were still clear trends toward increasing concentrations of nitrogen in agricultural and urban areas. The catchment appears in better ecological health in the upper catchments, and there is a general trend of deteriorating river health from highlands to lowlands.

The biological indicator groups reflected poorer level of health than the water quality indicators. In particular, algae, invertebrates and fish indicators suggested some sites were in poor to critical conditions of health. This difference may reflect that ecological indicators integrate ecosystem condition and stress over time, but more broadly highlights the importance of not just relying on water quality to assess aquatic ecosystem health.

Biological indicators showed responses to land use disturbance at the buffer-scale (the strips of land along each side of the river) as well as catchment-wide land use, although the results were not always consistent. With only a small sample size, it is difficult to draw firm conclusions as to the relative influence of these two scales. At the local scale, however, indicators of riparian condition did highlight the poor condition of riparian zones at a number of sites (both in terms of width and degree of fragmentation), which will have a direct influence on the in-stream scores due to the reduced buffering capacity against neighbouring land use.

The assessment of hydrology, based on monthly data, suggests stream flow patterns have not been substantially affected by reservoir construction, although anecdotal evidence still suggests that low flows during the dry season have been an issue in recent years. Whether these periods of extreme low flow are too short to be captured by monthly data, and what their impacts may be also needs to be examined via more detailed studies. The assessment of physical form highlighted the impacts of barriers on fish migration and the local effects of dams used for hydroelectric power generation on local hydraulic habitat conditions.

While not well reflected in the biological indicators, longer-term trends in fish diversity in the catchment raise questions about factors relating to the health of fish assemblages. As well as potential water quality issues, the effects of barriers and fishing pressure warrant further consideration.

The limited number of sites sampled and, as a result, the limited size of the data set, poses challenges for making robust conclusions about the health of the river, as does the lack of suitable reference values, due to an absence of existing guidelines or a paucity of data. Further monitoring, both within the Gui River and elsewhere in China, will contribute to filling this knowledge gap.

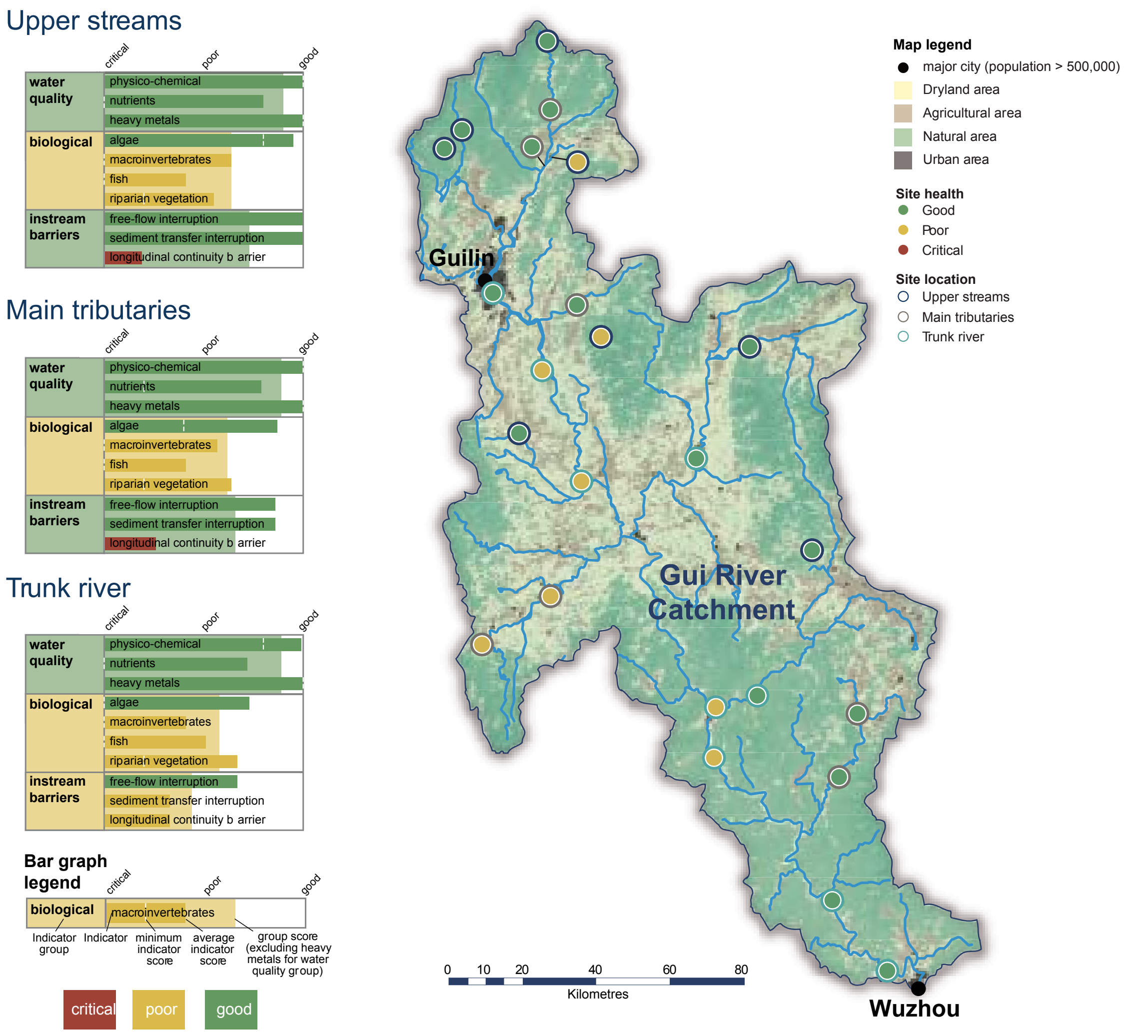
It is challenging to make robust conclusions on river condition on the basis of a single investigation. The natural variation in time and space of river health indicators is an important constraint on river health assessments, especially when they are based on preliminary data sets, or those with limited spatial and temporal resolution. Establishing suitable reference values is a particular challenge when first implementing a monitoring program. In the early stages of an investigation, reference values are likely to include a level of uncertainty. The conclusions on the actual health of the river described above, and the recommended management responses below, need to be read with an understanding of these limitations. Over time, the outcomes of future river health assessments will improve as larger data sets become available, the local aquatic conditions are better understood, and reference values are refined.

6.2 Communicating the results

Effective communication of the results is an important part of a river health assessment. Internationally, there are a number of examples of the use of report cards to present the results of detailed technical analyses of river condition in a way that is readily comprehensible by a wide range of (non-technical) stakeholders. Report cards can be a valuable tool for disseminating the results of river health studies, as well as a way of generating political and local support for actions to improve river health.

As part of this study, a report card was prepared to summarise the project work and the results of the assessment. An extract from the report card is shown in Figure 32. The full report card is included in the appendices (section 5). The report card shows the overall scores (graded from critical to good) for each sampling site, together with more detailed information on each of the seven different indicator groups, broadly grouped into water quality and biological indicators.

Figure 32. Map showing the condition of different sites sampled during the study.



Note: The horizontal bars symbolise the scores for each indicator group for different regions of the Gui River catchment.

In preparing a report card, careful consideration needs to be given to the objective of the report – including the intended audience, the level of technical detail that is appropriate for the audience, and the particular message being conveyed.

The integrity of report cards depends on the scientific process that underpins them; a glossy brochure is not a substitute for a sound scientific study. It is critical that any limitations of the scientific assessment are not lost as part of the simplification of the information for the report card.

6.3 Future monitoring research and programs

Further work is needed to refine the method applied during the pilot study to improve the quality of the results, particularly before they can become the basis for a routine monitoring program. It is recommended that the following research topics be considered as part of any future monitoring:

- Confirm initial results, or refine the set of recommended indicators, by repeating some of the work undertaken in correlating indicator values with levels of catchment disturbance.
- Assess seasonal variability to determine if the correlation between indicator scores and catchment disturbance is different at various times of the year. This current study relied on a single sampling undertaken during spring. Some indicators may be more or less suitable for assessing river health at different times of the year.
- Refine existing water quality guidelines, including developing Chinese standards for total nitrogen (TN) in rivers and streams, and refine river health target levels using a load-based approach for indicators such as nutrients and sediments.
- Investigate linkages to down-stream ecosystems, such as the estuary and coastal zone. This investigation may include modelling nutrient and sediment budgets and their likely impacts on estuarine and marine ecosystems.

In addition to the further development of the river health science, a shift towards a routine monitoring program requires significant investment of time and resources to develop the necessary systems and human capacity. A considered approach to these issues is important to ensure the program will be effective and sustainable over the long term. Experience gained from ten years delivery of the South East Queensland ecosystem health-monitoring program (EHMP, 2010) has shown that the success of such a program relies on an adaptive approach that integrates scientific knowledge and research, policy and management, and effective stakeholder engagement.

The key attributes of an effective and ongoing monitoring and assessment program include:

- The presence of drivers that provide an incentive for governments or other parties to invest in the program and ensure adequate funding is sustained. Examples of such drivers include: (a) the requirement for agencies to report on the health of the natural resources they manage and (b) the presence of strong public and political support.
- The generation of useful and easily comprehensible information to all stakeholders (e.g. a report card).
- The adoption of a standardised approach to monitoring, evaluation and reporting.
- The use of adaptive management approach embodied within a strategic catchment management plan that requires regular review of progress towards management goals and the consequent revision of management actions to ensure goals are met.
- The establishment of a sound governance framework to ensure effective strategic planning and implementation as well as providing transparency and accountability.

From the results of the Gui River health assessment pilot study, the following steps are proposed to move to an ongoing monitoring and assessment program:

1. Determine the sampling regime for all chosen indicators: considering both spatial and temporal scales.
2. Investigate the usefulness of alternate indicators of river health that have been trialled elsewhere in China.
3. Develop standard operation procedures and train field and laboratory staff in their use.
4. Develop a quality assurance/quality control (QA/QC) plan.
5. Prioritise a list of targeted research activities that are designed to improve the science and effectiveness of the program.
6. Consider ways to incorporate the program into existing policy and management frameworks.
7. Consider expanding the program into neighbouring catchments and the downstream estuarine waterways.

6.4 Management actions to improve river health

The results of the pilot study demonstrate a clear link between human disturbance and river health. Improvements to river health will require a concerted, long term and adaptive effort focused on reducing the impacts of both past and present human activities across the catchment.

The preliminary nature of this study makes it difficult to identify specific management responses to address poor river health in the catchment. Based on the pilot study, and other similar studies, it is reasonable to assume that river health will be improved by targeting urban and industrial pollution, through improved land management practices to reduce the sediment, nutrient and chemical load entering the waterways, and with the rehabilitation and revegetation of riparian land. The implementation of an environmental flow regime, in accordance with the flow objectives identified in the environmental flows study, would also be expected to improve river health.

However, the real benefit of a river health assessment system in guiding management actions will only be realised with further monitoring and an improved understanding of the basin's ecosystems. A mature monitoring program may be able to provide more specific information on the state of the river basin and specific causes of poor health. For example, which pollutants are having the greatest impact on the ecology and their source – such as whether high nutrient loads are principally the result of human or animal waste, or which parts of the catchment are contributing to increased sediment loads. Such information can allow more targeted responses.

6.5 Application of results to national level policies

Improving river health and, as part of that, monitoring and assessing river condition is a high priority for the Chinese government. In 2011, water management and conservation was, for the first time, the focus of China's *Number 1 Policy Document*, a statement issued annually by the State Council that highlights the top policy priorities of the country. China's Ministry of Environmental Protection is part of the way through implementing the National Water Pollution Control and Treatment Program, a 15-year, multi-billion RMB project aimed at improving the health of Chinese rivers. The program includes a major component on river health assessment. At the same time, the Ministry of Water Resources is currently piloting a national river health assessment program and has issued draft guidelines to support this work (NTWGHARL 2010).

The work undertaken during this pilot study provides a number of lessons that should be considered in developing and implementing these national monitoring programs.

The pilot study was successful in trialling an international method for river health assessment in the Gui River Basin. The approach of assessing the results for different indicators against a various disturbance gradients identified a number of indicators that appear to respond to changes in catchment disturbance and may be suitable for use in a river health assessment program.

This method is underpinned by the understanding that indicators should respond predictably to changes in the catchment, and therefore to changes in river health. Importantly, it cannot be assumed that indicators that are suitable for one river basin will necessarily be suitable in another location – different local conditions can affect the response and the suitability of different indicators. Ideally, indicators should be tested for their responsiveness within different settings.

Establishing appropriate reference values against which indicator values can be assessed is a major challenge. The pilot study set reference values based on a combination of existing Chinese guidelines, international standards, and by extrapolating the data collected during the study, and were furthermore based in several cases on indicators devised in overseas programs. While these were adequate for the purposes of this study, these indicators and their reference values have significant limitations and need to be refined to ensure their suitability to Chinese conditions. For example, while indicators based on the tolerance of different species of macroinvertebrates are, in principle, readily transferrable to China, the actual tolerance values may not be. Chinese specific tolerance values are needed, based on local taxonomy and the tolerance patterns of individual taxa. Establishing a central repository of ecological data collected as part of river health assessments would provide an excellent basis for developing reference values that are appropriate for Chinese rivers.

Reference values will also vary significantly between different rivers and regions within China. The abundance and composition of different biota in healthy rivers is likely to vary, for example, between upland and lowland streams, between tributaries and trunk streams, and between the wet and dry catchments. Water quality parameters can also show significant natural variation. Reference values therefore need to be established for different river types.

To support this, a river classification should be developed based on landscape and climatic features that are known to influence water quality and biota (such as rainfall, runoff, temperature, geology, topography and other landscape features), but are not directly influenced by human activity. This could be done at a relatively coarse scale initially and refined as the need arises.

The river classification would allow grouping together rivers and catchments that are similar to one another**.** The selection of indicators and threshold values for indices can then be determined for each class of river. This would include identifying for each river type:

- standards and thresholds for water quality and biological indicators
- aspects of the flow regime that are environmentally significant.

It may be possible to adapt existing classification systems to meet present needs.

A common objective for national governments in developing (national) river health assessment programs is to be able to compare the relative health of different rivers. This allows government to identify priorities for funding of restorative action and to assess the relative success of conservation and restoration activities. This can result in pressure to adopt common indicators and reference values across a country. However, this is not a scientifically sound approach because the health of different types of river ecosystems (e.g. from tropical to arid zone environments) may best be assessed using different indicators. It can be argued that it is more important to establish a common reporting framework, by which the results for different indicators from different rivers can be compared against one another. Provided results are scaled in the same way – so that 'good' scores or 'poor' scores are equal – it does not necessarily matter if different indicators or indicator groups are used in calculating river health scores: the scores can still be compared with one another.

In implementing a national river health assessment program, a balance should be struck between avoiding prescriptive guidelines on indicators and reference values, while ensuring that the methods for data collection and analysis are sufficiently similar to allow results from different rivers and regions to be compared.

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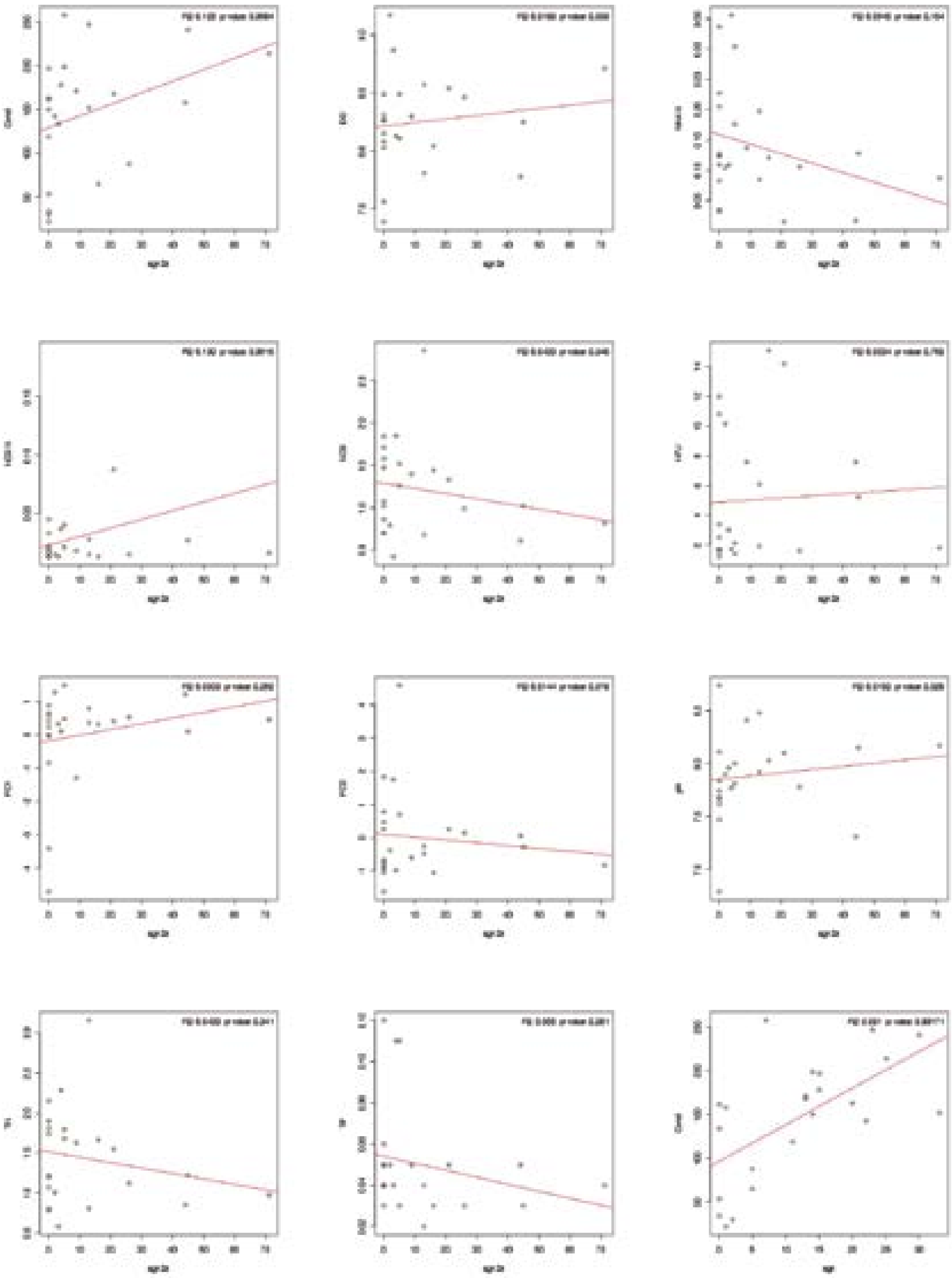
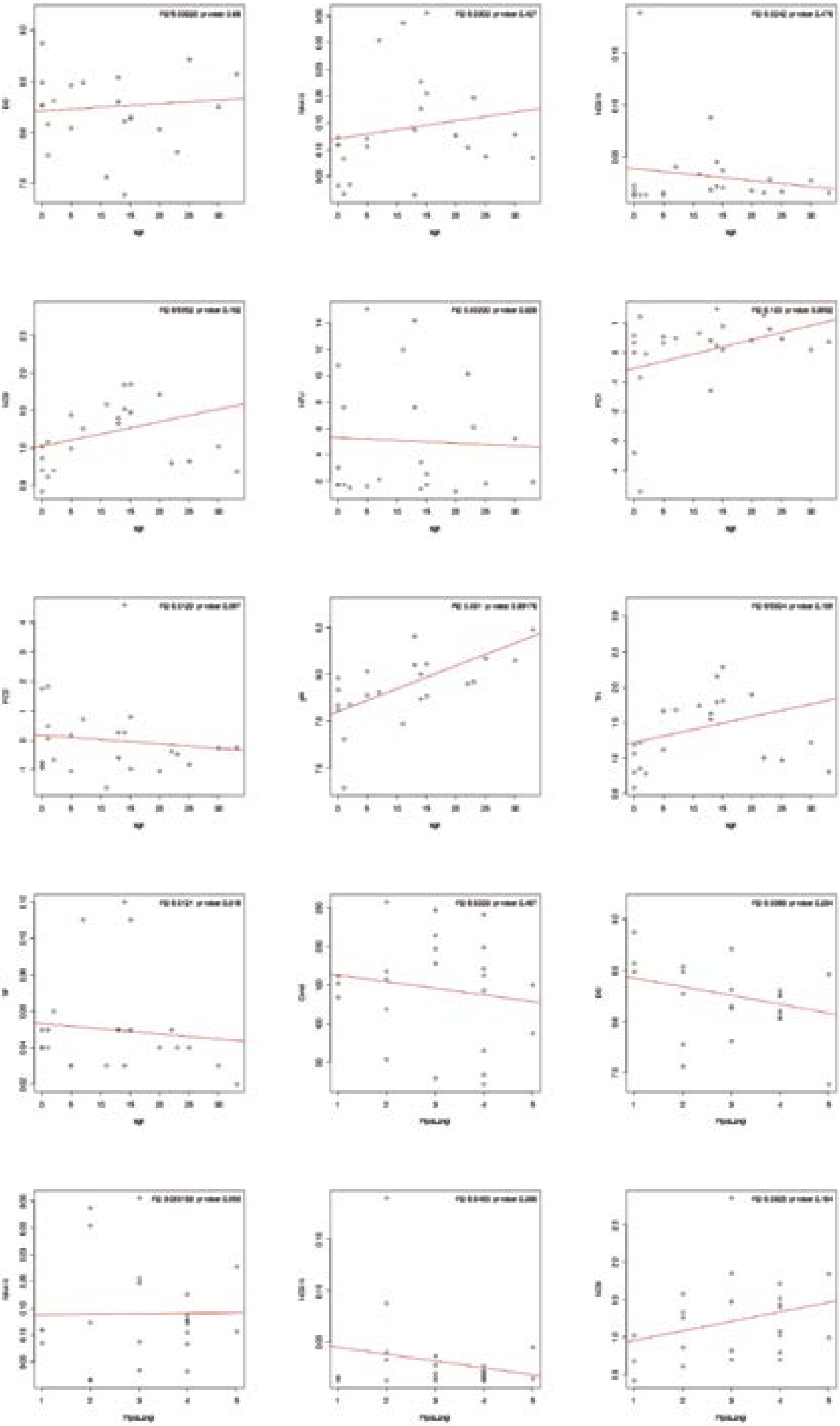
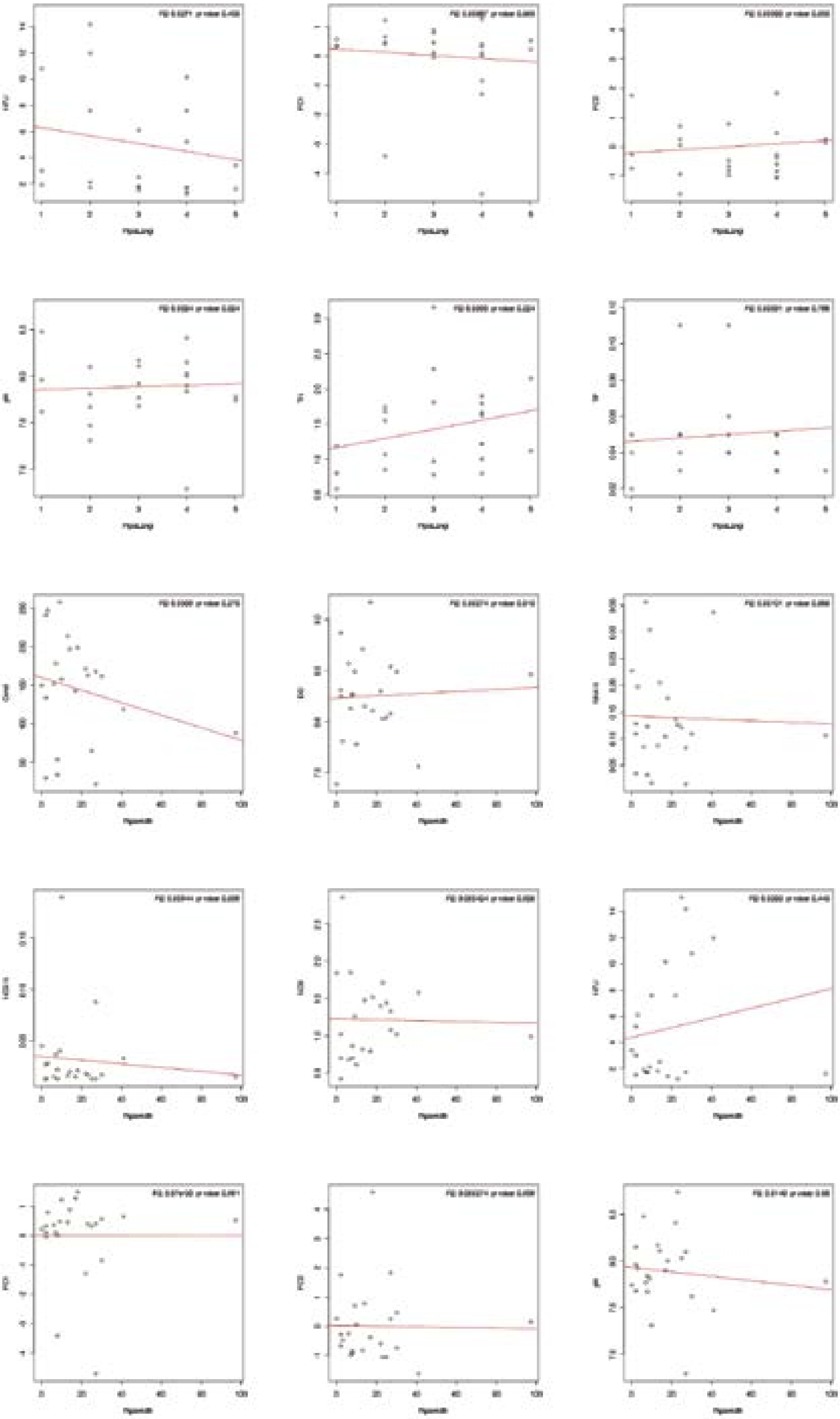
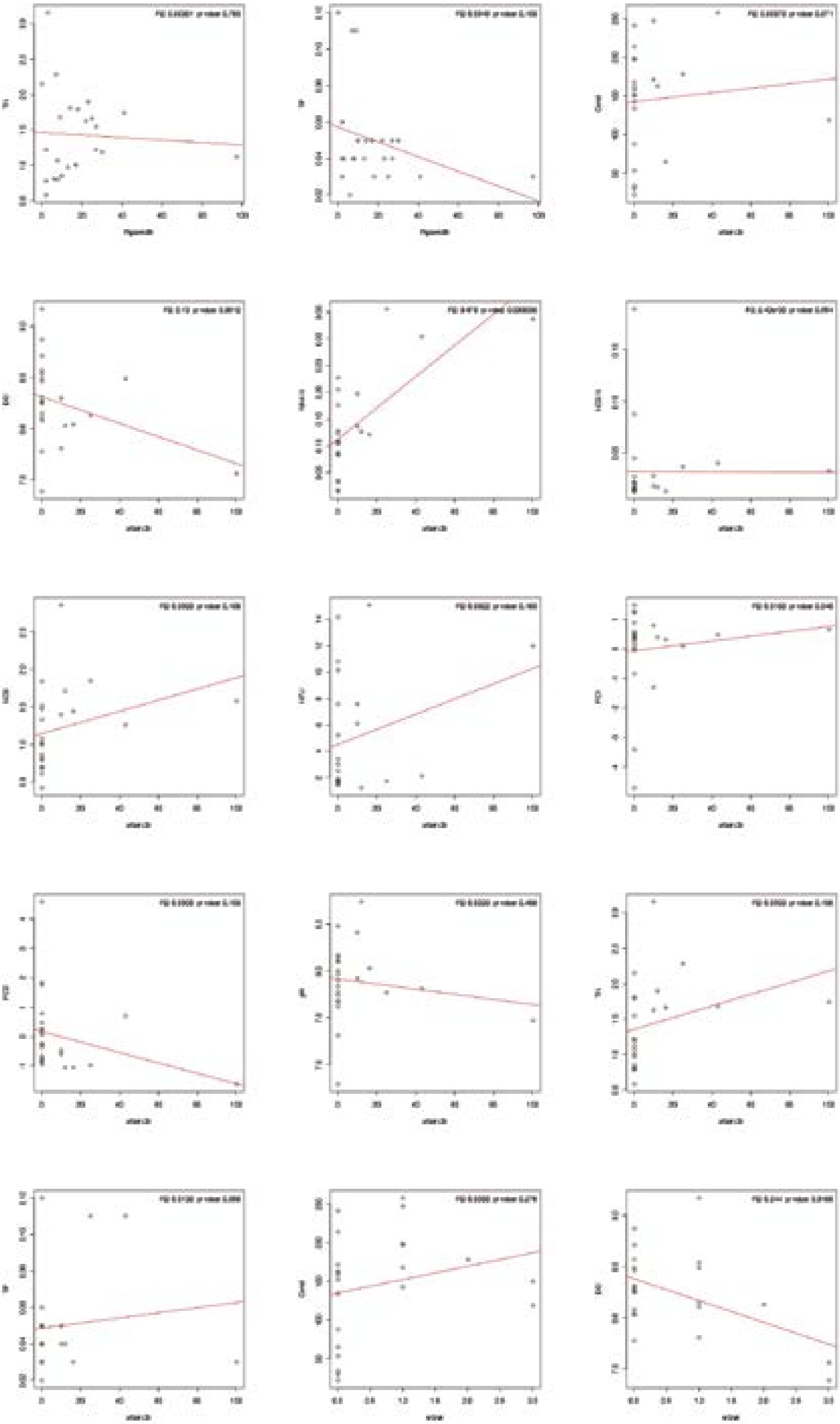
8. Appendices

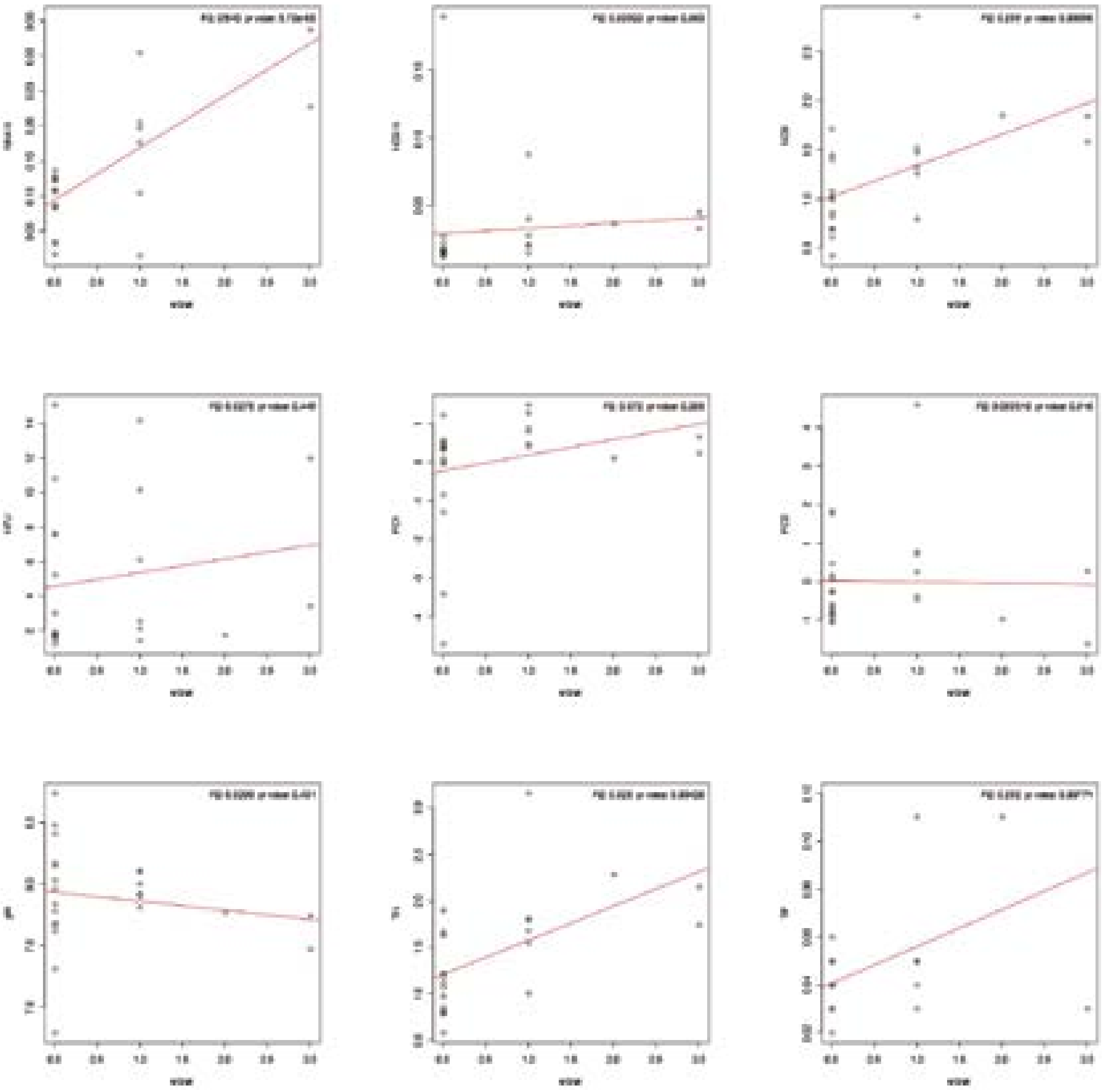
8.1 Relationship between land use and water quality





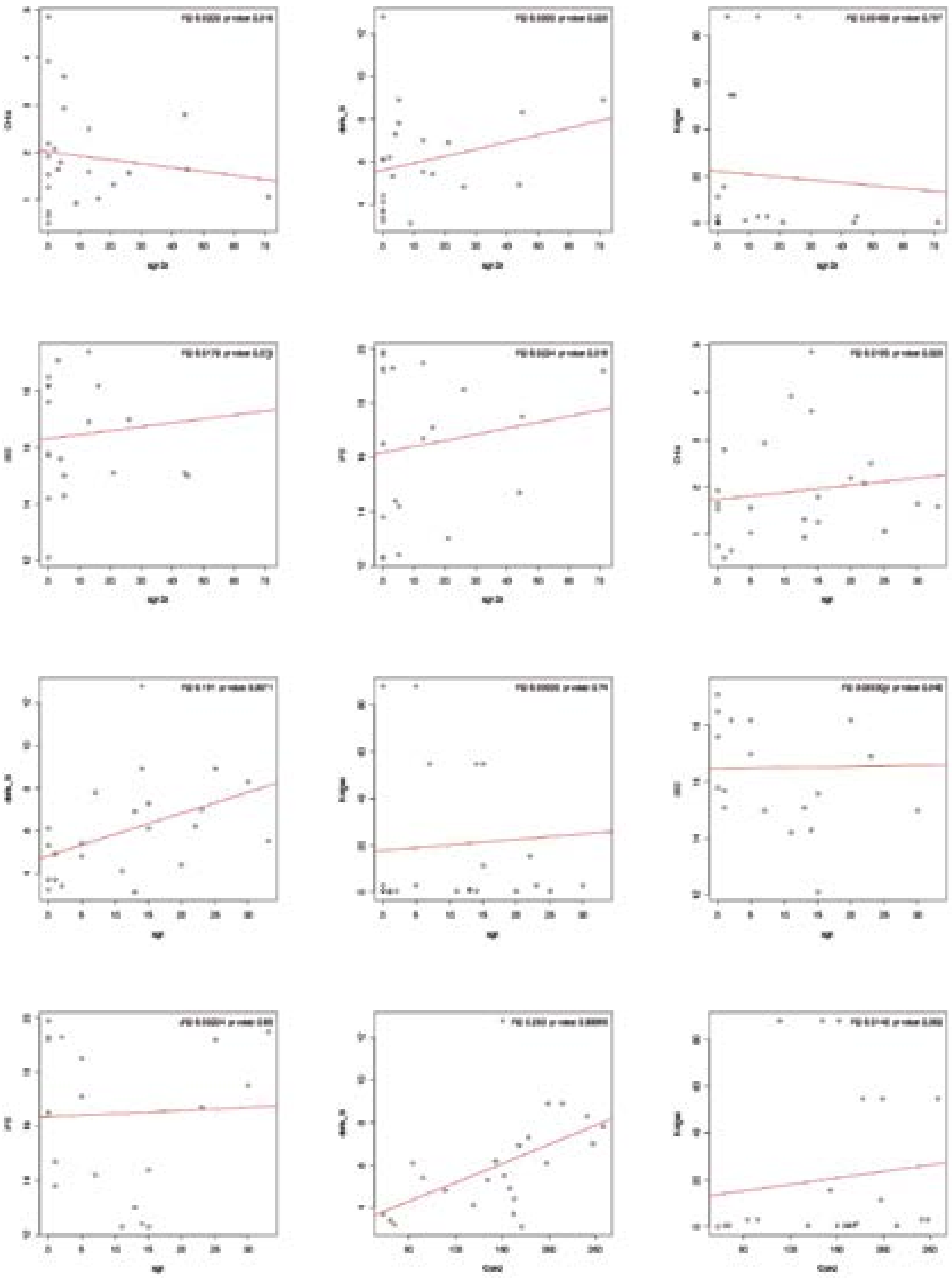


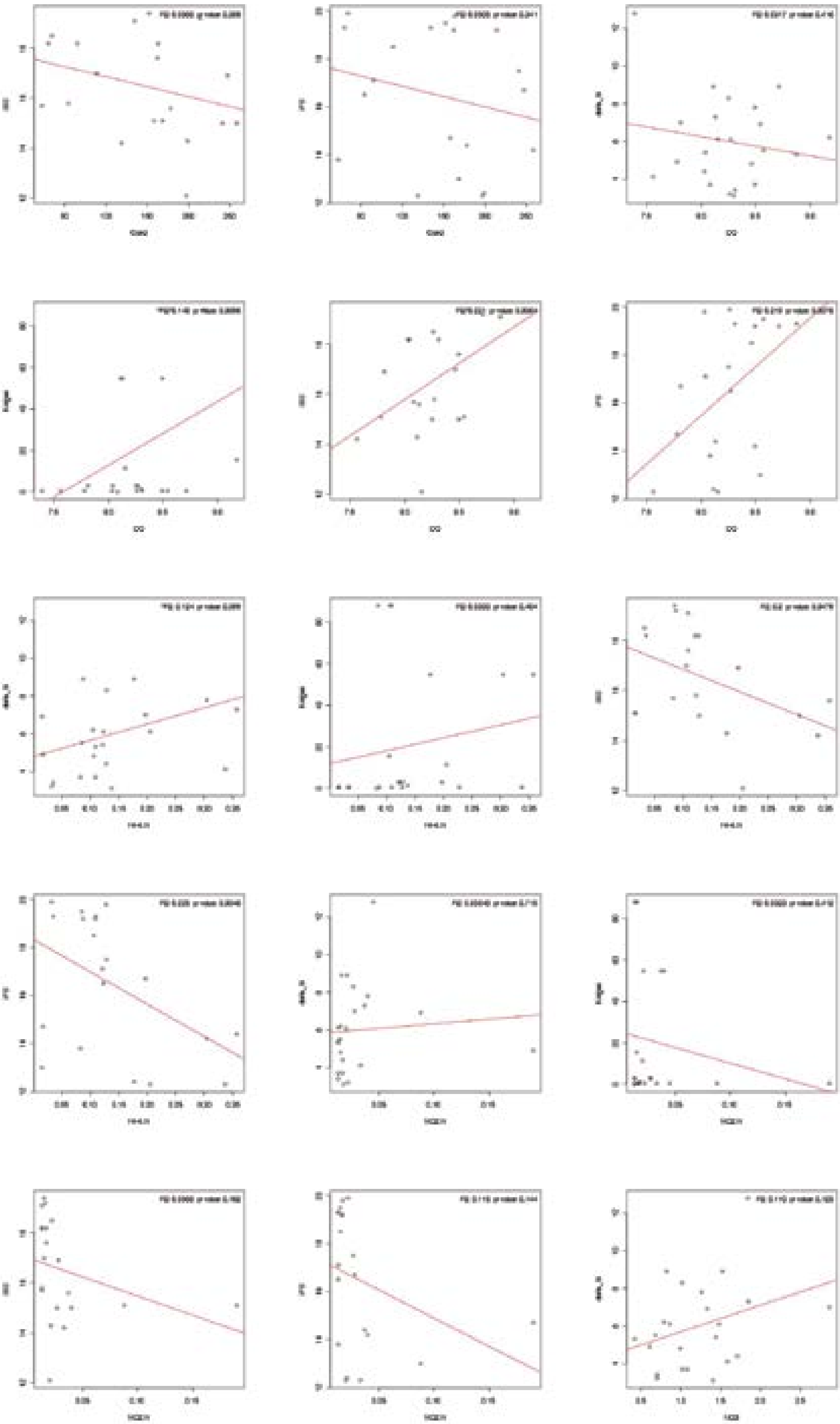


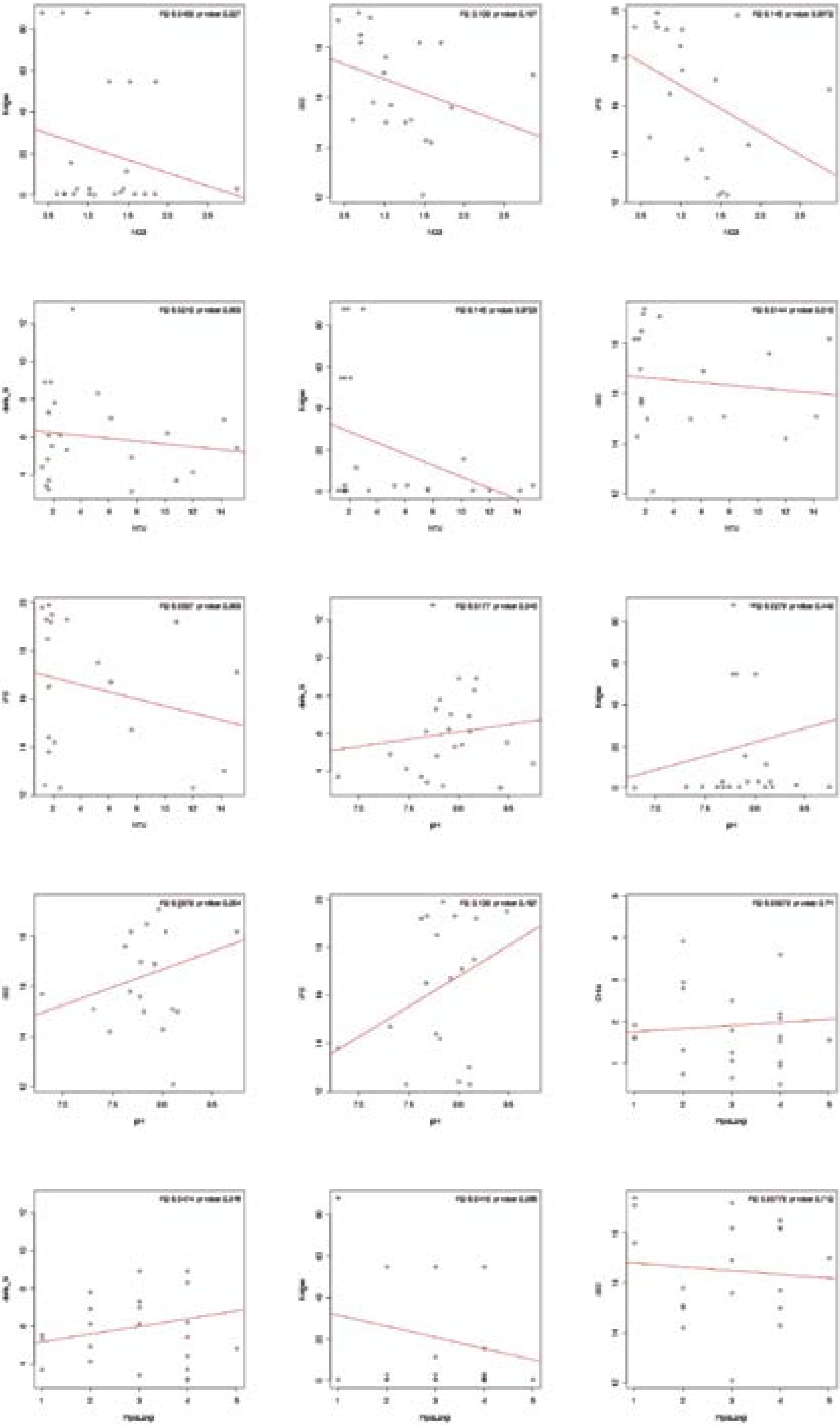


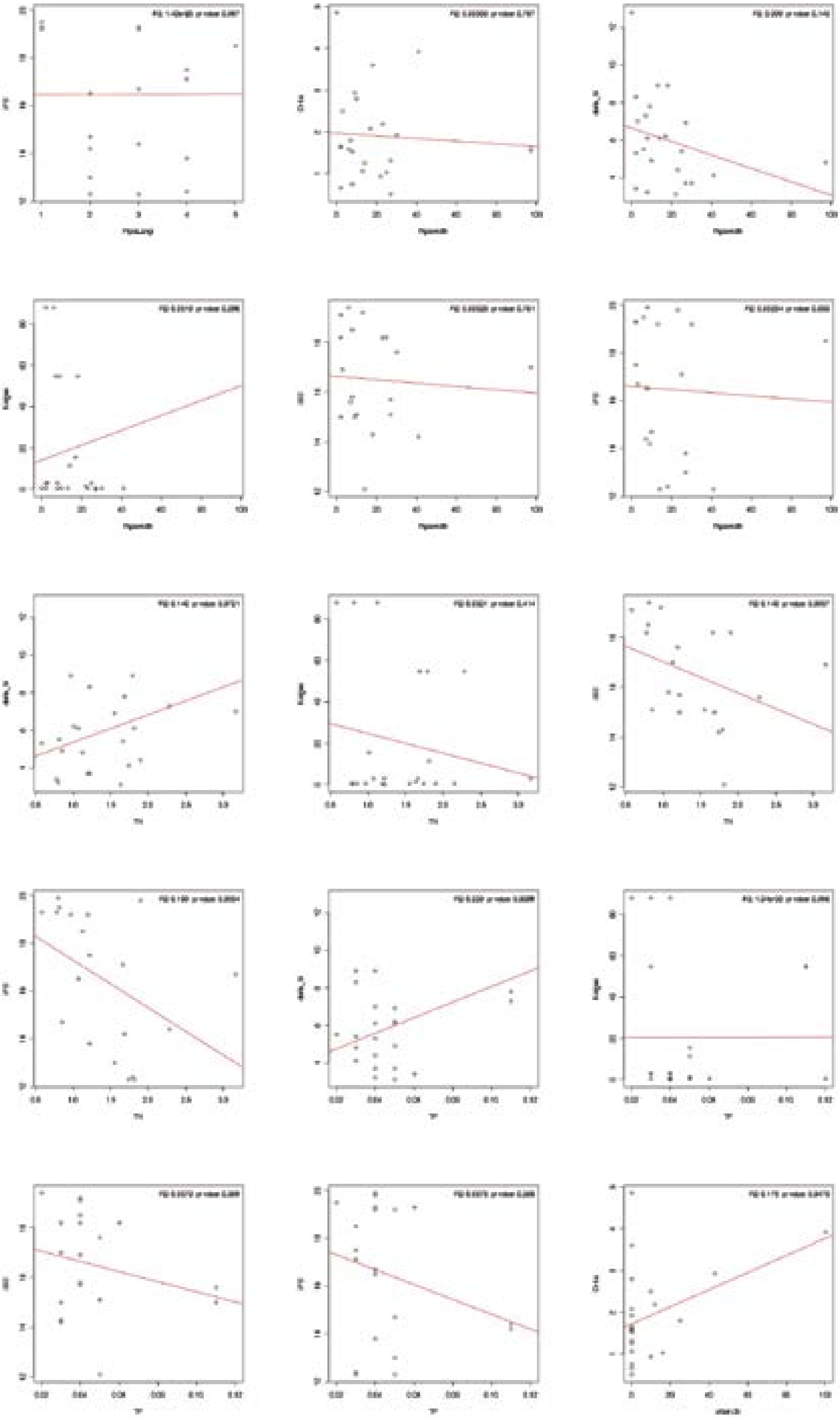
8.2 Relationship between algal indicators and land use

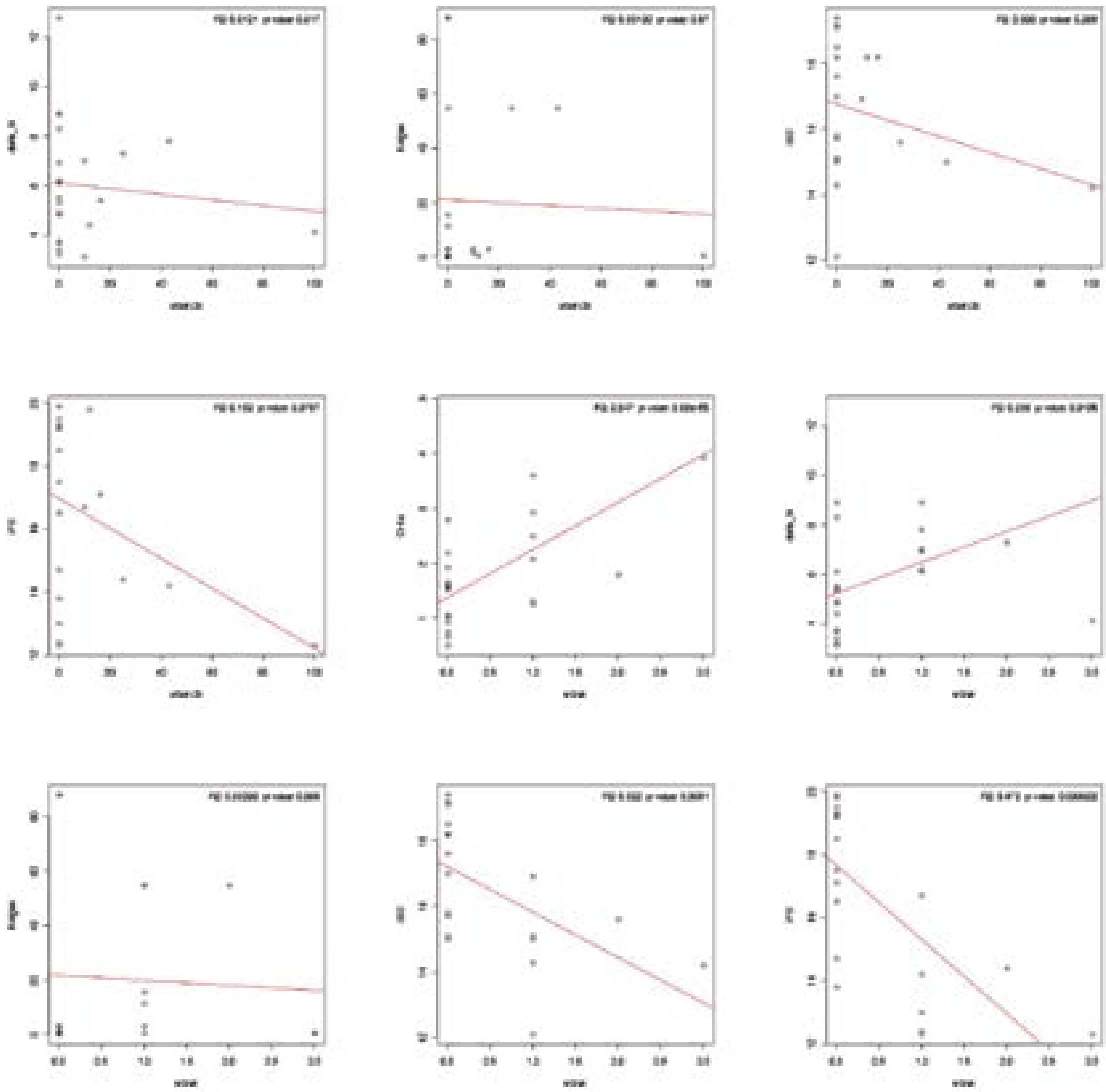
The following graphs show pairwise relationships between algal indicators and land use (primary) and water-quality (secondary) disturbance gradients. The red lines indicate linear regression fit.











8.3 Relationship between invertebrate scores and land use

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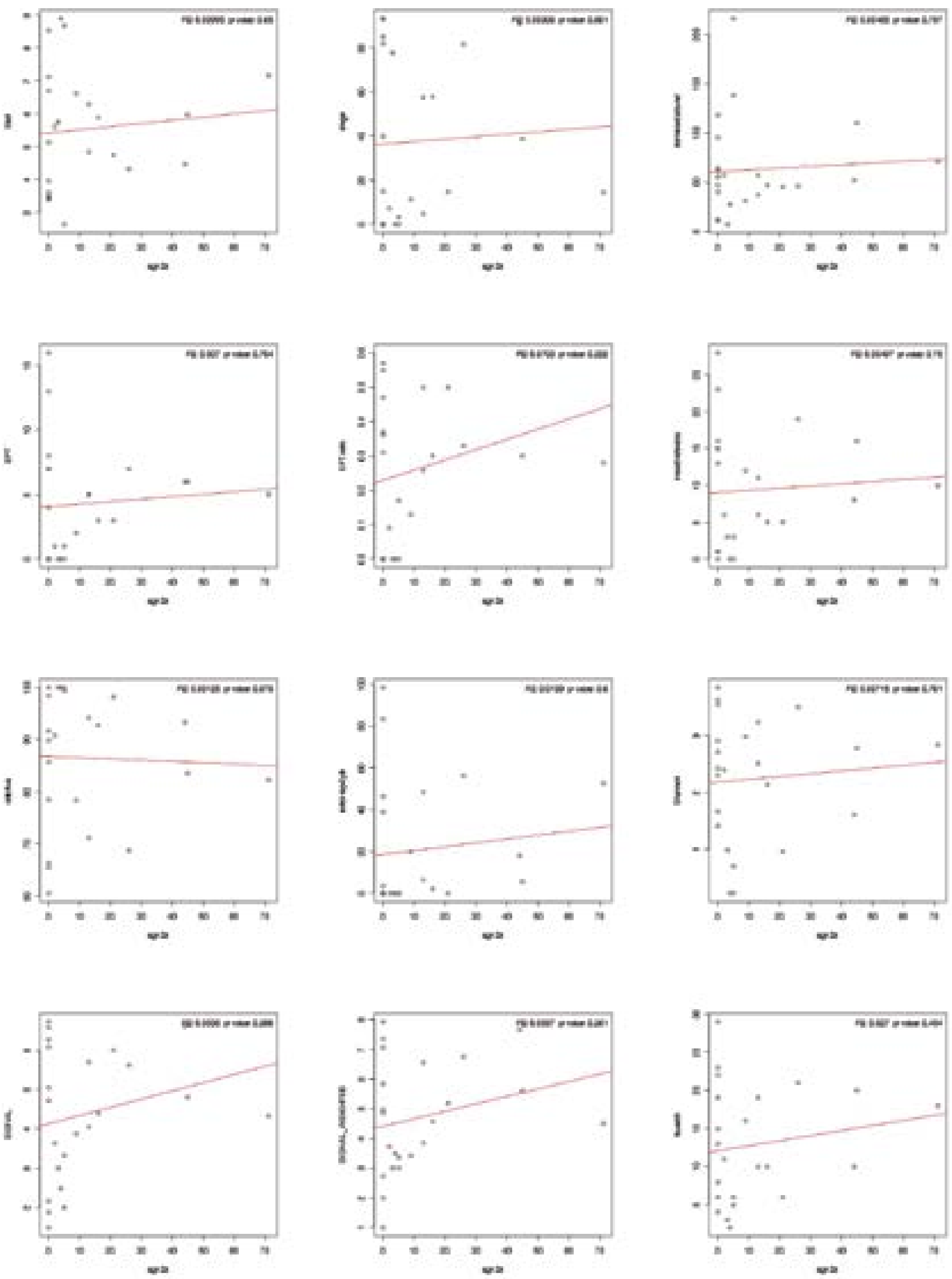
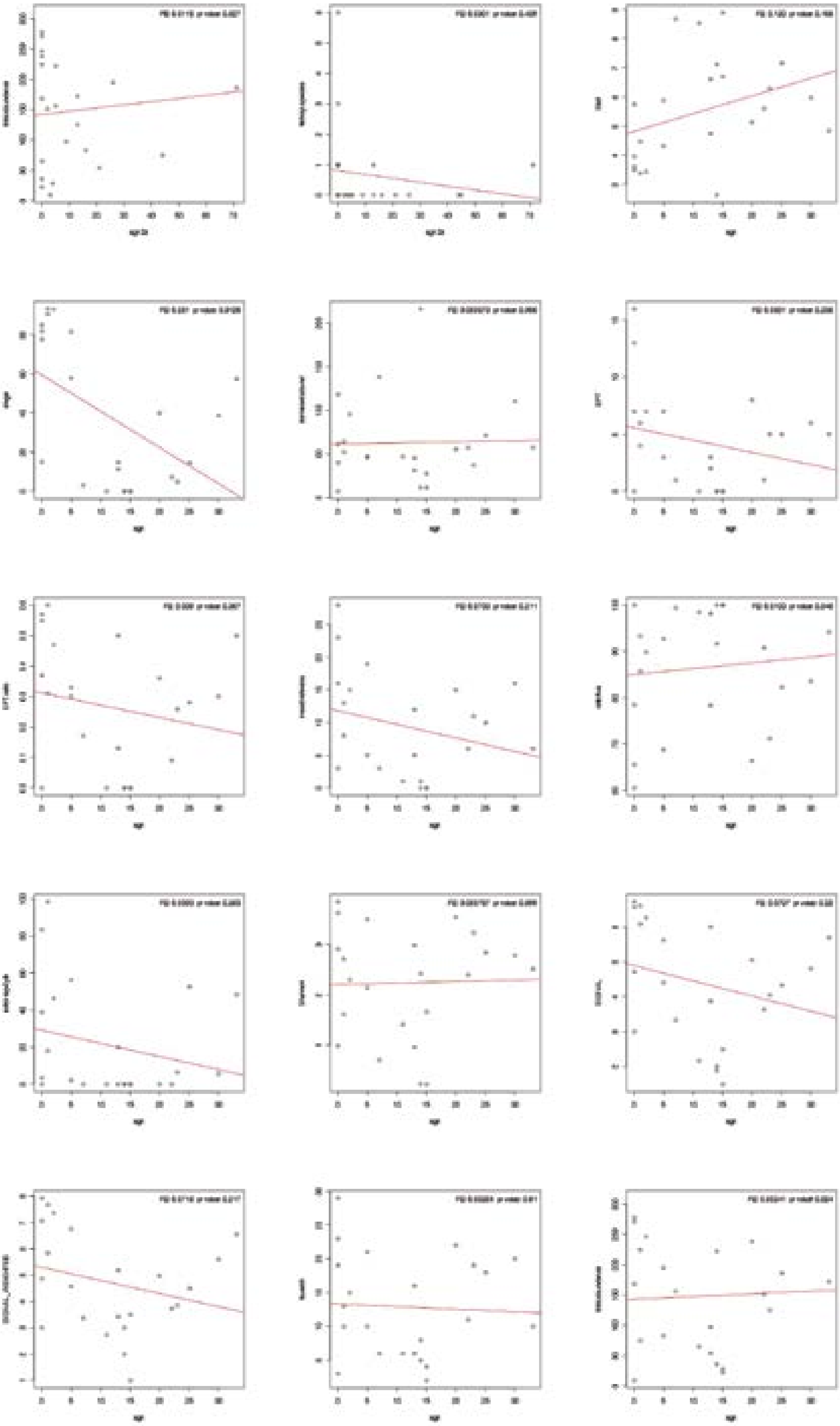
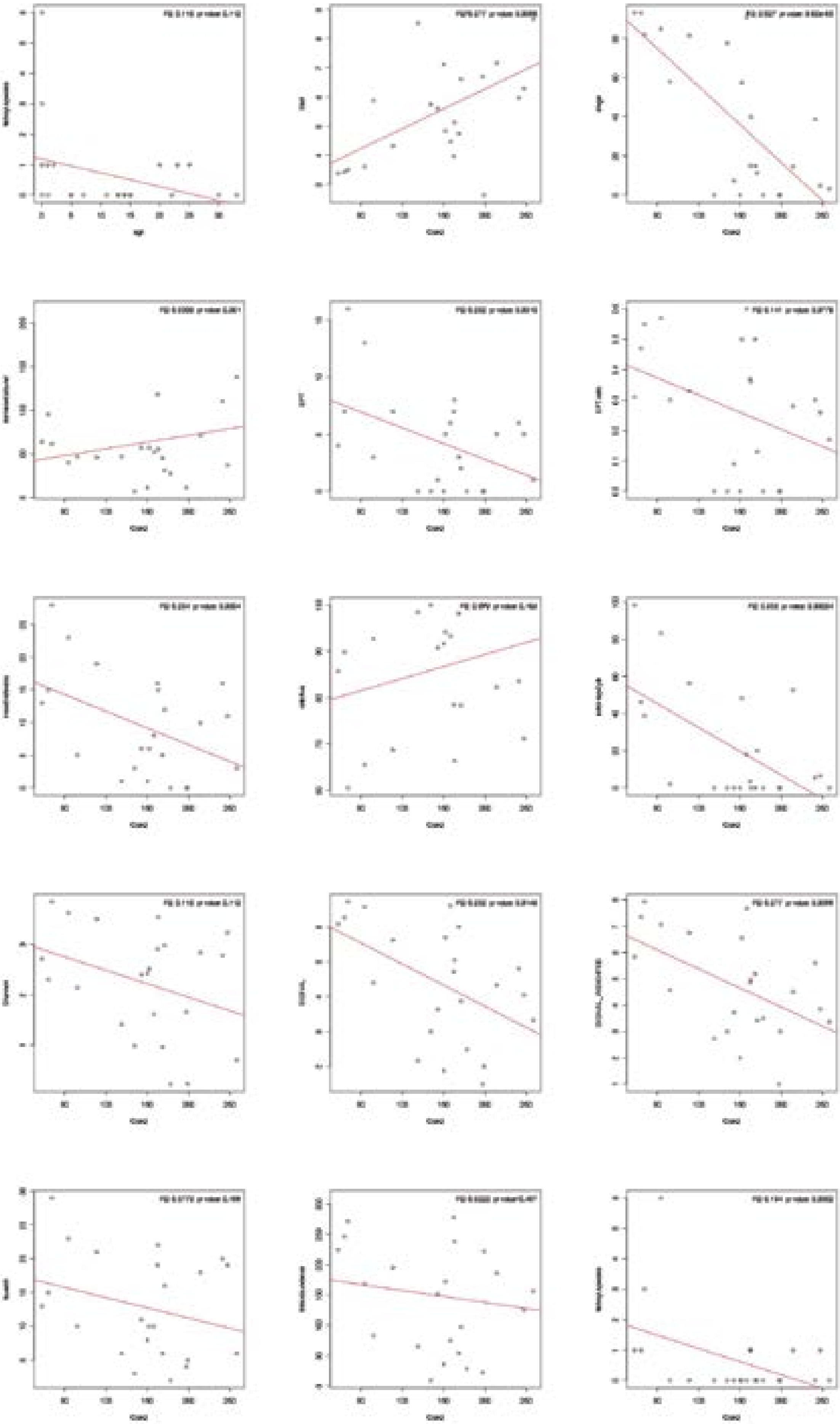
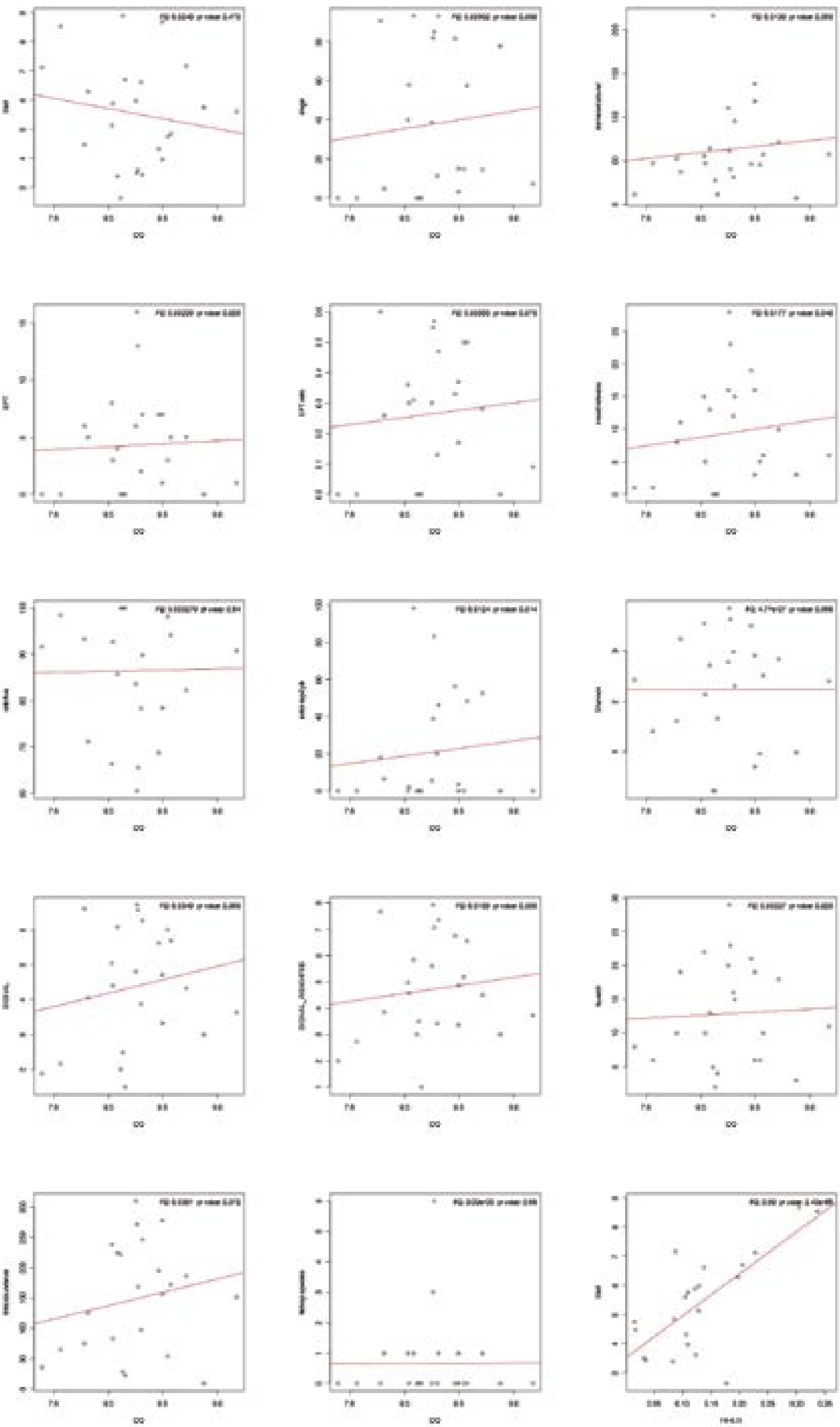
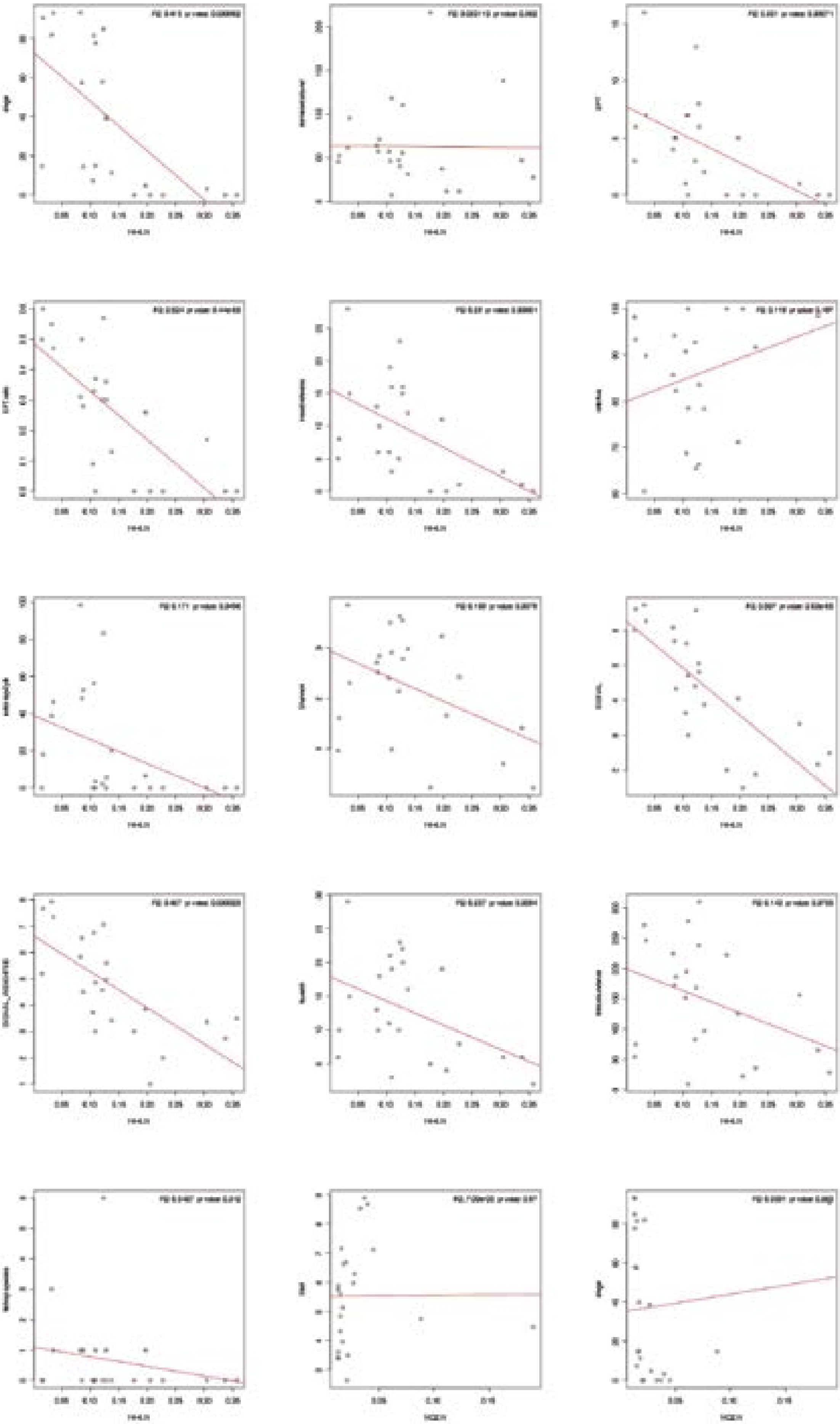
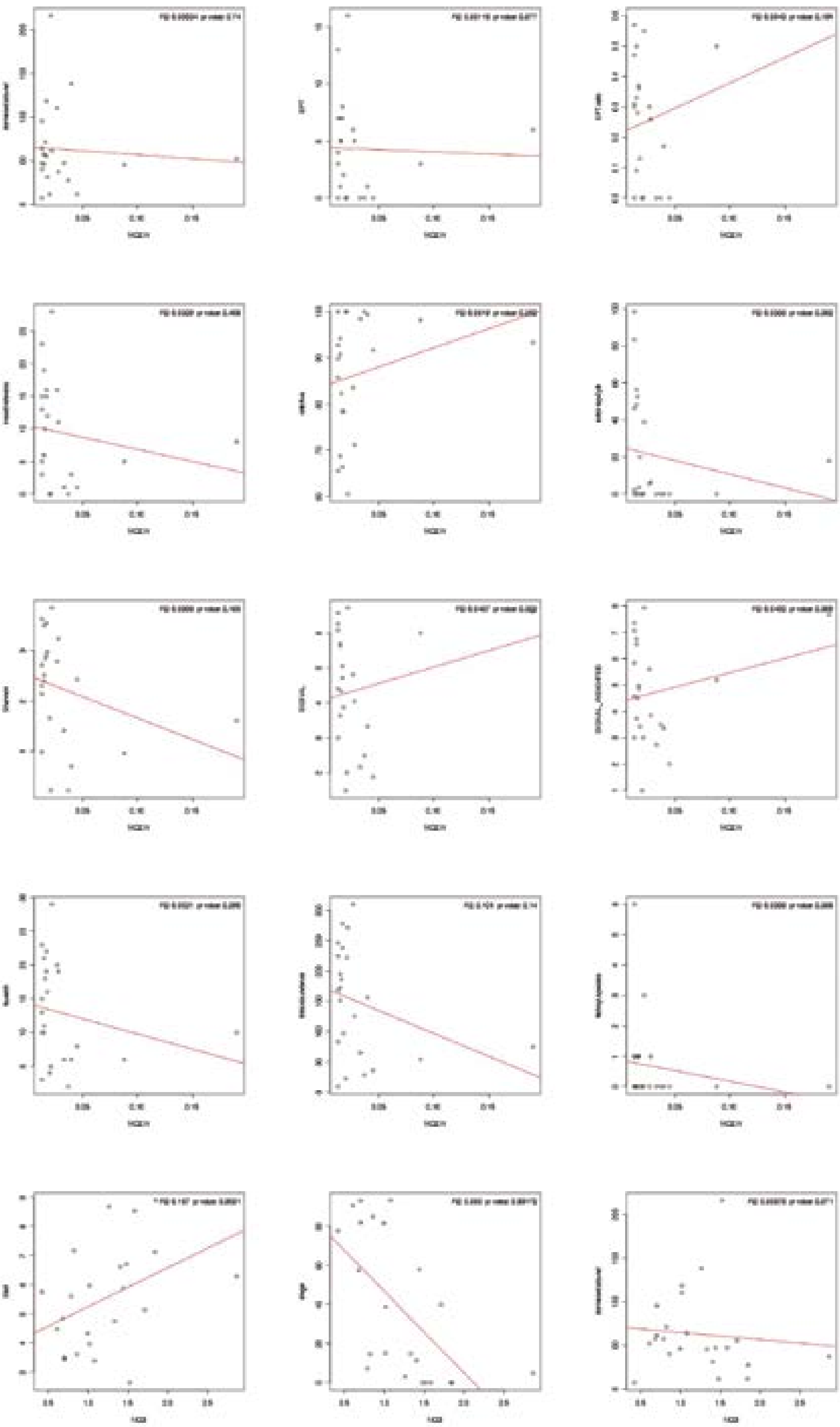


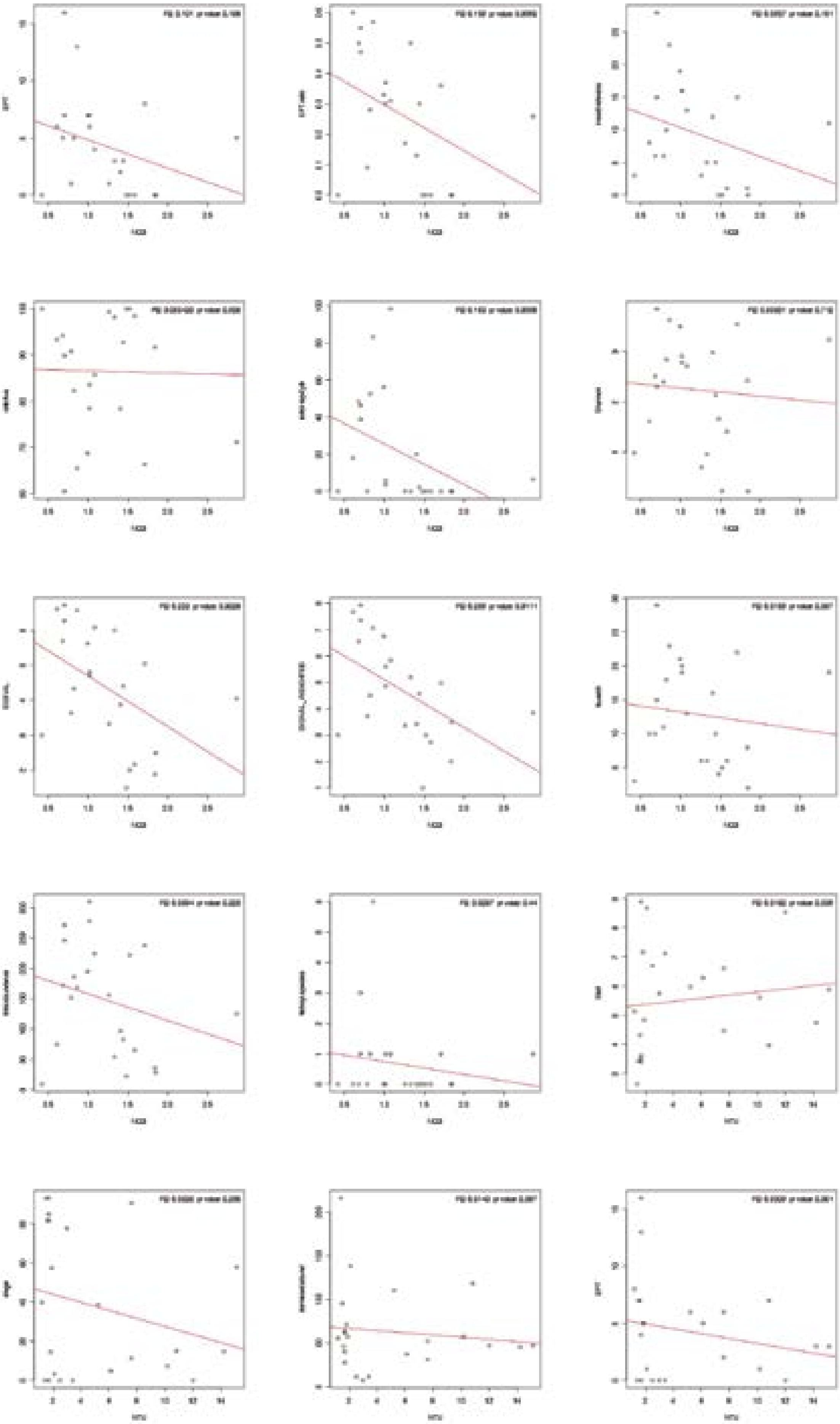


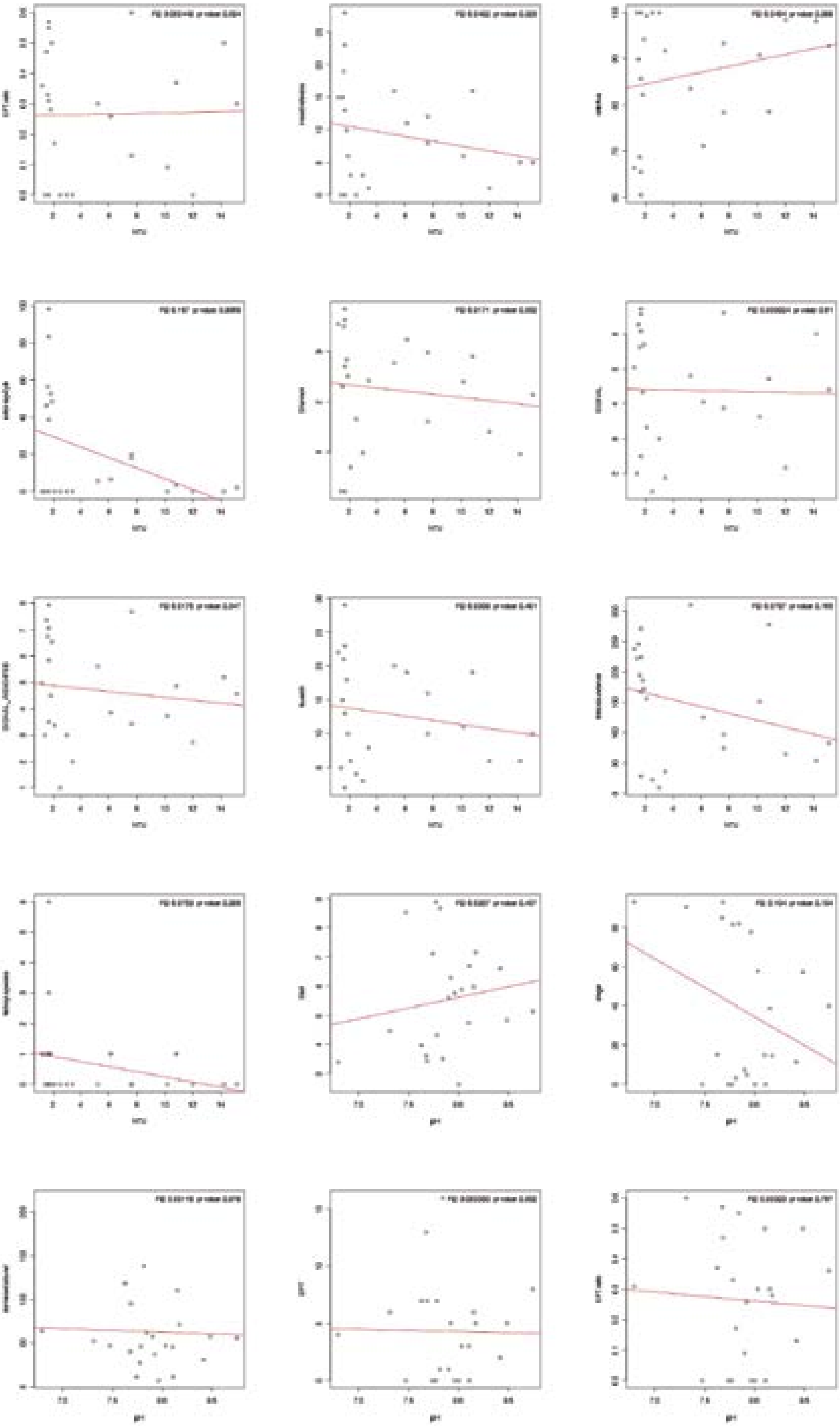


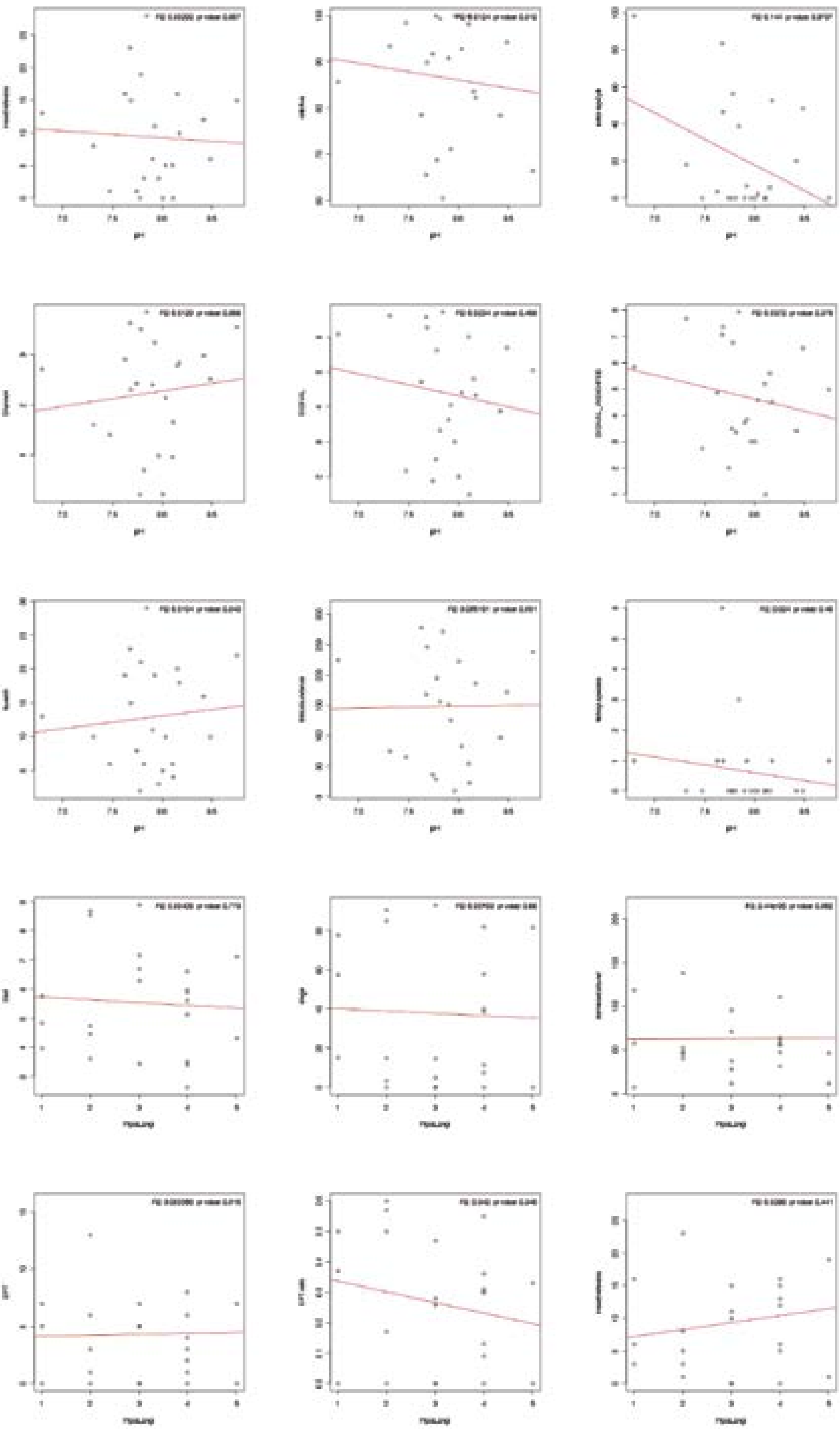


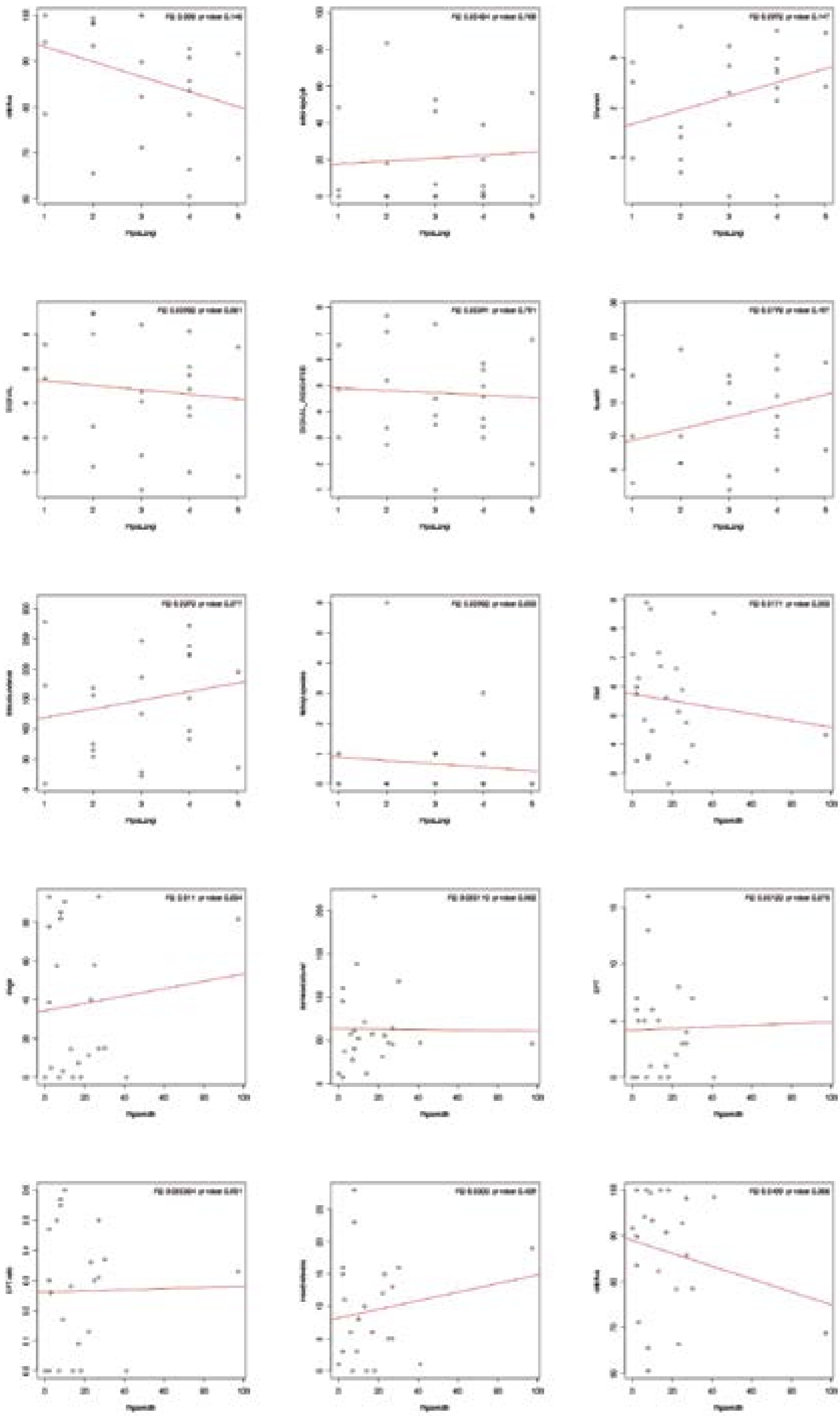


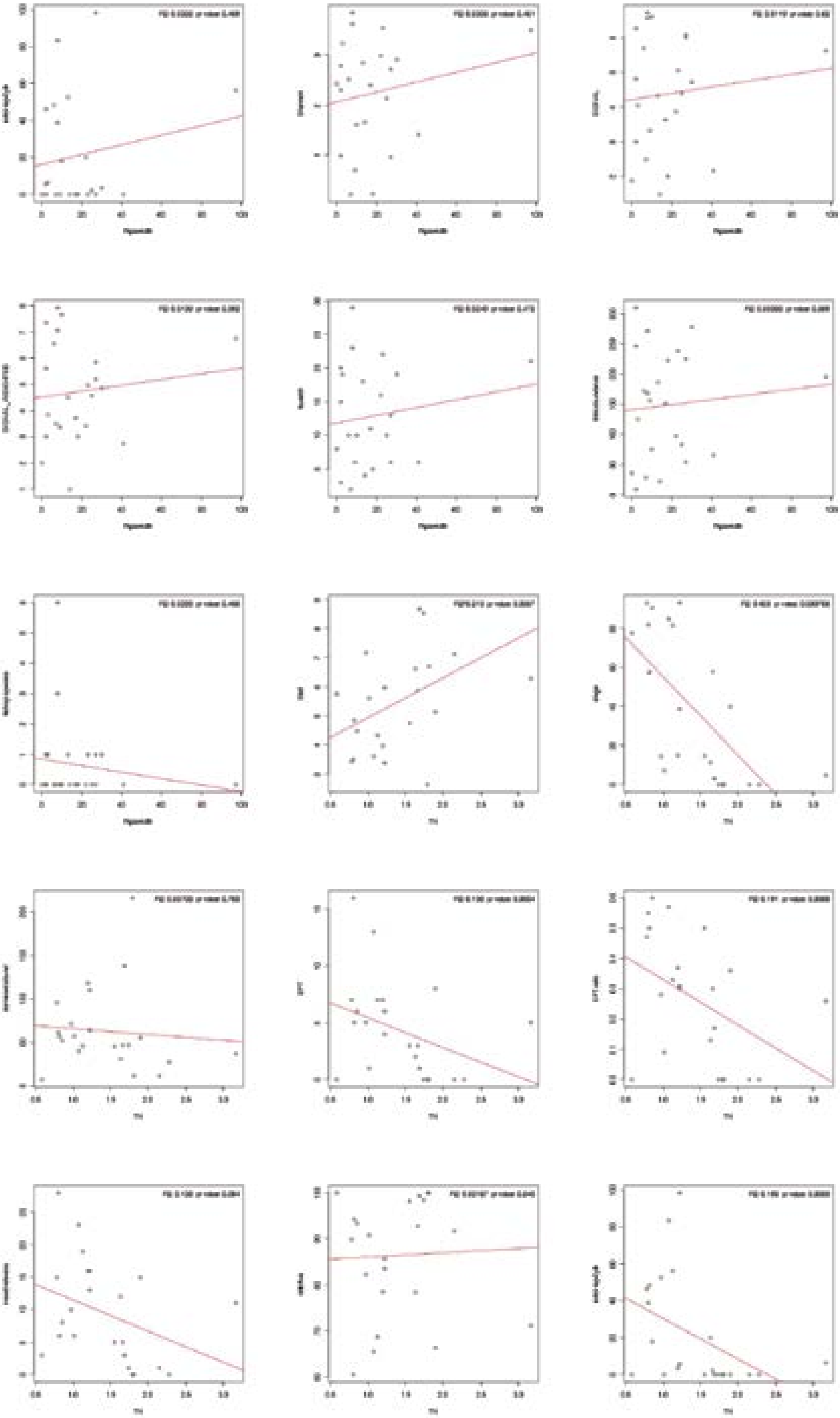


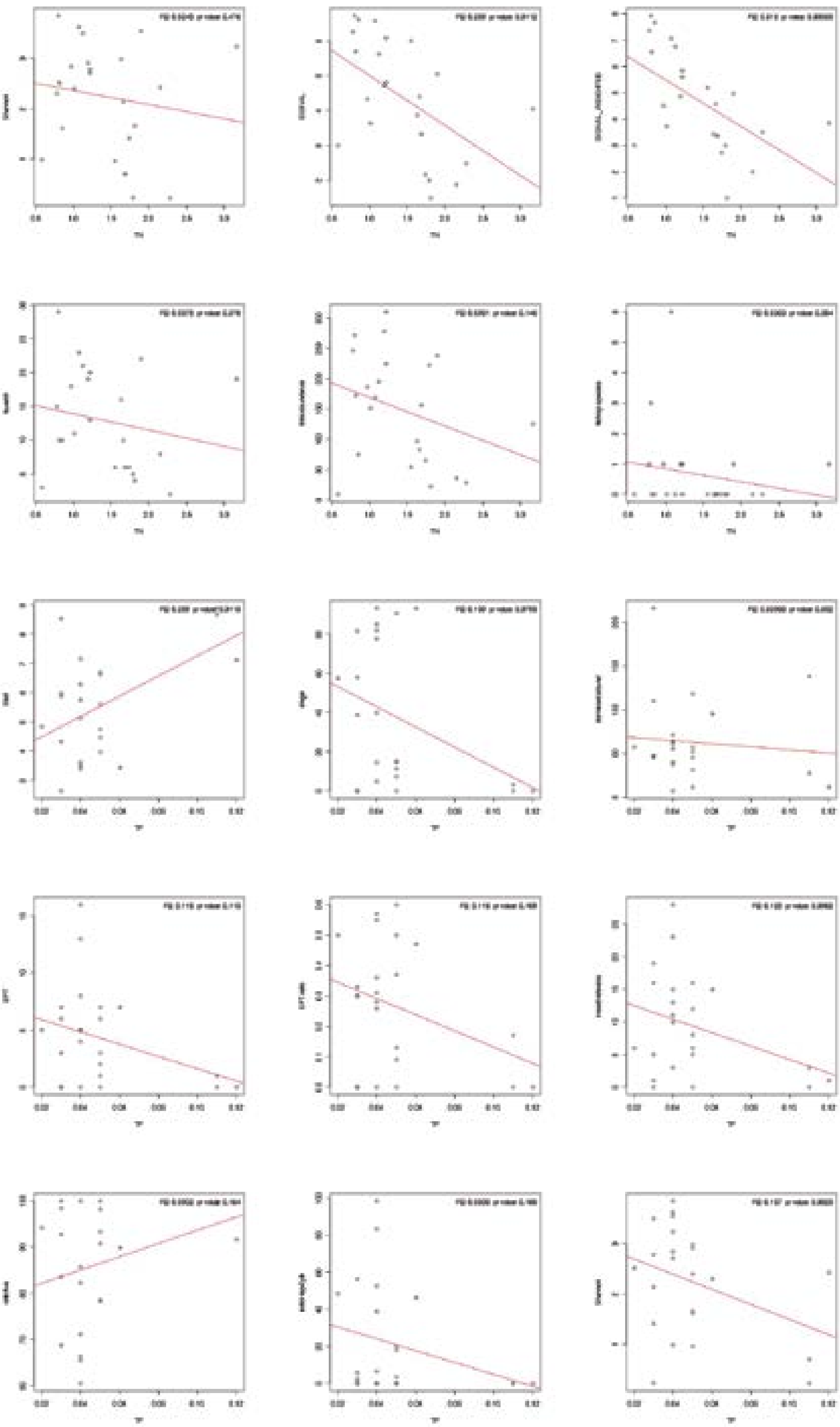


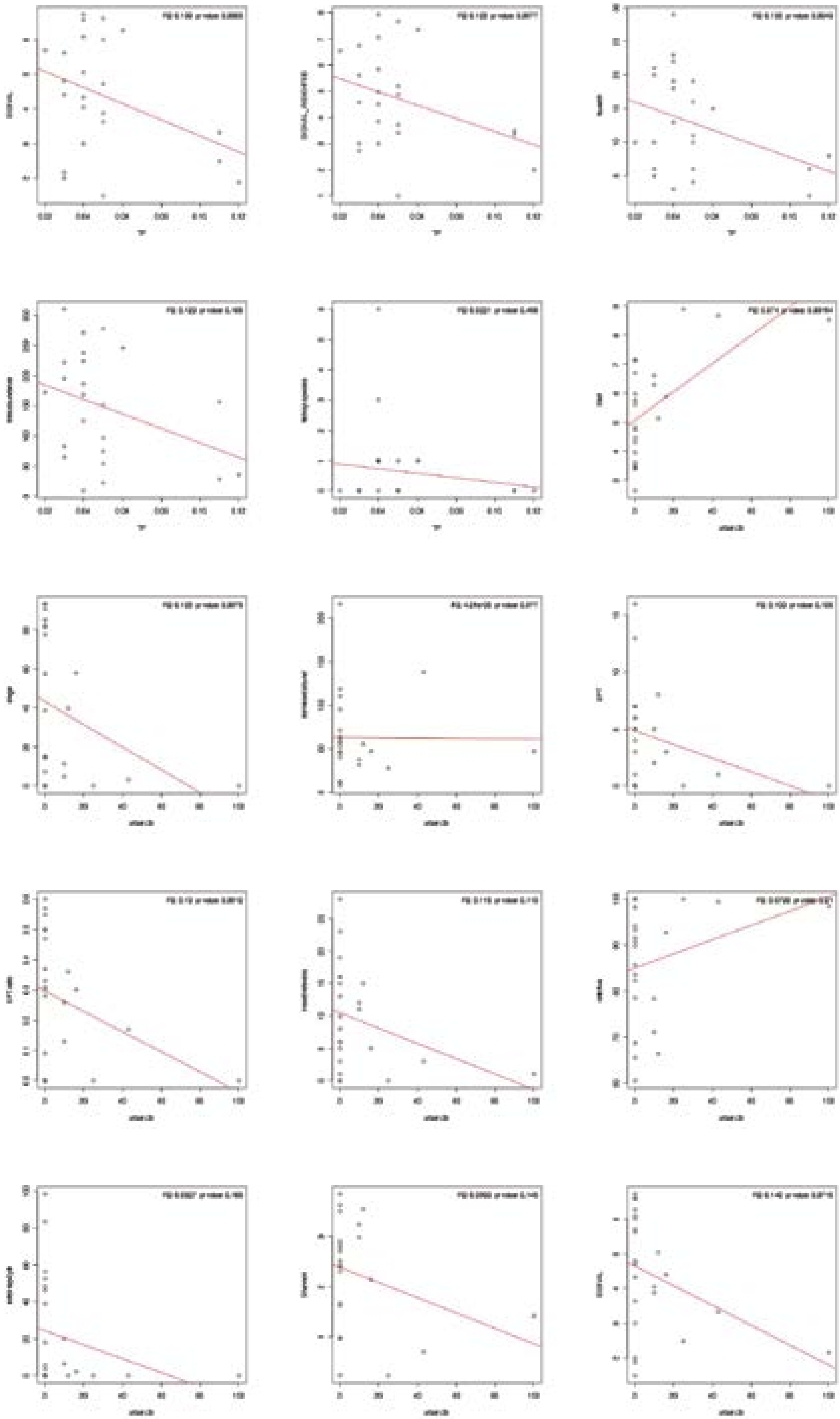


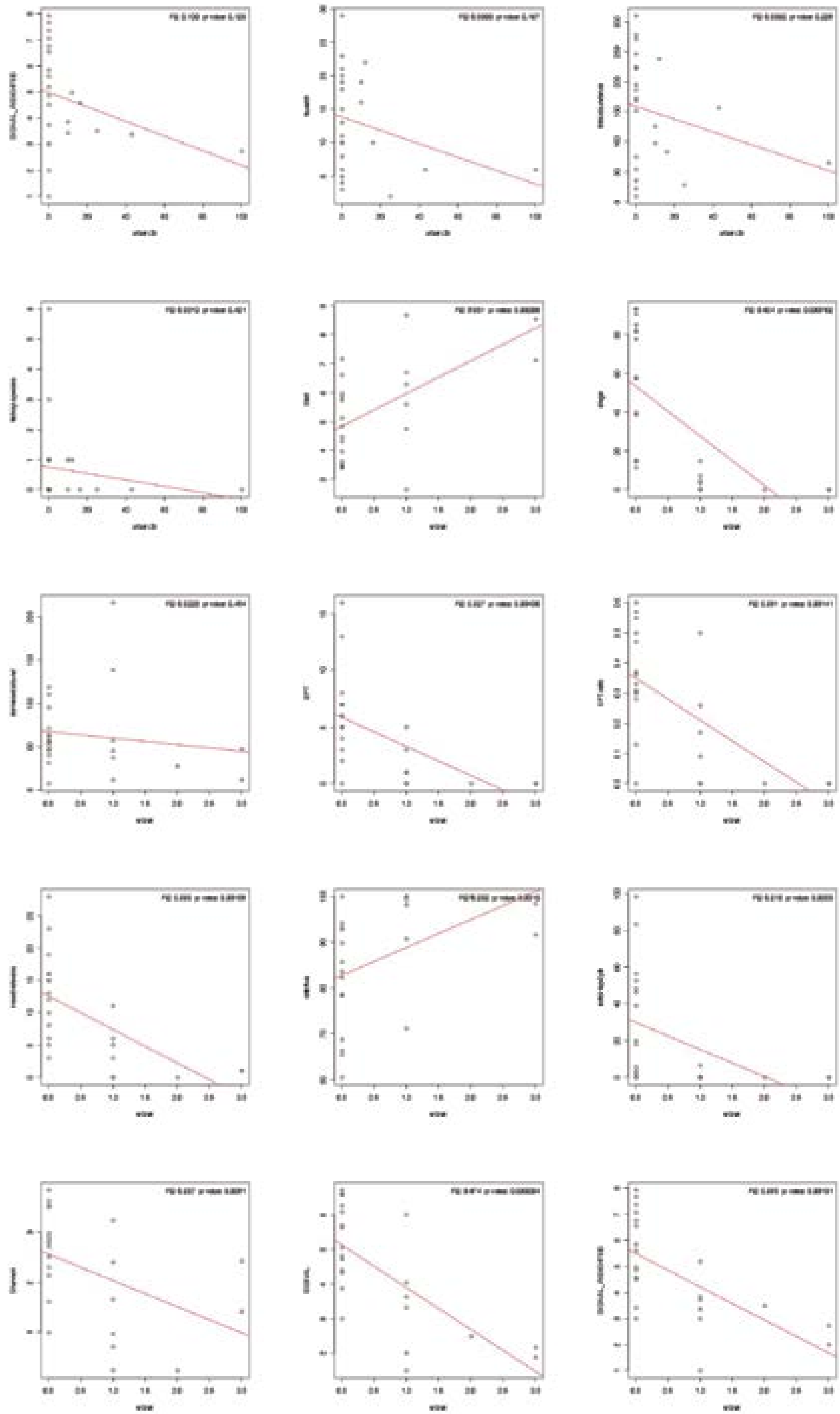


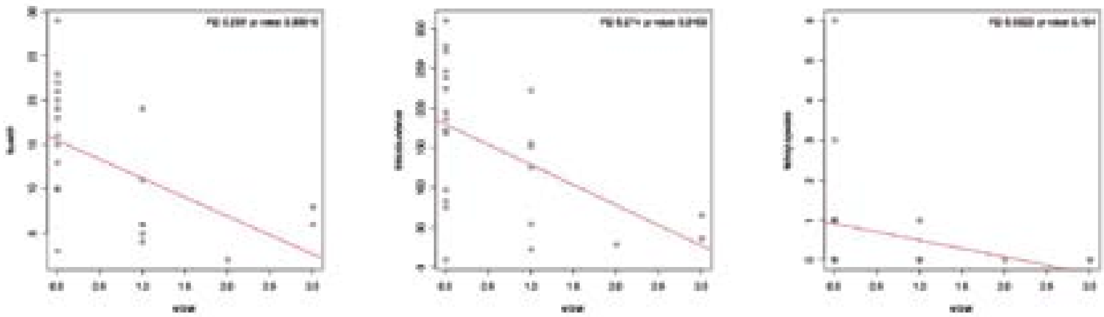






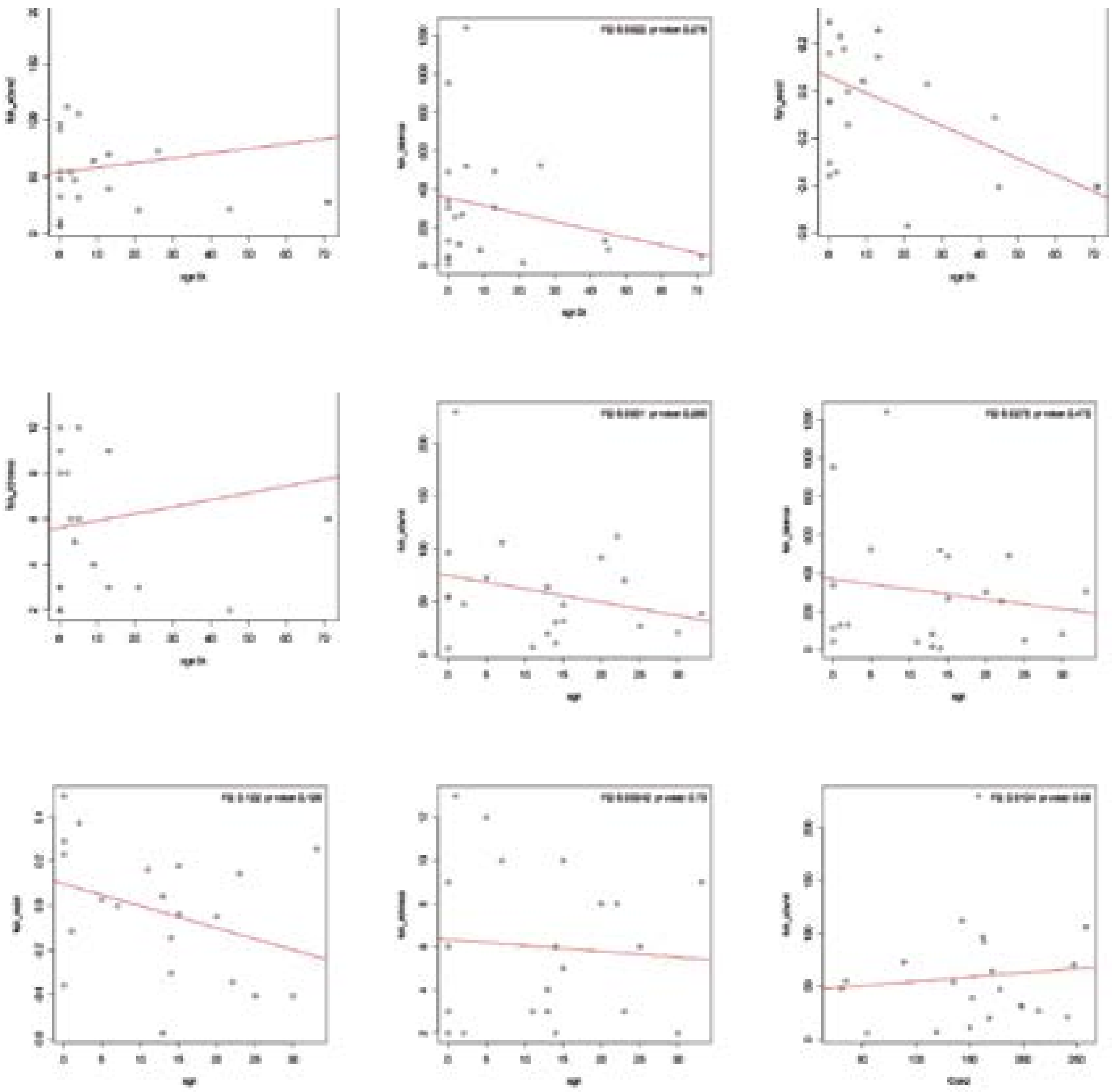


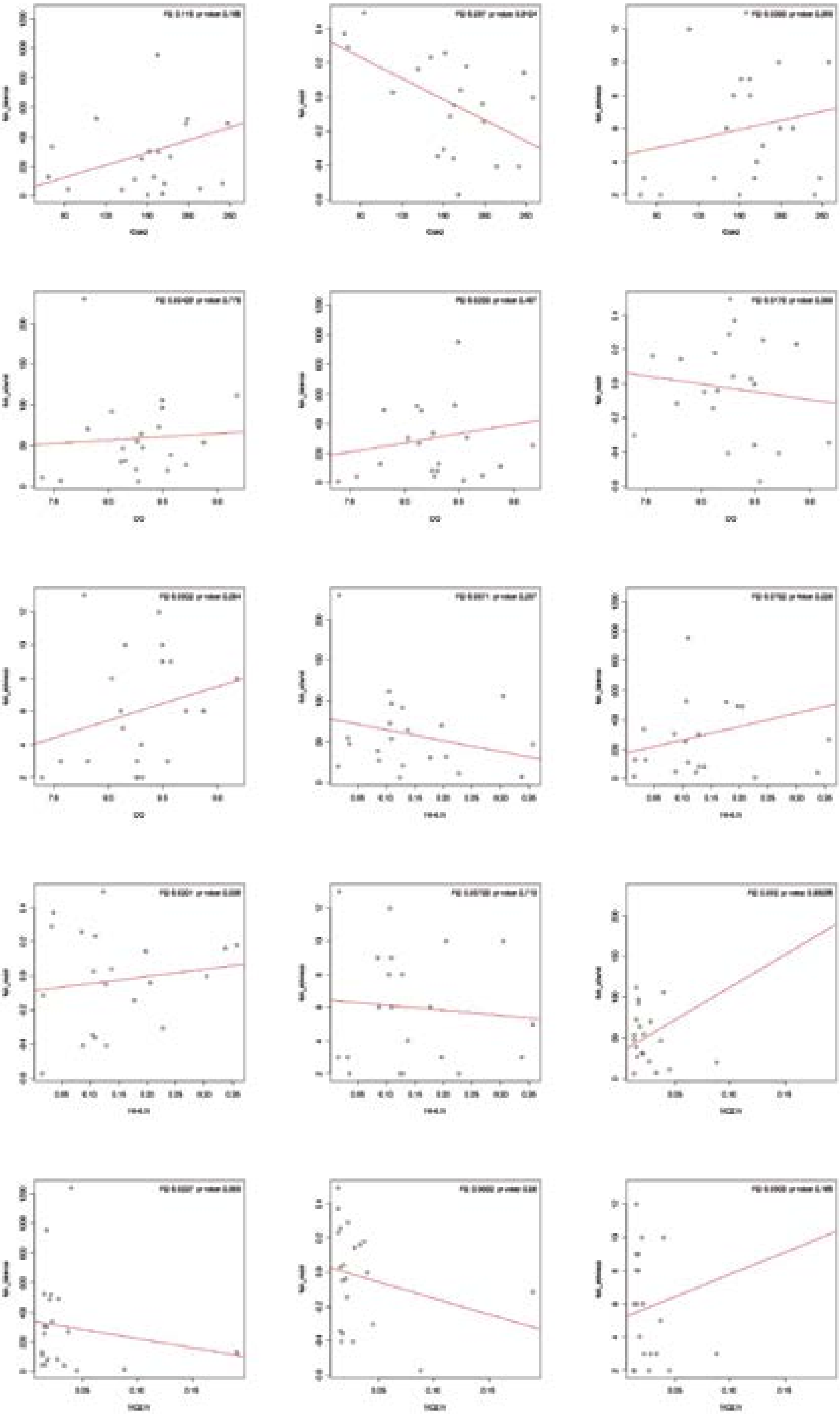


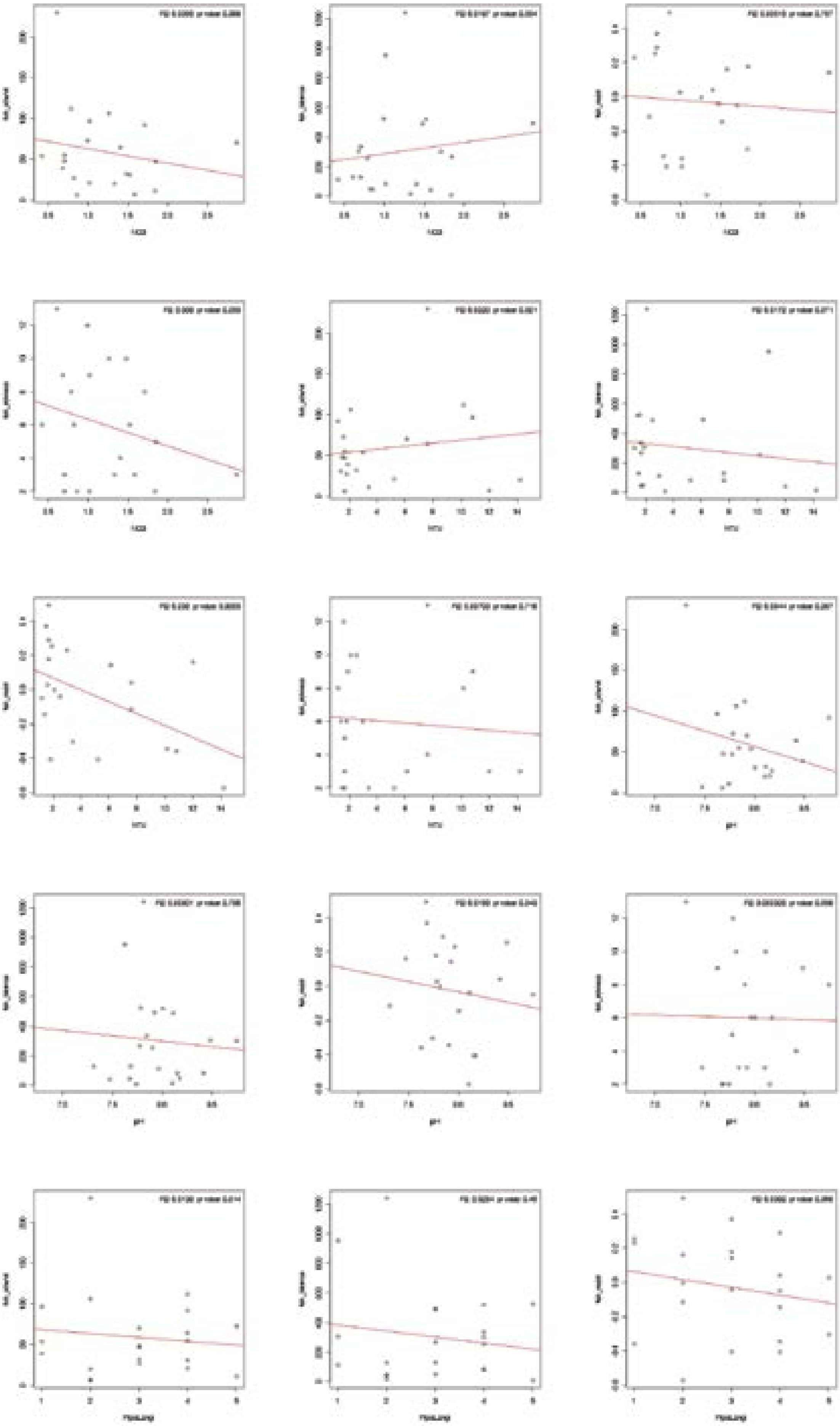


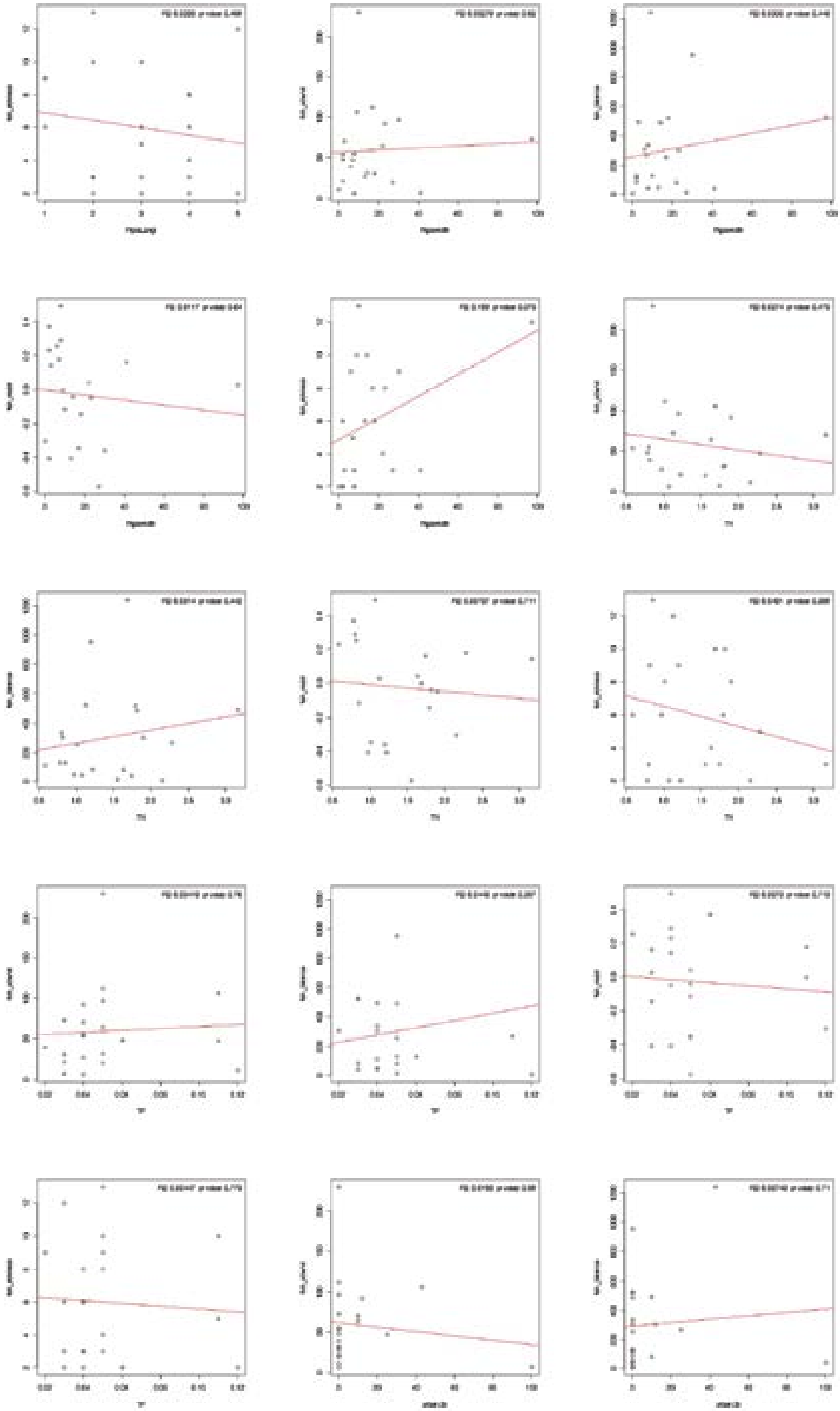
8.4 Relationship between fish, land use and water quality

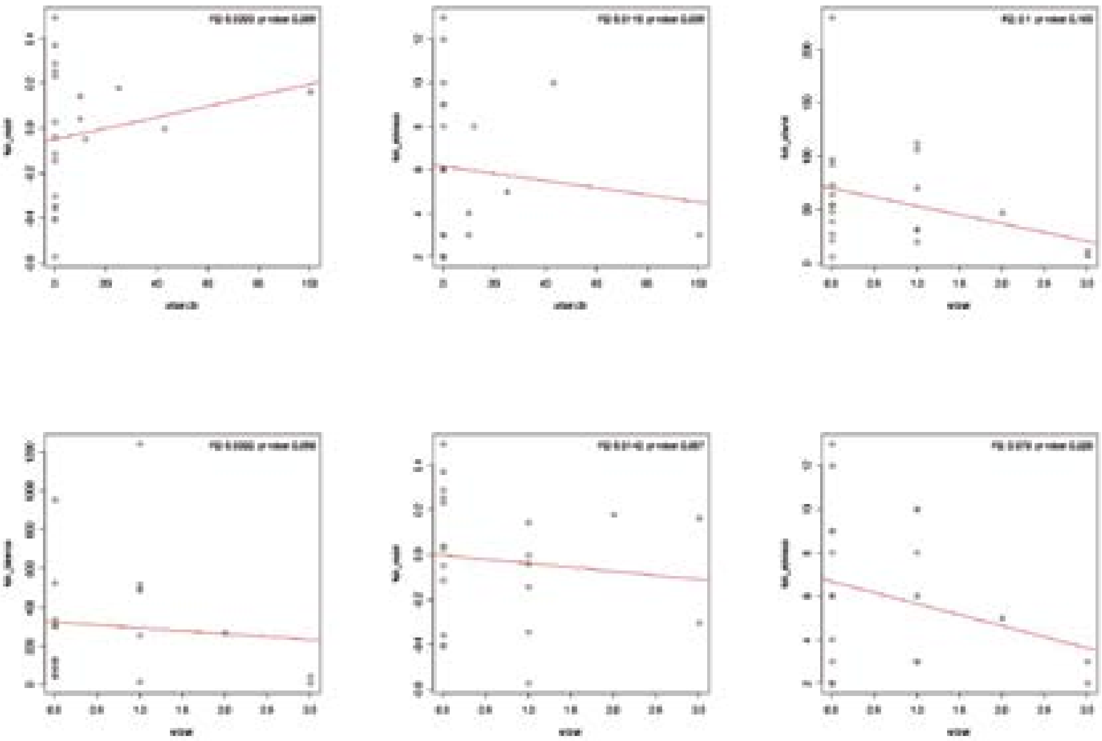
The following graphs show pairwise relationships between land use (primary) and water quality (secondary) disturbance indicators and fish ecosystem health indicators. The red lines show the linear regression.











Gui River

river health report card

About this document

This document has been prepared as part of a joint project between the Australian and Chinese Governments, funded by the Australian Agency for International Development, AusAID, as part of the Australia-China Environment Development Partnership. The project ran from August 2009 until February 2012 with the goal of strengthening China's national approaches for improving river conditions through monitoring river health, estimating environmental flows, and policy responses.

The project involved pilot studies in subcatchments of the Pearl River (in the Gui River), Liao River (in the Taizi River) and Yellow River basins. The work in the Gui River involved the Chinese Ministry of Water Resources, the Pearl River Water Resources Commission, local Chinese water agencies, and a team of Australian experts led by the International WaterCentre. In addition to the river health assessment described in this document, a detailed environmental flows study was undertaken for the Li River, a river within the Gui River catchment.

Further information on the project, including detailed technical reports on the Gui River health assessment, is available at:

http://www.watercentre.org/research/applied-research/acedp

Australian Government
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Gui River
river health report card

What is river health?

The concept of "river health" incorporates ecological and human values. A "healthy" river is one which has retained its ecosystem integrity. The health of a river depends on its ability to maintain its structure and function, to recover after disturbance, to support local biota (including human communities), and to maintain key processes, like sediment transport, nutrient cycling and energy exchange.

River health is important. Healthy rivers provide water for drinking, for agriculture, and for industry; fish and other produce; buffers against flooding; transport and recreational opportunities: and assimilate waste products. As rivers become unhealthy, they lose their capacity to provide these valuable goods and services.

Assessing river health

Maintaining and improving river health requires an accurate assessment of the current ecological state of river ecosystems. River health assessment can involve consideration of all elements of a river ecosystem, including water quality, the structure, abundance and condition of aquatic flora and fauna, hydrology, levels of catchment disturbance, and the physical form of the channel system. Each of these can provide information on river condition. This process can:

- Identify those rivers that are in poor health, or at risk of poor health
- Identify the likely causes of poor health
- Help prioritise funding for river restoration, and guide effective management actions
- Assess the effectiveness of management actions
- Allow for reporting on river health

Assessing the health of the Gui River

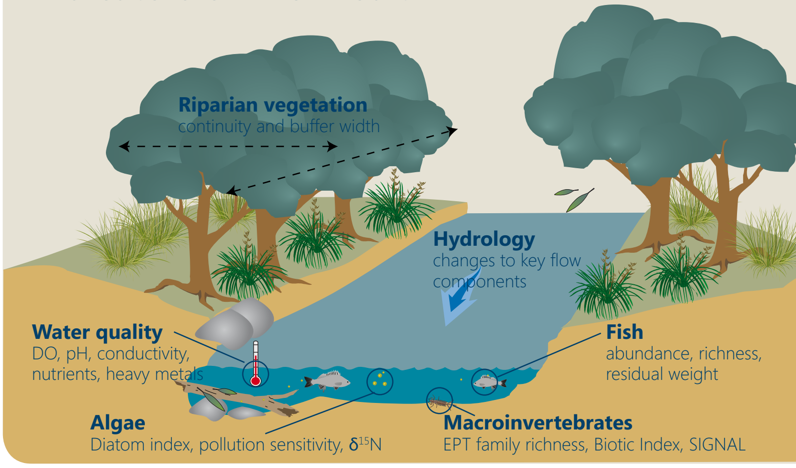
This document is the result of a pilot river health study in the Gui River catchment, part of the Pearl River Basin. As part of the study, data on the water quality and ecology of the river was collected during a field investigation. Existing information, including hydrological data, was also used.

Indicators that were suitable for measuring river health were identified by comparing changes in indicator values across the catchment. The study also determined what indicator values would be expected in a healthy river, as well as the values that would suggest a river in poor health. This information was used to make an assessment of health across the catchment's waterways.

The different indicators assessed as suitable and used in this study are show in the figure below. This document provides a summary of:

- The river health science behind the pilot study, including the significance of each of these indicators
- The work undertaken during the study
- An assessment of the current health of waterways in the catchment
- Recommendations for future monitoring

Indicators of river health



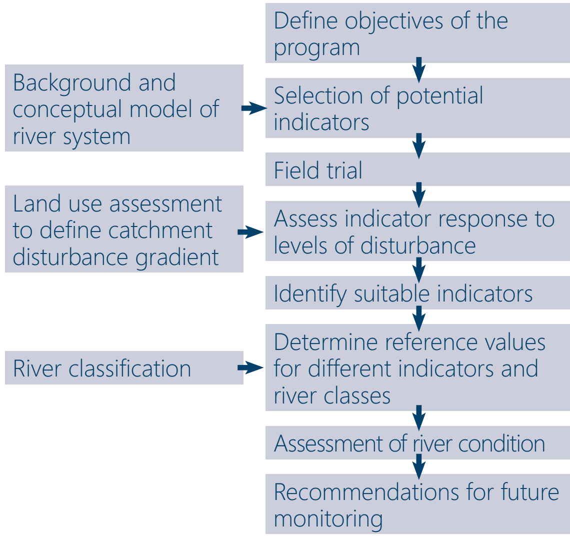
Gui River health assessment

Background to catchment

The pilot study was conducted on the Gui River, a northern tributary of the Pearl River Basin. Although small in comparison to other tributaries of the Pearl, the river drains a unique Karst landscape and is an important tourist destination.

Goal of the pilot study

The pilot study was a first step towards the implementation of a routine monitoring program. The study aimed to establish a method for selecting indicators, and to make an initial assessment of river health in the catchment.



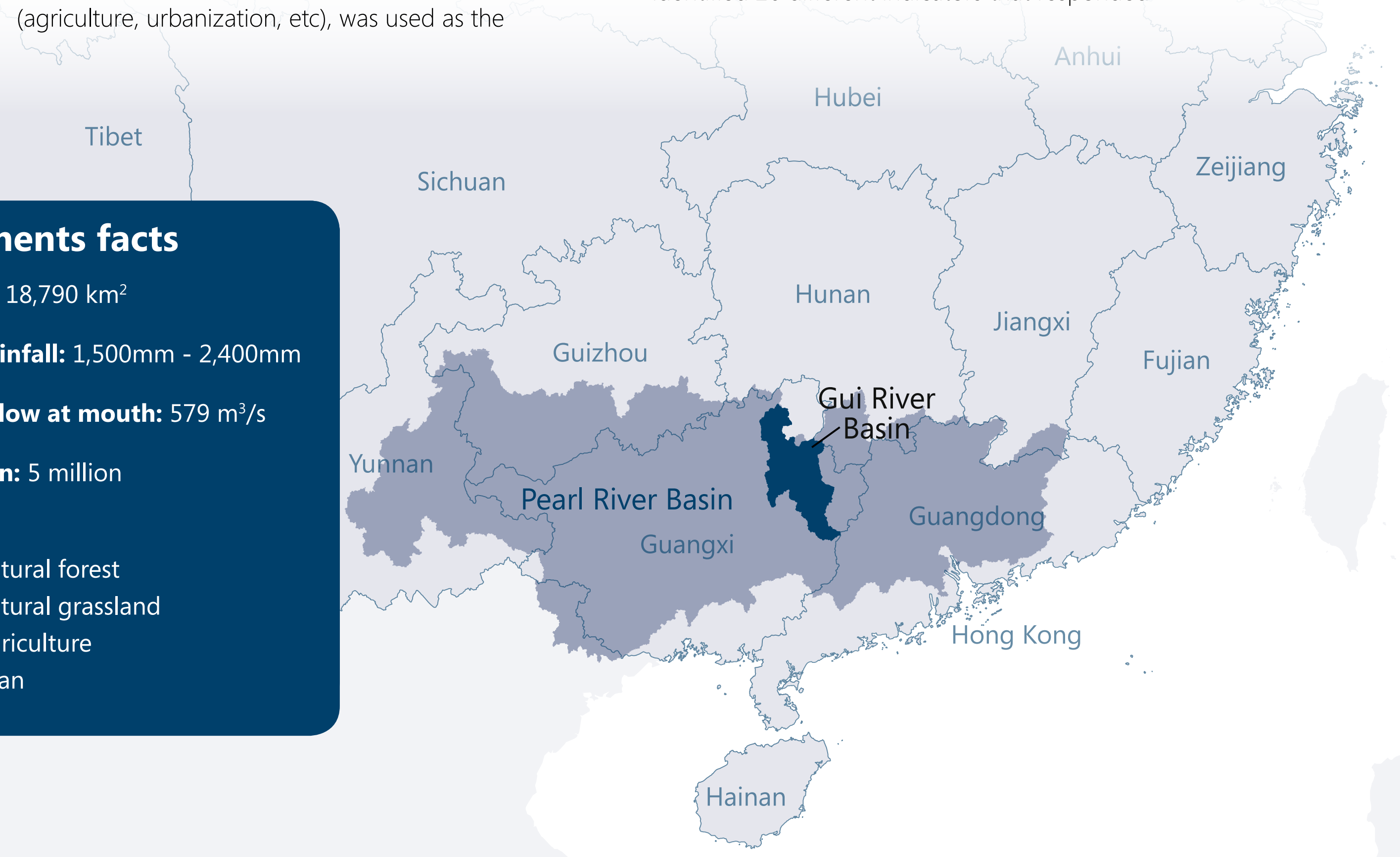
Key steps in the study

Objectives: The study proposed that any future monitoring program should focus on protection of the high conservation and aesthetic values of the catchment.

Field trial: A field trial was undertaken in April 2010, during which 24 sites across the catchment were sampled, including disturbed and undisturbed sites. At each site, an assessment was made of water quality, benthic macroinvertebrates, fish, algae, aquatic and riparian vegetation, and physical form.

Land use assessment: Land use practice (agriculture, urbanization, etc), was used as the primary disturbance gradient by which to test potential indicators. The percentage cover of different land use categories was calculated using GIS software for the entire catchment upstream of each site, and within a 1 km wide buffer area extending 5 km upstream from each site.

Identification of suitable indicators: A total of 45 different indicators across six different indicator groups were tested against the disturbance gradients. This included indicators that were measured (e.g. water conductivity) and some that were derived from raw data (e.g. ratio of different species). This process identified 26 different indicators that responded



Catchments facts

Drainage: 18,790 km^2

Annual rainfall: 1,500mm - 2,400mm

Average flow at mouth: 579 m^3/s

Population: 5 million

Land use:

48% natural forest
36% natural grassland
13% agriculture
1% urban

predictably to changes in disturbance, and thus may be suitable for future use.

Classification: Categorising similar types of rivers into groups is crucial for setting appropriate reference values and ensures that comparisons are only made between comparable river systems. Rivers were divided based on stream order (1st order, 2nd order, 3rd order and above) to reflect the expected differences between upland and lowland systems. In a larger basin, it would be more appropriate to classify rivers based on a wider range of factors, including climate, geology and altitude.

Reference values: Reference values were established using expert opinion and a combination of targets and thresholds taken or derived from:

- pre-defined Chinese standards (e.g. existing water quality standards)
- data collected from sites in the catchment which was used to set the upper (targets) and lower (threshold) values directly
- values derived from international studies and standards. This last option was used in the absence of existing Chinese standards, and, should be phased out as soon as additional local data becomes available.

Where necessary, different reference values were defined for different river types, to recognise the variance even within different (healthy) river systems.

Scoring sites and indicators: At each site, for each indicator a score from 0 – 1 was assigned, using the reference values as a benchmark. These scores were then aggregated to produce combined scores for different indicator groups, sites, and regions. Scores ranked along a scale from good to critical.

Key considerations for future work

- An assessment of a larger number of sites will be necessary to refine selection of the indicators and assist development of locally derived reference values
- An improved site classification would be valuable to help set regional reference values
- Further work is required to identify indicators suitable for measuring the health of large lowland rivers

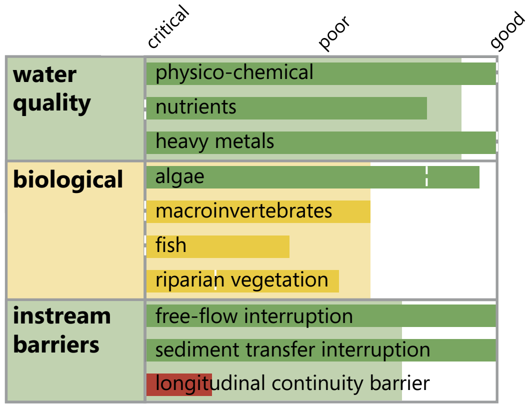
Potential target values for indicators of aquatic ecosystems in very good condition and potential critical values for indicators representing the threshold at which aquatic ecosystem health collapses

Group	Indicator	Region	"Very good" Target	"Critical" threshold	Basis for values		
					Chinese standards	International research/standards	Pilot study data
Water quality	pH	All	6-9	<6 or>9	✓		
	Conductivity (µS/cm)	All	≤400	≥1500	✓		
	Dissolved oxygen (mg/L)	All	≥7.5	≤2	✓		
	Metals (mg/L)	All	various	various	✓		
Nutrients	NH_4 (mg/L)	All	≤0.15	≥2	✓		
	Total nitrogen (mg/L)	All	≤0.2	≥2	✓		
	Total phosphorus (mg/L)	All	≤0.02	≥0.4	✓		
Algae	Biological diatom index	All	>16	1-4		✓	
	Specific pollution sensitivity index	All	>16	1-4		✓	
	$\delta^{15}N$	All	>5	>10		✓	
Macro invertebrates	SIGNAL Score	All	>6	<3		✓	
	Biotic index	Highlands	>4.16	>7.05		✓	
		Midlands and Lowlands	<5.24	>7.71		✓	
	Ephemeroptera/ Plecoptera/Trichoptera (EPT) family ratio	Highlands	>0.45	0.0-0.25		✓	
		Midlands	>0.34	0.0-0.16		✓	
		Lowlands	>0.33	0.0-0.18		✓	
Fish	Species richness	Highlands	>3	<2			✓
		Midlands and Lowlands	>7	<2			✓
	Abundance	All	>20	<5			✓
	Residual weight	All	>55	<-0.61			✓
Vegetation	Buffer width (m)	All	>25	<2			✓
	Buffer continuity	All	5	1			✓

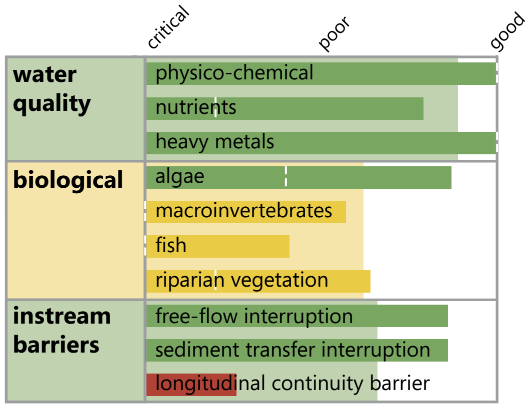
Further information on the project, including detailed technical reports on the Gui river health assessment, is available at: **http://www.watercentre.org/research/applied-research/acedp**

Report Card Results

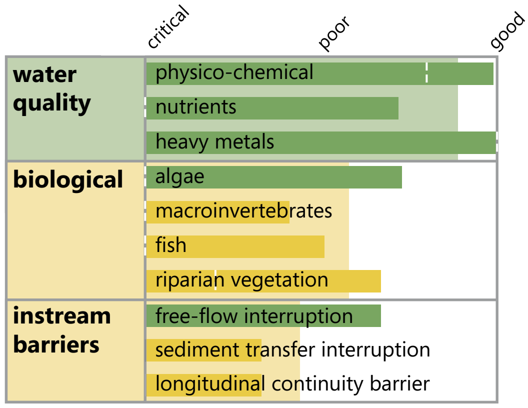
Upper streams



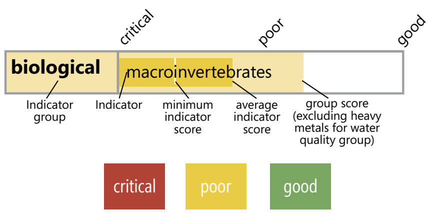
Main tributaries

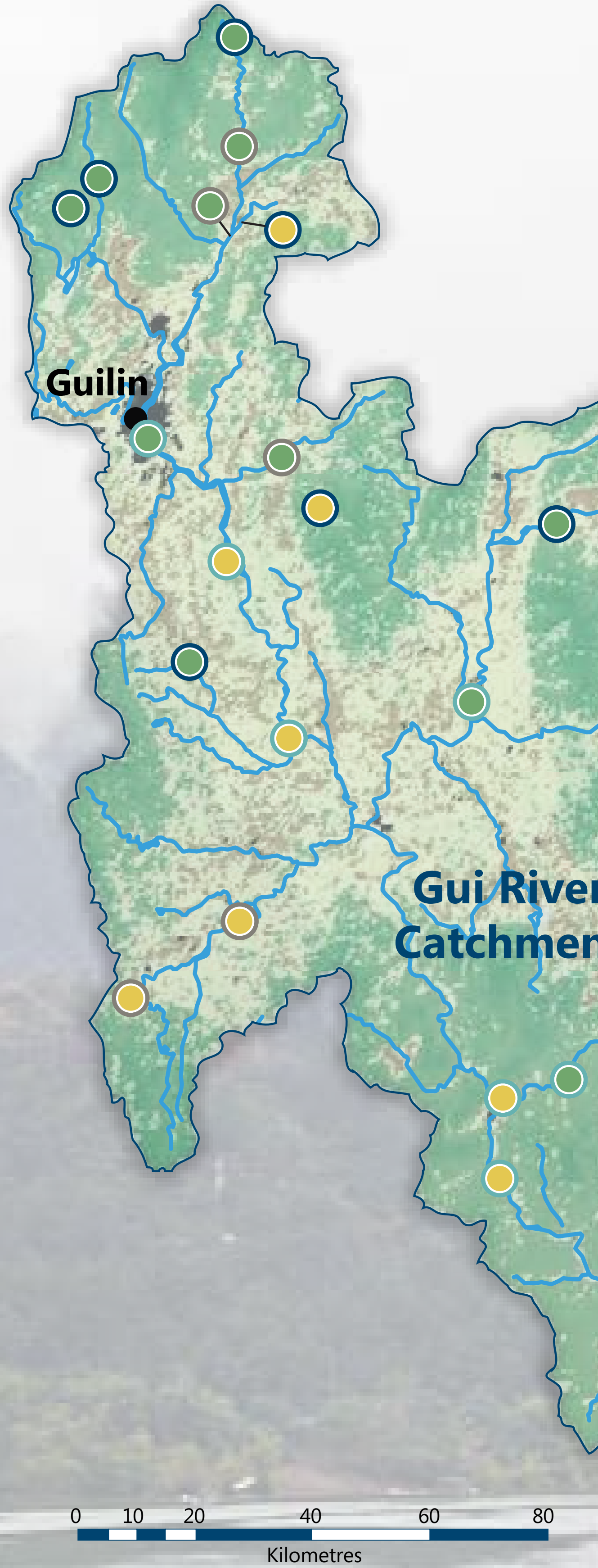


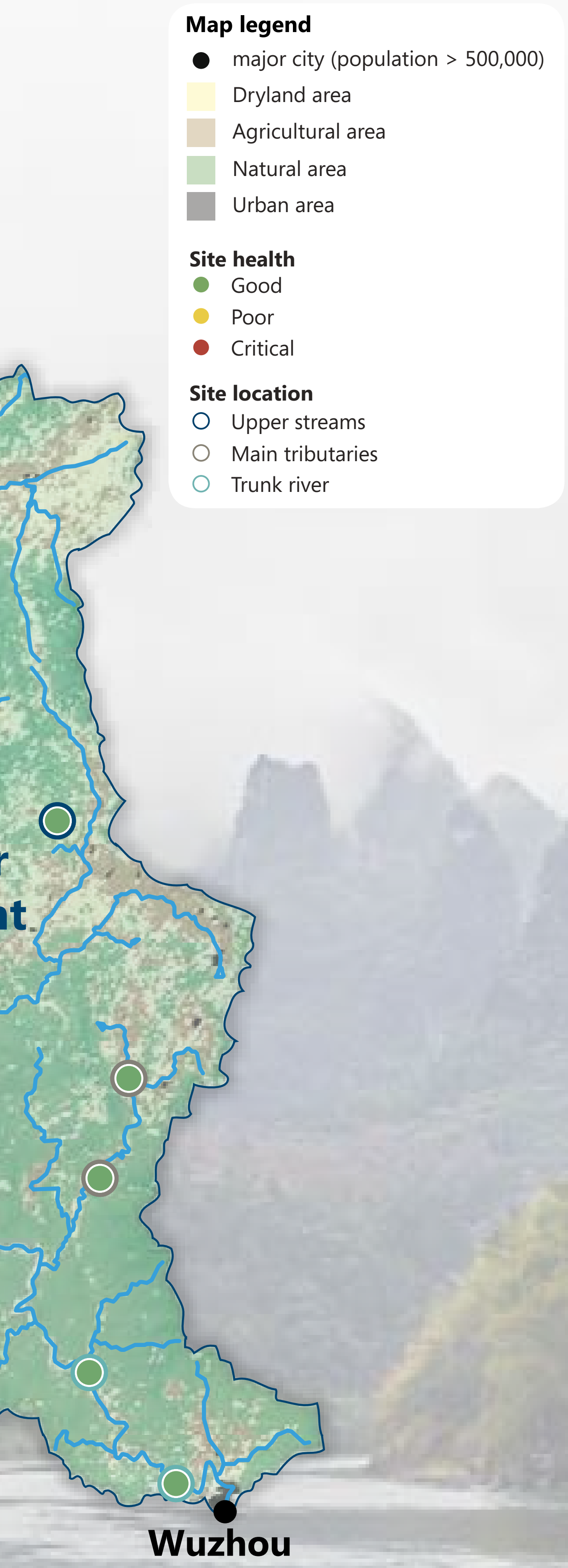
Trunk river



Bar graph legend







Selecting indicators of river health

Internationally, there is a large range of indicators available. Which indicators will be suitable will vary with the type of river system, and the likely threats. Indicators need to be carefully selected in building a monitoring program.

Indicators need to respond predictably to disturbance in the catchment, and to changes in the river. Testing a range of indicators to ensure they respond as expected is an important step in developing a river health monitoring program. Often the choice of indicators is refined over time as more data are collected. To test if indicators show a predictable response, it is necessary to first establish the levels of disturbance across the catchment. This usually involves considering known impacts on river health, such as agricultural development and urbanization. The values for different indicators can then be tested against this disturbance gradient. Those that respond in a predictable way may be suitable for future use.

The graph above shows two different indicators which are responding in a predictable way to increasing levels of human disturbance.

Characteristics of a good indicator

An indicator should:

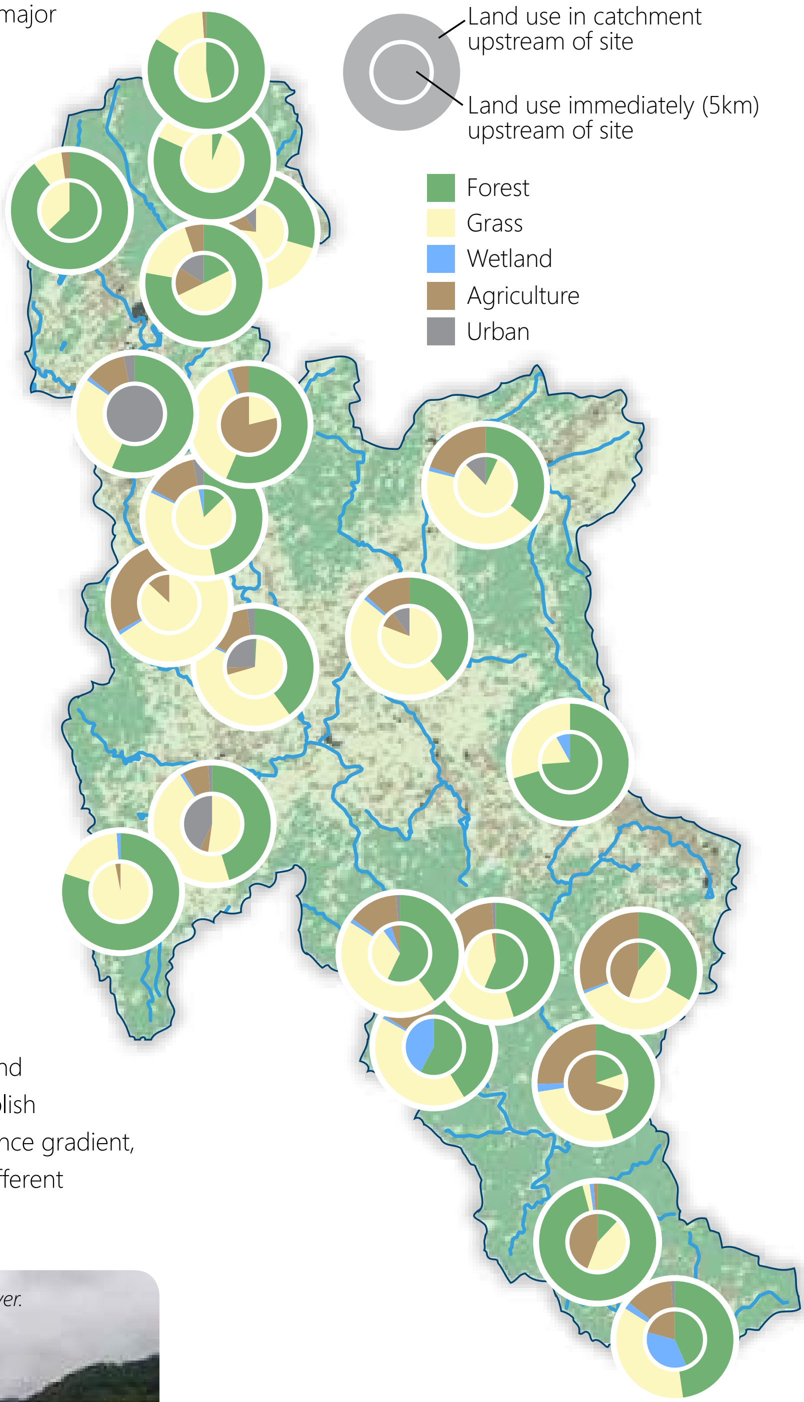
1. Quantify threats and assets
2. Provide easily interpretable outputs
3. Respond predictably to damage caused by humans but be insensitive to natural variation
4. Relate to appropriate scales
5. Be cost effective to measure
6. Relate to management goals
7. Be scientifically defensible

Catchment disturbance

Land use change is thought to be the major human-induced factor affecting river health in the Gui River catchment. For example, clearing of vegetation can affect catchment water balances, can increase erosion, and can lead to increased sediment and nutrients entering the river system. Urbanisation can increase pollution loads from stormwater runoff.

Land use and land cover compositions of the catchment upstream of each of the sampling sites were extracted from Landsat images using GIS software. The percentage cover of each of the different land use categories (agriculture, forest, urban, etc.) was calculated within the entire catchment area upstream from each site, and within a 1km buffer area extending from the sampling site to a point 5 km upstream.

This information is included here as an indicator of the likely condition of the river system based on land use, both in the immediate surrounds and the entire upstream catchment. This land use information was also used to establish the primary (human-induced) disturbance gradient, against which the responsiveness of different indicators was tested.



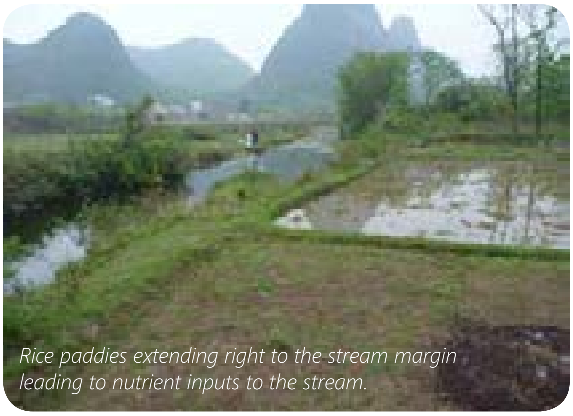
Boats used for mining for gold on the Gui River.

Riparian vegetation and physical form

Riparian vegetation

The riparian zone can act as a buffer between the river and activities in the surrounding catchment. Healthy riparian zones are an effective way of achieving a healthy river – helping filter nutrients, trapping sediment runoff, and maintaining food-web and other important links between the terrestrial and aquatic environments. They are also important environments in their own right, and often harbour a high diversity of plant and animal life such as birds. Reinstating a vegetated buffer, especially in agricultural areas, provides a potential management action to improve river health.

Riparian vegetation indicators assessed the width and continuity of the riparian buffer zone. These are included in the scores for each site. Future reporting could include some measure of naturalness, based on species composition.



Rice paddies extending right to the stream margin leading to nutrient inputs to the stream.

Large mats of filamentous algae from nutrient enrichment at this site.

Physical form

Physical form is concerned with the morphology and sediment characteristics of the bed and banks of the river and the floodplain environment. These characteristics create habitat for the biota. Fragmentation by dams and levees also impacts on the physical environment of the river. Direct management of physical form is common practice (such as through channel rehabilitation and sediment control), and hence it is useful to include physical form as a river health indicator. However, the wide range of physical habitat preferences of aquatic biota and the dynamic nature of channel morphology make it very difficult to derive reference values for physical form indicators.

Several physical form indicators were trialled in the field and these methods could distinguish highly modified streams with simple physical form (canals, and channelized streams) from natural streams with high variability in sediment, bank shape and bed forms. However, there was a high spatial variation in the physical form indicators. Due to the limited data collected, river health scores based on physical form are not reported here, but should be included in future reporting as methods are refined and more data collected. Our recommendation at this stage is that physical form indicators focus on quantifying the presence of human pressures known to modify physical form, such as lateral barriers (levees, hard-lined banks) and factors that alter sediment sources (land-use) and transport (e.g. instream barriers). Information on instream barriers is included elsewhere in this report card due to the additional influence of barriers on patterns of streamflow, habitat alteration, and the movement and migration patterns of aquatic biota.

Water quality

Why measure water quality?

- Water quality is a key component of aquatic ecosystem condition, and can be both an indicator as well as a cause of poor health
- Nutrient and pollutant levels can indicate the likely cause and source of water quality decline, and help identify areas to be addressed by management actions
- Water quality data is often already gathered as part of existing monitoring programs, and there are often existing water quality standards

A critical problem with monitoring water quality, however, is that most parameters vary significantly according to recent runoff history. This must be considered when interpreting the data.

What was measured?

Measurements were taken of:

- chemical properties, including dissolved oxygen, conductivity and pH
- nutrient concentrations
- toxicants, such as heavy metals

What do the results show?

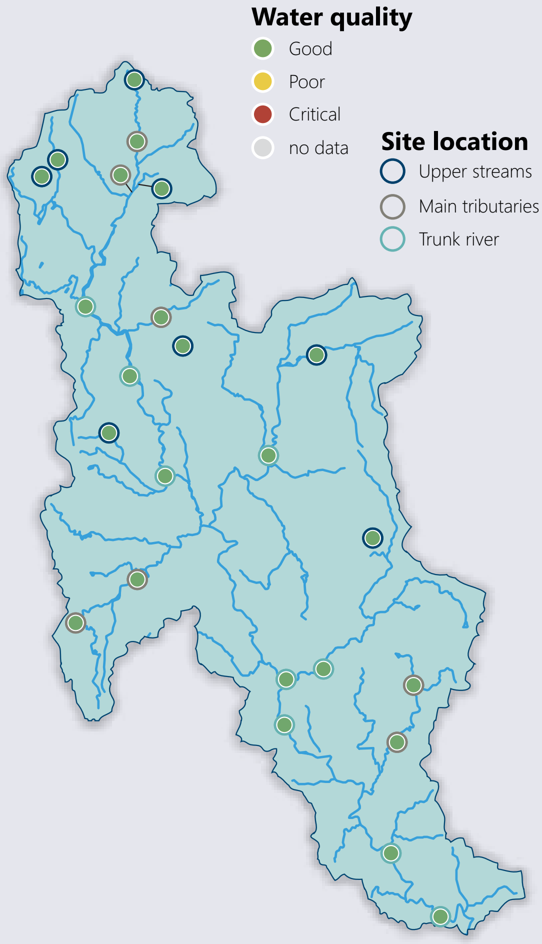
The strongest trends between indicators and levels of disturbance were for increasing pH and conductivity in agricultural areas, and increasing nutrient concentrations and decreasing oxygen concentrations associated with urbanization.

Values were assessed against existing Chinese water quality standards. In general chemical parameters were very good. Nutrient concentrations were elevated at a number of sites, largely the result of elevated NH_4 and NO_3 concentrations, particularly in more urbanized reaches. This resulted in only moderate condition scores with respect to this indicator. Phosphorus and heavy metal concentrations were low at all sites.

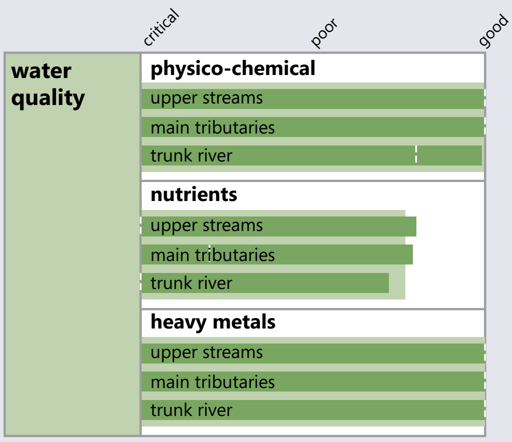
Recommendations

- Parameters that showed the expected response to the disturbance gradient and are recommended for inclusion in future programs were: pH, conductivity, dissolved oxygen, total nitrogen, NH_4, NO_3 and total phosphorus
- It would be beneficial to monitor different nutrient indicators, rather than just total nitrogen, as this may provide evidence of the source of the nitrogen

Site scores for water quality



Indicator scores



Algae

Why measure algae?

- Algae (diatoms) are abundant in most streams and respond rapidly to changed conditions
- They are relatively easy to sample, and their tolerance to environmental conditions is known for many species due to the wide distribution of many taxa
- Algal abundance (e.g. measured as chlorophyll concentration) and isotopic signatures can detect nutrient enrichment and nutrient sources

What was measured?

Benthic algae were collected from rocky substrate at each site, based on which the following five algal indicators were examined:

- Chlorophyll a and filamentous algae, which measure algal abundance
- Biological Diatom Index (IBD) and Specific Pollution Sensitivity Index (IPS), which take account of the tolerance of different taxa to declining water quality
- $\delta^{15}N$ enrichment in filamentous algae was used to indicate likely nutrient enrichment from agriculture and untreated human wastes.

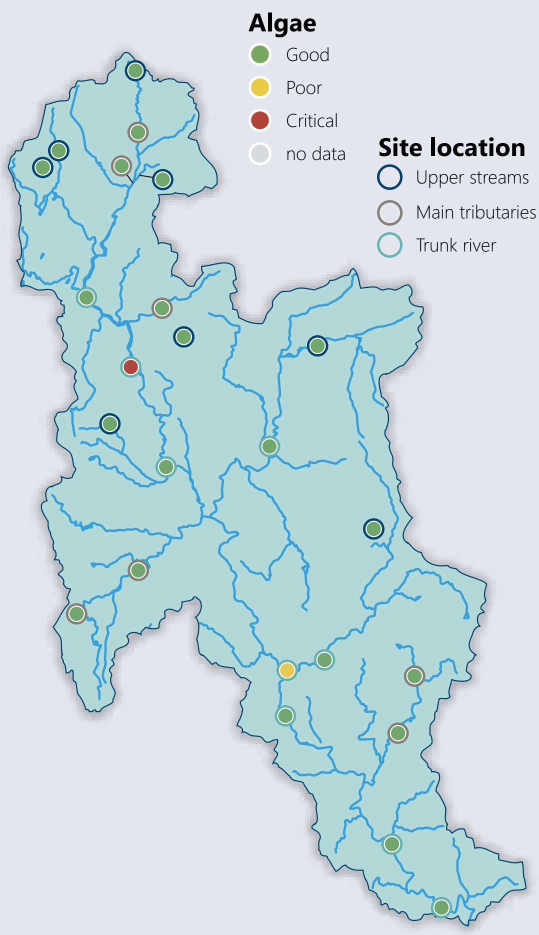
Benchmarks were established based on international literature.

What do the results show?

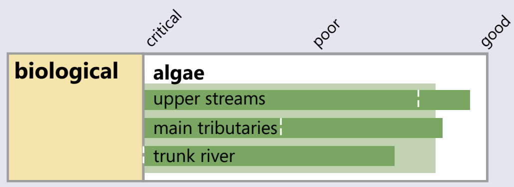
All indicators showed a response to urbanization or agriculture, except for filamentous algae. $\partial^{15}N$ values increased with the proportion of agriculture in the catchment, while Chlorophyll a concentrations indicated higher algal abundances in urban catchments. Sensitivity indices IBD and IPS both declined strongly with urbanization.

Unsurprisingly given the elevated nutrient concentrations, algal indicators scored poorly at many sites. This included both measures of community structure (IBD and IPS) and elevated $\partial^{15}N$ ratios in algal tissue samples, which supports the role of human or animal waste in increasing nitrogen enrichment. This suggests that efforts to reduce nutrient loads, through decreased urban and agricultural runoff, may improve river health.

Site scores for diatoms



Indicator scores



Recommendations

- Algal indices showed clear and consistent relationships with levels of agriculture and urbanization.
- Nevertheless, existing (international) sensitivity grades should be refined based on further studies of Chinese conditions.
- Considerable taxonomic expertise is required to utilise these algal indicators. These requirements, and associated costs need to be weighed up against alternative indicator groups in selecting suitable indicators for inclusion in a monitoring program.

Benthic macroinvertebrates

Why measure benthic macroinvertebrates?

- Benthic macroinvertebrates are found in most habitats, are an important food source, and contribute to carbon and nutrient processing
- They have limited mobility and are easy to collect
- They are sensitive to short- and medium-term disturbances
- Different taxa show a with wide range of sensitivities to changes in both water quality (of virtually any parameter) and habitats
- There are many well established indices based on macroinvertebrates

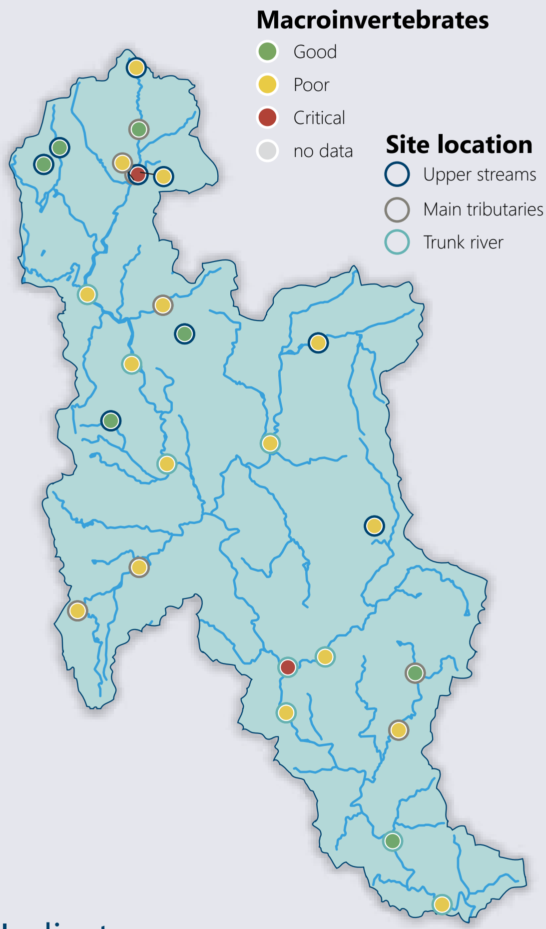
What was measured?

Macroinvertebrates were collected from a 10m section of the streambed using a kick net. The contents were then live-picked by two staff for a period of 30 minutes and subsequently identified, generally to genus level. The widely used indicators that were calculated included total density, taxa richness, EPT ratio (i.e. the proportion of total species richness comprised of Ephemeroptera, Plecoptera, and Trichoptera taxa), and Berger-Parker Dominance ratio. In addition two tolerance metrics were calculated; the Biotic Index (BI) and weighted and unweighted SIGNAL Scores, which reflect the overall tolerance of the assemblage and broadly assume that only more tolerant taxa will persist in more polluted environments.

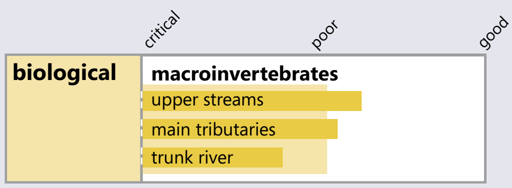
What do the results show?

Invertebrate scores indicate river health is poorer than is suggested by the other indicator groups measured, with few sites being considered in good condition. There was also a consistent trend towards lower scores in the more lowland sites, which is consistent with these sites generally having higher levels of catchment disturbance, but may also reflect changes in habitat types in larger rivers. There was also consistency between algal and invertebrate scores in the relative scores between sites.

Site scores for macroinvertebrates



Indicator scores



Recommendations

- Indicators that showed the expected response to disturbance were: EPT taxa, Biotic Index, Dominance ratio and SIGNAL.
- In selecting from the large number of potential indicators, the emphasis should be on indicators that show predictable and consistent responses to the disturbance gradients, and for which there is scientific justification.
- While indicators based on tolerance such as the Biotic Index and SIGNAL are in principle readily transferrable to China, the actual tolerance values may not be. Chinese specific tolerance values are needed, based on local taxonomy and tolerance patterns of individual taxa

Fish

Why monitor fish?

- Fish have a range of sensitivities to water quality, hydrology alteration and habitat deterioration
- Fish are relatively easy to sample and identify in the field
- Their place in the food chain mean fish integrate effects of lower trophic levels, and can be reflective of integrated environmental health
- Their mobility and longevity mean they can be used to assess macrohabitat and regional differences, as well as impacts of long-term changes in stream health
- Fish are often valued socially and economically

What was measured in the study?

Fish were captured using boat and backpack electro-fishing, seine nets and gill nets. At each site where fish were collected, around 30-60 minutes was spent sampling fish over a length of stream, typically around 150 m long. Each species was photographed for later identification, and individuals were measured and weighed. Indicators that were then examined focused on species abundance, total biomass, diversity of species, and the condition (health) of individual fish.

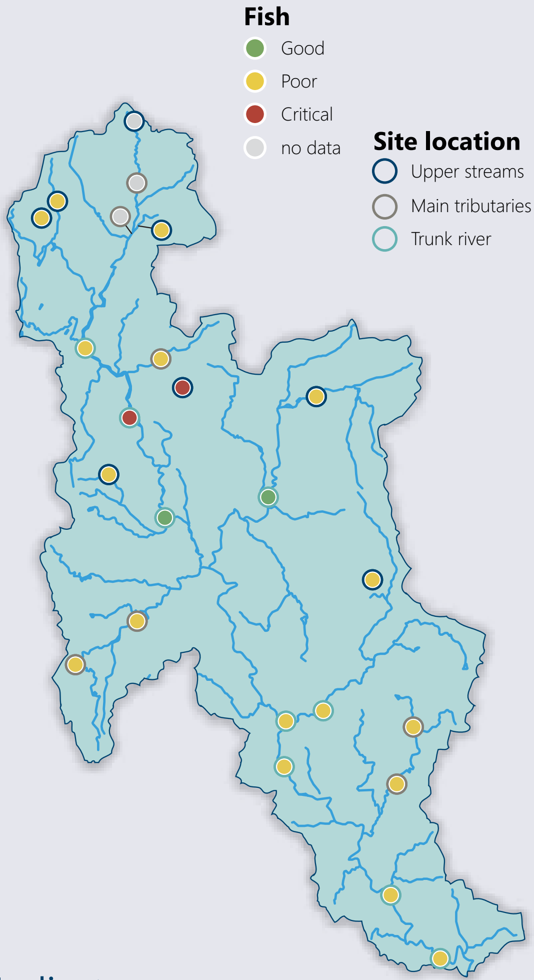
What do the results show?

It was difficult to make conclusions based on the fish data collected, in part because:

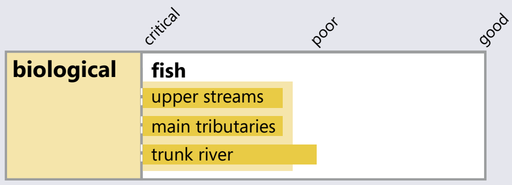
- The methods used for sampling varied between sites, making comparisons difficult
- Limited information was available on historical patterns of diversity, making the establishment of suitable targets difficult. This was exacerbated by a lack reference values that could be adopted from other regions or countries, even on a trial basis. This differed from invertebrates and diatoms.

Probably as a result of these issues, the results showed limited relationship between different indicators and levels of human disturbance. The sampling did show that most sites harboured several species of fish, and that the individual species collected appeared to be in good health, for example, with few signs of lesions or deformities that can occur in heavily polluted rivers. Overall however, fish diversity was lower than expected at most sites leading to relatively low indicator scores.

Site scores for fish



Indicator scores



Recommendations

Species richness, abundance and tolerance metrics should be considered as part of future monitoring programs. However, further work is required to allow fish to be used as an indicator of river health, including work to:

- Develop a suitable and consistent sampling methodology
- Review multimetric and tolerance indices (e.g. Fish IBI) from overseas and future development of these for use in China
- Determine appropriate benchmarks for all indices, including diversity and abundance metrics

Barriers

Why measure instream barriers?

Barriers such as weirs and dams can impact on longitudinal (upstream and downstream) connectivity within a river system, limiting the passage of fish and other species. Weirs and dams also indirectly impact the instream habitat by creating ponded conditions where previously the water was free-flowing. Hydropower stations can affect both water levels (and thus habitat) as well as flows at the daily time scale (which is not captured by the hydrology indicator). Barriers can also impact on sediment transport and thus influence physical form.

What was measured?

Three indicators were calculated using data on instream barriers within the catchment area. These indicators related to:

- whether a site was immediately downstream of a hydropower station or within the backwater of a dam or weir ("free-flow interruption indicator")
- whether a site had a dam or weir immediately upstream, and the size of the dam or weir ("sediment transfer interruption indicator"), and
- the total number of dams and weirs (without a fish passage) between the sampling site and the river mouth ("longitudinal continuity barrier indicator").

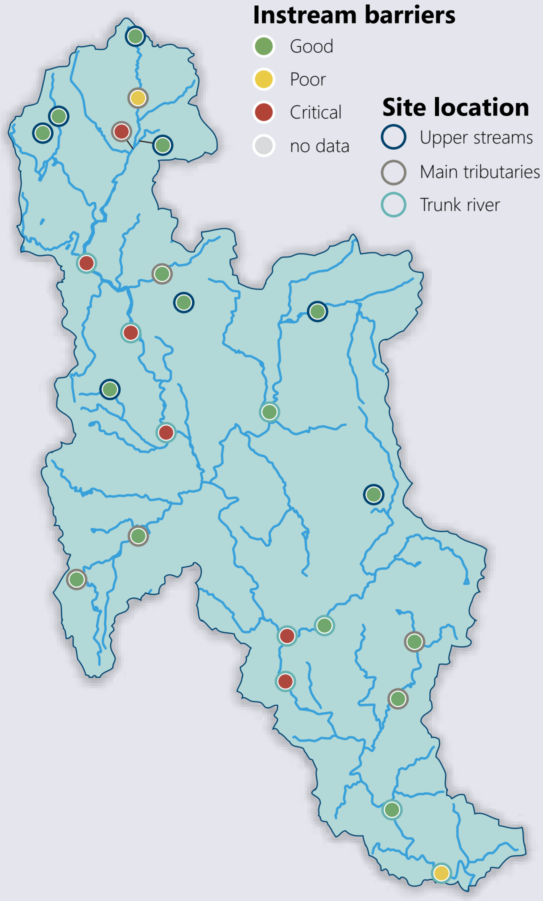
What do the results show?

There are approximately eight major dams within the Gui catchment (data on small dams and weirs were not available). None of these dams have fish ladders. The results reflect the spread of these dams across the catchment and their proximity to the different sampling sites. As expected, those sites located immediately downstream of dams scored the worst.

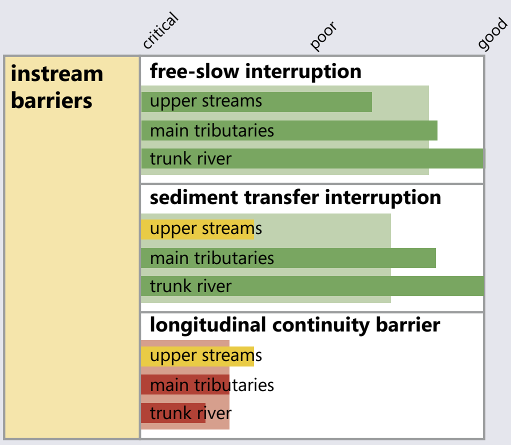
Recommendations

- The indicators can be readily calculated using existing data and provide a general picture of the number and influence of barriers within the system, which are considered to have a significant impact on river health in the Gui. The scores reported will not change unless different sites are sampled, dams are built (or demolished), or fish ladders are installed at existing barriers. The installation of fish ladders or the adoption of other mechanisms to allow for fish passage would be likely to improve river health.

Site scores for instream barriers



Indicator scores

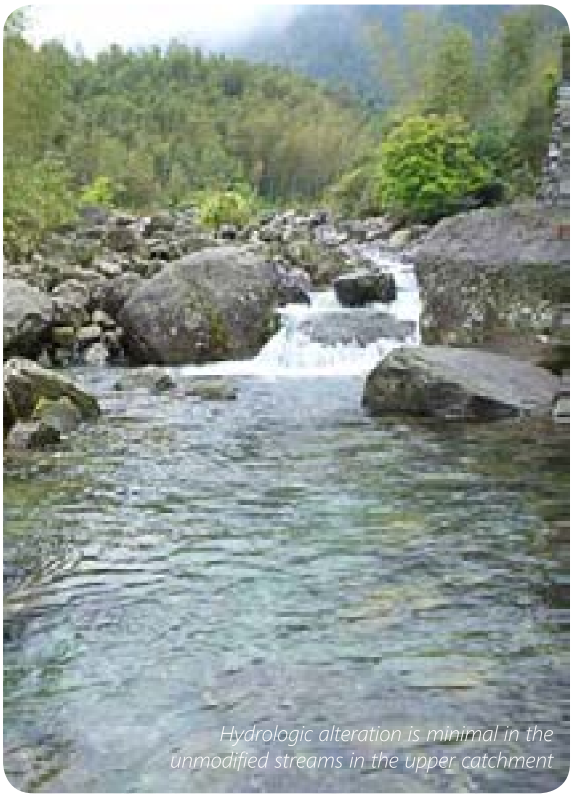


River flows

Hydrology

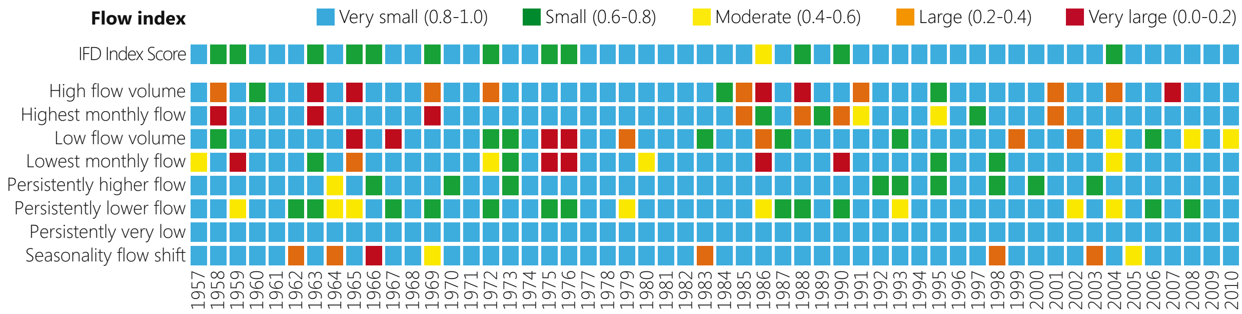
Hydrologic alteration due to water abstraction and flow regulation are major drivers of change in aquatic ecosystems and impact on river health. The extent of hydrologic alteration can be measured by examining how patterns of flow variability have been altered by water resource development. For the Gui River, an Index of Flow Deviation was used to assess the change in hydrology compared with pre-regulation flows. The index consists of eight indicators, each with a conceptual link to ecological health. The indicators relate to the total flow volumes at different times of the year, the maximum and minimum flows, the extent to which flows are persistently higher or lower than during the pre-regulation period, and changes to seasonality.

An annual score was generated for three gauging stations for each indicator, for each year in the period from 1957-2010. The results for the Guilin gauging station are shown below. The results show both changes from water resources development as well as natural climatic variation and suggest the hydrology has not been greatly impacted by development.



Hydrologic alteration is minimal in the unmodified streams in the upper catchment

IFD score for the Gui River from 1957 to 2010. The overall score for each year is the minimum score of any component.



Further information on the project, including detailed technical reports on the Gui river health assessment, is available at: **http://www.watercentre.org/research/applied-research/acedp**