UNIVERSITY OF SOUTHAMPTON

FACULTY OF SOCIAL AND HUMAN SCIENCES

School of Geography and Environment

FACTORS AFFECTING THE DESIGN AND IMPLEMENTATION OF DECISION SUPPORT SYSTEMS WITHIN ORGANISATIONS: LESSONS FROM TWO CASE STUDIES WITH THE ENVIRONMENT AGENCY, ENGLAND AND WALES.

by

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ABSTRACT

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Decision Support Systems (DSS) are computer tools that combine models and data, to a user interface to help decision-makers solve complex problems.

Despite their perceived usefulness, DSS are often not used. Past and recent reviews of existing decision support tools have shown a lack of implementation. Reasons behind their rejection were multiple, from poor design to more complex organisational and personal issues. Researchers have advocated the use of a more user-centred design framework for DSS development. A series of approaches aimed at involving users in the design process have been developed and applied with mixed results.

In this thesis, I argue that DSS success or failure may be due to a lack of fit between the design process and the culture of the organisation in which it is being implemented. Through literature reviews on science, decision-making, DSS and organisational culture and two case studies, I show how the assumptions taken by scientists and DSS developers on decision-making and problem-solving become embedded within the systems they produce and may conflict with that of users.

I further propose a novel approach that is centred on an understanding of the cultural system in which DSS will be used. The culture-centred iterative design approach is based on a constructivist theoretical perspective using methodologies borrowed from the social sciences. It follows an iterative design process such as that described by Sprague and Carlson (1982) with an embedded investigation of the working culture of the organisation. The study of culture is performed through group and individual interviews and aims at identifying areas of potential frictions between the DSS stated aims and user norms and values. The results from the analyses are then used to produce a DSS that will maximise outputs whilst minimising the risk of rejection.

The approach was applied to the development of ToolHab, a DSS for prioritising habitat enhancement work on rivers for the Environment Agency Thames Region Fisheries section. The Environment Agency is a government organisation responsible for the management and regulation of river ecology, pollution, discharge, abstraction and for the protection of land and property against flooding.

Through this case study, I show how the use of a cultural enquiry as part of the design process can lead to the resolution of potential conflicts and a greater acceptance of DSS.

A Bob, et à sa Colombe …

… à Auguste et Marguerite.

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Declaration of authorship

I, Marc Naura

declare that the thesis entitled

Factors affecting the design and implementation of Decision Support Systems within organisations. Lessons from two case studies with the Environment Agency, England and Wales.

and the work presented in the thesis are both my own, and have been generated by me as the result of my own original research. I confirm that:

- this work was done wholly or mainly while in candidature for a research degree at this University;
- where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
- where I have consulted the published work of others, this is always clearly attributed;
- where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
- I have acknowledged all main sources of help;
- where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
- some of this work has been published before submission:
    - Chapter 3 and 4 and associated appendices were published in an Environment Agency internal report: Naura, M. (2005a) Decision support tools for biodiversity Phase I. pp. 70. Environment Agency.

Signed: Marc Naura

Date: 15 December 2011

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Abbreviations

AI: Artificial Intelligence

BAP: Biodiversity Action Plan

CAMS: Catchment Abstraction Management Strategy

CCW: Countryside Council for Wales

CEBC: Centre for Evidence-Based Conservation

CFMP: Catchment Flood Management Plan

CVF: Competing Value Framework

DSS: Decision Support System(s)

EBDM: Evidence based Decision Making

ELD: Environmental Liability Directive

EMDS: Ecosystem Management Decision Support system

EA: Environment Agency (England and Wales)

EN: English Nature

EPA: Environmental Protection Agency

ES: Expert System

FRB: Fisheries Recreation and Biodiversity

FRM: Flood Risk Management

GDSS or GSS: Group Decision Support System

GIS: Geographic Information System

HD: Habitats Directive

IS: Information Systems

IT: Information Technology

ISO: international standards organisation

KB-DSS: Knowledge Based Decision Support System

KMS: Knowledge Management Systems

KPI: Key Performance Indicators

LEAPS: Local Environment Agency Plans

NFCDD: National Flood and Coastal Defence Database

NFPD: National Fisheries Population Database

NRA: National Rivers Authority

OCP: Organisational Culture Profile

OCS: Organisational Culture Survey

PPA: Post project Appraisal

PVA: Population Viability Analysis

QA: Quality Assurance

RHOs: River Habitat Objectives

RHS: River Habitat Survey

SAC: Special Area of Conservation

SEA: Strategic Environmental Assessment directive

SPA: Special Protection Areas
SSSI: Site of Special Scientific Interest
UCD: User Centred Design
WFD: Water Framework Directive

Chapter 1 Background

Preamble

When introducing a new piece of research, I believe it is important to state where it is coming from and why the researcher followed the path he/she took.

It is too easy and somewhat misleading to present science as a continuous linear process where scientists follow strict methods and rational frameworks to bring about solutions to clearly stated problems. More often than not, the scientific process of investigation is a messy business. Problems are poorly defined at the outset and clarity and focus tend to emerge from the iteration of trial and error cycles through the lifetime of a project. The final problem and solutions may end up looking very different from what was stated on the application form originally submitted to the increasing scrutiny of funding bodies.

When science eventually gets published, all this disappears. Problem-solving is pictured as a straight trajectory from problem identification to hypothesis testing to results -to follow the canons of Popperian science and publication writing. Hidden behind the single tree of a successful experiment stands the forest of failed attempts, unexpected outcomes and thickets of deep thoughts leading to precious moments of realisation and true discovery. It is those moments that shape scientific research and that are behind many choices of scientific problems and methods.

When I embarked on this research project, I started with a very different title, aim and objectives. My aim was to apply Decision Support Systems (i.e. computer software) to the management of biodiversity. During the course of my research, I gradually became aware of some difficulties with running the project and producing meaningful outputs. In particular I felt increasing resistance to what I was proposing and trying to achieve. These difficulties started to resonate with similar experiences I had in the 10 years I had worked in applied research. Discussion with colleagues and researchers further afield reinforced my sentiments and made me realise that my problems were experienced elsewhere by other scientists in similar settings. This led to the realisation that there was a pattern worth studying. The present title of the PhD reflects this change of emphasis of my research, from being about the development of Decision Support Systems to the study of factors affecting their design and uptake in organisations.

In my investigations, I came to hypothesise that organisational culture could play a major role in the uptake of Decision Support Systems -as well as science- within organisations. To make sense of this sudden change in direction and explain the relevance of both the problem (i.e. the resistance to science and technology) and hypothesis (i.e. the role of organisational culture), I felt I needed to tell the story that led to that shift. This involved not only narrating my first attempt at producing DSS as part of the PhD, but also my previous experience as a scientist in a government organisation.

The result is a form of narrative that combines anthropological, sociological and scientific methods of discourse. The combination of different perspectives and scientific paradigms within the thesis may therefore at first feel disconcerting to the reader, but it represents the true journey of my research.

In the next section, I will summarise the journey of my research interest, going back to the day I started working for the National Rivers Authority (now the Environment Agency) in 1995, to the development of the PhD case studies. I will then provide some background on some of the issues and concepts the PhD will discuss (Chapter 2) before describing the methods used in all parts of the study in more detail (Chapter 3). Chapters 4 to 7 will concentrate on the case studies and my previous experiences in the Environment Agency. Chapter 8 will draw conclusions on the research and discuss the ramifications of the findings.

The PhD journey

My interest in developing tools to support decisions dates back from 1995 when I joined the National Rivers Authority. At the time, I had graduated from a Masters in Science by research and I was keen on using my analytical skills towards developing models and techniques to better manage the environment and protect biodiversity. Since 1992, the year of the Rio summit, environmental management had become increasingly popular through the appearance of the new and fashionable concept of 'sustainable development'.

During this time, I held firm beliefs that as a scientist, I should 'go native' to make a difference and join an environmental organisation to carry out applied research. The opportunity presented itself soon after graduation when I was employed on an R&D project on river habitats by the Conservation and Ecology section in the National Rivers Authority (NRA), the precursor to the Environment Agency.

My job for the following eight years was to manage a national survey of river habitats, analyse data and more importantly produce applications and tools for better managing rivers.

The Conservation section in the Environment Agency was and still is one of the smallest units in the organisation; small in number and in relative influencing power. When I left the Environment Agency in 2006, it represented some 200 members of staff for an organisation that counted more than 14,000. I was once told the surprise of a newly appointed senior manager when visiting the local Conservation team who said: '*Is that all? I thought the Environment Agency was full of ecologists!*'

Conservation staff comprised strongly minded individuals who cared intensely about their jobs. Their task was difficult as their sole ways of making a difference was through influencing other players inside and outside the organisation. Beside the well-known issue of pollution, most damage to the environment was brought about by local landowners, local authorities and sections of the Environment Agency such as Flood Defence (now Flood Risk Management). To protect valuable houses and land from flooding, Flood Defence was intensively managing rivers, cutting trees that could obstruct bridges, deepening channels to carry more water through and concreting banks to prevent erosion. The impacts of these management practices, as identified by the 1994-96 survey of river habitats were significant (Raven *et al.* 1998). Complete sections of river had been wiped out which had provided valuable habitats for fish, invertebrates, plants, mammals and birds. In these settings, conservationists were largely in a position of trying to convince and argue their case against parties far stronger in number and power, and who often paid for their advice.

I soon realised that science was not a significant part of Conservation staff's jobs. Despite a majority being graduates in a scientific discipline, the nature of their job and the little time they had to make decisions had taken them away from the principles of scientific enquiry. Their main aim was to make an impact and make it fast. Decisions were made on the spot using one's best judgement.

At the same time, the organisation was collecting huge amounts of data through its monitoring programs and non-routine works whether on water quality, biological quality, River Corridor Surveys or River Habitat Surveys. Research outside the organisation was progressing and new knowledge was emerging on river and population ecology, geomorphology and river restoration practices. Computer systems had improved tremendously since the beginning of the 90s and powerful PCs were becoming widely available. By 1995, most staff had access to a PC linked to e-mail and the Internet. The concept of data sharing through a private network or Intranet was gaining popularity amongst large organisations and the Environment Agency was one of many considering its adoption.

New environmental legislation and initiatives, putting a strong emphasis on biodiversity management, were emerging or being discussed at national and European level: through the UK Biodiversity Action Plan (1994); the Environment Act (1995); the EU Environmental Impact Assessment and Strategic Environmental Impact Assessment directives (European Union 1997; European Union 2000b); the EU Water Framework Directive (European Union 2000a) and the Environmental Liability Directive (European Union 2004).

A culture of accountability was also developing across governmental organisations requiring managers and practitioners to justify their advice and decisions based on evidence and cost benefits. ‘Strategic’ and ‘holistic’ were the new buzzwords of environmental management and ‘value for money’ was the theme of the day.

Conservation staff were under increasing pressure to develop and deliver management strategies for species and habitats across catchments taking account of complex spatial interactions and temporal factors such as climate change. This was by no means an easy task, as it required the ability to analyse data on a large scale and forecast changes in a highly uncertain environment.

The time seemed right for using available data, knowledge and technology to create tools for supporting decision-making within Conservation and help staff deliver on existing duties and new expectations.

I therefore embarked, with the team I was heading, on a series of projects that aimed at analysing existing species, habitat, land use and water quality data, to produce models and applications that would help Conservation staff in their decision-making. The applications were delivered through a flexible database interface that also allowed users to carry out their own analyses and interpretation of data. Database and application manuals were written and staff were offered training sessions and online support.

Despite all our efforts, few staff seemed to be keen on using our data and models. Even fewer were developing their own applications using the versatile tools that we thought we had delivered. Feedback from users and managers suggested that we might have taken an overly academic approach towards supporting decision-making and that a more customer-centred approach was required.

After setting up customer groups and more business-like services for our customers, with feedback processes, surveys and complaint procedures, we saw little improvement in user uptake. Customer surveys suggested that users’ main concerns were not the relevance of the applications that we had developed, but the time it took to implement them, the lack of resources and the quality of the user interface.

At this time, I was promoted into a new position and was offered to spend time researching tools and software that could help decision-making in Conservation. I saw this project as an opportunity to further my interest in developing tools based on science and identify potential solutions to the problems we had come across in previous projects. It was then that I came across the concept of Decision Support System (DSS).

DSS are computer tools combining databases and models to a user interface for the resolution of complex problems. In essence, DSS use technology to make complex models and analytical techniques accessible to fairly non-expert users. As such, DSS represent potential means of delivering science to practitioners in an effective and meaningful way, increasing science and technology uptake in organisations, and enabling faster adaptation/response to environmental changes. Considering the availability of data in the Environment Agency as well as the challenges faced by Conservation staff, DSS seemed to be an ideal response to the situation.

I therefore developed what I considered a strong case for Decision Support Systems in Conservation and proposed a series of applications based on the knowledge and feedback I had acquired. This research became part of my PhD's first case study and I produced two reports and 4 project proposals for the Environment Agency.

The proposals generated a mixed response and the whole project was eventually overturned by management. The reasons behind this rejection were complex, but combined with previous experience, it led me to hypothesise that beyond the stated technical and system usability problems, laid more important organisational issues that were affecting the uptake of tools and models. I grouped these issues under one overall concept: organisational culture.

Organisational culture represents a series of assumptions, beliefs, ways of behaving and solving problems that are taken for granted in organisations and that newcomers have to learn. Organisational culture, according to its theorists is a filter through which new ideas, ways of working, tools and processes go through before being accepted or rejected. It is impalpable, yet tangible in its expression within the group. It is: '*the way we do things here*' that is different from the way business is conducted elsewhere.

In Edgar Schein's words, organisational culture is: '*a pattern of shared basic assumptions that the group has learned as it solved its problems and that has worked well enough to be considered as valid and to be taught to new members as the correct way to perceive, think and feel in relation to those problems*' (2004).

Being a scientist from a foreign country in a non-scientific organisation with a strong British white middle-class social background, I had always been aware of my position as both an insider and outsider. This led me to observe as much as participate. I had gradually become aware of the importance of organisational culture through observing the tensions and frictions between departments with conflicting aims and work ethos. Having been part of two major reorganisations, the first one leading to the creation of the Environment Agency through merging more than 50 different organisations, I was now observing the impact of organisational culture at a micro scale within a department on the uptake of new tools and techniques.

I decided to change the emphasis of my PHD to the study of those factors that affect the design and implementation of DSS with specific reference to organisational culture. An important part of my research was now to develop new methods for taking account of organisational culture when developing DSS. This implied a major change in research investigation methods, analytical techniques and overall paradigm.

So far I had been carrying out my research within the implicit theoretical framework of positivist science. Methods to identify cause-and-effect relationships through experiments and statistical testing were all part of the positivist science framework that is the undisputed foundation of biological and ecological research. Dealing with humans and something as intangible as culture, was a different matter and required a more appropriate theoretical framework such as those used by sociologists and anthropologists.

Investigating new approaches to scientific research led me to cast a critical eye on scientific methods and gave me further insight on the possible causes to the apparent incompatibility between science and organisational culture. The works of sociologists and epistemologists such as Latour (Latour 1987), Kuhn (Kuhn 1996) and Chalmers (Chalmers 1999) helped me further theorise around my observations. Regular contact with other scientists at conferences and elsewhere also helped me gauge how widespread the problem was.

This new approach led to the development of the second case study with the Environment Agency Fisheries section. I had worked on a series of projects with Fisheries staff and managers around the country that had generated positive feedback. At the time I was looking for a second case study. Two departments, Fisheries Science and Thames region Fisheries were considering running projects on developing tools for better managing fish populations. The three initiatives converged into a single project which provided the material for the second case study.

The second case study enabled me to try a completely different approach to DSS development, based on my hypothesis that organisational culture influences the uptake of DSS. It is not a proper test of the theory as my sample size was limited to a single organisation and department and therefore sub-culture, and cause and effects could not be easily ascertained in such complex environment. However, it is a first attempt at highlighting its strengths and weaknesses, potential validity and relevance.

Thus, this research is in many ways the result of an iterative process that started long before the beginning of the PhD. It encapsulates a series of issues that pervaded through my 10 years of employment as a scientist in the Environment Agency and that, I believe, are commonly found in the wider world of applied science. It has resulted in the development of a new approach towards designing and developing tools that takes account of both technical and organisational factors, as will be discussed in the following chapters.

The thesis structure has an underlying element of chronology, but is essentially designed to illuminate the links between the positivist science that drives the case study DSS pilots and the much wider-ranging philosophies and methodologies that have underpinned the exploration of the drivers and constraints of change implementation in organisations. Given the likelihood that many readers will be unfamiliar with one or other of these intellectual traditions, I have incorporated a rationalisation of the approaches where necessary.

In chapter 2, I will be reviewing and discussing theories around rationality and decision-making. This will provide insight into the choices and assumptions taken by DSS developers when designing decision support tools. This will also inform the Decision Support System review in chapter 3, which will more specifically look into DSS use, their stated benefits and implementation success. Chapter 4 represents my first case study as part of this PhD with the Environment Agency Conservation and Ecology unit. It was done at the time I was still employed in the Environment Agency and it was published as an internal R&D project report in 2005. At the end of Chapter 4, I will briefly discuss the main learning points from the first case study which will form the basis for the development of a new approach towards designing DSS (Chapter 5) and its application to the second case study with the Environment Agency Fisheries section in Thames region (Chapters 6 and 7). In Chapter 8, I will discuss the overall approach and attempt to generalise the findings to DSS design and applied science.

The aim of this research is to investigate the links between organisational culture, science and decision support technology use within organisations by

- reviewing existing literature on decision-making, Decision Support Systems, their use and implementation success;
- reviewing existing knowledge on organisational culture and decision support to inform our understanding of organisational culture and science interaction;
- developing a methodology for accounting for cultural factors in the design of DSS;
- running two case studies with a conservation organisation for the development of DSS including scientific tools and models using traditional DSS design techniques and a more organisational culture-centred approach;
- discussing and generalising the findings within the context of existing research on DSS design and implementation.

Chapter 2 Decision-making

Before embarking on the subject of using science and technology to support decisions, it is important to describe the various theories surrounding the concept of decision-making. This is of particular relevance as different world views of what constitutes decision-making are likely to lead to different models of decision support.

Rationality

One crucial issue in decision-making theory is that of rationality. Rationality is perceived by many to be at the centre of decision-making. It stems from the Latin word 'ratio' meaning calculus, counts, methods, plan, ability to count, reason and judge. It is what enables us to judge and it is classically considered as the sole property of human beings. It is a concept that holds different meanings depending on the context in which it is used. Descartes defined it as '*the power of forming a good judgment and of distinguishing the truth from the false*' (Descartes 1637). Rational thinking is thus what helps us seek the truth and is based on principles of logic and determinism.

This vision of rationality is essentially a western construction derived from Greek philosophers such as Plato and Aristotle. The existence of truth outside the realm of observed reality is assumed, as well as the existence of a method to reach it, mainly based on principles of mathematical logic and causality. Some philosophers enthusiastically described it as a universal principle of explanation and justification:

> '*The idea of the reason of things sheds light on everything, coordinates everything and guides the moralist, politician, historian as well as the naturalist, physicist and geometer. It is everybody's torch. It therefore has to be the philosophers torch*' (Cournot 1875).

Such views are echoed in August Comte Positivism and its subsequent interpretations: a paradigm that assumes that all true knowledge is scientific and must follow the principles of deterministic rationality (Bouveresse 1979).

Philosophers and scientists have argued against this vision of rationality. Kant had already warned that '*Human thinking must renounce to this idea which, in fact, was at the origin of Plato's endeavour: building absolute knowledge*' (Châtelet 1992), as man can only apprehend reality through unconsciously processing information perceived through his senses.

Many anthropologists, sociologists and psychologists refute this vision of rationality and scientific knowledge, as it is normative, i.e. it tries to impose models and standards of rationality. Applied to decision-making, its impact and biases are obvious; it would tend to:

> '*tell us how we ideally should or ought to reason, make judgements and make decisions. These theories, particularly formal logic, probability theory and decision theory give us rules to follow or conform to that supposedly make our thought rational*' (Over 2004).

Whatever does not conform to those norms of 'rationality' becomes 'irrational', giving this vision of rationality not only a strong theoretical, but also a value-laden content appealing to common sense.

Psychologists and neuroscientists interested in decision-making, tend to adopt a more encompassing less normative view of rationality. David Over calls it 'instrumental rationality'. Instrumental rationality is not normative, but descriptive. It does not set standards on how one should judge or make decisions, but it describes how one does. It is not objective in the way that everyone would agree with, but subjective i.e. it links to individual goals. It is not theoretical, but practical:

> '*What we ordinarily call 'reason' is usually theoretical reason: it is aimed at acquiring rational beliefs about the world using rational inferences. Practical reason is often a matter of what we ordinarily call 'judgement' and it is aimed at selecting rational actions*' (Over 2004).

Cognitive scientists and psychologists are mainly interested in rationality in action:

> '*This is the instrumental view of rationality. According to this view, rational action to achieve goals is the primary notion and rational belief and rational inference are secondary and derived. The fundamental standard for instrumental rationality is having reliable means to achieve goals*' (Over 2004).

What is important is how we come to conclusions, not what methods we should have used. This is the essence of instrumental rationality.

Theories of decision-making

Theories of decision-making can be split into two groups depending on which view of rationality they support: prescriptive (normative) theories and descriptive theories.

Prescriptive (normative) theories

Prescriptive theories view decision-makers as optimisers of some stated value. Their role is not to explain but to set standards of decision-making. They are mainly concerned with developing methods that enable decision-makers to find the optimal solution to a given problem. The methods used are generally mathematical, probabilistic or statistical (Over 2004).

Decision-making process is generally assumed to follow Herbert Simon's model that splits decision-making into three consecutive phases: intelligence, design and choice (Simon 1960). 'Intelligence' is about problem identification and diagnosis, 'design' is about generating alternative solutions and 'choice' is about evaluating and selecting alternatives. Other authors have added additional phases to the process, mainly implementation and monitoring/feedback (Lee, Newman & Price 1999; Beach & Connolly 2005; Turban, Aronson & Liang 2005) as decision-making may not be a single linear process but a more iterative one involving trial and error (Gorry & Morton 1989).

Prescriptive theories generally require the ability to measure outcomes. In economics, the value often used is utility. Utility is a value of 'goodness'. 'Goodness' comes out of achieving one's goals and will therefore vary according to individuals, cultures and personal preferences. The more one achieves one's goals, the more utility one gets (Baron 2004).

Other prescriptive decision-making techniques include Bayesian probability, decision matrices, decision trees and game theory. They are all based on probabilities and analogies to gambling. All these techniques are prescriptive, because they define norms of data processing and calculations and they assume decision-making is carried out within a rational probabilistic framework.

When tested in real situations, it appears that peoples' judgement does not always follow prescriptive theories principles and are instead affected by in-built mechanisms or biases that prevent decision-makers from optimising outcomes (Tversky & Kahneman 1974; Tversky & Kahneman 1988). Simon had already observed that when making decisions, individuals generally do not "optimise" but instead "satisfice", i.e. they find solutions that are 'good enough' (Simon 1956).

Decision-making can also be tainted by values, beliefs and emotions. Moods have been shown to affect risk-taking, creativity and decision-making efficiency (Rottenstreich & Shu 2004; Beach & Connolly 2005). Neuroscientists have shown that emotions play an important part in decision-making and even affect the way we perceive problems (Damasio 1996; Berthoz 2003). Personal values and beliefs may also affect the way we consider problems and choose alternatives (Keeney 1988; Lee, Newman & Price 1999; Beach & Connolly 2005; Ariely 2008).

Considering the whole picture, it appears that prescriptive theories of decision-making are based on assumptions that are not supported by observed behaviours. Decision-making seems to be done within a personal, social and emotional context that influences the way decision-makers see and act on problems, which results in decision-makers adopting strategies that are removed from the prescribed standards of normative theories.

Descriptive theories

Heuristics

In the search for theories of decision-making that described what people actually do, researchers started first by trying to figure out what people did 'wrong'.

Tversky and Kahneman (1974) found three in-built problem-solving strategies or heuristics that introduce biases in the estimation of event probabilities or quantities. They found, for example, that individuals tend to give higher probabilities to rare events if they happened recently (the 'availability heuristic'). When asked to classify objects from a known population, individuals tend to estimate the probability that an object belongs to a particular class by judging the degree to which it is representative or typical of that class (the 'representativeness heuristic') and fail to take account of the statistical evidence available to them (i.e. the object relative occurrence in the population). When deciding between potential options, it was found that decision-makers tend to choose alternatives that they recognise or are familiar with rather than assess their potential merits (Gigerenzer 2004). Group decision-making suffer from similar biases. When making decisions, groups tend to focus on information that is shared by all and ignore relevant data held by individuals (Stasser & Titus 1985). Also, they tend to make decisions based on the majority rule, even when the opinions held by the majority may be blatantly wrong (Stasser & Titus 1985; Berthoz 2003; Gigerenzer 2004).

These simple problem-solving strategies are in sharp contrast with Simon's rational framework for decision-making. The heuristics approach to problem-solving shows that decision-making does not necessarily follow the rational process of intelligence-design-choice that most theories take for granted. As put by Tversky and Kahneman:

> '*The logic of choice does not provide an adequate foundation for a descriptive theory of decision-making. We argue that the deviations of actual behaviour from the normative model are too widespread to be ignored, too systematic to be dismissed as random error, and too fundamental to be accommodated by relaxing the normative system*' (Tversky & Kahneman 1988).

Framing

Framing is an important concept that has emerged from research on heuristics. Framing is about: '*embedding observed events in the context that gives them meaning* ' (Beach & Connolly 2005).

When facing a problem, individuals frame the events leading to the situation in time and space: how it occurred, who was involved, where it happened and try to gather similar events from experience. This process helps decision-makers quickly make sense of situations. Novel events that do not have matching frames will require decision-makers to build new ones. Framing is used by experts as a way to quickly assess situations.

Context will influence the way a problem is framed:

> '*While the information from a particular problem may remain the same, it may be perceived, organised and interpreted differently; it may be structured differently; and the problem may be solved in a different context, by different people or at different times. Collectively, we refer to any of these different ways of looking at the same problem as a different frame*' (Soman 2004).

Framing recognizes that the way information is presented influences the way problems are perceived. When making group decisions, people tend to align their frames consciously through discussion, or unconsciously when they share the same culture.

Prescriptive vs. descriptive models of decision-making or the value of expertise

In the previous sections, we have discussed two strands of decision-making theories: one that attempts to set standards for decision-making and one that attempts to describe what decision-makers actually do; one that is based on logic and mathematical models and the other that relies on programmed problem-solving methods called heuristics; one that claims to be neutral, objective and effective, and the other that uses values, beliefs, personal experience and intuition.

Since the advent of science as a dominant paradigm, and the appearance of new scientific disciplines such as Operations Research, Management Research and Economics, rational prescriptive models of decision-making have come to dominate management literature; and their virtue: objectivity, efficiency and transparency, have been promoted widely in society. Multi-criteria analysis, cost benefit analysis, sensitivity analysis, decision trees *etc.* all sprouted from the vast literature on rational decision-making and have been the core of DSS development (Angehrn & Jelassi 1994; Eom *et al.* 1998).

At the same time, experts whom we will define as **individuals who rely on their experience, skills and in-built heuristics for their decision-making in specific domains of expertise**, have made the headlines for the failure and consequences of their advice, and the partiality of their judgement.

As a consequence, public confidence in experts seems to have declined, whilst rational decision-making processes have spread through public and private sectors in the past decades in the shape of what is often perceived as a plague of bureaucratic initiatives (Checkland 2005).

Beyond the controversies surrounding this fairly recent phenomenon, one can question the respective values of prescriptive models of decision-making and heuristic-based expert judgement at delivering good decisions and practice.

The cognitive scientists view.

Evaluating decisions is problematic as it necessarily involves an element of circularity: decisions evaluated by other decisions (Keren 1992). The assumptions and theoretical framework used as part of the evaluation process are likely to influence the outcomes and introduce a bias. A prescriptive normative framework would set gold standards of decision-making based on measurable outcomes. A descriptive approach may be more fuzzy and instead rely on an assessment of decision 'adequacy' by peer review groups or an assessment of the decision-making process.

Decisions can be assessed against outcomes or process. Judging decisions by outcome can be difficult as it assumes that the outcomes can be defined in advance and are measurable. Outcomes can be fuzzy, not directly measurable and can be perceived differently by different people. Judging by process is even more complex as part of the decision-making process may be hidden and may be influenced by framing effects.

Overall, most studies have concentrated on assessing the quality of decision by outcomes rather than process. Only those decisions that can be effectively measured such as crop yields, patient survival, weather forecast or stock market investments, have been the subjects of study. As a result, studies have mainly concentrated on the ability of experts to correctly diagnose or predict events in situations where feedback could be quickly obtained. Decisions where feedback is slow, quality criteria are more subjective and outcomes are potentially affected by unpredictable factors have been comparatively neglected.

Results from early experiments painted a grim picture of expert performance. It appeared that in many domains, experts barely outperformed novices or simple predictive models. A comprehensive review of decision-making studies linked to forecasting and planning is presented by Hogarth and Makridakis (1981). It shows that the performance of recognized experts and institutions in the financial market domain is generally poor and outperformed by simple linear models. Bolger and Wright (1992) performed a similar review across many disciplines: medicine, weather forecasting, business and sports. They found that in most studies, experts were poor at forecasting and providing probabilities of events, and that they often performed no better than novices or statisticians. Shanteau (1992) found similar patterns in such as corn, wheat and soil judges.

These studies identified the same biases as observed by Tversky and Kahneman (1974). Experts tended to be overconfident and optimistic in their decision-making.

They tended to make probabilistic judgements ignoring statistical evidence and were influenced by recent events and irrelevant information. They were susceptible to framing effects and tended to be biased by their own practice (e.g. cardiologists tend to see more cardiac problems than there really are) (Ayton 1992).

Closer to our concerns, in the field of ecology and conservation, studies that have used and tested experts, found that expert opinion and predictions showed high levels of variability and sometimes inconsistency (Alho, Kangas & Kolehmainen 1996; Alho & Kangas 1997; Pearce *et al.* 2001; Bojorquez-Tapia *et al.* 2003; Yamada *et al.* 2003; Johnson & Gillingham 2004) . In one study where expert forecasting ability was assessed against statistical techniques, predictions derived by experts were outperformed by statistical models (Pearce *et al.* 2001).

These reviews suggest that experts are plagued by the same heuristics and biases as lay men. Hogarth and Makridakis (1981) made a long list of all the potential biases and hindrances to good decision-making, starting with our sensory system and perception ability, to the processing of information, the evaluation of outcomes and the ability to learn from feedback which has been built upon and added to since (Gilovich, Griffin & Kahneman 2002; Berthoz 2003; Ariely 2008).

This raises one question: with all these hindrances to decision-making, how do experts manage to make good decisions? Considering the vast number of good decisions and remarkable achievements that expert professionals and sportsmen display every day around us and on television, these results seem rather counterintuitive. As a matter of common sense, one would rather be treated by an expert clinician than a student in medicine.

Part of these confounding results can be attributed to researchers' lack of understanding of decision-making processes, combined with an attachment to normative views of decision-making leading to inappropriate experimental design and testing. Indeed, research in cognitive psychology has revealed key differences in the way experts perceive, analyse and solve problems compared to novices (Shanteau 1992; Chi 2006):

- Expertise is domain and task specific and generally does not translate to other disciplines. Experts will therefore do well when asked to make decisions they are accustomed to.
- Expertise is context dependant within a domain. The way a problem is framed will influence expert performance.

Lee Roy Beach (1992) argues that experts tend to use two types of reasoning: probabilistic reasoning which relies on computing general statistics and trends, and causal reasoning which involves the study of single cases and their unique characteristics. He found that the way a problem is presented will trigger one or the other strategy. Experiments aimed at assessing the statistical abilities of experts have sometimes been framed in such a way that they induced causal reasoning thus biasing the outcomes. Experimental setup and assumptions about the nature of expertise based on normative theories, may therefore have led to erroneous accounts of expert performance.

Another limitation may be in the choice of experts. There is no clear and absolute definition of what is an expert and what constitutes expertise. In dictionaries, an expert is: "*a person who is very skilled at doing something*", and expertise is defined as a: "*special skill that is acquired by training, teaching or practice*" (Collins 1993). Generally, experts are identified through their professional qualifications, organisational membership, experience, training or by their peers. Rarely is there an objective rating system based on performance, with the notable exception of chess masters. Where expert performance is not directly measurable, the whole issue of assessing the value and nature of expertise becomes problematic.

Studies on experts/novices decision-making processes, as opposed to performance, have led to important insights into the exact nature of expertise. In particular:

- Experts have got superior ability in spotting subtle features and patterns compared to novices (Chi 2006).
- Experts spend more time framing and defining problems whereas novices tend to react to stimuli (Ayton 1992).
- Experts tend to invoke superior strategies for problem-solving (Ayton 1992).
- Experts tend to concentrate on a limited number of relevant pieces of information compared to novices (Ericsson & Charness 1997).
- Experts can store and recall from memory information relevant to the decision-making environment faster than novices (Ericsson & Charness 1997).
- Experts tend to anticipate future events or look ahead (Ericsson & Charness 1997).
- Experts tend to critically evaluate outcomes and feedback and engage in regular deliberate practice. Deliberate practice is defined as '*a thoughtful activity motivated by the goal of improving performance*' (Ericsson & Charness 1997) and involves training with feedback and repetition. It is estimated that it takes 10 years of deliberate practice for someone to reach expert performance levels.
- To solve problems, experts rely on their personal database acquired through experience (Feltovich, Prietula & Ericsson 2006).

- Like novices, experts use simple heuristics in their decision-making but their superior ability to identify relevant cues enable them to identify the quickest path to a satisfying decision (Gigerenzer 2004).

Although comparisons of experts versus statistical models have shown that even simple models tend to perform better than experts (for more recent reviews, see (Dawes, Faust & Meehl 2002; Fischhoff 2002), the difference observed may be due more to decision-making context than to their problem-solving strategies.

Predictive models also have limitations. They do not perform well with non-linear data or with unusual cases. They require large amounts of data especially when dealing with low probability events. They can be expensive to develop and take time to implement.

Experts, on the other hand, use additional contextual information that can be essential to the decision-making. Chalos (1985) found that a group of experts was more accurate than a predictive model for performing credit scoring. The reason was that experts included additional historical information in their decision-making. The same can be said of doctors' diagnostic. The ability of doctors to consider not only the symptoms but the whole patient history and his/her physical and psychological profile can be essential in determining the nature of someone's condition. Although predictive models are elegant simplifications of complex systems, they tend to decontextualise the problem and focus on those cues that are relevant in general, to the detriment of specific and sometimes unique cases (Bolger & Wright 1992). This criticism and limitation of statistical techniques is likely to resonate with patients, as few of us like to be treated merely as statistics and one would rather be considered for one's unique individual characteristics and needs.

Which leads to another important aspect regarding the value of expertise: its social value.

The sociologists view.

So far, we have looked at the relative performance of experts versus novices and predictive models. Now, we will look at another aspect of expert performance which is surrounding the role they perform in society and organisations.

Historically, the name and concept of 'expert' appeared for the first time in France around 1870 (Fuller 2006). Experts were used in court as witnesses to provide their opinion on possible hand writing forgeries. Experts were defined as people:

> '*whose specialised training enable [them] to speak authoritatively on some matter*'.

When presenting their evidence, experts were not asked to justify their decisions. Only another expert colleague could challenge their good judgement.

Since then, the expert witness has been one of the pillars of national laws in the UK and the US where experts can sit on trials as witness and testify on anything that is felt relevant (Mieg 2006). Expertise is presented as a self-regulated practice but is it? To the philosophers, the collegiality of expertise makes it an ideal form of power that is rarely challenged (Fuller 2006). To the scientists, experts are dubious sources of knowledge that do not lend themselves to the transparent process of falsification. Experts' databases and mental models are hidden away and cannot easily be retrieved or contested.

According to sociologists, one does not become an expert solely by acquiring knowledge through training and practice, but through a process of social determination. Expertise may be personally constructed, but it is socially selected according to criteria defined by the experts' constituencies. Constituencies can be made of professionals, organisational members, consumers or even the wider public. Agnew *et al* (1997) suggest that constituencies select experts based on the perceived usefulness of their knowledge.

> '*The social perspective differs from the view that expertise reside merely in the expert. Instead, the construct of expertise is seen as jointly determined by individual skills and knowledge, and the needs, perceptions, and activities of the members of the social system with whom the expert interacts*' (Stein 1997).

The constituencies beliefs, norms and values are therefore likely to influence the selection of those who will play the role of experts. Conversely, experts and their expertise are likely to reflect the wider beliefs and culture of their constituencies.

The role of experts is to provide answers to complex situations and manage the uncertainty society and individuals are facing (Mieg 2006). Experts are associated with 'truth'. They are expected to provide answers closer to the truth and they are trusted to do so based on their status.

Agnew *et al* (1997) distinguish two levels of expertise. Level 1 experts have expertise that is personally constructed and selected by their constituency, but it may not be relevant to the real world (i.e. it may fail when tested on real examples). Level 2 experts are those that have the same characteristics as level 1 but their knowledge has been tested in scientific experimentations:

> '*Very few experts fall into this category because most constituencies do not apply the principles of rigorous scientific testing in their evaluations*'.

Science is not the only way that experts' pedigree can be checked. Companies and professions have their own ways of regulating expertise through licensing, charters *etc.* that can be just as effective.

The social selection of expertise would explain why some experts performance can be poor despite being viewed as experts. It could also explain the level of trust that experts command. Expertise is not self-proclaimed, it is recognised.

Trust between expert and lay person is important in more than one way:

> '*Lay people must place their trust in professional workers (electricians and plumbers as well as lawyers and doctors) and, as a result, some professionals acquire confidential knowledge. Professionalism requires professionals to be worthy of that trust, that is, to maintain confidentiality and protect private knowledge and not exploit it for self-serving purposes. In return for this professionalism in relation with clients, professionals are granted authority, rewards and high status*' (Mieg 2006).

Expertise is often associated with prestige, privileges and power. Not surprisingly, experts were found to be confident individuals with good communication skills and a sense of responsibility, all qualities that promote trust and respect (Shanteau 1992). In experiments where individuals were presented the same piece of advice from either an expert, a novice or an Expert System, it was found that experts were trusted more than novices or the Expert System, even when evidence was produced demonstrating the superior accuracy of the Expert System (Lerch, Prietula & Kulik 1997).

To conclude, the jury is still out on the relative value of expertise and experts compared to that of scientists or proponents of normative decision-making techniques.

What we can say is that we have two largely opposing views of knowledge and decision-making. Normative theories and associated scientific methods value knowledge as derived from controlled experiments through the process of falsification and mathematical/statistical analysis. Knowledge is explicit in the shape of reports, equations and publications and open to scrutiny. Peer-review of knowledge outputs is essential to the making of scientific knowledge. Decision-making forms a rational framework where affects are put on one side and formal logic determines the shape and content of the decision-making process. Decision-making aims at optimising desired outcomes.

Experts on the other hand, derive their knowledge from years of training and deliberate practice, by trial and error and close contact with 'the field'. Deliberate practice is a critical occupation that requires experts to constantly observe and analyse feedback from the environment. Knowledge is mainly tacit, i.e. implicit, hidden in their brains in the shape of databases of encoded patterns and decision-making models. Decision-making follows simple heuristics and generally aims at finding from memory good enough solutions rather than optimal ones. Rationality does not rely on the abstraction of problems using formal logic for the identification of possible 'truths'.

Instead, it is 'instrumental' and incorporates organisational, professional and societal values and needs for the achievement of 'acceptable' and 'adequate' solutions.

Scientific evidence demonstrates that expert performance can be at least equalled or surpassed by quite simple statistical models or Expert Systems in domains as important as clinical diagnosis, drug prescription (Mullett *et al.* 2001) and financial investment. But performance is only part of what constitutes value. From a sociological perspective experts perform a role that is highly valued by society. Their role is to reduce uncertainty and provide solutions to complex situations. Experts are selected by their constituency based on their fit to the constituency belief system as well as their performance. They respond quickly to problems and offer solutions that are compatible with the theoretical and cultural framework of their constituency. As such, they command respect and are trusted more than models, even when their performance are demonstrably inferior to that of a software. Their status, privileges, power and sometimes fees, and the critique they face (Selinger & Crease 2006), are a tribute to their influence and how much society values their input (Sturdy, Newman & Nicholls 1992; Mieg 2006).

Summary

We started this chapter with the aim of better understanding the processes underpinning human decision-making so as to inform the development of decision support tools. What we found was a clear dichotomy between two sets of theories, one that attempts to prescribe optimal decision-making methods, and one that describes the way decisions are actually made.

Although prescriptive theories have shown their limitations in describing/predicting decision-making, their proponents still claim superiority with regards to finding optimal solutions to problems. They put forward their objectivity, reliability, transparency, consistency as well as the strength of their knowledge as qualities that reflect their fundamental value. Supporters of descriptive theories highlight the theoretical weaknesses of prescriptive theories and their inadequacy to the 'real' world.

Both sides have put their champions to the test: on the prescriptive side, the models; on the descriptive side, the experts. The results show quite unambiguously that models tend to outperform even the best of decision-makers. As demonstrated by cognitive scientists, humans are plagued with biases and other affects that alter their judgements.

But that is assuming that 'value' is solely viewed on a performance basis. The work of sociologists and psychologists has shown that decision-making and knowledge are socially constructed. They are fashioned in action and are influenced by the social, cultural and personal context in which they occur. Problems are framed before being solved using the decision-makers values, norms and working culture. Individuals are selected by their constituencies to play the role of experts and provide the advice on how to deal with the uncertainties they are facing. In return, these experts are trusted and evidence suggests that they are trusted more than predictive models. The issue of value is therefore more complex than we thought.

What we can retain from this review is that there are two opposing sets of theories that have very different views on knowledge and decision-making. Both have their claims to superiority in quite different domains: 'validity' and 'performance' for prescriptive theories; 'adequacy' and ' social acceptability' for descriptive ones.

We will now see how this debate translates to the world of decision support and the relative importance of these theories in the design and implementation of Decision Support Systems. I will also show how I applied both approaches towards decision-making to separate case-studies with different success and outcomes.

Chapter 3 Decision Support Systems

Background and definitions

Decision Support Systems

Decision Support Systems stemmed from the emergence during and after the second world war of new disciplines such as Operations Research and Management Science, the development of our understanding of human cognition and the availability of computers. Operations Research is the application of mathematical models and analytical techniques to the resolution of complex logistical and management problems. In 1960, Nobel Prize laureate Herbert Simon paved the way for the development of computer software for programmed and non-programmed decisions (i.e. decisions that can be automated and decisions that require human input and intuition) in his essay on “The new science of management decision" (Simon 1960). His vision was to develop computer tools based on the discoveries of cognitive scientists:

> ‘*to supplement natural intelligence with artificial intelligence in management decision-making - to bring in the computer as a problem-solving aide to the manager* ‘.

The Decision Support System concept fully emerged at the end of 1960s in the United States and France where it was applied to management and marketing decisions (Klein & Methlie 1995). It has since turned into a wide research programme that has led to the development of Expert Systems, Artificial Intelligence, business intelligence, web applications *etc.*.

There are no commonly accepted definitions of Decision Support Systems (DSS) other than DSS are computer-based systems to support and enhance managerial decision-making (Angehrn & Jelassi 1994). A series of other definitions have been proposed, but they generally failed to capture the wide diversity of applications that are found (Turban, Aronson & Liang 2005).

DSS are designed for very complex issues. Rauscher calls them ‘wicked’ problems (Rauscher 1999).

> ‘*Wicked problems are tricky, complex, and thorny, typically with ambiguities, conflicts, internal inconsistencies, unknown but large costs, a lack of organized approaches, institutional shock and confusion, a lack of scientific understanding of management consequences, and turbulent, rapidly changing power centres*’.

‘Wicked’ problems are basically complex decision areas or tasks that may have more than one potential solution and that, traditionally, require a lot of intuition and user input, and where the outcomes are uncertain.

These problems are also referred to as 'unstructured' or 'semi-structured' problems (Morton 1971). Morton classified problems according to their level of complexity and the availability of structured approaches towards resolving them. Structured problems have well-known solution pathways as opposed to unstructured ones that are characterised by incomplete knowledge, a lack of clear decision-making processes and high uncertainty in outcomes. Table 1 describes the main differences between structured and unstructured decisions. In between these two extremes are what Keen and Morton (1978) call semi-structured problems for which some knowledge and practice exist.

Table 1: Comparison between structured and unstructured decisions (Holsapple 2008)

Structured decisions	**Unstructured decisions**
Routine, repetitive	Unexpected, infrequent
Established and stable contexts	Emergent and turbulent contexts
Alternatives clear	Alternatives unclear
Implications of alternatives straightforward	Implication of alternatives indeterminate
Criteria for choosing well-defined	Criteria for choosing ambiguous
Specific knowledge needs known	Specific knowledge needs unknown
Needed knowledge readily available	Needed knowledge unavailable
Result from specialised strategies (i.e. procedures that explicitly pre-specify full set of steps to follow in order to reach decisions)	Result from general strategies (e.g. analogy, lateral thinking, brainstorming, synthesis used in the course of reaching decisions)
Reliance on tradition	Reliance on exploration, creativity, insight, ingenuity

The boundaries between structured, semi-structured and unstructured problems are fluid. With time, practice and research, knowledge is gained on unstructured problems and more structured decision-making processes are gradually developed. According to Keen and Morton (1978), DSS are computer systems designed to help decision-making for unstructured or semi-structured problems. Examples of such problems in ecology and conservation are: developing large-scale management strategies for species/communities; accounting for climate change impacts on social and economical issues and; creating nature reserves networks and wildlife corridors.

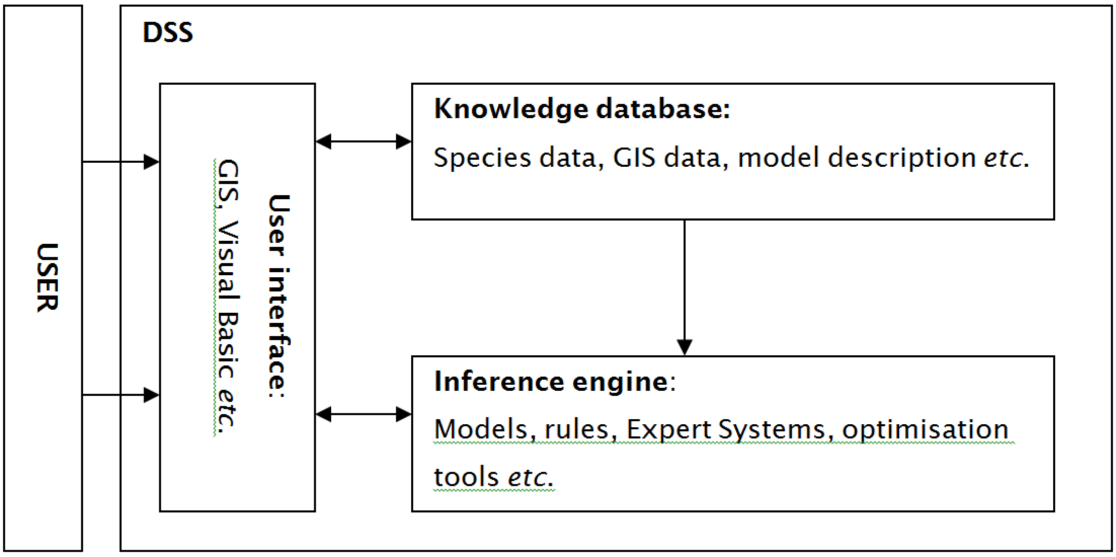
DSS are typically made of a user interface linked to a knowledge database and an inference engine running tools such as predictive models, Expert Systems *etc.* (figure 1). Typical DSS are computer models or simulation tools, for example software simulating the effect of floods on floodplain inundation. In this case, DSS can be used to design flood protection schemes to minimise human and economic impacts of floods. When linked to GIS, they are called Spatial Decision Support Systems (SDSS).

DSS help users analyse complex problems, identify issues, develop and evaluate making, not dictate it.

> '*The role of DSS is to amplify the power of the decision-makers without usurping their right to use human judgement and make choices*' (Rauscher 1999).

Databases are an essential part of DSS. They summarise the knowledge that a DSS needs to function. Knowledge is extracted from various sources: existing databases, guidance documents, scientific publications, survey of experts *etc.* Guidance documents or scientific publications on their own do not constitue DSS, but they may contain material essential to the development of the knowledge component of a DSS.

Figure 1 Decision Support System typical structure



Expert Systems

'*Expert Systems (ES) are computer systems that apply reasoning methodologies on knowledge to render advice or recommendations much like a human expert*' (Zeleznikow & Nolan 2001).

They require the presence of a knowledge database and procedures to make inferences. These procedures originally were simple rules of thumb, but more sophisticated techniques such as fuzzy logic, neural networks and Bayesian inferences are increasingly used (Naura 2005b).

Knowledge Management Systems

Knowledge Management Systems (KMS) are designed to enable the elicitation, encoding, storage and retrieval of knowledge within an organisation. Most knowledge is in people's head and at organisational level, the sum of everyone's knowledge is called 'organisational memory'. KMS generally comprise communication tools allowing users to access knowledge and communicate with each other; collaboration tools to facilitate brainstorming, knowledge elicitation and group work; and storage and retrieval tools (Turban, Aronson & Liang 2005).

Knowledge-based Decision Support Systems

When a DSS and ES are combined, we have a Knowledge-Based Decision Support System (KB-DSS) (Klein & Methlie 1995). For the purpose of this study, we would like to extend the concept of KB-DSS to DSS that are linked/include a Knowledge Management System.

KB-DSS enable users not only to test hypotheses and run simulation, but also direct them in the decision-making process by making suggestions and helping interpret outputs. KB-DSS, compared to DSS, open a whole new range of applications. They are particularly suited to decision environments where knowledge and skills are limiting factors. They not only enable better and more consistent decisions but more importantly, they promote learning (Nemati *et al.* 2002).

Group Support Systems

Group Decision Support Systems or Group Support Systems (GSS) are computer tools facilitating collaborative work, brainstorming and communication amongst members of a group. GSS include Web enabled software for conferencing, brainstorming, document sharing and writing (Turban, Aronson & Liang 2005).

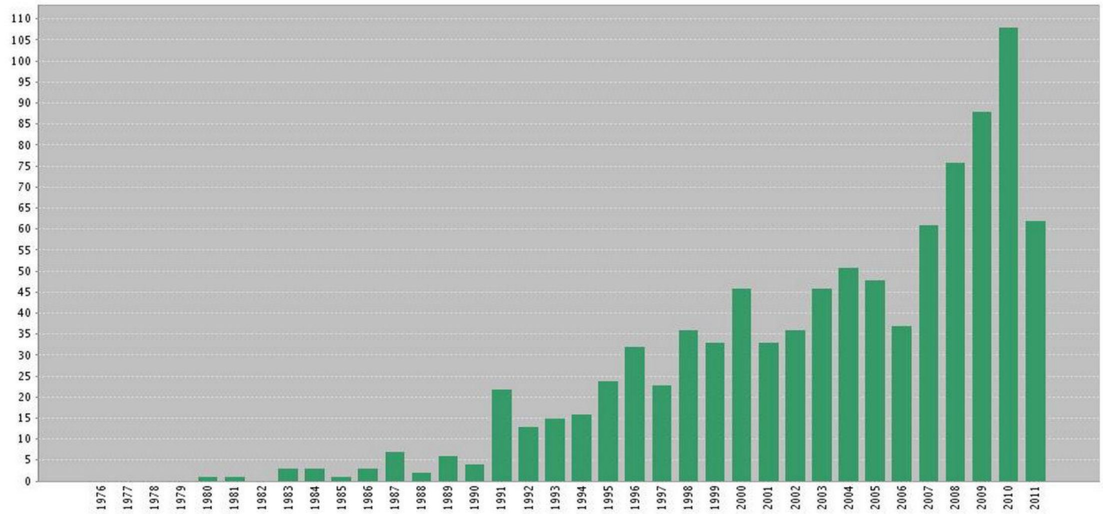
Uses

There is considerable evidence on the growing importance of DSS development within the academic and the applied world. Since 1985, a journal (Decision Support Systems) is specifically dedicated to practical and theoretical issues surrounding the development and implementation of DSS. At about the same time, two other journals, "Expert Systems" and "Knowledge-Based Systems" appeared, covering the development of Expert Systems and KB-DSS.

DSS have been developed in many fields, from medicine (Vanoirbeek *et al.* 2000) to land use planning (Cox & Madramootoo 1998), economy (Tian *et al.* 2007), water management (Young *et al.* 2000), agriculture (Kristensen & Rasmussen 2002) and forestry (Garcia-Quijano *et al.* 2005). DSS are mainly used in business and in the private sector where there are many examples of successful development and implementation (Davenport & Prusak 1998; Watson, Fuller & Ariyachandra 2004; Turban, Aronson & Liang 2005; Tian *et al.* 2007).

In conservation, the development of DSS is a relatively recent phenomenon. A search for publications combining the words 'decision support system' and 'conservation' on the ISI Web of Science database between 1970 and 2011 returned 1452 publications (figure 2). Although the first paper on the subject was published back in the seventies, three-quarters of all publications were printed after the year 2000. A majority of these publications were about the development of spatial DSS applied to farming, land use planning or species management. Obviously, this is not to say that tools to support decision-making were not developed before under different names, but it gives a useful insight in the time it has taken for the concept to emerge in conservation.

Figure 2: Number of publications between 1970 and 2011 using the words ‘Decision Support System’ and ‘Conservation’ on the Web of Science.



Amongst environmental organisations such as the US Environmental Protection Agency (EPA) and the US Department of Energy, DSS development is increasingly seen as a priority (US EPA 2004). Examples include the development of the Regional Vulnerability Assessment Environmental Decision Toolkit. It is a simple visualisation toolkit used by EPA and partners in state and local government to address a suite of assessment questions crucial to reducing ecological risk. The Australian National Park and Wildlife Services also produced DSS for environmental management. They developed a conservation planning software called C-Plan (NPWS 2001) that was used to design nature reserves in Australia but also South Africa (Ferrier, Pressey & Barrett 2000; Cowling *et al.* 2003).

Benefits

According to their supporters, DSS can deliver the following benefits:

- improved performance;
- help users solve complex issues;
- underpin decisions with up-to-date science and knowledge;
- participate to knoweldge management ;
- promote organisational learning;
- enable organisations to adapt and respond to new challenges.

In commercial organisations, DSS are generally introduced to increase performance by improving effectiveness (i.e. the level of goal achievement) or efficiency (i.e. productivity) (Turban, Aronson & Liang 2005).

> '*Improving the performance is the ultimate objective of information systems-not the storage of data, the production of reports, or even 'getting the right information to the right person at the right time.' The ultimate objective must be viewed in terms of the ability of information systems to support the improved performance of people in organisations* '(Sprague 1989).

Effectiveness can be achieved by directing the decision-making processes through an agreed path. Efficiency can be improved through the use of optimisation tools.

Through the use of tools within the inference engine, DSS enable the resolution of very complex problems. Typical examples include the use of complex mathematical optimisation techniques for selecting sites for building nature reserves (see chapter 4). In this case, tools are used to select combinations of sites that maximise conservation benefits whilst minimising the cost of buying land.

DSS promote the use of scientific evidence for decision-making. At the heart of DSS are knowledge databases containing the most recent scientific data, knowledge and models. DSS outputs embody this knowledge and thus provide scientific backing for decision-making.

Knowledge is essential to organisations. Most knowledge is hidden in people's minds. It cannot be read, easily expressed or communicated. It is somebody's 'know-how' and it can only be shared by interacting, demonstrating and observing (as an apprentice does). We call it 'tacit' knowledge as opposed to 'explicit' knowledge that is contained in documents, databases, textbooks and software that can be shared and communicated easily. Tacit and explicit knowledge flow through an organisation. The ability to manage and direct their flow is what makes an organisation creative and effective (Davenport & Prusak 1998). Tacit knowledge has been linked to personal, organisational and management success as well as performance improvements (Cianciolo *et al.* 2006).

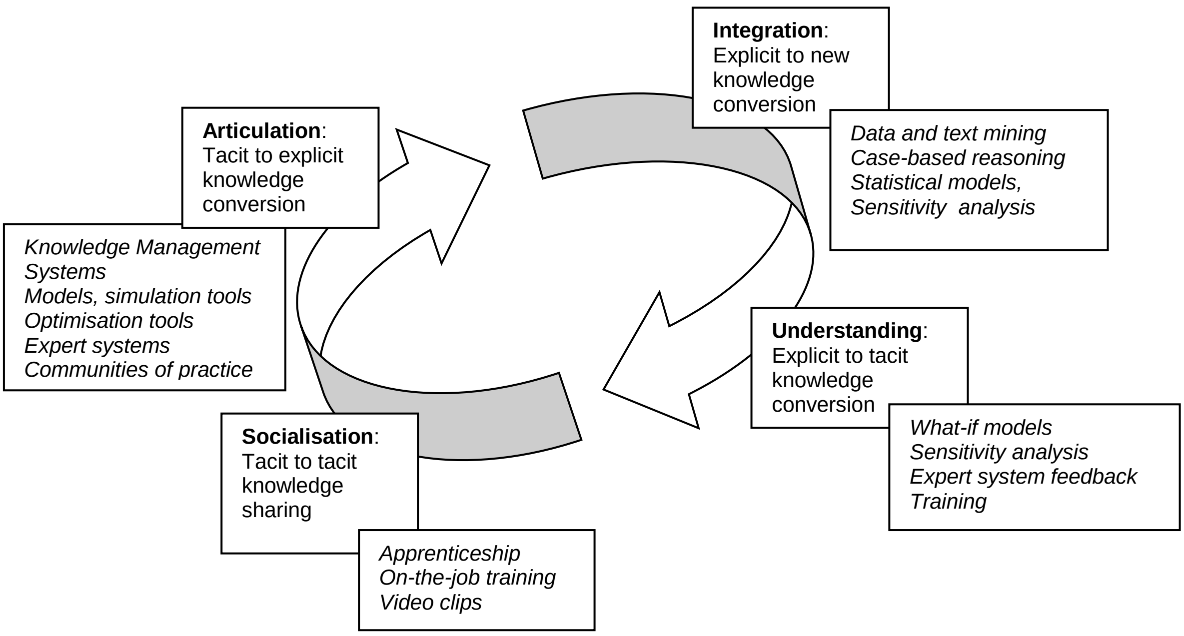
DSS participate to knowledge management. Nemati *et al.* (2002) describe knowledge management as '*the practice of adding actionable value to information by capturing tacit knowledge and converting it to explicit knowledge; by filtering, storing, retrieving and disseminating explicit knowledge; and by creating and testing new knowledge*'.

New knowledge is created in a four-step process of socialisation, articulation, integration and understanding called the knowledge spiral (Nemati *et al.* 2002) (figure 3):

- In the 'socialisation' step of the process, tacit knowledge is exchanged between individuals by interacting, demonstrating skills and sharing experiences (in management linguo, we refer to it as 'on-the-job' training).
- In the 'articulation' step, tacit knowledge is converted to explicit knowledge using words (description of tasks, problem solving strategies *etc.*) mathematical and logical expressions (predictive models, rule-of-thumb, 'if-then' statements), digitisation (analysis of movement using sensors) or any other knowledge representation technique (mind maps, critical path diagrams, flow charts *etc.*). This step generally occurs '*within groups of people who informally come together to exchange knowledge and experience in a shared domain of interest*' (Cianciolo *et al.* 2006). These groups are called communities of practice.
- The 'integration' step is about creating new knowledge, for example, by applying existing techniques or concepts to a new research environment.
- 'Understanding' is about individuals turning explicit into tacit knowledge through a process of testing and validation. Before internalising knowledge, decision-makers need to assess its fitness-for-purpose.

DSS can participate in many ways to the knowledge spiral. At the 'socialisation' step, Group DSS such as video-conference and digitised video clips can help users share experience and learn from each other.

Figure 3: The four steps of the knowledge spiral with associated technology. Adapted from Nemati *et al.* (2002).



At the 'articulation' step, Knowledge Management Systems and decision support tools such as statistical methods and Expert Systems can be used to convert tacit knowledge to explicit knowledge in the shape of mathematical equations or logical statements. Group Support Systems can help create and maintain communities of practice.

In the 'integration' step, tools such as data and text mining, cased-based reasoning, statistical analysis and sensitivity analysis can be used for creating new knowledge. Data and text mining tools help identify key parameters or key words potentially leading to the identificaton of patterns in the data. Case-based reasoning is about analysing the outcomes of previous cases. It implies having databases of decision-making with adequate recording of cases and adequate search functionality. Statistical modelling and sensitivity analysis enable users to investigate relationships in the data, identify key factors and test the sensitivity of models to parameter changes. Eventually, these methods may lead to the discovery of new patterns and the generation of new explicit knowledge.

The 'understanding' step can be helped by using tools such as 'what-if' simulation tools, sensitivity analysis or expert system feedback. Simulation tools and sensitivity analysis enable users to explore the full range of potential impacts of changing parameter values on final model outcome. It is a way for users to internalise the knowledge contained in explicit models and also test their applicability and limits. Expert Systems also offers the possibility of providing feedback and suggestions to users during the decision-making process. Phillips *et al* (2004) see such systems as a way of building expertise by engaging individuals in deliberate practice through computer assisted feedback and coaching.

DSS can bring a major contribution to organisational learning. Organisations constantly interact and adapt to their environment. In a rapidly changing environment, the ability to adapt becomes critical to the organisation's survival and efficiency. Effective learning and knowledge-sharing processes then become essential functions of an organisation. Organisational learning can be of two sorts, single-loop and double-loop learning (Bhatt & Zaveri 2002). Single-loop learning is mainly concerned with detecting errors in existing process outcomes and feeding them back so that the process can be improved. Double-loop learning involves feedback on the process outcomes and on the process assumptions and objectives. Double-loop learning increases user knowledge and may lead to a challenge to an organisation's objectives, norms and policies and the creation of new procedures, processes and knowledge.

DSS may promote double-loop learning:

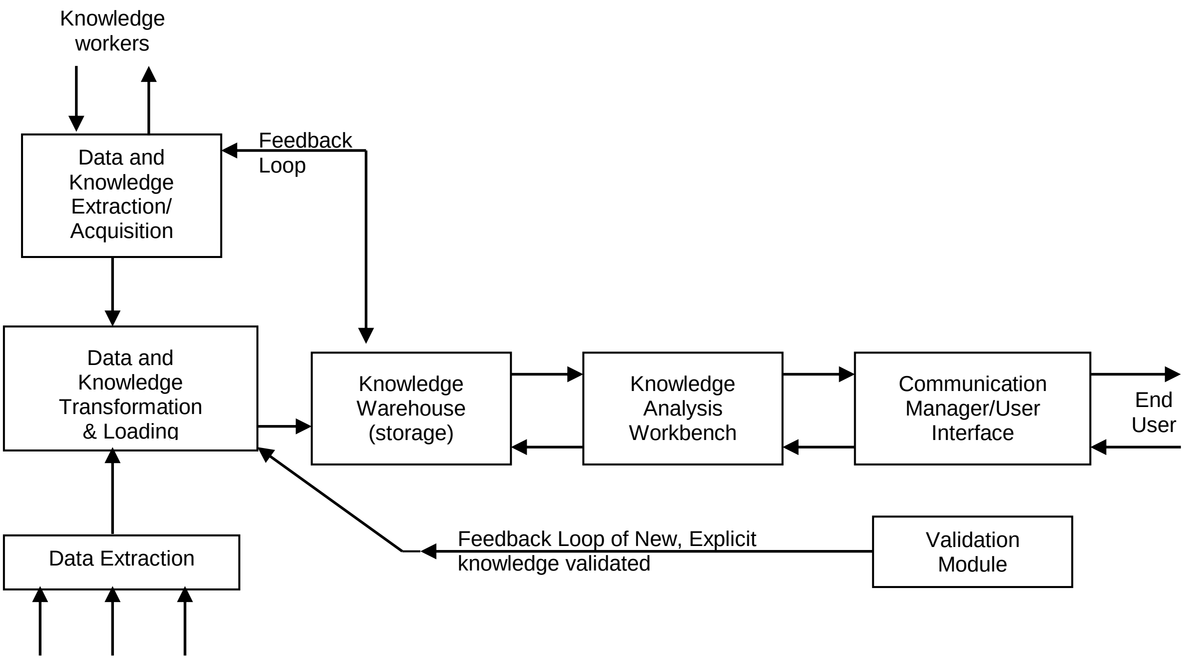
- By helping users understand complex relationships and build their own expertise.
- By giving them direct access to up-to-date knowledge databases.

- By letting them test their own assumptions, run simulations, compare the merits of different decisions and explore a wide range of potential options and outcomes.

Eventually, users may challenge DSS assumptions and bring in new knowledge that may lead to a change in its structure, content or even of the fundamental principles underpinning it.

In 2002, a new concept for using DSS as a way of promoting organisational learning was developed: the Knowledge Warehouse (Nemati *et al.* 2002). A Knowledge Warehouse has as its core DSS coupled with Expert Systems and feedback mechanisms leading to the effective dissemination and derivation of knowledge (Figure 4). According to the authors, if embedded within an organisation practice, such system can potentially improve an organisation's ability to adapt and respond to new challenges.

Figure 4: Knowledge framework architecture from Nemati *et al.* (2002).



Building DSS, success criteria

DSS development has steadily progressed since the 60's and we now find them in many aspects of our working lives. Applications have been built on a wide variety of platforms such as Geographic Information Systems (GIS) and Web servers that help customers choose their holidays, plan trips, select products based on individual preferences *etc* (Turban, Aronson & Liang 2005). On the DSS development side, applications for building Decision Trees, Genetic Algorithms and multi-criteria analysis can easily be found at reasonable cost.

There is a wealth of studies on DSS theory, design and development but few studies followed the fate of implemented systems and actually tested their ability at delivering the goods. Even fewer have looked at the impacts of DSS on individuals and groups. The reasons behind the lack of reporting of DSS success and failure is not clear. Parker and Sinclair (2001) suggest that it may be due to the unwillingness of DSS developers to publicise the failure of their own software, but it could simply represent a lack of interest from journals for this type of research.

It is often taken for granted that, because DSS help resolve very complex problems, they must represent added value; this is an assumption that some research contradicts. In a study on the impact of DSS use on task completion, Montazemi *et al.* found that, in some instances, users perform no better with the help of a DSS (Montazemi *et al.* 1996). They explain some of the misperformance by the lack of fit between the nature of the task and the support provided by the DSS. Reviews of medical DSS showed varying levels of success with regards to practioner performance and patient outcome (Garg *et al.* 2005; Smith, Depue & Rini 2007; Pearson *et al.* 2009).

It is also taken for granted that, because DSS help resolve problems that could not be resolved adequately before, they would be used. Following the development of numerous DSS, researchers found that many were not being implemented or even used (Kaplan 2001a; Stuth, Hamilton & Conner 2002; Uran & Janssen 2003).

DSS design and implementation issues have been the concern of a new field of research since the beginning of the 1990s (Eom 1998). De Dombal (1993) produced an analysis of medical DSS across 40 years, Finlay and Forgani (1998) ran a comprehensive survey of DSS use in business and Parker *et al.* assessed the successes and failures of 20 agricultural DSS (2001). A few additional studies could be found on smaller numbers of DSS (Keil, Beranek & Konsynski 1995; Argent & Grayson 2001; Westmacott 2001; Stuth, Hamilton & Conner 2002; Uran & Janssen 2003). From these research studies, a series of lessons can be learnt.

According to user surveys and feedback DSS failed because they were:

- too detailed;
- too time consuming;
- too costly to use;
- too complex;
- they bear too much uncertainty;
- they did not match the task;
- they could not be used on existing equipment.

Authors highlight the need for a better match between DSS design and user needs and expectations. Many DSS were developed without involving users at an early stage or even considering their working environment. This led to researchers developing tools mainly suited to themselves (Stuth, Hamilton & Conner 2002) or not adapted to the task and decision-making environment (Keil, Beranek & Konsynski 1995). Another issue is that DSS are often not driven by needs identified by clients but academics, sometimes as a means to publicise particular modelling techniques and decision approach to attract further funding. Users then see DSS as a complex way of dealing with problems that are suitably addressed by current practice (Chenoweth, Dowling & St. Louis 2004).

Beyond technical issues surrounding the design of DSS, most researchers agree that there are also very strong individual and organisational issues that will influence the development and implementation of DSS. Westamcott (2001) lists a series of potential obstacles to DSS use:

- Resistance and apprehension towards new technology.
- Opposition to change that a model is usually designed to assist in making.
- Opposition to the DSS approach to problem-solving.
- Suspicion about objectivity of the model development.
- Commitment to existing non-threatening concepts and difficulty in understanding new concepts.
- Different perceptions as to who will gain and who will suffer from using DSS to develop new policies.
- Apparent irrelevance due to failure to identify what questions are of primary interest.
- Blurred decision-making authority as opposed to the single decision-maker.

DSS most often represent a significant change in technology and decision-making process. They will therefore require additional efforts in terms of training and learning. In a series of experimental studies, Todd and Benbasat (1994) showed that decision-makers tend to adopt methods that minimise efforts regardless of potential gains in accuracy. For example, decision-makers in the business environment prefer using their own subjective assessment for forecasting trends rather than simple statistical models that have been proved more accurate (Remus, O'Conner & Griggs 1996). To overcome user reluctance, Chenoweth advocates two types of activities: training courses and demonstration workshops (Chenoweth, Dowling & St. Louis). Chenoweth found that most users would use more complex models provided they were trained on the system and they could see for themselves that accuracy increased (i.e. the complex models were worth the effort).

In introducing new concepts and methods such as complex modelling tools which are conceptually far away from current practice, DSS may also impact on user self-esteem. What was formerly seen as 'best-practice' and, in the case of 'best judgement' the result of years of personal experience, is suddenly perceived as obsolete, inadequate or undesirable (Pearce & Walters 1987). Similarly, DSS may change the role of users in the decision-making process. This may be perceived and resented as a loss of control and power which, in the case of consultants, can represent a threat to their income (Pearce & Walters 1987; Parker & Sinclair 2001). DSS developers stress the fact that DSS are there to support decision-making, not dictate it. They are nonetheless likely to make part of the decision-maker's knowledge redundant and thus generate personal and professional insecurity.

DSS are therefore likely to introduce change in an organisation. Their introduction is often motivated by managerial demands for increased performance. DSS developed with the view of optimising existing tasks and decision-making processes generally recommend the use of mathematical models and complex analytical techniques. This may represent a significant change compared to current practice and have significant effects on the way individuals and groups perceive their roles, skills and practice.

> '*Often a shift in organisational culture is required. When badly managed, new systems are often doomed from the start. User expectations must be managed. They must buy into the new system and any new work methods…Resistance to change should be expected and managed*' (Turban, Aronson & Liang 2005).

Researchers have come up with a series of solutions for increasing the implementation success of DSS.

First, they listed a series of evaluation criteria that DSS should fulfill. Finlay and Forghani (1998) list eight of them:

- Adaptability.
- The benefits it provides to decision-making.
- Ease of use.
- Quality of the learning and support infrastructure.
- The match of the system to the issues needing support.
- Quantity and quality of the information displayed.
- Time taken to deliver components of the system to the user.

- Extent to which the user understands the DSS and the degree to which the user understands their own contribution.

Nielsen (1993) developed the concept of 'usability' based on the International Standards Organisation (ISO) definition: the usability of a computer product is:

> '*the extent to which the product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*' (ISO 9241; 11: 1994).

He then produced a list of techniques for assessing usability: surveys, interviews, contextual inquiry, heuristic evaluation and cognitive walkthrough *etc*. (Hom 1996).

Keil *et al*. (1995) suggested testing DSS according to two criteria, usefulness and ease of use. Perceived usefulness is defined as:

> '*the degree to which a person believes that using a particular system would enhance his or her job performance*'.

Perceived ease of use is:

> '*the degree to which a person believes that using a particular system would be free from effort*'.

Using surveys, DSS usefulness and ease of use can be assessed, mapped on a grid and classified into 4 types: rejects, toys, analyst's tools and super tools (figure 5). Figure 5 shows an application of the method to three integrated coastal management DSS. In a separate study, Wu *et al* (2008) showed how the two concepts influenced the willingness of medical practitioners to use a DSS in their daily practice using statistical modelling techniques.

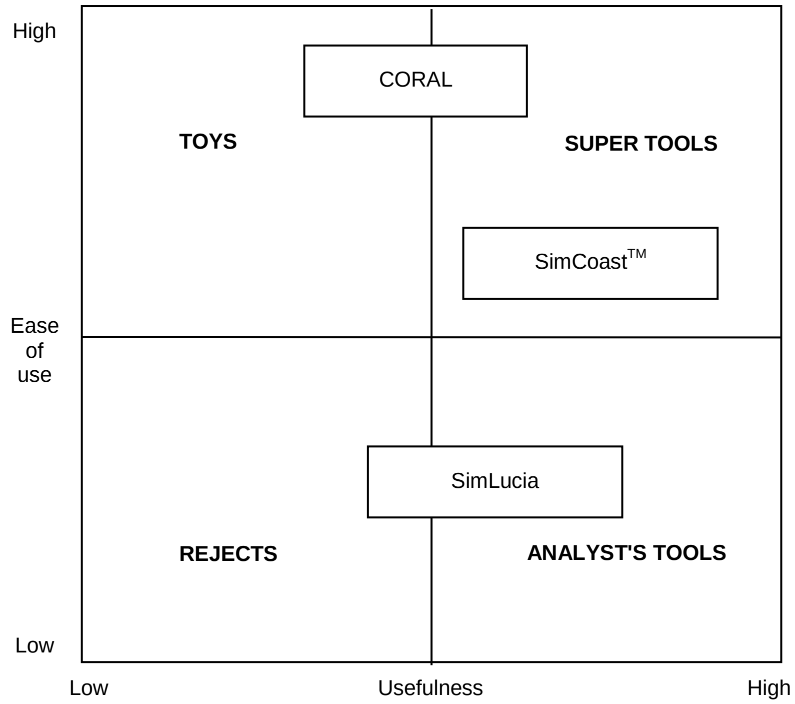
Rather than simply evaluating a finished product, Adelman (1992) proposed to run the evaluation process as part of the design and development phases using prototyping methods. Prototyping methods, such as Rapid Application Development software enable developers to demonstrate how a DSS will actually work before it is developed (Argent & Grayson 2001). It is based on the premises that:

> '*Users don't know what they want or need but they do know what they like*' and

> '*it is a lot easier to answer the question 'How do you like X?' than 'How would you like it?'*' (Adelman 1992).

The active involvement of users in the design of DSS is now a common theme of DSS development literature. As early as 1982, Sprague and Carlson had advocated the involvement of users in what they called an iterative or adaptive design approach (Sprague & Carlson 1982). The iterative approach consists in repeating over time the design cycle with user involvment until a satisfactory and stable version has been achieved.

Figure 5: Position of the three coastal models (CORAL, Simcoast™ and SimLucia) within the grid defining a DSS in terms of perceived usefulness and ease of use (Westmacott 2001).



Some authors advocate the involvement of all users (managers and practitioners) at all stages of DSS development (Argent, Grayson & Ewing 1999; Carroll *et al.* 2002). Parker and Sinclair call it User-Centred Design (UCD) and see in UCD a way of overcoming technical, organisational and personal issues (Parker 2001; Parker & Sinclair 2001). Shim *et al.* (2002) even see it as a mean of embracing cultural elements such as organisational, personal and ethical perspectives.

User involvement was pushed one step further by the introduction of the AGILE methodology where developers use short iterative design cycles in close collaboration with users. In some instances, it is recommended that a user representative actually works with the software development team to provide daily feedback (Lindstrom & Jeffries 2004). AGILE requires strong customer commitment and regular meetings. Its aim is to maximise customer satisfaction. AGILE comprises a series of design methods such as Rapid Application Development where prototypes are quickly produced and iterated to define user requirements (Ben Ayed *et al.* 2010). AGILE was originally aimed at software design but was recently advocated as a suitable method for developing DSS (Gharaibeh *et al.* 2009).

Although there is evidence that UCD and other DSS design methods benefit the technical content of DSS, the case that it can cater for more cultural issues is less clear. Most evaluation and design methods suggested by Adelman and others refer to the technical components of DSS. Few deal with personal and cultural issues (Kaplan 2001b). In their review, Shim *et al.* (2002) vaguely refer to the use of 'group sessions' to help resolve them. Turban *et al* suggest (2005) strong management support and the application of change management strategies consisting of user involvement and communication plans. Although the iterative design approach and AGILE methodology promote a more intense involvement of users in the design process, it is mainly for providing system requirements and feedback and does not necessarily lend itself to account for deeper issues such as culture. It is a consistant bias within DSS literature that can be explained by the history of DSS development.

Originally, the field of DSS design and application was vast and included research fields such as psychology or cognitive science. In practice, research has been dominated by the more technical fields of Management Science/Operations Research and Management Information Systems (Angehrn & Jelassi 1994). As a result, the technical and rational aspects of DSS development have been emphasised to the detriment of cultural and psycho-social dimensions.

One key expression of this bias is in the adoption of Simon's "intelligence-design-choice" problem-solving model (Angehrn & Jelassi 1994). It is a highly rational framework that was applied both to the decision-making framework and the structure of DSS. It assumes that all elements in the decision-making process can be rationalised and accounted for when we have seen that many DSS failed because they did not account for organisational and individual factors. It also restricts the use of DSS to a particular model of problem-solving when DSS can benefit decision-making in different ways (e.g. through the provision of feedback or suggestions to users). It also assumes that decision-making is a 'one-step' process when there is evidence that problem-solving is iterative (Gorry & Morton 1989).

DSS have also strongly concentrated on the production of models aimed at optimising outcomes in the pure tradition of prescriptive normative views of decision-making.

> '*Mingers and Rosenhead describe moving away from mathematical models and towards facilitated, 'enriched' decision-making process that involves group processes. This may make the decision-makers feel good about the process, but it ignores the fact that many models embedded in DSS are available just for the taking. Organisations that do not use the models may feel good, but firms that utilise the model will definitely make more effective decisions. When tools are available and are effective, they should be used for competitive advantage*' (Turban, Aronson & Liang 2005).

In an application on the river Cooum in India, Bunch showed how DSS development can account for organisational and cultural issues (Bunch 2003). He used the Ecosystem Approach (Kay *et al.* 1999) and Soft System Methodologies (Checkland & Scholes 1990) to create a DSS for managing the Cooum catchment. The Ecosystem Approach recognises that human systems and biophysical systems are mutually interrelated in complex ways. Ecosystem management therefore requires the identification of societal and individual values and needs, as well as an understanding of the system we want to manage (figure 6). Soft System Methodologies are methodologies used to deal with complex 'messy' problems. They use workshop techniques such as the drawing of 'rich pictures' to identify problems. These techniques are particularly well suited to DSS development in multi-user/stakeholder environment with conflicting interests and values (Bunch & Dudycha 2004). In the case of the river Cooum, the development of the DSS led to a change in user perception of what the problem was. It started with a specific issue, water quality, and expanded into the wider issue of catchment management. It eventually ended with the identification of innovative solutions that involved, for example, education or the promotion of recreational activities.

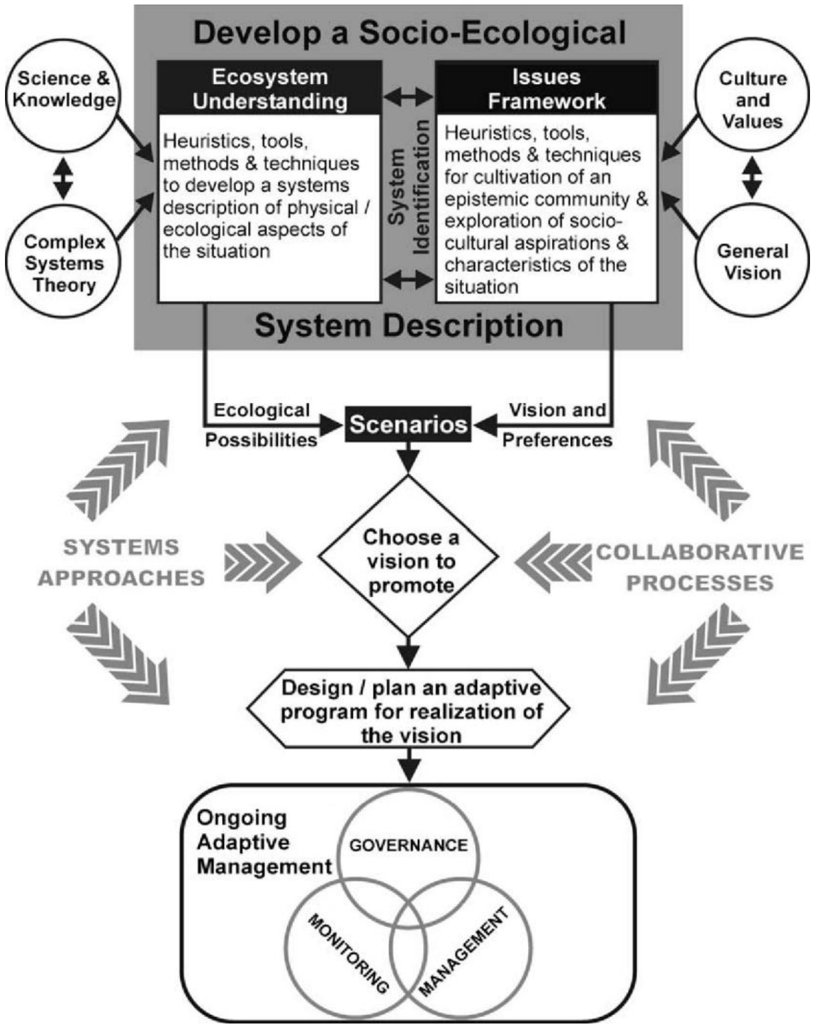
Beyond technical and user considerations, there is another important factor to be taken into account when developing DSS: cost-effectiveness. DSS can be costly to develop and take significant amounts of time. For example, it may take as much as 5 to 10 man years to develop an expert system (Geraghty 1993). A web-enabled version of River Habitat Survey (RHS) database in England and Wales was estimated to cost in excess of a million pounds (Helena Parsons, personal communication). Before developing DSS, it is not enough to know that they are worth the effort but also worth the expense.

Evaluation methods such as cost-benefit analysis or value analysis can be applied to DSS development. Cost-benefit analysis provides meaningful results to managers but has limited application when resources are scarce and benefits cannot be expressed in hard currency. It is indeed of little use to calculate the pound value of returning otter populations, for example, when in actual fact the money will never materialise to offset the costs of development. The value of cost-benefit ratios as decision-making tools is also debatable, as in many instances benefits will be based on very empirical and variable valuation methods such as 'willingness to pay'.

Value analysis is an original technique that gives more importance to benefits than costs (Sprague & Carlson 1982). In value analysis, benefits and development costs are assessed using a prototype DSS developed with users. Managers then make an intuitive judgement by comparing the list of benefits to the planned costs of development.

The choice of evaluation method depends on many factors such as the nature of the benefits, the decision-makers and the decision-making environment. In the case of DSS benefiting biodiversity in the Environment Agency, it may be more appropriate to use intuitive methods such as value analysis, as benefits are mainly intangible and resources are limited.

Figure 6: The ecosystem approach from (Bunch 2003).



Conclusion

DSS development and use is mainly restricted to academia and the private sector although there is a growing interest from conservation organisations in what they can achieve. Most DSS in conservation were designed to deal with spatial planning issues (land use and agricultural), species and habitat management.

Despite being originally viewed as tools for supporting and amplifying the decision-making power of managers, DSS to date have followed a very prescriptive normative approach to decision-making. The presence of Simon's rational model of decision-making in most DSS design textbook (Sprague & Carlson 1982; Sauter 1997; Turban, Aronson & Liang 2005) and the calls for the adoption of rationality as the dominant paradigm behind DSS development is a clear indication of the rational prescriptive orientation of decision support.

> '*The place to begin is with the definition of rationality. Everyone knows that rational decisions are better than those that are not rational*' (Sauter 1997).

Some authors (Angehrn & Jelassi 1994) have highlighted the limitations and bias of such an approach but they do not seem to have been widely heard.

According to its supporters, DSS can greatly enhance the efficiency of an organisation and help resolve highly complex problems. Particularly, they underpin decision with scientific evidence and enable learning within an organisation.

In practice, surveys of existing DSS have revealed a general lack of use of DSS. Reasons behind DSS rejection were multiple, from poor design to more complex organisational and personal issues. Researchers have advocated the use of a more user-centred design framework for DSS development. Importantly they found that for DSS to be successful, users need to feel that they are needed, that they are worth the effort and that they are not threatening their ability to make decisions. A true challenge in DSS design is to account for technical, organisational and personal issues with all concerned users. It is thus important to analyse the technical and cultural framework in which DSS may take place before developing them.

DSS can be costly to develop. In an environment where resources are scarce, the investment of significant resources in computer design need to be justified. Tools such as cost-benefit analysis and value analysis can greatly help in the process, but care needs to be exercised to properly take into account intangible as well as tangible benefits.

Chapter 4 DSS for Biodiversity management

The first case study was initiated when I was employed in the Environment Agency (EA). The majority of this chapter was extracted from an R&D project report that I produced at the end of 2005 (Naura 2005a). In this chapter, I present the analyses as they were carried out at the time and the conclusions that I included in the final report. It is important to note that this chapter is a historical document. A lot of the tools reviewed have since disappeared or changed. The Environment Agency has been through a reorganisation. The purpose of this chapter is to demonstrate the approach I first took towards developing a DSS for biodiversity management in the EA and to discuss its impacts and limitations. I have made a few changes to the text of the original document, apart from some fairly minor modifications to either provide some contextual information, or adapt the style so that it could be included in this thesis. The original document contained a literature review that I extracted and expanded upon, and that formed the basis for my review in chapter 3. As part of the project, two additional sets of documents were produced:

- A review of habitat modelling techniques was initiated to evaluate the scope for using available Environment Agency data for assessing habitat suitability (Naura 2005b).
- Three R&D project proposals were also written up and submitted at the end of the project. A summary version of the three projects can be found in appendix 3.

The aim of this project was to investigate the potential opportunities and benefits of Decision Support Systems in delivering improved decision-making in biodiversity management. Managers in Conservation had become aware of the existence of decision support tools and were interested in their potential benefits. At the time, there was a growing perception among senior managers that staff did not use existing scientific evidence when making decisions, but rather, relied on their expert knowledge and, at times, limited experience. Many Conservation staff were quite young and, as older and more experienced members of staff where moving to management positions, critical expertise was being lost. Conservation was also affected in some areas by high levels of staff turnover.

New European legislation such as the EU Habitats Directive (European Union 1992) and Water Framework Directive (European Union 2000a) were also putting Conservation at the forefront of organisational decision-making, a position it was not used to occupying. Whereas in the past, Conservation was attempting to mitigate the impacts of high priority activities (e.g. flood protection), now ecology was becoming a priority.

Local and global businesses, local authorities and other stakeholders were expecting Conservation to provide not only advice but also the means to achieve Water Framework Directive and Habitats Directive targets. This in turn created a whole new problem: from thinking locally, Conservation suddenly had to think globally and be able to clearly define and communicate its knowledge and requirements to all involved stakeholders; from being reactive, it had to become proactive and build plans and forecasts. This was by no means a simple issue. DSS therefore may have appeared as a potential solution to this new situation.

The next sections of this chapter represent the main parts of my original report as delivered to the Environment Agency in August 2005. My approach towards developing DSS at that time is reflected in the chapter structure of the report. I first started by identifying needs for DSS with users and managers and put together a series of issues or questions that needed resolving. I also ran a survey of user skills and competencies. I then reviewed existing DSS for managing biodiversity and assessed their applicability to identified issues and their compatibility with EA systems and user skills. Following these reviews, I identified one issue that would benefit most from the use of decision support tools and suggested the structure of a DSS that was eventually put to the project board for approval. At the end of this chapter and in the following chapters, I will reflect on the case study, its success and how it resonates with my previous experience in the Environment Agency and evidence from the literature. From this, I will derive some hypotheses surrounding the issues that surfaced during the case study and suggest strategies to overcome them. This will form the basis for the methods and strategy implemented in the second case study.

Introduction to the first case study

The English and Welsh Environment Agency is the biggest environmental protection organisation in the UK. It is responsible for water quality monitoring, pollution prevention, flood protection, fisheries management, waste management, ecology, conservation and navigation. It is split into eight regions representing major hydrological basins. Each region is further split into a number of areas that varies according to regions. There are 26 areas in England and Wales. Each region and area has its own management structure. The regional teams are co-ordinated by the Environment Agency Head Office 'Functions' with at their top, a Head of Function reporting to directors and to the Environment Agency Board. Ecology and Conservation is one of the Environment Agency Functions. There are around 14,000 staff working in the Environment Agency, 200 of them in Conservation. They are spread between Head Office Policy, Process and technical units, and 26 local teams working in the areas. Local teams report to local management structures. There is no direct management link to Head Office Functions.

Under the Environment Act (1995), the Environment Agency (EA), has a general duty to 'promote and further conservation wherever possible'. Biodiversity management is not its main responsibility. However, as an environmental regulator and stakeholder, the EA holds a key role for the successful implementation of environmental legislation. Under the UK Biodiversity Action Plan (BAP), the EA is the lead contact or partner for 39 species and 5 habitats (Environment Agency 2000). It is also one of the competent authorities responsible for the delivery of ecological targets set out in both the Habitats and the Water Framework directives (WFD). Biodiversity management is an important part of its corporate strategy (Environment Agency 2003a). It features in 'an enhanced environment for wildlife' as one of nine themes in its environmental strategy (Environment Agency 2003a). Biodiversity concerns are also specifically addressed in two additional corporate documents: the Biodiversity Strategy (Environment Agency 1997) and an Action Plan for Conservation (Environment Agency 1998).

The management of biodiversity within the Environment Agency is complex and multiform. It involves scientists, managers, operational staff but also conservation organisations (e.g. English Nature), businesses and members of the public. It is spread across numerous other management planning processes such as Catchment Abstraction Management Strategies (CAMS), Catchment Flood Management Plans (CFMP) or licensing activities, all with their own decision-making framework, procedures and tools.

There is a growing perception that Conservation staff do not always utilise the best available scientific evidence when making decisions. When they do use 'sound science', it is generally because the question is so important that they are prepared to invest time and expertise. Conversely, lack of time and expertise may be the reasons why they do not use science most of the time. Scientific knowledge is also lacking. Despite growing public interest in biodiversity and other environmental issues, knowledge of species and the way they react to environmental changes is limited (Hall 2005).

One way of building science within a complex decision-making framework is through the use of specific decision support tools called Decision Support Systems (DSS). DSS are computer programs combining predictive tools and knowledge databases to help resolve complex issues. Examples of DSS include planning software for modelling the impact of changes in land uses on river flow, species distribution and economic revenue. Within DSS are complex mathematical and empirical models representing the scientific state-of-the-art in hydrology, hydraulic modelling, impact forecasting and risk analysis.

The aim of the first case study is to investigate the potential opportunities and benefits of DSS and associated tools in delivering improved evidence-based decision-making for biodiversity management.

In this chapter, I will identify the main issues faced by Conservation staff within the organisation. I will then review existing DSS and suggest ways they can be used to support decisions with scientific evidence. Then, I will propose a process and a potential DSS structure for dealing with one selected issue of importance. Finally, I will discuss the potential contribution of DSS to evidence-based decision-making within Conservation, and I will propose a way forward for developing DSS within the organisation as part of Phase 2 of the research project.

The following analyses and proposals are based on:

- A survey of Conservation staff skills and decision-making practices (Appendix 1).
- A survey of Conservation staff on conservation issues of importance (Appendix 2).
- Two workshops with managers and operational staff.
- A series of interviews of individual managers, academics and operational staff.
- A series of meetings and presentation to internal and external stakeholders (Appendix 4).
- A review of existing literature and web sites.

What does the Environment Agency need?

There is a growing perception within conservation bodies that, when they make decisions, they do not use the best available scientific evidence. A recent survey of English Nature staff found that decision-making is mainly justified on the basis of experience with little reliance on scientific inputs (Pullin & Knight 2003). Pullin found that published scientific literature was regularly used by only 25% of respondents. Most respondents relied on their own expertise, expert opinion, or past management plans.

Underpinning decisions with science is one of the Environment Agency organisational goals (Environment Agency 2004). In this chapter, I will present the result of surveys of staff skills, competencies and decision-making preferences within local Biodiversity (i.e. Conservation) teams. I will analyse the surveys within the context of Biodiversity staff tasks and discuss the potential risks associated with current decision-making.

DSS success strongly relies on users feeling that they will add value to their work and help their decision-making. There is little point in developing DSS for issues that are perceived by Biodiversity staff as being adequately addressed by current practice. We therefore conducted a series of surveys, interviews and workshops where we asked panels of users to list the main issues they felt they needed help on.

In the final section of the sub-chapter, I will discuss all results and attempt to tease out the dominant issues Conservation is facing in its decision-making and potential implications for the Environment Agency and the development of DSS.

Use of scientific evidence in decision-making

A survey was designed and conducted as part of the project in collaboration with Jo Cullis (Biodiversity Officer, South West Region) by sending a multiple-choice questionnaire to all Biodiversity team leaders asking them to forward it to their staff (166 staff in total). We used a simple one-page questionnaire (Appendix 1) similar to the one used with English Nature staff (Pullin & Knight 2003). We received 45 responses (27%) that were analysed and the results can be found in Appendix 1.

During the lifetime of the project, another survey was carried out by the Conservation and Ecology Policy and Process team (Bywater 2005). The survey was part of a national review of skills and competencies of staff and got a higher response rate with 87 staff out of 166 (52%) filling in a detailed questionnaire.

Responses to questions common to both surveys (e.g. time spent in the organisation) indicate that the two groups are different. Our survey seems to be biased towards less experienced staff compared to the national skill review. As neither surveys was comprehensive nor provided a statistical basis for making inferences (e.g. through a random selection of participants), we have to take the results with some caution. Also, none of the surveys investigated 'soft' skills such as influencing and negotiation skills. However, from a combined analysis of the surveys, it is possible to get an insight in decision-making and skills in Conservation in the Environment Agency.

The survey results were very similar to that of Pullin. In our survey, we found that staff mainly use opinion from colleagues (82%), books and handbooks (47%) and web-based material (44%) when making decisions. Published scientific papers were rarely used (16% of the time), mainly because of access difficulties and lack of time to read (64% respectively). Most respondents stated that they would use scientific evidence if it was more accessible (91%).

Both surveys highlighted a lack of knowledge in scientific methods despite having a highly academically skilled workforce. Around 85% of the workforce had at least one degree with some 39% of staff holding a post-graduate qualification and 3% a doctorate (Bywater 2005). Although 57% of staff stated that they were 'quite confident' in analysing and interpreting data and 5% were 'very confident', a minority (23%) considered themselves as more than beginners in the use of statistical software (Appendix 1). In the Bywater survey, 54% of respondents admitted having little or no knowledge of basic statistics, and a vast majority had little experience of statistical packages (Minitab: 83%; Multivariate statistical package: 90%). Only 10% of staff considered themselves as having a good or very good knowledge of basic statistics.

Staff skills were strong on survey methodology, the identification of species, the ecology of species and habitats, and on natural heritage and biodiversity legislation (Bywater 2005). Interestingly, most staff did not use existing DSS such as the River

Habitat Survey (RHS) database (62% never used it), Biology for windows (87%) or Rivpacs (89%) (Appendix 1). A large majority of staff were confortable with using Microsoft Office software, navigating the Internet and using GIS (Bywater 2005).

The survey results suggests that most decision-making is made on the basis of personal judgement with, as a prefered source of advice, the opinion from colleagues. Primary scientific literature is rarely used unless it is in a compact form such as handbooks, reviews or guidance documents. Scientific skills are scarce and existing DSS and scientific packages are rarely used. Instead, there is a very strong dominance of more naturalist skills such as species identification and knowledge of ecological processes.

The survey was not followed by more detailed interviews but, instead, a workshop was organised with volunteers. At the workshop session, Biodiversity staff directly expressed their need for better knowledge support and better access to scientific information. Scientific publications take time to read and are often in formats that do not appeal to them. Ideally, they would like more condensed information in a format tailored to their needs. Questions were raised as to whom they should turn to get advice on specific issues or species. The range of species (UK BAP, Habitats Directive), habitats (RAMSAR, SSSIs, Habitats Directive *etc.*) and issues (pollution, herbicide use advice, river management practice, geomorphological issues, hydrological issues) is ever increasing and regular changes in environmental legislation make their task more complex. The Bywater survey found that there was a lack of expert knowledge on most BAP species. Unfortunately, existing guidance documents do not always provide answers to all questions and get quickly out-of-date. Also, best practice examples developed locally are not shared nationally. The turnover of local staff and the potential loss of local knowledge was also a cause of concern.

To help put these findings into context, we tried to identify the types of decisions that Biodiversity staff make as part of their job (Jo Cullis, personal communication).

The workload of Biodiversity staff can roughly be split into two sets of tasks: proactive and reactive tasks. Each set was estimated to take about 50% of an individual's time but there may be differences between areas, some doing less proactive work and mainly concentrating on reactive tasks. Table 2 provides a short description of the tasks and the role of Biodiversity staff in delivering them.

Most tasks could be best described as reach-based reactive tasks, i.e. they would result from a specific application/activity potentially impacting on a stretch of river. Biodiversity staff would be called to give an assessment of impacts or suggest ways of mitigating them. Staff mainly act as advisers. Their only powers are through their ability to influence and through the quality of their advice. Biodiversity staff can object to applications such as land drainage consents or planning applications and their advice is taken into account when making decisions. Between 2,000 and 3,000 land drainage consents and some 9,000 planning applications were reviewed in 2004 by Biodiversity teams (John Rogers and Matthew Kean, personal communication). Because of the reactive nature of the tasks and the short time scales involved, staff tend to use their best judgement in their decision-making.

Table 2: Tasks carried out by Biodiversity staff within the Environment Agency.

	Task name	Task description	Biodiversity staff role	Decision aide
Reactive tasks	Land Drainage Consent	Review of applications for modifying rivers or introducing man-made structures.	Consultee	Judgement and GIS screening tools
	Planning Application	Review of individual planning applications potentially having an impact on the river environment.	Consultee	Judgement and GIS screening tools
	Flood Defence non-routine maintenance work	Advice on work on Flood Defence maintenance work such as de-silting.	Consultee and key adviser	Judgement and GIS screening tools
	Flood Defence routine maintenance work	Advice on work on Flood Defence maintenance work such as grass cutting.	Consultee and key adviser	Judgement and GIS screening tools
	Flood Defence Reactive works	Work outside programmed work or emergency. Includes tasks such as tree management.	Consultee and key adviser	Judgement and GIS screening tools
	Flood Defence Capital works/EIA	Consulted on environmental impact appraisal of Flood Defence capital schemes. This represents a few schemes per year and is labour intensive.	Consultee and adviser	Judgement and GIS screening tools
	Water abstraction licensing	Screening of water abstraction licences applications	Consultee	Judgement and GIS screening tools
	Discharge consenting	Screening of discharge consents applications	Consultee	Judgement and GIS screening tools
	Waste licenses	Screening of waste license applications	Consultee	Judgement and GIS screening tools
	Customer requests	Any request by members of the public	Adviser	Judgement and GIS screening tools
	Environmental Impact Assessment	Consulted on environmental impact assessments, mainly on Flood Defence schemes.	Consultee and adviser	Judgement
	Advice to local councils	Provision of advice to local council	Consultee and adviser	Judgement and GIS screening tools
Proactive tasks	Planning Application	Influence 5-year local development plan.	Consultee	Judgement and GIS screening tools
	Project specific work	Run or participate to project work such as Water Level Management Plans.	Project partner, decision-maker or adviser	Judgement and GIS screening tools
	River restoration schemes	Development of river restoration schemes on river reaches, often on an opportunity basis but with elements of catchment planning.	Project partner, decision-maker or adviser	Judgement and GIS screening tools
	Biodiversity enhancement projects	Project aimed at improving biodiversity (e.g. reed bed management) often on an opportunity basis but with elements of catchment planning.	Project partner, decision-maker or adviser	Judgement
	Biodiversity enhancement and amenity projects	Project aimed at improving biodiversity in urban areas often on an opportunity basis but with elements of catchment planning.	Project partner, decision-maker or adviser	Judgement
	Local Biodiversity Action Plans	Participation or lead on Local BAP plans. Definition of action plans for UK BAP species and habitats.	Project partner, decision-maker or adviser	Judgement and expert advice

In the case of straight-forward applications, impacts are easy to judge and best judgement may be considered as adequate. For more complex situations, such as the introduction of structures potentially splitting populations and affecting their chances of survival, an assessment based on personal opinion may have its limitations. This is a decision-making area where less experienced operational staff have expressed a need for help.

Fewer tasks were identified as proactive but they still represented around half of Biodiversity staff's time. They are centred around local collaborative projects and opportunity. They generally involve some form of planning and prioritisation but it is mainly done using personal judgement. Examples of proactive activities include the development of local BAP contributions and Water Level Management Plans.

Policy, process and operational issues
Surveys, followed by interviews, brainstorming and a workshop session were conducted to identify issues for which Biodiversity staff require some help (Appendix 1 and 2). Two surveys of Biodiversity staff were run as part of the project and two workshops were organised with operational staff and managers. The project also benefited from another Environment Agency-led project investigating gaps in biodiversity data. The Biodiversity Data and Information Acquisition project (Hall 2005) recorded and prioritised all biodiversity actions identified by local and national area staff to deliver on UK BAP targets. Issues and actions derived from both initiatives were shaped as a series of questions (Appendix 1 and table 4). From the list of questions, a typology was developed (table 3) to facilitate the analysis of issues facing Biodiversity staff.

Three main question types were identified: strategic proactive, strategic reactive and operational questions. Table 3 displays the three types along with their characteristics, domain of applications and some specific examples of related projects and existing DSS. Table 4 classifies the priority questions identified by staff into their respective types.

Strategic questions are about helping/informing planning. Planning is a process to determine goals and objectives and to devise the means by which they can be accomplished. When goals and objectives are predetermined (e.g. European legislation targets) planning is about identifying, defining, and determining courses of action necessary to achieve them. Actions such as restoration work are expensive and need to be carefully planned to ensure an effective use of resources and maximum impact. Planning questions by nature relate to large-scale issues over medium to long time periods.
Strategic questions are divided into 2 types: strategic proactive and strategic reactive.

STRATEGIC PROACTIVE QUESTIONS

Many 'must-do' business legislation-driven questions require strategic proactive decision-making. They are driven by UK or European legislation, the EA duties and commitments. They are large-scale issues the organisation is accountable for. They include issues such as:

- '*How do we set effective measurable targets for species?*'
- *'How do we prioritise management actions across regions and catchments for the delivery of biodiversity targets?'*
- *'How can we best plan investment in river/wetland restoration work nationally?'*

Strategic questions were dominated by the need for planning (i.e. setting targets, developing action plans, prioritising). Planning is an integral part of the UK BAP initiative. Plans are required for the identification and prioritisation of sites for surveys or designation. The re-introduction of endangered species also needs to be carefully planned to ensure maximum success and minimum impact on ecosystems. There is also a need for integrating UK BAP species management into existing planning processes. The EA additionally needs to plan the control and eradication of invasive species. Species such as Japanese knotweed and American crayfish are spreading throughout the country and causing damage to native species and river bank structure.

Another important concern is the need for assessing the feasibility of options and testing their relative merits (costs/effort versus benefits) before investing resources into implementing them. For example, questions were raised about the cost-effectiveness of investing resources into weed control (is it feasible and is it worth it?) and large-scale restoration work.

Finally, many strategic proactive questions were about testing hypotheses or common belief, potentially leading to the development of policies and best practice guidelines. Amongst these were the beliefs that riparian vegetation management affects the distribution of otter or that invasive plants impact on biodiversity.

The River Habitat Objectives and the River Avon Conservation Strategy are examples of projects where decision support tools could be used effectively. The River Habitat Objectives methodology combines modelling tools, the RHS database and an expert system for setting habitat improvement targets for individual river reaches (Walker, Diamond & Naura 2002). The River Avon Conservation Strategy is a plan of action to deliver Habitats Directive targets based on an analysis of species/habitat needs and the identification of potential environmental pressures (Wheeldon 2003). The project followed the typical 'intelligence-design-choice' problem solving model but could have benefited from the use of DSS such as simulation tools for the evaluation of options and their impacts.

Table 3: Typology of biodiversity management questions.

	Strategic proactive	**Strategic reactive**	**Operational**
Drivers	UK BAP, WFD, HD, SEA, ELD, Corporate Plan, SSSIs, other commitments.[1]	Problems and opportunities at regional/catchment scale.	Problems and opportunities at reach/site scale.
Scale	National/Regional/catchment	Regional/catchment	Reach/site
Time	Medium to long-term	Medium to long-term	Short-term
Application domains	Setting national/catchment targets for species/habitats. Prioritising catchments for river restoration/habitat creation *etc*. Deriving policies. Allocating resources.	Flood Defence non-routine maintenance work (de-silting). Project specific work: -planning river restoration works at catchment scale; -land use management (e.g. forestry); -water level management plans; -silt/erosion control; -biodiversity enhancement.	Land drainage consents, planning applications review. Flood Defence routine maintenance work (grass cutting). Flood Defence reactive work (tree cutting). Flood Defence capital schemes. River restoration schemes. Fisheries enhancement schemes. Water abstraction licensing. Discharge consents. Waste licenses. Customer requests. EIA.
Examples of applications or DSS	Setting River Habitat Objectives in England & Wales. UK and local BAPs. River Avon cSAC Conservation strategy.[2] Testing the impact of land use policies on the environment using NELUP (DSS).	Upper Wharfedale best practice project. River Wandle and Beverley brook landscape assessment. Bassenthwaite catchment fencing project. Creation of natural assets registers using RHS.	Applying RHS to land drainage consents and planning applications (DSS). Diagnosing and predicting river health from biological survey data using Expert Systems (DSS).
Examples of questions	See text and table 4		

STRATEGIC REACTIVE QUESTIONS

Strategic reactive questions are driven by opportunities or problems. They tend to be at the scale of catchments or regions. They often originate from the appearance of specific issues that can be very localised in space but whose resolution requires a broad-scale strategic approach (e.g. siltation, erosion or diffuse pollution). They also include strategies driven by opportunities (lottery money for habitat enhancement schemes across a catchment). Typical questions are:

- *'How can we identify the best sites for habitat enhancement/restoration work?'*

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[1] Acronyms: UK Biodiversity Action Plan, Water Framework Directive, Habitats Directive, Strategic Environmental Assessment directive, Environmental Liability Directive, Site of Special Scientific Interest.

[2] SAC: Special Area of Conservation.

[3] Local Environment Agency Plans were developed in the 1990s. They were supposed to replace Catchment Management Plans and bring together all functions for the

[2] SAC: Special Area of Conservation.

- *'Where habitat fragmentation is having an impact on population viability, can we identify the best areas to develop river corridors?'*

Real-life examples of projects related to this type abound and are specifically centred around the management of catchment habitats and the development of management strategies around specific issues (table 4).

OPERATIONAL QUESTIONS

Operational questions relate to local operational decisions such as land drainage consents, planning applications or Environmental Impact Assessments. They are part of Biodiversity staff day-to-day work and are mainly reactive. They tend to be small-scale and short-term. They include questions such as:

- *'How can I predict the impact of weirs on the viability of water vole population?'*
- *'How can I predict the likely impacts of tree-cutting or de-silting on species habitats?'*

A lot of operational questions were about measuring impacts when dealing with consents, licences, maintenance works or specific schemes (habitat enhancement, river restoration works). Other questions included the provision of guidance for designing restoration schemes or for managing individual sites for species.

A series of specific DSS have been developed to deal with operational issues. The RHS database was applied to the assessment of land drainage consents and planning applications. The procedure made use of the database querying facility and aimed at identifying and protecting rare or high quality habitats. The applications were rarely used. Following a survey. It appeared that users felt the applications were too time consuming, too complex, they did not feel confident interpreting the data and they did not have the time and resources to apply them (Parsons 2001).

Discussion and conclusion

The project started with the assumption that Biodiversity staff do not always utilise the best available scientific evidence when they make decisions. The results from the surveys, interviews and workshops tend to support this assertion. We found that Biodiversity staff in the organisation tend to be strong naturalists, with a lot of experience of the natural environment gained from years of practice in the field which they use in their decision-making. They rarely use scientific information unless it has been summarised in the shape of handbooks and reviews. They seldom perform data analysis using statistical software or use existing DSS.

Personal judgement or the opinion of colleagues seems to be the basis for most decision-making. Is it really an issue? We can attempt to answer this question by addressing it from two angles. First, we can assess whether staff perceive it as an issue themselves; second, we can take a more managerial perspective and evaluate the risks associated with current decision-making.

From the survey, interviews and workshops, there seems to be recognition amongst staff of the limits of using best judgement in aspects of their decision-making. They identified strategic issues such as planning and policy-making as tasks in need of support. Fewer operational issues were identified, but the ones highlighted were related to impact assessment and complex design and management schemes.

Planning issues are intrinsically complex. They require decision-makers to assess issues at large scales and develop solutions to reach a desired future state. It requires both the ability to analyse data and make predictions about the future. Most decision-making in Conservation is on small-scale short-term issues therefore requiring less forecasting ability. Researchers interested in the psychology of decision-making have shown that humans tend to be best at making forecast over short periods of time. Our ability to learn from experience is also heightened when the results from our actions can be observed in short periods of time. On the other hand, our ability to learn from experience and make medium to long-term forecasts (more than 3 months ahead) is poor and even simple statistical models can outperform our predictions (Hogarth & Makridakis 1981; Mocan & Azad 1995). Although the reviews mentioned above mainly concerned business forecast, there is no reason to believe that the psychological biases and limitations they identified in this particular decision-making environment would not apply to Conservation. As mentioned in chapter 2, studies that have used and tested experts for conservation planning have found high levels of variability (Alho, Kangas & Kolehmainen 1996; Alho & Kangas 1997; Pearce *et al.* 2001; Bojorquez-Tapia *et al.* 2003; Yamada *et al.* 2003; Johnson & Gillingham 2004).

Biodiversity staff directly expressed the need for easier access to scientific knowledge to support their decision-making. They complained about the lack of knowledge flow through the organisation and sharing of best practice. Reach design and site management operational issues in table 4 further reflect this need.

What are the risks of relying on expert judgement in decision-making? For strategic planning issues, the risks are obvious. Wrong or poor predictions and evaluation of spatial and temporal issues may result in the development of inadequate plans with little chance of success. This could potentially result in misuse of resources, failure in achieving targets, loss of reputation and environmental damage (Loiselle *et al.* 2003). In the long-term it may affect staff morale and belief in the effectiveness and value of planning (e.g. the Local Environment Agency Planning experience[3]). From a corporate

[3] Local Environment Agency Plans were developed in the 1990s. They were supposed to replace Catchment Management Plans and bring together all functions for the development of 'holistic' plans covering all aspects of water management. They were

perspective, it means that the Environment Agency may not reach targets set by initiatives such the UK BAP, the Habitats Directive and the Water Framework Directives. Failure to comply with the last two legislations could potentially incur substantial financial penalties. From a biodiversity perspective, the Environment Agency could potentially fail to protect and enhance wildlife and habitats.

The situation is worsened by the lack of knowledge flow and management within Conservation. The use of outdated ecological knowledge may result in inadequate decisions being made at operational level (consents reviews). Discrepancies in decision-making will be increased by the fragmentation of Conservation teams across 26 areas. This could potentially result in challenges by local developers, conservation organisations and societies on the basis that the Environment Agency did not use best available evidence or that similar cases in other areas were treated differently. This could, in turn, greatly affect the organisation's reputation at local and national levels.

The lack of sharing, quality assurance and feedback on knowledge acquisition can potentially lead to the creation of 'myths' and bad practice (Sutherland *et al.* 2004). There is, for example, a belief that structures such as deflectors and artificial riffles can improve species diversity in lowland rivers. Independent research on a series of habitat enhancement schemes in lowland rivers have shown that these structures had little impacts on the diversity of fish, invertebrates or failed to function as anticipated (Pretty *et al.* 2003; Harrison *et al.* 2004; Sear & Newson 2004). The reasons for the observed failure of the schemes varied from a lack of consideration of limiting factors such as water quality and land use, to a fundamental inadequacy of introduced structures with regards to river type. Also, schemes were designed at reach scale without taking account of large scale factors affecting population dynamics such as the presence of nearby sources of colonising species. Myths could be dispelled using appropriate guidance and systematic post-project appraisals (PPA). Unfortunately, despite having guidance on how to run PPA (Environment Agency 2003b) few are actively carried out (Bruce-Burgess & Skinner 2002). A mechanism for sharing knowledge and best practice would also enable the dissemination and evaluation of new knowledge. Such 'myths' may result in waste of resources, environmental damage and loss of reputation.

Finally, the use of judgement instead of scientific forecasting techniques for impact assessment at operational level may lead to significant environmental damage. The evaluation of the potential impact of channel structure on the viability of riverine populations, for example, is a very complex issue that requires a detailed knowledge of species biology, ecology and the structure of existing populations. Tools such as

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abandoned following a major reorganisation as they had not fulfilled their expectations and few of them had been implemented.

Population Viability Analysis have been developed to deal with these specific issues. These tools are at present not available within the organisation.

This is not to say that expert judgement is unacceptable. In most cases, best judgement will be perfectly adequate to cover most of the daily issues encountered by staff. And there is clearly a need for sharing expertise and best practice within the organisation. However, when dealing with complex issues at large spatial and temporal scales, research and staff feedback suggest that there are risks associated with using personal judgement.

It is not the purpose of this report to propose ways of managing knowledge within the organisation. Instead, I will concentrate on the potential contribution of DSS to decision-making within Conservation and to the knowledge management process. In the next section, I will suggest ways DSS can be used to underpin our decisions with scientific evidence and solve some of the complex issues highlighted by the Environment Agency staff. I will propose next a framework for developing DSS for dealing with strategic planning issues.

Table 4: Examples of questions for DSS derived from staff surveys, workshops and a review of UK BAP actions.

Strategic proactive	**Strategic reactive**	**Operational**
Planning How can we set catchment targets for delivering national BAP targets? How can we best manage individual catchments for BAP species and achieve the catchment targets? What is the potential impact of invasive weeds on biodiversity across and within catchments? How can we best plan control and surveillance work for invasive species and pests nationally? What catchment/site could potentially hold populations of rare species to inform survey work/designation/re-introduction? Cost-effectiveness Can large-scale river restoration schemes be adopted in the UK, and would they be more cost-effective than traditional hard flood defences? Are conservation monies best spent on invasive species such as grey squirrel, signal crayfish and Japanese knotweed, when they are so well established? Will the creation of new marine national parks/SACs around our coastline adequately protect marine wildlife? Leading to policy development Is riparian habitat limiting otter population sizes in the UK? Is the distribution of submerged aquatic vegetation in UK rivers significantly altered by anthropogenic phosphate additions? Are airborne nitrates a threat to some nutrient-poor habitats? Do Himalayan balsam, Japanese knotweed and giant hogweed reduce the diversity of native flora? Mink – is effective control really possible and if so at what scale? Surveillance and prevention How do we identify potentially invasive species in a changing environment?	Problem-driven How can we best plan control and surveillance work for invasive species and pests? Where habitat fragmentation is having an impact on population viability, can we identify the best areas to develop river corridors? What effect does removing energy from river systems by creating hydroelectric facilities have on river geomorphology and ecology? What are the wildlife implications of offshore or terrestrial wind farms? Opportunity-driven How can we better plan for biodiversity work locally? How can we plan for restoration work?	Impact assessment Can we assess the impacts (present and future) of river modifiers (weirs, culverts, gravel removal, habitat fragmentation *etc.*) on species population viability, dispersal *etc.*? Is riparian tree management likely to affect the abundance and distribution of bat populations at the local scale? What is the risk to biota associated with particular regimes of lake-level fluctuation? Do unnatural lake level fluctuations affect the biota of lakes? Reach design How can we best identify suitable habitat restoration techniques for individual habitat improvement schemes? Do in-stream habitat improvement devices (e.g. groynes) increase the size of fish populations? Site management What actions can be taken locally to make riparian habitats more hospitable to water voles? Does riparian vegetation structure affect fish abundance? How can we best manage individual sites for species and habitats?

Existing DSS and tools, a review

What tools are available?

Two exhaustive reviews of DSS have been carried out for forest ecology management (Rauscher 1999; Forestry 2004) and for land use planning (Johnson & Lachman 2001). No review was found on DSS for managing biodiversity but a search through the World Wide Web and existing literature on models and tools for conservation revealed a series of DSS and tools of interest.

The review includes fully functional DSS but also predictive models, software for the derivation of predictive models, knowledge databases, Expert Systems and tools for the selection of nature reserves.

A distinction shall be made between fully functional DSS and tools associated with DSS. A DSS comprises at least a user interface, a knowledge database and an inference engine (figure 1). I found few fully functional DSS but a lot of tools that could be included as part of Decision Support Systems. Here, I present the most relevant ones. An in-depth review of tools and techniques associated with DSS for assessing the suitability of management units for species is available in a separate technical report produced for the Environment Agency (Naura 2005b).

One difficulty in reviewing DSS was the choice of evaluation criteria. I decided to use Keil's concepts of 'usefulness' and 'ease of use' (Chapter 3) as they provide a simple and straightforward graphical classification of DSS.

Because my judgement of what is 'useful' and 'easy to use' is likely to be influenced by personal factors that are not representative of target users (e.g. personal computer skills), I decided to subdivide each criterion into three sub-criteria. Usefulness, in my view, represents a combination of (i) the estimated time to reach a solution; (ii) the relevance of the outputs and (iii) the availability of data to run the DSS. Ease of use was composed of an assessment of (i) interface simplicity, (ii) computer/software compatibility and (iii) user skill compatibility. The eight criteria are presented in tabular format using three quality thresholds: good ☺; moderate 😐; poor ☹.

I chose these sub-criteria for the following reasons:

- Estimated time to reach a solution is an essential component of usefulness. Many Conservation activities are time-limited. According to research (chapter 3), DSS users tend to go for the least effort strategy in their decision-making. A system that cannot deliver a response faster than current decision-making or within reasonable time is likely to fail.
- Output relevance is a clear indication of DSS usefulness. The final product should match what is required by the user and provide support towards answering identified issues.

- Data availability is a common limiting factor in any research activity and changes in data format can be a very onerous task. DSS have varying data requirements and it is important that they match the data available within the organisation.
- Interface simplicity was identified by research and past experience as a key factor in user uptake (chapter 3).
- Computer and software compatibility is important as the EA now has very strict rules with regards to the implementation of new software and hardware.
- The compatibility between the level of skills required to run the DSS and available skills amongst staff is an important success factor. A mismatch would require organising training courses and producing guidance documents. This would increase the amount of efforts required from users which, as seen in chapter 3, is a key cause of DSS rejection.

It is important to note that this review represents my views on the applicability of DSS tools to issues identified by Biodiversity staff in chapter 3. I assessed the tools against average Biodiversity staff's skills, competencies and likely expectations using survey results and my personal experience. A more thorough assessment would have involved a panel of Biodiversity staff who would have tested DSS on specific work-related applications. For logistical reasons, this was not possible within the time frame of the project but it could be considered for future evaluations.

A few of the DSS could not be tested as they required specific licensing or software. Some failed to work despite following the set-up procedures. However, using guidance documents and other evidence (publications, web-site information, PowerPoint presentations), I was able to provide some assessment of DSS quality in most cases.

Habitat assessment/evaluation DSS
EMDS

The Ecosystem Management Decision Support system (EMDS) is a Spatial DSS that works using an ArcView 8/9 interface. It contains two sets of inference tools, one for building and running fuzzy logic models and one for building multi-criteria evaluations. Both sets of tools are directly connected to ArcView thus enabling easy retrieval and transfer of data. The EMDS was applied to the Chewaucan catchment in the United States to assess its suitability for salmon and to prioritise reaches and sub-catchment for restoration work (http://www.fsl.orst.edu/emds/powerpoint/chewaucan.pps). Models built using EMDS are simple to apply but the model building process can be complex and require substantial expert input.

POTENTIAL USE OF EMDS

EMDS models could be built for strategic proactive and reactive issues such as the planning of restoration work, the production of programmes of measures for the WFD or the production of catchment action plans for UK BAP species.

For example, simple models could be run using RHS and geomorphological data to assess the hydromorphological quality of large management units (e.g. WFD waterbodies) and identify the main pressures on habitats. The multi-criteria tools could then be used to prioritise river restoration work based on environmental benefits, costs and land use constraints.

Criteria	Sub-criteria	Comments
Usefulness ☺	Time to reach solution 😐	EMDS was not tested but running the system on large catchments is likely to take a lot of processing time
	Relevance of outputs ☺	Maps are ideal for laying out plans and GIS is widely used amongst Biodiversity staff
	Data availability ☺	A wide range of GIS data compatible with ArcView is available on the EA network.
Ease of Use 😐	Interface simplicity ☺	The EMDS interface is intuitive and easy to use
	Computer/software compatibility ☹	EMDS works on standard GIS software but requires specific set-up and set-up of 2 additional software to run the fuzzy logic and multi-criteria engines
	User skills compatibility ☺/😐	The modelling interface would be difficult to use by Biodiversity staff. However, models can be built for them and the user interface is compatible with most user skills

In the case of programmes of measures for the WFD, expert habitat suitability models for target communities could be developed and applied to all river reaches within waterbodies. Individual reach results would then be aggregated within each waterbody. Information on pressures and factors affecting community distribution would be added to provide an overall assessment of waterbody suitability. The assessment would enable the identification of pressures and their impacts on community distribution. Multi-criteria evaluation would then be applied to best locate and prioritise restoration work so as to achieve the 'good ecological status' target whilst minimising costs. Models simulating the impacts of management actions on habitats and ecological status could also be developed to enable user to test different management scenarios.

SWAMP

Spatial Wetland Assessment for Management and Planning (SWAMP) is a tool developed in the U.S. for examining wetland functions using ArcView 3 (www.csc.noaa.gov/swamp/swamp.html). SWAMP has two modules, tidal and riverine, that examine how individual wetlands within a watershed contribute to three wetland functions: water quality (cleansing function), hydrology (flood attenuation and channel maintenance) and habitat.

The primary objective of SWAMP is to aid land use planning and management by providing information about the relative ecological importance of wetlands within a watershed. SWAMP can also be used to predict the impact of future changes in land use on wetland functions.

SWAMP examines wetlands by applying assessment rules in a prescribed manner (i.e. it is a rule-based model). These assessments are based on published research and expert knowledge. It uses site-specific characteristics (obtained from soil, vegetation, and land use descriptions) and landscape characteristics (obtained from geographic information system analyses) to derive the parameters used for examining the three wetland functions.

The inference models are based on in-built rules using set parameters. But the interface allows users to determine how the parameters are assembled into overall assessments of water quality, hydrology, and habitat functions. The output is a map showing the relative importance of existing wetland to water quality, hydrology, and habitats (figure 7).

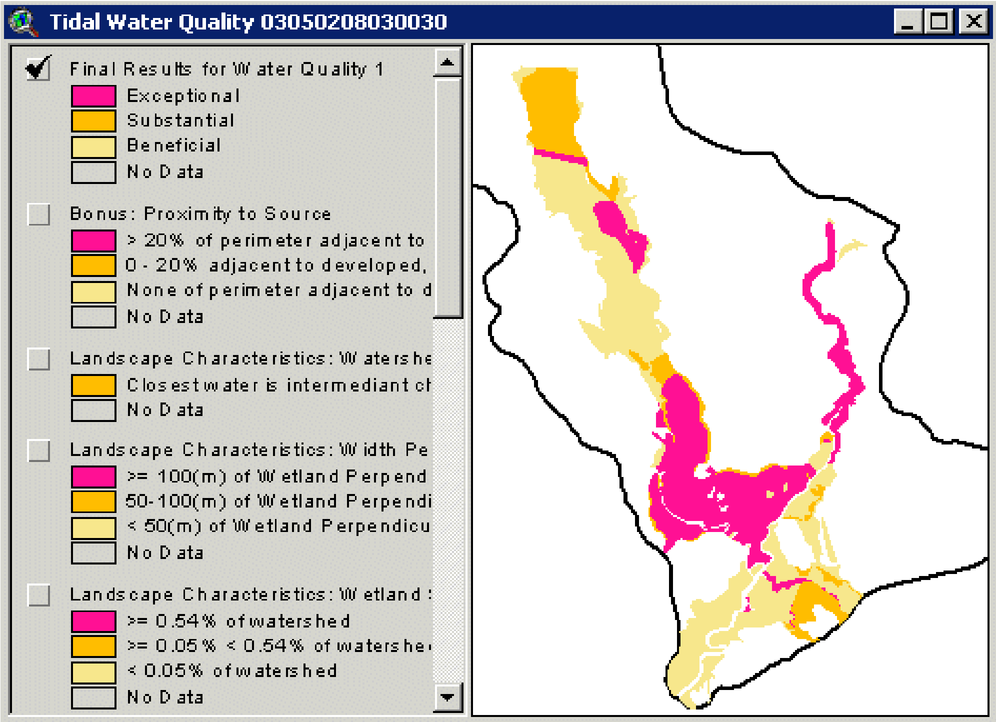
POTENTIAL USE OF SWAMP

Combined with SITES (see page 64), SWAMP could help identify areas where wetlands would most benefit biodiversity, water quality and flood protection and help the prioritisation of restoration work. It would particularly help influence the Catchment Flood Management Planning (CFMP) processes and Catchment Management Abstraction Strategies (CAMS).

Criteria	Sub-criteria	Comments
Usefulness 😐	Time to reach solution 😐	SWAMP was not tested but running the system on large catchments will take a lot of processing time
	Relevance of outputs 😐	SWAMP is relevant for the identification and prioritisation of sites for wetland restoration. However, the classification of wetlands does not match the UK classification.
	Data availability 😐	The data required are available within the Agency but would require formatting so as to ensure compatibility with the software standards (US data standards).
Ease of Use 😐	Interface simplicity ☺	The basic interface is simple to use. The modelling interface is complex but makes a judicious use of graphs and tables to help the user through the modelling steps.
	Computer/software compatibility ☹	SWAMP works on ArcView 3, which is not supported anymore within the organisation. It also requires a specific set-up.
	User skills compatibility ☺	It is straightforward to use and requires little additional skills.

SWAMP was designed for US catchments and wetlands. The classification of wetlands used is specific to the U.S. Fish and Wildlife Service (Cowardin *et al.* 1979) and may not be applicable to UK wetlands. SWAMP was also designed for a version of ArcView that is not compatible with new standards.

Figure 7: Maps showing the relative importance of the wetlands cleansing function.



Knowledge databases

Evidence-based-decision-making is becoming a common concern amongst conservation organisations. New ways of accessing knowledge are being developed. They include on-line species databases featuring data on species biology, ecology and life history, but also knowledge databases and services providing information on species and habitat management techniques.

FishBase and LarvalBase

The FishBase (http://www.fishbase.org/search.cfm) holds information on some 28,000 freshwater and marine fish species from around the world. User can learn about species, their size, ecology, life history *etc.* Lists of relevant scientific publications are also available. A separate on-line database, the LarvalBase (http://www.larvalbase.org/frame_oben.htm) complements the FishBase by providing detailed information on larval stages for nearly 200 fish species.

Criteria	Sub-criteria	Comments
Usefulness 😐	Time to reach solution ☺	Simple web application
	Relevance of outputs 😐	The database only covers some of the species relevant to Biodiversity staff
	Data availability ☺	The application does not require data from the organisation
Ease of Use ☺	Interface simplicity ☺	Simple web interface
	Computer/software compatibility ☺	Compatible with organisational standards
	User skills compatibility ☺	Very easy to use

Wildspace™

Wildspace (http://www.on.ec.gc.ca/wildlife/wildspace/intro-e.html) is a web-enabled database for birds in Canada (Wong *et al.* 2003). It features information on species, their life history, behaviours and migration patterns, and it gives access to photographs, sound tracks and even distribution maps using an in-built GIS interface.

One originality of Wildspace is the availability of a desktop application that turns it into a proper DSS. The DSS gives users the ability to extract data from the knowledge database (e.g. life history parameters *etc.*) and GIS (distribution maps) and feed them into a data analysis and visualisation module. The module features various statistical and modelling tools for investigating trends and relationships across space and time. Models can be produced and fed into a 'Scenario Gaming' module that can simulate the impact of various changes in the environment (i.e. climate) on species distribution.

Criteria	Sub-criteria	Comments
Usefulness 😐	Time to reach solution ☺/😐	The database is fast. The analytical component is more complex and involves the use of several modules, which increase data analysis time.
	Relevance of outputs 😐	The DSS was designed for birds and features very useful analytical tools for looking at spatial and temporal trends. It would have to be adapted to run on British watersheds and riverine species and habitats.
	Data availability 😐	The system is capable of handling Access files and ESRI shapefiles but they have to be properly formatted before import. It hosts its own GIS.
Ease of Use 😐	Interface simplicity ☺	The knowledge database and GIS interface are simple to use. The analytical tools are more complex.
	Computer/software compatibility ☹	Wildspace would have to be installed as a separate application
	User skills compatibility ☺/😐	The use of the knowledge database and GIS is very straightforward. The analytical tools require more expert users

POTENTIAL USE OF WILDSPACE

Wildspace was originally designed for the Canadian Wildlife Service but could potentially be adapted to the EA needs. The desktop application would be particularly suited to technical specialist staff (local and national) for analysing spatial and time series data for strategic issues (analysis of population trends along time, analysis of spatial distribution patterns, test of hypotheses *etc.*) for project work or policy. The analytical tools would require users experienced in the application of statistics to biological data.

FreshwaterLife

Freshwater life (http://www.freshwaterlife.info/) is a collaborative project hosted by the Freshwater Biological Association.

'Within the overall framework, FreshwaterLife has 4 principle focus areas, or work programmes:

- The habitat and life-history of freshwater animals and plants is captured in the *Freshwater*Life *Ecological Database*.
- Identification guides and training tools, principally through *online taxonomic keys*.
- Collation and promotion of standards and methods for scientific research, monitoring, policy implementation and biological data storage and exchange.
- Improving the flow of information and discussion between different parties involved with freshwater (researchers, regulators, policy makers and implementers and the general public). A vehicle for this is the *Freshwater*Life *Network*.'

Criteria	Sub-criteria	Comments
Usefulness ☺	Time to reach solution ☺	The web site is fast.
	Relevance of outputs ☺	The information in the database is very relevant to biodiversity staff work
	Data availability ☺	No data from the organisation is required
Ease of Use ☺	Interface simplicity ☺	Simple interface
	Computer/software compatibility ☺	Compatible with internet explorer
	User skills compatibility ☺	Basic internet skills required

The ecological database is very similar to FishBase but information on species life history and ecology is referenced. Users can directly check the quality of referenced data and assess their relevance to their specific issues or geographical area. The presence of online taxonomic keys as well as management and scientific information makes it a very useful resource to biologist and conservationists alike. The developers of FreshwaterLife are also very keen to develop solutions tailored to the EA needs.

Evidence Based Decision-Making tools

Evidence Based Decision-Making (EBDM) is becoming an increasingly popular concept amongst conservation academics and managers. The concept originates from the medical field (Box 1). Recently, the EBDM concept was adopted and applied to conservation (Pullin & Knight 2001; Pullin & Knight 2003; Sutherland *et al.* 2004). Two initiatives were started: the CEBC and the ConservationEvidence.com web-database.

Centre for Evidence-Based Conservation (CEBC)

The CEBC (http://www.cebc.bham.ac.uk/) aims to support decision-making in conservation by providing systematic reviews and expertise to staff from conservation organisations. The CEBC started following a review of decision-making in English Nature by Pullin (2004). The CEBC is hosted by the University of Birmingham and is planned to have between 10 and 20 staff dedicated to providing support to conservation organisations. It will also feature a network of experts who will provide advice in specialist fields.

The CEBC will work in the following way: Conservation staff will contact the CEBC with a particular issue (e.g. what treatment methods are effective for eradicating Japanese knotweed?) and the centre will then produce a comprehensive literature review on the subject.

Box 1: Evidence Based Medicine, a short history

The EBDM concept originates from David Sackett and the Clinical Epidemiology Department of McMaster's University in the 1980s which sought to improve the medical curriculum and training of future physicians. EBDM then focused on encouraging physicians to stay on the cutting edge of knowledge by searching and critically evaluating the available literature using new databases of scientific research.

The aim was to create the ''gold standard'' of patient care, or ''the conscientious, explicit and judicious use of current best evidence in making decisions about the care of individual patients''.

The process and practice of EBDM has enlarged beyond academia into a common practice and standard utilised by the majority of scientists and medical practitioners today. EBDM has evolved into four major types of pursuits: (i) critical evaluation of individual research studies, (ii) systematic reviews of studies in a particular area or practice, (iii) evidence-based practice guidelines outlining standards for the profession, and (iv) evidence-based systems of care focused on implementation.

The growing movement of EBDM can also be seen in The Cochrane Collaboration, a British undertaking with the goal of evaluating exhaustively all medical procedures, and the Evidence Based Medicine Journal, produced regularly to publicly display the gold standard and procedural rankings of various techniques and practices.

Overall, the emphasis is on supplanting the less reliable bases of opinion, common sense, experience and inferential judgement in favour of empirical, objective and scientific standards to evaluate and validate procedure. (Villanueva-Russell 2005).

Potential use of the CEBC

The CEBC can benefit the Environment Agency by providing reviews on strategic policy issues such as methods of control and efficacy of large-scale Japanese knotweed control.

Unless relevant reviews have already been produced, it is less likely to be used for operational issues as these are short-term and require fast processing. The format of the reviews is very important. In the medical world, systematic reviews are mainly used by researchers, policy-makers and guidelines developers; most clinicians do not use them as they do not find the review format adapted to their needs (Daya 2005). In the survey, Biodiversity staff expressed the need for scientific evidence that is accessible, readable and up-to-date. There is a risk that literature reviews written by scientists are in a format and language that will not appeal to operational staff. Also, there does not seem to be an update mechanism for keeping existing reviews abreast of scientific progress.

Criteria	Sub-criteria	Comments
Usefulness ☺	Time to reach solution ☹	A review can take several months to perform. It would not be adapted to reactive work or medium term proactive work unless a review has already been performed. It is mainly adapted to policy related tasks.
	Relevance of outputs ☺	Very relevant to the organisation aim to underpin decision-making and policies with science.
	Data availability ☺	No data is required from the EA
Ease of Use ☺	Interface simplicity ☺	It is a simple web-site with downloadable PDF files
	Computer/software compatibility ☺	Compatible with internet explorer
	User skills compatibility ☺	Basic internet skills required

ConservationEvidence.com

Another initiative is the web database of conservation actions set up by the University of East Anglia (http://www.conservationevidence.com). Its aim is to provide an on-line database of conservation management practice to support decision-making.

The principle is that any practitioner can input information on projects or experiments they have carried out. The information does not need to be quantitative or even subject to the standards of published literature. It can be as trivial or anecdotal as a single trial of a chemical to kill a single stem of invasive weed. The idea is that other users can query the database and extract a list of case studies relating to a particular problem.

The website also features meta-reviews. Meta-reviews are reviews of published scientific reviews and are aimed at answering specific questions. Examples include meta-reviews on the effects of wind turbines on bird or the effect of habitat fragmentation on avian nesting success over multiple spatial scales.

POTENTIAL USE OF CONSERVATIONEVIDENCE.COM

This tool would be best suited to reactive operational issues. Facing a particular problem, staff would be able to query the database and extract information on similar cases. It would help them reach a judgement as to what approach is likely to succeed. Similarly, it would benefit other users as Biodiversity staff would be able to store their own casework on the online database.

The meta-reviews could be extremely useful both for operational and strategic issues. They would provide a scientific basis on which to base decisions.

The database could also be used as a research tool for writing reviews and best practice guidelines, or for identifying new avenues of research

One major issue is data quality. There is no formal quality assessment process for inputting data on the database. Also, it should be emphasised that, despite being called 'evidence', there is no guarantee that the information in the database will stem from scientific experiments. Case studies may be based on single observations or personal judgement. There is a risk that the database becomes burdened with thousands of individual observations of little interest, which will make it difficult to use. At present, there is no way of querying the database on the basis of scientific relevance.

Criteria	Sub-criteria	Comments
Usefulness ☺/😐	Time to reach solution ☺/😐	Search engine effective but it could take time to filter the right case studies and read them all. Once the database has grown beyond a certain size, it may be fairly taxing to use.
	Relevance of outputs 😐	Outputs would be about sharing 'experiences'. Some may have a scientific content but many will be anecdotal. It could potentially be a good research tool and a way of sharing best practice but it could equally lead to the dissemination of bad practice.
	Data availability ☺	No data required
Ease of Use ☺	Interface simplicity ☺	It is a simple web-site
	Computer/software compatibility ☺	Compatible with internet explorer
	User skills compatibility ☺	Basic internet skills required

Optimisation tools

Optimisation tools in conservation are typically used for selecting sites for designating nature reserves (Cowling *et al.* 2003; Rouget 2003). When preparing plans for building nature reserves, conservationists often face a very complex problem of choice. There may be tens or hundreds of suitable sites resulting in thousands or millions of potential combinations. Amongst them, a few may fulfil identified conservation criteria and economic constraints.

To help the decision-making process, a series of techniques have been developed. The simplest ones apply rule-of-thumb or multi-criteria models to species, land use and economic data in a GIS environment (Llewellyn *et al.* 1996; Thompson, Larcom & Lee 1999; Gkaraveli, Good & Williams 2004) Others perform landscape analyses using more complex algorithms that take account of site proximity and species migration ability to create a network of linked sites (Hoctor, Carr & Zwick 2000; Bruinderink *et al.* 2003; Larson & Sengupta 2004; Nikolakaki). Mathematical and statistical algorithms have also been developed such as linear programming (Csuti *et al.* 1997), irreplaceability analysis (Ferrier, Pressey & Barrett 2000) and heuristics methods (Woodhouse *et al.* 2000). These algorithms run a series of iterations through the data and attempt to identify the configuration of sites that will fulfil all specified criteria (e.g. conservation targets, nature reserve size and cost of buying and maintaining the land).

A series of optimisation software using a variety of techniques and platform already exist. Among them, EMDS uses Multi Criteria Analysis, SITES (ArcView 3.2; http://www.biogeog.ucsb.edu/projects/tnc/toolbox.html) uses heuristic algorithms, C-Plan uses irreplaceability analysis (ArcView 3.2; http://members.ozemail.com.au/~cplan/), RLEM uses linear programming (http://www.fs.fed.us/institute/planning_center/plan_relm.html) and RESTORE uses rule-based and fuzzy models (built-in GIS; http://biosys.bre.orst.edu/restore/).

SITES: an analytical toolbox for ecoregional conservation planning

SITES was designed for nature reserve selection. SITES works on GIS ArcView 3.2 It allows users to identify the best combination of management units or sites across a region for achieving conservation goals whilst minimising the cost of buying land. Management units are polygons on a GIS layer. Each polygon contains information on species/habitats and land cost. The algorithms will select the best combination of sites to achieve the conservation objectives whilst minimising the costs.

SITES enables users to specify landscape requirements such as the level of contiguity and maximum distance between patches and minimum patch size (figure 8). The shape and spread of nature reserves is important both from a management and a species/habitat conservation perspective. A compact nature reserve may be easier and cheaper to manage than a fragmented one, but it will be more susceptible to large scale extinctions due to disease outbreaks, pollution incidents or fires.

POTENTIAL USE OF SITES

SITES could be used to prioritise areas for wetland restoration. For example, SITES could produce maps showing areas where wetlands could be restored. Each wetland site (existing and potential) could be attributed a cost based on restoration costs and/or maintenance. A national target for each wetland type would then be set based on UKBAP targets or other conservation objectives. The algorithms would then be run to identify the best selection of sites to meet the Conservation targets whilst minimising maintenance and restoration costs. In case of limited resources or funding, it is possible to set a cost threshold as an additional criteria. It is equally possible to program SITES to always include specific wetland sites that the EA wishes to keep in the final portfolio (e.g. existing SSSis *etc.*). SITES could also be used in combination with SWAMP (see page 56). SWAMP would provide an assessment of wetland benefits to biodiversity, water quality and flood protection that could be included in the optimisation process as additional targets.

Figure 8: Effect of changing the value of the Boundary Modifier values (BLM) on the clustering of sites. Increasing boundary modifier values will increase site clustering.

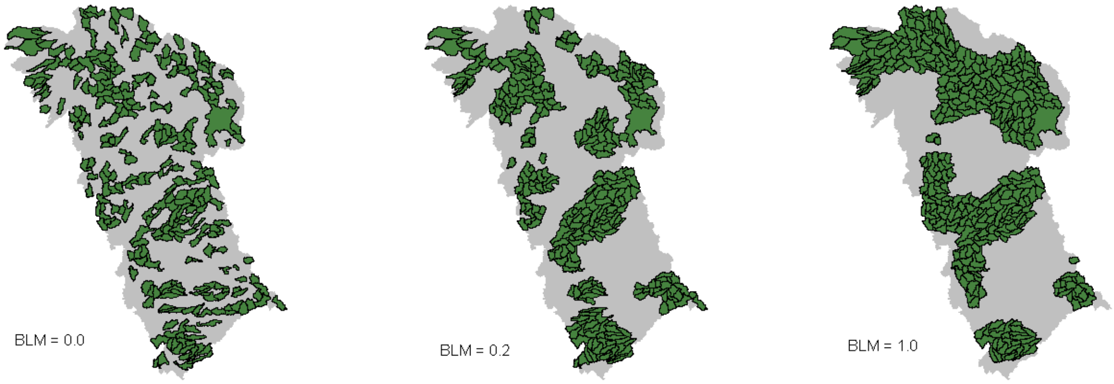
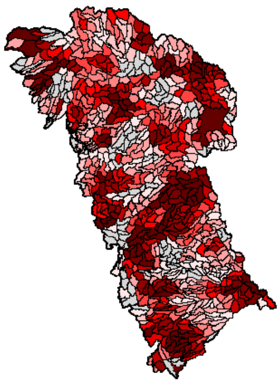


Figure 9: Relative importance of sites in achieving overall targets



Another feature of SITES is its ability to produce maps of the relative importance of individual sites in achieving conservation targets (figure 9). The darker the color, the more important a site is for the achievement of overall targets. This is a helpful tool for prioritising land purchase or management action (protection, enhancement work *etc.*).

SITES could also be used to prioritise river restoration work at catchment scale. A catchment would need to be split into units and each unit would be attributed a score representing the benefits of restoration work (benefit scores could be a combination of impacts on biodiversity and/or economic/recreation activities) and their cost. SITES would then select the units that maximise biodiversity and social/economic benefits whilst minimising costs.

SITES could also be used to prioritise habitat enhancement work for species and communities at catchment scale. Every river reach could be given a score representing the length of suitable habitat for species and communities and a cost representing the cost of restoring/maintaining habitats (reaches with good quality habitats would have zero cost and degraded reaches would have fairly high engineering costs). SITES would then select a combination of reaches that would maximise the length of habitat available (or a target representing the amount of habitat necessary to support viable catchment populations could be set) whilst minimising costs.

Criteria	Sub-criteria	Comments
Usefulness 😐	Time to reach solution 😐	SITES was not tested but running the system on large catchments is likely to take a lot of processing time
	Relevance of outputs 😐	SITES was designed for nature reserve selection but could be applied to wetland/river restoration prioritisation with some adaptations, or to the prioritisation of catchments for delivering national biodiversity targets.
	Data availability ☺	SITES is compatible with the EA GIS data. Sites works on the basis of planning units (i.e. geographical areas). It is best suited for working at sub-catchment, waterbody or catchment scale. Data have to be entered in a specific format.
Ease of Use 😐	Interface simplicity ☺	The interface in ArcView is simple to use
	Computer/software compatibility ☹	SITES works on ArcView 3.2, which is not the EA organisational standard anymore. It also requires setting up separate applications
	User skills compatibility ☺	SITES does not require any specialist skills.

Predictive tools

There is a wealth of predictive tools and techniques that can be used for various purposes, from assessing habitat suitability to prioritising management actions. The use of predictive tools for assessing habitat suitability is reviewed in Naura (2005b). In this chapter, I will review how predictive tools can be used for wider issues.

I divided predictive models into 3 broad categories: statistical models, population models and Expert Systems.

Statistical models

Statistical models are widely used for assessing the suitability of habitats for species. The most commonly used techniques are regression analysis, logistic regression, neural networks and genetic algorithms. Generally, habitat suitability is expressed as the probability of finding species or communities (presence/absence models) or a density of individuals (density models) in a management unit. They are called distribution models or habitat suitability models.

Tools and software for deriving statistical models are widely available (SPSS, S-PLUS, Minitab *etc.*). Specific techniques such as Genetic Algorithms and Artificial Neural Networks require the use of specialist software such as GAFFER (South 1998) and Neuralyst (Shih 1994). Most of these packages enable the derivation of models in the shape of equation or decision trees that can easily be applied to GIS data for the production of maps.

There is a new generation of tools that incorporate statistical modelling techniques directly within a GIS framework and enable the automation of the production of predictive models. Genetic Algorithms for Rule Set Production (GARP; http://www.lifemapper.org/desktopgarp/) uses genetic algorithms to build habitat suitability models (Stockwell 1999), GRASP (Generalised Regression Analysis and

Spatial Prediction) relies on General Additive Models (Lehmann, Overton & Leathwick 2003) and BIOMAPPER (http://www2.unil.ch/biomapper/) uses Ecological Niche Factor Analysis (Hirzel *et al.* 2002) for presence only data.

Criteria	Sub-criteria	Comments
Usefulness ☺	Time to reach solution ☺/☹	Model building is lengthy, model use is fast.
	Relevance of outputs ☺	Models can be used for a variety of purposes, from assessing habitat suitability to predicting trends.
	Data availability ☺	A lot of data are available within the organisation that can be used for modelling species distribution and sometimes trends.
Ease of Use 😐	Interface simplicity 😐	Most packages require fairly expert users although MINITAB enables users to perform basic statistics in a simple way.
	Computer/software compatibility ☺	Modelling software such as MINITAB are organisational standards. Specialists' software are not supported.
	User skills compatibility ☹	Users are lacking basic statistical skills and would therefore struggle building or implementing models.

Statistical models for species and communities have been developed for the Environment Agency. Typical examples include RIVPACS that predicts invertebrate assemblages for unpolluted sites (Wright *et al.* 1984), and HABSCORE that predicts the density of salmonids in near-natural conditions (Milner, Wyatt & Scott 1993). Models for UK protected species can also be found in existing literature. Water voles: (Giraudoux *et al.* 1995; Telfer *et al.* 2001; Bonesi, Rushton & Macdonald 2002; Fedriani *et al.* 2002; Macdonald & Rushton 2003; Rushton, Ormerod & Kerby 2004); otters: (BenDavid, Bowyer & Faro 1996; Madsen & Prang 2001; Marcia Barbosa *et al.* 2003; White, McClean & Woodroffe 2003); and native crayfish: (Fenouil & Chaix 1992; Smith *et al.* 1996; Naura & Robinson 1998).

Models are rarely used within the organisation, probably because they are difficult to understand and require the ability to compute complex equations. However, with the availability of GIS, they could easily be automated and disseminated.

Population models

Population models enable the prediction of the fate of individual populations or groups of populations across landscapes. Population survival depends on a series of factors, the most important ones being population size, the size and suitability of habitat patches and species life history (survival rates at different life stages, maturity, fertility). Habitats and populations may also be fragmented over a landscape and individual populations may be more susceptible to local extinction. The survival of populations at landscape scale (the metapopulation) over time may depend on migration and re-colonisation of empty patches by individuals from surrounding patches (Fahrig & Merriam 1994). Population models account for these complex relationships.

Many models for the assessment of populations have been developed in the past 20 years (Boyce 1992; Beissinger & Westphal 1998; Akcakaya 2000). They range from simple Population Viability Analysis (PVA) models for single populations, to complex metapopulation models where population dynamics is modelled within and across populations taking account of migrations and other landscape processes. Other kinds of population models make specific reference to species behaviour (migration, competition *etc.*) for the prediction of demographic patterns. They are called Individual Based Models and behaviour-based models.

Population models are mainly used for:

- Predicting the risk of extinction of individual populations.
- Deriving minimal population size for viable populations.
- Comparing management strategy.

Population models require detailed data on species life history that are most often not available (fecundity, mortality *etc.*). Parameter estimates can be used, but their variability create a lot of uncertainty in the final predictions. As a consequence, most authors recommend against using population models for making exact predictions.

PVA has been shown as particularly useful for comparing management options. Lindenmayer and Possingham (1996) showed that PVA was effective at ranking management strategies even when taking account of parameter and model uncertainty. PVA can also be used to identify development stages that are affected by external pressures.

Several types of PVA software exist. The most commonly referenced systems are RAMAS (Akcakaya 2002), ALEX (Possingham & Davies 1995), VORTEX (Lacy 1993), GAPPS (Harris, Metzgar & Bevins 1986), INMAT (Mills & Smouse 1994) and META-X (Grimm *et al.* 2004).

Recently, PVA packages have been associated with GIS so as to enable the study of metapopulations (RAMAS GIS [http://www.ramas.com/] and PATCH [http://www.epa.gov/wed/pages/models/patch/patchmain.htm]) but their GIS interface is specific to the PVA software.

POTENTIAL USE OF PVA

Within the organisation, PVA could be used to study the impacts of fragmentation on population viability and to compare management strategies. PVA would then give some insight on the potential impacts of various management strategies on population viability. Care should be taken with the interpretation of data because of the uncertainty surrounding PVA predictions.

PVA could potentially be applied to invasive weed control. In this case, PVA would be used to identify management strategies to drive invasive species to extinction.

Criteria	Sub-criteria	Comments
Usefulness ☺/☹	Time to reach solution ☹	Models take time to set-up and model processing is a lengthy process.
	Relevance of outputs ☺	PVA is highly relevant to the EA business but there are concerns with the variability of the results. It may be best used for comparing management options or for impact assessment.
	Data availability ☹	Detailed biological and ecological data on most species apart from vertebrate and some fish species are missing (e.g. vitality rates *etc.*). Models can still be run using estimates but outputs will be variable.
Ease of Use ☹	Interface simplicity ☺/☺	It depends on the software but systems such as RAMAS or ALEX have fairly simple interfaces.
	Computer/software compatibility ☹	None of these software are supported.
	User skills compatibility ☹	Existing software would require fairly expert users.

Expert systems

In conservation, Expert Systems are used for modelling species distribution, suggesting management options or identifying issues. Habitat suitability models derived using Expert Systems have been shown as being less powerful than statistical models. It is generally recommended to only use them when data are too scarce to produce predictive models using statistical techniques (Pearce *et al.* 2001).

Expert Systems are particularly suited to finding solutions to problems and identifying issues. Techniques include simple rule-of-thumb (if-then rules), fuzzy logic modelling, decision-trees and multi-criteria evaluation.

A range of software for the derivation of Expert Systems can be found (fuzzy logic: FLECO, Netweaver; multi-criteria evaluation: Expert Choice). A few systems integrate these within a GIS environment. For example, EMDS (Reynolds *et al.* 2000) offers the option of developing and applying rule-based fuzzy smodels and multi-criteria analysis directly from ArcView 8/9, whereas VVF (Valutazione della Vocazionalita Faunistica) uses a simple rule-base system and works on GIS Grassland (Ortigosa, De Leo & Gatto 2000).

POTENTIAL USE OF EXPERT SYSTEMS

There is potential for using Expert Systems for strategic planning issues. Models can be built to predict the distribution and model the habitat requirements of poorly known species. The maps can be used for organising surveys to discover new populations or for re-introduction programmes. Expert models could be built and implemented using existing systems such as EMDS.

Expert Systems could also be used to identify and quantify pressures and for suggesting and prioritising management options. The application of EMDS to river restoration for salmon provides a good example of how this could be achieved (Naura 2005b).

Criteria	Sub-criteria	Comments
Usefulness ☺	Time to reach solution ☺/😐	Model building is lengthy, model use is fast.
	Relevance of outputs ☺	Models can be used for a variety of purposes, from assessing habitat suitability to predicting trends, identifying issues or suggesting management options.
	Data availability ☺	A lot of data and experts are available within and outside the organisation that can be used for creating Expert Systems.
Ease of Use 😐/☹	Interface simplicity 😐	Most packages require fairly expert users.
	Computer/software compatibility ☹	Expert Systems software are not supported.
	User skills compatibility ☹	Models would be difficult to build for an average user .

Finally, Expert Systems could be used for operational issues such as reach design for river restoration. In her thesis, Richards (2000) showed how simple decision-trees and fuzzy logic models could be used for suggesting sustainable management strategies for catchments and for helping with the design of individual river channels.

Applicability of DSS to Conservation: discussion

The review

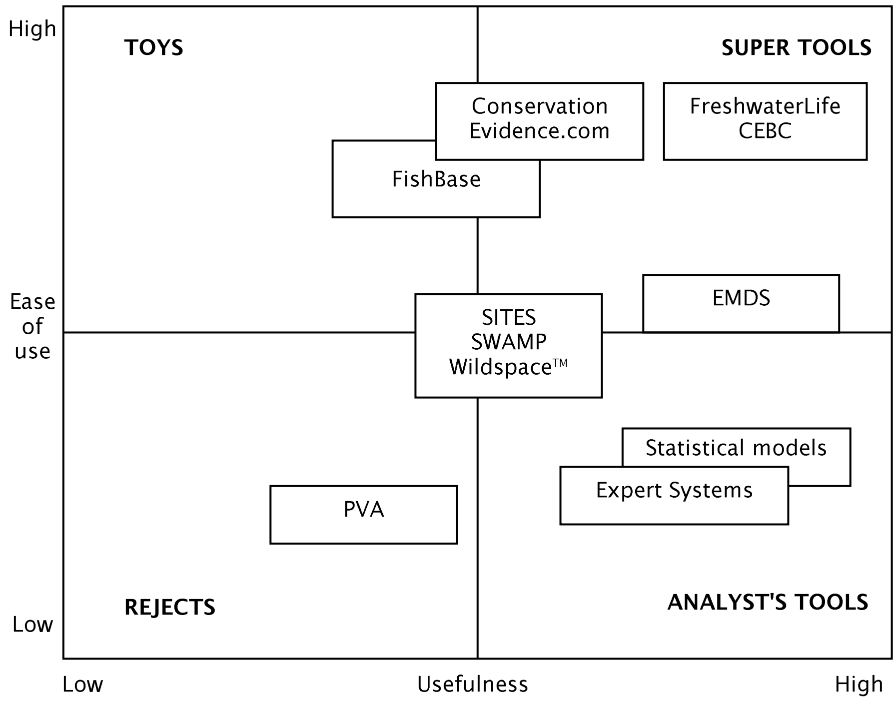
From the present review, we can map all DSS on the Usefulness/Ease-of-use grid from chapter 3 (figure 10).

Mainly all tools falling within the 'super tool' quadrant can be described as knowledge databases. They are easy to use, require little training, they work on standard software packages and give access to valuable knowledge. Most of them are already available or in development, and the developers are looking for potential partners and sources of funding. They are opportunities for 'quick win' applications. For a relatively modest cost, the organisation could contribute to these initiatives and have specific interfaces designed for its staff.

GIS-based tools such as EMDS, SITES and SWAMP are borderline super tools. Despite having many useful functionalities, they do not always match the tasks and issues faced by Conservation staff in the organisation and they are not always based on platforms that are fully compatible with EA standards. EMDS is the most promising and interesting software. It is a GIS expert system that could be extremely useful in dealing with strategic planning issues and could potentially be adapted to implement statistical models.

Statistical and Expert Systems tools fell within the 'analyst's tools' quadrant as, despite their usefulness, they are difficult to develop and implement. Model building requires expert users and should ideally be the concern of a small group of specialists within or outside the organisation. Once built, their dissemination could be facilitated by using simple software applications such as a GIS extension or Excel spreadsheet. Statistical tools and Expert Systems have a wide range of applications, from the analysis of data for policy development, to the production of decision-making trees for river restoration design. They are versatile tools that can benefit both strategic and operational work.

Figure 10: Position of 11 DSS and tools within the Usefulness/Ease of use grid as defined by the Environment Agency staff survey.



Population Viability tools and software fell within the 'rejects' quadrant. Despite their potential usefulness for dealing with specific issues such as option appraisal for management schemes or impact assessment, they are complex, data intensive and bear a lot of uncertainty. Existing software are not compliant with the organisation technological standards and would require expert users to run them. Substantial investments would be needed to turn them into super tools. In some instances, however, they may be worth developing. For example, PVA models have been developed and tested for some protected species under EA responsibility (e.g. water voles). A DSS application on ArcView could be developed at moderate costs to run the models and could be applied to operational issues such as environmental impact assessment.

Wider implications

From the analysis of staff preferences, needs and skills, and from a review of available DSS, tools and techniques, we can draw some general conclusions on the applicability of Decision Support Systems to Conservation and the more generic issue of the use of evidence in decision-making.

THE DECISIONS

The surveys suggest that most of Biodiversity staff decision-making is based on personal judgement or the opinion of colleagues. Research on decision-making has highlighted the risks associated with using personal judgement, particularly for planning and forecasting tasks.

Interestingly, planning and forecasting tasks were dominant in the list of issues identified by staff. They were mainly strategic issues consisting of the development of management plans for protected species or habitats but also included operational problems related to in-stream structures or the design of river restoration schemes. A general lack of access to scientific knowledge was also identified as a major issue.

There are substantial risks in using judgement as the basis for decision-making. There are risks that the EA will not deliver on biodiversity targets and legislation, with knock-on effects on its reputation and credibility as a regulator and champion of the environment.

THE USERS

Biodiversity staff are experienced naturalists and ecologists with in-depth knowledge of species and habitats. Their day-to-day activities are fairly reactive in nature, require fast decision-making and are often concerned with reach-scale issues. Part of their work is proactive and involves building plans and running projects sometimes at catchment scale. Despite being scientifically trained, they tend not to use scientific outputs or methods in their decision-making. Few use existing DSS. Their time and resources are limited.

DECISION SUPPORT SYSTEMS

DSS are tools to help solve complex issues. They have been successfully applied to the business world. DSS can help build science within the decision-making process and promote learning within an organisation. Many DSS are not used because they are poorly designed, they do not fit the task, they are not time-effective and users perceive them as a threat. User uptake of DSS may be enhanced by involving them in the design process (Parker & Sinclair 2001).

DSS AND QUESTION TYPES

Table 5 and 6 present a synthesis of the potential value of developing DSS for questions and question types. The evaluation represents my personal judgement based on the review of DSS and user needs. The criteria I used to derive the final evaluation were:

- technical feasibility;
- usefulness;

- ease of use;
- frequency of use;
- added value compared to current decision-making.

It does not contain any cost-benefit element. For the purpose of this research, I was not able to run cost-benefit analyses as it would have required developing a detailed evaluation of options for all DSS applications. Costs can also vary tremendously depending on the platform used for development (e.g. Oracle platforms are very expensive compared to Access applications). I did not include elements of prioritisation based on business needs or risk assessment as I believe it is a matter for managers to decide. Instead, a workshop was organised with key Conservation managers to prioritise identified issues. However, no clear priorities emerged from the brainstorming sessions.

From the evidence gathered as part of this project, we can suggest that DSS are more likely to succeed for the resolution of planning and forecasting issues in Conservation. Indeed,

- There is a perceived need for support in both activities.
- Strategic and forecasting issues are complex.
- Their resolution is most often beyond what can be expected from a human brain.
- DSS have been shown as providing effective help towards task resolution.
- A wide range of DSS and associated tools for strategic and forecasting issues is available.

Users are more likely to welcome such DSS as they would help them perform tasks that are otherwise difficult and taxing. From an efficiency viewpoint, planning and forecasting issues are likely to warrant the investment of resources required for DSS development as they are on-going activities.

Planning is often wrongly perceived as a cyclical activity with a beginning -the plan-, an implementation phase, and a review at the end of the cycle leading to the generation of a new plan and the inception of a new cycle. When dealing with highly uncertain, changing and unpredictable environments, this model of planning will prove quickly inadequate as new legislation or government, stochastic events and major discoveries may invalidate the assumptions on which plans are based. Expected changes may also fail to materialise and new environmental factors may suddenly appear. Modern planning accounts for the intrinsic variable nature of the environment (ecological, social, economical and political) by being adaptive. In Conservation, we call it adaptive management (Holling 1978; Clark 2002).

Adaptive management considers planning as an iterative process (figure 11). Within the duration of the overall planning cycle, plans are constantly revised to adapt to changes in the environment and the cycle is iterated many times. In adaptive management, the difference between the way the future unfolds and what was predicted is taken as an opportunity for learning. Much of the agenda of adaptive management is learning through experimentation rather than focusing on error avoidance (Kay *et al.* 1999). The adaptive management cycle is described in figure 11. The cycle goes through phases of planning, action, monitoring and evaluation. It is important to stress that for an adaptive management strategy to be effective, monitoring would have to be carried out on a regular basis to check that actions taken are yielding the desired outputs.

Table 5: Potential use of DSS for all question types. Symbols: ☺ = yes; 😐 = maybe; ☹ = no.

Question type	DSS?	DSS or associated tools
Strategic proactive		
Planning	☺	EMDS, SWAMP, SITES, Expert Systems
Policy	😐	Knowledge databases, Wildspace™ , statistical and expert models
Cost-effectiveness	☺	Optimisation tools (SITES), multi-criteria analysis
Prevention & surveillance	☹	Expert Systems
Strategic reactive		
Problem driven	☹	Local project and expert
Opportunity driven	😐	EMDS, SWAMP, SITES, Expert Systems
Operational		
Impact assessment	☺	Habitat assessment tools, population models, Expert Systems
Reach design	😐	Expert Systems
Site management	☹	Knowledge databases, local project and expert, adaptive management

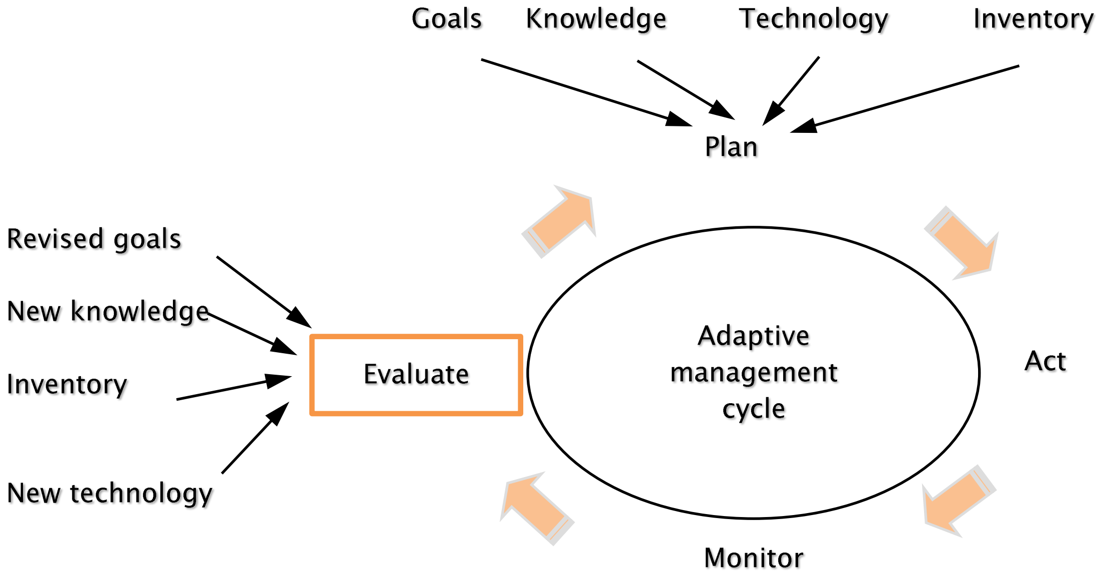
The iterative nature of the adaptive management cycle is likely to make the development and use of DSS cost-beneficial. It would, however, increase maintenance costs, as DSS would have to be regularly updated to reflect current knowledge and scientific advances.

Systems exist that can be readily applied to planning activities. In this chapter, I have given examples of three systems -EMDS, SITES and SWAMP- and I have suggested how they could be applied to planning river and wetland restoration and habitat management planning. Issues covered by planning tools could also include the delivery of UKBAP targets for protected species and habitats or the delivery of WFD programmes of measures. The next section will provide with an example of how DSS can support these planning processes.

Strategic cost-effectiveness issues would also benefits from DSS. Optimisation tools such as SITES or Expert Systems such as multi-criteria analysis are likely to help the decision-making process. DSS development is likely to be justified from an economical viewpoint by the importance of the issues, their potential environmental impacts and the resource involved. The questions identified by users in table 4 are quite demonstrative of the scale of the issues concerned. Most relate to major policies and have huge resource implications: flood protection policy, invasive species control and environmental designation policy effectiveness.

Forecasting activities are mainly linked to planning issues where they help predict future outcomes and consequences of management strategies and actions. They also have an operational expression in impact assessment activities for consents review. Land drainage consents or planning applications are often reach-scale but they can have dramatic impacts on biodiversity at larger scales. For example, construction of culverts or weirs may isolate populations making them prone to extinction.

Figure 11: The adaptive management cycle (adapted from Reynolds and Hohler)



Tools such as PVA or Expert Systems may provide help in performing impact assessments for consent reviews. PVA would enable the comparison of key population extinction risks in the presence and absence of proposed structures. Sensitivity analysis would enable the characterisation of uncertainty around the predictions and provide strong support for decision-makers. However, the development of PVA is only likely to be beneficial for well-studied species with known life-history (Naura 2005b).

Areas of decision-making that may not benefit as much from DSS are strategic proactive policy issues, strategic reactive opportunity driven issues and operational reach design issues. The main concern here is not so much on the feasibility of DSS or their potential benefit to the decision-making process, but on their cost-effectiveness.

Most strategic proactive issues could have been classified as policy related issues. Planning activity will effectively deliver management policies, cost-effectiveness issues will often lead to national policies, and surveillance and prevention concerns are likely to result in policies, if not legislation. The activities described in table 4 under the policy heading are mainly research issues. They are concerned with assessing the large-scale impacts of activities or invasive species on biodiversity. They are hypotheses that need some form of appraisal or testing. Because of the scale of the issues, scientific experimentation is unlikely to be feasible and may yield results too late to be useful. In this context, knowledge databases and services such as the CEBC could be useful resources to draw conclusions from previous research and evidence. A Conservation version of the Wildspace DSS supported by specialist users could be of great benefit to the resolution of such issues. The tool would effectively be an analytical system that would derive data from GIS layers and use the statistical component of Wildspace to analyse trends and identify patterns. The development of such DSS would require time and efforts but may well pay off in the long-term.

Strategic reactive questions driven by opportunity could equally benefit from DSS, but their unpredictable nature makes them a more risky investment. They generally result from the availability of under-spent money, national lottery grant applications, multi-functional projects or negotiated mitigation schemes. They often lead to the development of habitat restoration or enhancement schemes. A strong view put by local staff at our workshop was to have the ability to prepare for these opportunities and develop a portfolio of schemes based on a strategic overview of catchment and biodiversity needs. Such strategies are developed as part of locally run projects (e.g. Upper Wharfedale best practice project, river Wandle and Beverley brook landscape assessment). Local planning DSS could be developed using systems such as EMDS or SITES. A case for their development would have to be made based on the recurrence of identified issues and the wider applicability of the DSS.

Problem-driven strategic reactive issues could potentially benefit from the use of DSS, but in many instances, the scale and frequency of the problems will not justify the development costs. Instead, it may be more appropriate to run single research projects involving local experts and scientists. Sometimes, a local issue may be shared by many other catchments and regions and even link to national policy (e.g. control and surveillance of invasive species). The achievement of national policy may then strongly rely on local achievement of desired targets. In this context, the development of DSS may be justifiable.

Operational site management issues are unlikely to warrant the support of DSS as issues may be very site-specific. Site managers may benefit from knowledge databases or Expert Systems, but local practitioners eventually have to apply this knowledge in the context of site and catchment history and their own experience. Judgement becomes key in making the right decisions and an adaptive management strategy can be taken towards site management. Errors and success become part of the learning process and can be shared with other practitioners through the use of knowledge databases such as ConservationEvidence.com.

Reach design issues may not benefit from DSS development for very similar reasons. Restoration scheme design requires careful consideration of geomorphological processes acting at reach but also catchment scale. An expert system could be built to help the process, but it may be wiser to invest instead in geomorphological audits and advice. However, a simple system could be built to suggest generic reach restoration options based on site characteristics, landscape influences and budget. The system could be based on existing guidance documents such as the manual of river restoration techniques (Vivash & Janes 2002) and be used to identify potential restoration sites.

Finally, prevention and surveillance issues could benefit from DSS but there are uncertainties surrounding their feasibility and applicability. It would be beneficial to identify invasive species before they reach their potential by analysing, for example, their life history traits and matching them to existing ecosystems. It would require a very good knowledge of species life history traits, ecological requirements and environmental tolerance. Unfortunately, we are lacking basic autecological knowledge on many endemic species we are responsible for. It is unlikely that we will ever have the resources to gather all the knowledge we need to make such tool valuable.

DSS AND EVIDENCE-BASED DECISION-MAKING

The contribution of DSS to evidence-based decision-making is not only theoretical but practical. Most of Biodiversity staff decision-making is based on judgement with little reliance on science. There are clear risks associated with using judgement as the basis of decision-making on all types of issues, strategic and operational. DSS are one way of building evidence in the decision-making process.

For planning issues, DSS can help shape the decision-making process in a way that is both logical and scientifically robust. They can, for example, be developed to follow the adaptive management cycle and support users through each step of the process and provide feedback. The presence of a knowledge database would enable users to consult up-to-date scientific evidence. The use of models built into the inference engine would ensure that latest scientific tools are part of the decision-making process.

DSS would also participate to the knowledge acquisition process. First, through building and updating DSS, developers would naturally go through the knowledge acquisition spiral steps. Tacit knowledge would be elicited from experts and turned into explicit knowledge in the shape of guidance, videos or Expert Systems. Explicit knowledge would then be disseminated and tested by developers and users, looking for patterns and inconsistencies. New knowledge would soon emerge from the confrontation of existing knowledge and the increasing availability of data and experience gained by users. From close contact to elicited knowledge available through

DSS, users would learn new ways of dealing with problems and further develop their expertise. New knowledge would be fed back to developers who would update the DSS thus enabling the knowledge acquisition process to pursue its course. A virtuous double-loop learning cycle would then be created leading, in the long-term, to challenges not only to DSS assumptions but also to common organisational assumptions.

But DSS are not and should not be the only way of building evidence in decision-making. Training, recruitment, access to scientific databases, journal and books as well as the development of knowledge management strategies within Conservation are potential complementary measures. More importantly, bringing users to use evidence requires a shift in working culture. In a value system, where personal experience of the environment is perceived as the main driver of quality, judgement is likely to be - and remain- the main basis for decision-making. For the same reasons, working culture is likely to be the main factor limiting the implementation and use of DSS. Most existing DSS are not used, and even DSS that were developed with users such the RHS database are under-used. Major shifts in working practice require more than just the power of conviction. As stated by Donnelly *et al.* (1995), their promotion should be the concern of senior managers as them alone can ensure that processes promoting a learning culture are put in place and acted upon.

Conclusion

A range of DSS and associated tools are available as software and freeware but few are directly applicable to issues highlighted by users as they either did not fully match the required tasks or they did not fully comply with our technological standards.

The review, however, highlighted the potential for using DSS in Conservation and for building evidence in our decision-making. Tools such as EMDS, SWAMP and SITES could be used for planning wetland and river restoration work or for helping deliver UKBAP or WFD targets. Knowledge databases on the Internet would give access to valuable information on species and management practice to Biodiversity staff and technical specialists for operational decision-making. They would also provide a source of knowledge to researchers for investigating trends and patterns, and identifying potential avenues for innovative research. Tools such as Wildspace™, statistical and expert modelling techniques could also be applied towards policy development for testing hypotheses. Combined or in isolations, all these tools and techniques showed tremendous potential in supporting and delivering better decision-making.

The main potential areas of success for DSS development were identified as being planning and forecasting issues. Planning and forecasting require the ability to work at large spatial and temporal scales and make predictions about the future. They are complex tasks beyond what can be expected from a human brain and staff have strongly highlighted them as issues where they need support.

Bringing more evidence in the EA decision-making will require more than just DSS. DSS can effectively contribute to the learning acquisition process and generate a double-loop learning cycle, key to organisational learning. However, they should be complemented with measures supporting a shift from a judgement-based to an evidence-based culture, driven and supported by management.

Table 6: Potential use of DSS for selected questions raised by EA Conservation staff.

Question	DSS?	Examples of DSS or associated tools
How can we set catchment targets for delivering national BAP targets?	☺	Habitat assessment tools, predictive tools, Expert Systems, optimisation tools.
How can we best manage individual catchments for BAP species and achieve the catchment targets?	☺	Habitat assessment tools, predictive tools, optimisation tools.
What is the potential impact of invasive weeds on biodiversity across and within catchments?	☺	Expansion models, Expert Systems (fuzzy logic).
How can we best plan control and surveillance work for invasive species and pests nationally?	😐	Expansion models, Expert Systems (fuzzy logic).
What catchment/site could potentially hold populations of rare species to inform survey work/designation/re-introduction?	☺	Habitat assessment tools.
Is riparian habitat limiting otter population sizes in the UK?	😐	Habitat assessment tools. Spatial analysis of otter distribution.
How do we identify potentially invasive species in a changing environment?	☹	Database of invasive species life history traits, prediction of habitat sensitivity.
Where habitat fragmentation is having an impact on population viability, can we identify the best areas to develop river corridors?	☹	PVA
How can we better plan for biodiversity work locally?	😐	Habitat assessment tools, predictive tools, Expert Systems, optimisation tools.
How can we plan for restoration work?	😐	Habitat assessment tools, predictive tools, Expert Systems, optimisation tools.
Can we assess the impacts (present and future) of river modifiers (weirs, culverts, gravel removal, habitat fragmentation *etc.*) on species population viability, dispersal *etc.*?	☺	PVA
Is riparian tree management likely to affect the abundance and distribution of bat populations at the local scale?	☺	Habitat assessment tools, density models, PVA.
How can we best identify suitable habitat restoration techniques for individual habitat improvement schemes?	😐	Knowledge database (River Restoration Centre database) and expert system.
Can large-scale river restoration schemes be adopted in the UK, and would they be more cost-effective than traditional hard flood defences?	☺	Optimisation tools, hydraulic models.
Are conservation monies best spent on invasive species such as grey squirrel, signal crayfish and Japanese knotweed, when they are so well established?	☺	PVA, simulation tools.
Will the creation of new marine national parks/SACs around our coastline adequately protect marine wildlife?	😐	Optimisation tools
Mink - is effective control really possible and if so at what scale?	😐	PVA
How can we best plan control and surveillance work for invasive species and pests locally?	☺	Expansion models, Expert Systems (fuzzy logic).
What effect does removing energy from river systems by creating hydro-electric facilities have on river geomorphology and ecology?	☹	Geomorphological surveys, hydraulic modelling.
What are the wildlife implications of offshore or terrestrial wind farms?	☹	Local impact assessment, research projects.
What is the risk to biota associated with particular regimes of lake-level fluctuation?	Unknown	
Do unnatural lake level fluctuations affect the biota of lakes?	Unknown	
Do in-stream habitat improvement devices (e.g. groynes) increase the size of fish populations?	☹	Hydraulic modelling, research project, post project appraisal.
What actions can be taken locally to make riparian habitats more hospitable to water voles?	☹	Knowledge database, guidance documents, expert opinion.
Does riparian vegetation structure affect fish abundance?	😐	Knowledge database, guidance documents, expert opinion.
How can we best manage individual sites for species and habitats?	☹	Knowledge database, guidance documents, expert opinion.
Are airborne nitrates a threat to some nutrient-poor habitats?	Unknown	
Is the distribution of submerged aquatic vegetation in UK rivers significantly altered by anthropogenic phosphate additions?	Unknown	

DSS for national and local planning for biodiversity

In this section, I present a conceptual framework for developing DSS for planning the delivery of Conservation objectives at national and catchment scales. I chose strategic planning issues as:

- They were prominent in the list of issues identified by Conservation staff.
- Their complexity and the reported shortcomings of using expert judgement to solve them make them an ideal ground for testing the potential benefits of DSS.
- They are important issues linked to the delivery of national and international legislation.
- Their resolution could bring major benefits to biodiversity in England and Wales and to the reputation of the Environment Agency.
- There are significant risks in not delivering them.

I will first present an overview of the decision-making environment and identify issues and needs. I will then suggest a decision-making process and illustrate how DSS can be used to support it, making reference to DSS and tools reviewed previously wherever possible.

The decision-making environment

At present, there is no explicit biodiversity management process. Instead, biodiversity management is implicit within many existing planning and operational processes such as Catchment Abstraction Management Strategies, Catchment Flood Management Plans, land drainage consent review, planning application review *etc.*

DSS are part of a decision-making process itself part of a decision-making environment. Decisions are driven by legislation, policy, and operational needs. The biodiversity management decision-making environment is summarised in figure 12.

The main drivers of biodiversity management are the Environment Agency duties, environmental legislation and the UK Biodiversity Action Plan. The Environment Agency has a general duty to promote and further conservation wherever possible and holds a key role for the implementation of environmental legislation. The EA main commitments are:

- Under the UK Biodiversity Action Plan, the Environment Agency is lead contact or partner for 39 species and 5 habitats (Environment Agency 2000).
- The Environment Agency is responsible for the review of consents and licences across Special Areas of Conservation sites (SACs) and Special Protection Areas (SPAs) as part of the Habitats Directive.

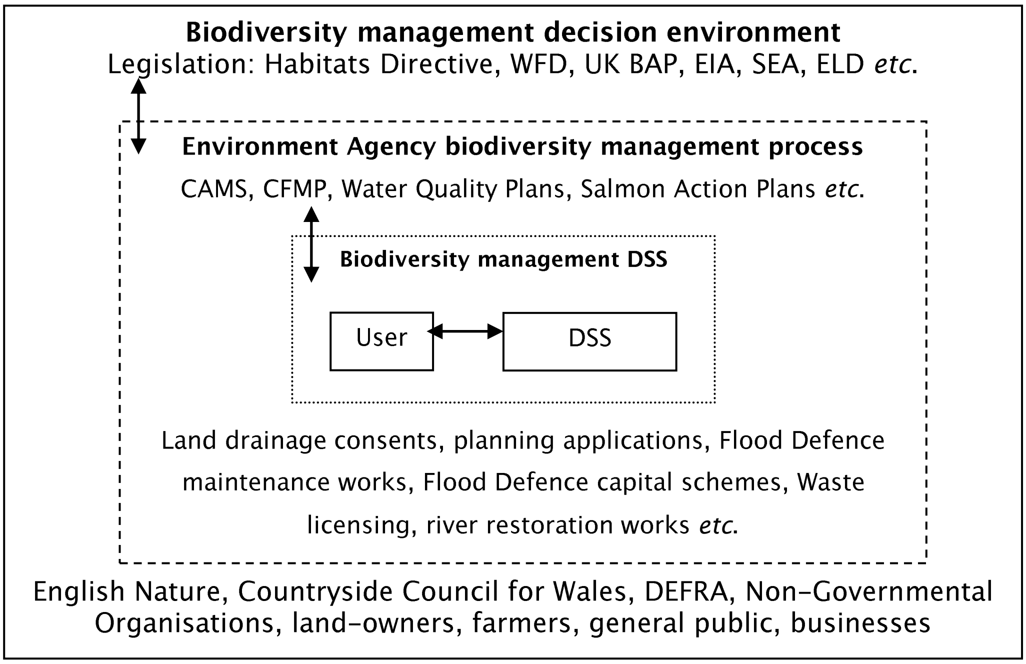
- The Environment Agency is one of the competent authorities responsible for delivering ecological targets set out in the Water Framework Directive.

The Environment Agency has committed itself through its Board to the delivery of UK BAP targets through the corporate plan (Environment Agency 1997). Most plans include:

- the maintenance and improvement of species distribution and.
- the need to identify species ecological requirements

as specific targets. National BAP targets are to be achieved through Local Biodiversity Action Plans, in general, and through Local Environment Agency Plans (LEAP) within the Environment Agency (1997).

Figure 12: Decision-making environment adapted from Rauscher (1999).



Under the Habitats Directive, the Environment Agency needs to ensure that the permissions it regulates will/do not have an adverse effect on the distribution of species, communities and habitats listed under Annex II and IV. Permissions will be reviewed against a series of criteria that define the *de-minima* status of a site (e.g. in terms of flow, water quality or any other habitat criteria considered important for the survival of the species). By achieving these criteria, a site is said to be in 'favourable condition'. Favourable condition criteria were produced by English Nature/CCW and have been published in the shape of tables. Planning will be carried out at the scale of SACs and SPAs but action planning is likely to be reach-specific.

For the Water Framework Directive, the Environment Agency must ensure that fish, macrophyte, invertebrate and phytoplankton communities are close to their natural conditions and develop programmes of measures (restoration, enhancement work) accordingly (European Union 2000a). Planning under the WFD is done at the scale of River Basins (hydrological unit or groups of hydrological units). However, specific actions such as habitat enhancement or restoration will be planned at the scale of a waterbody (i.e. a river, lake or part of a river or lake).

A common feature of these duties is that national targets are supposed to be delivered through building detailed local plans with programmes of actions at reach, waterbody or catchment scale. This implies that:

- There exists a process for implementing national biodiversity targets through local action plans with a reporting and review mechanism.
- There is an effective and consistent process for developing local action plans.

This is not fully the case. For Habitats Directive SACs and SPAs, the Environment Agency is reviewing all permissions it regulates potentially affecting them. The review will consider permissions in the context of other impacts outside the licensing remit (land use, flood protection) as well as cumulative impacts at catchment scale and may even consider alternative management options such as river restoration or relocation. The review, however, is not about setting targets for species and habitats but is mainly concerned with the potential and observed impacts of permissions on 'favourable condition'. For species and communities, the assessment of 'favourable condition' is unlikely to result from an analysis of species/community distribution at large scale taking account of landscape factors (e.g. habitat fragmentation, migrations) or stochastic events such as random extinctions. Instead, it is more likely that it will be assessed against a list of set generic criteria that may not deliver sustainable populations across protected areas. Therefore, the review process does not constitute a species/community management strategy *per se*, but would certainly benefit from one if it existed.

For UK BAP species. general Agency-wide action plans have been designed but they do not directly link to local action planning. Instead, national actions are cascaded to local areas that develop their own action plans, ideally at catchment scale. Actions are then fed through existing plans and processes such as:

- Catchment Abstraction Management Strategies, Catchment Flood Management Plans, Fisheries Action Plans, Water Quality Plans, Local Initiatives, Shoreline Management Plans,
- land drainage consent, discharge consents and planning applications,

for which Conservation has an input or an advisory role.

Without active coordination and planning, it is difficult to see how the sum of these individual actions spread through a complex network of plans and consents can lead to the achievement of wider targets.

Also, as seen before, the Environment Agency's main power is through influencing plans and processes. The EA's ability to influence other activities is likely to be enhanced if it can demonstrate:

- The links between individual advice and corporate targets and objectives.
- The scientific basis for advice and decision-making.

Considering all the elements mentioned above and previous analyses, we can identify potential risks with current decision-making. There is a risk that biodiversity targets such as UKBAP or HD will not be delivered because there is no clear planning process to translate them into local plans of actions that can be used to influence other activities and provide a consistant basis for the review of consents and licences. The lack of planning and use of scientific evidence may also affect the EA credibility, and in turn, its ability to influence.

There is therefore a need for:

- Making biodiversity management more explicit within the organisation.
- Establishing clear links between national targets and local actions.
- Developing consistant means of influencing other plans and processes for delivering national biodiversity targets.
- Grounding advice and decision-making in science.

The decision-making process

DSS are only effective if they support a defined process. There is at present no clear process for linking national targets and local actions. Before suggesting potential DSS for managing biodiversity, I will therefore need to identify a potential process for decision-making.

In this section, I suggest a potential process and DSS to help deliver national biodiversity targets. Applied to the UK BAP and the Habitats Directive, the process could help set and deliver national targets for species, communities and habitats, and translate these into catchment targets and action plans. It could also facilitate the production of programmes of measures for the WFD to deliver 'Good Ecological Status' and 'Good Ecological Potential'. Finally, it could -with some modifications- help deliver river and wetlands restoration targets for River Habitat Objectives (RHOs) and the wetland visioning project.

The proposed decision-making process will help:

(1) Decide evidence-based (and risk-based) conservation objectives at a national, catchment and within catchment scales.

(2) Appraise the effectiveness of different actions (decisions) in delivering those objectives.

There will be two sets of ouptputs:

- National maps showing achievable catchment targets for species/communities/habitats within each hydrological catchment.
- Detailed hydrological catchment maps showing actions required at the scale of river reaches (WFD waterbodies or any other relevant division) to achieve catchment targets.

I chose maps as a prefered format of outputs as:

- They are effective ways of communicating and disseminating information.
- Information is easily retrieved and viewed from maps.
- GIS is the most commonly used specialist software amongst Biodiversity staff.

The national maps will form the basis for:

- Prioritising management actions across catchments.
- Justifying investment in survey and restoration work.
- Reporting.

The catchment maps will:

- Present a consistent management strategy for species at catchment scale.
- Provide a strong justification for action by linking to the delivery of national targets.
- Provide a consistent basis for influencing other management plans and for reviewing consents and licenses.

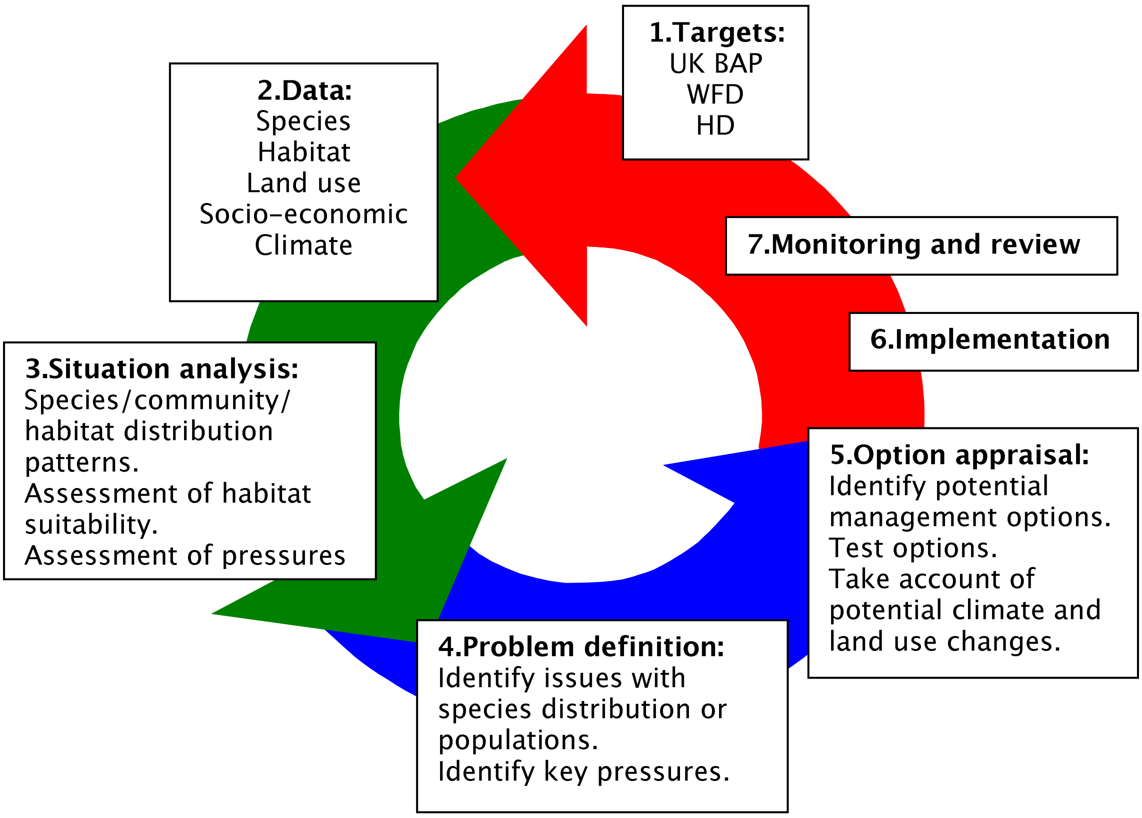
DECISION-MAKING PROCESS

The decision-making process will follow a simple management framework that is advocated both by the UKBAP and the WFD, and that is very similar to the adaptive management cycle (figure 13). Data are collated from existing sources and quality indices are derived to assess the state of management units (sites, reaches, waterbodies, catchments) for particular conservation objectives. Key issues are then identified along with potential pressures. Management options are drawn using a GIS interface and tested using simulation tools. The preferred plan is finally implemented along with a monitoring strategy for ensuring that actions have the desired effect.

This process will be applied at two scales:

- At national scale to set indicative targets for each catchment and species/community/habitat of interest
- At catchment scale to develop detailed action maps and refine the targets.

Figure 13: Biodiversity management decision-making process.



The catchment maps will display possible management actions on a reach basis that may contribute to the delivery of catchment and national targets. The action maps will feed into existing plans and processes where Conservation has an input: Catchment Flood Management Plans, Catchment Abstraction Management Strategies, Water Quality Plans, Salmon Action Plans, Land drainage Consents, Planning Applications, Discharge Consents *etc*.. They will also be used to direct non-statutory work such as River Restoration and habitat enhancement and influence Flood Defence maintenance programmes.

It is suggested that national maps are drawn by the National Unit for Conservation and that catchment maps are delivered by technical specialists in area Biodiversity teams.

The two sets of maps will be built using DSS based on GIS ArcView 8. The DSS could be built using a mix of in-house (the Risk and Forecasting Unit, the Bath Data Centre, the

National Technical Unit for Conservation and Ecology, the National Fisheries Technical team) and external expertise (Cardiff University, the Tyndal Centre at the University of East Anglia or the Centre for Life Science Modelling in Newcastle University). The map building processes for national and catchment maps are detailed thereafter.

NATIONAL MAPS

The **national maps** are designed to 'kick-start' the planning process. They will display indicative targets for species of interest based on a 'rough-and-ready' analysis of available data at national scale. The map-building process will follow a simple framework (figure 14). Existing data will be collated from local, national and external sources (Internet, external databases). A national team of technical specialists will analyse these data and assess the actual and potential contributions of individual catchments to national biodiversity targets under various climatic scenarios. These contributions will be weighed against costs and benefits and indicative targets will be set against all catchments.

Indicative targets are likely to be in the shape of a percentage increase and will be based upon (or referenced to) available data (i.e. 30% increase of accessible suitable habitat for Southern damselfly on selected catchments; 20% increase in water vole population; maintenance of viable populations of freshwater pearl mussels on key catchments).

The maps will then be sent to local Biodiversity team who will, using the same DSS, develop a more detailed analysis of their catchments and assess whether the indicative targets can be met or even increased. The detailed catchment maps will be fed-back to the national team for quality assurance (QA) and review. Following the national review, catchment targets may be revised and new local maps may have to be derived for species, communities or habitats not meeting their targets.

The final maps will present more precise and measurable targets agreed with local staff. Note that the iterative nature of the process not only helps refine catchment targets but may lead to changes to national targets. In fact, this process could also be used to set national targets.

The process will enable coupling of national and area decision-making. It will empower the areas in the identification of local targets and plans whilst enabling a national prioritisation and co-ordination of management actions. It should lead to a more cost-effective delivery of national targets.

Technically, the process will require specific data and decision support tools (figure 14).

Data gathering: data will be collated from readily available sources: existing and historic distribution maps, national surveys, national datasets, GIS, external databases on the web. Data required to run predictive models and tools such as land use, management pressures, socio-economic data (costs of habitat enhancement, poverty levels *etc.*) and other GIS data (altitude, slope, geology *etc.*) will be extracted. In the absence of data, expert opinion will be used.

Summary of catchment contribution to biodiversity targets: data will be analysed using a mix of expert opinion, local knowledge and predictive tools to assess the suitability of existing catchments for species, communities or habitats of interest and the costs of improving catchment status. Outputs from existing climate change models (maps of forecasted temperature, rainfall *etc.*) will be used to assess the likely suitability of individual catchments for species under various climatic scenarios.

Prioritisation of catchments for management action: a choice will have to be made on which catchments represent the best prospective contribution towards the achievement of national biodiversity targets, whilst minimising costs and other risks. This will be a complicated task with users facing hundreds of potential options. Users will be assisted in this process by optimisation tools. Using mathematical algorithms trawling through all possible combinations of catchments and targets, optimisation tools such as SITES enable users to identify sets of catchments and policy targets maximising conservation outputs whilst minimising costs.

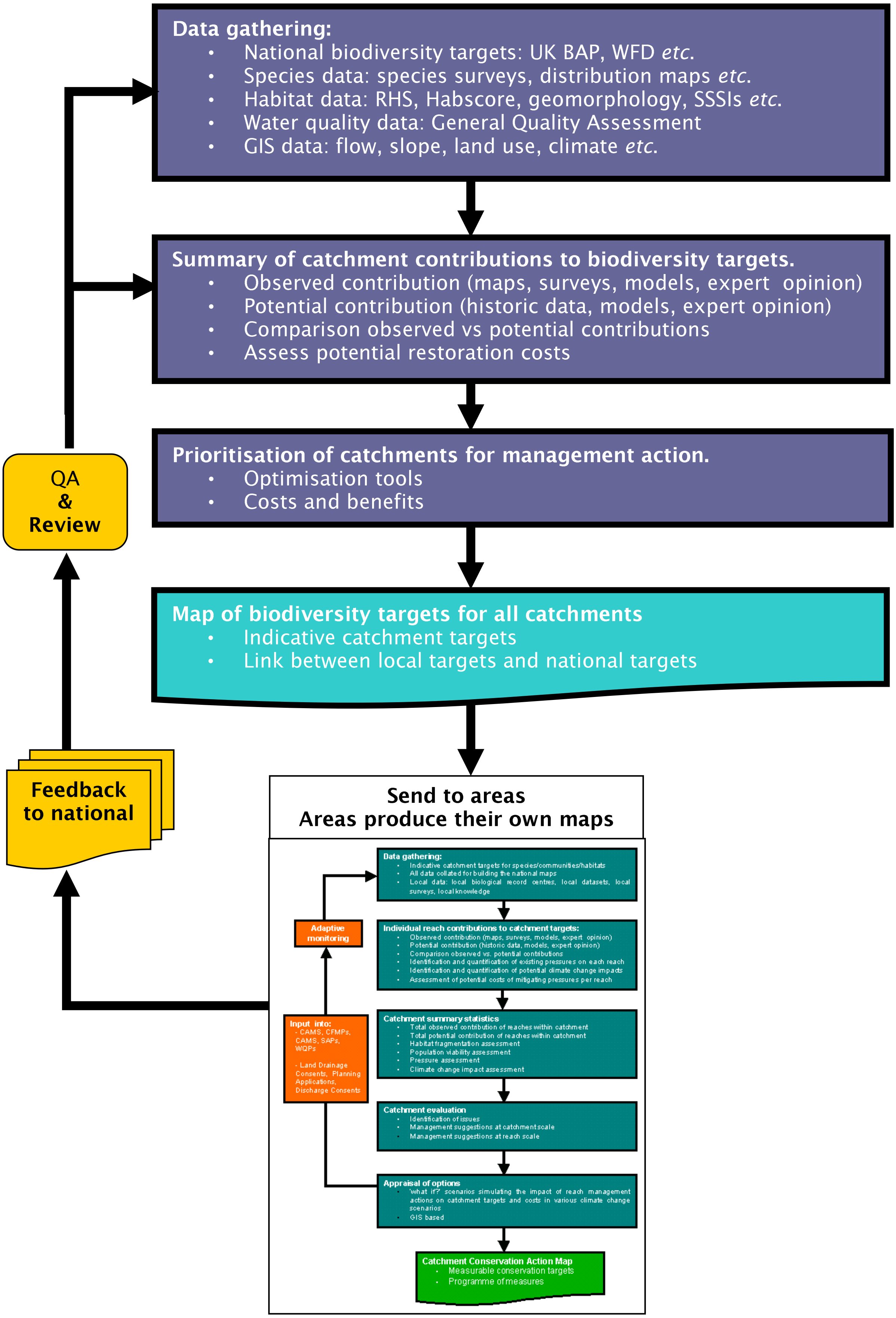
Map of biodiversity targets per catchment and feedback: following a series of iterations using the tools mentioned above, expert opinion and input from local technical specialists, a map of catchments will be produced along with indicative targets for all species, communities and habitats of interest. The map will be sent to all areas for feedback. Area staff will then develop throrough analyses using reach-scale data leading to detailed catchment action maps and revised catchment targets. The catchment action maps will be fed back to the national team for quality assurance and review.

CATCHMENT MAPS

Catchment action maps will detail, for each river reach, generic management actions (e.g. protection from modification, improvement of riparian habitat, restoration of natural forms *etc.*). They will be delivered with a summary of the evidence base and an assessment of the likely contribution of the programme of measures to catchment and national targets.

The framework for building catchment maps will be similar to that described in figure 14 but will be applied at the scale of river reaches (figure 15) and will make use of all potential sources of data and expertise (local datasets and experts).

Figure 14: Building national maps for biodiversity management.



Individual reach contributions to catchment target: data to support the analyses, for example on water quality, habitat, land use and species distribution will be collated across catchments and analysed using a mix of expert opinion, local knowledge and predictive tools to assess the suitability of existing reaches for species, communities or habitats of interest. Reach suitability in the absence of pressures will be predicted and compared to observed suitability to identify potential pressures and opportunities for improvement. Pressures will be quantified by using statistical techniques or expert rule-based systems. The costs of mitigating pressures will be estimated using a simple database of engineering work costs. Outputs from existing climate change models will be used to assess the potential impacts of climate change on reach suitability by applying simple rules describing species, communities and habitats tolerance limits.

Catchment summary statistics: the following catchment statistics will be drawn by aggregating reach assessment results:

- Percentage of observed good quality habitats.
- Percentage of quality habitats in the absence of pressures and modifications.
- Intensity of pressures on habitats.
- Cost of restoration work.

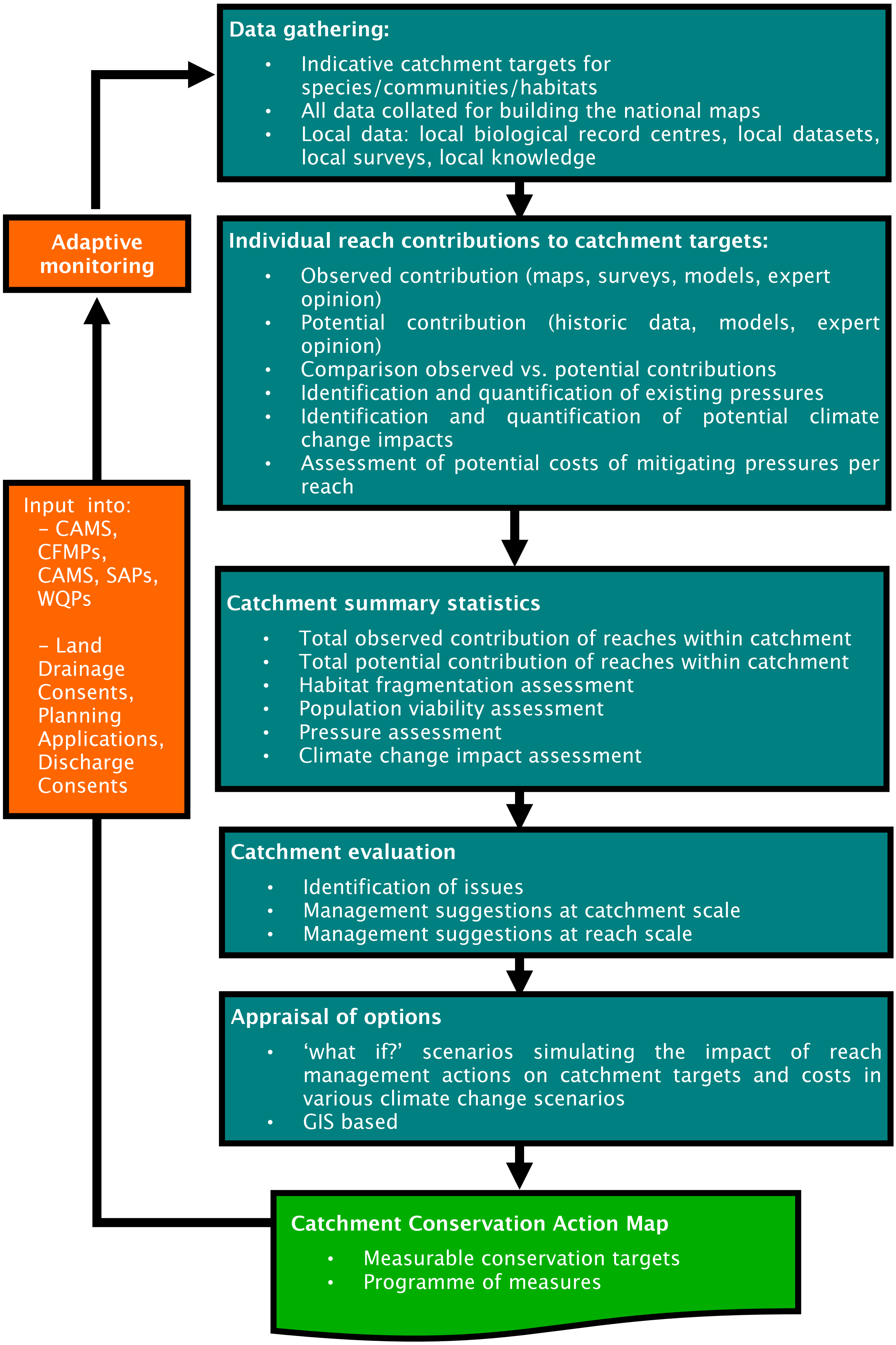
The assessment may also include landscape elements such as habitat fragmentation and population vability.

The aggregation process can be performed by running GIS ArcView code or using existing rule-based systems such as EMDS (see the previous section). Population viability assessment can be performed by RAMAS.

Catchment evaluation: in this part of the process, users will identify the main issues affecting species/communities and habitats and develop options for remediating them. They will be assisted by Expert Systems:

- A simple rule-based system will be built to link catchment and reach pressures to species, communities and habitats (e.g. using EMDS) based on known relationships (taken from literature reviews, scientific publications, handbooks and expert opinion).
- A multi-criteria tool will then be designed to assess their relative importance in driving species, communities and habitat distribution based on expert evaluation of impacts (e.g. EMDS).

Figure 15: Building catchment maps for biodiversity management.



- An expert system based on fuzzy logic (e.g. EMDS) or decision trees will be designed with expert geomorphologists to suggest sustainable management options at reach and catchment scales (i.e. options that will result in the recovery of natural processes and forms).
- Optimisation tools such as SITES could even be used to run a series of algorithms to help identify the best management strategy. The optimisation tools would use data on reaches, their observed habitat quality, their potential quality following restoration work, the cost of enhancing habitats and species/communities spatial requirements if needed (patch size, connectivity). The algorithms would then select the combination of reaches and actions that maximises conservation targets whilst minimising costs. The selected reaches and management actions could be displayed as a map.

Appraisal of options: users will use the outputs from the catchment evaluation to design their own management plan. Using GIS, they will be able to select reaches for protection or improvement and run simulation models to assess the impact of proposed management strategies on catchment indices, conservation targets, population viability and costs. Management options assigned to reaches will be generic and may include actions such as: improvement of riparian vegetation, re-introduction of specific features (riffles, pools, bars, berms, large boulders, gravel substrate), removal of major in-channel structures (weirs, dams, sluices, culvert), re-meandering, replacement of hard engineering by soft engineering *etc.* Where possible, simulation will be based on scientific peer-reviewed evidence of cause-effect relationships but in some cases may be driven by a synthesis of expert judgement or experience.

Catchment conservation action map: the final output will be a map of river reaches with management actions, measurable targets and a rationale. Ideally, only one map will be produced summarising actions for all species/communities/habitats of interest. The map should display measures of uncertainty and costs associated with actions. The action maps will be fed into Catchment Flood Management Plans, Catchment Abstraction Management Strategies, Water Quality Plans, Salmon Action Plans, Land drainage Consents, Planning Applications, Discharge Consents. They will also be used to direct non-statutory work such as River Restoration and habitat enhancement and will be used to influence Flood Defence maintenance programmes.

Monitoring: The predicted outputs from the maps are likely to bear a substantial amount of uncertainty. A way of dealing with uncertainty is to take an adaptive management approach. Monitoring is carried out on a regular basis at point on the catchments where changes are expected following management. If changes vary from those anticipated a review of the plan can be initiated.

Benefits and risks

The proposed process for delivering biodiversity targets would present a series of benefits compared to current decision-making:

- The process would link national and catchment biodiversity planning activities.
- The process would enable Biodiversity staff to plan biodiversity actions at catchment and reach scales.
- The process, through the use of scientific tools and techniques, would promote more evidence-based decisions-making in Conservation. It would help justify actions to the people Biodiversity staff try to influence. It would demonstrate willingness to base actions on science.
- The process and DSS would enable staff to learn new techniques, tools and knowledge. It would promote a learning cycle. Staff would not only learn from using the tools, but participate to their continual development by suggesting changes and adding their knowledge and expertise to the knowledge-base.
- The process would enable knowledge sharing between national and local teams, the derivation and dissemination of new knowledge and best practice. It would promote organisational learning and make the organisation more adaptive.

DSS and associated tools and techniques would play an important role in delivering these benefits but should not be considered in isolation. For example, DSS participate to the implementation of knowledge management strategies but they do not create them. Knowledge management strategy building is an activity of its own that requires consideration of:

- Corporate goals and objectives.
- Task requirement and available skills.
- Structures, processes and technology to capture and disseminate knowledge.
- Potential means of building a knowledge-oriented culture (Davenport & Prusak 1998).

Developing DSS in isolation is probably the main risk to their implementation success. DSS and science are not part of Conservation working culture. There is therefore a clear risk that, no matter how much effort is put into interface design and training, they will not be used. Changes in working practice are a matter for managers to decide and promote.

Demonstration projects

Following consultation with the project board and other potential users, it was recommended to take a stepped approach towards developing DSS for biodiversity management. It was suggested to develop projects for demonstrating the benefits of using DSS for biodiversity management using the approach suggested above on a limited number of species of interest.

Three demonstration projects proposals were put together and were submitted for approval. We chose one data-rich (water vole) and one data-poor (depressed river mussel) species to demonstrate the benefits of using DSS in various knowledge environments. We also put forward a demonstration project for Japanese knotweed, an invasive weed that is having significant impacts on river bank structure and potentially on biodiversity.

The detailed project descriptions can be found in Appendix 3.

Summary
In this section, I have taken a generic issue, biodiversity planning, have analysed current decision-making and suggested a process and DSS to support its resolution. The suggested process makes use of existing data to set targets for species, communities and habitats at national and catchment scales and develop programmes of management actions across catchments. The resulting action maps can then be used to influence other planning processes (CFMPs, CAMS *etc.*) and for the review of licenses and consents. The process and associated tools provide an integrated way of coupling national and local decision-making for planning the delivery conservation objectives. Altogether, they could make conservation priorities more explicit within the Environment Agency and provide a more consistant basis for decision-making.

Conclusion

Building science in the Environment Agency's decision-making is a task that cannot be resolved using DSS alone or in isolation. Throughout this chapter, I have shown how DSS can be used to support complex decision-making and underpin it with science within the context of the organisation. I have shown the limitations of DSS and factors affecting their successful implementation. I have also attempted to analyse the organisational context of decision-making with specific reference to working practice and culture in Conservation. From this broad overview, a series of points strongly emerge:

- DSS can be used to underpin decisions with science.
- DSS can benefit decision-making in Conservation.
- DSS can be used to promote knowledge flow within the organisation.
- Existing DSS and scientific tools are not widely used.
- DSS implementation is likely to face cultural resistance or indifference.

The main issue therefore, is not so much whether DSS can benefit decision-making in the organisation, but the context in which they will operate.

First, they are only one very specific way of delivering science within an organisation; other options such as training, recruitement should also be considered and be part of a wider strategy for promoting science in Conservation. The dissemination of best practice and the generation of new knowledge depends on the ability of knowledge to flow through the organisation. At present, examples of best practice may emerge in one of our 26 areas and be ignored by the rest. The lack of knowledge flow not only impedes knowledge creation but creates inconsistancies that could damage the EA reputation and lead to litigations. Knowledge is the only asset that grows when you use it. Managing knowledge is the priority of many modern companies (Nonaka & Takeuchi 1995; Davenport & Prusak 1998). The promotion of evidence in decision-making should be addressed by a knowledge management strategy, dealing with all aspects of knowledge, scientific and experience-based, tacit and explicit, and using a panoply of tools, including DSS.

Second, the promotion of scientific tools such as DSS requires a cultural shift. At present, the decision-making culture is very much dominated by the power of personal experience and judgement. This is something that runs deep in society in general; the basis of the 'expert witness' is a fundamental building block in national law. In Conservation, it is likely to be one of the main hurdle to the implementation of science in decision-making and to the use of scientific tools. But personal experience and science are not incompatible. In fact, they complement and feed each other. Personal experience participate to tacit knowledge. Science participate to explicit knowledge. The knowledge acquisition process shows how tacit and explicit knowledge interact and lead to the creation of new knowledge, which in turn will be interiorised as new tacit knowledge. Experience and science then become intertwined.

Maybe, we have here the key to the problem. For science to play a broader part in the Environment Agency's decision-making, judgement and evidence need to be promoted as not mutually exclusive. The application of the knowledge acquisition concept to the organisation would marry them in a creative process and may demonstrate to all the benefits of their interaction.

Discussion

What happened next?

The R&D project that formed the basis of this chapter first started with the aim of investigating the potential use of decision support tools for improving decision-making in the EA Conservation section. After two years of work on the subject, my final recommendation was that DSS could indeed hugely benefit the organisation but there were two major stumbling blocks: current practice and working culture. At the time, I felt that the way to overcome them was strong managerial support as advocated in the DSS design literature (Donnelly, Gibson & Ivancevich 1995).

The two reports produced were peer-reviewed by members of the Environment Agency and academics. The conclusions from the reports were broadly supported on the academic side but were received with circumspection by EA managers. Some managers expressed doubts with the overall approach and its potential for delivering biodiversity management on the ground. It was however decided to put it to the test by submitting the 3 demonstration projects for approval by the EA R&D adjudication panel. The bids were unsuccessful and nothing further happened.

The lack of success of the overall approach could be explained by a series of factors:

- from a cultural perspective, the EA could be viewed as a reactive organisation. Its work was mainly centred around dealing with pollution incidents, flooding and regulating the many companies and users of the environment. Conservation and Ecology had their own sub-culture dominated by strong beliefs in the value of expertise and personal judgement in decision-making.
- From a management perspective, there were no formal processes to support proactive catchment management planning activities, and levels of budget and time allocated to such activities were restricted.

In this context, the promotion of science-based tools for the production of plans and strategies was likely to generate doubts and reservations with regards to their applicability, suitability and desirability.

From a DSS design perspective, it is apparent that the methodology chosen for this case study somewhat failed to take into account the cultural and management factors cited above. Overall, the methodology used followed a very rationalist positivist perspective and attempted to 'abstract' the problem from the social cultural context in which it occurred. The solutions and tools offered not only conflicted with user skills and practice but also with their beliefs on what constitutes valid knowledge and decision-making. The proposed approach was therefore going against existing culture and practice and was not supported by any process whether formal (i.e. planning activity) or informal. The lack of convergence between the approach and organisational culture and practice may explain the overall lack of uptake of the case study findings.

Science and DSS uptake across organisations

Informal discussions with scientists in other departments and organisations in the UK but also in Europe revealed similar patterns across industries and countries. At around the same time as these case study was carried out, a European project called Harmoni-CA (Harmonised Modelling Tools for River Basin Management) had specifically been set up to deal with the issue of science and DSS implementation within organisations.

The overall objective of Harmoni-CA was to create a forum where a dialogue could take place between operational water managers, water policy makers, researchers and technology providers on the use and development of IT-tools (i.e. DSS) relevant to integrated river basin management and the implementation of the WFD (http://www.harmoni-ca.info/). One of the aims was to attempt to bridge the gap between science/research and implementation practice (De Lange, Luiten & Blind 2002). In one of the project reports (Giupponi *et al.* 2005), a literature review on DSS had highlighted the high rate of implementation failure and some of its root causes including differences in norms and values (i.e. culture). The authors had recommended the involvement of users in the DSS design process and the development of an understanding of the social and organisational context in which it will operate.

As part of the 3rd forum and conference of HarmoniCA, I gave a short presentation and poster on the limitations of current practice in DSS design and the importance of culture and invited participants to feedback on their experiences (Naura 2006). From a series of informal conversations with users and developers, it emerged that both sides had very different perspectives on the nature of the problems at hand and on the way they should be solved. Scientists viewed them as ecological and hydrological puzzles that could be optimised through the use of normative scientific tools and decision-making procedures. Practitioners framed problems within a socio-environmental context where solutions had to be found (with the help of scientific tools) with environmental stakeholders as part of a negotiation process. Whilst scientists put the emphasis on the technical side of problem solving, practitioners focused on social interaction. Both sides expressed similar levels of frustration at the other's lack of understanding of their own perspectives.

The issue of DSS design and more generally science implementation in conservation organisations seemed to be much more widespread and generic than originally thought. Cultural factors had been identified as potential root causes of implementation failure, and it seemed that differences in world views between scientists and practitioners may play an important part in this problem.

The PhD journey

At the end of the first case study, the PhD journey took a different path. Having identified culture as one potential factor affecting the uptake of science and technology in organisations and having realised the limitations of current DSS design methods, I saw the need for an approach that was radically different from a practical and theoretical viewpoint.

In the next chapter, I will investigate further the interaction between science and culture and provide a critique of existing DSS development methods and techniques for studying culture. In chapter 6, I will propose a new method for designing DSS based on this review that will be applied to the second case study.

Chapter 5 Applying science and technology within cultural systems: the need for new methodological perspectives

Introduction

The first case study highlighted the difficulty associated with applying scientific methods and tools within a sociocultural environment and the limitations of current DSS design methods in accounting for cultural factors.

In this chapter, I will reflect on the first case study and examples taken from the literature to develop further my hypothesis that organisational culture influences the implementation and use of science and scientific tools within organisations. I will then suggest the outline of a different methodological approach that will be applied and detailed further in the next chapter.

To better understand how science and culture interact, we first need to attempt to define them or at least identify their main characteristics. As my final purpose is to develop a method for accounting for cultural phenomenon whilst designing DSS, I will review and critique the various approaches towards defining and studying them. This, in turn, will inform my choice of methodological framework for the second case study.

Science

Science, arguably, is a way of deriving knowledge to describe, explain, control or predict the world **as we perceive it** (e.g. see Latour (1987) and Chalmers (1999)).

The last four words of the sentence are extremely important as they suggest that science does not happen in isolation but is instead used within the context of our perception of the outside world. This perception is not neutral and is itself influenced by what we know, i.e. our existing knowledge but also beliefs, values and physical perceptual differences.

Reality perception and Knowledge derivation are two components of science that are referred to as **ontology** and **epistemology** (Martin 2002; Denzin & Lincoln 2005; Guba & Lincoln 2005).

Ontology represents all the assumptions we take to describe the nature of reality. The 'real world' can indeed be assumed to be complex and unpredictable or, simple and reducible. Reality, for example, can be viewed as the result of interacting physical and biological forces or as the complex interaction of natural and cultural systems.

The existence of reality itself can be the subject of ontological challenge. In the positivist science framework, it is assumed that reality exists outside perception and can be objectively described using observations, experiments, concepts and language.

Concepts such as 'habitat suitability' and 'population viability' become real entities that can be measured or assessed. Fish have 'preferences' and the 'forces' of evolution exist. In contrast, social scientists believe reality is constructed by the observer and that more than one reality may exist (Guba & Lincoln 2005). They insist on the use of interpretive analytical methods where subjectivity is recognized and part of the process (Silverman 2005).

Epistemology represents our assumptions about knowledge and the way it is generated. Whether we are physicists, biologists, sociologists, or simply experts, we use different tools, methods and methodological approaches towards generating knowledge. Experts will use experience, intuition and informal experiments to gather mainly tacit knowledge. Biologists will use lab experiments, mesocosms, controlled environments and statistics to generate explicit knowledge in the shape of equations, models and tests of significance. Sociologists and anthropologists will use observations, interviews, thick descriptions and discourse analysis to derive 'meaning'.

Defining knowledge

One major epistemological difficulty is in defining knowledge. First, there are different types of knowledge:

> 'knowing how to play the piano' implies having musical competencies;
> 'knowing John' means that I am acquainted with him;
> 'knowing that an equilateral triangle has three sides of equal length' implies that I have some factual knowledge about triangles;
> 'knowing about trigonometry' means that I am able to calculate the straight distance between two points given their altitude and slope angle.

Knowledge can be tacit or explicit. Tacit knowledge is embedded in people's minds whereas explicit knowledge can be expressed as words, equations or diagrams.

The generally agreed definition of knowledge is that it is ' justified true belief'. For me to know that 'trout like clean water', the following three conditions must be fulfilled:

1. it is true that trout like clean water;
2. I believe that trout like clean water;
3. my belief is justified.

This is called the **tripartite definition of knowledge** (Lehrer 2000).

The definition poses a series of problems. First, it can be argued that true knowledge can be based on false evidence. The presence of fish in a river can have little to do with water quality and instead can be the result of coincidental fish stocking activities.

Another limitation of this definition is that it assumes that knowledge is associated with truth. As we have seen, the concept of truth participates to specific ontological perspectives and may not be easily applied in an uncertain environment or in a world that can only be perceived subjectively -such as the social environment.

Finally, it is difficult within the confines of this definition to account for different types of knowledge such as tacit knowledge, which is embedded within practice and is difficult to explicit or justify. The same goes for expert knowledge or any knowledge derived from experience. The lack of explicit and coherent justification will cast doubts on whether it can qualify as knowledge rather than belief or myth.

A functional definition of knowledge

To remedy these difficulty, we can suggest a more restrictive and **functional** approach towards defining knowledge. It starts by making the difference between data, information and knowledge.

Data provide **information** (i.e. a removal of uncertainty) on specific aspects/characteristics of object/subjects (Shannon 1948). Data and information are not in themselves knowledge, they are simply facts and statements such as 'I know John' or 'an equilateral triangle has three equal sides'.

From data and information, we can gather knowledge which can be defined as a **model/set of models** that enable us to explain the past and present states of our subject of enquiry and predict future states.

Models are representations of the world. There is no requirement for justification. They can be physical, mental, mathematical, conceptual or in the shape of narrative/thick descriptions.

As a result, knowledge can be 'given' or 'revealed' through experience or ‘deducted’ from experimentation. Tacit and explicit models can both lead to the production of predictions and diagnostics. No assumption is made on the true nature of knowledge; therefore models can yield multiple answers whose validity can nonetheless be tested.

With this definition, beliefs and myths can also be considered as forms of knowledge as they tend to explain the way the world is, and can be used to make predictions about the future. The issue of validation (implied in the link between justification and truth in the formal definition) can be disassociated from the notion of knowledge. Different types of knowledge can be validated by assessing their ability at explaining past and current states and making predictions against the future.

By taking a more functional point of view, we restrict the field of knowledge to models at the expense of factual knowledge, but we considerably extend its remit by including types of knowledge that would otherwise have been considered as not explicit enough, irrational or less justifiable within a positivist framework. This definition of knowledge is similar to that proposed by proponents of Cybernetics and Complexity Science (Turchin 1993; Von Glasersfeld 2002).

Scientific paradigms

Ontology, epistemology and the perceived world interact in complex ways. As shown by philosophers of science, knowledge is not simply derived from facts. The enquiry leading to experiments and the generation of hypotheses/theories stems from preconceived ideas of the way the world is, and from existing knowledge and theories (Chalmers 1999). Similarly, the way the world is perceived will change because of the development of new investigative tools and techniques and will influence/challenge our assumptions on reality and the methods we use to apprehend it (Kuhn 1996).

The combination of ontology and epistemology forms what social scientists call a **paradigm** or **interpretive framework** defined as '*a basic set of beliefs that guides action*' ((Guba 1990) in (Denzin & Lincoln 2005), page 22).

'*All research is interpretive; it is guided by the researchers set of beliefs and feelings about the world and how it should be understood and studied. Some beliefs may be taken for granted, invisible, only assumed, whereas others are highly problematic and controversial. Each interpretive paradigm makes particular demands on the research, including the questions the researcher asks and the interpretations he or she brings to them*' (Denzin & Lincoln 2005), page 22).

Table 7: Basic beliefs of alternative enquiry paradigms (from (Guba & Lincoln 2005), page 195)

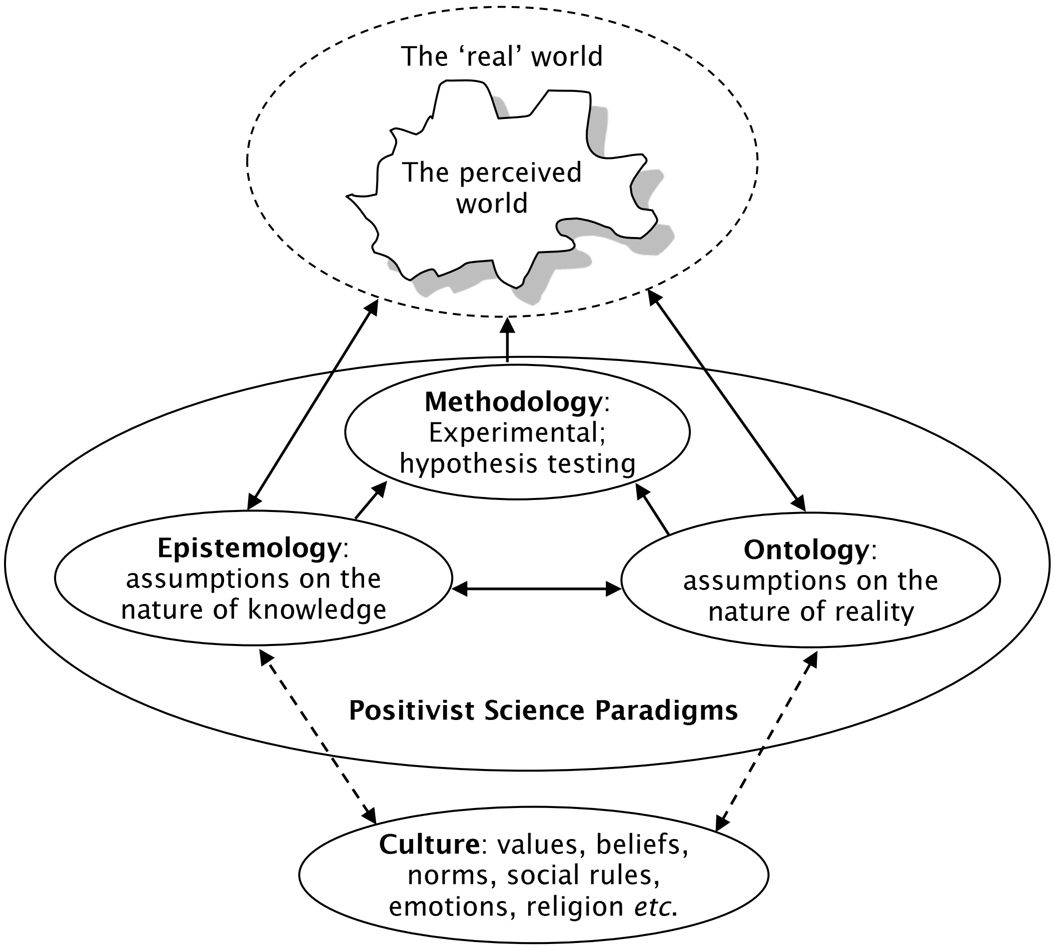
Issue	**Positivism**	**Post positivism**	**Constructivism**
Ontology	naive realism– "real" reality but apprehendible	Critical realism– " real " reality but only imperfectly and probabilistically apprehendible	Relativism– local and specific co-constructed realities
Epistemology	Dualist/objectivist; findings true	Modified dualist/objectivist; critical tradition/community; findings probably true	Transactional/ subjectivist; Co-created findings
Methodology	Experimental/ manipulative; verification of hypotheses; chiefly quantitative methods	Modified experimental/manipulative; falsification of hypotheses; may include qualitative methods	Hermeneutical/ dialectical

A series of dominant paradigms can be identified along with their domains of application (table 7). I will present here three paradigms for their relevance to this research and for their historical importance as they represent major steps in the development of the physical, biological and social sciences: the positivist, post-positivist and constructivist paradigms.

Positivist paradigms

In the positivist and post-positivist paradigms, reality exists independently of thought (figure 16). The 'real' exists and can be approached through the use of methods and tools that reduce the noise introduced by subjective elements such as thoughts, beliefs, emotions and myths (Guba & Lincoln 2005). Its epistemology is objectivist in nature and aimed at obtaining the 'truth that is out there'. It is dualist in the Cartesian sense that it opposes the objective to the subjective, truth to false, right from wrong, mind and body. Methods are experimental and attempt to isolate the observed phenomenon from natural and cultural noise so as to best describe its true nature.

Figure 16: Relationships between ontology, epistemology, methodology and culture: the positivist scientist view

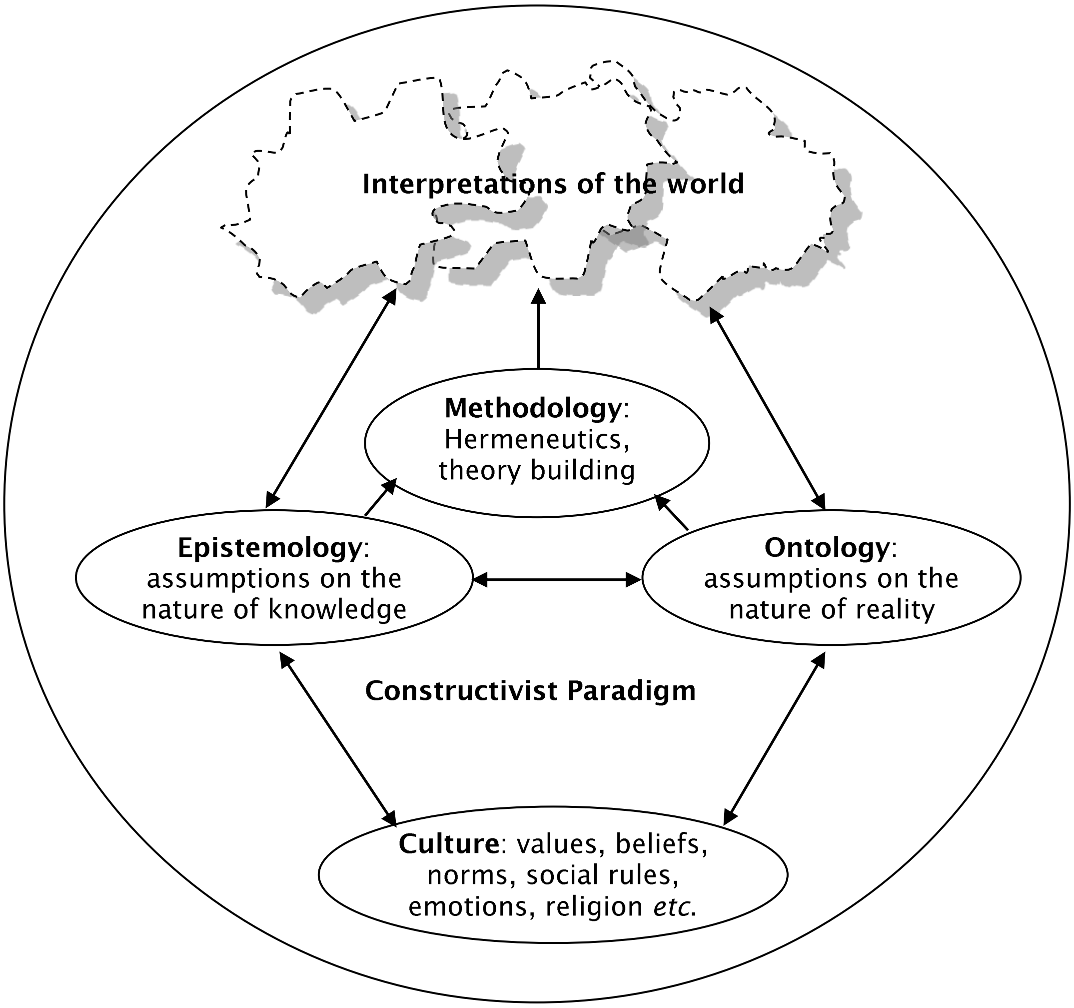


The post-positivist perspective claims about the nature and existence of reality and our ability to apprehend it objectively, softens to account for the difficulty and sometimes impossibility in finding one 'true' answer. Cause-and-effect can indeed be difficult to isolate experimentally. Attempts at modelling biological systems have shown that in a complex environment, competing models can have equivalent validity when compared for their ability to explain and predict present and future states (Burnham & Anderson 2002).

Constructivist paradigm

The constructivist paradigm applies mainly to the social sciences but also to Cybernetics and Complexity Science (Heylighen & Joslyn 2001). Its ontology is relativist as it assumes that there is no unique truth but instead recognizes that truth and reality are constructed, therefore more than one interpretation of reality may exist. Its epistemology is subjectivist in nature as reality can only be constructed through the use of words and is mediated by experience and emotions. The constructivists insist on the fact that reality is an act of co-creation and that the researcher is not free of cultural and personal influences (Von Glasersfeld 2002; Denzin & Lincoln 2005).

Figure 17: Relationships between ontology, epistemology, methodology and culture: the constructivist perspective.



Methods of research are based on interpretation rather than experimentation. Hermeneutics is the science of interpretation. From it was derived a series of approaches towards studying, analysing and interpreting social phenomenon.

Scientific enquiry within the constructivist paradigm does not attempt to underestimate the importance of values and beliefs on the research process but instead integrate them and make them explicit to readers and reviewers in the shape of personal statements and the practice of what is called reflexivity.

Reflexivity is the ability of the researcher to express and account for his subjective biases and the potential impact they may have on the relationships he/she builds with the object/subject of research, the observed phenomenon and their interpretation (Fontana & Frey 2005).

The constructivist paradigm offers a very interesting perspective on the relative importance of ontology, epistemology, culture and the place of the researcher in a study of the world. Figure 16 could be redrawn in the following way (figure 17).

There is not one reality but different possible interpretations of the world. Values, beliefs and emotions contribute to the interpretive process. Culture can now be seen to influence the researcher's ontology and epistemology. In the positivist view, the position of the researcher is abstracted and he/she is supposed to be a neutral objective agent. In the constructivist perspective, the position of the researcher is highlighted and englobes all other dimensions. It is through the confrontation of data and the researcher's assumptions about ontology, epistemology, values and beliefs that interpretations of the world emerge.

Summary

From this short and incomplete 'exposé' on what constitutes science, we will retain that scientists work within an overall theoretical framework or paradigm that has its own views/assumptions on what constitutes reality and knowledge and its own theories around the way the world works.

To sustain their claims of objectivity, scientists from the positivist traditions try as much as they can to separate their enquiry from the influences of more subjective factors such as values, beliefs or religion. There is, however, another strain of science that does not hold the same claims of objectivity. Social scientists follow the constructivist paradigm whose ontology and epistemology account for the subjectivity of the researcher in the analytical process, and opens the possibility of the existence of multiple views of the world.

With that in mind, we will now look at what constitutes culture and then critically examine how science and culture may react and interact, and define some hypotheses around the way they may conflict.

Organisational culture

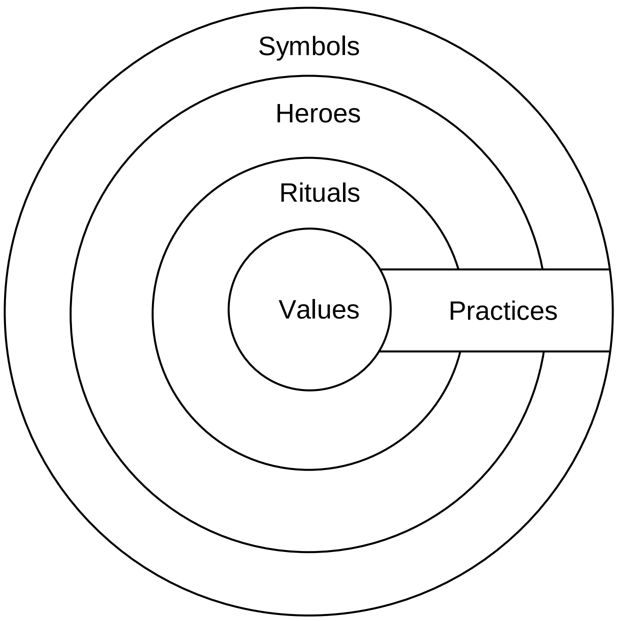
The study of culture and more particularly culture itself presents many difficulties from a conceptual and methodological point of view. There is no standard definition of culture. Culture is not an object or entity that exists outside the world of ideas; it is a concept. Despite its lack of material existence, it has been studied using both positivists and constructivist theoretical frameworks. In this review, I will contrast both approaches using the work of two of its main proponents: Geert Hofstede and Edgard Schein.

Studying cultures, the positivist approach.

The positivist approach towards studying organisational culture aims at developing methods and tools to measure its fundamental dimensions. The best-known account was produced by Geert Hofstede and his team who ran a survey questionnaire on 116,000 members of staff of IBM across 72 countries (Hofstede 2001). Their aim was to describe differences in culture between countries within IBM.

Hofstede defines culture as '*the collective programming of the mind that distinguishes the members of one group or category of people from another*' (Hofstede, 2001, page 9). At the core of individuals' mental programs, that are partly inherited, partly learnt, is a set of values that are shared amongst members of the group and different from the core values of another group (figure 18).

Figure 18: The 'onion diagram': manifestations of culture at different levels of depth (from Hofstede, 2001, page 11).



Values are themselves defined as '*belief that a specific code of conduct or end-state of existence is personally and socially preferable to alternative modes of conduct or end-*

states of existence' (Hodstede, 2001, page 5). Values are generally hidden away but are expressed in observable behaviours and practices (e.g. rituals, heroes and symbols).

Values can be split into two categories: desired and desirable. Desirable values represent what one 'ought to do' whereas desired values are what one really wants to do. Desired values can be accessed by asking respondents questions on whether they feel values are important/unimportant (e.g. having little tension and stress at work is important). Desirable values can be assessed by asking respondents whether they agree/disagree with general value statements (e.g. when a man's career demands it, families should make sacrifices).

Hofstede used questionnaires and Factor Analysis to derive a series of dimensions of culture which were further validated using secondary data taken from the literature. Dimensions were selected according to their ability to differentiate between countries and their independence from other dimensions (assessed using correlations) (Hofstede, 2001, page 73). Factor Analysis was not performed on individuals' responses but on averages per country. Four dimensions of culture were identified and a fifth one was added later following a repeat survey in China (table 8).

Table 8: Five dimensions of national culture by Hofstede (2001) (description taken from Auguinis 2003)

Power distance refers to the degree of inequality between a supervisor and his/her subordinate. It was derived from questions addressing perceptions of a supervisor's style of decision-making, co-workers' fear to disagree with superiors, and the type of decision-making that subordinates prefer in their supervisor.
Uncertainty avoidance refers to the degree of tolerance for uncertainty. It was derived from questions addressing rule orientation, employment stability and stress.
Individualism refers to the type of relationship between the individual and the collectivity which prevails in a given society. It was derived from questions addressing work goals (e.g. 'I have a job which leaves sufficient time for my personal or family life'; 'I have considerable freedom to adapt my own approach to the job').
Masculinity-femininity refers to the degree of endorsement of "masculine" (i.e. advancement and earnings are more important) as opposed to "feminine" (i.e. interpersonal aspects, rendering service, and the physical environment are more important) goals.
Long-term versus short-term orientation (originally called 'Confucian work dynamism') refers to Confucian work ethics and is reflected by the endorsement of such items as persistence, thrift, and having a sense of shame.

The same methodology was applied to study differences between organisations. The IRIC project (Hofstede *et al* 1990, Neuijen, 1992) covered 20 organisational units across Denmark and the Netherlands. It was based on a questionnaire that included questions on values but also on practices (i.e. rituals, heroes and symbols). They found that the organisations studied did not differ in national culture values but in practice (Hofstede *et al* 1990). This led the authors to suggest that the core of organisational culture is made of 'shared perceptions of daily practices'. Six main dimensions of practice were identified (table 9).

Table 9: Six dimensions of organisational practice (Hofstede *et al* 1990)

Dimension	**Title**	**Description**
P1	process oriented versus results oriented	P1 opposes a concern with means (process oriented) to a concerned with goals (results oriented)
P2	employee oriented versus job oriented	P2 opposes a concern for people (employee oriented) to a concern for getting the job done (job oriented)
P3	parochial versus professional	P3 opposes units whose employees derive their identity largely from the organisation (parochial) to units in which people identify with their type of job (professional)
P4	open versus closed	P4 opposes open systems to close systems and describes the organisation communication climate.
P5	loose versus tight	P5 refers to the amount of internal structuring in the organisation from 'tight' (e.g. strict dress code) to 'loose' (e.g. informal communication style)
P6	normative versus pragmatic	P6 deals with the popular notion of customer orientation. Pragmatic units are market-driven; normative units perceive their task as the implementation of inviolable rules

Hofstede's approach towards studying and measuring culture has got some problematic methodological and theoretical limitations, the majority of which are recognised by the author himself.

<u>The claim for objectivity or 'does theory precede discovery?'</u>

Factor Analysis is presented as a way of extracting universal dimensions of culture. The dimensions are based on scores (such as the Likert 1-5 scores) for a series of questions averaged at the level of nations or organisations. Altogether, this gives the impression of an objective selection of statistical dimensions. In practice, we find that the analyses are more subjective than the reader may think.

The questions selected for the national survey were not theory independent. The process for selecting the most relevant and interesting questions was heavily reliant on existing knowledge, previous research, the researchers' beliefs, and management needs. Pilot interviews, the use of previous survey questionnaires and research led to the identification of a set of best questions (Hofstede, 2001, page 43 and 48). To a large extent, theory preceded data analysis and the resulting dimensions have to be considered with regards to the prior assumptions taken by the researchers on culture. Two of the five dimensions were in fact derived without Factor Analysis. Power Distance and Uncertainty Avoidance were developed by combining question scores selected for their assumed importance in describing culture (Hofstede, 2001, page 53).

In the case of the IRIC survey, the link between theory and survey design was made more explicit. The authors described how 180 interviews were first carried out to '*create a qualitative empathic description of the culture of each of the 20 units*' (Hofstede *et al*, 1990, page 395). The results from this qualitative enquiry were then used to design a questionnaire.

These points strongly suggest that the questionnaires were in fact the result of the development of prior theories around culture. As such, the questionnaire becomes a way of creating scoring systems using Factor Analysis or handmade equations for known or supposed dimensions.

<u>The choice of statistical technique and the criteria for dimension selection</u>

The subjective choice of questions representing unstated themes of interest may also influence the relative importance of dimensions. Factor Analysis is a methodology that defines dimensions according to the level of covariance between question scores. A dimension may be identified if the answers to two or more questions are strongly correlated. Themes of interest to the researcher or the client are likely to have more than one question related to them, therefore increasing the likelihood that answers will covary and statistically 'strong' dimensions will emerge. A theme of marginal interest may be the subject of only one question and may be considered as insignificant, even if it shows strong discrimination between national responses. The choice and number of questions representing themes of interest is therefore likely to influence the nature and strength of observed dimensions following Factor Analysis.

This bias is illustrated by the latter discovery of a fifth dimension on 'long-term versus short-term orientation' following a separate survey in China. This dimension was not found in the IBM survey according to the author because of '*the western minds of the designers of the IBM questionnaire and other values lists used in international research so far*' (Hofstede, 2001, page 351).

Another bias is in the rejection of potential dimensions if they are found to be correlated with other dimensions or demographic data. In the analyses of IRIC project data, three new dimensions were dismissed because of strong correlations with national dimensions and demographic data (e.g. age, gender *etc.*). These were 'work orientation' (intrinsic versus extrinsic), 'identification' (with company versus non-company interests) and 'ambition' (concerned with money and carrier versus family and co-operation).

It is not clear from a theoretical viewpoint why dimensions linked to demographics should not be considered. Even if demographic elements such as age or gender are driving value differences, they are unlikely to be the result of random processes, and most probably stem from cultural or organisational choices/biases (such as gender discrimination).

Also, if culture is '*an interactive aggregate of common characteristics that influence a human group's response to its environment*' (Hofstede, 2001, page10), we should expect some sort of interaction between dimensions of culture. It is difficult to understand why (apart from the fact that it is a requirement of Factor Analysis) dimensions of culture should be independent from each other.

Even if correlations are observed between dimensions, this does not mean that they are equal. Subtle differences between them may provide additional insights on important aspects of culture. For example, Hofstede *et al* (1990) discarded a dimension of organisational culture called 'need for security' because of its resemblance to Uncertainty Avoidance and Power Distance. The dimension combined questions on beliefs about work, its importance relative to family and life in general, societal values, beliefs on the need for equality, job preferences and opportunities, and power distance. On close examination, the dimension seemed to reflect the way groups value work with regards to other pursuits in life, and beliefs on their role in society. It could potentially have provided very interesting insights on organisational culture beyond that of Uncertainty Avoidance and Power Distance.

<u>The use of statistical measures.</u>

The choice to summarise individual responses at the level of nations by using mathematical averages opens the door to potential misrepresentation and misinterpretation of the results. Hofstede, in his definition of culture implies that culture is made of assumptions that are shared by a group and different from another group. However, by using averages to describe and compare national scores, he puts himself in the position where he cannot achieve both conditions with confidence. Indeed, an average score of '3' to a specific question may result from a group where all individuals answered in the same way or where half the respondents answered '1' and the others '5'. In his study, Hofstede checked for the shapes of the distribution curves before performing the analysis but, by using national averages without making standard errors explicit, he does not allow the readers (and himself) to judge whether differences between groups are statistically significant or not.

<u>Culture as differences.</u>

Hofstede's definition of culture implies that culture is best studied by looking at differences between groups, assuming groups are homogeneous. In Hofstede's words: '*paradoxically, the cross-national research in IBM did not reveal anything about IBM's corporate culture, except that it engaged in a survey project of this size: all units studied share the same corporate culture, and there were no outside points of comparison. However, the cross-national study was a model of how a cross-organisational study could be undertaken. Instead of one corporation in many countries, we would study many different organisations in one and the same country*' (Hofstede *et al*, 1990, page 289). As we have seen, there is no guarantee by simply looking at average scores that scores represent shared values within groups. Also, because of the use of Factor Analysis, values shared by all or a majority of groups (i.e. universal values) are very unlikely to be identified. These values are likely to be important in defining culture and will not be revealed by the analyses.

<u>Validating dimensions of culture.</u>

For the validation of dimensions of culture, Hofstede used the following approach:

'*Information about a population can be considered scientifically valid only when it meets the following four criteria:*

1. *it is descriptive and not evaluative (judgemental);*
2. *it is verifiable for more than one independent source;*
3. *it applies, if not to all members of the population, at least to a statistical majority;*
4. *it discriminates; that is, it indicates those characteristics for which this population differs from others.*

If these four criteria cannot be met-which has often been the case for statements about national character-the statements are unsupported stereotypes.

A stereotype is a fixed notion about persons in a certain category, with no distinctions made among individuals' (Hofstede, 2001, page 14).

From this, he suggests that validation can be done by:

- replication: by repeating the same analyses on different samples and comparing results using correlations;
- comparison: by comparing dimensions to other dimensions derived from other studies using correlations.

Attempts at replicating the IBM's survey have shown mixed results as described by Hofstede himself (Hofstede, 2001, page 66) and Aguinis and Henle (2003) with some studies confirming some of the dimensions observed and others not. Attempts at correlating the dimension scores to the data demonstrated better results but only a selected set of studies was presented (Hofstede, 2001, page 68).

Missing from the analysis are tests of significance related to criteria 3 and 4. The use of mean population statistics without taking account of standard deviations restrict our ability to test scores and dimensions against these two criteria, with the risk that results are interpreted as stereotypes.

Conclusion

Objective methods for defining and measuring culture are faced with the ontological difficulty of turning something intangible into something real and measurable. The choice of questions, their numbers, and the themes of interest will all influence the nature and strength of resulting dimensions. It is therefore difficult to affirm that dimensions were discovered following data analysis as they may have been assumed in the questionnaire design. It is also hard to claim that one dimension is more important than another based on statistics as questionnaire design can strongly affect the relationships found. From a practical viewpoint, these kinds of surveys may be useful in comparing groups but less so in identifying the shared elements within an organisation. This last point is a key limitation to the use of questionnaire surveys and Factor Analysis in studying organisational culture. Other important limitations will be discussed in the next sections.

Other attempts at measuring culture.

Reviews of methods for measuring dimensions of culture are provided in Ashkanazi *et al* (2000) and Scott *et al* (2003). A significant number of cultural studies seem to have followed a similar methodological framework as Hofstede, using literature reviews and qualitative analysis to derive a series of questions around themes of interest that are then processed using Factor Analysis to identify important dimensions and produce scoring systems (Aguinis & Henle 2003; Leidner & Kayworth 2006).

The Organisational Culture Profile (OCP) (O'Reilly, Chatman & Caldwell 1991) and the Organisational Culture Survey (OCS) (Glaser, Zamanou & Hacker 1987) are two examples amongst others. The OCP used a set of 54 value statements that respondents had to order according to levels of desirability to provide ratings of preferences. Scores were averaged per organisation and a Factor Analysis was produced to derive eight dimensions of culture.

With the OCS, a 62-item questionnaire was first derived from literature reviews and open-ended interviews. The resulting questionnaire was filled by every employee and six dimensions were extracted using Factor Analysis. The questionnaire was then applied to another company and average dimension scores between levels of management were compared using ANOVA. At the same time, independent researchers ran a series of interviews with a random sample of employees to identify major themes related to organisational culture. The results from the questionnaire were compared to the outputs from the qualitative analysis. This approach is called a **triangulation approach**, as it attempts to use different methods to describe the same phenomenon to increase the validity and reliability of the results. The qualitative and quantitative methods seemed to generate complementary outcomes. '*Questionnaire data revealed expressed attitude. The interviews illustrated why a particular attitude was held and how respondents made sense of what they believed to be true*' (Glaser, Zamanou & Hacker 1987), page 190).

This kind of triangulation approach has been advocated widely to '*maximise a single methods benefits while neutralising its limitations*' (Glaser, Zamanou & Hacker 1987), page 175). It also has the benefit of complementing the use of questionnaires by enabling researchers to extract meanings out of individual responses.

Indeed, one serious limitation of questionnaires is that they tend to reveal superficial aspects of organisational culture and may not address deeper assumptions. Ashkanazi *et al* (2000) use Schein's three level typology (Schein 2004) to characterise the depths at which cultural surveys operate (table 10). In Schein's typology, organisational culture is made from a set of basic assumptions that are reflected in expressed values and beliefs and, on a more superficial level, artefacts and patterns of behaviours. According to Ashkanazi *et al*, all 18 questionnaire-based methods they reviewed tended to deal with observable expressions of culture and none really managed to reveal deeper assumptions.

Table 10: Levels of culture based on Schein (2004)

LEVEL 1: ARTEFACTS	Visible organisational structures and processes: structure, physical space, rituals, dress code *etc.*
LEVEL 2: ESPOUSED BELIEFS AND VALUES	Espoused values: strategies, goals, philosophies, mission statements *etc.*
LEVEL 3: UNDERLYING ASSUMPTIONS	Unconscious, taken-for-granted beliefs, perceptions, thoughts and feelings: rule of the game, norms, mental models, embedded skills *etc.*

Organisational culture: the constructivist approach.

The constructivist approach towards studying culture attempts to go beyond the level of artefacts and stated values to address the deeper assumptions that underpin organisational culture. One important proponent of this approach is Edgar Schein. Schein defines culture as '*a pattern of shared basic assumptions that the group learned as it solved its problems of external adaptation and internal integration, that has worked well enough to be considered as valid and, therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to these problems*' (Schein 2004), page 17). Culture is therefore learned through a process of socialisation in the workplace. Culture has a function, which is to enable the group to respond to the demands of its internal and external environments.

If we accept the definition of knowledge proposed earlier, culture can then be described as a set of shared models to solve common problems within the groups and with regards to its external environments. It is, in a sense, shared knowledge (Sackmann 2001; Lemon & Sahota 2004).

According to Schein, organisational culture generally starts and is strongly influenced by the personality of its founding leader. The author identifies six primary and six secondary mechanisms for leaders to teach organisational members how to feel, think and behave (table 11).

Table 11: How leaders embed their beliefs, values and assumptions (Schein, 2004)

Primary Embedding Mechanisms • What leaders pay attention to, measure, and control on a regular basis. • How leaders react to critical incidents and organisational crisis. • How leaders allocate resources. • Deliberate role modelling, teaching, and coaching. • How leaders allocate rewards and status. • How leaders recruit, select, promote, and excommunicate.
Secondary articulation and reinforcement mechanisms • Organisational design and structure. • Organisational systems and procedures. • Rites and rituals of the organisation. • Design of physical space, facades, and buildings. • Stories about important events and people. • Formal statements of organisational philosophy, creeds, and charters.

The actions of leaders, what they pay attention to, the way they allocate resources, rewards success or punish failure have a very important role in shaping behaviours and highlighting desired values. Not every individual will react in the same way to the leader's charisma and needs. Assumptions accumulated from previous socialisation processes, whether at school or in another company may conflict with that of the leader or the organisation. Recruitment and dismissal are therefore powerful tools to generate and maintain a consistent culture. By selecting people who already share the company's values, a more cohesive culture can be created.

Culture can also be reinforced and expresses itself through secondary mechanisms. These are the rituals (e.g. team away day), physical spaces (e.g. open office), stories, statements (e.g. mission and value statements), systems and structure that are the emergent part of the cultural world. To a newcomer, some of these manifestations may seem odd or idiosyncratic at first, as there 'raison d'être' is hidden away from the grasp of rationality.

As an organisation matures, secondary mechanisms may become the primary forces in maintaining existing cultures and, in the face of change (e.g. in legislation or organisational priority) may stifle the organisation and prevent it from adapting to new conditions.

It is not the only change that may affect an organisation with time. As companies increase in size, departments may develop different sub-cultures under the leadership of local managers because of values inherited from a specific line of professional training or the specific issues they are facing. Flood protection engineers, conservation officers and nuclear safety managers do not face the same problems and are unlikely to share the same assumptions. They have sub-cultures of their own that help them deal with their own work environment and decision-making.

Studying culture.

The observation of artefacts and the identification of espoused values and beliefs provide a limited access to underlying assumptions. Espoused values may indeed be created to promote a desired cultural change. Artefacts can also be misleading. Schein (2004) gives the example of a company whose assumptions were egalitarian in nature but had designed a very hierarchical head office building to match the expectations of its main customer, the Ministry of Defence. They found that customers were more comfortable in an environment whose artefacts reflected their own cultural beliefs.

An analysis of culture based on artefacts, behaviours, beliefs and values can therefore lead to erroneous conclusions. Schein's methods for eliciting underlying shared assumptions is inspired from the social sciences and involves running focus groups. His approach consists in the description by group members of artefacts, behaviours, beliefs, and values and a critical analysis of their consistency/inconsistency in order for underlying assumptions to emerge.

Although questionnaires and surveys can highlight inconsistencies in values/beliefs and behaviours/artefacts, we can see that the meaning behind these inconsistencies cannot easily be inferred from the survey responses alone, but need to be elicited through a Socratic process of 'sense making' involving critical thinking.

Schein suggests a 10-step process for deciphering culture.

1. Obtaining leadership commitments: there must be a problem worth fixing or studying that managers are keen to tackle. Without leadership commitment, a cultural study is likely to yield little insights.
2. Selecting groups for interview: group selection needs to be done according to:

- the problem of interest;
- the organisation structure;
- the potential presence of sub-cultures;
- the level of trust and openness in the organisation.

3. Selecting an appropriate setting for the group interviews.
4. Explaining the purpose of the group meeting: this is best done using a manager to show leadership commitment.
5. A short lecture on how to think about culture.
6. Eliciting descriptions of artefacts.
7. Identifying espoused values.
8. Identifying shared tacit assumptions.
9. Identifying cultural aides and hindrances to the problem identified by management.
10. Reporting assumptions and joined analysis of the link between culture and identified problems and possible ways forward.

To aid the analysis of culture, he further proposes a series of dimensions of culture taken from his own experience and the literature. These dimensions can be summarised and displayed as a conceptual map (figure 19). I will give a brief description of each dimension as they will form the basis for my analysis of culture in the next chapter.

Schein identifies eight major dimensions of culture representing assumptions on the nature of truth, reality, time, space, human nature, human activity and relationships, and internal and external adaptation. When relevant, I have added dimensions taken from other studies and some from my own experience that I felt were of particular relevance to both case studies.

External adaptation represents all the shared assumptions regarding the way the organisation interact with the external environment. It includes the definition of missions, strategies and goals, along with the means, measurement devices and corrective actions necessary to achieve those. These terms are not meant in the classic corporate management sense as pieces of paper and grand plans, but as a collective understanding of staff and managers on what the organisation is all about, its social function and the way its mission should be delivered. The way they will deliver their missions is defined in common based on members' and leaders' belief systems. Views on what constitutes adequate goals, means, measurements and corrective actions will differ whether an organisation is constituted of engineers, experts or environmental activists.

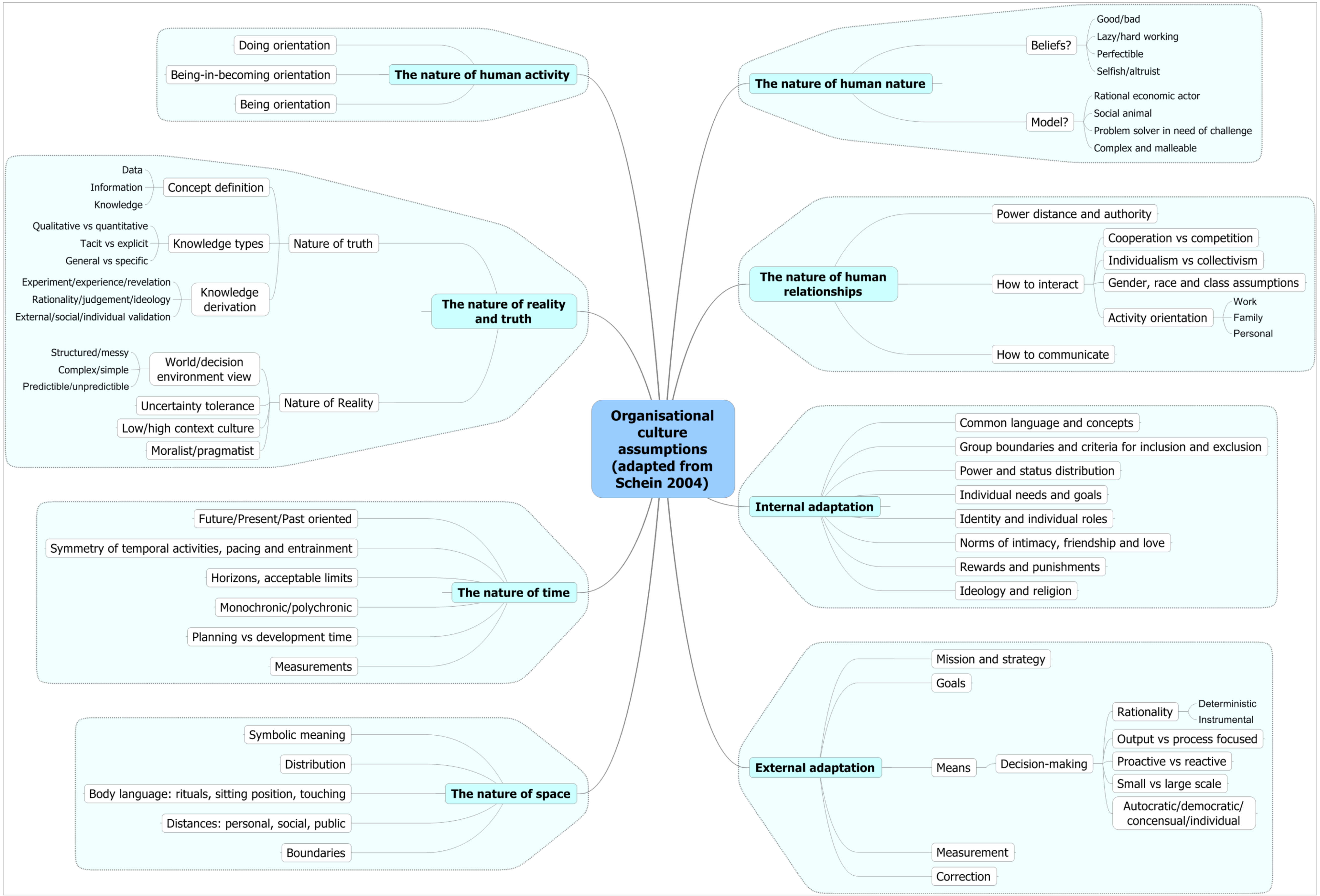
Within the 'means' dimension, I created a sub-dimension related to decision-making. Decision-making proceeds and is influenced by other assumptions on internal adaptation, human relationships, reality, truth, space and time. It encapsulates a large number of shared assumptions on the way organisations deal with their external and internal environments and take action. Decision-making can be defined according to the nature of rationality (deterministic or instrumental): the relative priority given to process and outcomes (dimension derived from Hofstede *et al.*, (1990) and O'Reilly *et al.* (1991), the level of planning in time (proactive versus reactive) and space (large to small scale), and the nature of the process (autocratic, democratic, consensual, individual).

Internal adaptation relates to assumptions about the way the group is organised, the distribution of power and status and all processes regulating life within the organisation. Reaching agreement about common language and concepts is essential for individuals to understand each other and communicate effectively. Groups have shared views on group boundaries and what is acceptable behaviour. They will also develop unwritten rules on how power and status are shared, individual needs and goals are accounted for, and how rewards and punishments will be allocated.

I added two sub-dimensions: 'individual needs and goals' and 'identity and individual roles' to represent aspects of culture otherwise present in the literature that I had experienced in the Environment Agency.

‘Individual needs and goals’ is related to assumptions around the way the organisation should look after its members and develop their skills and competencies. It is similar to the 'involvement' dimension identified by Denison *et al* (2005) which was composed of three sub-dimensions: empowerment (of employees by the company); team orientation (i.e. cooperative work is valued) and capability development (of employees). It is also closely linked to the 'supportiveness' dimension identified by Sarros *et al.* (Sarros *et al.* 2005) and the 'development of the individual’ and 'humanistic workplace' dimensions described by Ashkanazi *et al.* (2000).

Figure 19: Conceptual map of organisational culture dimensions according to Schein (2004) and other authors.



'Identity and individual roles' refers to a dimension that I found important during my employment and during the first case study in particular. I was very surprised when joining the EA of the strength of people's professional identity and their beliefs on their role in society. Of particular interest was the way individuals presented themselves as 'ecologists', 'conservationists', 'biologists', 'geomorphologists' and how important these labels were to them. I also found that these labels were associated with a series of beliefs on knowledge, behaviours, skills, society membership that were shared to the extent of being important in the recruitment and socialisation of new staff. This sense of identity did not necessarily come from prior socialisation at university. In fact, a lot of staff who considered themselves as conservation experts had previously been trained as scientists. I also realised that this sense of identity was not specific to the Environment Agency but cut across environmental organisations such as English Nature and the Wildlife Trusts.

This dimension relates to the sociological concepts of communities of practice (Hatch & Cunliffe 2006), page 129): ' *communities of practice are based on the idea of self-organisation through co-ordinated activity. They are formed when groups of people share ideas and knowledge that allow them to develop new practices as they learn together*'. They are '*groups of people informally bound together by common interest and shared repertoires (e.g. routines, vocabularies)*'.

'Identity and individual roles' therefore deals with assumptions on the way individual identities and roles are defined and their importance in structuring the group. Are they allocated by the group, the organisation, or chosen by the individual? Are Identities driven by previous training, professional environments, or existing communities of practice?

The nature of human relationships dimension relates to assumptions on agreed/accepted modes of communication, interaction, power and authority. The power distance element is taken from Hofstede's analysis of national cultural differences (table 8).

Interaction can be seen in different ways depending on:

- whether a group values co-operation versus competition, individualism versus collectivism (Hofstede, 2001), gender, race and class differences;
- the relative priority given to work compared to family and personal activities.

From these two sub-dimensions will emerge a series of assumptions on how communication is performed, its shape (e.g. its level of formality) and content.

The nature of reality and truth dimension is extremely important as it reflects the overall world views or theoretical paradigms assumed by members of the organisation.

They can be assimilated to the ontological and epistemological constituents of scientific paradigms described earlier.

Assumptions around the nature of reality are the organisation ontology. How is reality perceived? Is it complex, simple, reducible? Reality can be defined at the level of the individual, constructed by society or instead be viewed as something external, independent that can be revealed through experimentation alone. The low and high context cultures differ in their perceptions of reality. Low context cultures assume that cause and effect can be clearly and unambiguously established whereas in high context cultures, there is no such assumption and events can only be understood in context. Cultures will display different levels of tolerance towards uncertainty. For engineers, uncertainty needs to be reduced or controlled; for social workers, uncertainty is part of their day-to-day work. 'Moralism versus pragmatism' differentiates cultures where individuals seek validation of their perception of reality in experience (e.g. experts or scientists) or in a general philosophy, moral system or tradition (e.g. dogma/religion).

Assumptions around the nature of truth will deal with questions such as: what constitutes data, information and knowledge? Cultures may value different types of knowledge: qualitative, quantitative, tacit or explicit, general or specific (e.g. local knowledge), and may have different views on how to derive it. Some may insist on the use of controlled experiments, others may believe in experience as a way to gather knowledge, and some may see knowledge as something that is revealed (e.g. shamanic cultures). Knowledge generation may therefore be based on rationality, judgement or ideology/religion. Its evaluation may be carried out in an objective way (external validation), through a social process or at the level of the individual (e.g. expert).

The nature of human nature relates to sets of models and beliefs on what it means to be human, what our basic instincts are, and what kinds of behaviours are considered inhumane and ground for rejection from the group. Humans can be perceived as intrinsically good or bad, lazy or hard-working, rational or irrational, adaptable or not *etc.*

The nature of human activity describes human relation to nature. 'Doing orientation' assumes that humans can actively control their environment whereas 'being orientation' will regard nature as powerful and will adapt rather than dominate. 'Being-in-becoming orientation' assumes that individuals need to live in harmony with their environment and put the emphasis on 'self-development' and 'self-actualisation'.

The nature of time and space. The last two dimensions address assumptions on the way time and space are perceived.

Space definition, distribution as expressed in physical layout, body language, visible or invisible boundaries, carries symbolic meaning and reflects other dimensions such as power distance, relationships and status distribution.

Time may be measured in different ways. Time horizons, acceptable limits and attitudes towards deadlines (planning versus development time) may vary whether we are in an engineering or research organisation. There may also be differences in the way time and tasks are managed: monochronic cultures will deal with one task at a time whereas polychronic cultures will happily multitask. The occurrence of both trends within an organisation may create an asymmetry that can generate frustrations and inefficiencies.

Summary

Throughout this section, I have presented a series of dimensions taken from the work of Schein and others which provide a conceptual framework for understanding culture within an organisation. The list is by no means exhaustive and more dimensions may be added.

It is important to remark that despite being separated on the culture map, all dimensions will interact and influence each other in complex ways. The main part of the work of the researcher is not only to characterise each dimension but above all to understand how dimensions influence each other. Only from the analysis of these relationships can emerge a model of how culture works. This methodological point is extremely important in differentiating the (post) positivist from the constructivist approach. Not only is the emphasis put on what is shared rather than differences, but there is no requirement for dimensions to be statistically independent. Instead, it is in the analyses of relationships between set of assumptions that the researcher can make sense of the data, extract meaning and reach the level of basic assumptions. As put by Geertz, '*man is an animal suspended in webs of significance he himself has spun, I take culture to be those webs, and the analysis of it to be therefore not an experimental science in search of law but an interpretative in search of meaning*' (Geertz 1973), page 5).

Other qualitative approaches.

A range of qualitative approaches for assessing culture where reviewed by (Davey and Symon (Davey & Symon 2001). They can be broadly split into two groups: psychological and anthropological approaches depending on the methods used. Anthropological methodologies are probably the most widely used. They are based on ethnography or analyses of organisational history or stories. Ethnographic studies involve the observation by the researcher of behaviours, rituals and artefacts whilst participating (actively or not) to the organisation life. 'Rich' descriptions of culture are then produced and compiled into books or monographs. The aim of ethnographic studies is not to produce generalisable knowledge or predictions, but to concentrate on the specific and, through an in-depth analysis of a single or a small number of cases, extract the dominant themes of interest that enable a better understanding of the culture studied. The themes may have value or not for describing cultures and may be used for making broad predictions on future changes; but ethnographers do not claim any form of objectivity or replicability. Knowledge is instead constructed as part of a social process involving researchers and participants. It is therefore vital that researchers state their own biases and take these into account when analysing data.

Ethnographic studies can be long and costly to run and require the researcher to be accepted over a significant period of time by the organisation and its members. An alternative is for researchers to run discussions or interviews with a selection of individuals focussing on specific aspects of culture. Schein suggests carrying out the analysis of culture with representative members of the group. The researcher therefore acts as a facilitator for the analysis that is performed by the group subject of study. The sample studied is not necessarily representative in a statistical sense but is selected according to the aim of the study and prior discussion with managers. Schein calls this method the 'Clinical Research Model'.

Validation

Validation in such studies is problematic as the interpretation of data is subjective in nature and cannot easily be reviewed. A standard way of ensuring validity and reliability is by having several independent researchers participating to the observation or analysing interview transcripts and comparing results (Silverman 2005). Schein identifies two components for judging validity: factual and interpretative accuracy. Factual accuracy can be assessed by a process of triangulation where data are gathered from other sources, studies and documents. Interpretative accuracy can be tested by using independent researchers account and by producing predictions of future organisational behaviours (Pliskin *et al.* 1993). Another way of validating constructs and testing their generalisability is to produce questionnaires that specifically tackle the themes identified and run them across a series of organisations. The questionnaire responses can then be analysed using a combination of statistical techniques such as Confirmatory Factor Analysis or Structural Equation Modelling (Benamati & Lederer 2008; Yu, Lu & Liu 2010).

In summary, the strength of qualitative studies is that they enable access to deeper assumptions of culture and in-depth analysis of specific cases. Their weakness is in the researchers’ ability to validate and test models of culture and generalise the findings to other organisations.

Summary

As with our review of science and to some extent decision-making, we see emerging the same dualism between positivist (*sensu lato*) and constructivist perspectives on culture. Positivists tend to 'reify' culture, perceive it as a real entity that can be measured using objective means. Constructivists view culture as a 'construct' socially engineered that can only be described and explained using discourse and subjective interpretation.

Positivist methods are limited in scope and outputs. They rarely go beyond the level of espoused values and visible artefacts but they are generalisable and repeatable. Constructivist methods enable access to deeper assumptions, but at a cost: studies are more difficult to justify, validate and replicate; generalisation is not readily possible and their predictive ability is limited.

However if one is interested mainly in specific assessments rather than general theory building, constructivist methods offer more flexibility, depth and subtlety. They also consider culture as a whole and do not attempt to slice culture into organisational, national, gender, or professional components.

Interactions of culture and science/scientific tools.

From these reviews, we can start building hypotheses around the way science and culture interact and relate those to the first case study and other examples taken from the literature.

When facing a problem to solve, scientists develop their own world views based on their own ontology and epistemology. These will result from a legacy of training in the sciences at university and in the workplace. They will be influenced by their own profession and, community of practice and will generally tend to assume a (post) positivist stance towards knowledge building and a deterministic rational perspective on decision-making.

The world is real, and it can be apprehended and explained using experiments and statistical analysis. Problems can be simplified and solved using a rational process aimed at optimising identified outputs.

In the first case study, I identified what the main problems where, sifted through the literature and the Web to find possible scientific models and tools, and then designed and proposed a rational process for delivering catchment management for species/communities. Most of the publications that I reviewed as part of this research took a similar approach.

The Decision Support Systems proposed carried the same ontology and epistemology and decision-making assumptions that I had assumed for its design. This was in keeping with my own assumptions taken from years studying as a scientist, and also my willingness to apply sciences to the field of conservation, which had motivated me joining the Environment Agency.

As resistance against the proposed approach built up, I started to realise that my customers had very different world views. People kept telling me that what I was proposing was '*unrealistic*', '*too simple*', that '*the world is more complex*' that it was '*not specific enough*', that every river was '*unique*'. I also realised that, rather than perceiving themselves as scientists (as suggested by their degrees) they considered themselves as experts and put a lot of value on other experts' opinions. Decision-making seemed to be complex and based on influencing other departments and environmental stakeholders, a process that requires flexibility beyond the simple framework of deterministic rationality.

There was a hidden conflict between the world views supported by the DSS and myself and the world views of the users. Differences on assumptions about reality (ontology), knowledge (epistemology) and decision-making (rationality) appeared to have led to the lack of enthusiasm for the proposed DSS.

There also seemed to be a psychological dimension linked to identity and perception of self-worth and influencing power. Conservation staff take pride in their expertise and ability to make decisions based on their experience and gut feelings. By presenting models that are simplifications of reality and that produce accurate predictions without the recourse to expert opinion, the proposed DSS was in effect devaluing their expertise and affecting their sense of self-worth. This was expressed in reflections such as '*we don't need models, we already know what is needed*' or '*models don't work*' and statements regarding the potential threat posed by making model outputs accessible to the public and the customers they regulate. Issues of power, professional and personal identities seemed to be important in their attitude towards the proposed tools.

All these aspects could be linked to aspects of organisational culture as they relate to the perception of the group within the organisation and the perception of individuals within the group.

<u>Science and culture in the literature</u>

As seen in chapter 3, the issue of DSS rejection is widespread in the literature. It is even more evident when broadening the search to all Information Systems (Hartono, Santhanam & Holsapple 2007) and Information Technology (IT) in general. For example, Ramamurthy, Sen and Sinha report statistics that suggest that only 15 to 20% of companies having adopted a Data Warehouse system reported successful implementation, and more than 50% resulted in failures. The same applies to Enterprise Resource Planning (ERP) systems which showed implementation successes of less than 25% (Burns & Hewitt-Dundas 2009).

The role of organisational culture in IT acceptance was suggested as early as 1974:

'*Systems are designed in terms of a vision of man and man's needs and abilities which is greatly influenced by the system designers own values, training and experience. In a situation where the potential users of the system may like time, knowledge, and perhaps the motivation to become involved in the design process, the system designer is left to create his own organisational reality and this may not coincide with the reality of people in user departments*' (Hedberg & Mumford 1974).

Pliskin *et al*. (1993) expanded on existing methods for studying resistance to Information Systems by adding a cultural dimension. In a case study example, they showed how a computerised Employee Evaluation System aims and objectives conflicted with user assumptions on power, relationships, activity orientation, decision-making, performance and rewards, conflicts which ultimately led to its rejection.

Jones, Cline and Ryan (2006) explored the cultural barriers to knowledge sharing during the implementation of an ERP. They found that two dimensions of culture: 'orientation to change' and 'basis of truth and rationality' seemed to explain differences in ERP implementation success between companies who adopted a similar system within the same industry.

Rivard *et al* (2011) explored reasons behind acceptance or rejection of DSS in a study of Clinical Information Systems (CIS) implementation in hospitals. They conducted their research using Martin's three theoretical perspectives on culture which considers cultural manifestations not only at the level of the organisation, but also amongst smaller groups or sub-cultures and individuals (Martin 2002). This approach led them to identify a series of cultural factors affecting the uptake of CIS and the development of propositions around culture and CIS interaction. The value of using a more interpretive approach towards studying culture-DSS interactions was further demonstrated in a similar study on the implementation failure of a Virtual Learning Environment DSS by Jackson (2011).

Culture does not only act at the level of technology acceptance by users, it also affects the development process. Kankanhalli *et al*. (2004) showed how national cultural values such as 'masculinity-femininity' and 'individualism-collectivism' within Information Systems (IS) teams affect the technical and economical content of IS project management.

In a study of a software development company, Iivari and Abrahamsson (2002) showed how software engineers, managers and usability specialists had different perceptions of User-Centred-Design methodology. Managers and usability specialists tended to be more enthusiastic towards UCD whereas software engineers were more sceptical about its usefulness. Similar results were found by Wurster, Lichtenstein and Hogeboom (2009) for the implementation of IT systems into a large hospital.

Leidner and Kayworth (2006) and Kappos and Rivard (2008) provide comprehensive reviews of the links between culture and Information Technology development and implementation. Leidner and Kayworth reviewed 82 papers of which 51 looked at the impact of national cultures on IT and 31 concentrated on organisational culture influences.(Kappos & Rivard 2008)reviewed 56 papers on IT and culture impacts. Both reviews identified a series of common themes of interest to this research.

Theme 1 - Culture and Information Systems development: a series of studies looked at the relationship between cultural values and the way IS are developed and found that different nations or groups may have different perceptions of the IS development process.

Theme 2 - Culture and Information Technology adoption and decision. 24 studies out of 82 reviewed by Leindner and Kayworth looked at the specific issue of IT adoption from the perspective of national (16 studies) or organisational culture (8 studies). A lot of the studies used Hofstede's or similar Factor Analysis derived dimensions to explain levels of IT adoption. 'Uncertainty avoidance', 'power distance', 'individualism-collectivism' and 'masculinity- femininity' where all linked to IT adoption. For example, high uncertainty avoidance cultures would tend to resist the adoption of computer tools. Also, '*groups are more likely to adopt a technology if their own values match or fit the values embedded within the technology of those associated with its development*' (Leidner & Kayworth 2006). The authors concluded that technology is not value-neutral and comes with its own assumptions about work practice and decision-making. These can be perceived as a threat or annoyance by users and may result in conflict or resistance to technology. A similar theme emerged from Kappos and Rivard review who found that '*culture moderates the relationship between IS characteristics and user acceptance/resistance of the IS*' (page 610).

Theme 3- Impact of IT on culture. The potential threat that IT may pose to culture and work practice is exemplified in Leindner and Kayworth 5th theme which deals with ' the impact of IT on culture'. When IT solutions are implemented within organisations, it is often to change or streamline existing work practices. The assumptions built into the system may often reflect the developers but also the manager's perspective is on how things should be done. IT may therefore be used in this context to promote change. The few studies that have looked at the impact of IT on culture have found that IT can have significant impacts on user perceptions and beliefs. For example, Doherty and Perry (2001) found that a Workflow Management System introduced in a company resulted in stronger cultural values related to ''customer orientation', 'flexibility', 'quality focus', and 'performance orientation'. In their review, Kappos and Rivard came to the same conclusion and found that IS has the ability to transform culture by promoting desired practices through the implementation of systems embedding those practices.

Theme 4 – Impact of culture on the use and outcomes of IT. Both sets of reviews found that organisational and national cultures have strong influences on the way IT systems are used. '*While the majority of the research looked for the direct implications of national or organisational cultures on some aspects of IT, the notion of cultural fit has emerged as an important concept in the IS-culture literature. The concept of fit is that the level of congruence between a given group's general values and values embedded in a given system will determine how the social group perceives and ultimately use the system*' (Leidner & Kayworth 2006), page 373).

They go on to develop a tripartite theory of IT–culture conflict where conflict arises from the interaction of group members values, IT values (i.e. the way a group perceives the role of IT with regards to their work) and values embedded in a system.

They identify three types of conflict (figure 20):

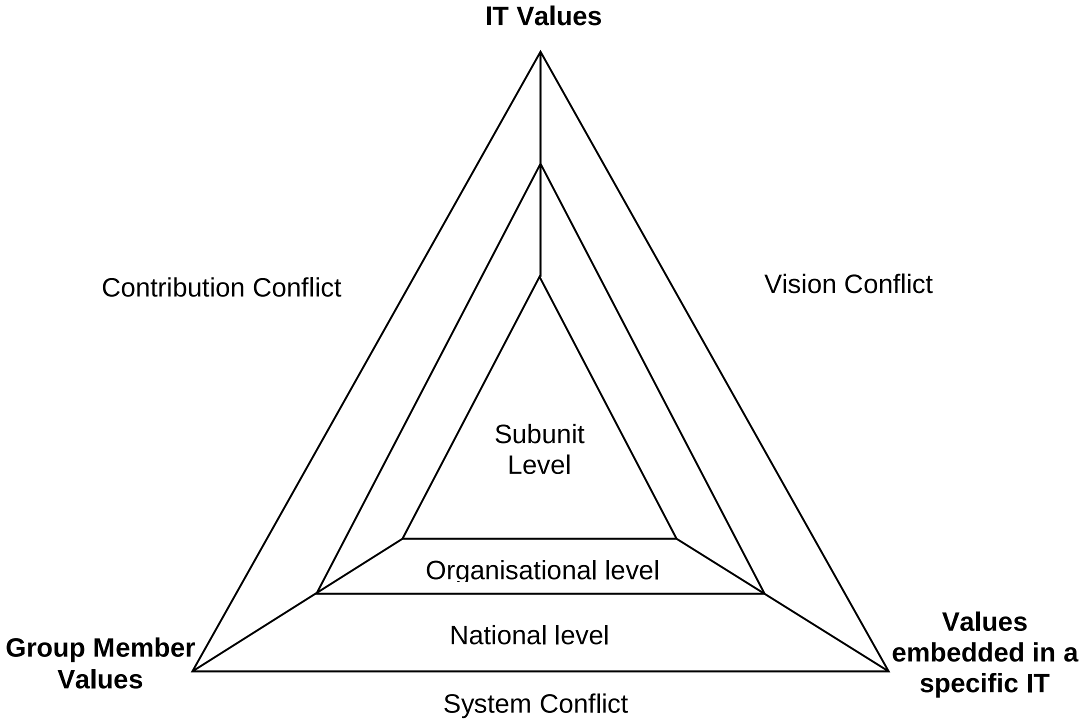
- **System conflicts** between group member values and values embedded in IT.
- **Contribution conflicts** where IT and group members values are diverging. For example, IT values may promote management control and accountability at an organisational level, whereas local cultures value individual decision-making and power delegation.
- **Vision conflicts** oppose IT values to values embedded in a specific system. An organisation may for example promote an efficiency-savings system within a group that sees IT as additional red tape.

Both reviews advocate the study and integration of cultural aspects in IT development to reduce frictions and minimise conflicts. The way the two should be linked is not clearly laid out but the authors suggest instead a series of propositions on potential cause and effect relationships linking cultural dimensions and IT implementation success.

Wang and Yeoh (2009) used a typology based on the Competing Value Framework (CVF), a model for classifying organisations based on two statistically-derived cultural dimensions, to identify the type of information system that would fit and benefits an organisation. Doherty and Doig (2003) also used the CVF as a tool to predict potential cultural hindrances to IS development and implementation. A series of other studies have also used the CVF the study the relationship between DSS uptake and cultural dimensions (Lopez-Nicolas & Merono-Cerdan 2009; Jackson 2011)

It is notable that most studies, if not all, looked at relationships between culture and IS following implementation to produce hypotheses on potential causes of failure. Few attempted to test those hypotheses or design a methodological approach around them to produce and implement a system.

Figure 20: A tripartite view of IT-Culture conflict from Leidner & Kayworth (2006), page 374.



DSS methodological frameworks

As far as design frameworks are concerned, an extensive review of DSS by (Arnott and Pervan (2008) highlights a series of issues that give some insight on DSS development. The authors reviewed 1093 DSS articles published in 14 journals from 1990 to 2004. They identified eight overall issues with DSS development. They found that DSS generally have low relevance to the problem considered or the industry concerned. Only 36% of them could be classified as having high or very high relevance.

The dominant theoretical framework for DSS research was overwhelmingly positivist in nature with 92.8% of studies following that approach. Only 0.4% of papers used more interpretive methodologies such as Action Research. There was also a lack of theoretical foundations for DSS research with nearly 50% of all publications with no reference to judgement and decision-making theory. The focus of DSS development concentrated very much on the development of software solutions (44% of papers) rather than having an impact on the organisation or on decision outcomes.

They linked the lack of relevance to the positivist theoretical framework used and suggested an increase in the number of case study research using a more interpretive (i.e. constructivist) framework. They cite Lee (1999), page 667) who '*argues that the dominant positivist approach in IES research has adversely affected the relevance of the fields. Interpreted and critical social theory investigations are needed to develop deep understanding of professional practice*'.

Conclusion

Throughout this chapter, I have tried to articulate what was originally an intuitive hypothesis that I generated during my efforts for developing DSS in the first case study. I have tried to reflect on my own assumptions and that of the users to find possible causal relationships. My main hypothesis is that organisational culture influences the uptake and implementation of science and technology in organisations. Following the first case study and a review of the literature on science, IT, organisational culture and their interaction, I suggest a possible explanation to DSS rejection or implementation failure linked to DSS design methods and organisational culture mainly that:

- DSS are not assumption and intent free. The theoretical framework of the developers and the reasons behind their introduction will influence their design and cultural content.
- Assumptions about ontology, epistemology, decision-making and other dimensions of culture contained in DSS may therefore not be recognized or conflict with that of the users.
- Cultural frictions and conflicts may result in resistance or rejection of DSS.

We have seen that these issues have been fairly recently identified and highlighted in the wider IT literature. Facing fairly high levels of rejection, researchers have first tried to overcome them by investigating potential problems and developing solutions within their own positivist paradigms, and then gradually started looking into softer issues such as organisational culture. Although there has been some studies describing organisational culture and its impact on IS implementation success, none were found to apply the findings to actual system development. Furthermore, a majority of studies took a very positivist stand towards researching culture which was shown previously to have limited capabilities for eliciting deeper assumptions and extracting meanings.

I suggest the successful development of DSS within a cultural framework requires more than the study of cultural artefacts and espoused values. The first case study analysis illustrated how the lack of success of the DSS was probably based on deeper grounds as the proposed approach affected beliefs on reality, truth, knowledge, decision-making, and above all, the way individuals and groups perceive themselves.

In the next chapter, I will therefore propose a culture-centred methodology based on the constructivist theoretical framework for designing, developing and implementing DSS which will be applied to case study 2. The approach represents a major shift from current practice but will build on existing DSS design approaches. I will also show how the approach can influence the more traditional field of biological modelling and bridge the gap between empirical research and environmental practice.

Chapter 6 Culture-centred DSS design

Introduction

In our first review of DSS success and failures we have seen how DSS were perceived to fail because of problems of usability, ease of use or simply relevance. In the previous chapter, we have discussed the possibility that rejection of DSS and IT in general may also stem from a disparity of fit between the goals and assumptions of developers and those of users. This is specifically manifested in terms of the positivist rationalist frameworks of the overwhelming majority of DSS. These typically make the following broad assumptions:

1. the goals of the users match those embedded in the DSS by the designers;
2. the perception of the problem by users matches that of the designers;
3. the designers, DSS and users share similar ontology, epistemology and assumptions on rationality and decision-making; or users recognise the inherent superiority of the DSS and designers theoretical framework to solve the problem.

Consequently, a failure on any of these conditions is likely to result in:

- users feeling that the DSS is not helping achieve their goals or 'doing the wrong thing';
- users not understanding the DSS conceptualisation of the problem;
- users feeling that it is not adapted to their decision-making environment;
- disagreement on the way the problem should be modelled and solved;
- users feeling threatened by the DSS approach.

As a result, this may lead to DSS being resisted, abandoned or rejected. The main response of researchers and designers to failures on assumptions 1 and 2 has been to adopt strategies to involve users in DSS design (e.g. UCD, Iterative Design Approach) or researchers with the users (e.g. AGILE methodology). These have, however, always remained within the same positivist rationalist framework. Conversely, little has been done to tackle problems related to assumptions 3. When the issue of IT and culture fit was investigated, it also generally involved the use of positivist approaches towards defining culture and studying its impacts post-hoc.

With root flaws traced to this embedded positivist rationalist framework, this chapter explores an alternative constructivist theoretical framework for the design and development of DSS. The emergent methodology will then be used to account for organisational culture and individual needs.

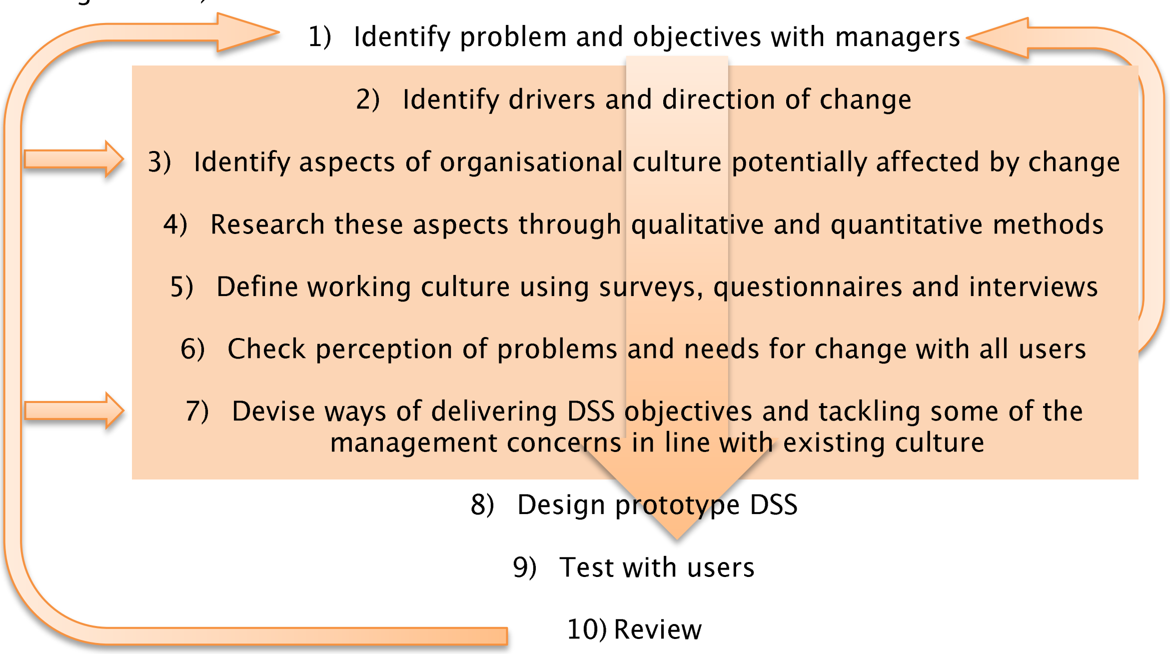
Following the first case study, I was approached by the Environment Agency national Fisheries Science team to help with the development of decision support tools for habitat management for fish. Previous work with Fisheries in the EA had shown the potential for using the data I was managing at the time (i.e. the River Habitat Survey data) for modelling fish habitats and planning habitat enhancement work. The project was at its inception stage and had been broadly defined, leaving a lot of uncertainty as to what exactly it was supposed to achieve and how. At the same time, the Fisheries team in Thames region wanted to make use of existing data to help prioritise sites for habitat enhancement work. The two initiatives eventually merged into one. Identifying this as an important opportunity to address a research gap, I decided to develop this project into a PhD aimed at developing tools to assist the efficient prioritisation of sites for habitat management work through a dual focus on organisational culture and practical ecology. This importantly develops ecological decision-making within a framework that recognises the cultural conditions that regulate agent choice.

Methods

For this case study, a constructivist theoretical framework was chosen. The methodology was based on hermeneutics, the science of interpretations and involved the analysis of interviews and group transcripts (Silverman 2005).

In the previous chapter, I built a conceptual map representing organisational culture following a review of existing literature. This map will form the basis for my investigations into the link between DSS aims and objectives and the Environment Agency Thames region Fisheries section working culture. The investigation steps can be summed up as a flowchart (figure 21). Steps 1 to 6 will be covered in this chapter. Steps 7 to 10 will be addressed in chapter 7.

Figure 21: Iterative design approach with embedded cultural investigation (in coloured rectangular box).



The investigative strategy chosen was based on the prior assumption that managers, in setting the development of a new DSS, were somehow dissatisfied with the way problems were solved and wanted to enact change in work practice. The overall DSS design framework followed the iterative design approach suggested by Sprague and Carlson (1982) but critically included an embedded cultural component aimed at defining culture and identifying solutions based on cultural preferences. I called this approach a culture-centred iterative design approach.

The first 2 steps aims were to:

- clarify the nature of the problem with managers;
- agree a series of objectives for the DSS;
- identify the main drivers and the direction of change needed.

A meeting with the project managers at national and regional level was convened and a presentation on the issue of culture and decision-making was given. The managers were then asked to debate the objectives of the system and the reasons/drivers behind it. A flipchart was used to gather all statements. The statements were then analysed and a conceptual map describing the needs for the DSS was produced using MindManager 6 (see figure 23 in the results section). A series of themes were identified and statements taken from the meeting were associated with each theme. The resulting map was distributed by e-mail for comments to the participants and presented at another meeting to obtain feedback.

A second map was drawn using the same data looking specifically at the drivers behind DSS needs (see figure 24 in the results section). These could be split into 2 groups: explicit and implicit drivers. Explicit drivers represented legislative or corporate objective-based need. Implicit drivers represented the internalised, cultural concerns of management with respect to Fisheries work practices.

A final map summarised the previous two maps and described changes in Fisheries officers work practice that needed to be supported by the DSS and lists aspects related to the delivery/implementation of change (see figure 25 in the results section).

The next step was to identify aspects of organisational culture potentially affected by change. The culture map produced in chapter 5 was annotated using the explicit and implicit drivers of change and themes identified in step 3 (see figure 26 in the results section). Each theme was allocated to one or more dimensions of culture. The cultural dimensions were then coloured according to the potential level of impact/friction generated by the suggested changes.

A series of questions were put together to investigate all cultural dimensions of interest at individual interviews, focus group meetings and internet/e-mail questionnaires. As group debates tend to lead to consensus based on the views of dominant members of staff, some questions were reiterated at group and individual interviews (Fontana & Frey 2005).

At the time of the research, the EA Thames region Fisheries section was split into four main teams dealing with specific sub-catchments of the river Thames (Appendix 8). These teams were associated with three main areas, each with their own management structure reporting to regional headquarters. Fisheries teams were part of the Fisheries Recreation and Biodiversity (FRB) unit. Each Fisheries team had a team leader, a technical specialist who was responsible for dealing with technical, analytical and methodological issues, and several catchment officers responsible for day-to-day fisheries work in specific sub-catchments. FRB is also represented at regional level where planning and coordination of Fisheries activities take place.

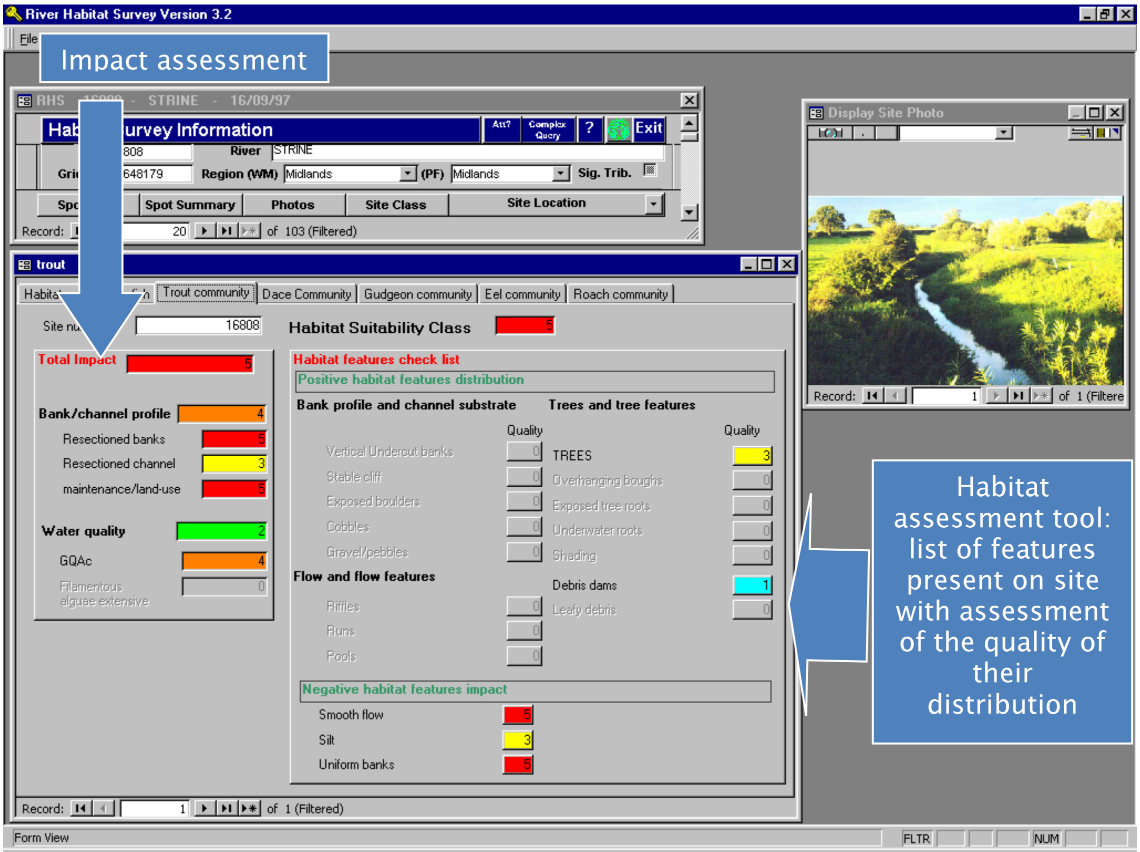
Focus group meetings were held with the three Fisheries teams corresponding to the freshwater side (i.e. nontidal) of Thames catchment. A focus group meeting was organised exclusively with technical specialists. Team leaders were not invited at group interviews to avoid potential self-imposed censorship or 'groupthink'. In an attempt to gain support for the process, the first focus group meeting was organised with more experienced members of staff, the technical specialists. The research motives and objectives were introduced by the regional Fisheries strategist.

All focus group meetings and individual interviews were run using a semi-structured interview protocol (Silverman 2005). Individuals were encouraged to speak and express their point of view and questions were often used to stimulate debate. Presentations of existing DSS taken from the literature review carried out as part of the first case study were also used to generate reactions. The interviews were recorded using digital and tape recorders. Permission to record individual and group meetings was asked at every interview. Interviewees were guaranteed confidentiality over their identity in any transcript or report published. Individual interviews lasted one hour and group interviews 2 hours.

Before starting interviews and focus group meetings, a short presentation on the aims and objectives of the project was given. Interviewees were presented with a summary of management concerns identified in steps 1 and 2 and asked to react to any of the material presented. Based on the outputs from the meeting with managers and the first focus group with technical specialists, a prototype DSS was produced to demonstrate potential options for addressing all issues identified. The prototype was developed using Microsoft Access 2007 and included real data whenever feasible. Interviewees were asked to react to the prototype at any point during the presentation. Several versions of the prototype DSS were developed as interviews went on to reflect interviewees' feedback and to include new elements or processes that matched the users' culture and preferences. For example, following the first group meeting with technical specialists, a new interface for inputting local knowledge on river reach history was introduced. Feedback was also used to refine perceptions of the main issues identified by management (step 1), aspects of organisational culture potentially affected by change (step 3) and devise ways of delivering change through the DSS design. In the same time, work was carried out on putting together the building blocks of the future DSS (literature review, data collation, modelling *etc.*).

The first version of the prototype contained a tool for assessing habitat quality for fish communities that was developed as part of previous research. The tool was mainly based on fisheries, River Habitat Survey and water quality data. It enabled users to assess fish habitat quality using a dashboard of habitat features and man-made pressures colour-coded according to their relative impact (figure 22).

Figure 22: Screenshot from the habitat assessment tool prototype DSS used for the first focus group meetings. This tool was developed as part of previous unpublished work with the RHS team to demonstrate the potential use of RHS for assessing habitat quality and pressures on fish communities for the Water Framework Directive (WFD). The tool included a habitat assessment tool with a checklist of habitat features associated with trout, and an impact assessment tool with a list of potential pressures on habitats.



My attitude as a researcher was at no point 'naïve' or 'candid'. My identity and working history was known by most members of staff. This had the advantage of giving me an insider status potentially fostering trust. I also tried to use informal discussion with managers and ex-colleagues and personal information gained from my own experience to build trust and facilitate open discussions and debates. I emphasised and described the iterative nature of the development process and the central role of users in driving the shape and content of the Decision Support System. I also explained the methodology used, the role of culture and the aims of group and individual interviews in defining work practice. The interviewees were told that the purpose of this exercise was to assess the need for a DSS and to develop a tool that fitted their ways of working. Transparency in the project aims, data analysis and results was required to avoid shadows that could suggest any hidden aims.

The individual interviews were transcribed by professional typists and analysed manually by the author. The group interviews were transcribed by the author as typists would not have been able to recognise the identity of individuals. Coding of the transcriptions was done by identifying a series of themes and subthemes appearing in the interviews (Saldaña 2009). The themes occurring consistently across most interviews and focus group meetings were linked to the map of culture produced in step 3 (figure 31). Themes were further organised in a hierarchical way and links and interactions between themes where indicated using arrows.

To get an idea of the relative importance of individual themes, their occurrence across all interviews was recorded into a table (see appendix 5) and their relative occurrence was derived (in percentage). Percentages were calculated using relevant sample sizes based on whether the questions were asked at all interviews, at focus group meetings only or at individual interviews.

The results from the table must be treated with caution. The aim was to derive meaning from a flowing conversation between researcher and interviewees. Because of time limitations, not all questions were asked at individual and group interviews. Priority was given to important topics identified in step 3. It is also important to note that some of the themes were specifically targeted using ad-hoc questions whereas others emerged 'naturally' in the conversation. Because it was only possible to interview each member of staff once, themes that appeared consistently at consecutive interviews and that seemed to be shared across the board were sometimes dropped to concentrate on other aspects of culture not already covered. A comparison of the relative occurrence of themes is therefore likely to be biased. Theme occurrence (TO) in percentage will be indicated in the result section along with the sample size used.

An additional online survey was performed to gather information on user computer, analytical skills and demographics and to learn more about their degree of confidence with using specialist software, analysing data and developing strategies. The data were analysed using simple descriptive statistics.

A final map summarising the EA Fisheries section working culture and potential interaction with the proposed DSS was produced. The map was used to identify a strategy for developing a Decision Support System that will achieve the aims stated by the project managers whilst minimising potential cultural frictions (figure 32).

A final prototype DSS was put together using Microsoft Access 2007 and an open source ActiveX mapping component called MapWindows (Ames 2006). The prototype DSS was presented to users at meetings and workshops to gain their feedback.

Results

Problem identification (step 1)

The brainstorming session with project managers yielded a series of themes that were grouped into simple headings (figure 23). The layout of the map in figure 23 follows a typical software/projects development format and includes five main sections: DSS drivers, perceived problems, DSS needs, users and criteria. Statements recorded during the brainstorming session were associated with each section. Statements sharing a common subject were grouped into themes such as planning, customer link *etc*.

At the centre of the map is the Decision Support System. The main aim of the DSS was described as '*prioritising sites for habitat enhancement work for fish*'.

DSS drivers and perceived problems

The main DSS drivers were corporate or legal drivers. The Water Framework Directive required member states to achieve Good Ecological Status by 2015 (European Union 2000a). This implied that sites were assessed for their naturalness, potential pressures on fish communities were identified and remediation action was taken in the shape of habitat enhancement work or other improvements (e.g. water quality improvement). At the time (2006), a substantial amount of funding was available for such work at national (£2 million per year) and regional levels. In Thames region, a special deal with the Flood Risk Management (FRM) section that looks after flood protection but is also responsible for environmental damage made £500,000 available each year for habitat improvement works. This money had been used by Fisheries officers to run habitat improvement schemes around the region in a fairly ad-hoc opportunistic fashion. Although this was going some ways towards fulfilling the aim of the habitat enhancement fund, it was considered by FRM and Fisheries managers as too opportunistic and with no clear benefits or contribution to wider targets such as the WFD. Additionally, the lack of audit trail in the shape of post-project appraisal schemes (i.e. monitoring) made it impossible to quantify or at least assess observed benefits to fish populations or anglers. This lack of transparency could potentially lead to litigation, a failure on WFD objectives, and an overall inadequate use of scarce resources.

Another perceived problem was knowledge management and staff turnover. It was felt that precious skills, experience and knowledge of local catchment had been lost through staff retirement, job change and restructuring. The EA had indeed recently undergone a major restructuring exercise called BRITE that had generated staff movement between teams and led to individuals leaving the organisation. Managers expressed concerns at inconsistencies in staff skills, an over-reliance on set processes available in the organisation process database (called AMS) and a lack of time to get to know local catchments.

DSS needs

All these concerns led to the identification of a series of needs or requirements for the DSS. The main need was to move away from opportunistic decision-making towards more planning and strategy-based development. The DSS would have to enable habitat enhancement planning and efficient uses of resources. The plan would feed into the business plan, team and individual objectives. It would help identify gaps in knowledge and data and setup monitoring strategies. It would bring more control and effectiveness in the decision-making. The approach taken would have to link to legislation and be based on the risk of failing existing environmental targets (e.g. WFD Good Ecological Status target). It would need to be transparent, demonstrate best practice and enable good communication with customers (e.g. Angling clubs, FRM staff *etc*.). It would need to be adaptive and help build knowledge and bring current information held in EA databases such as the River Habitat Survey (RHS) and the National Fisheries Population Database (NFPD) in the decision-making process.

DSS criteria

A series of criteria for the DSS were discussed. The possibility that the tool may be shared with external organisations was mentioned. It was suggested that a simple tool should be developed first whose remit could be broadened at a later stage. Questions as to how knowledge was updated within the tool and how it could account for different management strategies were raised.

Importantly, it was felt that the DSS had to enable internal consultation, it needed to adapt to user skill and preference, should not be too complicated, and ensure staff retained a sense of their own value to management. Implementation constraints were also identified. The EA had specific policies for IT development and delivery which had to be taken into account. The project would also have to explore potential links with existing initiatives such as the European Fish Index (FAME Consortium 2004) and the River Fish Habitat Inventory project (Wyatt 2004).

DSS users

Users, their needs and preferences were also the concern of the project management team. It was strongly advocated that the tool should not represent another layer of bureaucracy, that training should be minimised, that it should not bind users to the office, be simple and validate staff expertise rather than devalue it. Trust had to be fostered to ensure user ‘buy-in’. The DSS was also seen as a way of addressing perceived skill shortages in data analysis and interpretation and geomorphology. The DSS was advocated as a way of challenging existing knowledge and field skills.

DSS explicit and implicit drivers (step 2)

The above demonstrates a series of concerns and drivers of change behind the need for the DSS. Some were explicitly stated; others were more implicit in management's discourse (figure 24). Explicit drivers of change related to legislation, the need to prioritise sites and justify investment, the need for an audit trail and concerns relating to knowledge management associated with staff turnover. Implicit drivers of change could be grouped into four dominant themes or management concerns: knowledge quality concerns; communication concerns; power and influencing concerns and decision-making quality and validity.

Knowledge quality concerns related to the use of current data, information and knowledge in the decision-making process and the potential risks this posed to Fisheries credibility and ability to fulfil its requirements under the WFD. Two strong subthemes emerged: the use of current data and information, and user knowledge concerns. Management felt that Fisheries officers were not using all available and relevant in-house data such as the RHS, NFPD and other potential data sources within the organisation in the decision-making processes. There was recognition that these data were difficult to access but there seemed to be a tendency to mainly rely on fisheries data alone together with personal knowledge. Concerns over user knowledge were linked to a perceived loss of expertise due to staff turnover, individuals' attitude towards acquiring, updating and maintaining their own knowledge base, and concerns over the breadth of skills available within Fisheries. There were expressed concerns about knowledge gaps on critical issues such as the understanding of fish-habitat relationships, best management practice, the choice and delivery of catchment planning strategies and the general ability to assess the impact of pressures on habitats and fish. These were mirrored with concerns over skill gaps in data analysis, interpretation, the ability to understand river functions and processes and their links to habitats and fish.

Decision-making quality and validity was another strong theme emerging from the analysis. A general need for planning leading to greater control, effectiveness and credibility was stated as one important aim for the DSS. Current approaches toward site selection were considered as too opportunistic and not enough driven by available data and knowledge of river processes.

The interaction of perceived knowledge and decision-making issues led to concerns over communication with customers, their perception of EA Fisheries decision-making, work and overall credibility. There was also a need to improve internal communications with other teams and enable consultation with organisations outside the EA.

The last theme related to conditions potentially affecting the uptake and acceptance of proposed DSS and change. These were mainly issues related to power and influencing which highlighted the need to build trust, to get user 'buy-in', satisfy managers that ground staff feel valued and that the tools were not going to affect the way they work and devalue the expertise. This theme yielded interesting insights on the nature of power relationships between ground staff and their line management and the strength of resistance that may be effected by any attempt at changing existing practice.

Using the previous two maps, we may start building an overall picture of the problem at hand by identifying the nature and direction of change that the DSS needed to support. This is accompanied with a framework for implementation and associated issues (figure 25).

Nature and direction of change in need of DSS support (step 2)

The main changes required were linked to knowledge and decision-making (figure 25). Management's concerns with knowledge seemed to focus on the lack of use of data, models and scientific knowledge and the reliance on personal expertise and its limitations. They identified critical skills and knowledge gaps and hinted at the fact that Fisheries officers' knowledge needed to be challenged. Altogether, this change can be summarised as a move towards the use of a more scientific approach for data analysis and interpretation.

The second most important target for change was decision-making itself which was deemed too opportunistic, lacking planning, and not evidence-based enough. Decision-making of this sort was seen as lacking efficiency, potentially leading to a failure in the delivery of key targets together with a loss of credibility.

The 'Framework for change' theme was built around user preference and work practice. It catered to the needs of users to be in the field, to have bureaucracy and training minimised, and to foster a sense of expertise-value.

The main implementation issues surrounding the development of the DSS were linked to the EA computing department and the way the DSS could be delivered at low cost. Other issues dealt with communication to internal and external customers.

DSS and culture interaction: potential areas of friction (step 3)

The previous two maps were used to identify areas of organisational culture potentially affected by the introduction of a DSS (figure 26).

The main dimensions potentially affected by change related to knowledge and decision-making (in red), relationships and internal adaptation (in orange).

Changes to the way knowledge is perceived relates directly to agent assumptions about reality and truth, i.e. the users' world views on ontology and epistemology. Data and models carry their own assumptions on what constitutes valid knowledge and valid decision-making that may conflict with that of the users.

A move towards evidence-based strategic action planning is likely to impact on current decision-making processes and perceptions around mission, goals and ways of dealing with ecological targets and environmental stakeholders. It is likely to interact with assumptions on the nature of time.

Potential changes to work practice and skill base may conflict with individual perception on roles, identity, needs and goals, and on assumptions on human nature and activity. This may further impact on the way power and status are distributed, the criteria for inclusion/exclusion within the team, shared language and concepts.

Finally, DSS acceptance may be affected by assumptions around communication and 'power distance'. In strongly autocratic working environments, it is conceivable to design a tool that will enact change in a 'top-down' fashion and rely on management's control to deliver change. In more 'democratic' settings, change may not be imposed but negotiated and require everyone's approval.

Aside from cultural assumptions, the DSS could also impact other aspects such as user skills and preferences for learning, technology and information display. The current EA climate following the BRITE reorganisation and issues linked to demographics (e.g. age structure, gender *etc.*) could also influence the uptake of the DSS. These additional dimensions were added to the culture map as floating topics and were investigated as part of questionnaires and interviews.

Figure 26 was used to put together a series of questions to address all aspects of culture identified in the map. The questions are listed in appendix 6 under their respective cultural dimensions. The questions were allocated to individual interviews, focus group meetings and an online questionnaire.

Figure 23: DSS needs and requirements following a brainstorming session with Environment Agency managers. Statements in the shape of short sentences were recorded and organised into a mind map using MindManager 6.

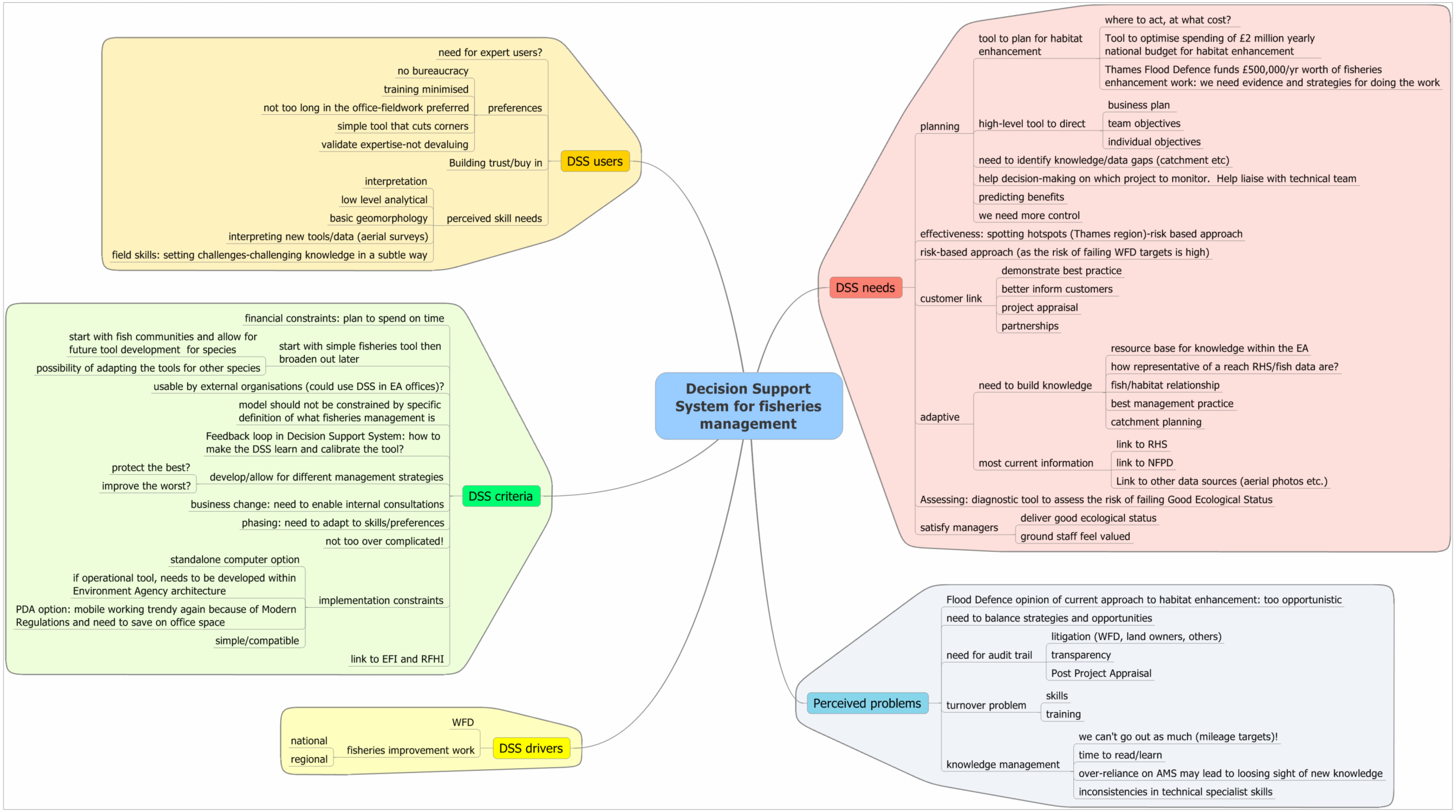


Figure 24: Explicit and implicit drivers of change.

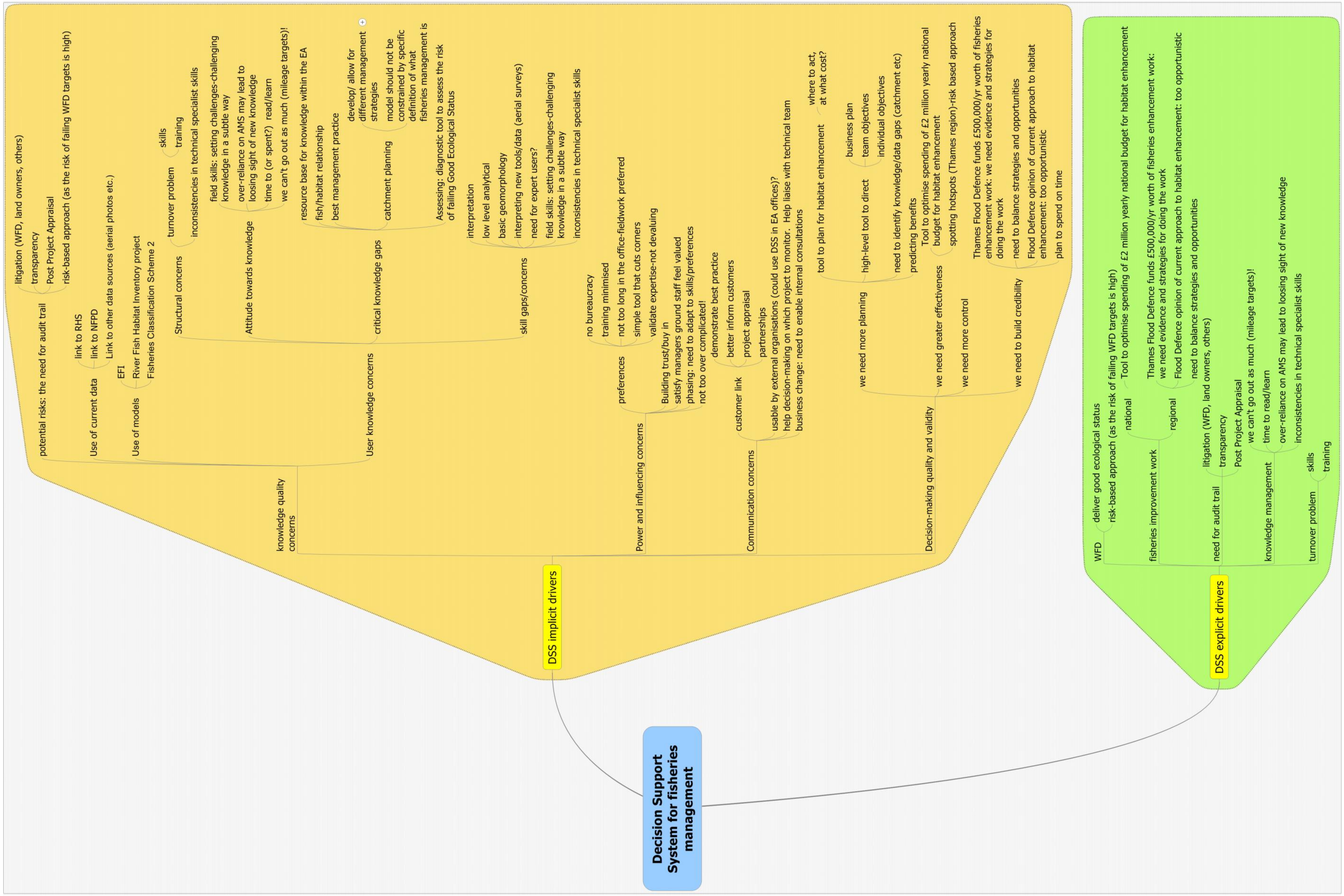


Figure 25: Nature and direction of change in need of support by a DSS along with framework for change and implementation issues.

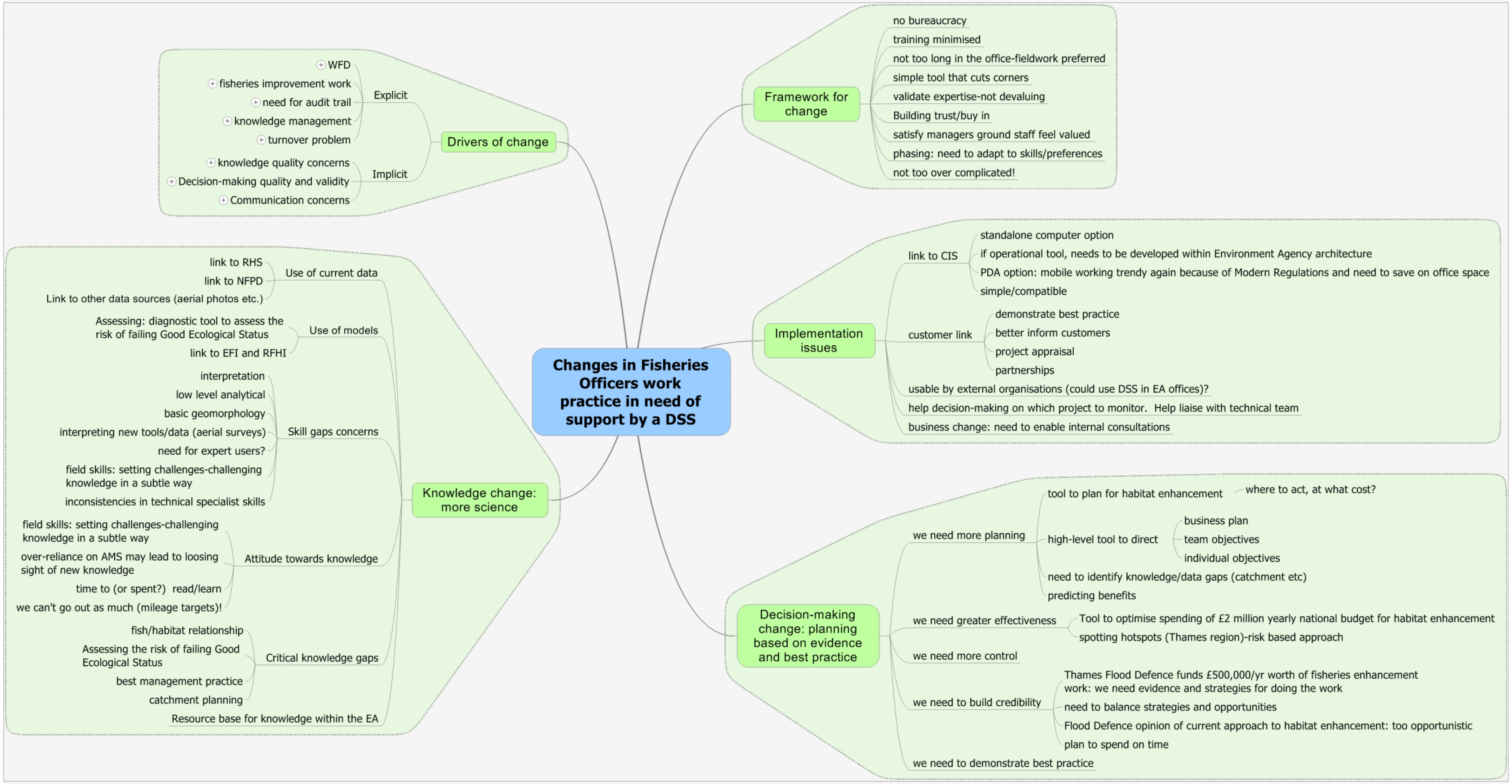
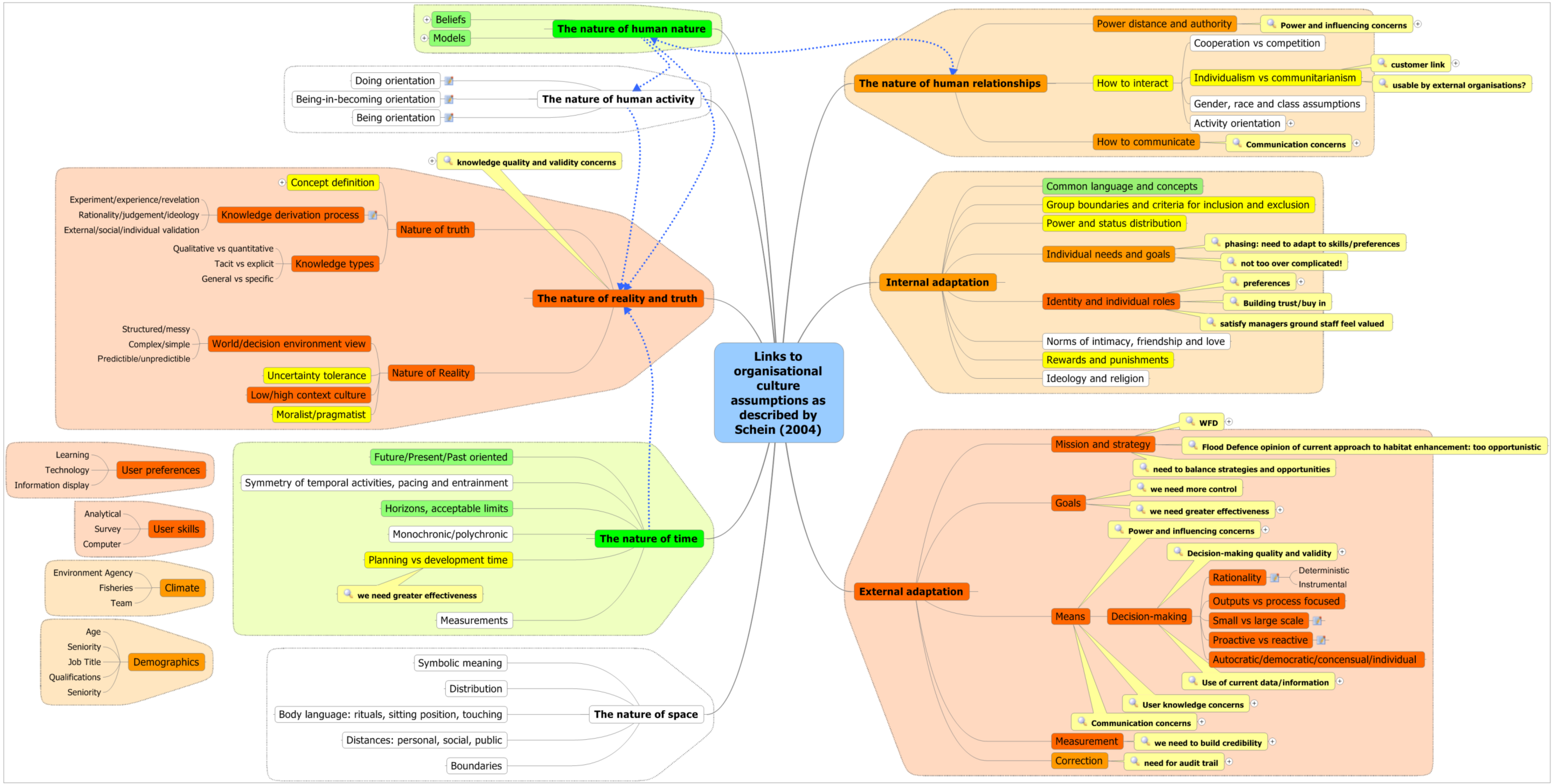


Figure 26: Cultural dimensions potentially affected by the introduction of a Decision Support System for prioritising sites for habitat enhancement work for fish. The cultural dimensions were colour-coded according to the level of 'friction' or impact the DSS may bring about from white (little friction/impact) to green, yellow, orange and red (high friction/impact) based on themes identified in figures 24 and 25 (callout topics in pale yellow).



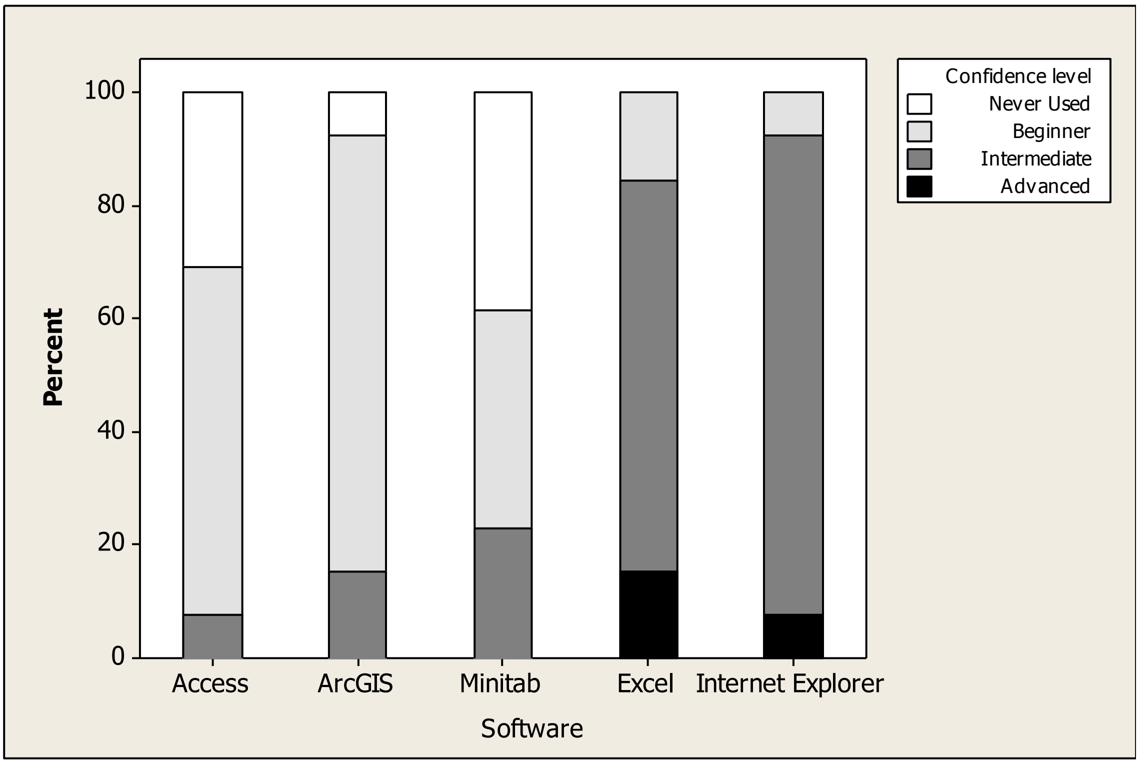
Investigation of culture (steps 4, 5 and 6)

Questionnaire results

The online questionnaire mainly included questions on demographics, the use of evidence in decision-making, proficiency with software and data analysis, and confidence with strategy building and environmental assessment (appendix 7). Thirteen members of staff responded to the questionnaire among them nine catchment officers and four technical specialists. A great majority of respondents were male. In fact there was only one female within the overall team of 21. Thirty percent of respondents were less than 37 years old and 62% less than 35. The median value for catchment officer experience in fisheries was six years and 17 years for technical specialists. Local catchment experience median values were two years for catchment officers and 14 years for technical specialists. Most Fisheries staff was educated at degree level or more (92%) and 38% had postgraduate qualifications.

With regards to computer skills, staff had limited knowledge of GIS software (with only 15% rating themselves above beginner level); database (8% above beginner level) and statistical software (23% above beginner level). Microsoft Excel and Internet Explorer showed the highest levels of proficiency with 84% and 92% of respondents rating themselves as intermediate or advanced users (figure 27).

Figure 27: EA Thames region Fisheries staff confidence levels with software use (N = 13).



When considering the use of existing database and specialist software for ecological appraisal, there were marked differences between the systems (figure 28). The NFPD was by far the most used system with 15% of staff reporting using it frequently and 69% using it sometimes. In contrast, the RHS database, Habscore (specialised software for salmonids) and RIVPACS (specialised software for biological assessment) were never used by the great majority of respondents (RHS: 69%; Habscore: 69%; RIVPACS: 92%).

Figure 28: EA Thames region Fisheries use of existing decision support tools (N = 13).

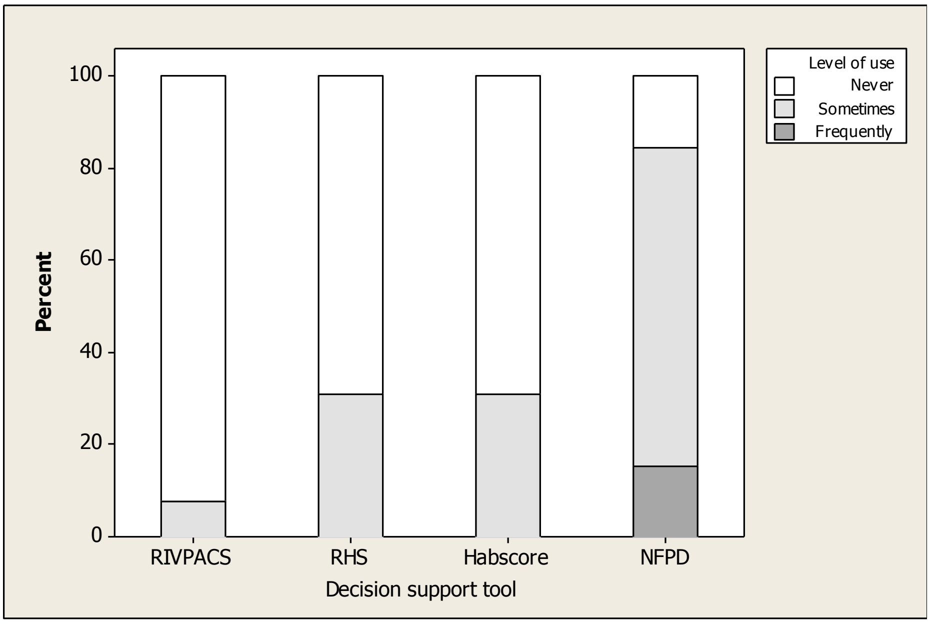
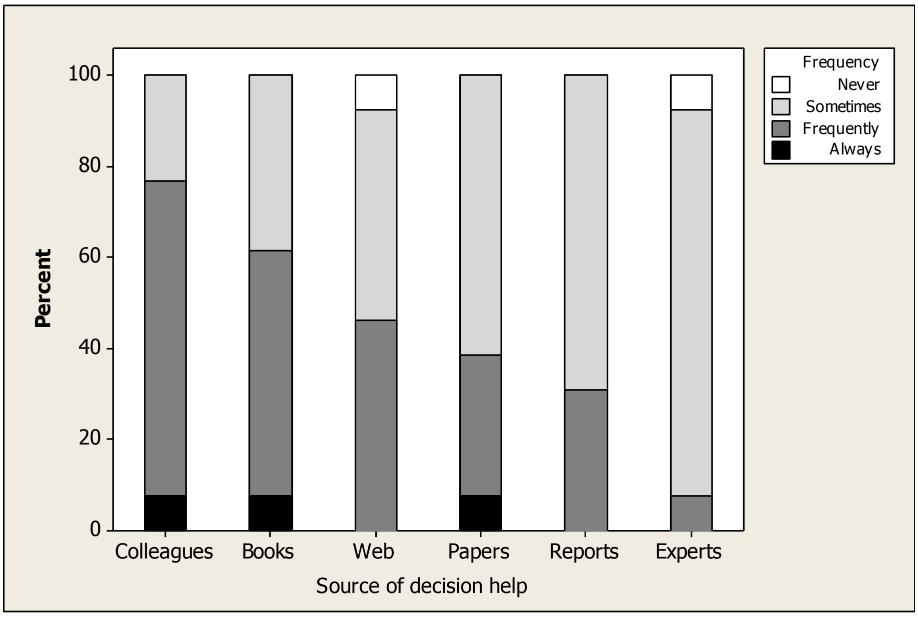


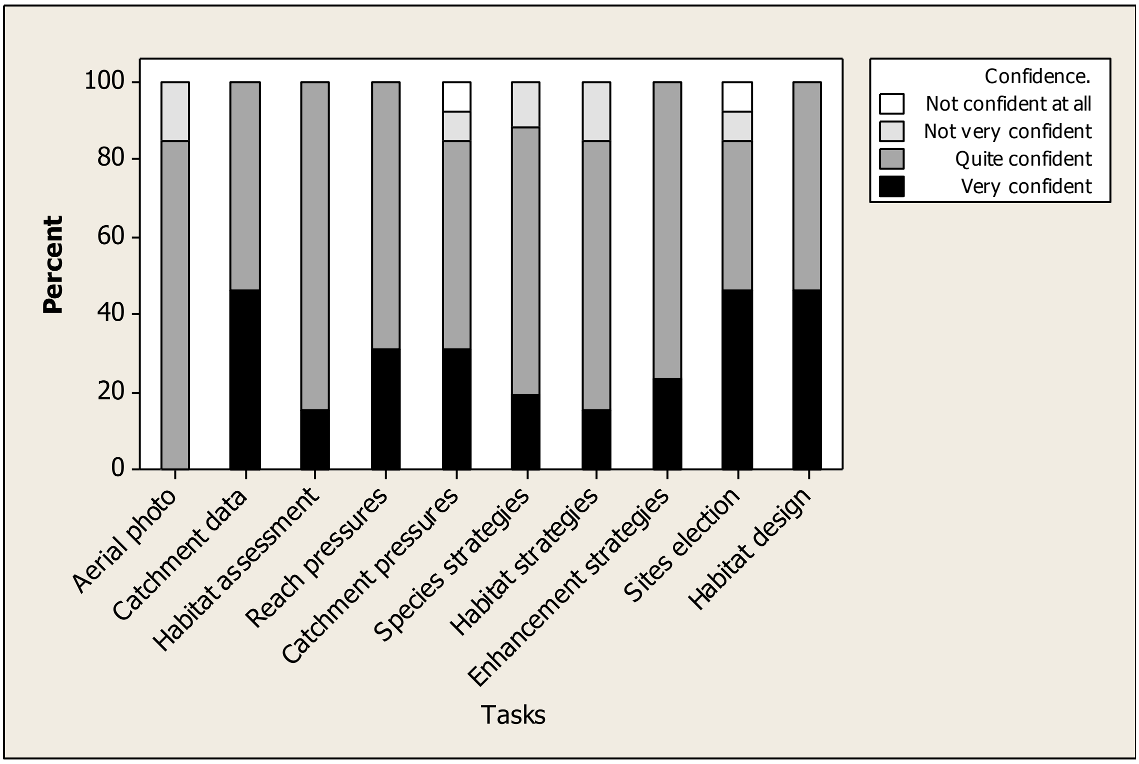
Figure 29: Frequency of use of decision help within Environment Agency Thames region Fisheries section (N = 13).



When making decisions, 77% of respondents sought advice ‘frequently’ or ‘always’ from their colleagues and 62% consulted books (figure 29). Reports and publications were less often used (reports, frequent use: 31%; publications, frequent use: 31% always used: 8%). The web was used frequently by a near majority of respondents (46%) as a source of information whereas advice from recognised experts was rarely sought.

Respondents generally felt confident with most aspects linked to planning habitat improvement work for fish (figure 30). This included data analysis and interpretation (questions 16 a and b) habitat quality assessment (question 16 c), identifying pressures on habitats at reach and catchment scales (questions 16 d and e), developing catchment strategies for managing species and habitats (questions 16 f and g), developing catchment strategies for habitat enhancement work (questions 16 h and i) and designing schemes and monitoring strategies (questions 16 j and k). Fisheries officers felt most confident with assessing habitat quality (46%), identifying and quantifying pressures on fish habitat at reach (46%) and catchment scale (31%), site selection (46%) and analysing and interpreting catchment data (31%). The results suggested overall higher levels of confidence amongst catchment officers than technical specialists but this could be a consequence of low sample sizes amongst technical specialists.

Figure 30: EA Thames region Fisheries staff confidence levels with performing tasks associated with planning for habitat enhancement work (N = 13).



Interview analysis and interpretation

Thames Region Fisheries team comprises 11 catchment officers, seven technical specialists and three team leaders. All but one team leader participated to either focus group meetings or individual interviews. The focus group meetings were attended by 9 out of 11 catchment officers, all technical specialists one team leader and one regional Fisheries staff. Sixteen individual interviews were held with 10 catchment officers, four technical specialists and two team leaders.

Focus group meetings and individual interview transcripts were analysed together. From the analysis, a series of dominant themes emerged which were allocated to relevant dimensions of culture (figure 31). The relative occurrence of individual themes within the interviews is recorded in appendix 5. I will now describe each theme within the context of their dimensions of culture and provide quotes from the transcripts as illustrations. In the transcripts, the interviewer was denoted by the letter 'I' and the respondent by the letter 'R'. A reference to the transcripts will also be given along with line numbers corresponding to the quote.

Whether at focus group meetings or individual interviews, themes surrounding knowledge and reality perceptions were consistent across most respondents. As suggested during the brainstorming session with managers, individuals tended to present themselves as experts rather than scientists. Their world views were constructed in accordance with their perceived identity. Respondents described reality as being complex (TO = 65%, N = 20), unpredictable (TO = 20%, N = 20) and ultimately revealed through experience. The idea that reality could be simplified and approached using blunt statistical tools or models seemed unrealistic or suspicious. This was sometimes expressed in colourful ways by participants.

' *Jim: you know one of the problems with this kind of database is that fish don't read books and, you know, you do get some real anomalies. You get the most fantastic looking habitat ( ) and you get concrete channels which are full of fish.*' (Focus group meeting 1, 1513-1516).

Nature is complex and unpredictable. Fish do not read the books scientists write about them and they follow patterns that cannot always be predicted. Complexity was not only environmental but contained a social element (TO = 20%, N = 20). Fisheries officers had to deal with landowners, anglers and other users of the environment in their day-to-day duties.

Complexity was also about building an understanding of rivers in space and time. Gathering data over a limited area at one point in time may not reveal the whole picture. What is therefore important is local and historical knowledge.

'*James: this is the thing, it seems to be... they are trying to establish a tool that gives you advice based on data but when in reality that is local knowledge over time, over* *history that is the most important component to that decision. Because if you've got that, then that is a very complex decision based on history and not just snapshot in time but knowing everything about the catchment and how that influences what you have and that is really difficult.'* (Focus group meeting 3, 38-44).

Reality was therefore complex and could only be apprehended by immersion in the environment: physical, biological and social. It was revealed by experience (TO = 85%, N = 20). Knowledge building was centred around personal experience of the local environment (TO = 80%, N = 20). Learning was achieved through walking and physically experiencing the river and its environment.

'*So, yeah, so getting to know it [the river], walking it, physically knowing it, having a mental image of every bit of that river in your mind. …' cause the fishery officers, I would say, get to know a catchment and the habitat a lot better than most people because they actually get in the river, and electro-fish … they are generally carried out wading … if you wade in a section of the river, and you are pulling out fauna, literally pulling out with the electro-fishing gear, you're walking so you can feel the substrate under your feet … you can see all the structure in the bank, you can feel the profile. Your colleagues are either side of you, see the profile as you walk along, you know the macrophyte there, you are walking past and through, and you are pulling at it, making very distinct associations between habitat, micro habitat and macro habitat and the fish coming out of it, and I think you get to know, literally, you get to know the river very intimately doing those surveys.*' (Ian, 93-115).

Survey, monitoring is what enabled catchment officers to build up knowledge on habitat and species relationships and their ability to judge the quality of habitat and develop a diagnostic. Intuition based on experience (TO = 70%, N = 20) was the ultimate driver of personal judgement.

'If I see a river, I know pretty much what's wrong with it and what needs doing to it to improve a section.' (Neil, 97-99).

Knowledge is in people's heads and it is passed on through informal mentoring between more experienced members of staff, the technical specialists, and the catchment officers (TO = 60%, N = 20).

' *Yes…because a lot of that knowledge isn't written down anywhere. … a lot of the knowledge is in people's heads, you know, and some of it you could probably find if you looked through enough stuff but it would take you forever…there is so much to learn about those catchments, whereas through mentoring and showing them around, you can show them the big issues…the things that are most pertinent to that catchment … and introduce them to the different people they need to know and deal with.*' (Steve, 124-139).

From this vision of knowledge and reality, it follows that learning was primarily seen as performed in the field rather than in the office (TO = 55%, N = 20). Learning had a small structured component. New starters seemed to be looked after by technical specialists or more experienced members of staff. The bulk of training however, was done in an unstructured or semi-structured way (TO = 20%, N = 20). It was through interacting with other team members (TO = 45%, N = 20) and local stakeholders (TO = 20%, N = 20) 'on-the-job' (TO = 65%, N = 20) through 'trial and error' (TO = 20%, N = 20) using 'informal post project appraisal' (TO = 25%, N = 20) that learning was mainly performed.

'... and then you're going to plan your enhancement scheme and then afterwards you're only going to go back and look at it all again and say hopefully you've had an improvement. And if you have had an improvement then you can say right, what we did was okay, if you don't get an improvement then you're going to want to think start again.' (Richard, 648-653).

Because of increasing workload and 'red tape', 'learning by walking' was becoming more and more difficult.

'There's a lot more bureaucracy, a lot more bureaucracy and a lot more things to stop them doing, what's the important part of the job, which is knowing the catchments and knowing the people in the catchments.' (Nick, 15-18).

Learning then became opportunistic (TO = 30%, N = 20) and most learning therefore happened at small-scale (TO = 45%, N = 20).

' *So it's opportunistic. Most of the learning comes opportunistically through, for example, if you get a land drainage consent in a flood defence consent as they are now, or construction or a pollution incident or whatever, it takes you out into the field, and when you are there you just take the opportunity to look at a bit more than the bit you are looking at.*' (Ian, 60-66).

Experience had limitations that were highlighted by a few participants (TO = 45%, N = 20). Knowledge varied greatly in quality depending on the amount of experience individuals had. Beliefs based on limited evidence may become entrenched in practice (knowledge quality theme, TO = 20%, N = 20).

' *I think people look at a reach of a few hundred meters and they don't really have much of a view for the whole catchment and they hope that eventually in the course of their entire career, they will have eventually got to all of the bits in the whole river system and improved them all. I think people have a view of what a river should look like and that they try and impose that view on each opportunity that they get.*' (Graham, 111-122).

Opportunity to learn from experience was also limited by the lack of properly funded and applied post project appraisal (TO = 25%, N = 20) and the lack of formal policy.

' *But the learning structure there, is very poor when it comes to this sort of thing … you know I want someone to be able to look at my projects and go well you shouldn't really have done that, and that's not great and all that … the monitoring is difficult, because you need additional funding say, three, four, five years after you finish the scheme.* (Stuart, 1233-1269).

Data from various sources were not systematically used (TO = 20%, N = 20).

'*Graham: Yeah. I think Fred said that most Fisheries people start with fisheries data and I think that, in the past, quite a lot-certainly, I have been a bit guilty in that you start and end with fisheries data.*' (Focus group meeting 1, 650-653).

Science and its limitations was the subject of much debate at focus group meetings and across individual interviews. First, there was a lot of concern regarding the quality and validity of data used for modelling fish and their habitats (TO = 65%, N = 20). The methods used to gather such data were described as having flaws (TO = 50%, N = 20), being subjective (TO = 25%, N = 20), and generating a lot of variability (TO = 50%, N = 20). Talking about Habscore, a methodology for assessing habitat quality for trout and salmon, Neil made the following remarks:

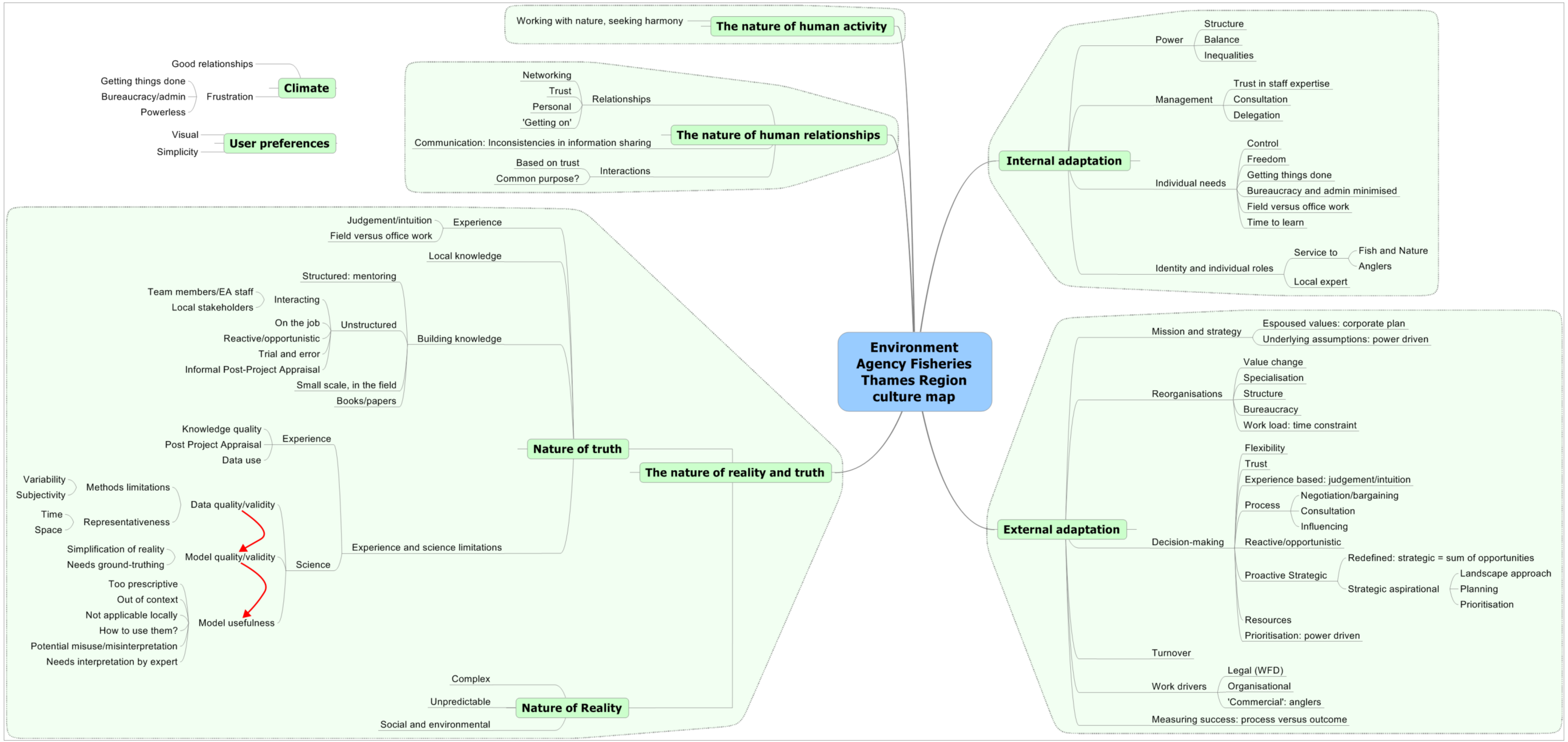
'*R: Yes, on Thursday we're going out to do redd counting, looking at Trout, Trout spawning areas and looking for where the Trout are spawning and as we go up there we Habscore, but from my point of view it's so subjective.*

I: Is it?

R: Yes, you're looking at, even a width of a river, some people are estimating how wide it is, some people are measuring how wide it is, the amount of tree cover, I could say 3%, you're looking at every 10 metres, I could say 3% and the next person's going to say 12%, so it's very hard to quantify unless you have the same person doing it all the time, in which case they might do it totally wrong anyway.' (Neil, 234-247).

Doubt was cast on the representativeness (TO = 55%, N = 20) in time (TO = 30%, N = 20) and space (TO = 50%, N = 20) of the monitoring data models were based upon.

Figure 31: Environment Agency Thames region Fisheries culture map with associated themes derived from the analysis of 21 interviews and focus group meetings.



' I can't understand it [the Fisheries Classification Scheme predictive models] at all, but I fear it's not working. But one of the problems, and this is what I was coming to, with our data and the index, it's always a problem, is site selection and our data itself. And we generally fish sites that we can wade because it's safe, and you know, so our priorities are easy access, safe and a range of habitats that we can sample.' (Ian , 798-805).

Doubts were expressed on model quality and validity (TO = 40%, N = 20). They were described as simplification of reality (TO = 35%, N = 20) and in need of ground-truthing (TO = 15%, N = 20). Concerns were expressed on the potential consequences of using existing data and models to build knowledge of the environment and make decisions.

'I think there is, to a degree, there is a different culture now, I think. Once upon a time it was rare to be in the office, that has changed; now it's rare to be ... rarer to be in the field and that's something that we constantly have to fight against because the danger is that, people sit and see data on a computer and that is their world view. Quite often, data on computers is out-of-date, can be completely inaccurate, so you have to test that with your own observations in the field.' (Nick, 147-154).

Models quality in turn impacted on individuals' perception of their usefulness in the decision-making process (TO = 55%, N = 20). They were described as 'too prescriptive' (TO = 20%, N = 20), 'out of context' (TO = 20%, N = 20), 'not applicable locally' (TO = 35%, N = 20) and there were doubts as to 'how to use them' (TO = 10%, N = 20). In the next extract, Chris describes his experience of using Habscore for assessing trout population.

'I didn't think it told you very much because it gave me some figures but I didn't have anything to compare my figures against ... I could interpret more from when I had actually been standing there making my notes about the habitat type on that one reach rather than the numbers that Habscore gave me ... It gives you a number and then I was, at the time, questioning and saying well what...does the number relate to anything?' (Chris, 671-684).

Limitations in data and models raised the risk of potential misuse or misinterpretation (TO = 25%, N = 20) and it was suggested that whatever model was produced needed 'interpreting by an expert' (TO = 30%, N = 20). The whole issue around science and experience was well summarised in an excerpt from one of the first focus group meetings. Concerns over data and model quality, validity and usefulness, the fact that they promote a different type of knowledge, that they take away the decision-making from the experts and that their use carry threats to their working culture were expressed by the participants. The excerpt starts at the end of a presentation I gave on the habitat assessment tools pictured in figure 22.

' *I: … so the tools would give you an insight into whether there may be a problem or not on the sites.*

Graham: it is only an indication isn't it, I mean the danger is that it is going to lead us and drive things according to these blue boxes.

I: and that is exactly the point. These things are only here to help the decision-making. They are not there to make decisions for you.

Fred: that's why there are quite a few questions that we need to answer: who should be the users?

Graham: yeah!

Fred: Should it be the officers or should it be the technical specialist? My view is that it is the technical specialist type of thing. It would be nice if the catchment officers could use it but they would have to understand the reasons for the tools quite clearly otherwise it could mislead decisions.

Other person: hmmm!

Jim: well that's the easy option is it, to do what it says?

Graham: yeah!

Jim: rather than to think for yourself

Graham: so much data and you've got red or blue!

Jim: yeah

Fred: the other thing is that it needs ground-truthing it is actually understanding; making sure that; that's part of; that was partly mentioned earlier part of the process is to ground truth the prediction that it is making so the number of example you go out on site and actually see, look at it!

Graham: yeah! … you need a tab at the end that says: 'now go out and have a look at it!' People just sit and look at the computer screen and don't go out. ((Laughter))'. (Focus group meeting 1, 114–202).

Another theme emerged from this conversation: the potential threat posed by models and decision support tools on user perceptions of their own job. Staff seemed concerned that they would be kept in the office and would have to rely on model outputs to make their decisions. Such concerns were expressed many times again and will be discussed in the next step of the analysis where we look in more detail at the potential interaction between science/models embedded in the proposed DSS prototype and working culture.

From the analysis of individual perceptions around reality and truth, we can derive a picture of Fisheries officers 'theoretical framework'. Reality was perceived as complex and unpredictable. It was not only environmental but also social. Complexity resulted from having to deal with events in time and space and the numerous environmental stakeholders. Historical knowledge was paramount as the impacts of past events could still be perceived nowadays. To apprehend this complexity, it was important to build detailed local knowledge. Fieldwork, monitoring activities, surveys and calls on-site were opportunities for learning. Interactions with elder members of staff and local stakeholders ensured continuity in the transfer of knowledge. Most learning was unstructured and opportunistic. Decision-making mainly relied on experience, judgement and intuition.

In contrast, science was seen as reductionist and less capable of capturing or predicting perceived complexity. Methods tended to yield unreliable data that were snapshots in time. Models were over-simplistic and were also perceived as threats to current ways of working. They were seen as too prescriptive, they could be misused and lead to the wrong conclusions. They could also prevent staff from going out and finding things out for themselves.

Altogether, Fisheries staff perceived themselves as local experts as opposed to scientists (internal adaptation theme: TO = 75%, N = 20). Their ontology and epistemology attempted to account for a complex physical and social environment that they made sense of by immersion in the field. Their 'theoretical framework in action' was interpretive in nature as it accounted for various perspectives on reality: that of the fish, the angler, the Fisheries officer *etc.* Assumptions around decision-making were strongly linked to perceptions of truth and reality. Decision-making was based on personal expertise and judgement (TO = 75%, N = 20).

' *It's difficult to measure habitat anyway…but, you know, as an experienced Fisheries officer you should know what's good and bad habitat.*' (Steve, 235-236).

There was a strong trust in personal expertise that seemed to be shared by other sections in the organisation. Trust and personal relationships were very important components as most decisions were made through a process of negotiation, consultation or influencing (TO = 50%, then = 20) with other departments.

' *So sometimes you also have to question assumptions that are made, and data is very important, particularly when you're making a case to colleagues, internally, to try and influence and persuade, because Fisheries doesn't have a lot of its own money, we have to persuade other people to spend their money to improve the environment of fisheries.*' (Nick, 175-181).

Fisheries lack of resources (TO = 60%, in = 20) seemed to influence the decision-making process and also the nature of their work. Improvement work was indeed seen mainly as reactive and opportunistic (TO = 85%, N = 20).

'*I think that things happen, it's an opportunity based thing, when there's an opportunity and it's normally due to a development of some description. … I don't think there's very much strategy behind it, because people don't know where the next big developments going to be and you just have to take your opportunities where they arise, I guess.'* (Graham, 93-103).

The opportunistic nature of the work also seemed to stem from the modes of operation of Fisheries staff and the difficulty they had in dealing with the complexity of the environment.

'*…it takes such a long time to get to know a catchment, a lot of the enhancement work we get is based on, say an angling club phoning us up … saying we're not fishing as much as we'd like, we'd like to do some more work here, or we would like to put a few angling schemes in here, or put some riffles in here, can you come out and advice? And because, realistically you're not going to know every bit of water, you're not going to know where there's a particular deficit like that, or habitat deficient reach, so we are quite reliant upon them as well.'* (Frank, 582-595).

Being proactive and strategic was redefined as joining up opportunities over a period of time using intuitive strategies (TO = 45%, N = 20).

' *but I have got a catchment plan where I have recorded past enhancements and ones that I have spotted, tried to have a look at the catchment views so that I can hopefully eventually link things up so although I don't have a catchment management plan for fisheries, it's very much like cigarette packet thing, it's on a sheet.'* (Focus group meeting 4, 409-412).

Strategies were collections of ideas that were kept until funding opportunities arose.

Duncan: so there is a constant process of idea generation and some of them like that one would be put on the backburner. The idea is that we have a lot of projects ready to go on the shelf so that when the money becomes available we can just pull them off and there we go.' (Focus group meeting 4, 416-465).

Schemes were prioritised according to:

- resources and multi-functional benefits;

'Ian: projects were brought to the table opportunistically with catchment officers so there wasn't probably a good proper strategic basis to that, but once they were brought to the table, then there was a way of prioritising between them. And that included an objective, sorry, an opportunistic score because if the opportunity was

great it would get a high score that it was very much about multifunctional benefit extending beyond biodiversity and it had to tick the FRM boxes as well as anything else.' (Focus group meeting 3, 303-310)

- landowners' agreement;

' Duncan: feasibility is a big one. If there is no landowner agreements you put it right back to the bottom of the pile. It is a fundamental thing, if it is not going to happen, however a good idea it might be, this is not going to happen.' (Focus group meeting 2, 452-455).

- Stakeholders' relative power.

'I: So how do you, how do you select places to do work?

R: Right.

I: And what are the criteria.

R: Realistically.

I: Yes, that's what I want.

*R: Realistically, the phone rings and it's whoever shouts the loudest and wants what done basically.' (*Kevin, 376-402).

This state of affairs was not seen ideal by many staff. As put by Stuart (310-312):

'Yeah, I mean the difficult bit in doing piecemeal approach to habitat enhancement is that you can never properly see the benefits on a larger scale because you are only doing it a bit.'

But even when a plan existed, delivery may follow a different path.

'I would say. Now in theory, we've got a Fisheries Action Plan, which is something that's put together from external people and it should highlight the priorities that, what we want to do, habitat improvements etc., but in theory it doesn't work like that. A project, an opportunity comes up and it starts from there basically. Does that make sense?' (Kevin, 404-410).

As Chris highlighted (399-406), the decision power may lie elsewhere:

'So, I suppose that's like creating an action plan, isn't it. But, from 20 sites I might have looked at and having written down what was wrong and what you could do about it, there might be only one of those sites where the people that own that land would actually agree for you to do it.'

Despite that, there were strong perceptible aspirations towards building and implementing strategies (TO = 40%, N = 20).

'Stuart: There isn't, we are trying to move towards more strategic way of doing things,

the kind of three-year plan where he use monitoring beforehand, do the work and monitor afterwards and each of the projects leads to the enhancement of the habitats over the entire catchment. But until now, I would say it is not the way that it's worked out at all. And I would suggest this is purely because of the way we are funded and the constraints we have internally of getting projects done within 12 months. It is very hard...' (Focus group meeting 4, 262–269).

Taking a landscape approach (TO = 30%, N = 20) with some planning (TO = 40%, N = 20) and prioritisation was considered as important.

'I mean something that I would like to see is answers to questions like 'Well how many kilometres of juvenile habitat do we need on a catchment to support a data population database'? 'How close do those habitats need to be to the spawning ground, to be viable?' and then we could, you can take a step back and actually plan some works.' (Stewart, 221–235).

Power was perceived as being an important factor in determining resource allocations, prioritisation and in driving work on the ground (TO = 70%, N = 20).

'David: we rely on FRM money for work we call habitat improvements whereas project money we get from rod licence sale, that is very much directed towards angling-based project so it might not necessarily involve any enhancement to the actual system and also there is huge difficulty in affecting and changing any in channel works in urban areas because of the increased flood risk.' (Focus group meeting 4, 287–292).

In the existing power structure, there were clear inequalities and Fisheries was perceived as low on the scale (TO = 40%, N = 20).

' *R: Because Fisheries can't do what it needs to on its own. It needs other people to help with funding, or with information, or with co-ordination, or communication, we can't, I think 10 years ago, 15 years ago in the NRA [National Rivers Authority], the NRA Fisheries function was quite an important one, but I think now in the Environment Agency we are definitely second tier, I think …*

I: Small fish?

R: We are, we are very low budget, we've got an enormous customer base of people that aren't co-ordinated enough to create a single body that then speaks for angling and so that makes us a very, very small voice, I think. There's kind of us and conservation and in Thames region, flood defence, navigation, they rule the roost really. And then water resources and water quality, and then Fisheries, navigation and then the people that work in the canteen and we're just above the people that work in the canteen.' (Graham 447–464).

Power structure was perceived as influencing the overall mission and strategy of the organisation enshrined in its corporate plan (TO = 75%, N = 4). The corporate literature was very much seen as aspirational. What was written did not always match what the organisation did in practice, which created frustrations.

'R: … because I think that even though we're supposed to be an environmental champion, we're the most environmentally destructive for our own capital works, flood risk management and operations programmes. And that's very difficult for me to take.

I: So, do you have the feeling at times what you do, somebody undoes?

R: Yes, and also that we put customers through the rigmarole of environment, environment, environment first, when we're not necessarily adopting that practice ourselves?' (James, 540-555).

Although work was widely seen to be driven by legal and organisational priorities, there was a strong sense that since Fisheries got directly funded by angling licenses in the late 1990s, it had acquired commercial duties towards their customers, the anglers (TO = 40%, in N = 20) which generated objections and concerns:

'*Tony: but the other thing is, you asked the question: are you doing it for anglers, are you doing it for biodiversity or are you actually doing it for the conservation aspect of fisheries, because you've got three. Because we have been told to shy away from conservation great stuff because the thing is you want more anglers on the rivers basically. The more anglers you can get, the more resource you are actually gonna get back. I think that is a mistake in a way.'* (Focus group meeting 3, 417-423)

It was perceived as clashing with what ultimately was Fisheries mission and individual beliefs that they should be working with nature (TO = 45%, N = 20),

'Steve: yes although we are aiming to improve the fish, we are aiming to improve the fish population to what would be their naturally.' (Focus group meeting 2, 538-545)

In turn, this affected individuals' perception of identity and role. Power and decision-making also influenced perceptions around the nature of human relationships. The lack of resources and power within the organisation required staff members to adopt decision-making strategies based on influencing, hence the need to manage relationships, to network (TO = 44%, N = 20), build personal relationships (TO = 38%, N = 20) and 'get on' (TO = 50%, N = 20) and build trust (TO = 13%, N = 20). The structure and size of the organisation seemed to impact on communication described were sometimes inconsistent (TO = 25%, N = 20) with regard to information sharing.

' *it can be very difficult when initiatives are cascaded from high above and then we're left to deliver it on the ground, and sometimes I feel that people external to the Agency know more about what's going on than I do, and that can be difficult at times, to say the least.'* (Jonathan, 430-434).

Interactions were based on trust but there was not always a sense of common purpose.

' *Yes, and I always think the justification of enhancement schemes is to right the wrongs of flood defence, and that is flood defence's contribution. They cocked it up severely.*' (Ian, 410-412).

Individuals were sometimes reminded of power balance as James once experienced when trying to negotiate with FRM colleagues (527-529):

'And I asked if there's any mitigation for this, given our conservation principles and duties, that would be a reasonable request and I was told just to live with it.'

Reorganisations such as BRITE were partly blamed for changes in the way the team was able to work (TO = 80%, N = 20) through splitting up the team (TO = 10%, N = 20) and specialisation (TO = 20%, N = 20) which led to a loss of valuable local knowledge and interaction.

'Jim: post BRITE, it has been split up of course, they used to be completely integrated Fisheries team. They used to do everything from survey to manual ( ) and of course post BRITE, the survey teams went their separate way. The enforcement officers who of course are the eyes and ears, very much the people on the ground knowing what is happening, they went off in another direction and then you have this technical Fisheries team which, deals with the day-to-day stuff.' (Focus group meeting 1, 893-906).

But reorganisations were also blamed for increased bureaucracy, office work (TO = 45%, N = 20) and workload (TO = 45%, N = 20) which impacted on staff ability to learn from the field.

'Look at how things were done fifteen, twenty years ago and we were literally rightly or wrongly - back of fag packets sort of thing. A few limited designs and little bit of consultation we would go ahead and do it. Now it's, there is so much to go through … but you know and there are so many potential - spanner in the works which can stop things from happening, which you find annoying.' (Rob, 308-322).

With bureaucracy came a change in value system. We see a hint of it in Rob's speech when he regrets the days when 'doing things' was most important. This shift from a devolved operationally-centred 'act and impact' to a more centralised 'command and control' organisation was further emphasised by Duncan (627-633):

'I think that's pretty, you know, a general way of summing it all up, is that things have become a little more prescriptive and a little more restrictive, whereas in the past you were more free to go and explore, you know, now you're kind of restricted to, you know, targets and KPIs [Key Performance Indicators] and, you know, the service levels and the creating a better place targets and what have you. So, you know, whereas those things may have been less important in the past.'

With reorganisations, staff had experienced a change in structure and ways of working. It also affected the power balance and their ability to influence decision-making.

Individual needs mirrored those perceived impacts. Fisheries officers expressed their needs to have time to learn (TO = 50%, N = 20) and 'get things done' (TO = 38%, N = 20) which implied spending time in the field (TO = 63%, N = 20) and minimising bureaucracy (TO = 88%, N = 20). With regards to their decision-making, Fisheries officers expressed a strong need for control (TO = 69%, N = 20) and freedom (TO = 56%, N = 20).

' *Yes, you get a lot of control. I like to have my decisions, I like to let R* know what my decisions are and obviously T* to some degree as well. But, I like to say to R* 'I'm doing this' and then he can say if it's the wrong decision.'* (Neil, 406-410).

Management was perceived as being supportive of staff need for control and freedom with management style being described as based on delegation or consultation (TO = 31%, N = 20). Managers also seemed to trust their staff expertise (TO = 38%, N = 20). The organisational climate seemed positive with Fisheries staff enjoying good relationships with their colleagues across sections (TO = 35%, N = 20). However, frustration was expressed with bureaucracy and admin work. Feelings of being powerless were regularly expressed (TO = 25%, N = 20) along with a sense of silent despair at one's inability to influence things.

'I: how do you know yourself whether what you've done was actually worth doing ?

Stuart: you don't

Neil: you don't

Stuart: you just have a small sense of satisfaction you have done something. To be honest. I don't know about you guys, that's how I feel about it!' (Focus group meeting 4, 375-384).

Turnover was mentioned by 45% of staff (N = 20) as being an issue especially with managing local knowledge and making sure that it was preserved and passed on to the next generations of Fisheries officers.

Summary

Having considered most aspects of Fisheries officers working culture, we can now attempt to summarise those in a single charts and include aspects of science and scientific tools that may impact on organisational culture. In figure 32, we used the most important themes from the previous analysis to draw a picture of organisational culture.

Overall, Fisheries officers perceived themselves as local experts. Reality and knowledge perceptions were interlinked and expressed Fisheries officers' belief in the importance of local knowledge in space and time. The world was complex and could mainly be apprehended through immersion and the build-up of expertise. Decision-making reflected the power structure within and outside the organisation. Power stemmed from legislation and organisational commitments but also from resource distribution and the ability to influence policies and priorities. Because of the link to Fisheries licence money, there was a perception that anglers had become customers and Fisheries aims had somehow taken a more commercial nature. In that context, Fisheries was perceived as being very low in the 'pecking order'.

Access to resources was limited and achieved through influencing other 'richer' departments. New legal frameworks such as the WFD may bring extra emphasis on fisheries work but, as pointed out by one of the first focus group meeting participants (484-492) *'there is actually no additional money to do any improvements under Water Framework Directive. That's what we keep on being told that. There is no extra money.'* Therefore, even the onset of new legislation was unlikely to change the balance of power in practice.

Power, work drivers and resources were all perceived to impact on the decision-making process. Decision-making was mainly based on influencing/negotiating and was opportunistic/reactive in nature and required a lot of flexibility. This was going contrary to staff's aspiration to take a more proactive attitude towards decision-making based on working with the natural environment rather than fulfilling customer needs. Hence building relationships and fostering trust with colleagues was very important in achieving Fisheries aims.

In accordance with their self-perception as experts, Fisheries officers required control and freedom over their own decisions. Line management seemed to be supportive of their staff's needs. There were frustrations at the impact of turnover and reorganisations on their ability to perform the necessary actions to maintain their expertise. Time to go in the field and learn from experience had become limited and bureaucracy was taking over.

Science and decision support tools were perceived as having negative impacts on most aspects of Fisheries officers working culture. Survey methodologies, data collection strategies, models and predictions were regarded with extreme caution and sometimes suspicion. The positivist frameworks assumed in ecological science contrasted with the more constructivist perspective taken by the experts. The 'real' was complex and could not be summarised or predicted. Scientists' naive determinism and their tendency to reify things were derided in statements such as 'fish do not read books'. Fisheries experts were not as interested in describing fish behaviours using statistics as on 'understanding' the needs of fish, rivers, landowners, anglers and colleagues from FRM. Each perspective required a different lens to be fitted and a different approach to be taken. Science was perceived as being unable to deliver tools to manage such environmental and social complexity. In this context, the positivist science theoretical framework was perceived as unhelpful.

More importantly, the misuse of science could lead to misinterpretation and affect the balance of power that had been carefully built up by Fisheries staff by potentially casting doubts on their judgements and ultimately expertise. External and internal individuals may use erroneous 'out of context' model outputs to contradict Fisheries officers expert judgement.

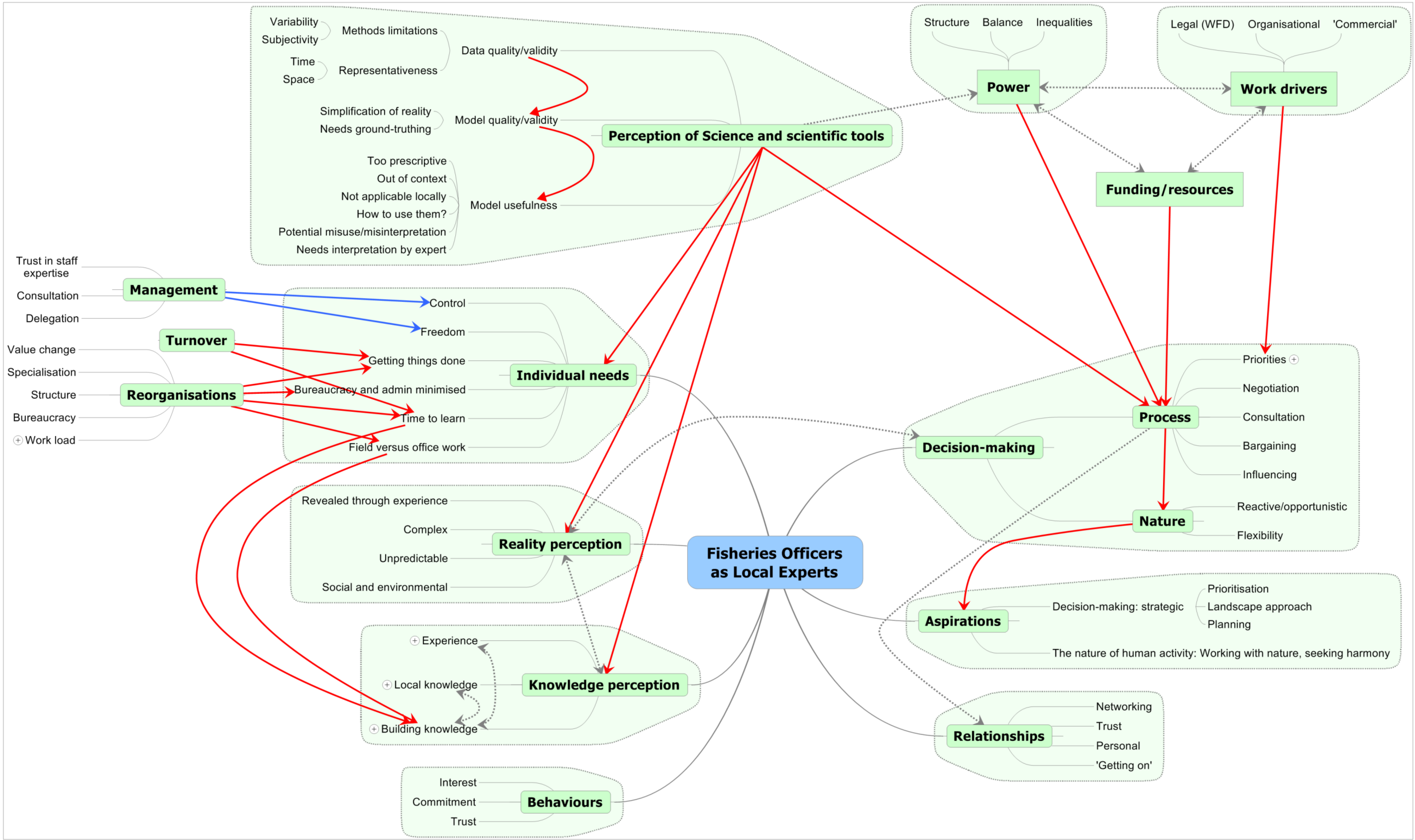
Additionally, the prescriptive nature of scientific outputs and their claim for truth may affect Fisheries officers need for control and freedom over their decision-making. DSS may then become associated with the bureaucracy that had accumulated from past reorganisations and interfered with existing working culture.

In summary, DSS supporting scientific methods and models were perceived as having potential negative impacts on important aspects of culture, on the balance of power and on the ability of Fisheries officers to make decisions and influence existing decision-making processes. As put by Stuart to whom this graph was presented at a follow-up meeting:

'*you need one thick red arrow linking DSS and the [Fisheries officers as local experts] blue box as it potentially undermines Fisheries officers in their status as local experts*'.

The summary map of culture (figure 32) and supporting analysis were presented to a subset of staff at all levels of the organisation at meetings, workshops and a conference. Feedback from participants indicated that it accurately depicted the working culture in Fisheries not only in Thames region but also in other regions and areas in the Environment Agency. One senior manager also remarked that elements of the culture map could be applied to other departments or the organisation as a whole. This is not in contradiction with the findings, as Fisheries culture was likely to be a reflection of the EA organisational culture.

Figure 32: Fisheries culture and Decision Support Systems/Science interaction. Red (negative) and blue (positive) arrows represent aspects of culture/science perceived to have a negative or positive impact on other aspects by respondents. Dotted grey arrows represent interactions between various aspects of culture inferred by the author from the analyses.



Discussion

The overall theoretical framework for identifying the nature of the problem at hand, investigating working culture and designing prototypes was constructivist in nature. It was based on the assumption that the reality faced by Fisheries officers, their decision-making and the complexity of their working culture cannot be apprehended properly by using Cartesian rationality, prescriptive theories of decision-making and statistical modelling techniques.

As discussed in previous chapters, a positivist approach towards developing DSS and solutions to real life problems may generate tools and outputs that are not adapted to the world views of practitioners, their decision-making framework and create frictions leading to rejection.

The results from the interviews and subsequent analysis seemed to vindicate this approach. There were strong criticisms of scientific world views, reductionist tendencies and focus on the general rather than the specific. Local staff valued local knowledge and expertise. Science was seen as too prescriptive. A rationalist approach towards decision-making and DSS design would have had a high probability of rejection and failure.

One of the limitations of the methodology chosen is 'what we gain in meaning, we lose in ability to generalise'. Hermeneutics is subjective in nature. The analysis of transcripts by several researchers could have led to different interpretations. It is generally recommended to have several researchers analysing the same transcripts (Silverman 2005). An alternative is to document, as I attempted to, the occurrence of themes by computing statistics across all interviews. The difficulty is that theme occurrence is not a random process. Some themes may be triggered by questioning and prompting whereas others spontaneously emerge. Themes were not addressed in all interviews, others were dropped because I felt they were less important, time was lacking or they seemed to be widely shared across the teams. The strength and importance of a theme cannot be assessed by statistics alone.

When analysing culture, it is the ability glean the implicit assumptions, those that are so taken for granted that they are not discussed anymore, that leads to an understanding of deeper levels of culture. One way of validating the analysis is by presenting the outputs to the participants and seeking their feedback. This is what I did at meetings with catchment officers, technical specialists, team leaders, Fisheries managers and senior managers at regional and national levels. The feedback was altogether positive and very encouraging. Some of it was recorded and transcribed in the analysis but it could have been formalised through a short questionnaire.

I will now show how these results were used to develop a DSS for prioritising sites for habitat management work and delivering on management’s aims and objectives.

Chapter 7 DSS development

Culture and DSS design interaction

The overall aim of the DSS as defined by management was to help with the prioritisation of sites for habitat enhancement work for fish by:

- introducing more scientific tools, models and data in decision-making rather than relying on personal expertise alone;
- moving towards more rational, strategic decision-making through planning activity based on objectives and data analysis.

From the cultural analysis in chapter 6 emerged a series of issues with regards to these objectives. The analysis of EA Fisheries officers working culture demonstrated that any DSS promoting scientific models and tools with a prescriptive approach towards decision-making was likely to face strong cultural resistance and ultimately rejection by users. Fisheries officers valued their expertise, local and historical knowledge, and their control over decision-making. As a result, they found scientific data and predictive tools not adapted to their decision-making environment. Importantly, their line management supported their views. This excluded any potential attempt at imposing change through 'top-down' managerial enforcement. Fortunately, there was some convergence of views between the project managers and Fisheries officers on the need for strategic plans, but the current decision-making process was very much based around experience-driven opportunistic work. The need to challenge existing knowledge through the introduction of new data and models within a decision-making process that did not affect user self-worth remained.

A further issue was identified in the scale at which Fisheries officers operated, together with their computer and analytical skill-levels. Catchment officers seemed mainly confident in dealing with data at the level of fairly short river reaches (i.e. 100m to several kilometres). Data and analytical skills were quite basic which indicated that analysing data at larger scales may be problematic. Furthermore, building catchment strategies required time to view and analyse data, evaluate options and identify a potential way forward. This would create office work potentially interfering with individuals' needs to be in the field. Such tasks, however, seemed to correspond more to technical specialists skills and preferences. Technical specialists had a greater amount of experience and felt more comfortable analysing data at larger scales and building strategies. The involvement of catchment officers and technical specialists at different stages of the strategy building process therefore opened the door to new possibilities.

A compromise had to be found to deliver the DSS objectives whilst respecting user needs, ability and working culture. It was decided to develop a DSS that would promote the use of data, models and local knowledge whilst respecting the ability of users to make their own interpretation, assessments and decisions.

The DSS was split into two linked decision support tools to reflect user preferences and ability (figure 33). The reach decision support tool would enable catchment officers to assess the quality of individual river reaches (i.e. segments of river from 500 m to several kilometres), identify pressures and propose management options. The catchment decision support tool would summarise reach assessments at catchment scale and enable technical specialists to review catchment officers' suggestions and develop management strategies. The interactions between the two decision support tools would ensure communication, quality assurance and knowledge exchange between the more experienced technical specialists and the catchment officers. Also, reach assessments and strategies would have to be inputted into the system and justified thus enabling future reviews and quality controls. As such, the DSS was designed to promote a learning cycle within Fisheries by making a wider variety of data and models available and fostering accountability and knowledge exchange.

A conceptual model for the decision-making process leading to the production of catchment strategies is displayed in figure 34.

The aims of the process were identified as involving:

- respect for user control over their decision-making;
- respect for user perception as expert;
- promotion and support of local knowledge;
- the ability to enable multiple perspectives on knowledge and decision-making;

The success of the process to achieve the above goals was identified as contingent upon its ability to:

- introduce data and models in a non-prescriptive way;
- promote learning by introducing knowledge management cycles;
- require justification for decisions and assessments.

On a schematic level, the decision-making process proposed was very similar to the one suggested as part of the first case study (chapter 4, figure 15). It was based on the requirements of the WFD and involved the assessment of habitat suitability for 23 species of fish, the identification of pressures and impacts and the derivation of programmes of measures. The main differences between the two case studies resided in:

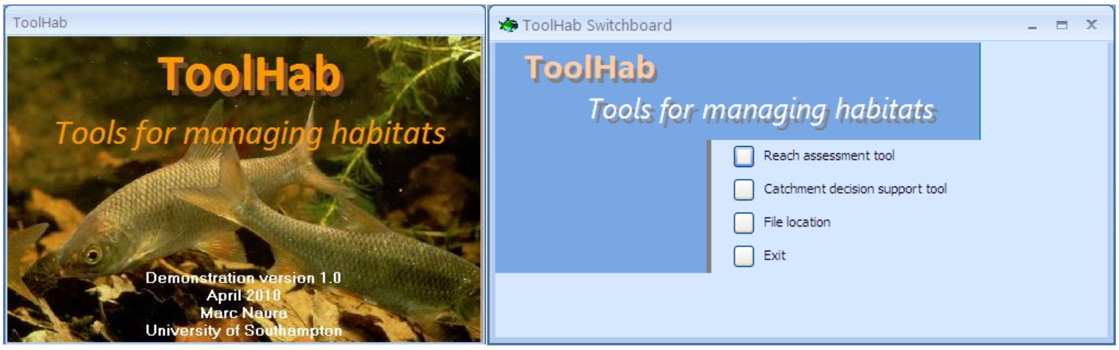
- the amount of control users can exert over their decision-making;
- the feedback loops within the DSS which ensured learning;

- the adaptation of the decision-making process and tools to user preferences, skills and culture.

DSS development: ToolHab

A series of prototypes DSS was produced and a final version was delivered to EA staff in April 2010. The DSS was called ToolHab, Tools for managing Habitats (figure 33 and appendix 10). It was based on a Microsoft Access 2007 Database interface and included an open source inbuilt GIS component called MapWindows. Microsoft Access was chosen because it was a simple to use programmable interface that was available on user desktops without the need to go through IT testing. Some of the potential users also had experience of the software. The whole DSS was designed around visual outputs for models and data and simple functionalities. I will now present the DSS along with screenshots of the designed interface. More information and screenshots can be found in the ToolHab help file available as additional material as part of the e-thesis.

Figure 33: ToolHab DSS splash screen and switchboard.

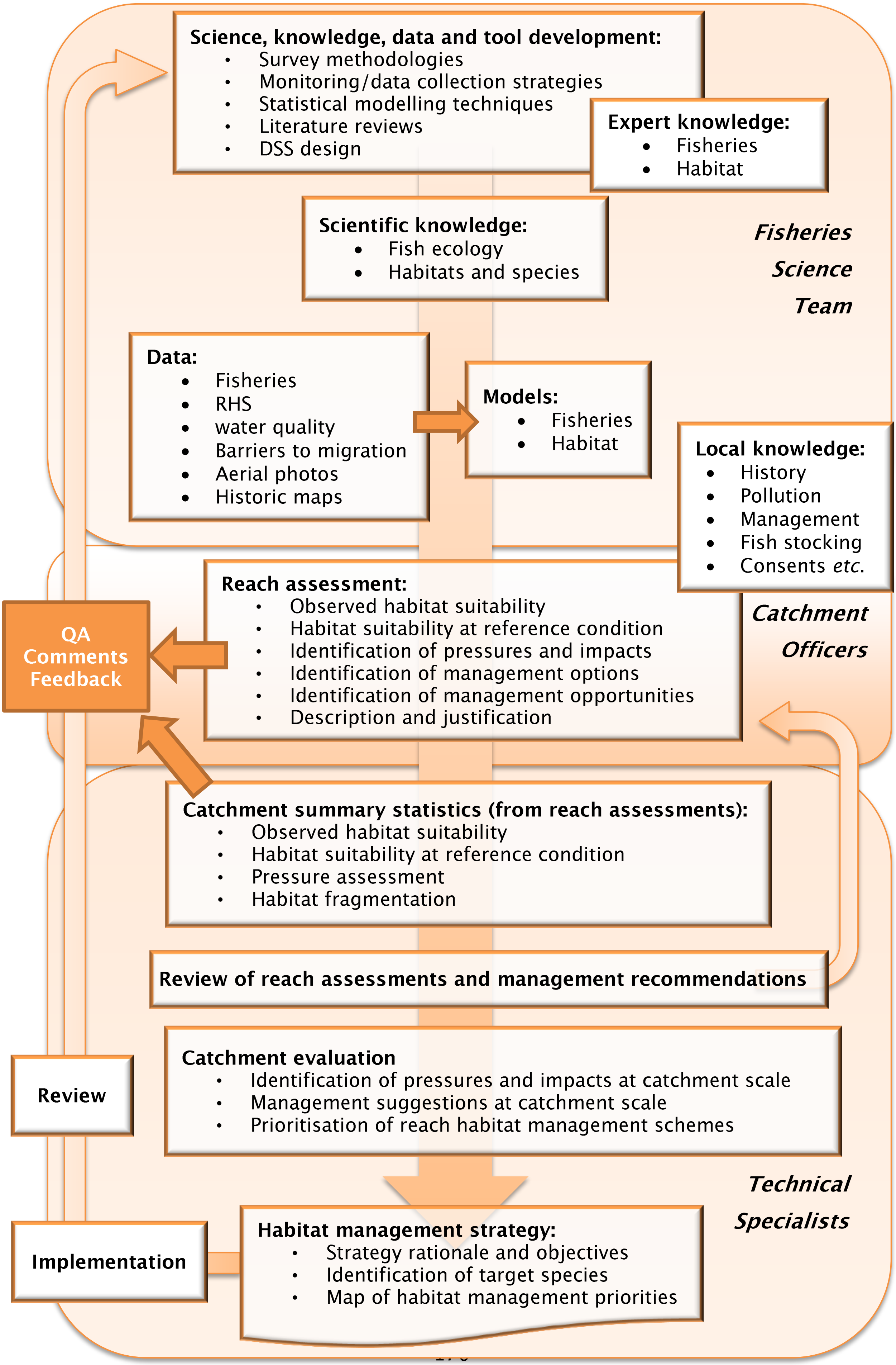


DSS overview

Figure 34 provides an overview of the DSS design and embedded decision-making process. On a broad level, three types of users are potentially involved: Fisheries Science staff, area catchment officers and technical specialists. Fisheries Science staff would be responsible for building and updating data, knowledge and models, reviewing catchment management strategies, DSS use and user feedback, and designing new interfaces and functionalities.

ToolHab was split into two user interfaces: the reach and catchment assessment tools (figure 33). The reach assessment tool was designed to enable the assessment of individual river reaches by catchment officers. River reaches were derived using predictive models following consultation with catchment officers and technical specialists. The detail of the models will be published separately.

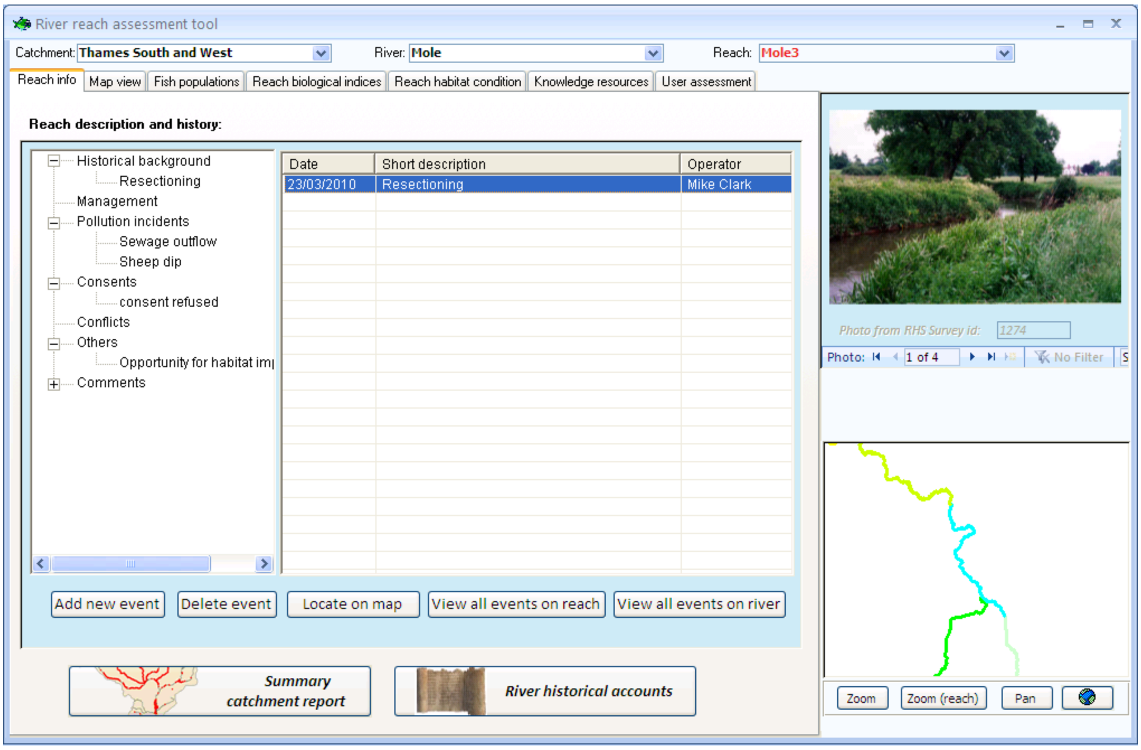
Figure 34: DSS component and decision-making process.



Reach assessment tool

A river reach can be defined as a homogeneous stretch of river with regards to current observable habitats and habitats at reference condition. Rivers were first split based on reference condition habitat structure using predictive models. The resulting units were then split according to observable habitat structure using existing RHS data (see box 2). A river reach may therefore only contain one observable habitat type and one reference condition type. This was deemed necessary to avoid having river reaches with multiple targets for rehabilitation (when there is more than one reference condition per reach) and multiple pressures and impacts (leading to multiple observable habitats).

Figure 35: Reach DSS showing the local knowledge and events interface (in the 'Reach info' tab) with a site photo of the Mole3 reach and a small location map (Mole3 reach represented in blue).



Each reach was given a unique identification code based on the river name and its position from source to sea. For the purpose of demonstrating the DSS to EA staff, 15 rivers were processed in Thames but also in North West and North East regions (figure 36).

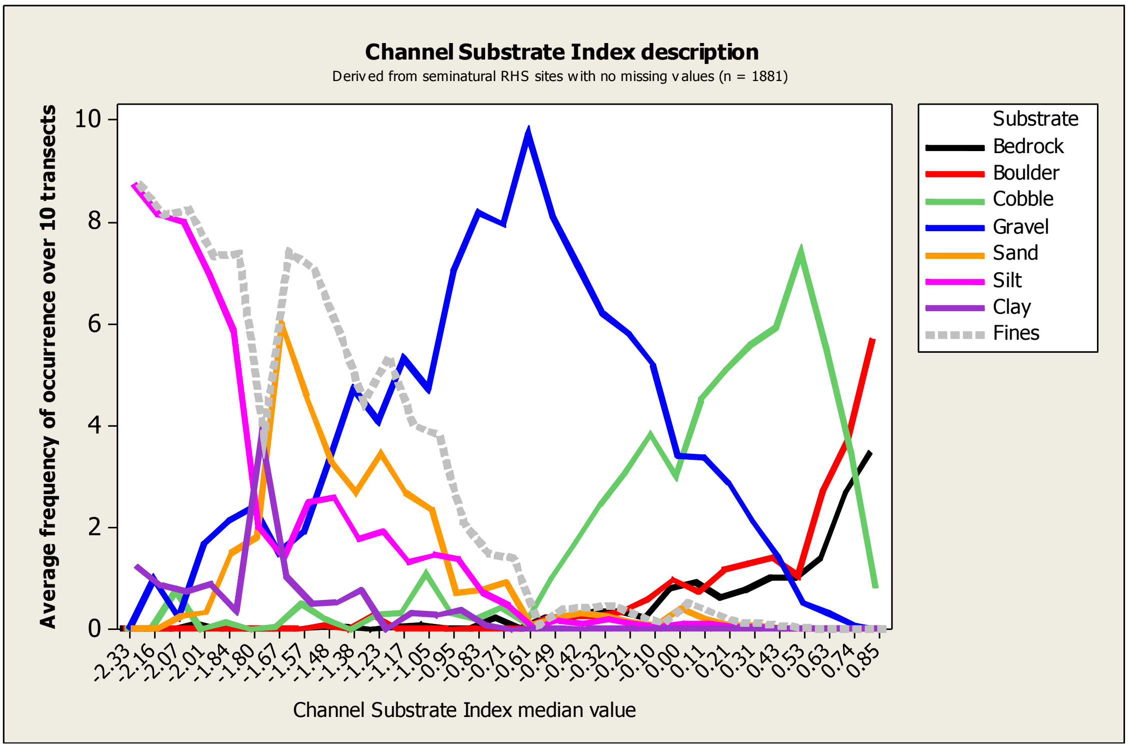
Box 2: Splitting the river network into homogeneous habitat reaches using river segmentation technique.

Rivers were split into reaches using a segmentation approach based on spatial similarity for a series of indices representing habitat structure. The approach consists of selecting a series of indices or attributes to represent channel morphology that are modelled and predicted using map-derived attributes such as slope, discharge, land use etc. The models are then implemented at regular intervals (e.g. every 500 m) along the river network. The predictions for contiguous river sections are compared and clustered using a statistical spatial clustering algorithm so as to maximise the variance between clusters and minimise the variance within clusters (or reach). Clusters can then be aggregated in the shape of river reaches whose variability can be described and predicted.

For the derivation of river reaches for ToolHab, habitat was defined as a combination of four structural elements: channel substrate, flow regime, erosion and deposition patterns and channel vegetation structure. River reaches were defined as homogeneous stretches of river with regards to the four structural elements as observed and as they would be in natural or near-natural conditions. The four habitats structural elements were derived using field data from the River Habitat Survey (RHS). The RHS is a methodology for recording habitat features that has been applied to more than 25,000 500m river sections in England and Wales since 1994 (Raven *et al.* 1997). The survey is organised in two major sections: 'spot-checks' and 'sweep-up'. The spot-checks are a series of ten 1 m wide transects across the channel at 50 m intervals, where bank and channel physical structure, as well as man-made modifications, land uses and vegetation structure, are recorded in a replicable manner.

Spot-check data on channel substrate, flow types, erosion and deposition features and channel vegetation were collated in four separate tables showing the occurrence of individual features (e.g. for channel substrate, the individual substrate types: bedrock, boulders, cobbles, gravel pebbles, sand, silt, clay, peat and artificial) across 10 spot-checks for existing RHS semi-natural sites. A semi-natural site is defined as a site with little or no signs of man-made modifications to the channel or the banks (Raven *et al.* 1997). The tables were analysed using Correspondence Analysis to extract the most important dimensions that were used as indices for describing the four habitat structural elements.

One of the four indices, the Channel Substrate Index (CSI) is represented in the figure below. The chart was derived for a subset of 1881 semi-natural RHS sites with no obvious signs of modifications and no missing values. The sites were grouped into 31 bins based on their CSI index value and the chart displays, for each bin, the average occurrence of 7 channel substrate types. The dashed line represents the average occurrence of fine sediments, i.e. silt, sand and clay. Finer sediments dominate on the left hand side of the chart (larger negative CSI). The CSI describes a gradient from fine sediment dominated rivers to coarse sediment typical of a upland-lowland shift in substrate size with increasing distance to source and accounted for about 20% of the total variability found in the data. The other indices described similar gradients.



The 4 indices were modelled against a series of GIS attributes using linear regression best subset selection procedure and tested using a jack-knife cross-validation technique. The models were spatially corrected using a series of methods. A simple methodology was to reiterate the existing model and add additional variables representing the index value for the closest RHS on the river network along with the site distance and its location upstream or downstream. Another method was to perform geostatistical analyses on the main model residuals (Bivand *et al.*, 2008). The outputs from all models were compared and the best models were selected.

Two sets of predictive models were derived for the four structural elements indices: one predicting habitat structure as observed during field survey and one predicting habitat structure as it would appear if the sites were semi-natural. The first model set was produced using all existing RHS sites, whether modified or not, and the second set was produced using only semi-natural sites. The R-square values for the best models are presented in the table below.

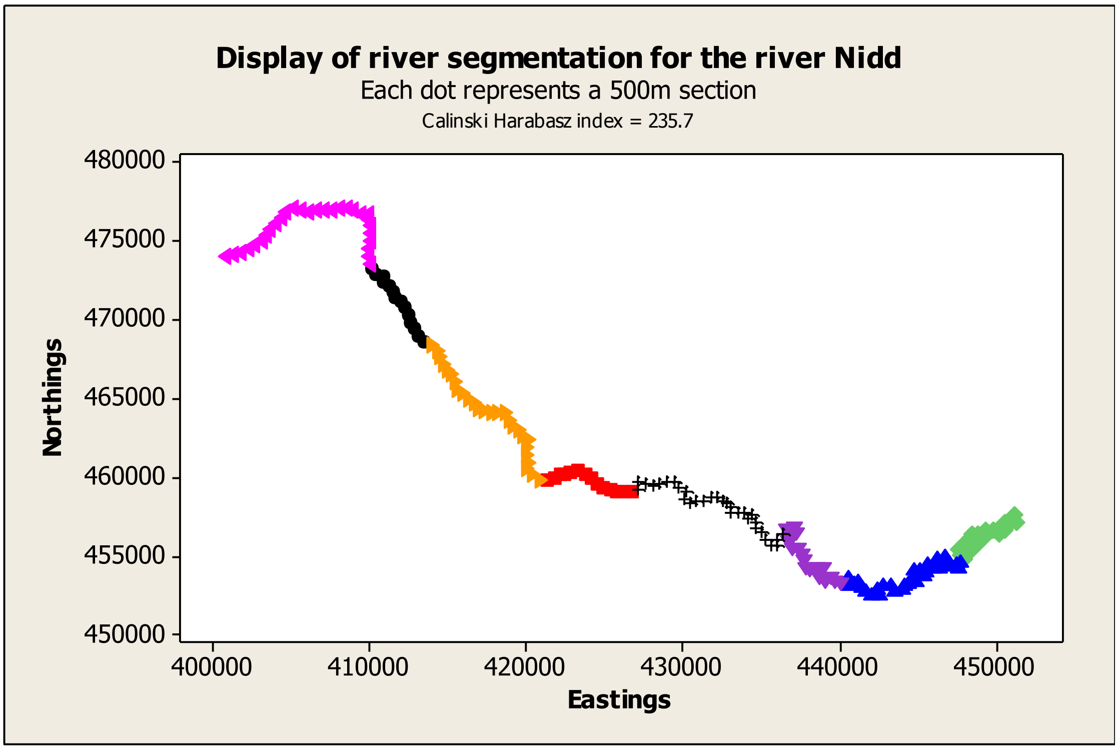
Amongst the four indices, the Channel Substrate and the Flow indices had the highest level of predictability with R-square at 68% and 56% respectively. The model for channel vegetation and activity in comparison explained 48% and 42% of the variability. Predictions for semi-natural sites showed similar levels of predictability despite the much reduced sample sizes. Spatial corrections brought about slight to moderate increases in predictive ability for the Channel Substrate, the Flow and the Activity Indices and quite significant improvements for the Channel Vegetation Index. Altogether, the predictive ability of the index value models was satisfactory.

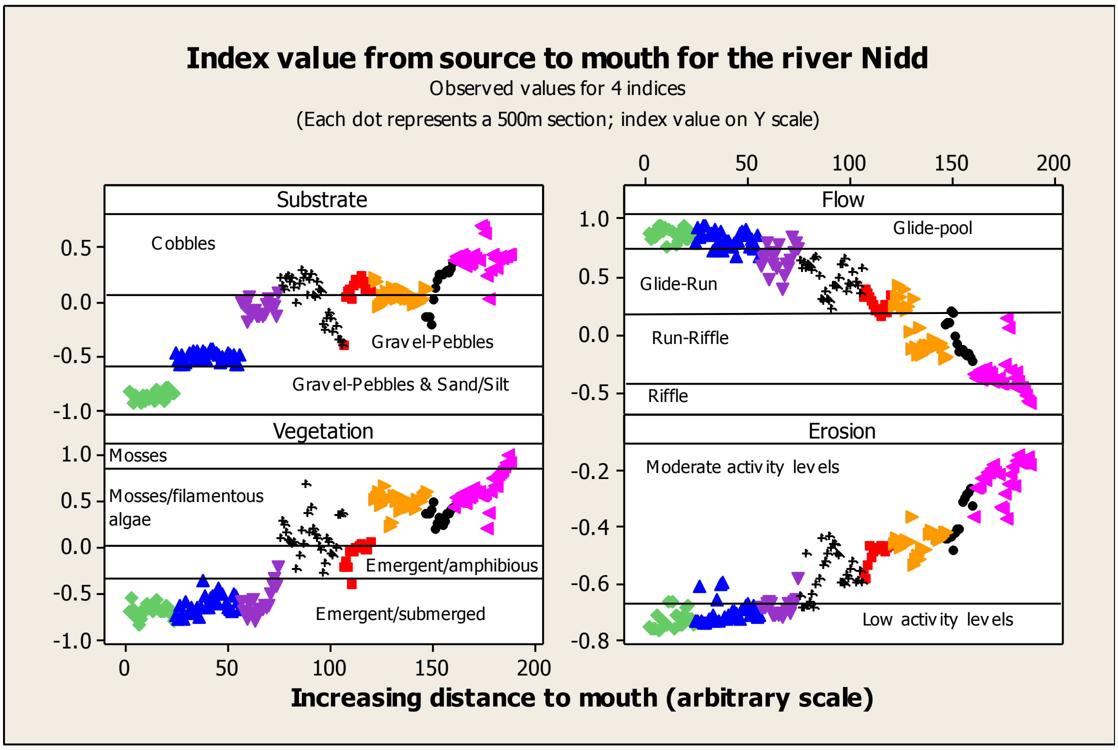
	Predictive models produced using all sites		**Predictive models produced using semi-natural sites only**	
Indices	Main model	Main model with spatial component	Main model	Main model with spatial component
Channel Substrate Index	**68%** *n = 9492*	**70.4%** *n = 5857*	**66%** *n = 1759*	**70%** *n = 604*
Flow Index	**55.9%** *n = 12983*	**61%** *n = 8282*	**53.6%** *n = 1997*	**67.2%** *n = 889*
Channel Vegetation Index	**47.9%** *n = 11196*	**58.7%** *n = 7811*	**52.2%** *n = 2036*	**67.6%** *n = 853*
Activity Index	**42.4%** *n = 12870*	**47.8%** *n = 9261*	**35.3%** *n = 2140*	**44.3%** *n = 986*

The spatially corrected predictive models were applied to all 500 m sections on the 15 rivers part of the DSS to predict observed and semi-natural values for all four indices. Adjacent 500 m sections were grouped using a spatial clustering freeware called VAST (Brenden *et al.* 2008). VAST was designed for clustering contiguous river segments based on their similarity with regards to attributes or indices and their spatial position within the river network. VAST offers a series of options for clustering river sections. Clustering can be performed starting from the top of the river or the bottom or it can be done randomly or based on similarity levels using various distance measures, linkage methods and affinity threshold values.

Each river was clustered by running the VAST algorithm using various combinations of options. The outputs were assessed using the Calinksi and Harabasz (1974) index (CH index), a ratio that compares variance between and within clusters. The fours indices were also plotted against the distance to source so as to allow visual checks and the identification of the most optimal solution. Sometimes, clustering was corrected following visual checks when obvious breaks in structural elements index values had been missed out by the clustering algorithm. An example of clustering is shown in the figures below. The first figure shows the best cluster combination found using VAST and the the CH index. The second figure shows the distribution of the 4 index values for each 500m point and cluster (in colour) from source to mouth.
The sections within each cluster were aggregated into river reaches using GIS ArcView.

The resulting maps were circulated to Environment Agency staff for comments as Google Earth kmz files and in pdf format.





Available data and indices for fish, habitat and water quality sampling points were averaged for each reach (data taken from the National Fish Population Database, the RHS database and the BIOSYS biological database). Data display was made as simple as possible using colour-coded graphs, charts and by recombining existing attributes into meaningful scalable indices. Figure 37 shows an example of the interface for fish. Fish densities for 23 species were displayed in bar charts but also as graphs allowing multiple views of the same data. Biological indices values along years of survey were also represented in a graph in a separate tab (figure 38). In figure 39, we see how more than 40 different attributes from the RHS spot-check section have been recombined into 6 indices describing channel substrate mix, flow regime, channel vegetation, erosion, deposition and bank and channel vegetation structure. In figure 40, the Habitat Modification Score (HMS) from the RHS is shown using standard WFD colour-code (red = poor; blue = good) and broken down into component sub-scores for various modification types.

Outputs from predictive models were also presented in a graphical manner. The FCS outputs are shown in figure 41. The overall quality score or EQR is displayed in a colour-coded box. The three columns enable the assessment of fish species presence and density against reference condition. In the left-hand column, the number of fish caught in the last electro-fishing survey is displayed. In the right-hand column is given the probability that each species would occur on that reach at reference condition. In the middle column is displayed the probability that more fish than observed would have occurred at reference condition. Probabilities greater than 33% and 66% are colour-coded in yellow and red to indicate increased departure from natural state.

A specific interface was developed to record local knowledge (figure 35). Users can input information about river and reach history, individual pollution events, management actions as well as information about fish stocking, land drainage or planning applications (figure 42). Each event is labelled with the author's name whose contact details are stored on the system (figure 43). The interface allows for the production of reports at reach or river levels. Events can be located on the map by manually inputting coordinates or by using the ‘map event’ option in the ‘map view’ interface (figure 43).

Figure 36: Map of 15 rivers covered by ToolHab DSS: the river Petteril, Wyre, Ribble, Calder, Nidd, Cherwell, Thames, Tame, Kennet, Loddon, Colne, Lee, Roding, Wey and Mole with a detailed map of the river Petteril showing river reach distribution.

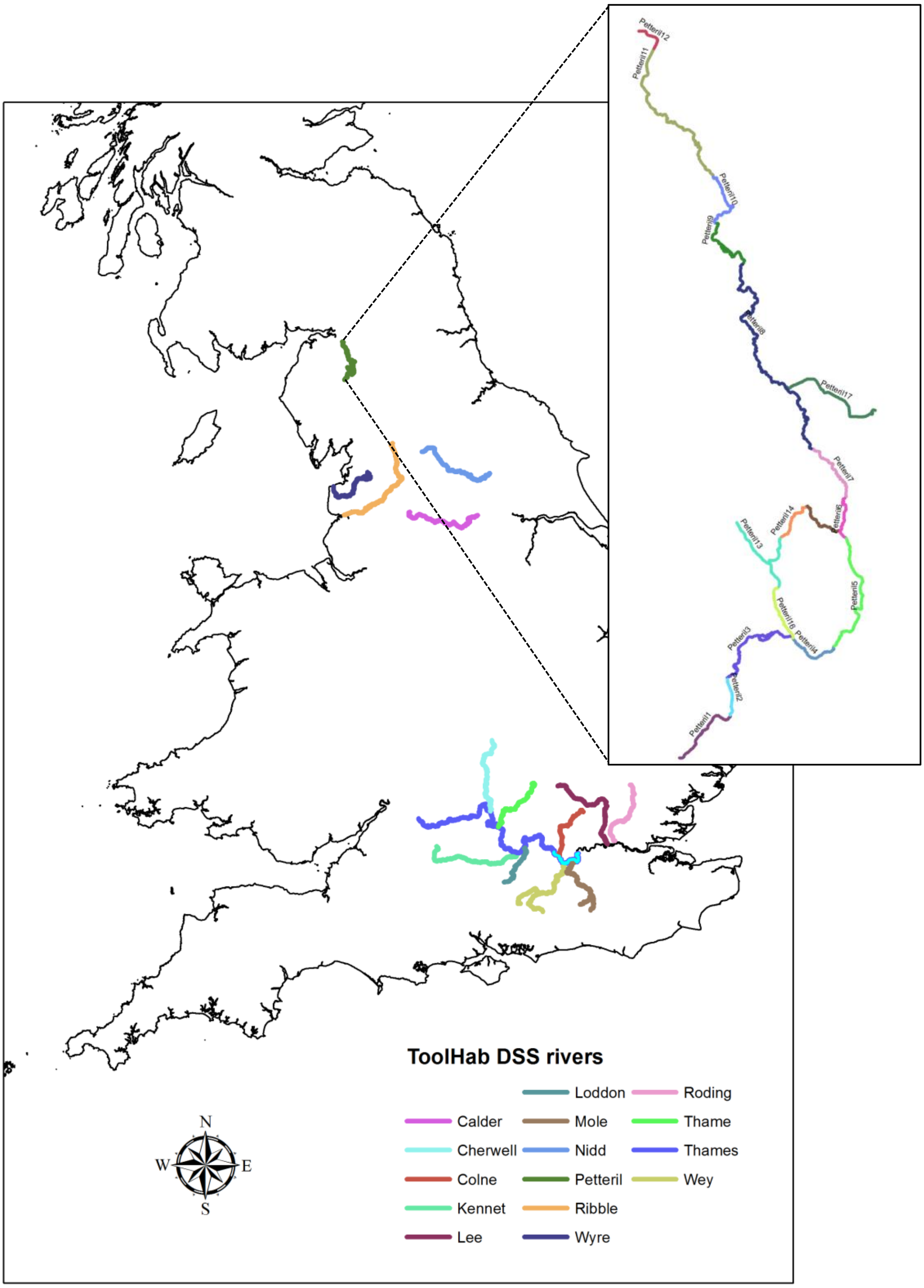


Figure 37: Reach statistics on fish populations using ToolHab reach interface. The first panel shows average fish density values for 23 species of fish across 4 years of survey. The second panel displays the same information in 4 separate bar charts for each year of survey (only 2005 data is shown here).

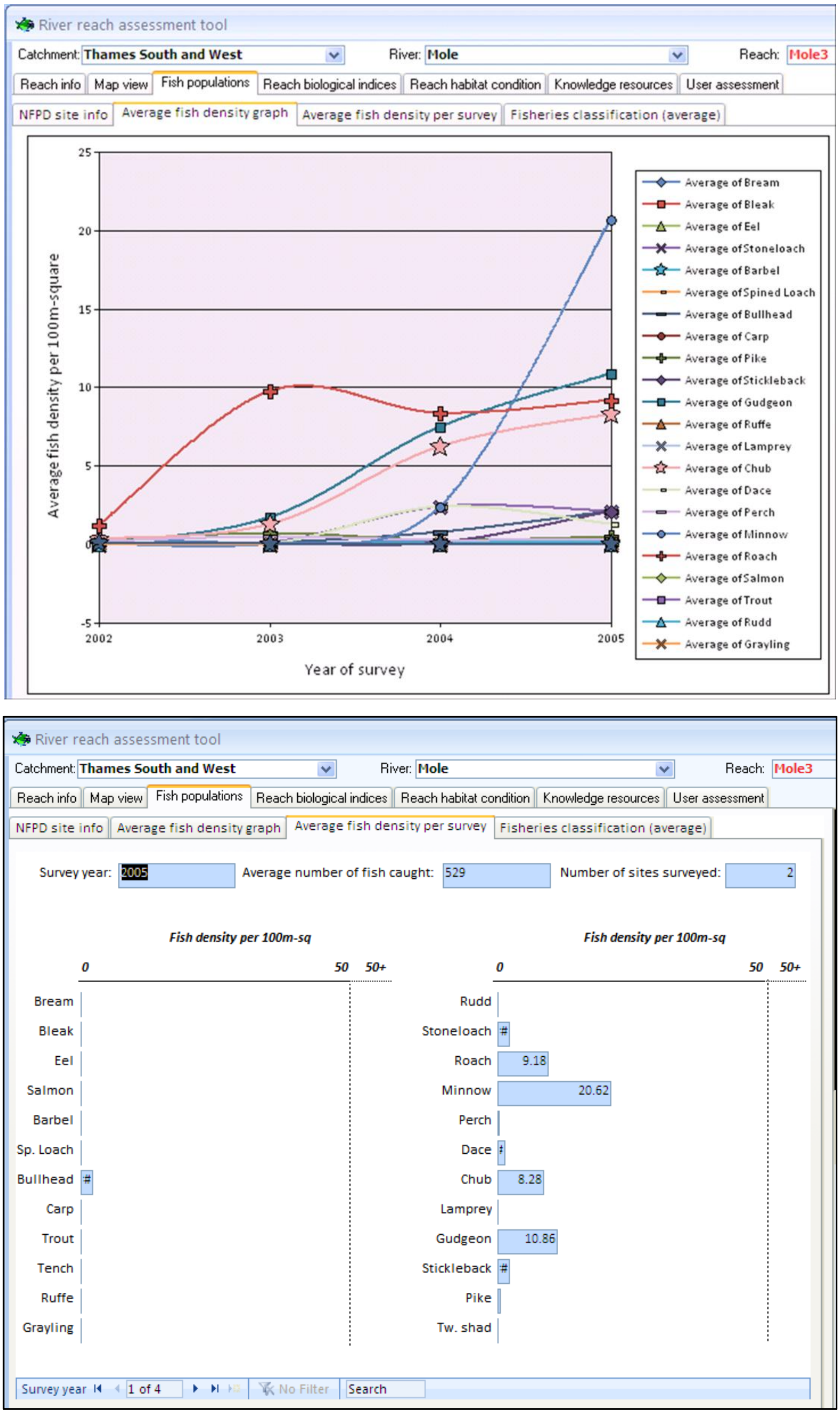


Figure 38: Average biological indices values for the Mole3 river reach from 1977 to 2007 using the ToolHab DSS reach interface. The biological indices indicate impacts on biological communities due to organic pollution and low flow events.

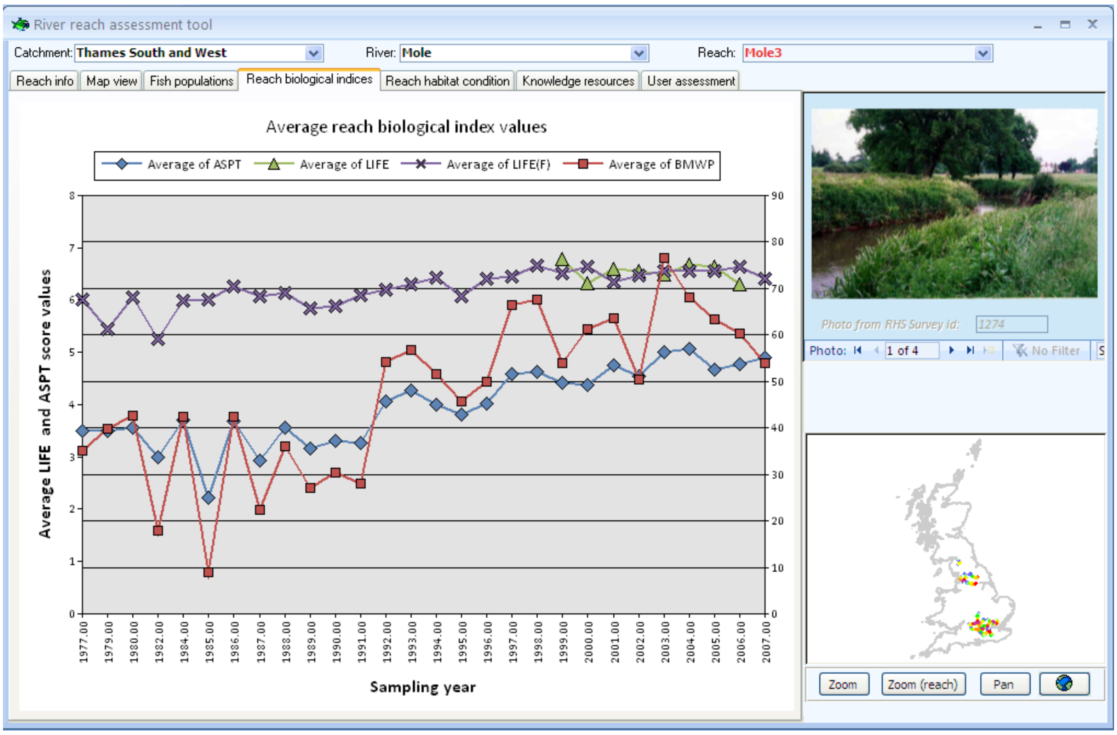


Figure 39: Average values for the Mole3 reach for 6 RHS derived indices describing channel substrate, flow regime, channel vegetation structure, activity (erosion and deposition), bank face and bank top vegetation structures. The indices are displayed as scales and the position of the reach on each scale is indicated by a square marker.

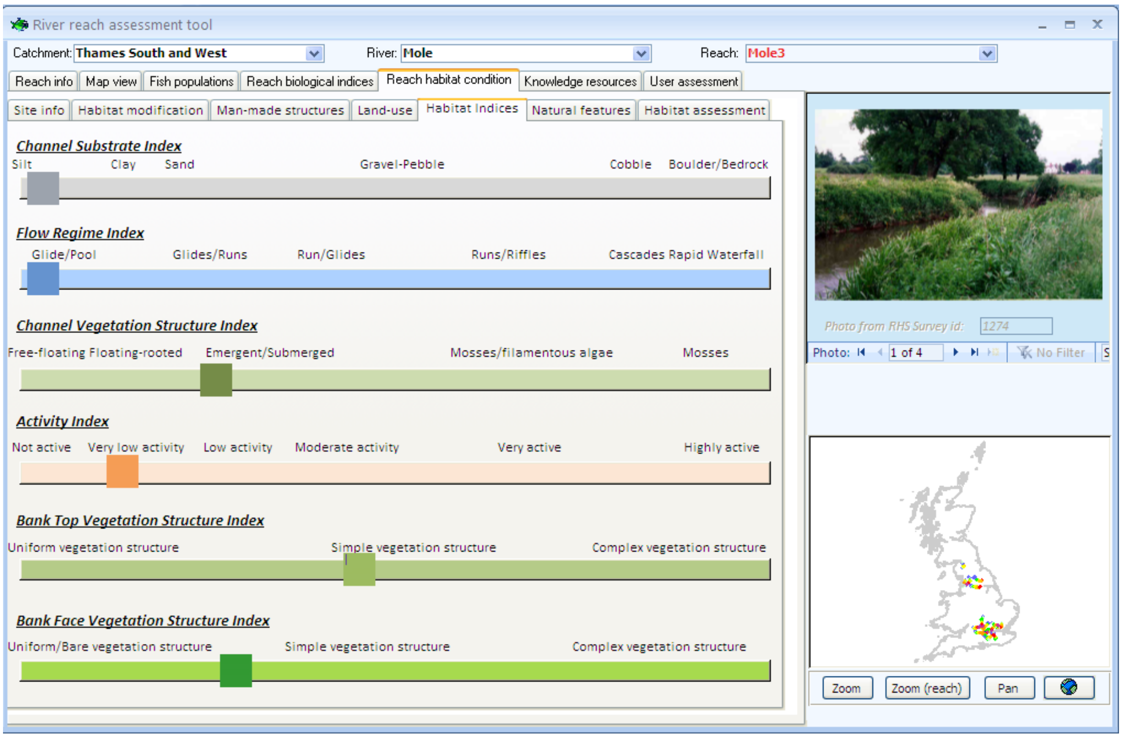


Figure 40: Average Habitat Modification Score (HMS) values for the Mole3 reach with corresponding Habitat Modification Class (Raven *et al.* 1997). The score box is colour-coded using standard WFD colour scheme. The HMS describes the extent and resilience of man-made engineering structures and modifications observed on the reach and varies from 0 (no modifications) to 3000 (heavily modified site). The bar chart shows HMS component sub-score values for specific structures and modification types.

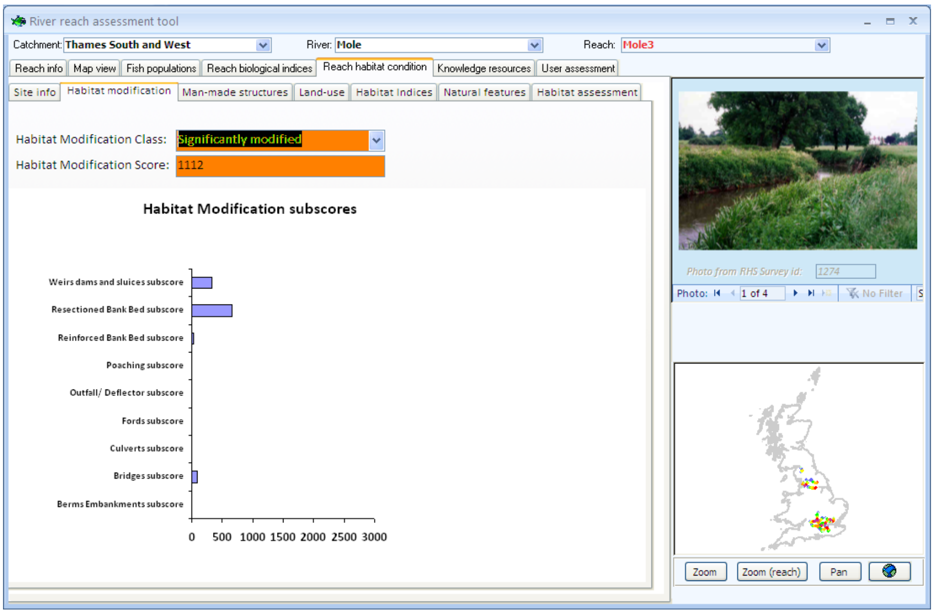


Figure 41: Average Fisheries Classification Scheme (FCS) values for the Mole4 reach showing the overall Environmental Quality Ratio (EQR) value and class, colour-coded using the WFD colour scheme. The three columns and bar charts represent the number of fish caught using single run estimates, the probability of finding more fish at reference condition, and the probability of species being present at reference condition.

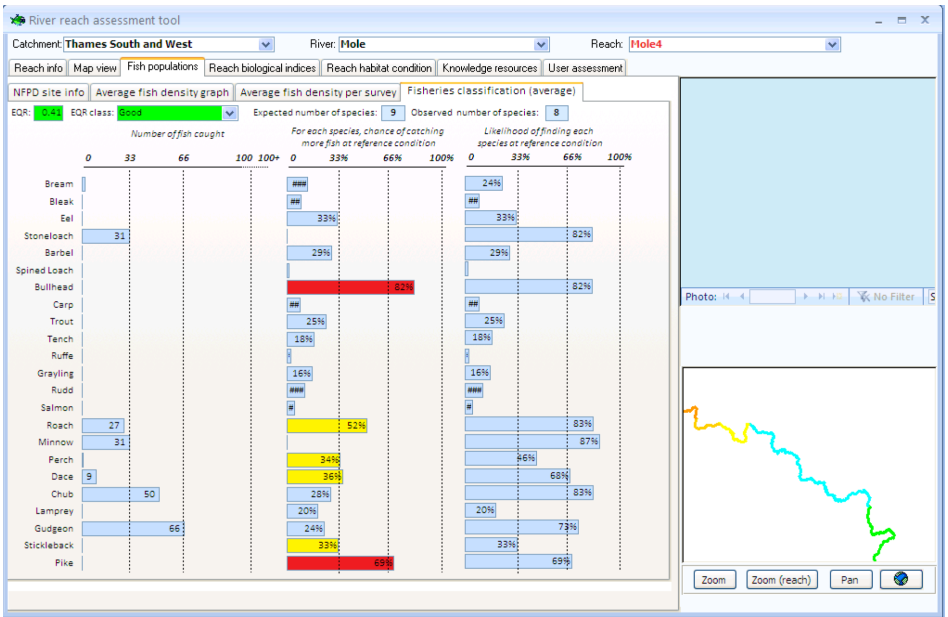


Figure 42: Local knowledge and events.

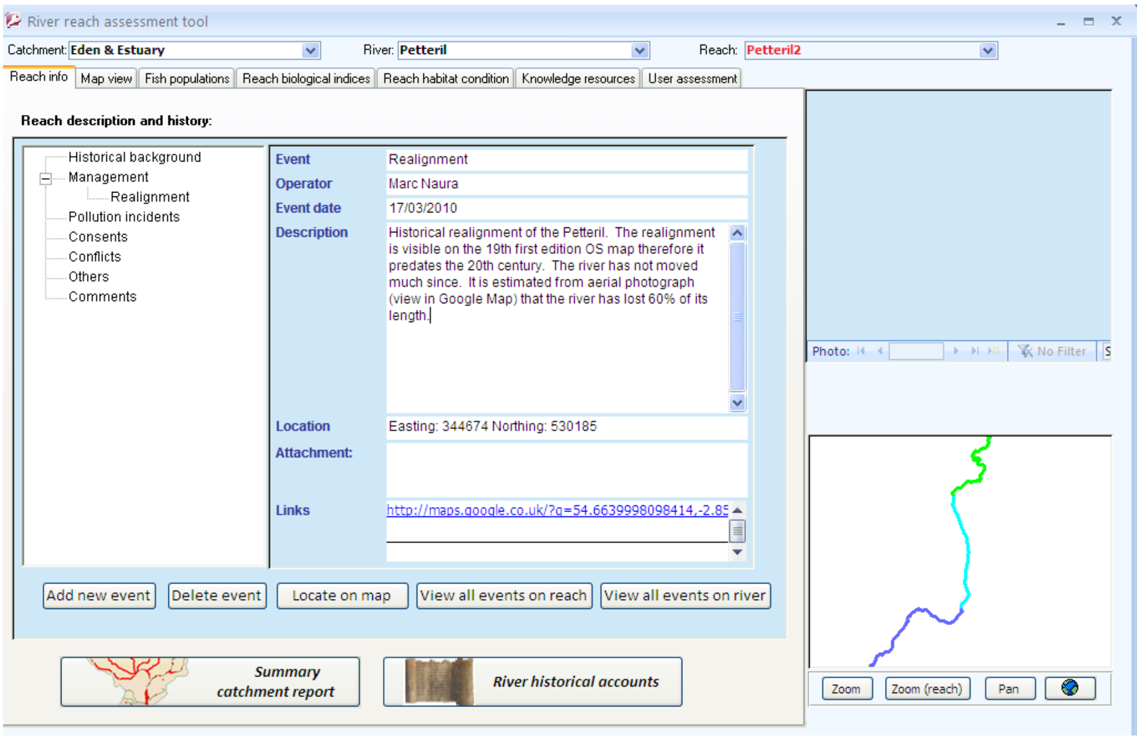
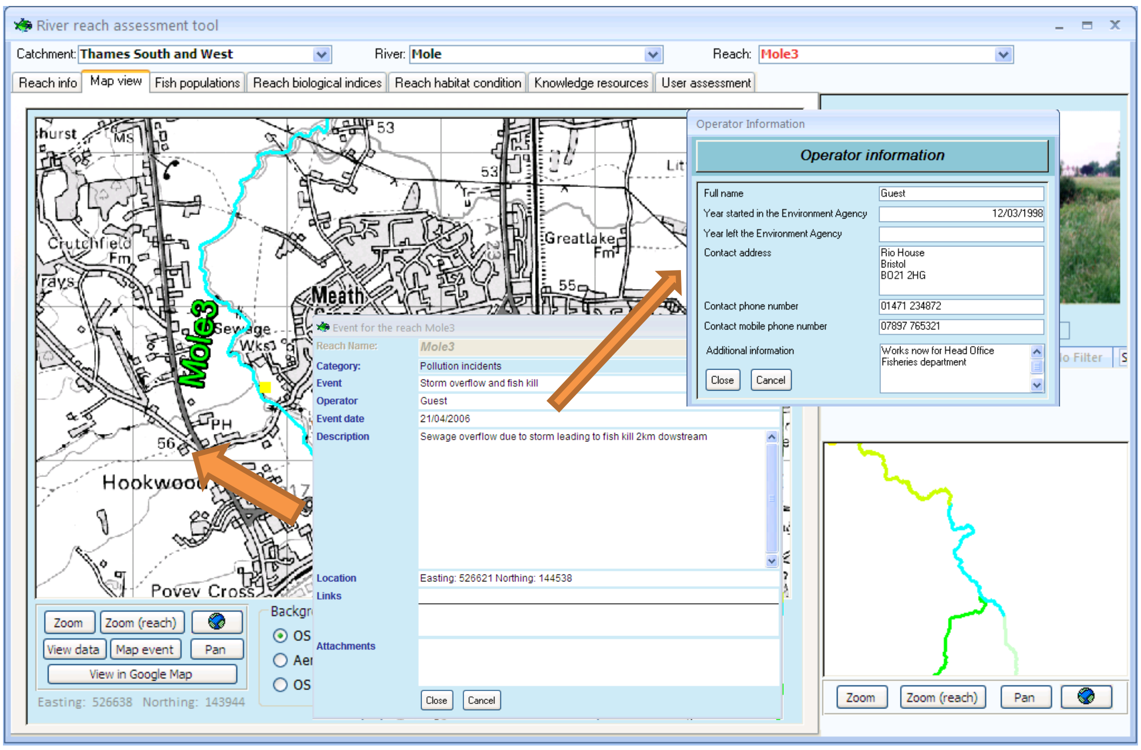


Figure 43: Local event creation using the 'Map view' interface and the 'Map event' button. By clicking on the map, an event is automatically created for the chosen reach. The event location is recorded and marked on the map with a yellow point. The operator name is recorded and his/her contact details can be consulted by double-clicking the 'operator' field.



A knowledge interface was also developed with links to known Internet resources. Conceptual models of fish habitat requirements for nine species and three life stages were built with recognised experts within the EA Fisheries section. Experts were gathered at two workshop sessions and habitat attributes, pressures and impacts were graphically displayed as mind maps with links of causality (figure 44). The conceptual models represent current knowledge from recognised EA experts on fish habitats and were supplemented by literature reviews produced by the Fisheries Science team.

The conceptual models were used to produce predictions. Each habitat attribute or pressure was linked to existing RHS, fisheries and water quality data, and predictive models were produced. One model was developed for trout using a technique called Partial Least Square Path Modelling (PLS-PM) (box 3). The model enabled the quantification of the importance and direction of causal links between pressures, habitat features and species density. A graphical interface summarising the model results at reach level was produced (figure 45).

All data included in the reach tool can be viewed at the scale of individual sampling sites using the map interface (figure 46) along with other data layers such as aerial photographs, 19th-century maps, barriers to migration (e.g. weirs, dams) and water quality data since 1990. The map tool also features a link to Google maps and satellite imagery.

The final reach assessment is recorded in a standard form in the 'user assessment' section (figure 47).

In the user assessment form, catchment officers must provide an assessment of:

- habitat quality for 23 species of fish as observed now;
- habitat quality for 23 species of fish at reference condition;
- pressures and impacts;

This assessment should be made along with suggestions for management action and an estimate of their likely impact on habitat suitability for fish. Additional information on opportunities, constraints and the potential cost of the suggested measures can also be included in the form.

Thus, the reach assessment tool enables users to view existing data and model outputs along with maps, aerial photography, local and historical knowledge to make decisions on habitat quality and remediation action. It is important to note that:

- at no point are users forced to use or view existing data or outputs from the models;
- users retain control over the whole assessment process. Experienced users may want to jump straight to the user assessment form without consulting the other modules;

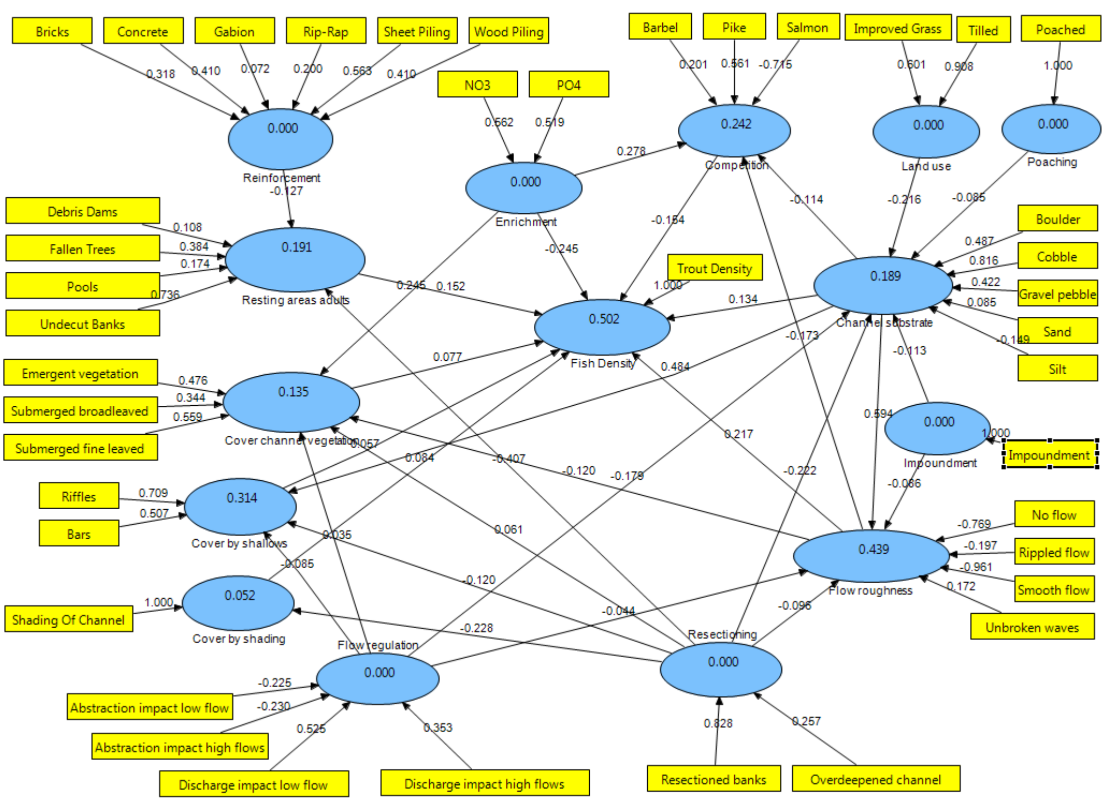
- users are asked to provide a clear assessment of river reach condition with information on pressures, impacts and recommendations along with an assessment of expected outcomes.

Box 3: Modelling the links between species, habitats and environmental pressures using expert opinion, monitoring data and Partial Least Square Path Modelling: an example applied to trout (*salmo trutta*).

A group of English and Welsh EA Fisheries experts and practitioners was gathered together to describe habitat features related to three life stages of trout along with the pressures affecting them.

Data from the Environment Agency fisheries, River Habitat Survey and water quality monitoring programs along with model predictions on abstraction and discharge impacts on water flow were paired using a Geographical Information System. Altogether, 2506 fisheries monitoring sites could be paired with River Habitat Survey sites, water quality and hydrology data.

Fisheries data consisted in single run electro-fishing survey species density estimates. Information on trout life stages was not available for the purpose of the analyses. The three conceptual maps for trout life stages were combined into one and analysed using Partial Least Square Path Modelling (PLS-PM) statistical technique with the SmartPLS freeware (Ringle, Wende & Will 2005) (see figure below).



PLS-PM has been advocated as a way of testing theoretical models of complex phenomena with links of causality (Schumaker 2004; Tenenhaus *et al.* 2005; Austin 2007). PLS-PM works by creating Latent Variables (LV) that represent dimensions linked to fish density (in blue in the figure). Each dimension or Latent Variable is derived using a Principal Component Analysis with relevant formative attributes (in yellow in the figure). For example, channel substrate LV was derived using a linear combination of substrate types using RHS data. The numbers between the manifest and latent variables show the contribution of each attribute to its corresponding LV. The numbers on the arrows represent the impact of latent variables on each other. The number within each LV represents the amount of variability that is explained by other explanatory LVs.

The model explained 50% of the variability in trout density. The model and coefficients highlight the complexity of the relationship between pressures, habitat attributes and fish density. The table below summarises the effect of LV on each other. Positive values close to 1 indicate a strong positive impact and negative values close to -1 a strong negative impact. Rows relating to environmental pressures were shaded in grey. Substrate, flow regime (ie roughness) and resting areas for adults had the highest positive impact on trout habitat. Enrichment by phosphates and nitrates, resectioning and the presence of competitors had the highest negative impact on fish and their habitats.

	Competition	Cover Channel Vegetation	Cover by shading	Cover shallows	**Fish density**	Flow Regime	Resting areas adults	Substrate
Substrate	-0.22	-0.07		0.48	**0.32**	0.6		
Flow Regime	-0.17	-0.12			**0.23**			
Competition					**-0.15**			
Resting areas adults					**0.15**			
Cover by shading					**0.08**			
Cover shallows					**0.06**			
Cover Channel Veg					**0.08**			
Enrichment	0.28	0.25			**-0.27**			
Resectioning	0.06	0.09	-0.23	-0.23	**-0.18**	-0.23	-0.41	-0.22
Landuse	0.05	0.02		-0.1	**-0.07**	-0.13		-0.22
Poaching	0.02	0.01		-0.04	**-0.03**	-0.05		-0.08
Reinforcement					**-0.02**		-0.13	
Flow regulation	0.05	0.05		-0.17	**-0.07**	-0.15		-0.18
Impoundment	0.04	-0.02		0.01	**-0.06**	-0.15		-0.11

Figure 44: 'Knowledge resource' interface with links to webpages and websites and a conceptual model module. Conceptual models linking 3 life-stages for 9 species and features participating to their natural habitat (in blue) and features and pressures having a negative impact on their habitat (in orange). Arrows show links of causality between pressures, habitat features and fish. In the model for trout eggs below, gravel pebble and fast flow velocities are associated with trout spawning habitat. Pressures such as resectioning and tilled land have an indirect effect on eggs by generating fine sediment that will infiltrate gravels and pebbles or by directly removing coarse sediment as part of dredging activity.

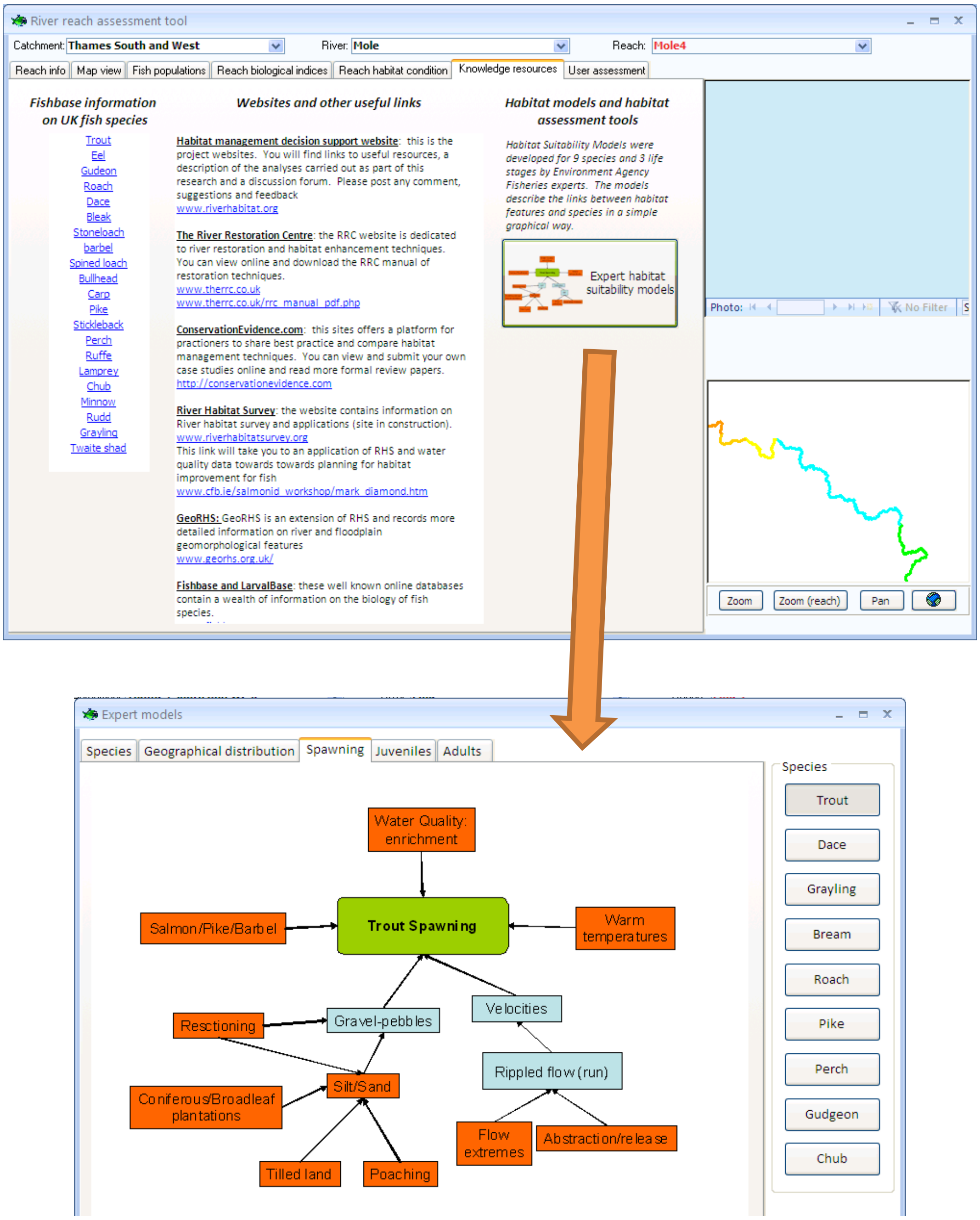


Figure 45: Graphical representation of a statistical model of trout-habitat relationship derived from expert conceptual models. In the middle column are habitat features normally associated with trout. Boxes are coloured according to their overall impact on fish densities (blue = high positive impact, red = low positive impact). The arrows show links of causality between features and trout. The thickness of the arrows represents the strength of the impact and the colour its direction (blue = positive impact, orange = negative impact). In the left-hand column are pressures on habitat features and fish. The colour of the boxes represents the level of impact each pressure has on total fish densities. The arrows represent the impact of pressures on habitat attributes or fish density.

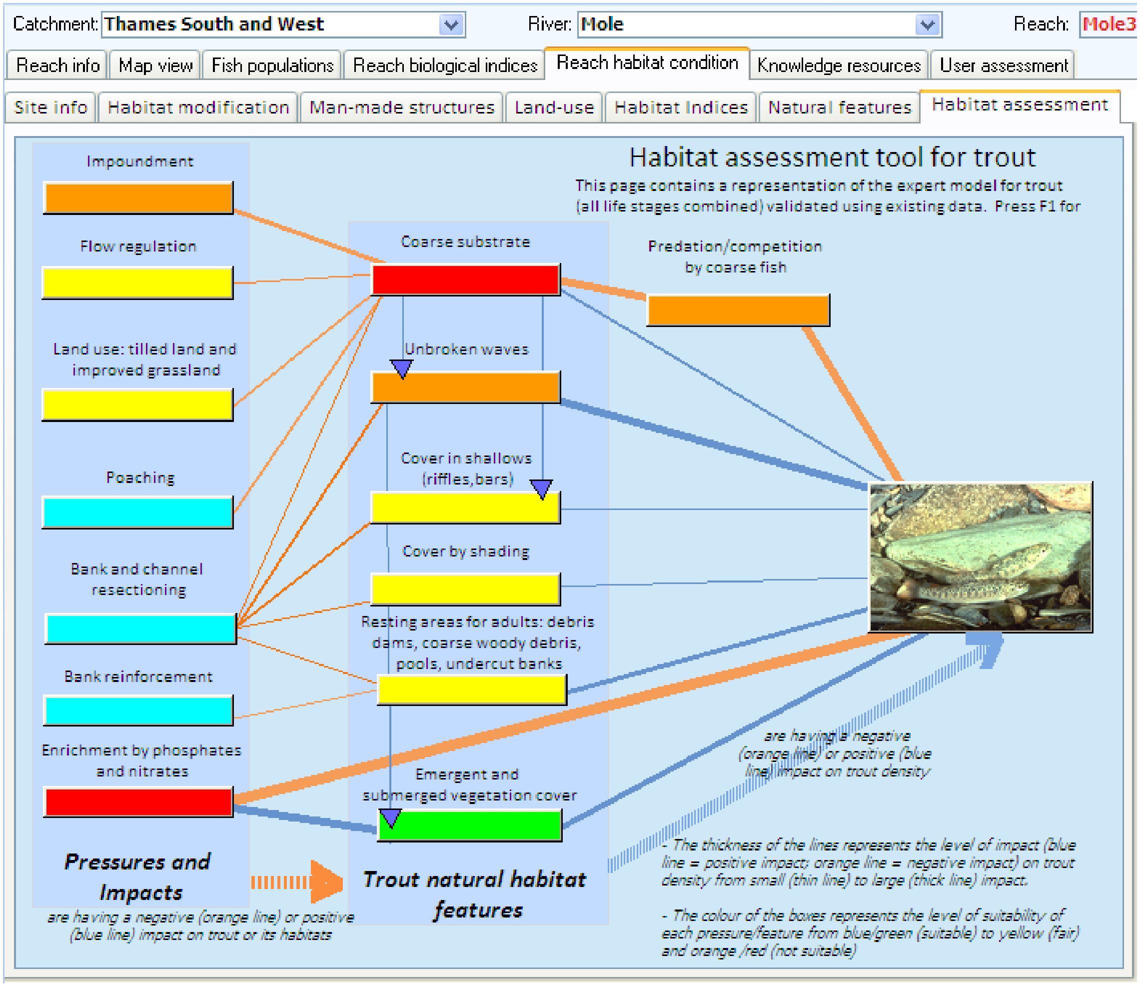


Figure 46: Using the 'Map view' tool to view data and models for individual sampling points. RHS sites are displayed in green and fisheries sites in blue.

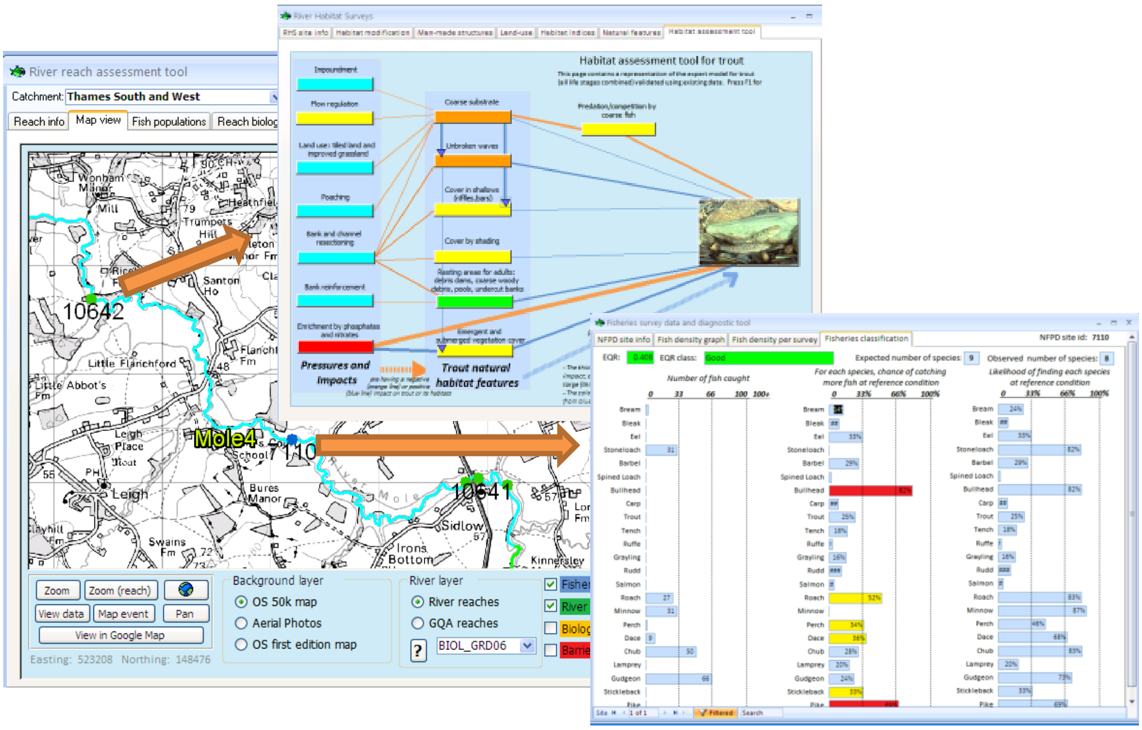
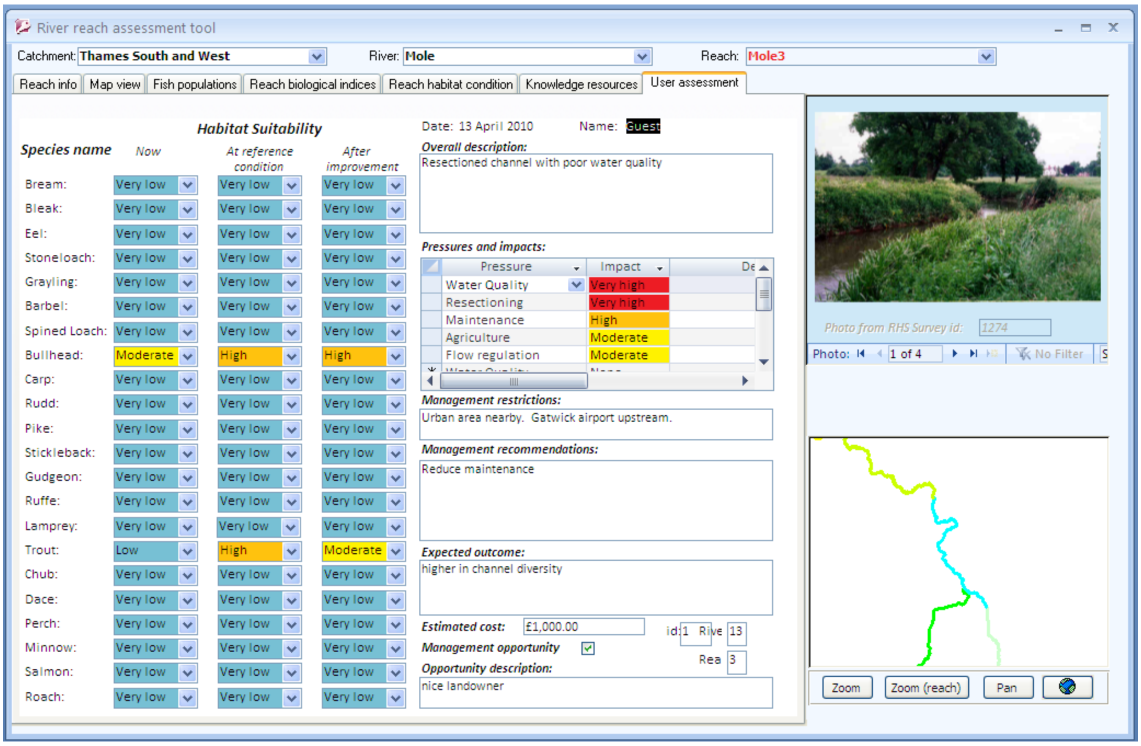


Figure 47: Reach assessment form.



Species name	Now	At reference condition	After improvement
Bream:	Very low	Very low	Very low
Bleak:	Very low	Very low	Very low
Eel:	Very low	Very low	Very low
Stoneloach:	Very low	Very low	Very low
Grayling:	Very low	Very low	Very low
Barbel:	Very low	Very low	Very low
Spined Loach:	Very low	Very low	Very low
Bullhead:	Moderate	High	High
Carp:	Very low	Very low	Very low
Rudd:	Very low	Very low	Very low
Pike:	Very low	Very low	Very low
Stickleback:	Very low	Very low	Very low
Gudgeon:	Very low	Very low	Very low
Ruffe:	Very low	Very low	Very low
Lamprey:	Very low	Very low	Very low
Trout:	Low	High	Moderate
Chub:	Very low	Very low	Very low
Dace:	Very low	Very low	Very low
Perch:	Very low	Very low	Very low
Minnow:	Very low	Very low	Very low
Salmon:	Very low	Very low	Very low
Roach:	Very low	Very low	Very low

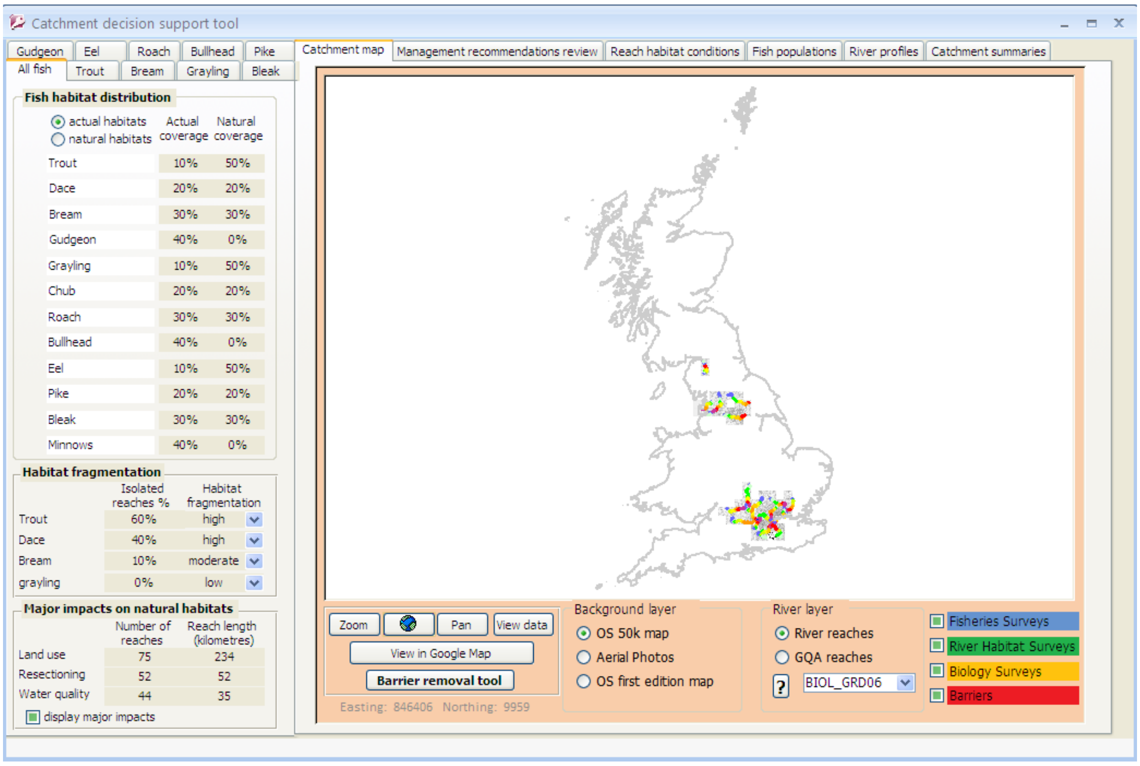
Catchment assessment tool

The second user interface was developed as a prototype only and contained no real data. Its principle follows from figure 34. It was designed to be used by technical specialists. Information on habitat suitability from the reach assessment forms is summarised at catchment level to help the development of catchment strategies.

The map forms the basis of the interface. Fish habitat suitability assessments are summarised across a catchment. The 'actual' and 'natural' potential coverage of high quality habitats for 23 species are quantified and displayed on the map. Fragmentation of habitats for each species is calculated and statistics on pressures and their impacts on habitats are displayed. Using the mapping tools, users are able to investigate the distribution of high impact pressures and identify catchment scale issues. They would also be able to display summary statistics and map attributes for individual species (figure 49).

The catchment assessment interface would also give users access to individual reach data, models and assessments and enable a review of management recommendations. This would enable feedback between technical specialists and catchment officers on data analysis and interpretation.

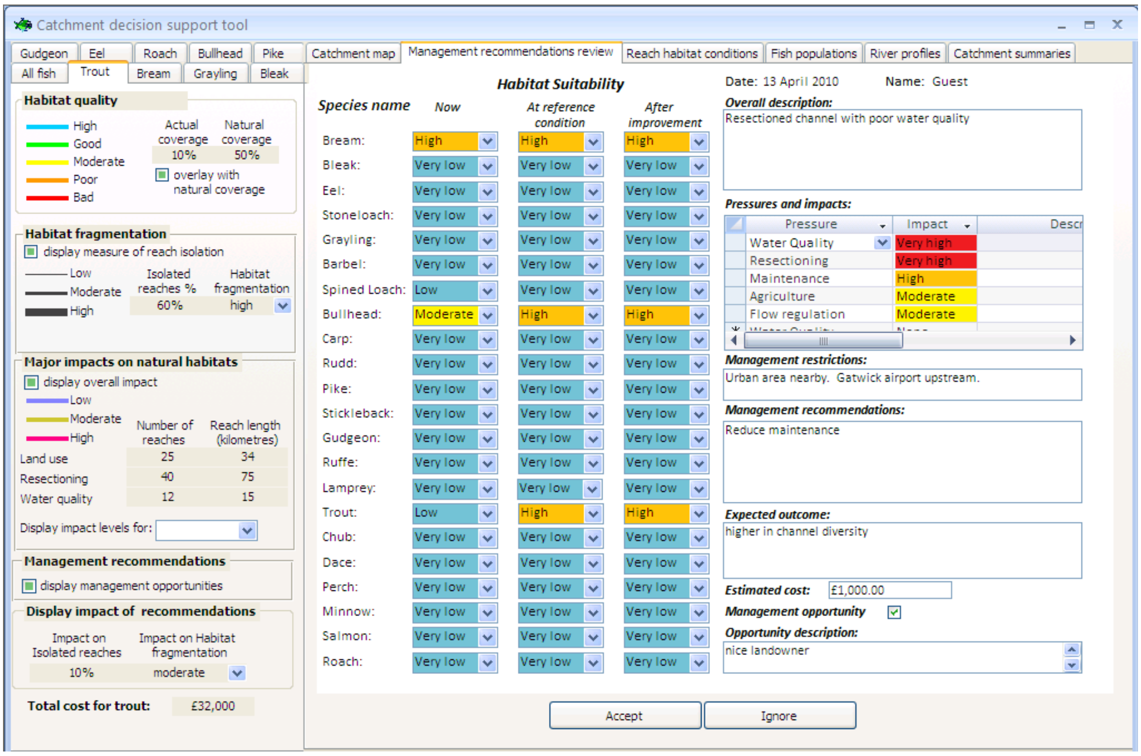
Figure 48: Catchment assessment prototype DSS. Data from the reach assessment forms filled in by catchment officers are summarised at the scale of individual catchments and displayed as maps and statistics.



Additionally, users would be able to view all potential barriers to migration and assess the impacts on species habitat fragmentation (figure 48). A barrier removal tool could be developed to simulate the impacts of removing or making a barrier passable to fish on habitat connectivity and fragmentation.

Using the tool, technical specialists would be able to build a strategy for habitat enhancement work across a catchment and prioritise individual sites and schemes based on target species, cost and benefits. The feedback from technical specialists on the catchment assessment tool was encouraging and positive despite the lack of a functioning interface. Further work has been planned and funding sought to finalise the tool.

Figure 49: Catchment assessment prototype DSS showing mapping options for individual species. The tool enables the display of habitat quality for individual species, habitat fragmentation and major impacts. It also provides an estimate of the impact of suggested recommendations on habitat fragmentation, reach isolation and cost. The user can review management recommendations for individual reaches, amend, accept or ignore them for inclusion in the final strategy.



User feedback

User feedback was gathered in a series of ways:

- by demonstrating the DSS to staff at interviews and focus group meetings during the design stages;
- by demonstrating the DSS at workshops and meetings at the end of the project;
- through a questionnaire sent to the project manager.

The feedback from catchment officers on the reach assessment interface was positive. Fisheries officers particularly liked the local knowledge module (TO = 55%, N = 20). The ability to access data from various sources in a simple-to-understand format generated much positive feedback (TO = 65%, N = 20). The visual presentation of FCS modelling outputs, which forms the basis for the WFD fish ecological assessment was also greatly appreciated as a previous interface using an Excel spreadsheet had generated a certain amount of confusion. This led to the development of a separate stand-alone Microsoft Access 2003 application requested by the EA Evidence Directorate for presenting and interpreting FCS modelling outputs that was made available to all fisheries officers and technical specialists in England and Wales.

The application was demonstrated at a series of workshops and meetings with catchment officers in Thames and other regions, technical specialists, Fisheries managers, managers and technical staff in charge of the Water Framework Directive implementation, and senior managers in Fisheries and Biodiversity. The application received positive feedback and was supported at all levels of the organisation. Water Framework Directive managers highlighted the potential for using the interface to help with the delivery of the WFD objectives.

Following feedback from the demonstration workshops, a project proposal for further testing ToolHab with selected users to assess its potential for implementation nationwide was put forward and is in the process of being approved. As part of the follow-up project, test protocols and methods for studying users decision-making pathways will be designed to gather feedback on the DSS ease-of-use and usefulness. Additional functionality and dataset will also be added to the DSS to make it compliant with WFD needs.

A short questionnaire was also sent to the Environment Agency project manager to gather some preliminary feedback on the application (see questionnaire and response in appendix 9). The project manager's feedback suggests that ToolHab may be very useful in providing a platform for learning about rivers and catchments for new staff, and for gaining knowledge on species habitat relationships. It may also benefit the development of strategies through providing catchment statistics not readily available and assessing pressures and impacts at catchment scale.

The tool was perceived as potentially beneficial for sharing knowledge between Environment Agency staff and experts and gathering information from available data and models.

The river reach assessment tool was perceived as the most useful part of the DSS because '*it attempts to build up a picture of functional reaches with relevance to fishery management which will differ from simplistic divisions based on WFD water bodies and CAMS [Catchment Abstraction Management Strategies] assessment points. The methodology used to do this has some logic and validity compared to very subjective views of river reaches that might otherwise be used*'. The interface designed for the PLS-PM expert model for trout was perceived as particularly useful. Overall, the DSS interface was perceived as generally '*intuitive*'and '*well within the technical grasp of modern EA staff*'.

ToolHab's main perceived benefit was in the provision of relevant data and knowledge at a relevant scale so that users can '*look at a river reach and very quickly gain access to all the data you need to see to build up a picture.*' The DSS can thus be used to quickly learn about local river systems: *'Even if you have the luxury of being able to walk the river bank, ToolHab enables access to lots more data than at present … you might need to contact four or five other people to obtain, or enter a number of other applications that the user might not be familiar with*'.

ToolHab was also highlighted as potentially useful for the implementation of the Water Framework Directive and '*as a communication tool for working with external stakeholders to identify options for fishery improvement-protection*'.

The feedback gathered was restricted to a limited number of users and managers, however, it shows the potential usefulness of the tool and it gives some insight on the relevance of the DSS design methodology. Formal testing as part of the next phase of the project will bring greater insights on user perceptions and the DSS potential benefits to Fisheries staff work, learning and decision-making.

Discussion

DSS design and culture

Cultural concerns and issues were built at different levels of the DSS design process. At a general level (see chapter 6, figure 21), a culture-centred iterative design approach was taken to identify the direction and nature of change in need of support by the DSS and potential frictions with working culture.

In the second case study, I started the analysis by listing management concerns with knowledge and decision-making and the need to move towards more evidence-based strategies and planning. Having investigated the working culture of Fisheries staff, I found potential conflicts between their world views and those promoted by the proposed DSS. I also found a strong need for freedom and control over decision-making which was supported by direct line management. I also became aware of the delicate balance of power between Fisheries and other richer departments such as FRM and the potential threats a tool could pose to their ability to influence.

The design of the DSS then shifted towards supporting current decision-making needs and knowledge acquisition framework whilst introducing data and scientific models and elements of knowledge management within the DSS decision-making process. Knowledge management became an important part of the DSS overall function. Knowledge management cycles adapted to Fisheries working culture were built within the DSS operations (figure 50).

Knowledge management cycles and culture

Knowledge management relies on pathways for knowledge exchange and on the existence of feedback loops within the decision-making process where existing knowledge and beliefs can be challenged, discussed and tested (Nemati *et al.* 2002). The decision-making process within the DSS contains pathways and feedback loops that were built around aspects of Fisheries working culture so as to maximise learning.

First, the knowledge embedded within the DSS follows from Fisheries officers' epistemology and makes an important place to local knowledge and expertise. The responsibility for collating and disseminating knowledge lies with Fisheries Science staff with the help of a group of recognised experts. Fisheries experts may be used to help build models, interpret outputs, provide feedback and recommend further investigations. The DSS is then made available to Fisheries officers who can contribute local knowledge and data.

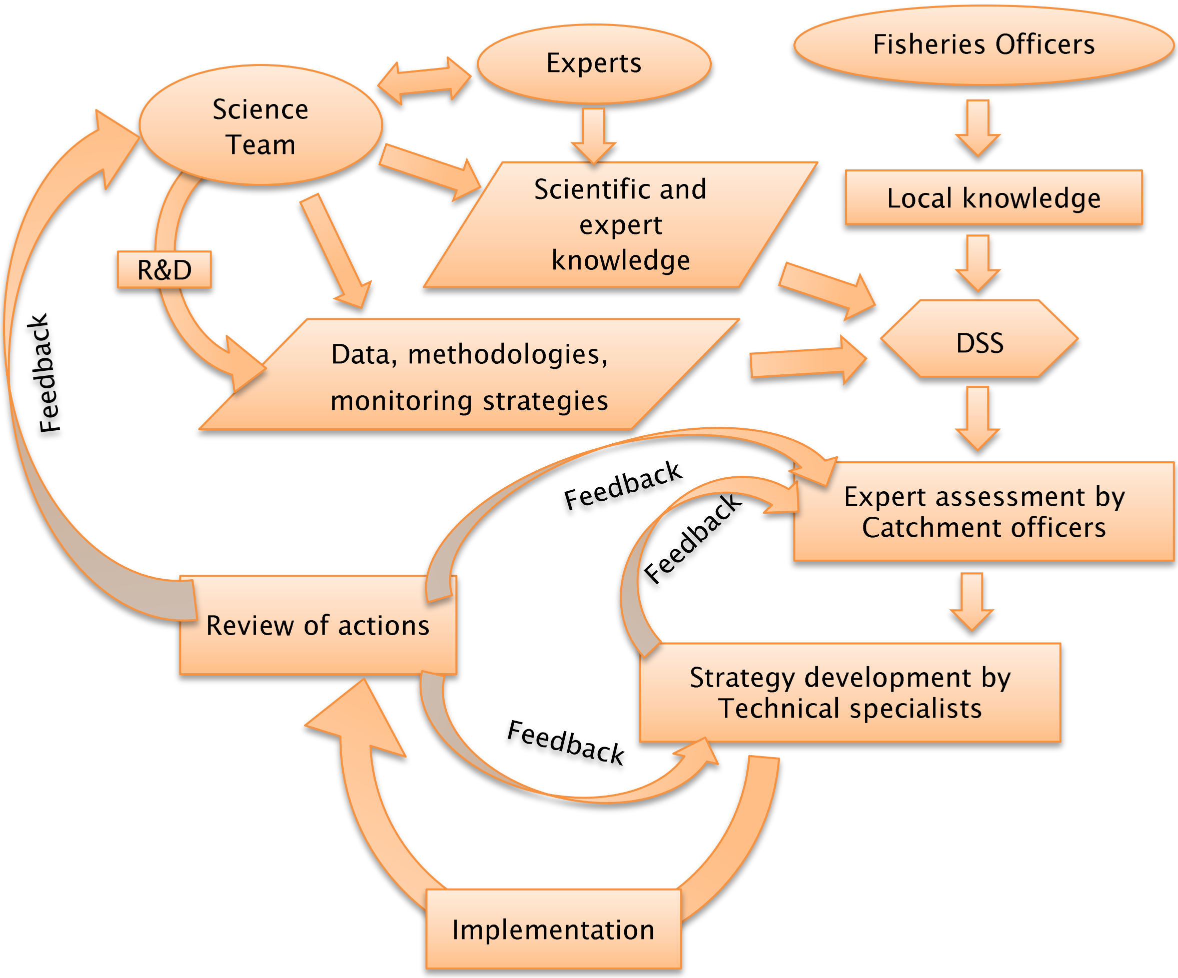
The first feedback loop builds upon the existing mentoring and learning framework within local Fisheries teams. Catchment officers use the DSS tools to assess river reaches and recommend management actions. Their assessments are reviewed by technical specialists whilst producing catchment strategies. The first feedback loop occurs between the technical specialists and catchment officers when producing strategies and reviewing river reach assessments and management suggestions.

From this interaction, a strategy and plan can be produced and implemented. During implementation, issues will emerge through natural environmental and/or stakeholder feedback. This will create the second feedback loop towards both catchment officers and technical specialists.

The review process may also generate questions around aspects of current knowledge that may trigger further investigations or R&D projects by the Science team and eventually generate new knowledge that will be fed back into the DSS. This is the third feedback loop.

The three feedback loops should ensure that knowledge flows within the organisation and is regularly challenged by emerging evidence and monitoring data for inspection by experts and practitioners. The decision-making process was designed so that feedback loops would occur naturally as a result of interactions between users trying to fulfil different tasks. This is important as compulsory feedback loops in the shape of Quality Assurance schemes, may lead to a feeling of 'being checked upon' and perceived as yet another layer of bureaucracy. Also, feedback loops and learning pathways were built around existing cultural processes thus maximising the chance that they will be activated.

Figure 50: Knowledge management cycles within the DSS decision-making process.

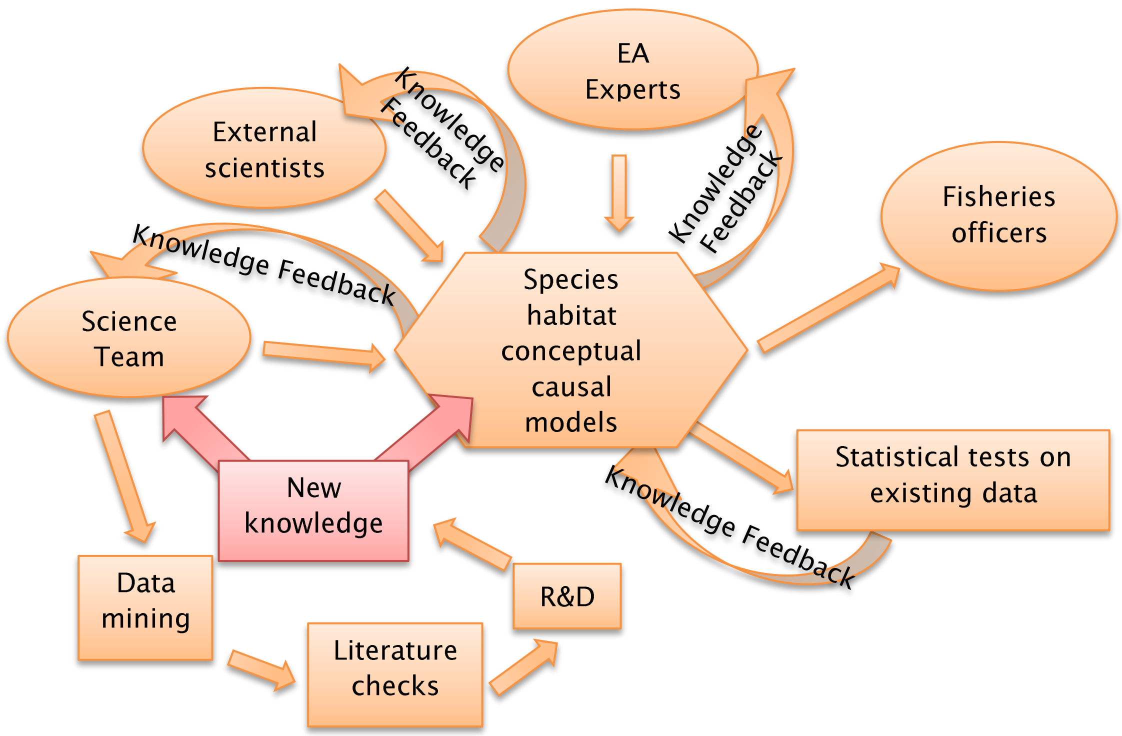


Culture-centred modelling

Within the DSS design process, another layer of culture/design interaction was built. The analysis of existing culture showed a strong distrust of statistical models and the preference for expert opinion and judgement. To make models within the DSS more acceptable, experts were actively engaged in the modelling process. This not only facilitated model acceptance by Fisheries staff, but also challenged/tested expert knowledge and beliefs.

In figure 51, the overall framework for building expert-driven models is described. Conceptual models of fish-habitat interactions were produced by Fisheries scientists, external scientists and EA experts from regional and area Fisheries teams. The models produced were tested using PLS-PM on real data thus providing feedback on the statistical significance of assumed relationships. Using data mining techniques, potential additional relationships between a range of data and fish were identified. The results were fed back to the experts and scientists for further consideration. If applied consistently, this process may challenge existing assumptions, unearth potential new relationships and trigger further investigation potentially leading to the creation of new knowledge.

Figure 51: Culture-centred modelling and knowledge generation framework.



Theoretical choices

In designing the DSS, I have made a series of theoretical choices which I will now summarise and discuss.

The high-level DSS design process followed the iterative design principles set out by Sprague and Carlson (1982) combined with Adelman's (1992) suggestion to run the evaluation process as part of the system development using prototyping. In designing prototypes, no *a priori* assumptions were made on the nature of the decision-making or any other aspects. Instead, the design was directed by outputs from the cultural enquiry and user feedback.

No theoretical assumptions on aspects of the DSS such as views on decision-making, rationality or learning were imposed *a-priori* on the DSS development. Instead, I used the 'theoretical toolbox' that I had reviewed in previous chapter to find the conceptual tools that best matched the DSS environment, aims and the users' working culture. The DSS development was an act of 'bricolage' to borrow a concept from the social sciences (it best translates as the action of 'pottering about' or 'DIY' i.e. 'Do It Yourself').

Whilst in the first case study I had assumed a prescriptive rational framework for decision-making with an embedded step-by-step process following Simon's 'intelligence-design-choice' model (Simon 1955), in the second case study I developed an interface that suited the intuitive nature of expert decision-making and enabled full user control on outputs and process. Data and models were present in ToolHab, but as part of a fluid and free decision-making process. The interface further enabled users to frame the problem in multiple ways and consider scientific, historical and expert evidence in a sequence of their choosing that best matched their preferred decision-making pathways. Data and models were also represented in multiple ways to accounts for analytical and perceptual differences.

The design and inclusion of the knowledge management cycles and features (e.g. local knowledge input module) were based around Lave and Wenger (Lave & Wenger 1991) 'situated learning' theory and the concept of 'communities of practice'. Whereas previous theories had described learning as an individual process which traditionally takes place in a classroom or training facility through the mediation of a teacher, Lave and Wenger hypothesised that learning also occurs through socialisation with a group of people sharing the same practice (Hughes, Jewson & Unwin 2007). They called those sometimes informal units 'communities of practice' and the learning process 'situated learning'. Learning is therefore part of a social practice. Individuals who share common practices with other individuals will learn along time through interactions, feedback, communication, observation and a wealth of knowledge will be exchanged and created in the process. Knowledge may be tacit or explicit. This theory of learning was not only important in designing the DSS embedded knowledge management cycles but also for understanding the process of culture formation for running the cultural enquiry. If we consider culture as a form of knowledge accumulated along time through a process of socialisation, then culture and its underlying assumption may well represent the product of learning situated within a community of practice (i.e. the organisation, department or team) Expert practitioners informally transmit knowledge to novices through participation in social activities. A community of practice does not need to have fixed administrative boundaries such as a team or a department but are defined by the loose boundaries of shared social interactions. Communities of practice within organisations may therefore overlap considerably.

For the interviews and the development of the DSS, I tried to identify within the Fisheries community of practice in Thames region the experts or leading figures. Particular attention and care was placed on their requirements and overall opinion of the proposed DSS. I realised that a negative opinion from a few experienced individuals commanding respect within the group may lead to rejection of the DSS. The development of the local knowledge module for example, was partly the result of input from these communities of practice leaders. I also made sure these individuals were fully involved in the DSS design process. The same thinking applied for the development of conceptual models for describing fish habitat relationships. In this case, the target community of practice was the Fisheries team at national level. I asked Fisheries experts to decide who would attend. The resulting group of experts were all well-recognised and experienced Fisheries specialists.

The concept of situated learning matched Fisheries officers' mode of practice. Learning was envisaged as the building of expertise through a process of socialisation with the team and members of the public, mentoring by an expert individual as part of work activities, and direct contact with the subject of learning, i.e. the environment. It was therefore important that learning as part of the DSS followed the same principles. As I was developing a computer system, learning had to be performed in the office away from Fisheries officers' preferences for learning in the field. The interface was designed to offer a different but appealing and complementary perspective on the environment Fisheries officers' experience. The user was offered a bird-eye view through maps and aerial photographs of river environments. Field photographs were included whenever available and data and models were turned into a series of visual interactive interfaces with a diversity of colourful graphical displays. Access to historical data and knowledge was also included to give access to additional dimensions novices would more rarely experience in the field. More importantly, the assessment process was built so that experienced team members would quality control the assessment made by catchment officers as part of the strategy building process, opening the door to feedback and knowledge exchange. Similarly, the models from the national experts would be likely to be discussed and criticised as part of the use of the DSS with the national Fisheries Science team acting as the manager of the DSS data and knowledge base.

The idea of building feedback loops within the DSS stemmed from the work of Bhatt and Zaveri (2002), who stressed the importance of feedback loops in the process of individual and organisational learning. The feedback loops were designed so that knowledge did not end up being fixed but was instead in constant flux and enabled the critique and update of existing knowledge and the emergence of new knowledge. I also suggested that the Science team set up a wiki page and let experts within the organisation contribute to it. This would reinforce knowledge dissemination but would also make the community of practice more explicit at national level and involve its members into knowledge sharing activities.

From the application of the concepts of 'situated learning' and 'communities of practice', I was therefore able to developed an interface with embedded knowledge processes and feedback loops that matched the structure of existing communities of practice, enabled greater acceptance and achieve the ultimate management aim of 'challenging people's knowledge'.

Conclusion on culture-centred DSS design

In the past two chapters, I have shown how a constructivist theoretical framework and a culture-centred iterative design approach can be applied towards the development of decision support technology. This approach is demonstrated as better matched to the working culture of an organisation together with individuals' beliefs, identity and needs. I also showed how an understanding of culture may not only help in guiding the overall design process but it could also be used to deal with specific aspects such as knowledge management or statistical modelling. Some preliminary feedback from users seemed to indicate greater levels of acceptance amongst users, a perception that the tool may be of help to their practice and that there is a willingness to use and apply it. Feedback from managers also suggests that the tool is delivering on their original stated aims. However, the system has not been properly tested and it is not possible to ascertain whether and how it will be used. Further tests on user perception, acceptance levels and impact on work practice will be carried out as part of a follow-up study that is in the process of being approved and set up.

The methodology proposed involved the deployment of methods generally not used in traditional software or DSS design such as focus group meetings, individual interviews and transcript analysis. It also required the developer to change focus and view the problems from different perspectives: that of the users, the managers, the local stakeholder or the fish. The skills necessary to perform this type of enquiry are generally not taught in mainstream ecological science or computing degrees. On the contrary, it seems that a good part of science teaching requires students to adopt positivist perspectives and Cartesian views on rationality and decision-making. It is therefore not surprising that most software, DSS and embedded decision-making processes capture and promote these specific worldviews and approaches. In dealing with what sociologists call the 'messy reality', this may lead to frictions and rejection of well-intentioned technology. The use of culture-centred approaches towards the DSS design requires skills and ways of thinking that are not necessarily available within the world of designers. Teaching such skills is feasible provided that a clear method is set and investigations follow a path that the designer feels comfortable with. The culture map and the investigation steps I proposed were attempts at bringing structure and rationality within a process that is interpretive and subjective in nature.

Studying cultures takes time and the proposed approach could well be criticised for this and the amount of resources required to develop a single prototype. In the second case study, the tasks of organising/running the interviews and analysing/transcribing the data were time-consuming. The use of professional transcription services greatly improved efficiency. In the discussion, I also suggested that with practice, it should be possible to analyse most issues using focus group meetings and short interviews with a subset of staff. Compared to current user centred approaches towards DSS design, the approach proposed should not require vast amounts of additional development time for mid to large sized projects. My experience with traditional software development and 'systems analysis' is that it takes months to achieve, it is costly to run and is likely to result in failure. Further research should be undertaken to enable a better understanding of the costs and benefits of culture-centred design methods compared to other techniques.

Chapter 8 Discussion and perspectives

The use of science and scientific tools within organisations is a subject that is being increasingly discussed in academia and in society in general (Anonymous 2007; Memmott *et al.* 2010). Scientists have demonstrated in countless experiments and case studies that models and tools built around a rationalist positivist framework can deliver optimal solutions to given problems and generate new knowledge and better decisions. DSS are one example of the many tools and techniques that have been developed to make scientific models available to environmental practitioners, managers and policy makers.

However, looking back at the past few decades of DSS development, we can see that the uptake within organisations has not been as successful as one would have expected considering their stated benefits. Expensive software systems have been developed and have failed to impress the users they were designed to help. A significant number of DSS never made the implementation phase (see chapter 3).

Researchers have gradually become aware of issues surrounding user acceptance of DSS. These reflections eventually led to the development of postulates around the interaction between DSS and organisational culture and its link to implementation success. So far, this hypothesis has mainly been investigated post-development in an attempt to tease out the dimensions of culture that favour DSS implementation. No studies have so far investigated organisational culture prior to DSS development to inform the design and implementation stages (chapters 3 and 5).

In this thesis, I have attempted to develop such an approach and applied it to a real case study with the Environment Agency Fisheries team in Thames region (chapters 6 and 7). The development of the methodology that led to the design of ToolHab was part of a process of learning which was initiated 15 years ago when I first attempted to produce models and database applications for the EA Conservation and Ecology section. My first attempts at generating DSS were met by many failures. The first case study, initiated at the beginning of my PHD, is one example of such failed attempts. Its comparison to the second case study, along with extensive reviews of the literature, illuminate some of the main factors that may contribute to DSS uptake. I will now discuss these findings and attempt to generalise them to the wider fields of DSS design and applied research.

The function of DSS.

DSS are often enthusiastically described by their promoters as tools to help decision-makers perform complex, difficult and taxing tasks. This somehow presumes that decision-makers are in need of help and that, facing complex messy problems, they will welcome any tool that can lighten their decision-making burden.

The reality of DSS is not as positive. Far from being seen as a 'helping hand', DSS are often perceived as a threat to current ways of working (chapter 3). In the minds of managers who commission DSS, they are ways to increase efficiency and correct or improve current decision-making. Users who are landed with a new piece of software on their desktop PC may therefore not fail to notice that somehow their current ways of working may not be adequate or acceptable anymore.

DSS may therefore be introduced to promote change in users' ways of working. In turn, this may affect user perceptions as professionals, individuals and decision-makers and their assumptions towards knowledge and problem solving; in other words, their culture. In both case studies, DSS were advocated as ways of bringing change in work practice. In the first case study, management had taken a more inquisitive open stance towards the use of DSS and no clear objective was set at the beginning of the project. The proposed DSS structure with its associated decision-making processes were suggested by myself and were in clear contrast with existing practice. They were aimed at bringing rationality, objectivity and accountability in a decision-making process that was very decentralised and based on uncoordinated actions. In the second case study, the nature of change required by managers was made explicit at the onset of the project. Beyond the stated objectives for the DSS were concerns over decision-making and knowledge and the need for more strategic planning based on scientific evidence.

The issue of change is central to DSS development and is applicable to the fields of software design and applied science. Research in organisational culture has shown that once a particular culture has formed within a company, any change is likely to face strong resistance (Schein 2004). In the EA conservation and Fisheries section, the working culture was not based on the principle of science, rational decision-making and the use of technology, but on expertise, instrumental rationality and the use of judgement (chapter 6). The rationality of the decision-making process was blurred by the need to account for external agents and power relationships between stakeholders.

This situation is by no means restricted to the EA and is likely to be widespread throughout organisations and society in general. The application of science and technology to organisations is likely to bring change to work practices and challenge user assumptions on problem-solving as well as their technical skills.

The assumptions of DSS.

DSS are not assumption free. They generally carry the assumptions of their developers and of the managers who commission them. When designing solutions to problems, DSS developers assume specific theoretical frameworks with matching methods and analytical approaches. Theoretical frameworks comprise assumptions on ontology (the nature of reality), epistemology (the nature of knowledge) and methodology. Scientists, engineers and software developers have generally been trained in the highly rationalist positivist scientific frameworks. They assume that reality exists independently of perception and truth can be approached through experimentation. They focus on the general rather than the specific and they advocate parsimony.

This may contrast and conflict with the views of the user community as exemplified in the first and second case studies (chapters 4 and 6). Catchment officers criticised the reductionist views of scientists. 'Fish don't read books' and the world is ‘more complex’. Their ontology allowed for environmental and social complexity and their epistemology was based on local experiential knowledge.

The mismatch between the tools’ frame of reference and that of the users is likely to generate rejection as it leads to a depiction of reality that does not reflect the user experience.

This issue is not restricted to our two case studies and may apply to software design and applied science in general. Ecological models tend to be reductionist and based on data collected in restricted spatial and temporal frames. DSS and other decision software are in their vast majority built around Simon’s prescriptive framework for decision-making (Simon 1960). We have seen in chapter 5 how pervasive the positivist stance of designers and researchers was, even for the study of culture, a field of research that has been the traditional ground of ethnographers and social scientists.

Because of the reactive nature of most management practice, and the need to make fast decisions in complex socio-environmental systems, practitioners are likely to resort to expertise rather than scientific methods for their problem-solving. A doctor examining a patient or a catchment officer reviewing a Land Drainage Consent do not have the luxury of time to frame their problems in a scientific manner and engage in detailed analysis. Expert judgement is therefore likely to become the norm within organisations that have to deliver decisions in highly sensitive and complex environments, the same environment that DSS were originally designed to help with.

This puts science and technology into a paradoxical situation where tools are produced that are by pre-conception unlikely to be adapted to the theoretical frameworks of the users they intend to help. The same can be said of attempts by scientists to develop complex modelling or survey techniques to help design policies and deliver effective management. The applied literature is full of scientific offerings that have never been met by a social demand for reasons most probably linked to a mismatch of theoretical perspectives and choice.

Bringing science in organisational practice.

The recognition that DSS, science and technology are neither ‘assumptions' nor 'intent'-free and that their aims, objectives and theoretical frameworks may conflict with the users working culture led to the development of the methodology I used in the second case study (chapter 6).

The methodology basically reverses the traditional DSS design framework and places the DSS development within the context of a social enquiry on organisational and individual culture. It makes explicit the issue of change and it analyses its potential interactions with existing practice and culture. It acknowledges the issues of power distribution and decision-making within organisations and it does not attempt to prescribe a particular approach to problem-solving.

The second case study (chapters 6 and 7) exemplifies this approach for a problem that was in many ways similar to that of the first case study. Whereas the DSS proposed in the first case study attempted to prescribe a rational step-by-step science-driven approach, the second case study DSS recognised the complex nature of user environment, their worldviews and their needs for control and freedom over their decisions.

To be able to achieve that, the design cycle had to be loosened and made flexible and responsive to change. The overall theoretical framework had to account for the possible existence of multiple perspectives on reality and knowledge. The tool development was itself an act of 'bricolage' (i.e. 'DIY') using the best matching tools available in my theoretical toolbox.

There is no reason why such an approach could or should not be applied to DSS design in general or to applied research, if what is required is a custom-made tool adapted to organisational practice. In developing models or tools for practitioners, scientists and engineers would benefit from understanding the social context in which they will be used and the potential conflicts they may generate. Modelling can be performed using a wide diversity of analytical techniques some of which may be more or less amenable to user assumptions and decision-making environments. More importantly, if the DSS aims are to promote the use of science, there are ways of making scientific tools available whilst respecting the users worldviews.

Evidence-based environmental management.

Through both case studies and the reviews of literature, we have seen that expert judgement is often the *de-facto* methods for making decisions (see also (Pullin & Knight 2005)). We have also seen the limitations of personal expertise and the many biases that affect each of us in our decision-making. Studies have highlighted the potential impacts of poor decisions and have shown the benefits of science and technology to reduce and correct human errors (see chapter 3).

With the advent of laws that require environmental practitioners to make complicated decisions on environmental dimensions/concepts (such as Good Ecological Status for the WFD) that are difficult to measure and assess against the unpredictable nature of future climate change impacts, there is a clear need to support decision-makers with scientific tools such as DSS. The alternative would be to resort to the heuristics and biases of experts whose domains of expertise do not always encompass all the skills and knowledge required to deliver these complex decisions.

Therefore, the main issue may not only be about decision help but more generally about knowledge. The lack of inroad of science and its tools within practice along with the lack of knowledge management policies and processes within organisations may lead to decision-making failures due to the quality and validity of the evidence used. Recent surveys have highlighted how rarely practitioners use monitoring data outside their domain of practice and consult scientific publications in their decision-making. Within the EA and many other organisations, there are no systematic policies, processes or budgets in place for monitoring and appraising environmental management schemes.

There is a danger that experts and scientific knowledge get dissociated and that decisions are based on anecdotal evidence and myths. This lack of interaction between science and practice would also affect scientists who could benefit from tapping into the vast resources of knowledge accumulated by local practitioners and experts over the years and getting access to monitoring data and 'grey' literature.

The need to bring closer together scientists and practitioners has recently been highlighted in a tribune in the journal Nature (Anonymous 2007). Such a move would imply that scientists and practitioners speak a common language or find ways of interacting despite their differences. The response of scientists to this problem has been to 'communicate better' (see chapter 4). The evidence-based movement is an expression of such attempts; the EU-funded HarmoniCA project is another. Communication, however, is often perceived as the removal of jargon and the delivery of more understandable messages. It is rarely assumed that the problem may not be in the way information is communicated but in the message itself.

As such, attempts at organising workshops between scientists and practitioners and involving users in DSS design may ultimately prove futile if they fail to consider the users' world views. Practitioners do not need to be explained why a model works better than current practice and why they should be using it, they simply need to be understood. Even in medicine, where the evidence-based movement originated, there has been and still is significant resistance to the concept as it is perceived by some as yet another attempt by positivist scientists to impose their own standards on medical practice (Buetow *et al.* 2006; Goldenberg 2006).

In the second case study, I have tried to illustrate how this stalemate could be resolved. By acknowledging the theoretical perspectives and cultural identity of users and developing knowledge management cycles within and around the DSS, it is possible to develop strategies that promote expertise and expert knowledge but subject them to the scrutiny of scientific validation. The building of a predictive model for trout was an example of such strategy: experts built conceptual models that were later validated against existing scientific knowledge and monitoring data.

Learning can then be a process where scientists and experts collaborate and learn from each other. If they are carefully designed and supported by surrounding processes and structures, DSS have the potential greatly to improve an organisation knowledge-base and create new knowledge. From a management viewpoint, DSS such as ToolHab would not only enable to build an evidence-base for future decisions but it would promote transparency, consistency and accountability in decision-making and permit future reviews and further learning.

Measuring success.

It is difficult when developing tools to measure success in an objective manner. We can attempt to define success according to four criteria:

- the satisfaction of users,
- the delivery of original objectives and aims,
- the use of the system,
- and the delivery of better decisions on the ground.

In the first case study, potential users expressed serious doubts on the ability of the DSS to deliver proposed changes. In the second case study, user feedback was positive and the DSS was perceived as delivering on the original project aims and objectives which was to make data and models more easily available to catchment officers and technical specialists. However, the tool still has not yet been tested and new organisational changes have emerged that may influence its acceptance in future tests. Since the project was finished, the EA has been through an important reorganisation that has seen 60% of staff in the EA Science team being made redundant and 25% nationally. At the end of the study, Thames region was merged with South East region and the remaining Fisheries staff were given extra duties and responsibilities. With the recession (2011), budgets have also been cut and moral wasreported as low.

Although ToolHab was not fully tested, parts of the application have proved popular with Fisheries staff. Following the end of the project, I was aked to develop an Access 2003 interface incorporating the module for representing outputs from the Fisheries Classification Scheme predictive model (see figure 41 in chapter 7). The application was perceived as a clear improvement on the existing Excel spreadsheet that was used to interpret the Fisheries classification outputs. The application has since been distributed to Fisheries officers in the EA.

Although we cannot say for certain that the methodology used led to implementation success and better decision-making, we can at least point to the greater levels of user acceptance and satisfaction compared to the first case study. Further tests are being planned and should bring some insights on the overall usabilty and fitness-for-purpose of the tool and its approach.

Challenges and limitations.

It is important to note that the second case study is only one example demonstrating the potential benefit of the culture-centred design approach. To be valid, we would need to replicate the study in other organisations and follow DSS uptake post-implementation. This can be done in many ways: by monitoring DSS use; by tracking decision-making as part of the DSS; by comparing decisions before and after implementation; by running user and management surveys; or through the use of participants observations.

Some of the main challenges to the proposed approach are the skills and incentive required to put it into practice. As discussed in previous chapters, such an approach requires the adoption of different methodological perspectives and the use of surveys and analytical techniques that are alien to many scientists and engineers.

Scientists are also valued and assessed in their practice against quality criteria that do not put the emphasis on the applicability, uptake, or social usefulness of outputs but on 'scientific excellence'. A shift towards 'softer' techniques of enquiry that are often perceived as less rigorous than traditional scientific methods, may not be seen as desirable by individual scientists or academic institutions.

In the second case study, I tried to formalise a methodology that took a clearly constructivist perspective with a structure for the enquiry that would appear more familiar to scientists like myself. The development of mind maps representing aspects of culture and the identification of a series of steps for building gradually more detailed pictures of culture and decision-making were attempts at bringing a more rational, logical framework to the study of something as impalpable as culture. Indeed, I do not believe that scientists would feel comfortable producing 'narratives' and 'thick descriptions' in the manner of anthropologists to justify their choices.

Obviously, the task of making sense of culture does not necessarily need to be the responsibility of DSS developers alone. In fact, there is a real opportunity for combining social scientists with DSS developers for the production of meaningful tools (Giupponi *et al.* 2005). This would create its own communication problems and would probably require the prior adoption of common concepts and language. It would nonetheless bring a welcome multidisciplinary addition to the field of applied science and it would enable modellers and engineers to concentrate on delivering high-quality scientific outputs and methods.

To conclude, research is a process of constant movement between the specific (the applications) and the general (the theories, models and concepts) which I have tried to reflect in the course of this thesis through literature reviews, theory building and case study work. I think it is important that DSS designers and applied scientists in general adopt a more encompassing out-of-the-box attitude towards developing applications. If what matters is the applied nature of science, there is a need to include within the research process a study of users, their environment, and an assessment of benefits to both beyond the usual well-wishing sentences that can be found at the end of many publications. The 'applied' literature is indeed littered with research ideas, models, tools, software that have never been put to practice despite their potential usefulness. As advocated in a recent editorial of the Journal of Applied Ecology (Memmott *et al.* 2010) it is time that applied scientists put their applications and recommendations to the test and face the messy reality that practitioners have to deal with.

When I embarked on the PhD journey, I had strong views on the nature of science, rationality and decision-making. My training as a scientist in the positivist framework had profoundly led me to believe that scientific tools, models and Cartesian rationality were the means to the identification of optimal solutions to given problems. Ten years of working as a scientist within the EA and a few more years delving deeper into the subject have shaken this belief, not in my assumption that scientific models are capable of delivering valuable information and optimal solutions, but in the realisation that ultimately a good model is a model that is being used, and good applied science is science that makes a difference on the ground.

Appendices

Appendix 1 Survey of Agency Conservation staff

Decision Support for Biodiversity: Questionnaire analysis

The questionnaire was sent out to all Area Biodiversity staff, via FRB Team Leaders and Biodiversity Technical Specialists (166 staff in total). The following figures are expressed as percentages of the total number of responses (45). Of the 45 respondents, there were 3 team leaders, 39 technical officers or equivalent and 3 technical specialists. A majority (60%) had an Honours Degree, 36% had higher degrees (MSc/MA/Mphil), 2% had a PhD and 2% had a Post-grad Diploma.

Experience in the field of conservation/biodiversity

Level of experience	**Years with the Agency (in Conservation/ Biodiversity)?**	**Years outside the Agency (in Conservation/ Biodiversity)?**
None	0	31
Less than 2 years	36	33
2-5 years	38	18
6-10 years	15	13
11-15 years	9	5
More than 16 years	2	0

- 74% of Biodiversity staff have less than 5 years experience of this field in the Agency.

Competence in the use of software

Level of Competence	**GIS software**	**Databases**	**Spreadsheets**	**Statistical software**
Never used	13	0	2	20
Beginner	27	42	11	58
Intermediate*	58	53	74	18
Advanced*	2	5	13	5

** staff considered 'experienced'*

- 60% of staff are experienced in the use of GIS software.
- 58% of staff are experienced in the use of databases.
- 87% of staff are experienced in the use of spreadsheets.
- 23% of staff are experienced in the use of statistical software.

Use of existing systems

Frequency of use	RHS	Biology for Windows	HABSCORE	RIVPACS	GIS e.g., FERGIS
Never	62	87	91	89	22
Sometimes	34	11	9	11	16
Frequently	2	2	0	0	20
Always	2	0	0	0	42

- 62% of staff never use the RHS database.
- 87% of staff never use Biology for Windows (biological database software).
- 91% of staff never use HABSCORE (software for assessing salmonid habitat quality).
- 89% of staff never use RIVPACS (software for assessing the naturalness of invertebrate communities).
- 78% of staff use GIS at least some of the time, whilst 42% always use GIS.

Information sources used when making decisions

Frequency of use	Opinion from colleagues	Opinion from Expert	Published reviews, books & handbooks	Published scientific papers or journals	Unpublished papers & reports	Electronic/ web-based material
Never	0	0	0	22	42	2
sometimes	18	78	53	62	51	54
Frequently	73	22	45	11	7	42
Always	9	0	2	5	0	2

- 82% of staff liaise with colleagues when making decisions.
- 100% refer to published reviews, books and handbooks at least some of the time.
- 22% of staff never refer to published scientific papers or journals, whilst only 16% frequently or always refer to them.
- 98% of staff refer to electronic or web-based information at least some of the time.

Reasons for not using scientific information

Problems	YES	NO
Lack of time to locate	64	36
Lack of time to read	64	36
Don't need to - very experienced	4	96
Inadequate information available or wrong format	7	93

	YES	NO	MAYBE
If information was more accessible, would you use it?	91	0	9

- 64% of staff consider that the main barriers to using scientific papers/journals are lack of time to locate and lack of time to read.
- 91% of staff would use scientific papers/journals they were more accessible.

Experience in analysing data and developing catchment strategies

Level of confidence	analysing and interpreting data	developing catchment strategies for managing species	developing catchment strategies for managing habitats	designing catchment monitoring strategies
not confident at all	5	9	9	7
not very confident	33	44	51	51
quite confident	57	42	35	40
very confident	5	5	5	2

- 62% of staff are at least reasonably confident in analysing and interpreting data.
- Over 50% of staff have little confidence when developing catchment strategies for species or habitats. Similarly, over 50% of staff have little confidence when designing catchment-monitoring strategies.

Areas of work where users feel they require support

- Long term Biodiversity data acquisition plan
- As a manager, I need to know enough to support/ prioritise and resource my staff.
- Flood Defence
- River Restoration
- EIAs
- HD review of consents, in-combination assessments, appropriate assessments
- statistical analysis and packages
- Developing management strategies for habitats/species

- It would be useful to have examples of how all the existing and new tools can be used i.e. for what specific purposes. Then if we haven't used them we may see where they could be of use.
- As a not particularly competent internet searcher I tend to get lost on the way to where I think I am trying to head! And then of course go no further!
- I am relatively new to the field of conservation and on a steep learning curve! More frequent running of general conservation training, or easinet based introductions to the work and the Agency's responsibilities.
- No specific area of support needed but biodiversity knowledge is constantly changing so I see this as a keeping up exercise
- More information regarding impact of large discharges into small watercourses.
- Difficult to pick out any one thing - something to cover the areas where I have no/little confidence (see questionnaire answers!). Also knowledge of all the databases available to conservation staff
- I'm not really involved in many conservation tasks, but being new to the job would appreciate help with all the EA systems that I have not used. I would also really like to have a better understanding of GIS software.
- Finding sources for information
- Use of Agency systems other than Arcview for screening.
- Computer systems/GIS
- Species/habitat management
- Linking WQ/WR data to ecological/biodiversity issues - large amounts of data within various functions of the Agency which are not easily interpreted/applied elsewhere. User friendly GIS would appear to be the easiest way to apply these various sources of info.
- Field studies - EIA
- Any user-friendly decision-making tools that aid's the ecologists decision-making processes and targeting its meagre resources.
- Environmental Impact Assessments

Appendix 2 List of actions, issues and questions for managing biodiversity within the Environment Agency.

(a) List of priority actions (priority class 4) for UK BAP species identified as part of the biodiversity data and information acquisition project;

Species/Habitat	UK BAP action needing Agency contribution
Water vole	Identify large, viable breeding populations of water vole and retain these with appropriate management and monitoring, from which a series of "key areas" should be designated.
	Incorporate water vole conservation into integrated area management plans (e.g. local BAPs, Environment Agency LEAPs, integrated catchment management plans *etc.*), initially targeting areas as identified in Action 3.
	Ensure that development schemes do not affect the integrity of water vole populations.
	Where necessary employ appropriate mink control as a conservation tool to protect large breeding water vole populations.
European otter	Monitor populations and distribution of otters throughout the UK, including local survey to monitor the expansion of fringe populations.
Marsh Warbler	Safeguard existing or recently abandoned breeding sites by carrying out appropriate habitat management, particularly scrub removal and maintenance of high water tables.
Allis & twaite shad	Obtain quantitative information on spawning and nursery sites and relate these to habitat models such as RHS to aid in the prediction of potential spawning areas within catchments.
Vendace	In Bassenthwaite and Derwentwater ensure that water quality, physical habitat and spawning grounds are protected.
Burbot	Consider the conservation justification of re-establishing the burbot as a viable component of UK biodiversity.
	Based on the outcomes of the above decide whether re-establishment of self-sustaining populations of the burbot to parts of the former range is desirable and feasible. If so indicate likely locations *etc.* as precursors to the preparation of a detailed reintroduction plan.
	Undertake reviews and further studies of the ecological requirements of burbot, and the nature of its niches in rivers.
	Assess rivers within the historic range in England against the results of the above to ascertain whether the ecological requirements of the species can still be met in any of them.
Bidessuss unistriatus	Conduct targeted autecological research to inform habitat management.
River shingle beetles	Address the requirements of these species in the LEAP process, and in relevant catchment management plans.
	Where possible, ensure that all occupied sites are appropriately managed, including the maintenance or restoration of appropriate flow regimes.
	Ensure that the habitat requirements of the species are taken into account in any development policies, plans and proposals, particularly in relation to river engineering.
	Continue to undertake surveys to determine the UK status of these species.
	Establish a regular monitoring programme for the species and their habitats.
Stiletto fly - *Cliorismia rustica*	Address the requirements of this species in the LEAP process and in relevant WLMPs.
	Take account of the requirements of this species in response to applications for water abstraction or sand extraction from rivers.
	Where possible, ensure that all occupied sites are appropriately managed by 2005, for example through site management agreements.
Stiletto fly - *Spiriverpa lunulata*	Address the requirements of this species through the LEAP process and in relevant catchment management plans and WLMPs.
	Take account of the requirements of this species in response to applications for water abstraction or sand extraction from rivers.
	Establish a regular monitoring programme for this species.
Bidessus minutissimus	Where appropriate, include the requirements of the species when preparing or revising prescriptions for agri-environment schemes and for river restoration schemes.
	Address the requirements of this species in the LEAP process and in relevant catchment management plans and WLMPs.

	Ensure that the habitat requirements of this species are taken into account in relevant development policies, plans and proposals, particularly in relation to river engineering.
White-clawed crayfish	Establish the feasibility of eradicating non-native crayfish populations from the wild where they threaten sensitive sites or important populations of native crayfish.
Southern damselfly	Encourage the uptake of beneficial land management schemes on land adjacent to occupied sites, including design of drainage schemes and other agri-environmental measures. * Also see Action 5.2.3 below and comments box.
	Ensure that, where possible, the hydrology of occupied sites remains favourable.
Little whirlpool ram's-horn snail	Establish and implement a ditch management cycle that allows the recolonisation of cleaned stretches from adjacent sections, taking into account the length of rotation necessary to avoid the ditch becoming choked with emergent vegetation.
Freshwater pearl mussel	Identify water quality requirements for the species and seek to ensure that these form the basis for setting Statutory Quality Objectives, including Special Ecosystem Standards for sites occupied by the pearl mussel.
	Seek to ensure that CAMs, flood defence activities, WLMPs and freshwater fisheries management take account of the requirements of this mussel, where populations still occur.
	Carry out research to investigate key threats, fish hosts, life cycle and life history in different places, tolerance to variation in acidity, genetic variation, viability of re-seeding populations, and the effects of commercial exploitation.
Glutinous snail	Undertake ecological studies to provide a description of current and desired water quality and flow and the physical habitat.
Ribbon-leaved water plantain	Identify water quality requirements which will maintain population levels at all known sites, and use these as a basis for setting standards.
Cut grass	As far as possible, ensure that all relevant agri-environment project officers, relevant drainage engineers and waterways managers are advised of locations of this species and its management requirements.
Multi-fruited river moss	Ensure that the requirements of this species are considered when developing Water Catchment Management Plans/Local Environment Agency Plans (LEAPs) for rivers where this species occurs.
Violet crystalwort	Ensure that the habitat quality of extant sites is not adversely affected by land drainage activities
Chara connivens	Ensure that the LEAP process and Water Level Management Plans take full account of the requirements of this species. The findings of 5.5.3 should be used to set water quality objectives and nutrient standards within these plans.
Nitellopsis obtusa	Review/establish water quality objectives and associated nutrient standards at all of the extant starry stonewort sites taking into account the requirements of this and other threatened aquatic species
Tolypella intricata	Ensure that Local Environment Agency Plans and Water Level Management Plans take full account of the requirements of this species. In particular, ensure that no further tassel stonewort sites are lost through increases in levels of water abstraction. This action should take account of the research outlined under 5.5.5.
Aquifer-fed naturally fluctuating water bodies	Ensure that water abstraction and groundwater protection policies take into account the specific requirements of aquifer fed naturally fluctuating water bodies and where necessary introduce new controls.
	Bearing in mind the possible effects of climate change, continue to review the use of water resources in the area affecting the hydrological balance of the Breckland meres. In the light of the monitoring programme (see 3.2) set consent levels and regimes for abstraction, which are compatible with maintaining the maximum nature conservation interest of the meres.
Chalk rivers	Review abstraction licences during LEAP production. Where abstraction is found to be damaging the quality of the chalk river habitat, consider amending of revoking the licence.
	Review licences for industrial/effluent discharge where these are found to damage the quality of chalk rivers.

(b) List of questions following surveys and workshops with Conservation staff and managers

A) Policy drivers

i) Environmental protection

1) Waste disposal and regulation - an environmental crisis - a threat to wildlife (e.g. competition for land, site after use. leachates and gasses *etc.*)?

2) The minerals industry - are we in danger of trading archaeology and landscape heritage for biodiversity opportunities?

ii) Land use

3) Agricultural set-aside, a lost opportunity to protect the water environment?

iii) Ecological process

4) How do we define terms such as 'good ecological quality' and 'significant ecological change'?

B) Habitat

i) Fragmentation

5) Are “river corridors” used as corridors by wild animals?

6) What effect does removing energy from river systems by creating hydro-electric facilities have on river geomorphology and ecology?

ii) Pollution

- Eutrophication

7) Is the distribution of submerged aquatic vegetation in UK rivers significantly altered by anthropogenic phosphate additions?

- Others

8) Do SUDS have a beneficial value to BAP / RDB species?

9) Is diffuse pollution a bigger problem to riparian wildlife than point sources today?

10) Are airborne nitrates a threat to some nutrient-poor habitats?

iii) Disturbance

11) What are the wildlife implications of offshore or terrestrial wind farms?

C) Conservation drivers

i) Priorities

12) Are conservation monies best spent on invasive species such as grey squirrel, signal crayfish and Japanese knotweed, when they are so well established?

ii) Species

13) Will the UK's biodiversity continue to decline?

14) Do Himalayan balsam, Japanese knotweed and giant hogweed reduce the diversity of native flora?

15) Mink - is effective control really possible and if so on what scale?

iii) Management policies

16) Will the creation of new marine national parks/SACs around our coastline adequately protect marine wildlife?

17) Do current flood management practices enhance wildlife?

18) Is managed coastal retreat a) necessary and b) a viable UK option? also c) will we be able to compensate for lost wildlife habitats? (by habitat re-creation)?

iv) Habitats

19) Do in-stream habitat improvement devices (e.g. groynes) increase the size of fish populations?
20) Is riparian tree management likely to affect the abundance and distribution of bat populations at the local scale?
21) What actions can be taken locally to make riparian habitats more hospitable to water voles?
22) Does riparian vegetation structure affect fish abundance?
23) Is riparian habitat limiting otter population sizes in the UK?
24) What is the risk to biota associated with particular regimes of lake-level fluctuation?
25) Do unnatural lake level fluctuations affect the biota of lakes?
26) Are species-level BAPs a threat to the general quality of some habitats?

v) Restoration

27) Can large-scale river restoration schemes be adopted in the UK, and would they be more cost effective than traditional hard flood defences?
28) Is it feasible to restore our floodplain woodlands?

vi) Prevention

29) How do we identify potentially invasive species in a changing environment?
30) Which invasive or potentially invasive species would have the greatest negative impacts upon biodiversity?
31) What is the likely impact on biodiversity from the use of non-native xenotypes for planting schemes?
32) What is the potential impact of invasive weeds on Biodiversity across and within catchments?

Appendix 3 Proposal for demonstration projects

Decision Support Tools for Biodiversity project. R&D SC03000204 Phase 2. Project proposals.

1. Background

The Environment Agency has a general duty to promote and further conservation wherever possible. Under the UK Biodiversity Action Plan (BAP), it is responsible for 39 species and 5 habitats. It is also one of the competent authorities responsible for the delivery of ecological targets set out in the Habitats Directive and the Water Framework Directive (WFD). So far, a series of generic action plans for UK BAP species have been identified and acted upon (Environment Agency, *Focus on Biodiversity, 2000*). Draft plans and strategies within the Agency for the implementation of the Habitats and the Water Framework Directives are still in development.

This project proposal represents the second phase of project SC03000204 on developing Decision Support Systems (DSS) for managing biodiversity. The objectives of Phase 1 were to:

Identify needs with regards to biodiversity management within the Environment Agency.

- Review existing literature and tools for managing biodiversity.
- Develop a research plan for phase 2 for the development of tools for managing biodiversity.

Phase 1 identified a series of challenges with regards to the management of biodiversity within the Environment Agency (see project report SC03000204):

- Biodiversity management is very complex because of the number of species we need to account for, the lack of knowledge on their life history, habitat requirements and factors affecting their distribution, and the fragmentation of biodiversity management within existing Environment Agency processes.
- To manage biodiversity effectively, a planning process would be required to set catchment targets for species at national level. At present, such process exists but it does not enable national managers to set quantitative targets for each catchment. Instead, it relies on regions and areas to feed back what actions they can take for particular species. Unfortunately, actions are most often qualitative and it is not always clear how they will be delivered.
- Locally, there is no consistent process for delivering biodiversity targets through proactive catchment planning. Biodiversity issues are managed on an opportunity basis, often at the scale of reaches or sub-catchments and there is no clear link to wider biodiversity targets.

- Biodiversity management requires a good understanding of species requirements and the way they interact with biotic and abiotic factors at reach and catchment scales. It also implies an ability to analyse and interpret complex biological and physical data at broad scale and a good understanding of catchment processes. A survey of Conservation Environment Agency staff found a general lack of confidence in building catchment strategies. It also found that 75% of staff have less than 5 years experience in Conservation within the Agency and that they mainly use opinion from colleagues in their decision-making.

The project identified 3 main needs:

- A national planning process is required to set catchment targets for all species to meet the Environment Agency biodiversity commitments.
- A local planning process is required to enable the translation of catchment targets into action plans.
- Scientific evidence and techniques should be better integrated into biodiversity management (use of models, scientific evidence, publications *etc.*).

Following a review of existing Decision Support Systems in Conservation and biodiversity management, 2 draft processes supported by computer tools were suggested to deliver national and local planning for biodiversity. The tools proposed include novel ways of modelling the fate of populations and supporting decisions. They include techniques such as landscape scale Population Viability Analysis and Fuzzy Logic modelling. They also include the development of simple GIS interfaces, decision tools and knowledge databases to help day-to-day decision-making. The project report was submitted and reviewed by the project board and it was decided to commission projects to demonstrate the benefits of the proposed approach and tools to all users.

The project board suggested choosing at least one data-rich and one data-poor species so as to demonstrate the benefits of using DSS in various knowledge environments. It also suggested developing management tools for species impacting on biodiversity such as invasive plants.

The project board recommended a series of species for inclusion in the demonstration projects. All species were considered along with other potential ones for which the Environment Agency has got responsibilities.

Water vole

The water vole is a mammal whose ecology and distribution have been extensively studied. It is one of the priority BAP species for which the Environment Agency has taken responsibility and it is protected under the Habitats Directive Annex II. Water voles were formerly widespread but the population has suffered a long-term decline since the 1900. Two national surveys were carried out in 1989-90 and 1996-98. The survey showed a severe population crash with a decline of 88% in 7 years. Water vole ecology is well known and guidance books have been produced. The water vole suffers from habitat losses but also from predation from minks. The wide distribution of water vole and our knowledge on its ecology makes it an attractive species for the purpose of this project.

Depressed river mussel

The depressed river mussel is one of the UK BAP priority species for which the Agency has taken responsibility. It is a freshwater unionid species whose ecology and distribution are not well known. Historically, the mussel presence was recorded in nearly all EA Regions. Its ecology and biology is thought to be similar to that of other unionid species such as Anodonta cygnea. Its past and present distribution and the ability to infer on the ecology of related species makes it an attractive species for the purpose of this project. It will ensure that chance of success of the tools are maximised whilst results will be relevant to most Agency regions. Other data-poor species such as River shingle beetles or hairy click beetle were first considered but rejected as their ecology is too poorly known and their distribution is too restricted to make them effective demonstration projects for area staff in the Agency.

Japanese knotweed

Japanese knotweed is an invasive species that is thought to have significant impacts both on biodiversity and flood protection work. Most control schemes carried out by the Environment Agency are done on an ad-hoc basis. Japanese knotweed control represents significant costs to ourselves and to businesses we regulate. It is estimated that the eradication of Japanese knotweed across the country could cost up to 1.6 billion pounds. The Agency would benefit from a more strategic approach to controlling the spread of Japanese knotweed.

Project proposals

The DSS development will follow a series of steps and constraints:

- First, relevant targets will need to be clearly identified using guidance from the UK BAP Species Action Groups and with the help of experts and EA staff.

- Tools and analytical techniques will be identified and their feasibility will be explored. Priority will be given to existing tools and techniques that can easily be applied to data owned by the Environment Agency, with a user-friendly interface ideally on GIS. In the absence of relevant off-the-shelf tools, new tools will be developed in a cost and risk-effective way. Expert Systems based on rules-of-thumb may be given priority over more complex and risky modelling techniques.
- Tools will have to make use of existing EA data or data widely available (e.g. NBN data *etc.*). No field data will be collected.
- The DSS should help the prioritisation of actions at catchment and reach scale based on an evaluation of potential biodiversity benefits and associated costs and risks.

Water vole

Overall aim: To demonstrate the benefits of using Decision Support Systems for delivering UK BAP targets for water voles.

UK BAP Targets:

- Maintain the current distribution and abundance of water voles
- Ensure that water voles are present throughout their 1970s range by 2010.

Questions to be answered

National scale:

- What is the state of catchments for water vole populations?
- What catchment could potentially hold new populations of water voles?
- What target shall we set for each catchment?

Local scale

- What is the state of the catchment for water voles?
- Are existing populations viable?
- What are the pressures on water vole distribution?
- How can we best manage the catchment for water voles and achieve the targets?

Objectives

- To compile all information on water vole ecology, life history, status and management and make it available on the Web on an existing database managed by the Freshwater Biological Association: the FreshwaterLife database.

- To develop tools to target sites for survey to find new populations and apply them to 5 catchments.
- To produce decision support tools for setting quantitative catchment targets for water voles to meet the national BAP targets and apply them to 5 catchments.
- To produce decision support tools for the development of detailed catchment action plans in the shape of GIS maps and apply them to 2 catchments.
- To demonstrate the way the DSS works at a user workshop.

Depressed river mussel

Overall aim: To demonstrate the benefits of using Decision Support Systems for delivering UK BAP targets for depressed river mussel.

UK BAP Target:

- Identify and maintain key populations of depressed river mussels

Questions to be answered

National scale

- What is the state of catchments with depressed river mussel populations?
- What catchment could potentially hold populations of depressed river mussel?
- What target shall we set for each catchments?

Local scale

- What is the state of the catchment for depressed river mussel?
- Are existing populations viable?
- What are the pressures on their distribution?
- How can we best manage the catchment for depressed river mussels and achieve the targets?

Objectives

- To compile all information on depressed river mussel ecology, life history, status and management and make it available on the FreshwaterLife database.
- To develop tools to target sites for survey to find new populations and apply them to 5 catchments.
- To produce tools for the development of detailed action maps for maintaining existing mussel populations and apply them to 2 catchments.
- To demonstrate the way the DSS works at a user workshop.

Japanese knotweed

Overall aim: To demonstrate the benefits of using Decision Support Systems for managing an invasive plant, Japanese knotweed, at national and local scales.

Specific aim:
To assess and manage the threat posed by Japanese knotweed spread to biodiversity assets.

Questions to be answered

National scale:

- What is the state of Japanese knotweed spread?
- What is the potential impact of Japanese knotweed on biodiversity across catchments?
- Which catchments/area should we concentrate our efforts on?

Local scale

- What is the state of the catchment for Japanese knotweed?
- What are the factors affecting its distribution?
- What are the potential biodiversity assets that Japanese knotweed could affect?
- How can we best plan control and surveillance work?

Objectives

- To compile all information on Japanese knotweed ecology, life history, status and management and make it available on the FreshwaterLife database.
- To produce generic tools for assessing the spread of Japanese knotweed and its potential impacts on biodiversity across catchments in England and Wales, with an assessment of costs of treatment and risks of failure, and to apply them to 5 catchments.
- To produce decision support tools for the management of Japanese knotweed at catchment scale.
- To develop detailed action maps for Japanese knotweed management for 2 catchments.
- To demonstrate the way the DSS work at a user workshop.

Appendix 4 List of individuals and organisations consulted as part of the first case study

Andrew Richman: Environment Agency, Bath Data Centre
Pam Nolan: Environment Agency, Policy and Process, Ecology
Sarah Pemberton Environment Agency, Policy and Process, Ecology
Alastair Driver: Environment Agency, Policy and Process, Conservation
Ann Skinner: Environment Agency, Policy and Process, Conservation
Marina Flamank: Environment Agency, Policy and Process, Ecology
Mark Diamond: Environment Agency, Technical unit, Ecology & Conservation
Geoff Phillips: Environment Agency, Technical unit, Ecology & Conservation
John Murray-Bligh: Environment Agency, Technical unit, Ecology & Conservation
Paul Raven: Environment Agency, Ecology & Conservation
Kevin Hall: Environment Agency, Technical unit, Ecology & Conservation
Jim Walker: Environment Agency, Technical unit, Ecology & Conservation
Nick Hopwood: Environment Agency, Habitats Directive
Sarah Peet: Environment Agency, Habitats Directive
Paul Logan: Environment Agency, Water Framework Directive
Richard Hemsworth: Environment Agency, Water Framework Directive
Glenn Maas: Environment Agency, Water Framework Directive
Lindsey Powell: Environment Agency, Water Framework Directive
Ruth Jones: Environment Agency, Water Framework Directive
Dave Martin: Environment Agency, Water Framework Directive
Bill Brierley: Environment Agency, Science team, Ecosystems
Liz Chalk: Environment Agency, Ecology, North East
Steve Garner: Environment Agency, Ecology, North West
Peter Fox: Environment Agency, Water Framework Directive, North West
Nigel Warren: Environment Agency, CIS, South West
Jo Cullis: Environment Agency, Ecology, South West
Martin Fuller: Environment Agency, Ecology, Midlands
Phil Griffiths: Environment Agency, Ecology, Southern
Chris Mainstone: English Nature
Keith Porter: English Nature
Roger Meade: English Nature
Roger Catchpole: English Nature
Rob Cathart: English Nature
Steve Ormerod, Cardiff University
Ian Vaughn, Cardiff University
Prof Ron Edwards

Phil Boon: Scottish Natural Heritage
David Corbelli: SEPA
Malcom Newson: Newcastle University
Steven Rushton: Newcastle University
Jennifer Gill: University of East Anglia
Nigel Holmes: Alconbury Consultants Ltd
Kieran Conlan: Cascade Consulting Ltd
Philip Bacon: CEH
John Hilton: CEH
Catherine Duigan: Countryside Council for Wales
Colin Catto: Bat Conservation Trust
Mike Clarke: Southampton University
Sarah Wiggins: Southampton University
Sally Priest: Southampton University
Chris Hill: Southampton University
Mike Dobson, Manchester Metropolitan University
Jim Ryan: Department of the Environment, Heritage & Local Government ,Republic of Ireland
Aime O'Connor: Department of the Environment, Heritage & Local Government , Republic of Ireland
Martin McGarrigle: EPA, Ireland
Kevin Clabby: EPA, Ireland
Chris Burns: EHS Northern Ireland
Peter Hale: EHS Northern Ireland
Imelda O'Neil: EHS Northern Ireland
Kearon McNicol: Freshwater Biological Association
Anne Powel: Freshwater Biological Association

Formal presentations:
Integrated River Basin Management meeting, November 2003
Biodiversity Conference, Environment Agency, November 2003 (given by Mark Diamond)
North-South Technical Advisory Group Rivers sub-committee meeting, Dublin, February 2004
Risk and Forecasting team brainstorm on Fuzzy systems, March 2004
Geography seminar, Southampton University, April 2004
Inter Agency freshwater forum: May 2004

Appendix 5: Occurrence of themes across all interviews and focus group meetings with an assessment of their relative occurrence across all interviews.

This table displays information on the occurrence of themes across focus group meeting FG1 to FG4 and 16 individual interviews with members of staff. Themes and subthemes are organised in a hierarchical way using numbering and colour-codes. In green are the overall cultural dimensions; in yellow are cultural dimensions of interest to the investigation and underneath are specific themes and sub-themes describing the orientation of respondents towards particular aspects of culture, The occurrence of references to specific aspects of culture, themes and sub-themes were assessed against the sample size column N. Sample size varied according to whether questions were asked at group or individual interviews.

Cultural dimensions and associated themes	FG1	FG2	FG3	FG4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	%	*N*
1 Internal adaptation																						
1.2 Power	1	0	0	1	1	1	1	1	1	1	1	0	0	1	1	0	1	0	1	1	70	20
1.2.1 Structure	1			1	1					1	1			1	1		1		1	1	**50**	20
1.2.2 Balance	1			1	1	1	1	1		1	1				1		1		1		**55**	20
1.2.3 Inequalities				1	1		1		1	1	1				1				1		**40**	20
1.3 Management					1	0	0	1	1	0	0	1	1	0	1	0	1	0	0	0	44	16
1.3.1 Trust in staff expertise								1	1			1	1		1		1				**38**	16
1.3.2 Consultation												1									**6**	16
1.3.3 Delegation					1			1	1			1	1								**31**	16
1.4 Individual needs	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100	16
1.4.1 Control	1			1	1		1	1	1	1	1	1	1				1	1	1		**69**	16
1.4.2 Freedom							1	1	1	1	1		1					1	1	1	**56**	16
1.4.3 Getting things done							1	1		1			1	1				1			**38**	16
1.4.4 Bureaucracy and admin minimised		1			1		1	1		1	1	1	1	1	1	1	1	1	1	1	**88**	16
1.4.5 Field versus office work	1					1	1	1	1	1	1				1	1	1	1			**63**	16
1.4.6 Time to learn					1		1		1	1				1		1	1		1		**50**	16
1.5 Identity and individual roles	1	0	1	0	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	75	20
1.5.1 Service to																						
1.5.1.1 Fish and Nature	1		1			1						1									**20**	20
1.5.1.2 Anglers			1			1		1	1		1	1						1			**35**	20
1.5.2 Local expert	1				1	1	1	1		1	1	1	1			1	1	1	1		**75**	16

Cultural dimensions and associated themes	FG1	FG2	FG3	FG4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	%	N
2 External adaptation																						
2.1 Mission and strategy																						
2.1.1 Espoused values: corporate plan	1	1		1	1						1			1					1		**75**	4
2.1.2 Underlying assumptions: power driven	1	1		1	1						1			1					1		**75**	4
2.2 Reorganisations	1	0	0	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	80	20
2.2.1 Value change	1			1		1	1											1			**25**	20
2.2.2 Specialisation	1					1		1								1					**20**	20
2.2.3 Structure	1					1															**10**	20
2.2.4 Bureaucracy	1				1		1	1		1	1							1	1	1	**45**	20
2.2.5 Work load/Time constraint				1			1			1			1	1	1		1	1	1		**45**	20
2.3 Decision-making																						
2.3.1 Priorities: power driven	0	0	0	1	1	0	1	0	0	0	1	0	0	1	0	0	0	0	0	1	**30**	20
2.3.2 Flexibility					1	1													1		**15**	20
2.3.3 Trust		1		1							1								1		**20**	20
2.3.4 Experience based: judgement/intuition	0	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	0	1	0	1	**75**	20
2.3.5 Process	1	0	0	1	1	0	1	1	0	0	0	0	0	1	1	0	1	0	1	1	**50**	20
2.3.5.1 Negotiation/bargaining				1	1										1		1		1		**25**	20
2.3.5.2 Consultation					1																**5**	20
2.3.5.3 Influencing	1			1	1		1	1						1			1		1	1	**45**	20
2.3.6 Reactive/opportunistic	1	1	1	1	1		1	1	1	1	1	1		1	1	1		1	1	1	**85**	20
2.3.7 Proactive Strategic																						
2.3.7.1 Redefined: strategic = sum of opportunities	1	1	1				1	1				1		1	1	1					**45**	20
2.3.7.2 Strategic aspirational	0	1	1	1	0	0	0	1	0	0	1	1	0	1	0	0	0	0	0	1	**40**	20
2.3.7.2.1 Landscape approach		1	1	1				1						1						1	**30**	20
2.3.7.2.2 Planning		1	1	1				1			1	1		1						1	**40**	20
2.3.7.2.3 Prioritisation		1	1	1																1	**20**	20
2.3.8 Prioritisation (cost, perception, impact)							1				1			1				1			**20**	20
2.3.9 Resources	1	1	1	1		1		1			1	1		1	1		1			1	**60**	20
2.4 Turnover	1	1	1			1	1						1		1		1				40	20
2.5 Work drivers	1	1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	45	20
2.5.1 Legal (WFD)	1		1							1											**15**	20
2.5.2 Organisational			1	1			1														**15**	20
2.5.3 'Commercial'																					**0**	20

Cultural dimensions and associated themes	FG1	FG2	FG3	FG4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	%	*N*
2.5.3.1 Anglers	1	1	1	1			1	1	1		1										**40**	20
2.6 Measuring success: process vs outcome	1	0	0	0	0	1	0	1	0	0	1	0	0	1	0	0	0	0	0	0	25	20
3 The nature of reality and truth																						
3.1 Nature of truth																						
3.1.1 Experience	1	0	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	**85**	20
3.1.1.1 Judgement/intuition			1		1	1	1			1	1	1	1	1	1	1		1	1	1	**70**	20
3.1.1.2 Field versus office work	1				1	1	1	1		1	1				1	1	1		1		**55**	20
3.1.2 Local knowledge	1		1		1	1	1	1		1	1	1	1	1	1	1	1	1		1	**80**	20
3.1.2.1 Building a picture in time and space					1	1	1	1		1	1	1	1	1	1	1	1	1		1	**70**	20
3.1.3 Building knowledge																						
3.1.3.1 Structured: mentoring						1	1	1	1	1	1		1			1	1	1	1	1		
3.1.3.2 Unstructured	0	0	0	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	**75**	20
3.1.3.2.1 Interacting					1	1	1		1			1					1			1	**35**	20
3.1.3.2.1.1 Team members/EA staff					1	1	1	1	1			1				1	1			1	**45**	20
3.1.3.2.1.2 Local stakeholders					1	1	1										1				**20**	20
3.1.3.2.2 On the job					1	1	1	1		1	1	1		1		1	1	1	1	1	**65**	20
3.1.3.2.3 Reactive/opportunistic				1	1		1			1	1			1							**30**	20
3.1.3.2.4 Trial and error						1		1						1			1				**20**	20
3.1.3.3 Small scale, in the field				1	1	1	1	1							1	1	1		1		**45**	20
3.1.3.4 Books/papers					1						1	1							1		**20**	20
3.1.4 Experience and science limitations	1	1		1	1	1	1	1													**35**	20
3.1.4.1 Experience	1	0	0	1	1	1	0	1	1	0	1	0	0	1	1	0	0	0	0	0	**45**	20
3.1.4.1.1 Knowledge quality	1				1						1				1						**20**	20
3.1.4.1.2 Post Project Appraisal (informal)	1					1		1			1			1							**25**	20
3.1.4.1.3 Data use	1			1					1						1						**20**	20
3.1.4.2 Science																						
3.1.4.2.1 Data quality/validity	1	1	0	1	1	1	1	0	0	1	1	1	1	0	0	0	1	0	1	1	**65**	20
3.1.4.2.1.1 Methods limitations	1	0	0	1	1	1	1	0	0	1	1	1	1	0	0	0	0	0	1	0	**50**	20
3.1.4.2.1.1.1 Variability	1			1	1	1	1			1	1	1	1						1		**50**	20
3.1.4.2.1.1.2 Subjectivity						1	1				1	1							1		**25**	20
3.1.4.2.1.2 Representativeness	1	1	0	1	1	1	0	0	0	1	0	1	1	0	0	0	1	0	1	1	**55**	20
3.1.4.2.1.2.1 Time		1		1								1	1				1		1		**30**	20
3.1.4.2.1.2.2 Space	1	1			1	1				1		1	1				1		1	1	**50**	20
3.1.4.2.2 Model quality/validity	1	0	0	0	0	0	0	1	1	0	1	1	1	0	1	0	1	0	0	0	**40**	20

Cultural dimensions and associated themes	FG1	FG2	FG3	FG4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	%	N
3.1.4.2.2.1 Simplification of reality	1							1			1	1	1		1		1				**35**	20
3.1.4.2.2.2 Needs ground-truthing	1								1						1						**15**	20
3.1.4.2.3 Model usefulness	1	0	0	0	1	0	1	1	0	1	0	1	1	0	1	0	1	1	0	1	**55**	20
3.1.4.2.3.1 Too prescriptive	1														1		1			1	**20**	20
3.1.4.2.3.2 Out of context	1							1				1	1								**20**	20
3.1.4.2.3.3 Not applicable locally							1	1		1		1	1					1		1	**35**	20
3.1.4.2.3.4 How to use them?										1		1									**10**	20
3.1.4.2.3.5 Potential misuse/misinterpretation	1														1		1	1		1	**25**	20
3.1.4.2.3.6 Needs interpretation by expert	1				1		1						1		1		1				**30**	20
3.2 Nature of Reality																						
3.2.1 Revealed through experience					1	1											1		1		**20**	20
3.2.2 Complex	1	1	1			1		1	1	1	1	1	1	1		1	1				**65**	20
3.2.3 Unpredictable	1	1	1			1															**20**	20
3.2.4 Social and environmental					1	1		1					1	1							**25**	20
4 The nature of human relationships																						
4.1 Relationships																						
4.1.1 Networking					1	1	1	1	1				1							1	**44**	16
4.1.2 Trust		1								1											**13**	16
4.1.3 Personal		1				1	1		1				1						1		**38**	16
4.1.4 'Getting on'		1			1		1	1	1	1		1	1								**50**	16
4.2 Communication				1	1				1	1									1		**25**	20
4.3 Interactions																						
4.3.1 Based on trust				1				1													**10**	20
4.3.2 Common purpose?					1					1				1							**15**	20
5 The nature of human activity																						
5.1 Working with nature, seeking harmony	1	1	1		1			1	1		1	1								1	**45**	20
User Skills																						
Low level analytical				1																	**5**	20
Low/moderate computer skills					1	1															**10**	20
User preferences																						
Visual	1					1				1											**15**	20

Cultural dimensions and associated themes	FG1	FG2	FG3	FG4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	*%*	*N*
Simplicity						1															**5**	20
Climate																						
Good relationships		1		1				1		1		1	1					1			**35**	20
Frustration				1									1								**10**	20
Getting things done														1							**5**	20
Bureaucracy/admin							1				1										**10**	20
Powerless				1	1				1		1			1							**25**	20
DSS impact on																						
Learning (negative)	1						1			1							1				**20**	20
Fieldwork (negative)							1			1							1				**15**	20
Identity/culture (negative)							1			1											**10**	20
Control of the decision-making (negative)	1									1											**10**	20
Capturing local knowledge (positive)	1		1		1	1		1	1	1							1	1	1	1	**55**	20
Data access (positive)	1	1	1	1		1		1	1	1		1	1	1		1				1	**65**	20
Catchment assessment (positive)										1			1								**10**	20

Appendix 6: Organisational culture assessment: list of questions for focus groups, individual interviews and questionnaires

Question type:

- Individual interview questions (normal font)
- **Focus group questions (Bold)**
- ***Questionnaire (Bold and Italics)***
- **<u>Questions for focus group and individual interviews (Bold and underlined)</u>**

The nature of human relationships

Power distance and authority

- How would you describe management style in your team ?
- How would you describe your relationship with your line manager (good, friendly, professional, awkward *etc.*)?
- How important is it to follow the rules?

How to interact

- How do people work in your team (together or each on their own)?
- What is the best thing about working in your team?
- What do you like least?
- Do people generally help each other (and how)?
- **How does your team interact with Flood Defence teams?**

How to communicate

- **How do you communicate with Flood Defence teams? Do you find communication easy (and why)?**

Internal adaptation

Group boundaries and criteria for inclusion and exclusion

- I have been told that there is a high turnover within teams in Fisheries Thames region; do you have any idea why people are coming and going?
- When you first joined the organisation, what were, during the first few months, the things you first noticed with regards to work practice, the way people interacted, the buzzwords *etc.*?
- What do you thing it takes to fit in the organisation?
- When somebody joins in, how fast can you tell whether the person is going to fit in or not and why?

Power and status distribution

- Does your manager frequently check on your work or does he/she let you get on with your job?

- Do you get a lot of directions from your manager on the tasks you have got to perform, how you should do it *etc.*?
- Does your line manager set personal objectives for you and how specific are they?

Individual needs and goals

- How do you see your job developing in the future?
- What are the things that you like and dislike the most about your job?
- **<u>Do you think you're getting the level of support that you need for the tasks that you've got to do?</u>**
- **<u>Which area of your work do you think you would need support on and what type of support would you expect?</u>**
- **<u>How do you interact with other teams such as Science, Fisheries Head Office and Fisheries regional teams?</u>**
- How important is it to have freedom and control in your job?

Identity and individual roles

- What is your job?
- What is your role within your team and how is the team organised?
- What are the things that you mainly do?
- What attracted you to your job?
- If one thing, what gets you out of bed in the morning to go to work?
- How did you end up working for Fisheries in the Environment Agency?
- What do you think makes you good at your job?
- What do you think are the essential skills and knowledge required for doing your job?

Rewards and punishments

- If a member of staff fails to meet his/her objectives or finish a project on time, what happens?
- Do you normally get credit for the work you do?
- What is the best compliment you have had for a piece of work you've done?

External adaptation

Mission and strategy

- **In your view, what is the Environment Agency all about and how does Fisheries fit in the big picture?**

Goals

- **What are your team plans for achieving the EA vision (strategy, goals)?**

Means

- **Management stated that they needed to be able to better justify to flood defence their choice of sites for fisheries enhancement work. How do you feel about that?**
- **How are sites chosen for fisheries enhancement work at present?**
- **What do you think are the most important issues to consider when choosing sites for enhancement work?**
- **How would you go about it in an ideal world; what is constraining you?**
- **How you deal with uncertainty?**
- **What methods do you use (field methods and analytical techniques)?**
- **Do you think habitat enhancement work really makes a difference?**

Measurement

- **When you do some habitat enhancement work, how do you measure success?**

Correction

- **What corrective actions can you put in place?**

The nature of time

- How long does it take to learn the job?
- How is work organised; do you work with strong project management principles with set deadlines *etc.*?

The nature of reality and truth

- How did you learn your job?
- How do new recruits learn the job?
- When faced with a problem for which you haven't got an answer, what do you do?
- If you need help with a fisheries issue, who do you normally ask?
- **<u>Do you think that in the job you do, science really matters (and why)?</u>**
- How can you tell whether a fisheries site is in good condition or not?
- How can you tell what is needed (e.g. remedial action *etc.*)?

See also questions in ‘identity and individual roles’

User preferences

Learning

- **If one thing, what would you like this project to achieve?**
- See questions in ‘User skills’

Technology

- **Are there tasks/decisions that you feel uncomfortable with? Which one?**
- **How useful are computers in your job?**

- **What do you think of existing tools and techniques such as Habscore, RHS, FAME, aerial photographs etc.?**

Information display

- **Demonstration of different user interface and discussion.**

User skills

- ***Academic qualifications?***
- ***How do you rate your skills in the following computer systems (ARC GIS, Database Access, Excel, Internet Explorer, Statistical software)?***
- ***Which of the following Environment Agency systems do you currently use (RHS database, NFPD, Habscore, RIVPACS, others)?***
- ***When making decisions, what source(s) of information do you use (opinion from work colleagues, opinion from outside expert, published reviews books and handbooks, published scientific papers, unpublished papers/reports, electronic/web-based material, other)?***
- ***Do you feel confident with :***
    - ***analysing and interpreting aerial photographs;***
    - ***analysing and interpreting catchment data;***
    - ***developing catchment strategies for managing species;***
    - ***developing catchment strategies for managing habitats;***
    - ***developing catchment strategies for habitat enhancement for fish species and communities;***
    - ***designing monitoring strategies;***
    - ***assessing habitat quality for fish species and communities;***
    - ***identifying and quantifying pressures on fish habitats at the scale of a reach (1km);***
    - ***identifying and quantifying pressures on fish habitats at catchment scale;***
    - ***designing habitat enhancement schemes for fish species and communities;***
    - ***identifying and selecting sites for habitat enhancement work.***

Climate

Environment Agency

- What do you like and dislike about the Environment Agency?

Fisheries

- See questions in ‘External adaptation’

Team

- Are you happy with your job?
- What is it like to be working in your team?

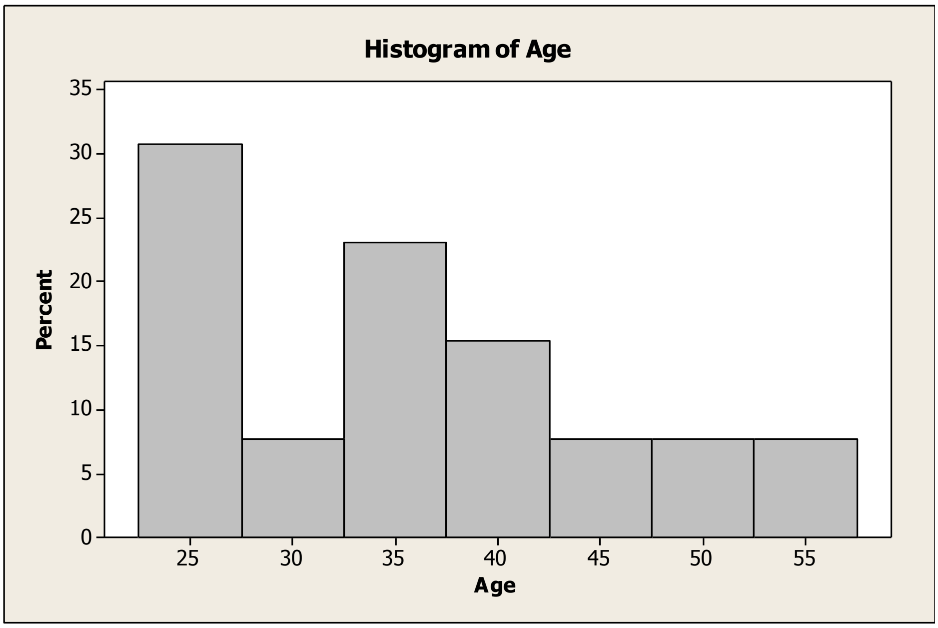
- Is there a very friendly atmosphere?
- Are people generally helpful?
- If you need support from your team leader, do you generally get it?
- Do you feel your job is secure?

Demographics

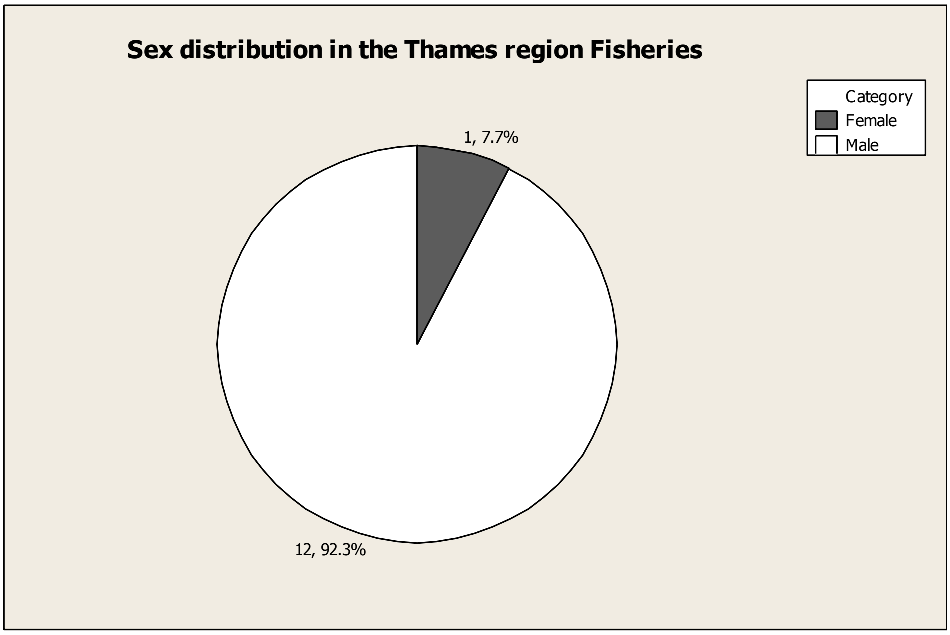
- ***Name***
- ***Age***
- ***Sex***
- ***Job title***
- ***Area***
- ***Catchment(s)***
- ***Number of years in the Environment Agency***
- ***Number of years working in Fisheries in the Environment Agency***
- ***Previous experience in Fisheries (years)***
- ***Number of years working in this area***
- ***Number of years working on identified catchment(s)***

Appendix 7: Questionnaire results

1. Name
2. Age



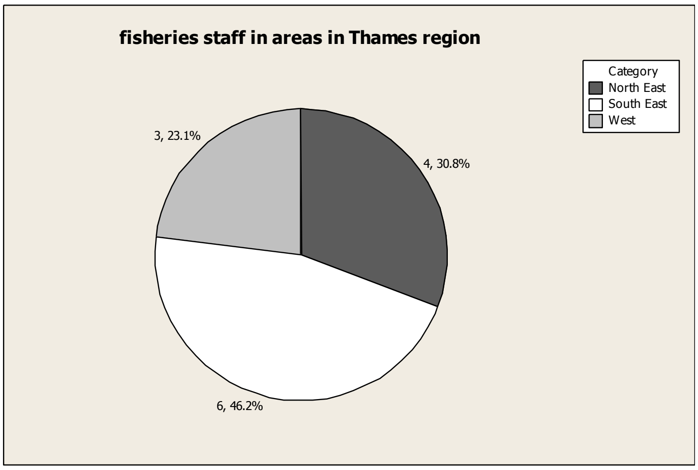
3. Sex



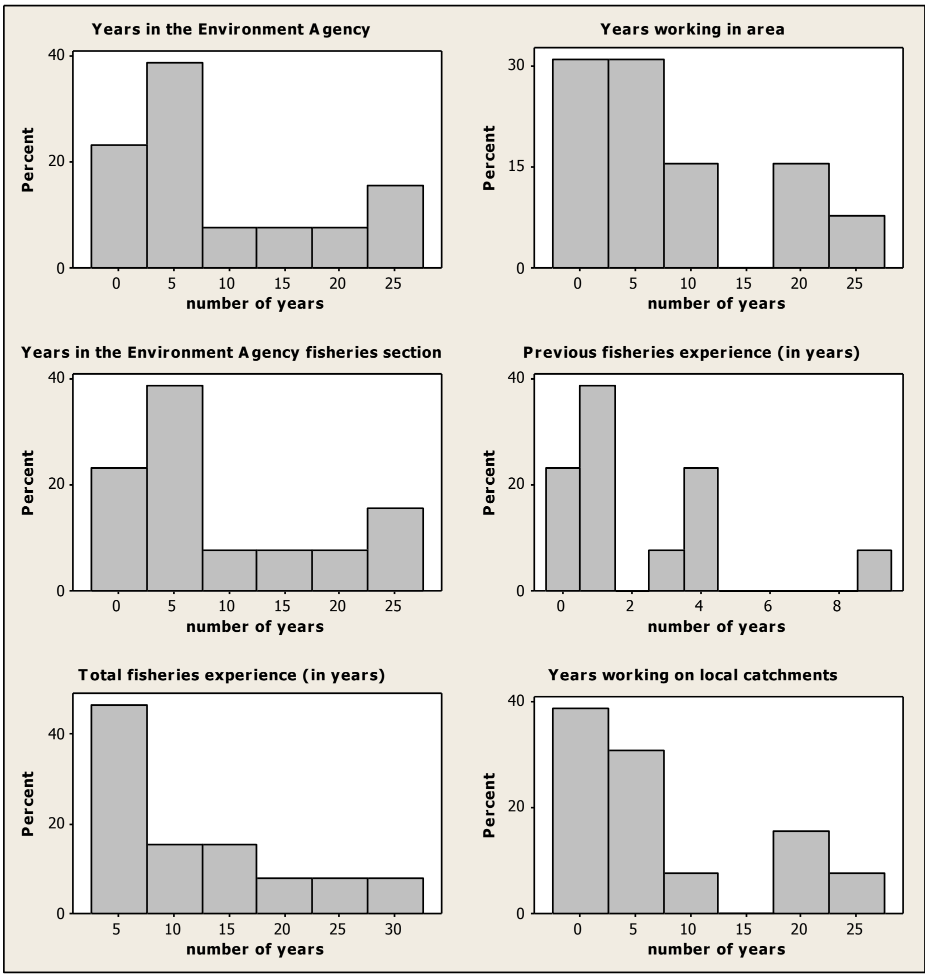
4. Job title

Job_title	Count	Percent
Technical Officer	9	69.23
Technical Specialist	4	30.77
N=	13	

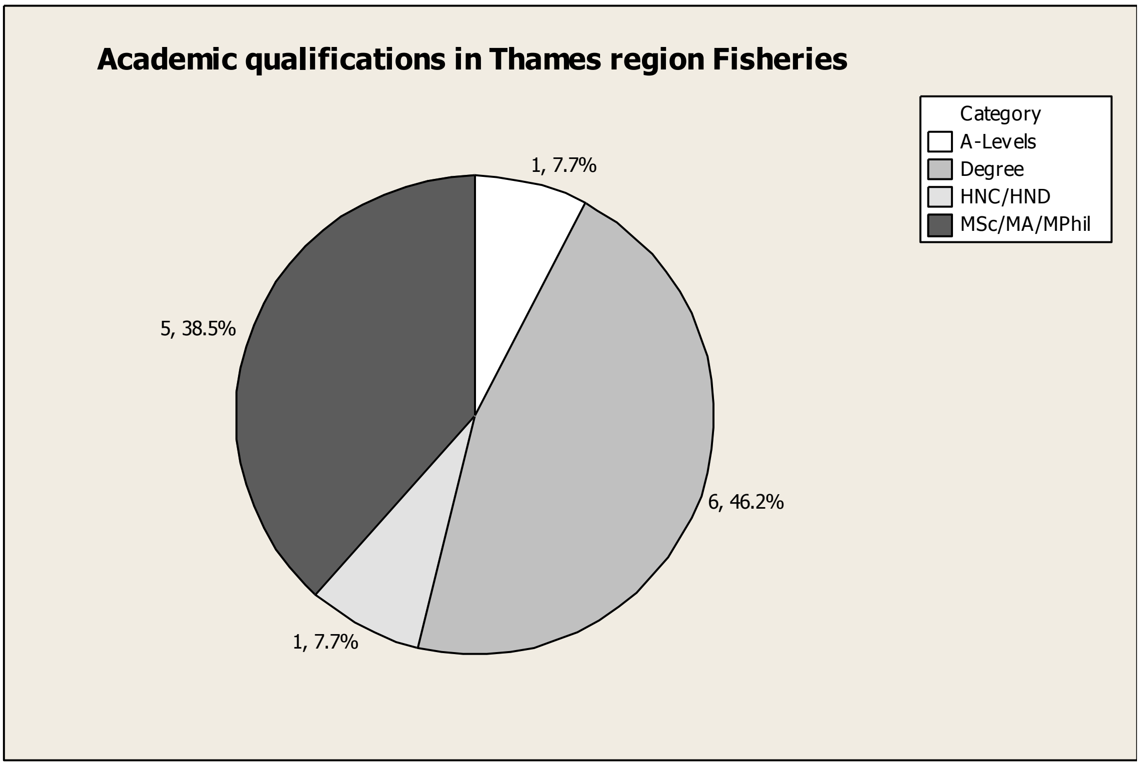
5. Area



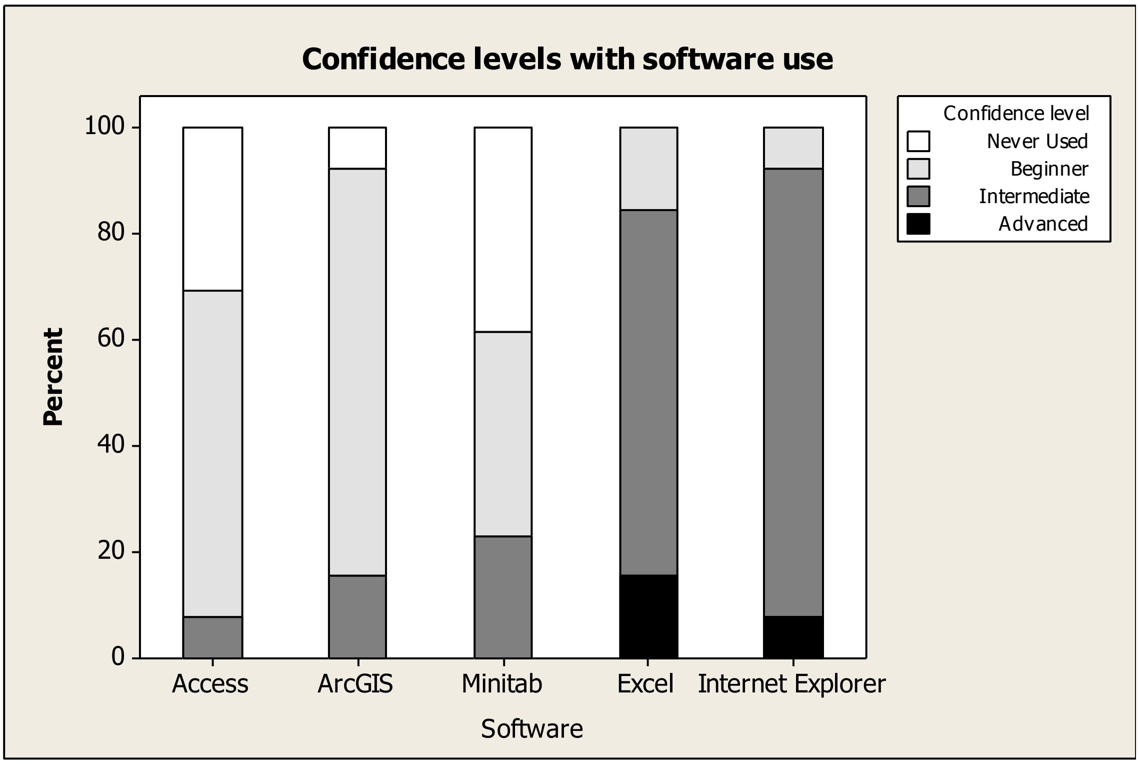
6. Catchment(s) covered by catchment officers
7. Number of years in the Environment Agency
8. Number of years working in Fisheries in the Environment Agency
9. Previous experience in Fisheries (years)
10. Number of years working in this area
11. Number of years working on identified catchment(s)



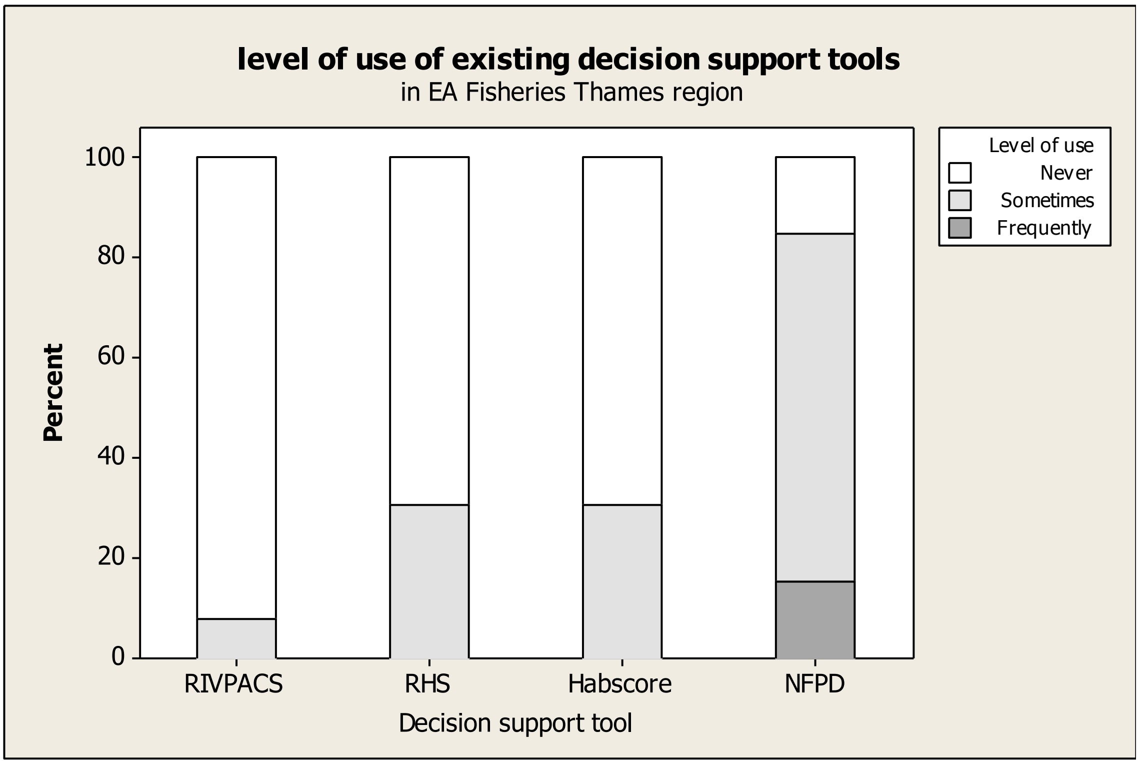
12. Academic qualifications?



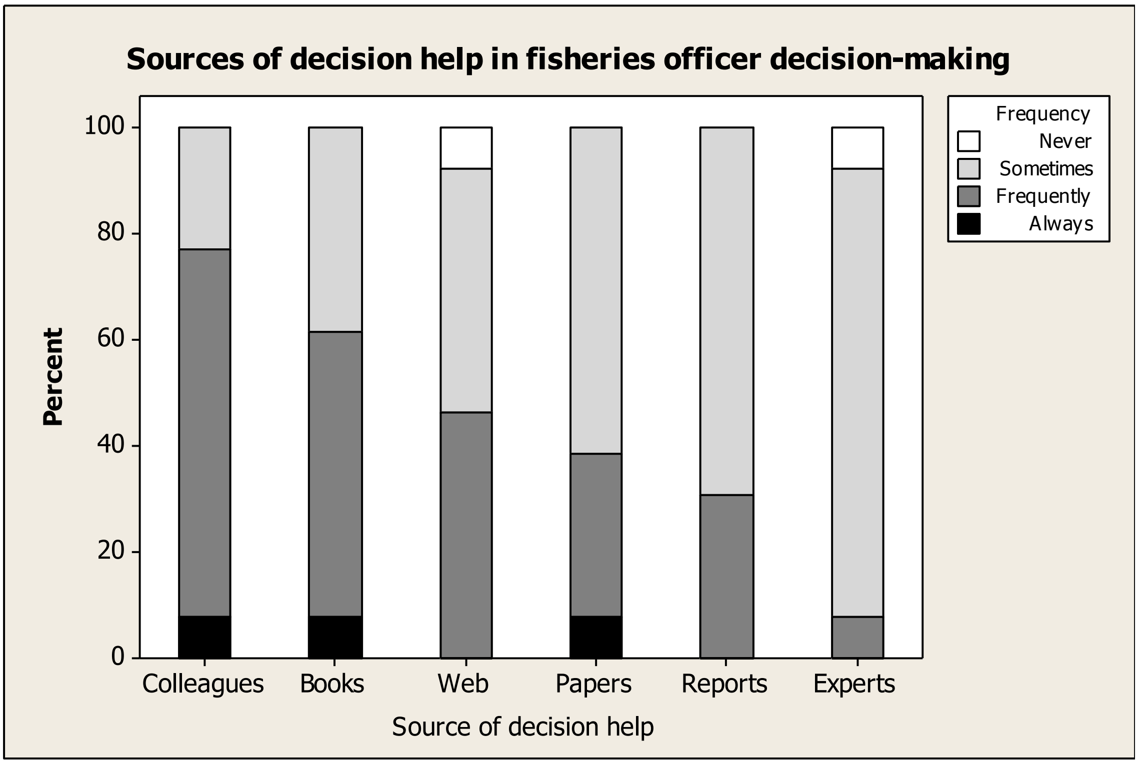
13. How do you rate your skills in the following computer systems (ARC GIS, Database Access, Excel, Internet Explorer, Statistical software)?



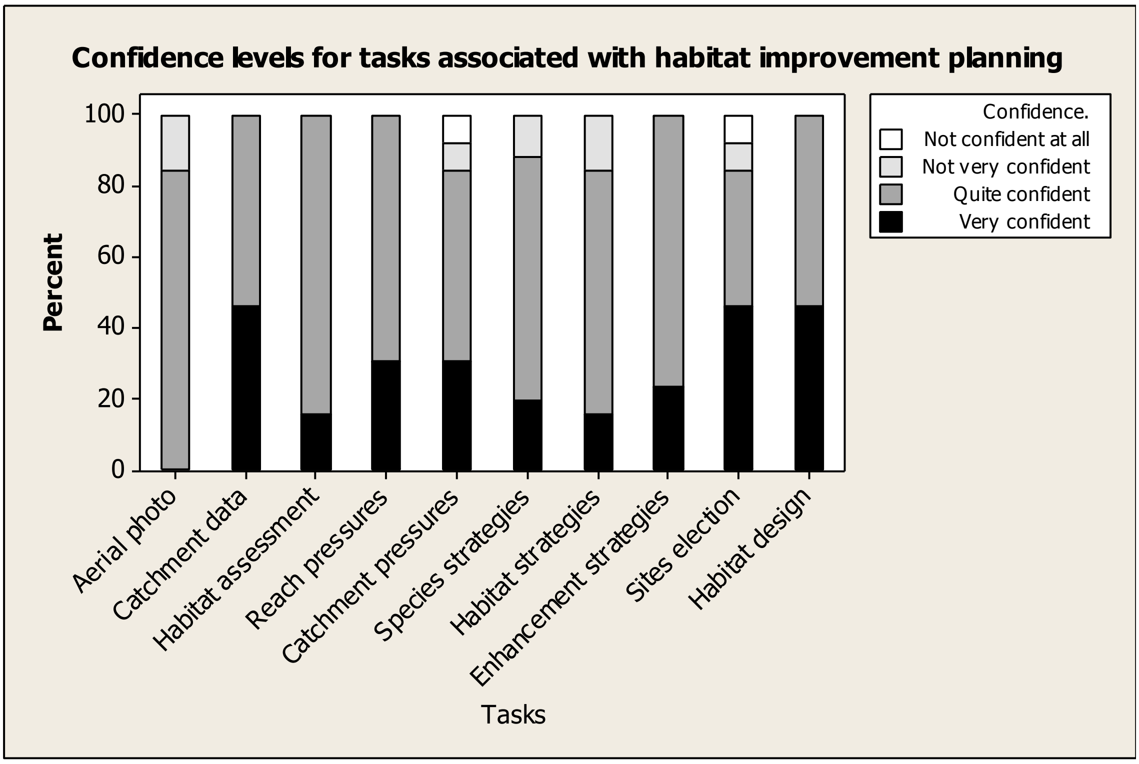
14. Which of the following Environment Agency systems do you currently use (RHS database, NFPD, Habscore, RIVPACS, others)?



15. When making decisions, what source(s) of information do you use (opinion from work colleagues, opinion from outside expert, published reviews books and handbooks, published scientific papers, unpublished papers/reports, electronic/web-based material, other)?

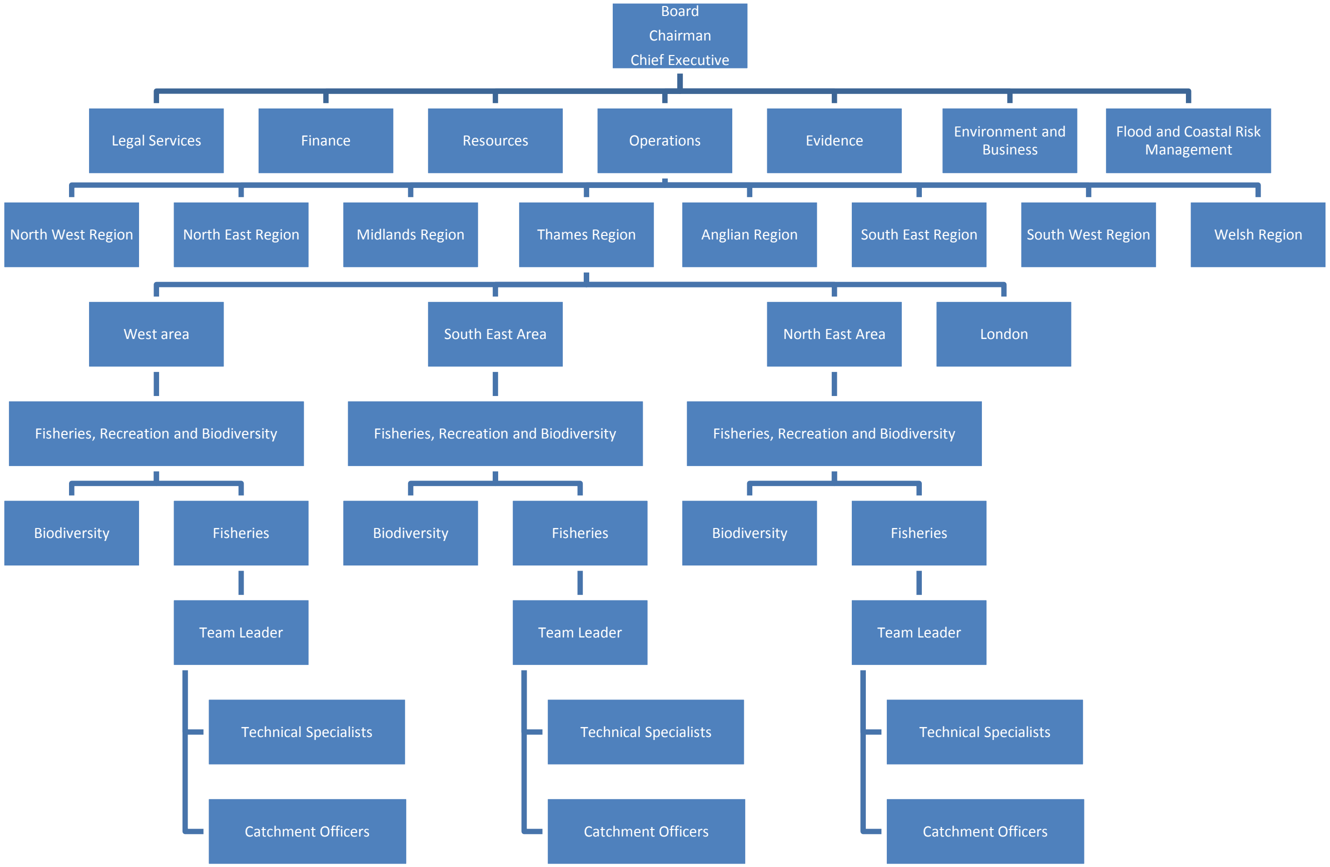


16. Do you feel confident with :
    a. analysing and interpreting aerial photographs;
    b. analysing and interpreting catchment data;
    c. assessing habitat quality for fish species and communities;
    d. identifying and quantifying pressures on fish habitats at the scale of a reach (1km);
    e. identifying and quantifying pressures on fish habitats at catchment scale;
    f. developing catchment strategies for managing species;
    g. developing catchment strategies for managing habitats;
    h. developing catchment strategies for habitat enhancement for fish species and communities;
    i. identifying and selecting sites for habitat enhancement work.
    j. designing habitat enhancement schemes for fish species and communities;
    k. designing monitoring strategies;



Appendix 8: Environment Agency Organisational chart

The Environment Agency is run by a board, chairman and chief executive. It is split into eight regions that are themselves split into areas. Each area and region has its own management structure reporting to the level directly above. Each area has a Fisheries, Recreation and Biodiversity section with a Fisheries team including a team leader, several catchment officers and one or more technical specialist.



Appendix 9: Feedback on the development, design, usability and fitness for purpose of ToolHab

Feedback from the project manager from the Environment Agency

Questions (normal font) and answers (in italics)

1- ToolHab usefulness: how useful do you think ToolHab may be with regards to the following aspects:

a. River reach assessment, identification of pressures and habitat enhancement work

Very useful especially nowadays when there is limited time to walk the river reaches and one individual may need to look at numbers of rivers or river reaches for various comparisons and to make quick decisions. Identification of pressures for species is based on our conceptual models and these could doubtless be refined, need more trialling and testing. In terms of habitat enhancement ToolHab presently will indicate likely pressures on target fish species or lifestages but the user has to take the next step and decide if, and what, enhancement or other action to take. This is fine, though there is a desire for a tool that takes the process further by recommending a costed course of action.

b. Catchment assessment of habitats for fish.

A catchment-scale module in ToolHab would be very useful and would assist in making catchment-scale decisions, for example the significance of migration barriers is influenced not only by the barriers itself but where they in relation to the habitat locations for different species and life-stages. It may also help in catchment approaches to fishery performance or status – eg answer questions such as what % of catchment stream length is good trout nursery habitat at present and what is the potential for improvement ? Phrased another way it would enable the user to compare natural, reference, trout nursery habitat with actual (river in impacted state) trout nursery habitat.

c. Effective prioritisation of habitat enhancement work.

Any prioritisation method has to take account of changing perceptions and business objectives – namely do we improve the worst first? Do we improve that which is currently moderate and try and make it good ? or do we simply protect the best ? Habitat work even nowadays tends to take place on a very opportunistic basis and therefore the DSS might only be required to highlight things that we SHOULDN'T do

d. Effective use of available data and models (please detail which data, models etc).

General: Current version of ToolHab needs to be linked to modern Agency data and models and be more closely aligned with Water Framework Directive processes and phraseology than it currently is.

The fish habitat suitability models need to be expanded to include a wider variety of species and some of the original conceptual / fuzzy models may benefit from revisiting and substituting other empirical models where these exist(trout, salmon, eel).

e. Sharing knowledge and learning.

ToolHab will be good for sharing knowledge and learning when it becomes more widely available and resources are committed to entering / linking all the data required – I am thinking there of the anecdotal information from fisheries officers and data from other information websites that help to build up the picture of the river.

2- According to you (and any other feedback from colleagues), what are the most useful parts/modules of ToolHab and why?

I think that the river reach definition tool is useful because it attempts to build up a picture of functional reaches with relevance to fishery management which will differ from simplistic divisions based on WFD water bodies and CAMS assessment points. The methodology used to do this has some logic and validity compared to very subjective views of river reaches that might otherwise be used.

The habitat suitability assessment module for brown trout is good and useful notwithstanding the comments in 1d above. I would like to see this expanded to other species and lifestages.

3- ToolHab ease of use: do you think the interface is easy to use and adapted to user needs and skills?

I have not used ToolHab for a while but I think that it is generally intuitive and well within the technical grasp of modern EA staff. ToolHab is however quite a big package and is likely to become more so as more functionality is added, it would benefit from a pop-up feature that lets the user see at a glance where s/he is in the system (many applications would benefit from this).

4- Do you think there would be any benefits in using ToolHab compared to current practice?

A big plus for use of ToolHab is as mentioned above the ability to look at a river reach and very quickly gain access to all the data you need to see to build up a picture. Even if you have the luxury of being able to walk the river bank, ToolHab enables access to lots more data that at present you might need to contact four or five other people to obtain, or enter a number of other applications that the user might not be familiar with.

5- Do you see any other potential applications for ToolHab (e.g. WFD, training etc)?

ToolHab or at least some of its key features should go on to form the basis of an integrated, modular tool for WFD catchment planning, different modules according to the different elements of the ecology, but using a similar approach and ethos. I think it has potential as a communication tool for working with external stakeholders to identify options for fishery improvement-protection.

6- Have you had any feedback on ToolHab by potential users and what has been their response?

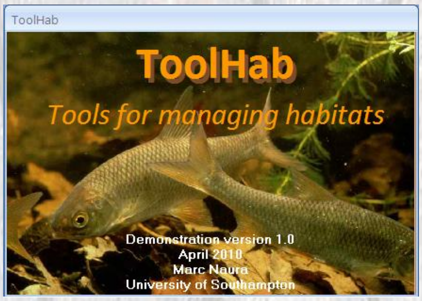
One or two people who have seen ToolHab as part of RHS training packages etc and external people e.g. Rivers Trust have said that this is something that they need. One or two have commented that it "tells you what you already know" or that it only tells you what some other system can tell you. As to the latter it's certainly true that some tools may tell you certain things as well or even better than ToolHab, none of them currently pull all the information together.

Appendix 10: ToolHab manual and user guide

ToolHab

Decision Support System

Tools for Managing Habitats



April 2010

Marc Naura

GeoData Institute
Environment Agency
University of Southampton School of Geography

Introduction

Welcome to the ToolHab Decision Support System.

ToolHab is a Decision Support System developed for the Environment Agency England and Wales to help assess and prioritise river reaches for habitat enhancement work.

ToolHab is one of the outcomes of a wider five-year research project sponsored by the Environment Agency and hosted by the University of Southampton (School of Geography) on decision support and river management. The aim of the research was to investigate the factors affecting the uptake of science and scientific products such as computer tools and models within a conservation organisation.

Through its servers, intranet and internet connections, Environment Agency staff have access to a wide range of data and knowledge of potential benefit to their many duties (e.g. the national fisheries database (NFPD), the RHS database, BioSys, GIS data, aerial photographs, satellite images, species databases etc). One major issue is to make these sources of information available to staff in a format that is relevant to their work and adapted to their skills and work practice.

Decision Support Systems are computer programs that help users in their day-to-day decision-making processes by providing them with information relevant to their jobs. Decision Support Systems combine databases and predictive models into simple user interfaces.

This particular project was initiated by the Environment Agency fisheries science team and Thames region Fisheries, Recreation and Biology team to investigate the potential use of existing data and computer software for managing fish and their habitats.

The aim of this project is to develop a prototype Decision Support System using existing knowledge, data and software for fisheries management in Thames region that will be tested on local rivers by Thames region fisheries staff.

The Decision Support System contains data for a total of 15 rivers of which 10 are located in Thames region, 3 in North West region and 2 in North East region. Only information for the main stems of the rivers where included in ToolHab. A range of datasets on fisheries, river habitats, water quality, biology and man-made structures are available through a built-in GIS interface and a series of simple forms and graphs. ToolHab also contains simple conceptual models of habitat suitability for nine species of fish and three life stages designed by fisheries experts from the Environment Agency.

Altogether, ToolHab provides simple and easy access to existing data and knowledge on rivers and fish thus facilitating the assessment of habitat quality, the identification of pressures and impacts, and the suggestions of measures for restoring/improving habitats.

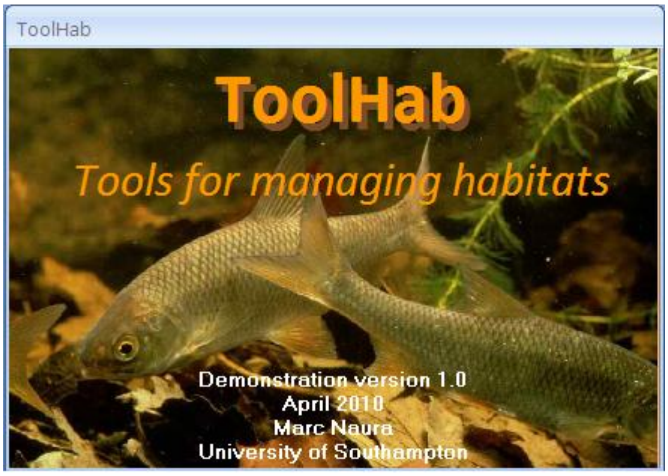
The project record will be soon available in the shape of a PhD thesis document downloadable from the University of Southampton and project web sites (www.riverhabitatsurvey.org).

Getting started

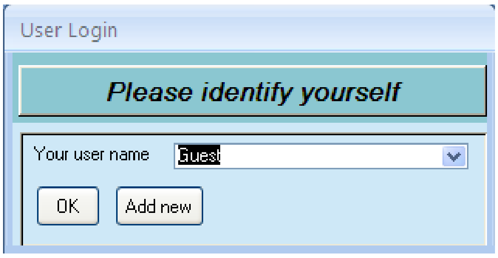
Getting started with ToolHab.

To start the application after installation, double-click on the ToolHab icon 

This will open the application and a first screen will be displayed for a few seconds



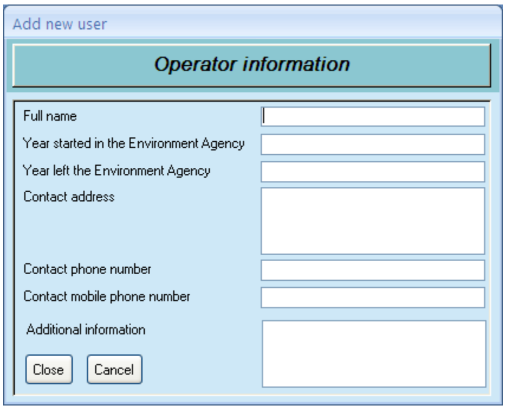
The next screen to appear will be the user login window



If you are already a registered user, select your user id and click ok.

If you are not registered yet, click on the 'Add new' button and the following screen will appear

Enter your details and press 'Close'



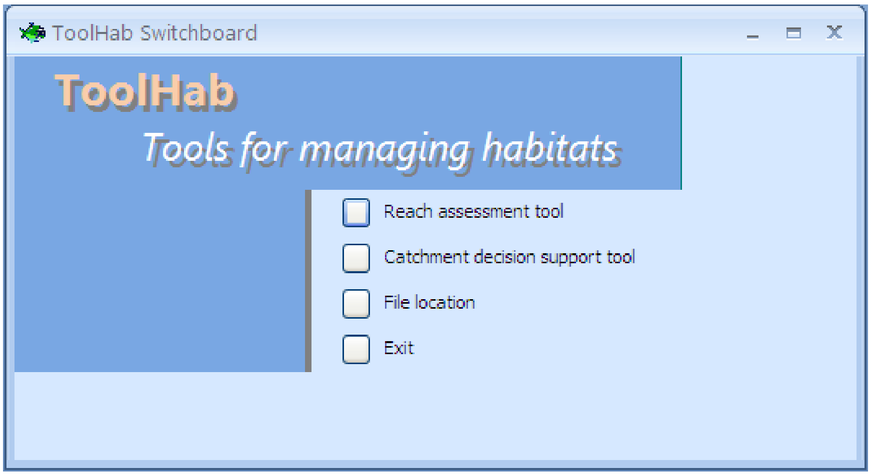
Switchboard options

The ToolHab switchboard has four options:

- The reach assessment tool option will open a tool for assessing individual river reaches. The tool gives users access to fisheries, biological, river habitat and water quality data along with maps and aerial photography. The data can be viewed for individual sampling sites but also at the scale of river reaches. Each river has been split into a series of discrete units representing homogeneous habitat sections. The tool also enables users to input their local knowledge using a simple interface. Historic information about river sections or individual events can be recorded and showed on map. The reach assessment tool was designed for Catchment Officers to help them identify pressures and impacts and suggest management actions. The tool is fully functional

- The catchment decision support tool summarises the information collected using the reach assessment tool at the scale of rivers (from source to mouth) or catchments. This decision support tool was developed for Technical Specialists within Environment Agency fisheries units to identify pressures and impacts at catchment scale and design strategies and programmes of measures. At the moment, this tool is not fully functional and is for demonstration purposes only. It will display information and enable to query GIS data but it will not enable a full assessment at catchment scale.

- The file location menu can be used to change the paths to aerial photo, maps and RHS photo directories.



Take a quick tour

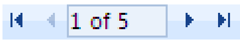
Quick tour

We will not take you through a quick application that will show how ToolHab can be used for assessing habitats, identifying pressures, impacts and potential measures.

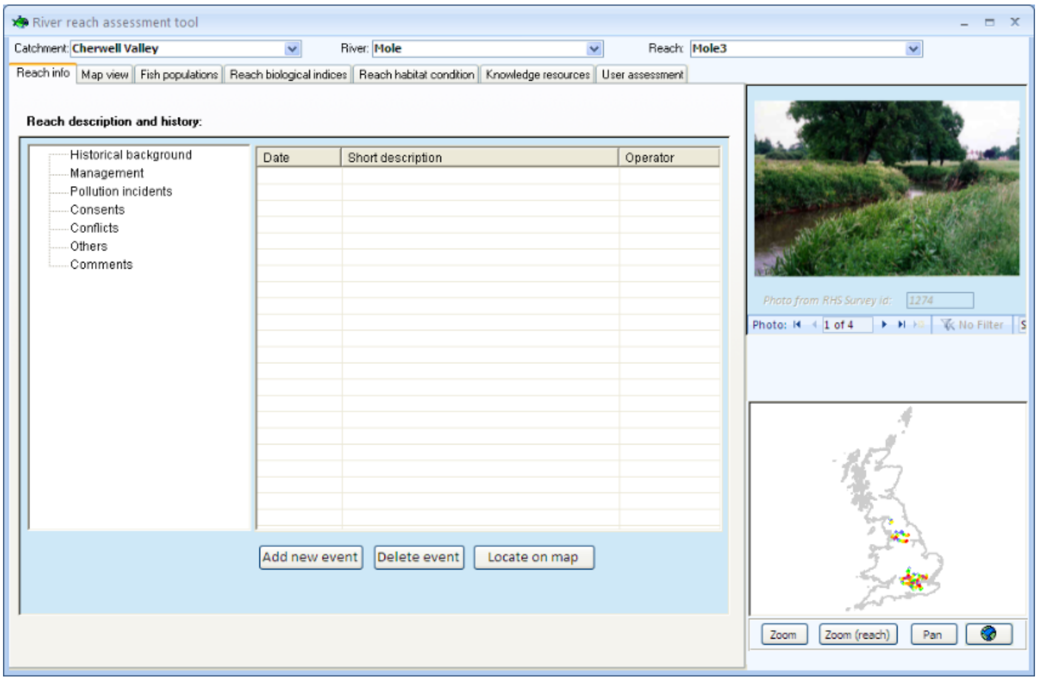
First we open the river reach assessment tool and we view the data associated with the default river reach on the river Mole.

The reach assessment tool contains seven tabs.

At the top of the window are three drop-down boxes with information about the selected reach. For each river, river reaches have been numbered in ascending order from source to mouth. River reach ids containing a '0' (e.g. Mole03) generally are on tributaries or on adjacent arms of the river.

Photographs of River Habitat Survey (RHS) sites associated with the selected river reach are displayed on the right-hand side. In our case, we have four photographs for the Mole3 reach. Click on the navigation buttons 

to flick through the photographs.



In the bottom right-hand corner, is a small map displaying all 15 rivers. You can zoom in and out of the map using the zoom button (left click to zoom in and right click to zoom out). You can also click on the 'zoom (reach)' button to display the selected reach.

Before we start the assessment of the reach, we will first look at the end of the process which is the 'User assessment' form.

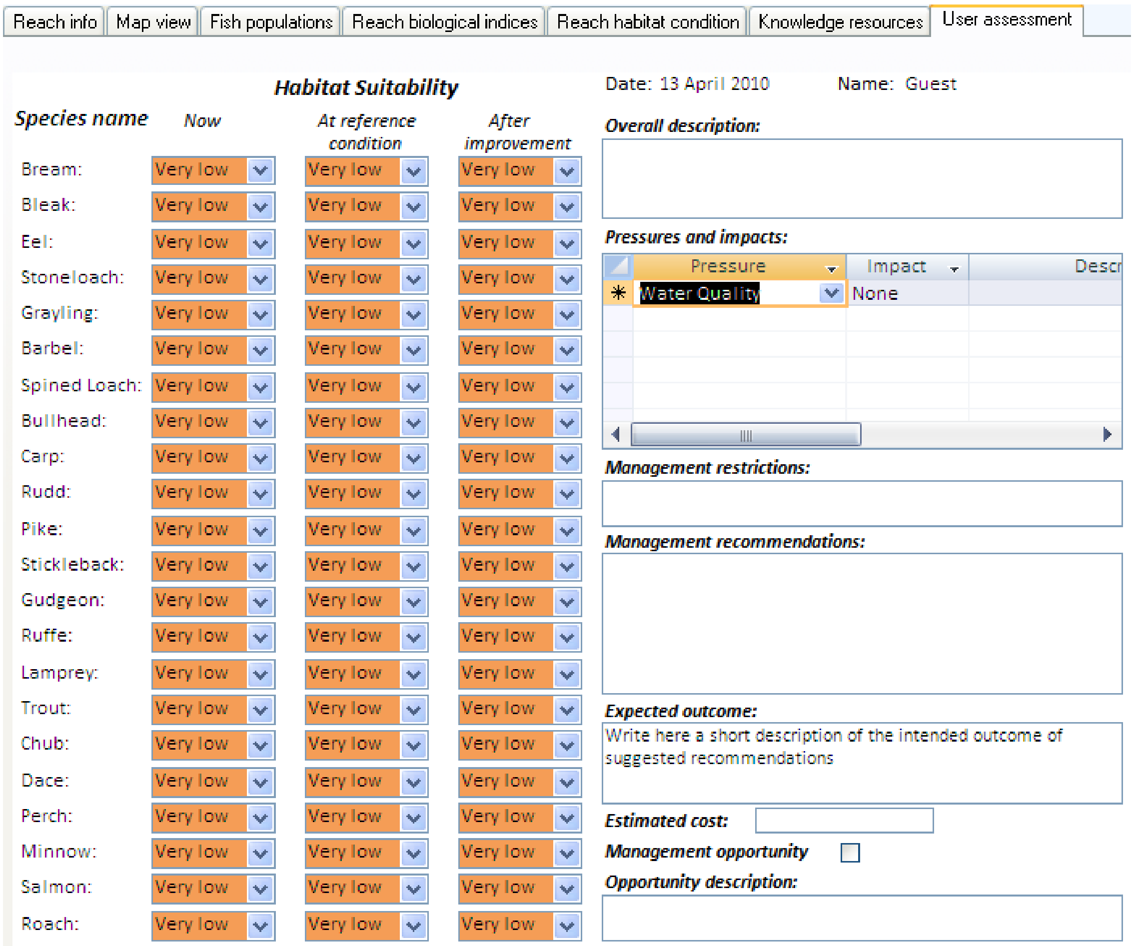
Take a quick tour

User assessment

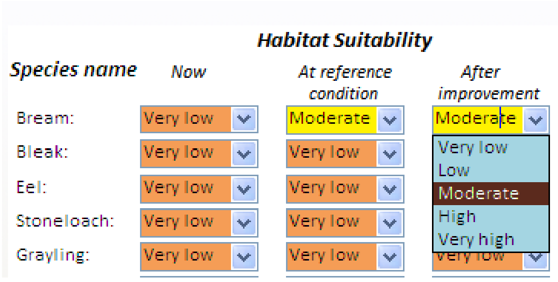
ToolHab gives users access to a wide range of data and knowledge to enable the assessment of river reaches for 23 species of fish. Reach assessment is done by using the form on the last tab. This forms contains all the management information that will be used to build catchment wide habitat improvement strategies. To help users in their decision-making, ToolHab provides access to a wide range of biological and environmental data as well as models and knowledge.

The aim of the whole assessment process is to assess the suitability of river reach habitats for each species:

- as they are now;
- as they would be at reference conditions and;
- as they would be following improvement work.

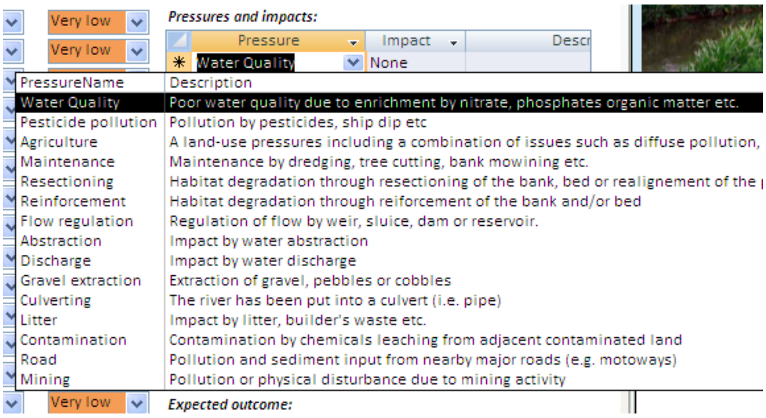


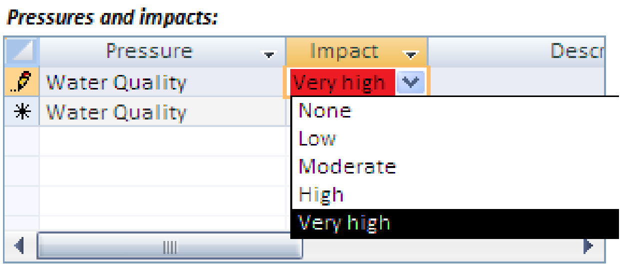
Users can use the drop down boxes to specify the quality of reach habitats for each species using 5 categories and give an assessment of their suspected impacts on reach habitats.



The form also give users the opportunity to enter an overall description of the reach, its conditions, pressures and impacts.

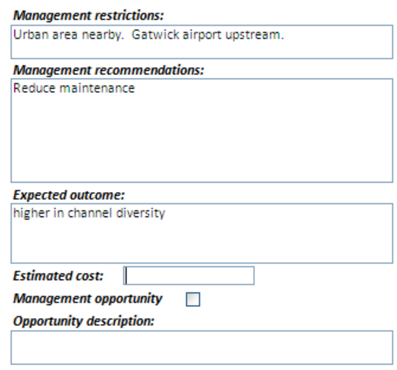
The 'Pressures and impact' box can be used to list all pressures,





Then users can recommend management actions for the reach and give information on potential restrictions (e.g. gas pipe, road etc) and opportunities (e.g. friendly land owner).

The system requires users to give a description of the expected outcome following improvement along with an estimated cost for the works (optional).

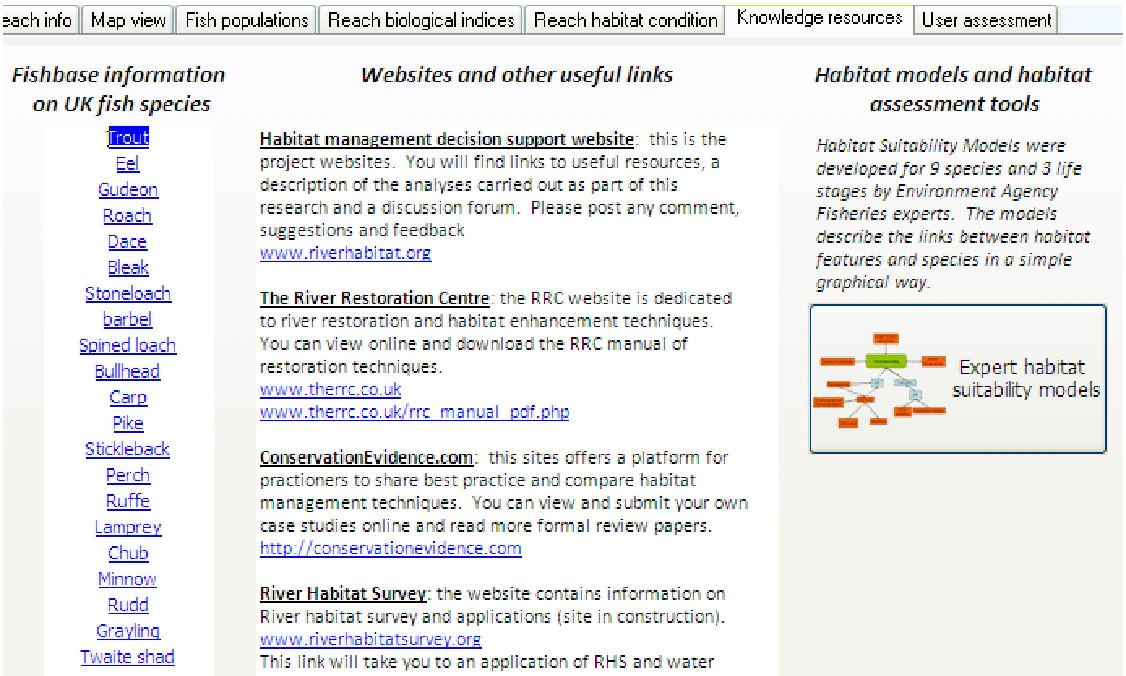


Take a quick tour

Knowledge resources

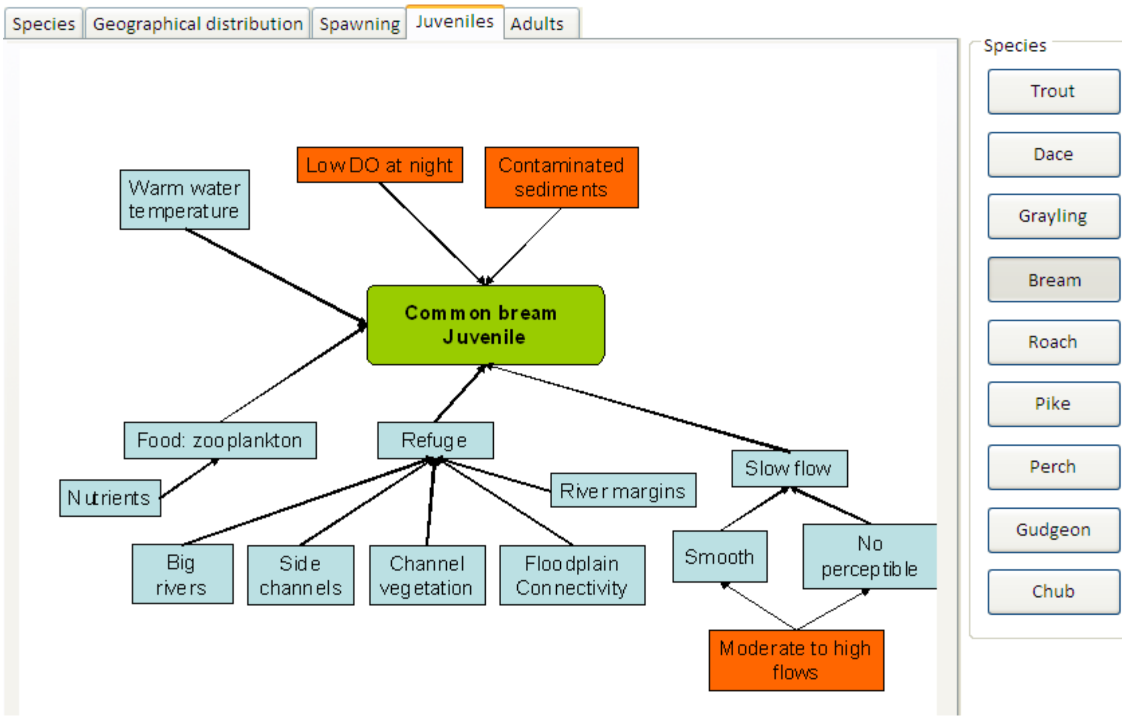
The knowledge resource tab contains links to online resources such as Fishbase and other useful websites. You will need to have access to the internet to access the links. To add links to the list, simply put the cursor in the window and type/copy new links to other useful resources with a short description.

The knowledge resource tab also provides access to the habitat suitability models built by Environment Agency Fisheries experts for 9 fish species and 3 life stages. To view these models, click on the 'Expert habitat suitability models' button.



A form with 5 tabs and 9 buttons (one for each species) will open. Using this form, users can view in a graphical way the habitat features (in blue) and the pressures (in orange) that define/affect fish habitats at different stages of their life cycles.

This tool can be used in combination with all the other tools and datasets available in ToolHab to assess the quality of river reaches for fish and the potential pressures and impacts on their habitats. We have tried, as far as possible to include in ToolHab all the data that are needed to carry out this assessment.


Species
Geographical distribution
Spawning
Juveniles
Adults
Low DO at night
Contaminated sediments
Warm water temperature
Common bream Juvenile
Food: zooplankton
Refuge
Nutrients
River margins
Slow flow
Big rivers
Side channels
Channel vegetation
Floodplain Connectivity
Smooth
No perceptible
Moderate to high flows
Species
Trout
Dace
Grayling
Bream
Roach
Pike
Perch
Gudgeon
Chub

Take a quick tour

Learning about the river history: The reach info tab

Most knowledge is in people's minds and memories. The Environment Agency for example, hosts on its servers vast amounts of data on water quality, biological quality and river habitats but there is no repository for local knowledge accumulated by generations of staff on the river history and associated events and anecdotes. As part of the research carried out for the project, local staff identified that a module for capturing and storing local knowledge on river reaches would bring tremendous added value to the Decision Support System.

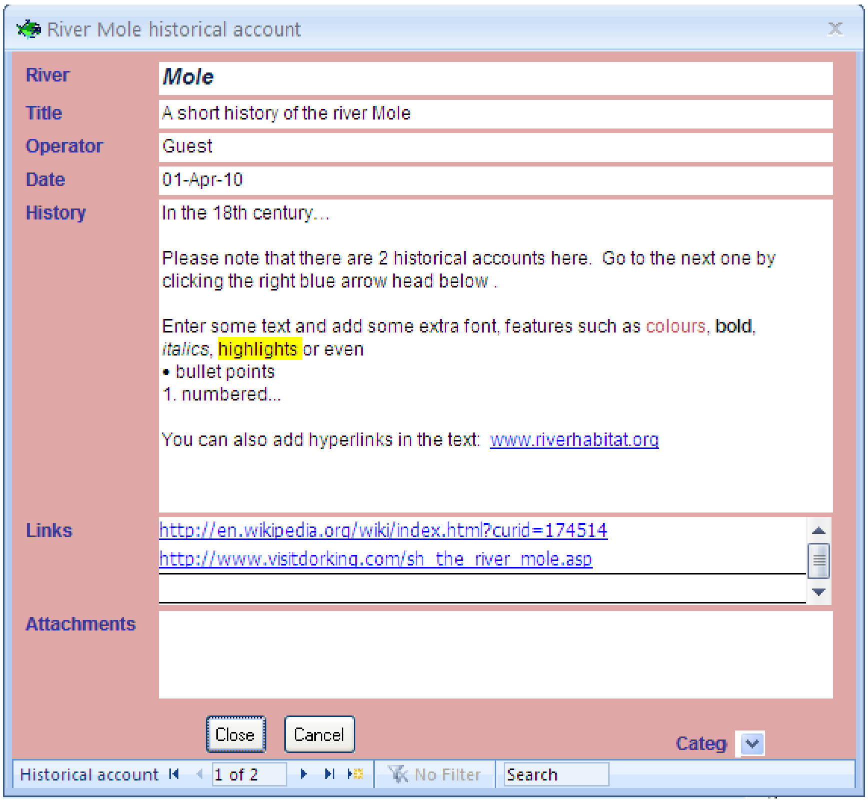
Using the reach info tab, information about historical events can be captured, dated and geographically located. The general history of the river can also be recorded.

River history

To get an overview of the river historical background, click on

.

This will open a window with a series of records on the general history of the river, its management, the land use etc.

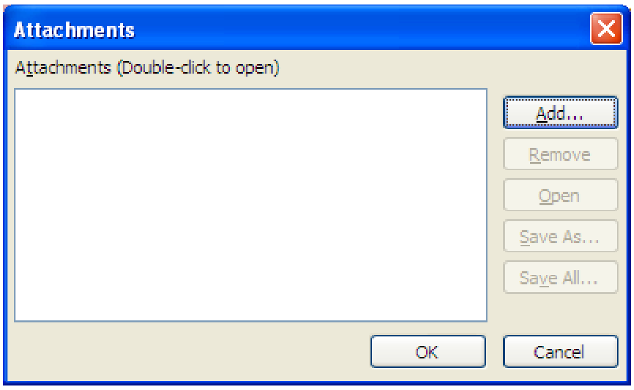


Please note that there may be more than one record for a single river. To create your own account of the river history, add a new record by clicking on the button in the navigation panel.

You can add links to websites or documents by copying and pasting the URL or path to the document.

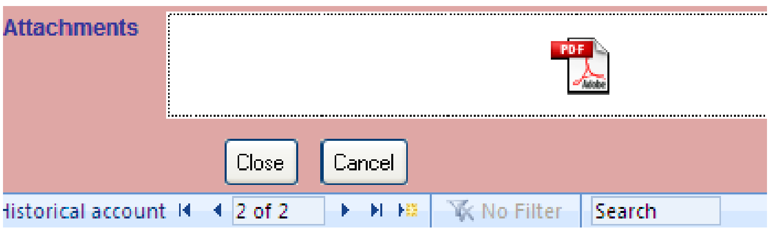
You can also import within ToolHab entire documents as attachments. The difference between a link and attachment is that attachments are included within ToolHab (they stay and 'travel' with it). 'Links' simply link to an existing file on the web. If the file disappears, moves or the website changes name, the link will be lost. Beware that attachments increase the size of the application.

To add an attachment, double-click on the attachment box and the following window will appear.

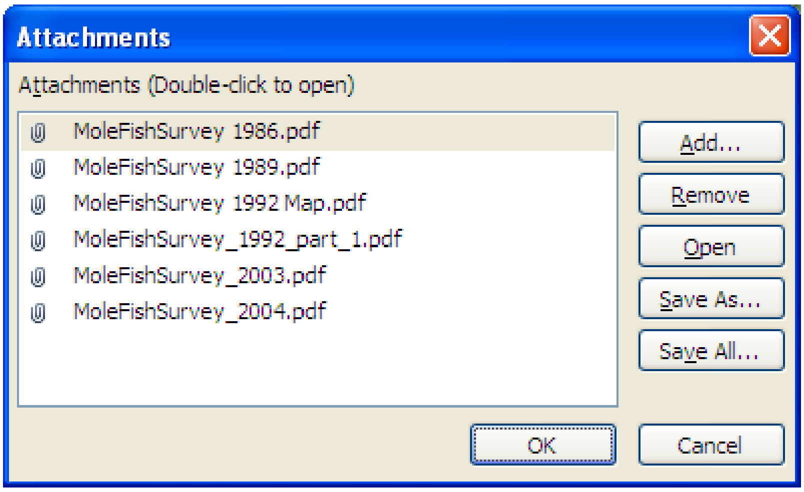


Click add to locate the file you want to attach. You can attach more than one file.

To view an attachment, double-click on the attachment icon (here a pdf file).



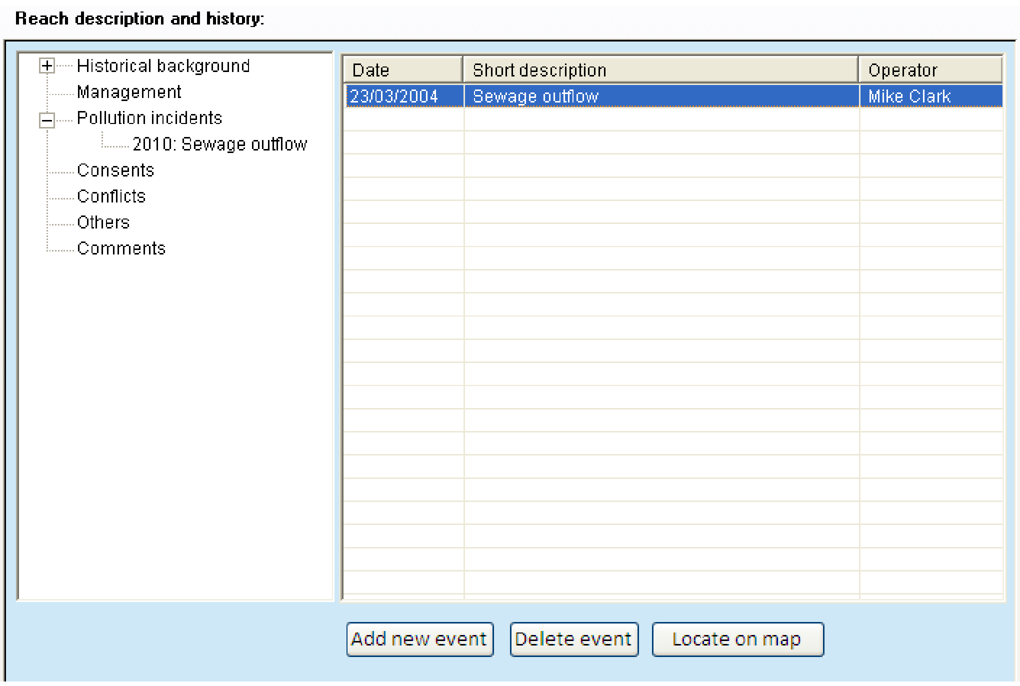
The attachments window will open and display all available files for this particular record. To view an attachment, select it in the list and click open.



Reach History

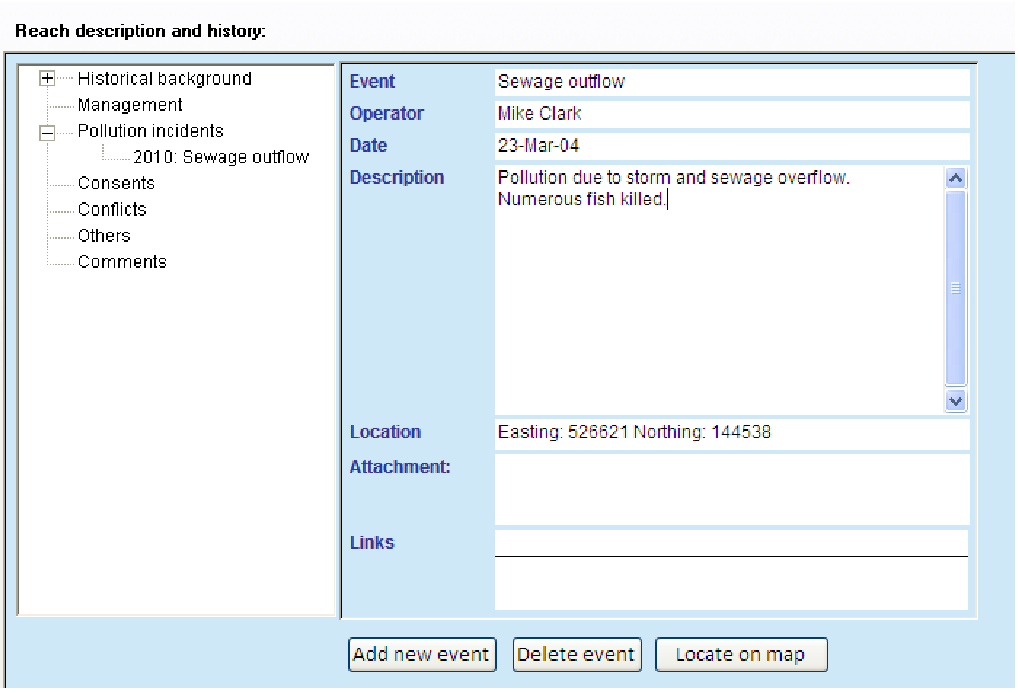
In the left-hand panel, there are seven categories of events that can be recorded or viewed. If you click on any category title, a list of associated events will appear in the left and right panels. To view an event, simply double-click on the corresponding line in the list.

Tip: instructions as to what to do will appear if you hover with the mouse specific parts of the screen

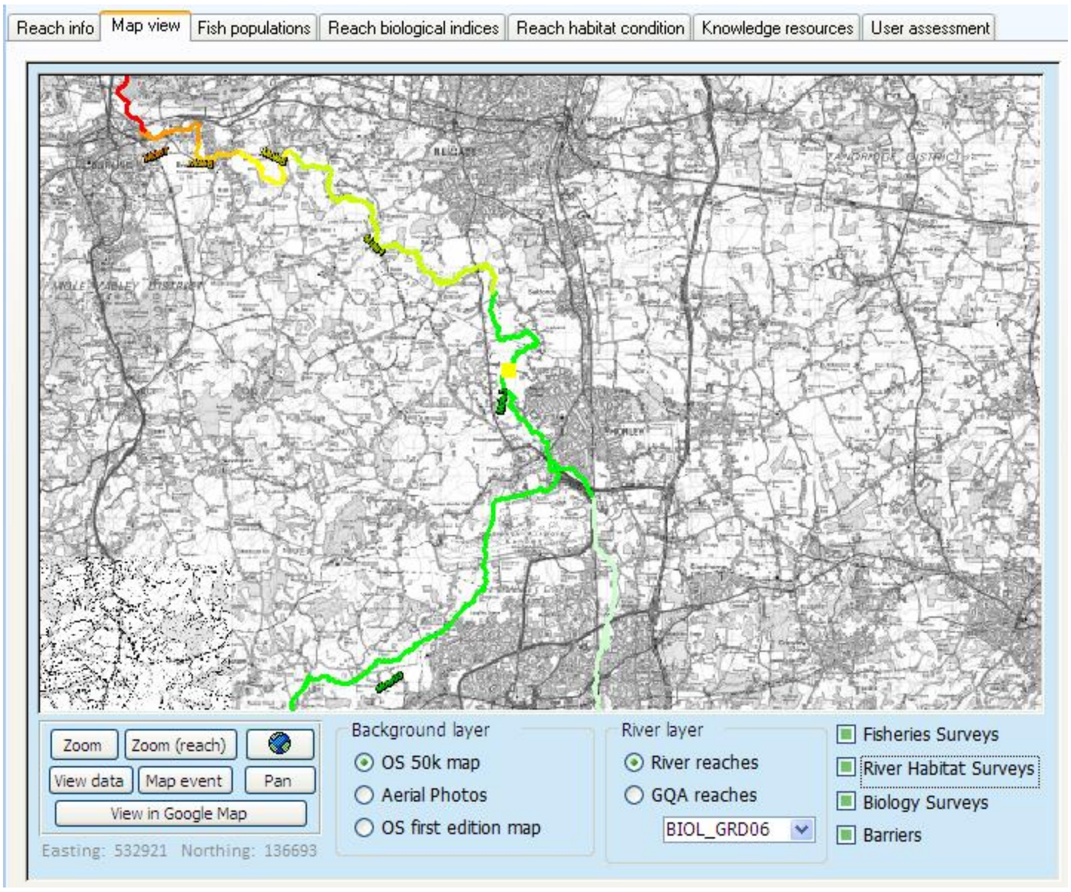


Double-click on the 'Sewage Outflow' to view the event.

Detailed information about the event is now visible. To learn more about the person who reported these particular pollution incidents, double click on his name.



When event coordinates are indicated, you can click on the ' locate on map' button and it will take you to the 'Map view' tab and locate the event using a yellow circle.



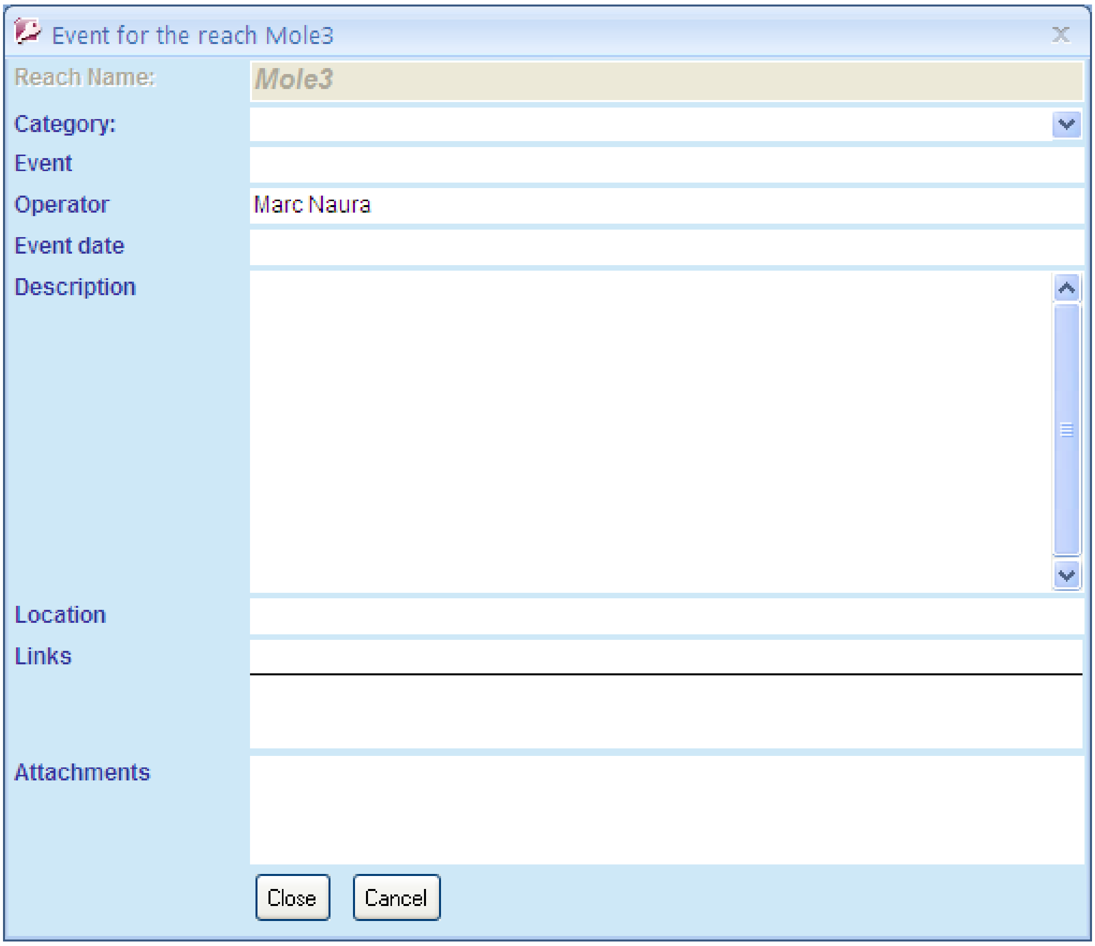
Take a quick tour

Local knowledge: adding events

Now we will quickly demonstrate how you can add events using the 'reach info' tab or the 'map view' tab.

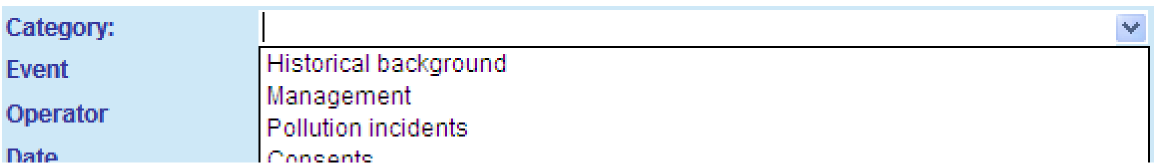
Adding an event using the 'Reach info' tab

Click the [Add new event] button. The following form will appear:



Please note that the reach ID and your name are automatically added.

First choose a category for the event using the drop-down box:



Now enter a short title for the event in the 'event' field, a date and a description.

If you want to, you can add:

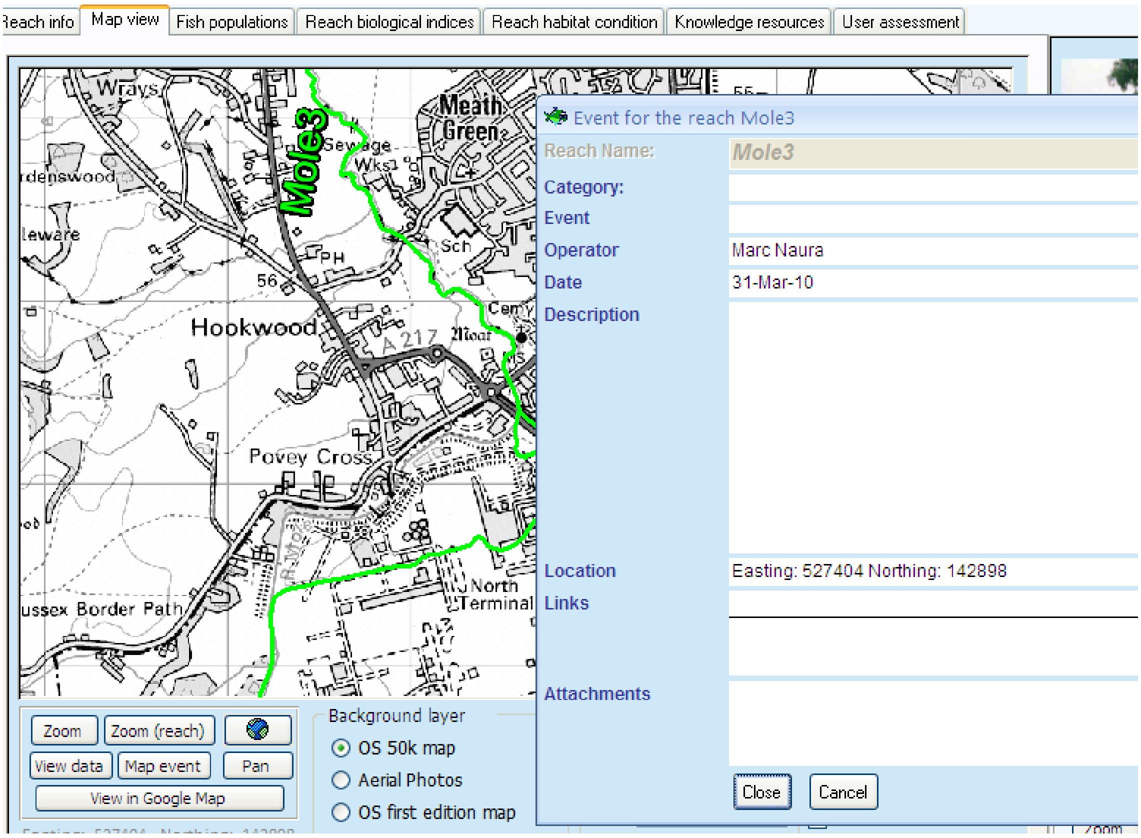
- The location of the event using six-figure Easting and Northing in the 'Location' field;
- Links to several websites or network folders/documents in the 'Links' list box;
- Several documents related to this particular event in the 'Attachments' list box.

Once you have finished adding information, click [Close]

Adding an event using the 'Map view' tab

It can be sometimes difficult to figure out the exact coordinates of events. It is possible to create events directly using the map. Go to the 'Map view' tab and click on [Zoom (reach)] to focus on the selected reach, then use the [Zoom] and [Pan] buttons to zoom to the right location. Finally, click the [Map event] button and then click on the map at the exact location where the event occurred. The same form as before will appear but this time, the Easting and Northing will have been automatically added. Proceed as before and click the [Close] button to save the event.

Now go back to the 'Reach info' tab and check that your event has been recorded.



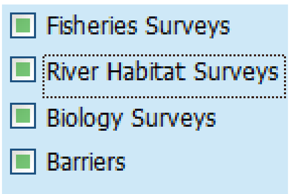
Take a quick tour

The map view

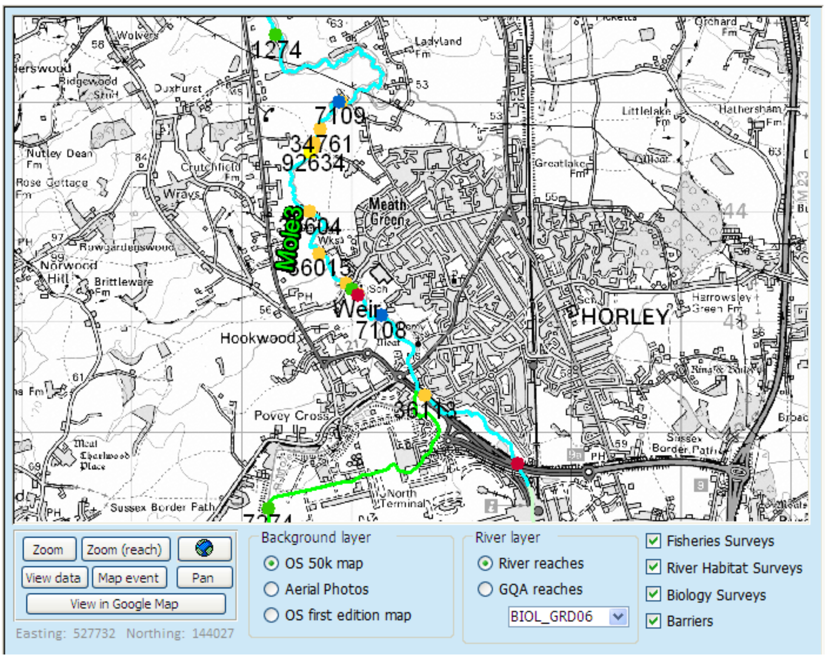
You can use the map view to display various data layers available in ToolHab. Three background layers are available: a black and white version of the 50,000 scale OS map, Environment Agency aerial photographs and the 1900s first edition OS maps. Not all first edition maps and aerial photographs have been loaded on the Decision Support System because of issues of speed and data storage.

Two river layers are available: the river reaches defined as part of this research project and the General Quality Assessment (GQA) reaches. The GQA reach layer contains various water quality and biological quality index values that can be displayed as a thematic map using the following drop-down box BIOL_GRD06. If you want to learn more about GQA, go to Appendix 1.

You can also view four point layers corresponding to major surveys carried out by the Environment Agency (Fisheries, Biology and RHS) and also to the location of physical barriers to migration (weirs and dams).



Click on any of the check boxes associated with the river surveys to display them on the map.

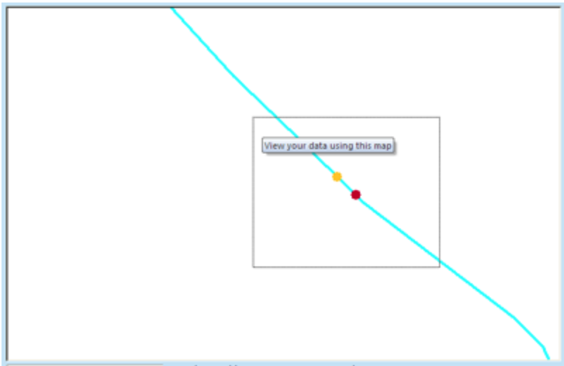


Take a quick tour

Viewing survey data

Using the map view, you can also view the data associated with individual sampling points.

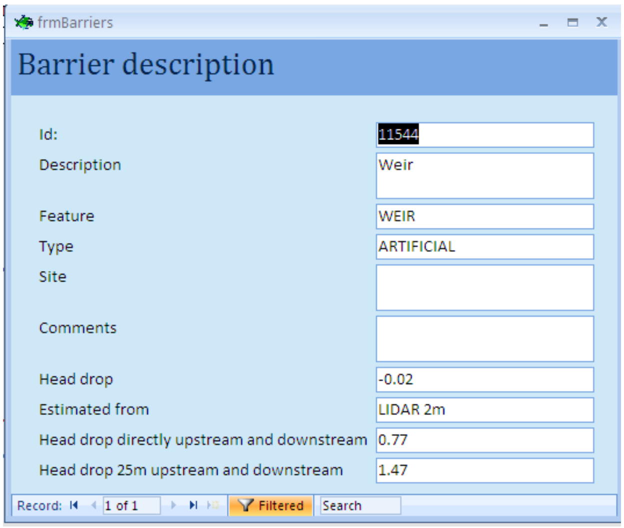
Check all four sampling points check boxes, then click on the View data button and select the sampling points you would like to view by left clicking, holding and dragging a square on the map.



Depending on the points you have selected, different forms will open and display the relevant data.

For example, in our case we have selected one biological sampling site and one barrier to migration. The following forms will appear:

The barrier description form provides detail on the nature of the structure and its potential impact on river connectivity. The difference in altitude before and after the layer have been estimated to be around 77 cm just upstream and downstream of the barrier and 1.47 m when measuring altitude 25 m upstream and downstream of the barrier.

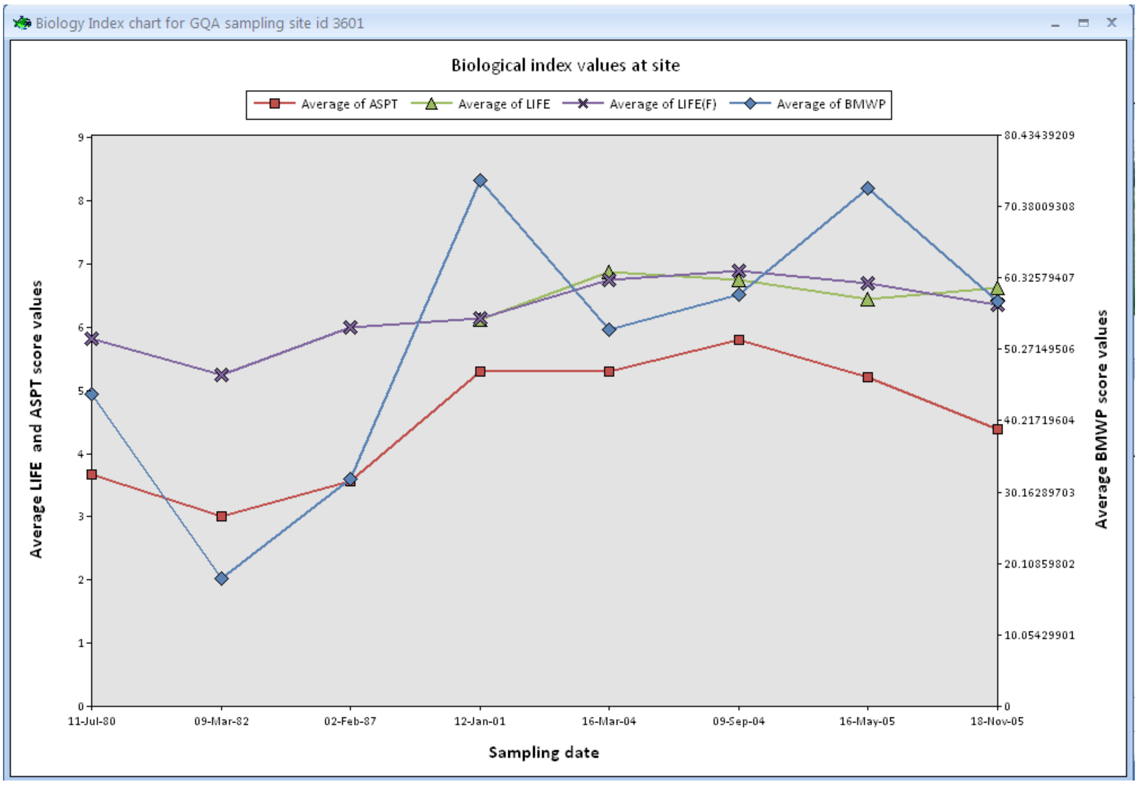

frmBarriers

Barrier description

Id:	11544
Description	Weir
Feature	WEIR
Type	ARTIFICIAL
Site	
Comments	
Head drop	-0.02
Estimated from	LIDAR 2m
Head drop directly upstream and downstream	0.77
Head drop 25m upstream and downstream	1.47

Record: 1 of 1 Filtered Search

A biology index chart is drawn for the GQA sampling point selected. The form shows the change in four index values along time:the Average Score Per Taxon, the BMWP, and two LIFE indices. If you want to learn more about the meaning and significance of biological indices, go to Appendix 2.

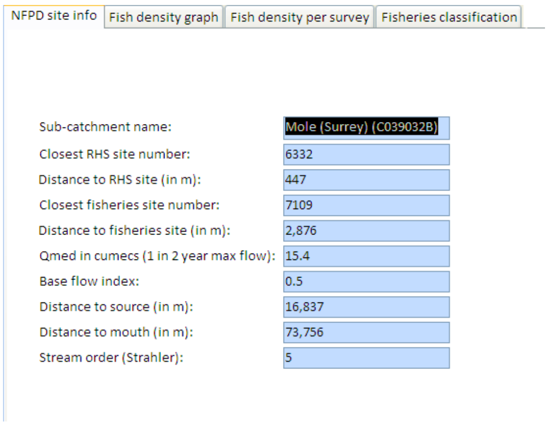


In the next section, we will have a closer look at the fisheries and River Habitat Survey data forms.

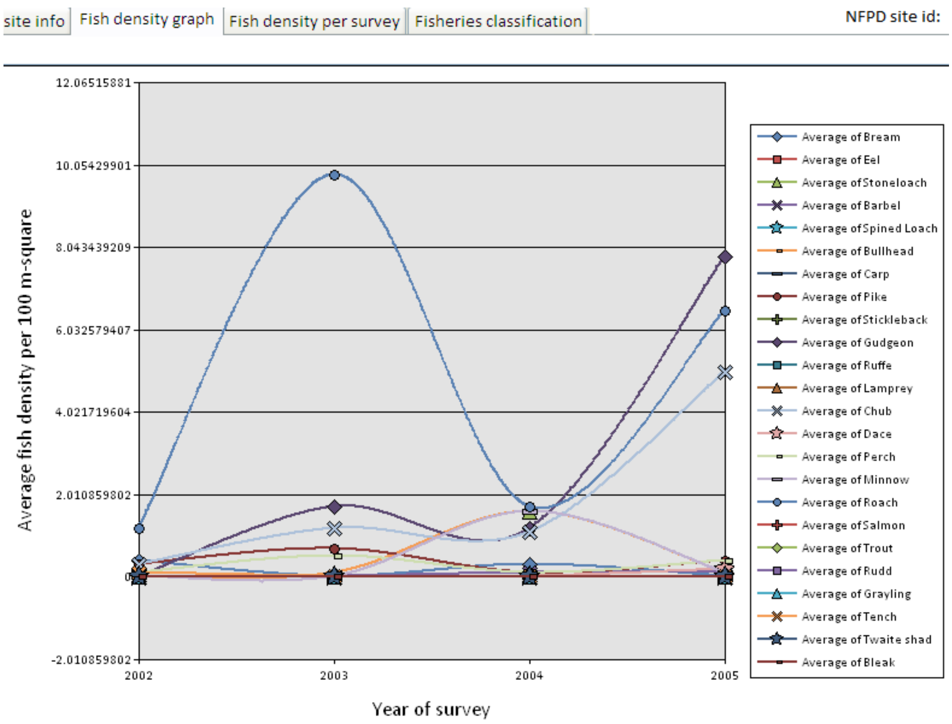
Take a quick tour

Viewing survey data: The fisheries data form

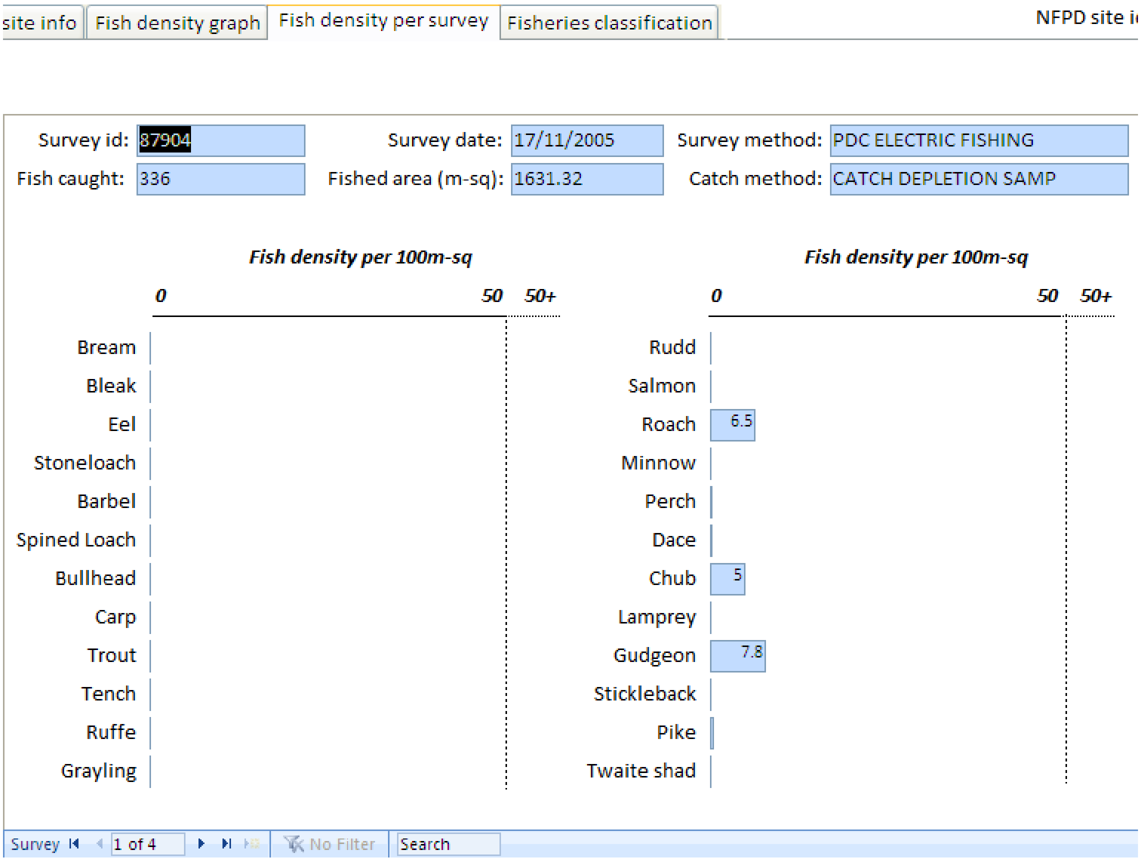
Select one or more of fisheries sites using the View data tool. The following form will open (see below). The number of sites selected and displayed is indicated at the bottom left of the form. The fisheries form has four tabs. The first tab displays general information about the fisheries sampling site.



The second tab displays a graph of fish density change along time. Each of the 23 species recorded during survey displayed using symbols joined by a line. To identify specific points lines, just hover with the mouse over the point/line.



The third tab contains the same information as the second tab displayed as individual bar charts for each survey year. Click on the navigation buttons at the bottom of the chart to move from one year of survey to the next.



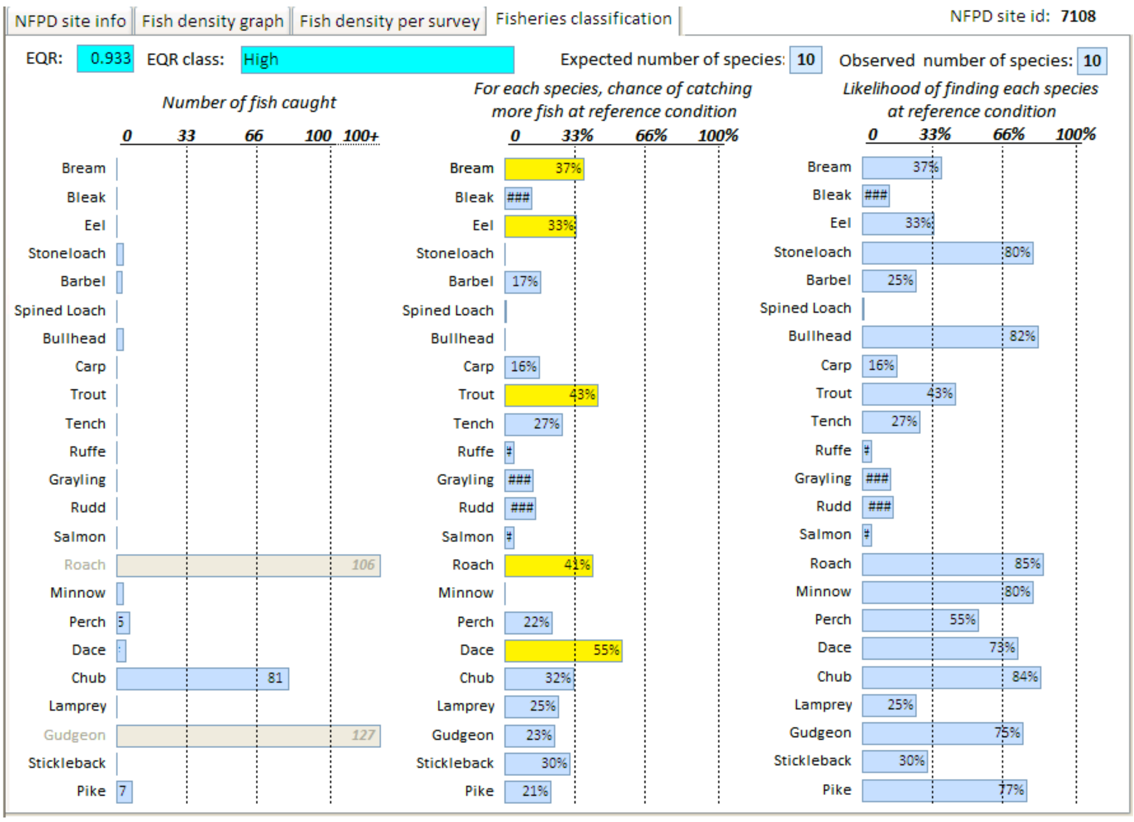
The last tab contains information taken from the Fisheries Classification Scheme (FCS2). FCS2 predicts, for most fisheries survey sites 3 indices:

- an overall Environmental Quality Ratio (EQR) score for the site. Values close to 1 indicate closeness to reference condition;
- an EQR class from high to poor;
- the expected number of species caught at reference condition;
- the likelihood of catching each species at reference condition;
- the likelihood of catching more fish than at the surveyed site at reference condition.

The predictions and the actual number of fish caught are displayed as bar charts. The bars on the two charts displaying FCS2 probabilities will change colour according to the probability levels from blue (0-33%) to yellow (33% to 66%) and red (66%-100%).

In the example below, the expected number of fish caught at reference condition exactly matches the number of species caught at the last survey. The overall EQR is very close to one and the EQR class is 'High' indicating High quality status.

All fish species that have a high probability of being caught at reference conditions (see red bars on the right-hand chart) were caught during electro-fishing (left-hand side chart) most of the time in numbers greater than predicted by FCS2 (middle chart). For example, roach were found in high numbers (106 individuals) and according to FCS2 predictions there is a 85% chance of finding roach at the site at reference conditions and a 41% chance of finding more fish than observed. The number of roach caught is therefore likely to be in line with what can be expected at reference condition.

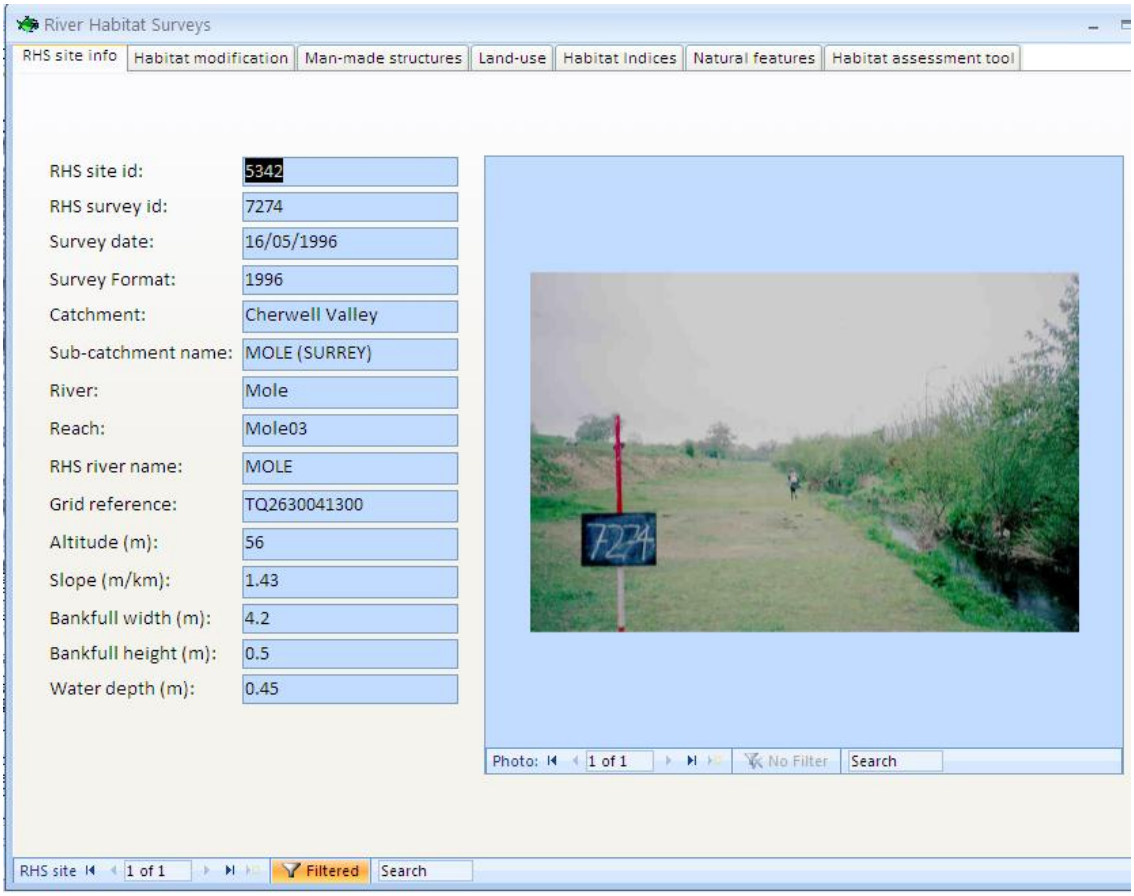


Take a quick tour

Viewing survey data: The River Habitat Survey data form

Select one or more of RHS sites using the [View data] tool. The following form will open (see below). The number of sites selected and displayed is indicated at the bottom left of the form. The RHS form has got 7 tabs. The first tab displays general information about the RHS site, its location, altitude whilst the other tabs provide information on habitat features, modifications, land use and habitat suitability for trout. RHS data have been summarised into indices or graphs/charts to facilitate viewing and data analysis.

More than one RHS site can be selected and displayed. To navigate between sites, use the navigation panel [RHS site 1 of 1] at the bottom of the window.

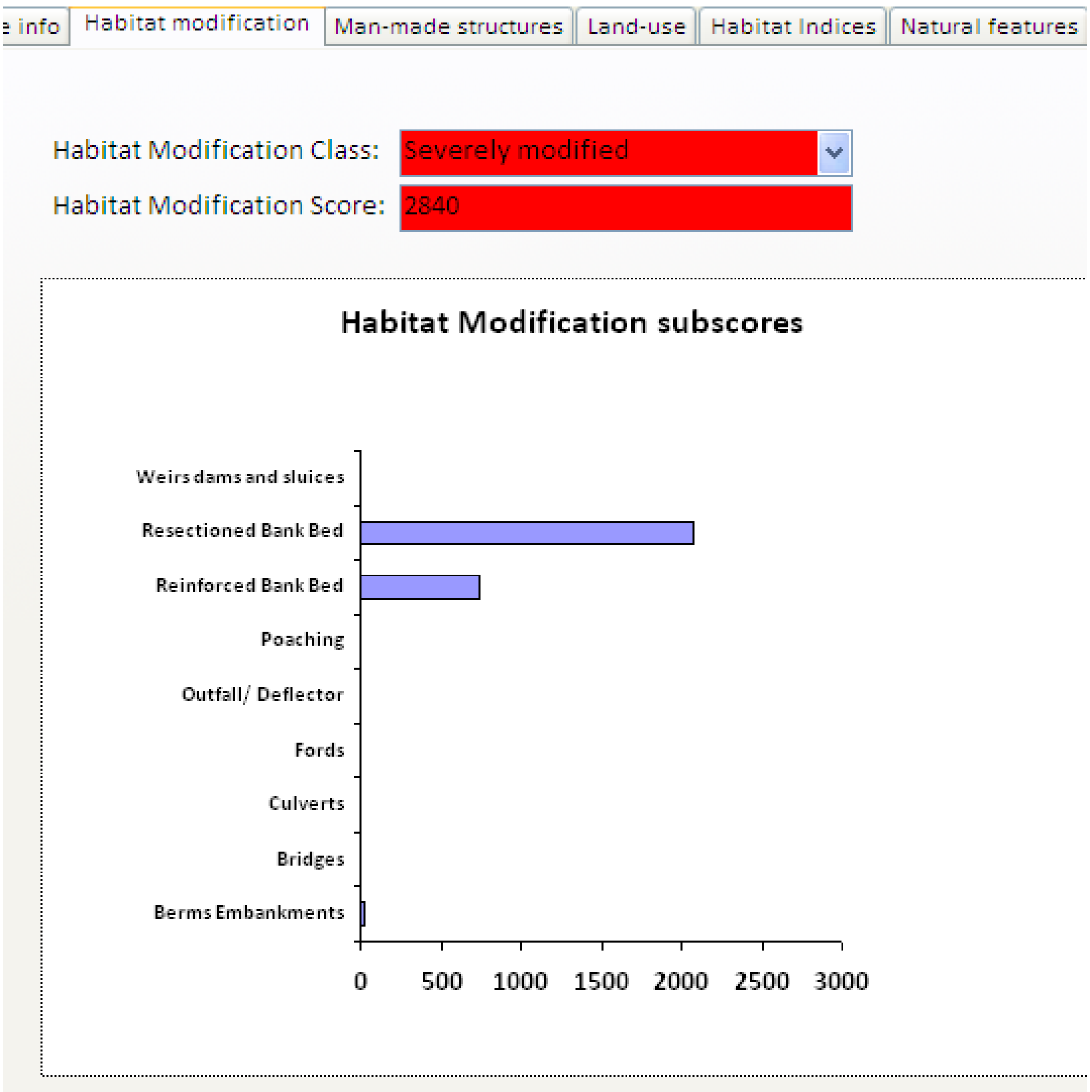


Take a quick tour

Habitat modification

The habitat modification tab contains a representation of the Habitat Modification Score (HMS) and its components. The HMS is a scoring system for engineering structures on watercourses. Scores are allocated according to the extent of the structure and its life expectancy.

HMS scores are further classified into 5 classes to provide with a simple modification index from Semi-natural (blue) to Severely modified (red). The total site score and index class are represented in the top 2 boxes. In the graph below, the HMS component subscores are indicated. The graph below shows that the site is severely modified with a score of 2840. The modifications accounting for most of this very high score are resectioning of the banks and bed and the presence of reinforcements. Berms and embankments are also present but account for a much lower part of the total score.



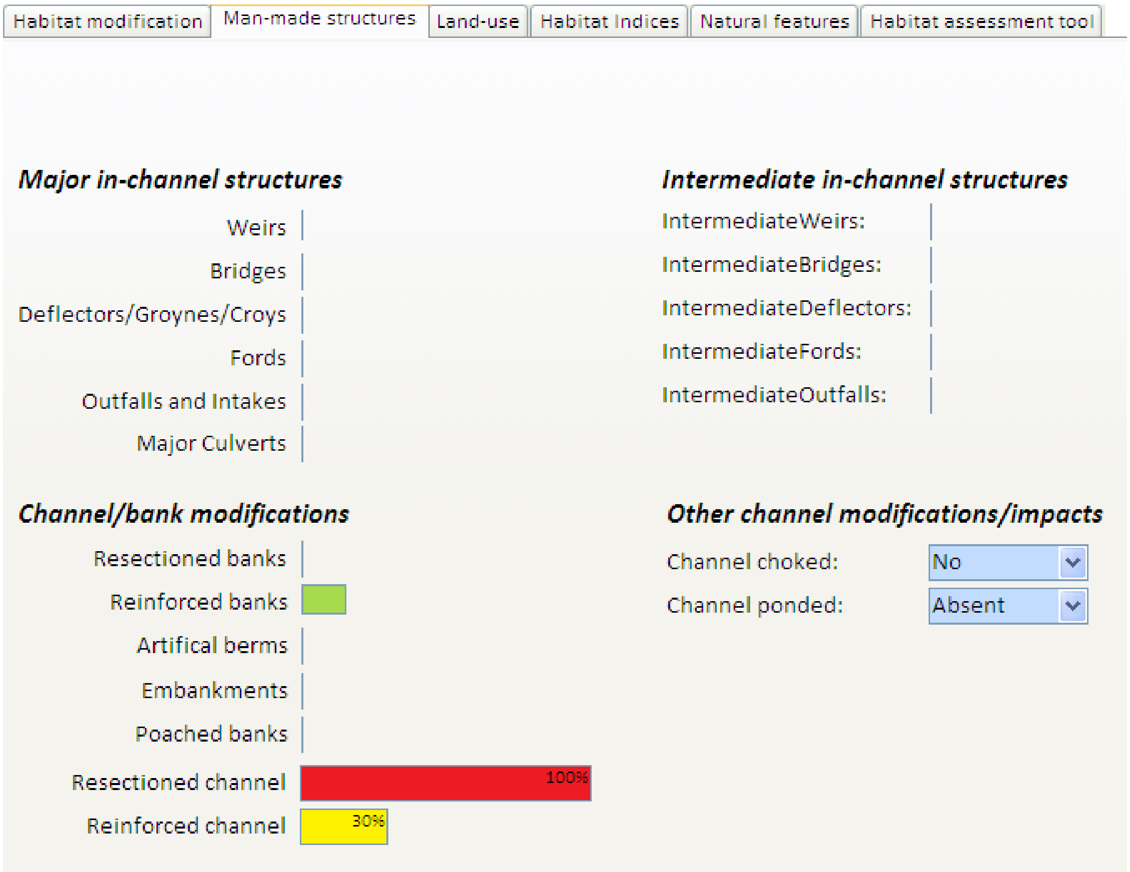
Take a quick tour

Man-made structures

The third tab contains more detailed information on made-made engineering structures.

The number of in-channel structures, and the extent of bank and channels modifications are shown using colour-coded bar charts (green: extent less than 30%; yellow: between 30% and 60%; red: extent greater than 60%).

The terms 'major' and 'intermediate' used to qualify in-channel structures refer to the RHS and reflect the size and impact of the structures on channel hydrology and morphology (see RHS manual).

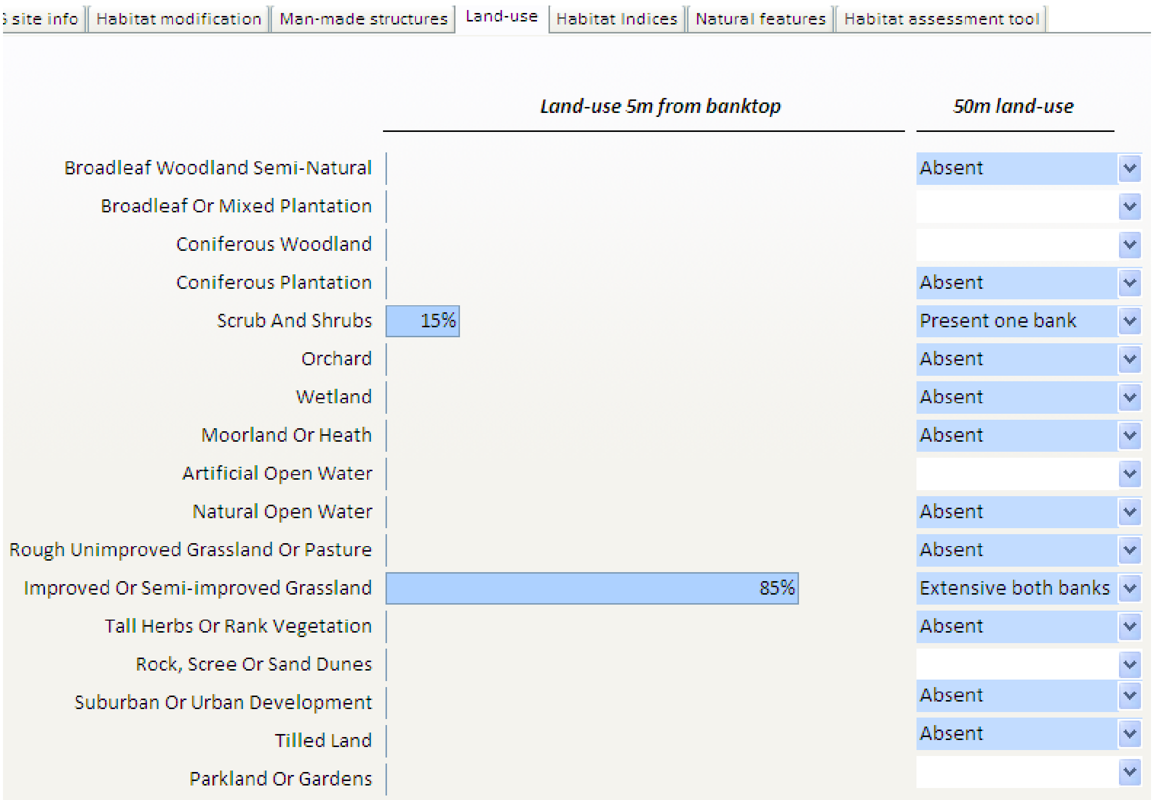


Take a quick tour

Land-use

At each RHS site, land-use extent is assessed within 5m and 50m of the banktop on both sides. The bar chart below shows the extent of 17 RHS land-use types along the river bank in percentage term for the immediate land-use and using a semi-quantitative scale (Absent, Present and Extensive) for the wider land-use.

The dominant land-use at our site is improved grassland both immediately at the banktop level and beyond.



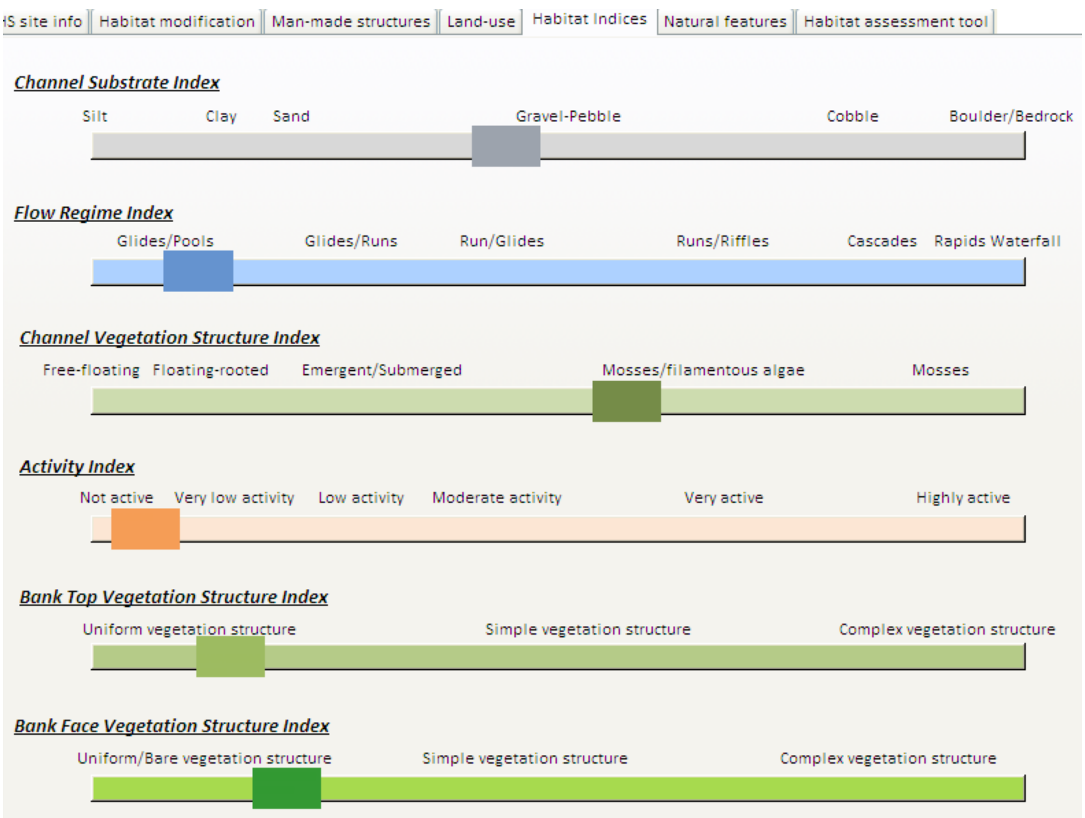
Take a quick tour

Habitat indices

Information on natural habitat features such as channel substrate, flow regime (e.g. riffles, glides and pools), channel vegetation structure, activity (i.e. erosion and deposition features) and bank vegetation structure (from bare to complex) have been summarised into 6 indices presented on sliding scales representing the main environmental gradients encountered in natural settings.

Each scale is labeled according to the feature(s) dominating at key points along its gradient. For example, the Channel Substrate Index represents a gradient between sites dominated by fine substrate on the left of the scale (silt, clay and sand) to sites dominated by coarser substrates (cobbles and boulders). This gradient represents the typical transition between headwater - upland and lowland streams. Similarly, the Flow Regime Index represents a gradient between sites dominated by slow-flowing features (glides and pool) towards sites dominated by faster-flowing habitats such as riffles and rapids.

The 6 scales enable a quick visual assessment of RHS site natural habitat features. For each scale, a marker indicates the location of the RHS site on the scale. In our case we can quickly assess that our site is dominated by gravel substrate but has slow-flowing features, little vegetation in-channel and poor bank vegetation structure. The site displays low levels of activity (erosion or deposition).



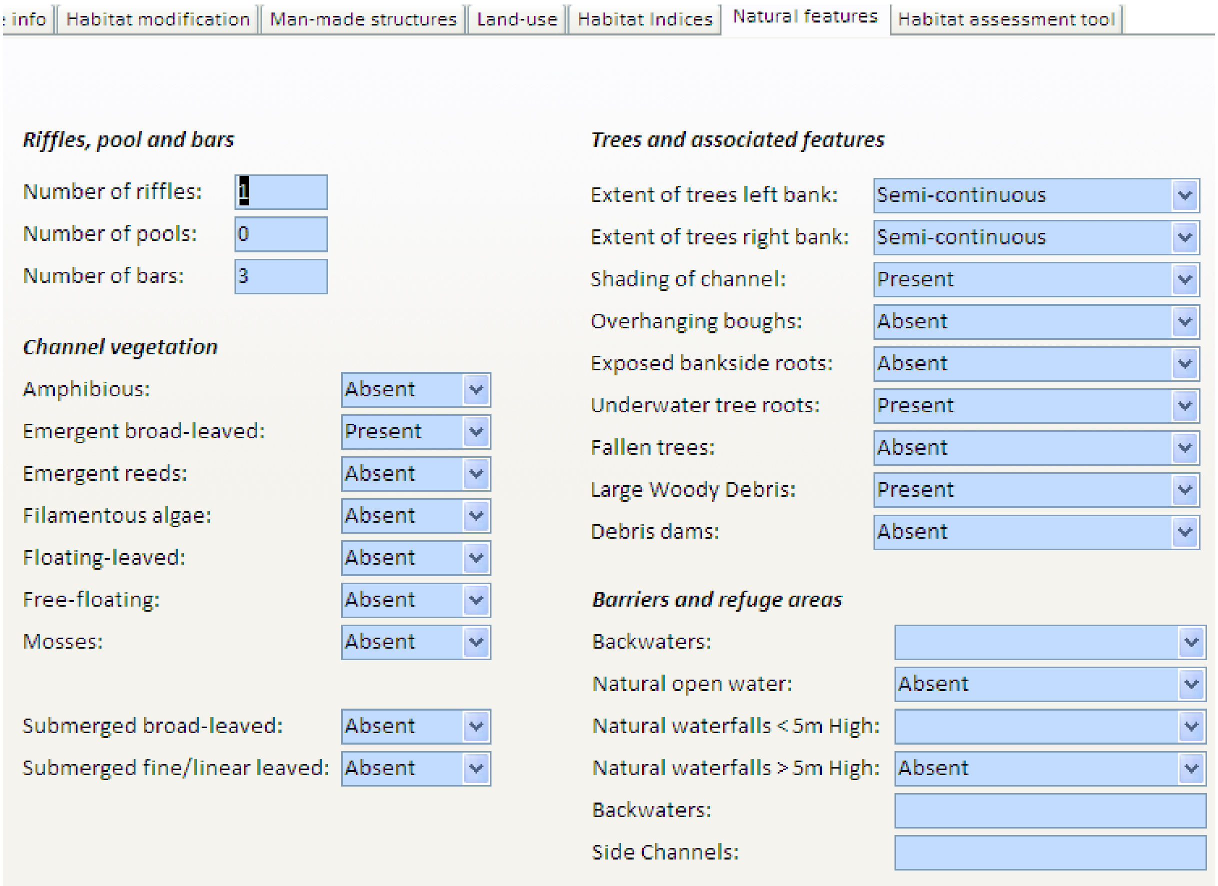
Combined with previous data on habitat modification and land use, these indices give us some insights into the potential impacts of the engineering structures and land management in general on river habitats.

Channel and bank resectioning are generally associated with an increase in channel depth and width resulting in slower flow types and lower levels of activity. Trees are also removed to let machinery access the channel to perform the work. Banks are regularly mowed and trees are cut down to reduce frictions and potential flooding risks.

Take a quick tour

Natural features

This sections contains information on natural features recorded in RHS that are not part of the derivation of the 6 indices. Features include the number of riffles, pools and bars and the extent of trees and related features. Channel vegetation extent is also recorded in a broad-brush manner as simple, absent/present/extensive indices.



Take a quick tour

Habitat assessment tool

The habitat assessment tool is based on combined RHS, water quality and land use data. It uses the conceptual models derived by experts (see 'knowledge resources') and turns them into predictive models using available data.

Expert fisheries officers from the Environment Agency were gathered to build simple conceptual models of fish habitat for 3 life stages (spawning, juveniles and adults). The models were combined and tested on existing fish and habitat data on a total of 2500 sites. The resulting model was then applied to all existing RHS sites and is presented here in a graphical way for trout (more species will be added in the future).

The factors affecting trout habitat can be split into 2 broad groups:

- Natural habitat features;
- Pressures and impacts.

On the figure below, all pressures and natural habitat feature have been grouped into 2 columns. Predation and competition was displayed separately.

The figure is 'read' from left to right using colour-coded boxes and lines.

The suitability of each pressure/feature is assessed using the colour of its box. The colour code is as follow:

- Blue: the observed pressure level/feature is suitable and very favourable to trout
- Green: the observed pressure level/feature is suitable and favourable to trout
- Yellow: the observed pressure level/feature is fair and somewhat favourable to trout
- Orange: the observed pressure level/feature is not suitable and unfavourable to trout
- Red: the observed pressure level/feature is not suitable and very unfavourable to trout

The coloured lined represent the impact of habitat features and pressures on each other and on trout.

The colour of the lines indicates the nature of the impact:

- blue is for positive impacts (e.g. coarse substrate impact positively on the presence of unbroken waves);

- orange is for negative impacts (e.g. tilled land-use will impact negatively on coarse substrate – by inputting fines).

The thickness of the line represents the level of observed impact from low (thin line) to high (thick line)

Example:

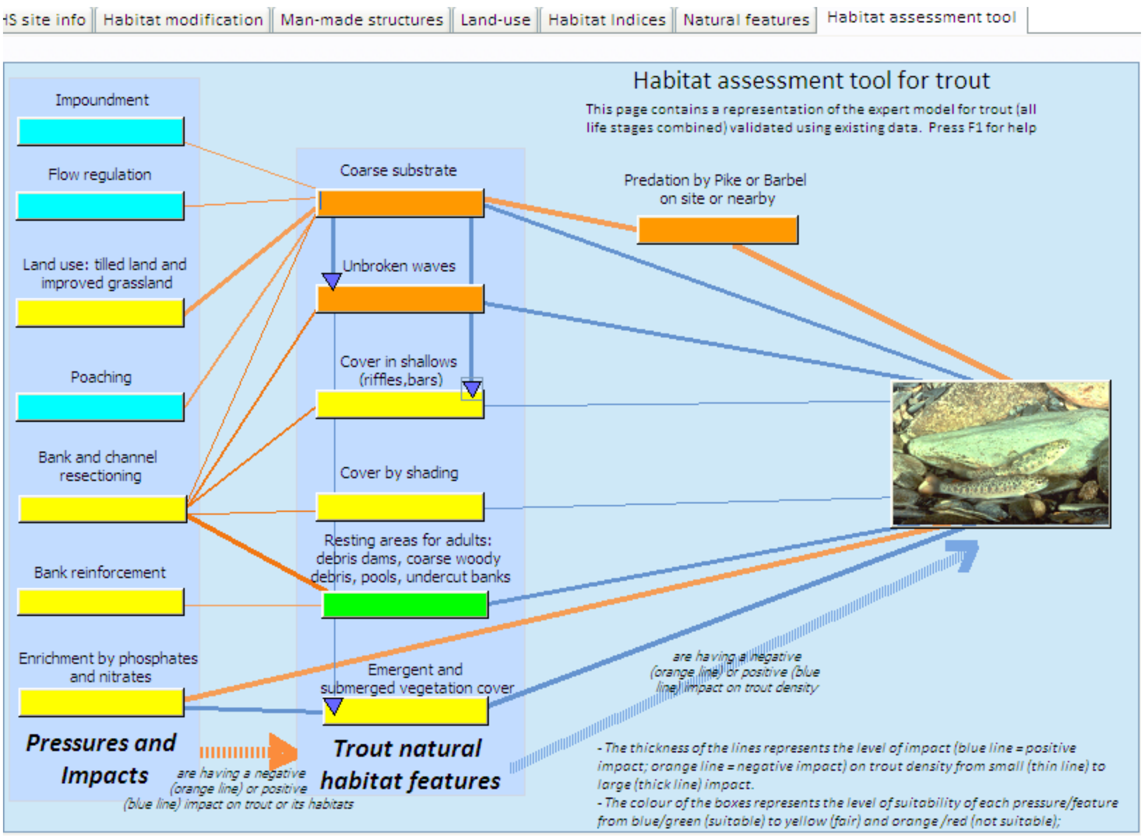
The figure next page suggests that site habitats are not very favourable to trout.

Natural habitat features normally associated with trout are either 'somewhat favourable' (cover in shallows or by shading, channel vegetation) or not favourable (channel substrate and flow type).

The model suggests that the level of pressures on habitats are having an overall moderate (fair) impact on trout (yellow boxes) and a moderate impact on associated natural features. Bank and channel resectioning, land use and enrichment are likely to be the pressures most affecting trout and its habitats either directly (i.e. enrichment) or indirectly (e.g. resectioning impacts on key habitat components such as substrate and flow-types).

These results have to be put within the context of the information provided by the fisheries classification tools.

We will see later how these tools can be used to assess habitat at reach scale.



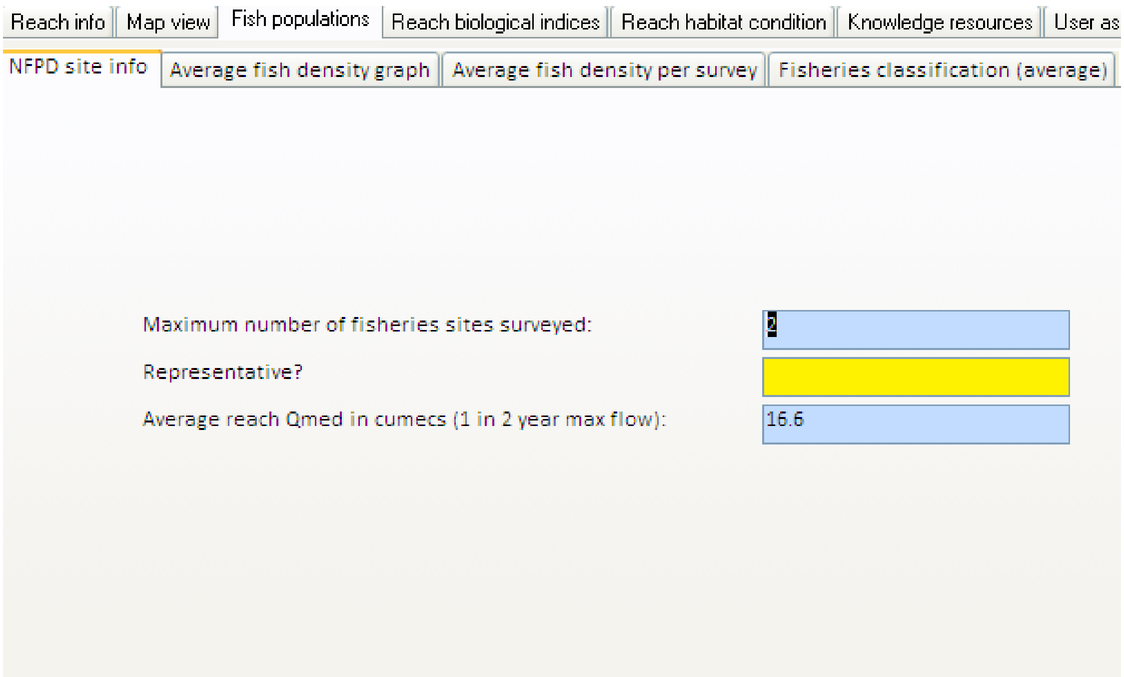
Take a quick tour

Reach statistics: Fish Populations

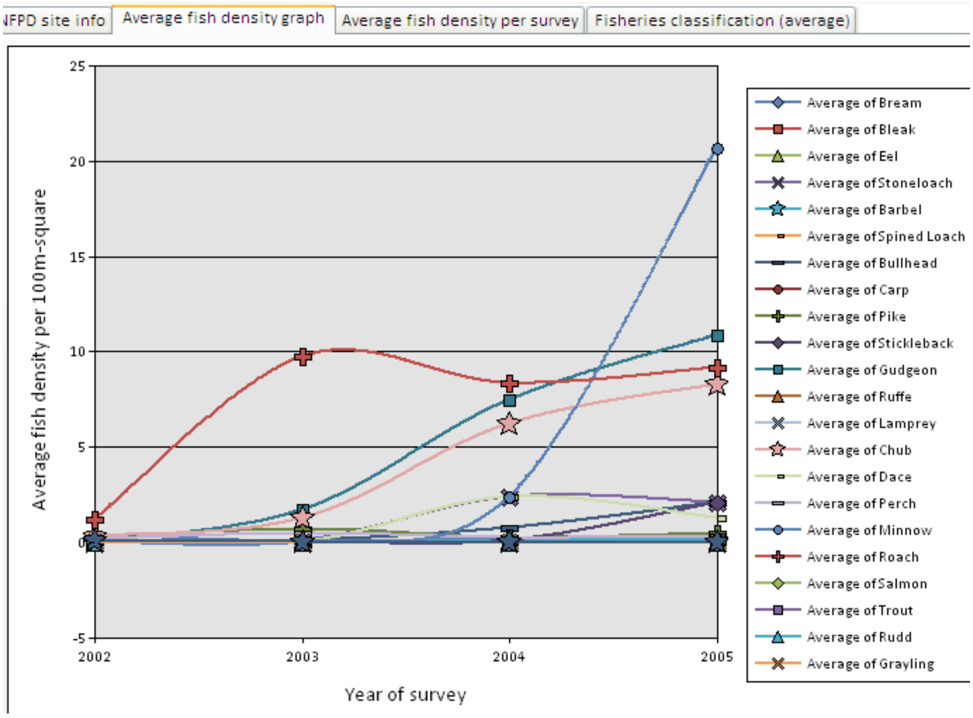
The fish populations tab provide summary statistics for fish density and classification for the selected reach.

This sections contains 4 sub-sections. The first one gives indications on the number of fisheries sites contained in the reach. It also gives an indication of the representativeness of the statistics produced based on the number of sites within the reach. Reaches with very few sites will provide statistics that are not reliable. As the number of sites surveyed per reach increases, we gain confidence in the statistics produced.

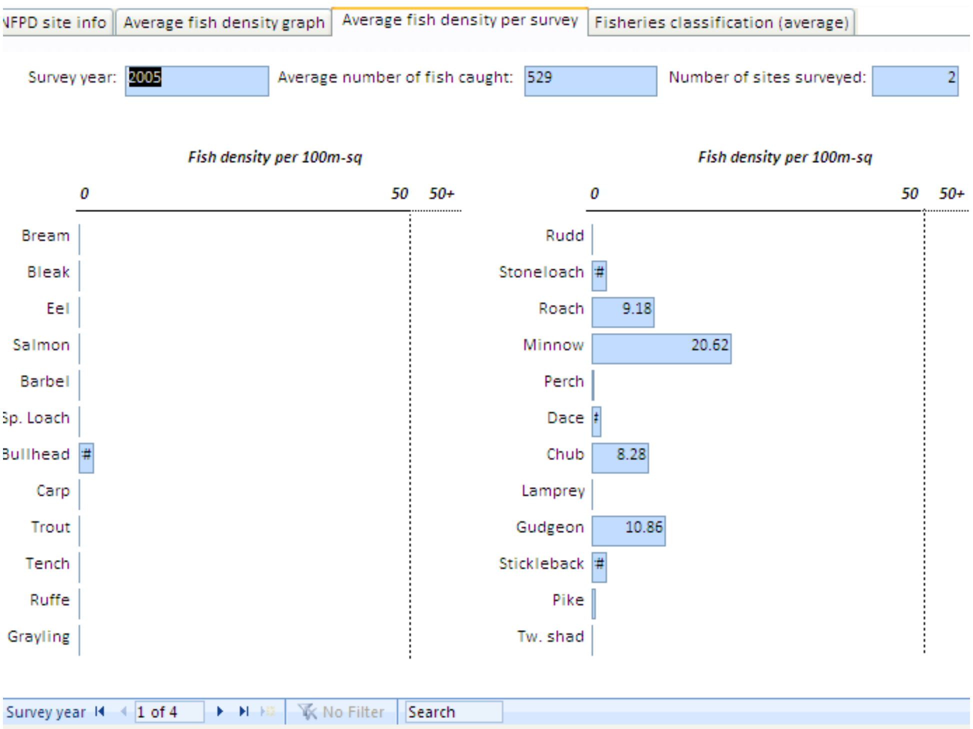
In the case of the Mole3 reach, we have 2 survey sites present which provides with a moderate level of representativeness.



The second tab displays a graph of average fish density change along time for all the NFPD sites in the reach (2 sites for the Mole3 reach). Each of the 23 species recorded during survey displayed using symbols joined by a line. To identify specific points lines, just hover with the mouse over the point/line.



The third tab contains the same information as the second tab displayed as individual bar charts for each survey year. Click on the navigation buttons at the bottom of the chart to move from one year of survey to the next.



Finally, the last tab contains information taken from the Fisheries Classification Scheme (FCS2). FCS2 predicts, for most fisheries survey sites 3 indices:

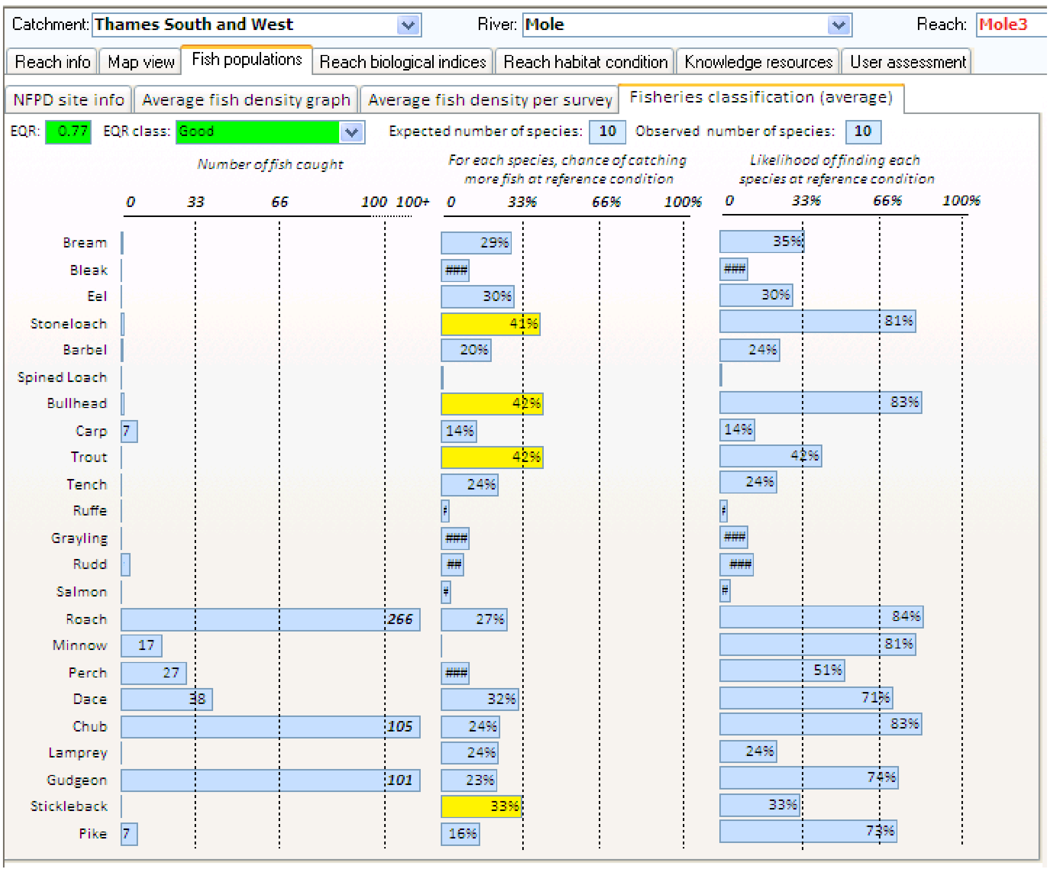
- an overall Environmental Quality Ratio (EQR) score for the reach. Values close to 1 indicate closeness to reference condition;

- an EQR class from high to poor;
- the expected number of species caught at reference condition;
- the likelihood of catching each species at reference condition;
- the likelihood of catching more fish than at the surveyed reach at reference condition;

The predictions and the actual number of fish caught are displayed as bar charts. The figures displayed are averages for all NFPD sites on the selected reach.

In the example below, the average expected number of fish caught at reference condition exactly matches the number of species caught at the last survey. The overall EQR is close to one and the EQR class is 'Good'.

All fish species that have a high probability of being caught at reference conditions (see red bars on the right-hand chart) were caught during electro-fishing (left-hand side chart) most of the time in numbers greater than predicted by FCS2 (middle chart). For example, roach were found in high numbers (266 individuals in average) and according to FCS2 predictions, there is a 84% chance of finding roach on the reach at reference conditions and a 27% chance of finding more fish than observed (in average). The reach therefore has shows higher numbers of roach than can be expected at reference conditions.

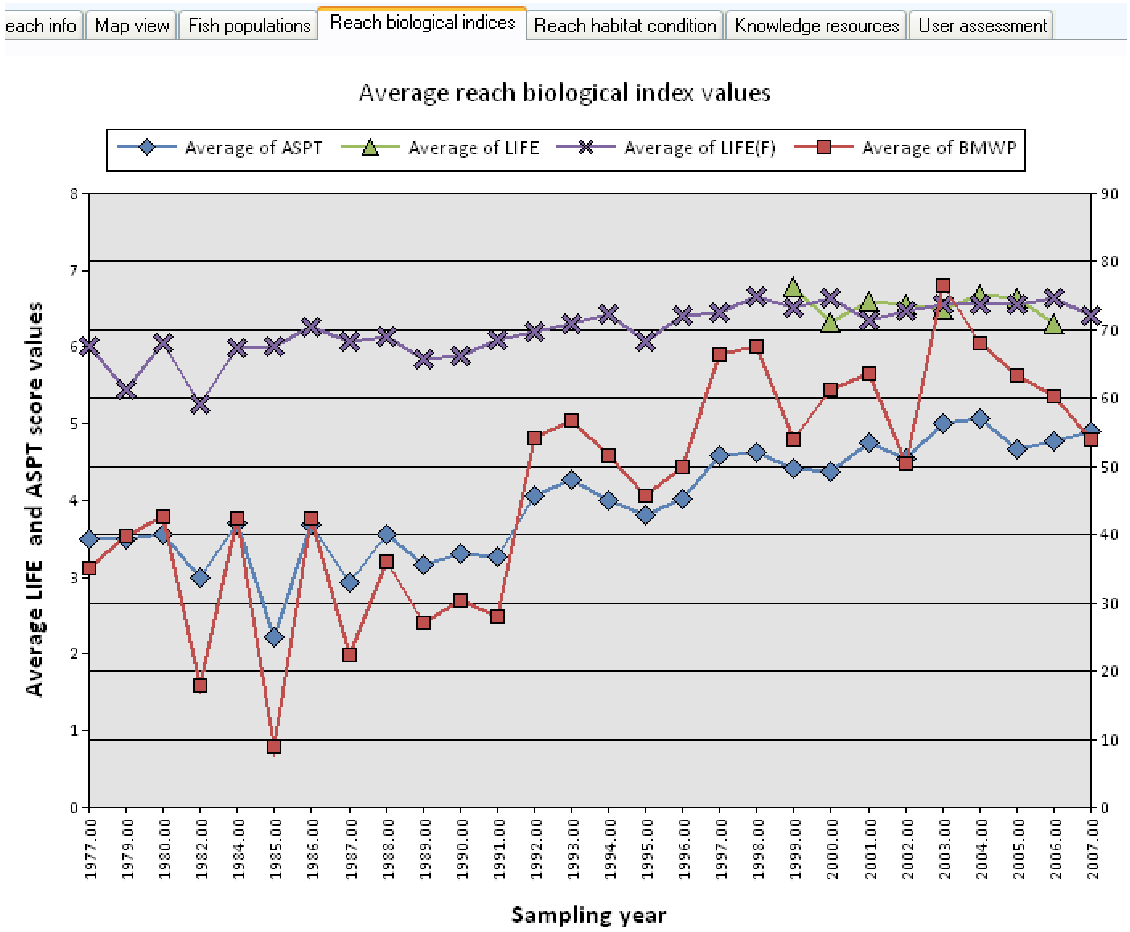


Take a quick tour

Reach statistics: Biological indices

A biology index chart is drawn from all the GQA sampling points within the selected reach. The form shows the change in four index values along time:the Average Score Per Taxon, the BMWP, and two LIFE indices.

If you want to learn more about the meaning and significance of biological indices, go to Appendix 2.



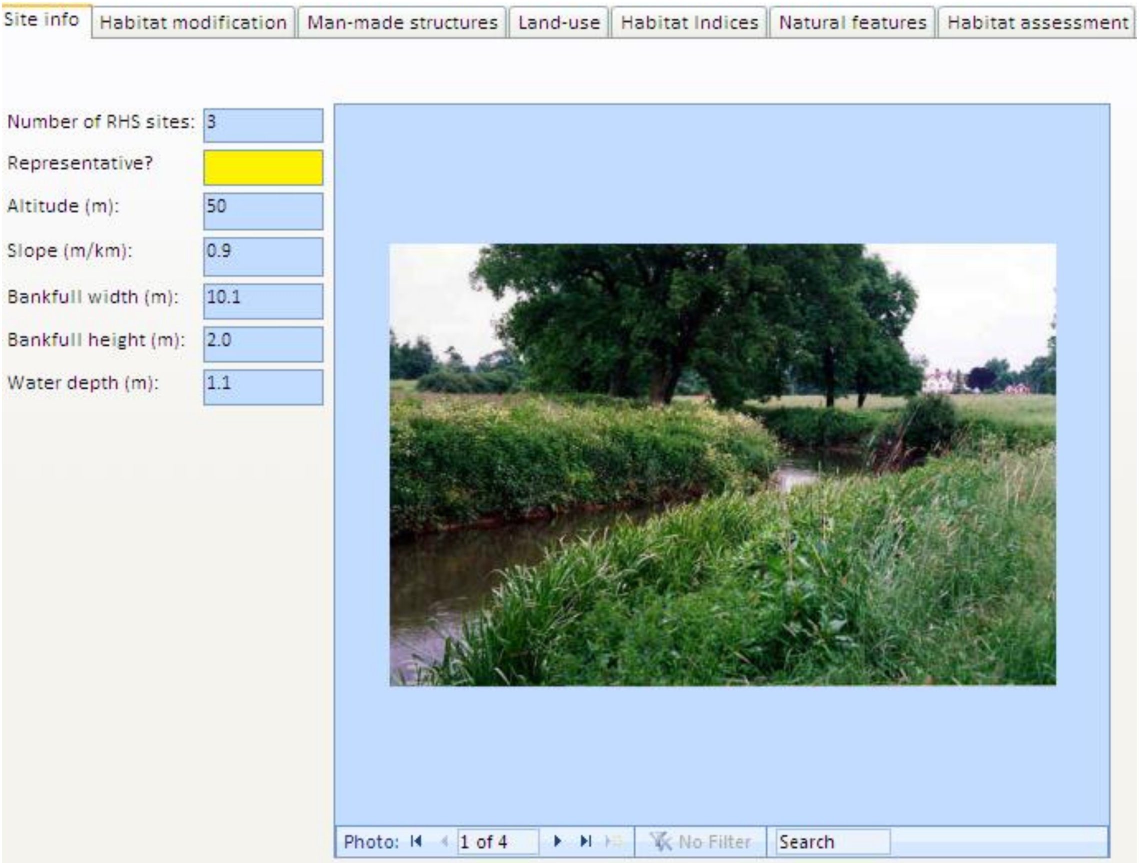
Take a quick tour

Reach statistics: Reach habitat condition

The reach habitat condition tab provide summary statistics for RHS data for the selected reach.

This sections contains 7 sub-sections. The first section gives indications on the number of RHS sites within the reach. It also gives an indication of the representativeness of the statistics produced based on the number of sites present. Reaches with very few sites will generate statistics that are not reliable. As the number of sites surveyed per reach increases, we gain confidence in the statistics produced.

In the case of the Mole3 reach, we have 3 survey sites present which provides with a moderate level of representativeness.



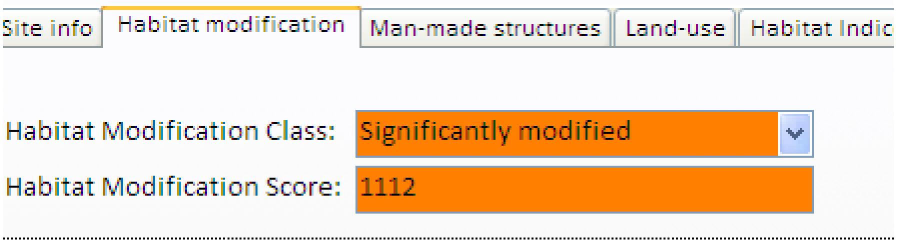
Take a quick tour

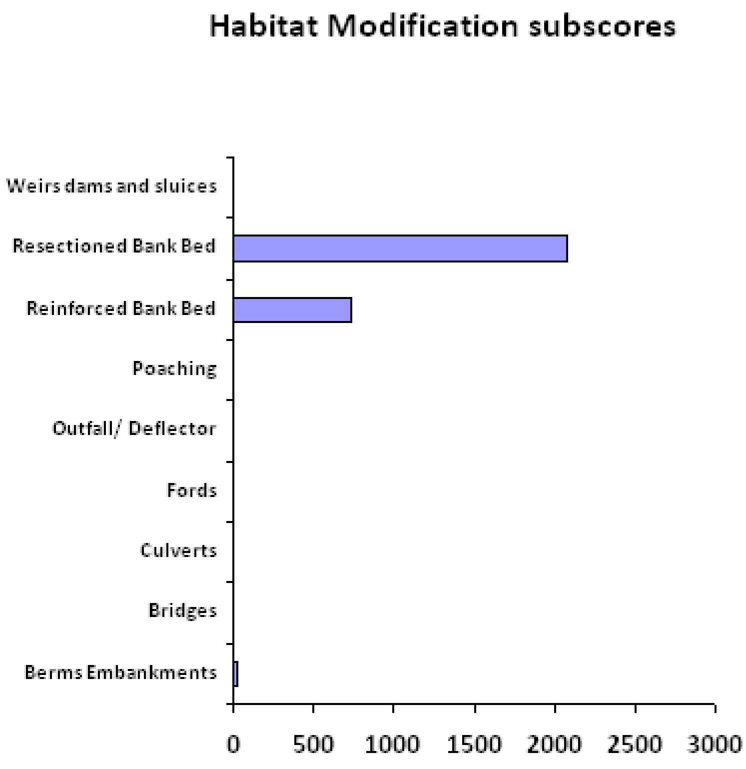
Habitat modification

The habitat modification tab contains a representation of the average Habitat Modification Score (HMS) and its components. The HMS is a scoring system for engineering structures on watercourses. Scores are allocated according to the extent of structures and their life expectancy.

HMS scores are further classified into 5 classes to provide with a simple modification index from Semi-natural (blue) to Severely modified (red). The total site score and index class are represented in the top 2 boxes.

In the graph below, the HMS component subscores are indicated. The reach is significantly modified with an average score of 1112. The modifications accounting for most of this very high score are resectioning of the banks and bed and the presence of reinforcements. Berms and embankments are also present but account for a much lower part of the total score.





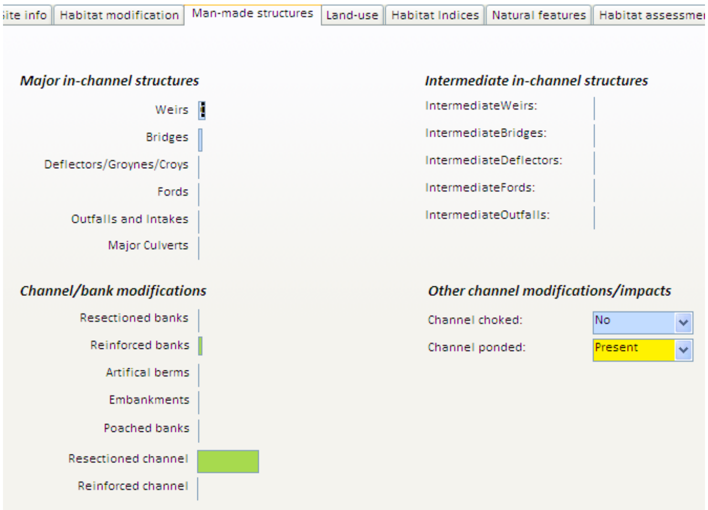
Take a quick tour

Man-made structures

The third tab contains more detailed information on made-made engineering structures.

The average number of in-channel structures, and the extent of bank and channels modifications are shown using colour-coded bar charts (green: extent less than 30%; yellow: between 30% and 60%; red: extent greater than 60%).

The terms 'major' and 'intermediat'e used to qualify in-channel structures refer to the RHS and reflect the size and impact of the structures on channel hydrology and morphology (see RHS Manual).



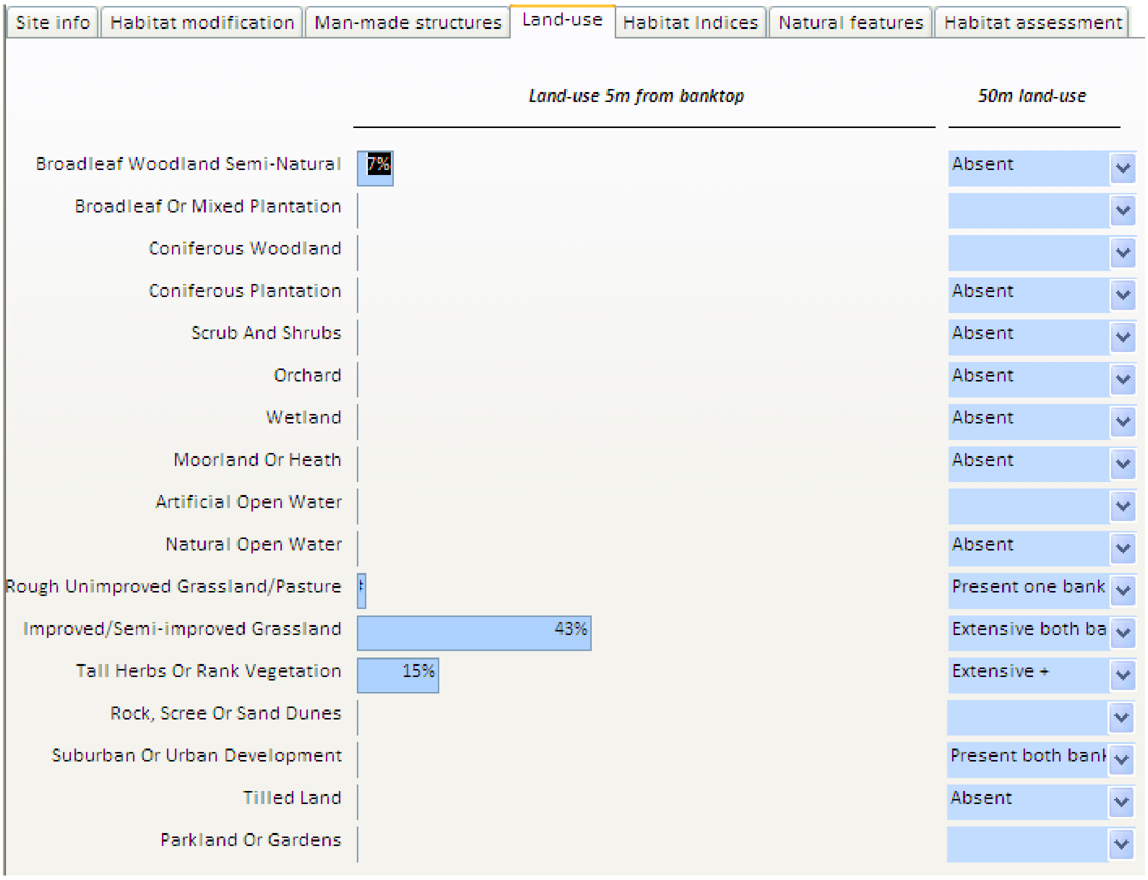
It seems that the major modification found on the reach is channel resectioning (i.e. overdeepening). Little bank resectioning was observed on the reach. This is surprising as bank and channel resectioning are generally associated. Indeed, when resectioning a river, engineers use diggers to overdeepen the channel and reprofile the banks to create a typical trapezoidal channel. If we look at the photographs of one of the 2 sites, site 1274, we notice that the banks have a fairly uniform 45 degree bankface. Also, trees tend to be scattered on the river bank. This suggests that the extent of bank resectioning on site may have been underestimated by the surveyors. We will bear that in mind when doing the final reach assessment.

Take a quick tour

Land-use

At each RHS site, land-use extent is assessed within 5m and 50m of the banktop on both sides. The bar chart below shows the average extent of 17 RHS land-use types along the river bank in percentage term for the immediate land-use and using a semi-quantitative scale (Absent, Present and Extensive) for the wider land-use. Greyed-out land-uses were not recorded.

The dominant land-use at our reach is improved grassland both immediately at the banktop level and beyond.



Take a quick tour

Habitat indices

Information on natural habitat features such as channel substrate, flow regime (e.g. riffles, glides and pools), channel vegetation structure, activity (i.e. erosion and deposition features) and bank vegetation structure (from bare to complex) have been summarised into 6 indices presented on sliding scales representing the main environmental gradients encountered in natural settings.

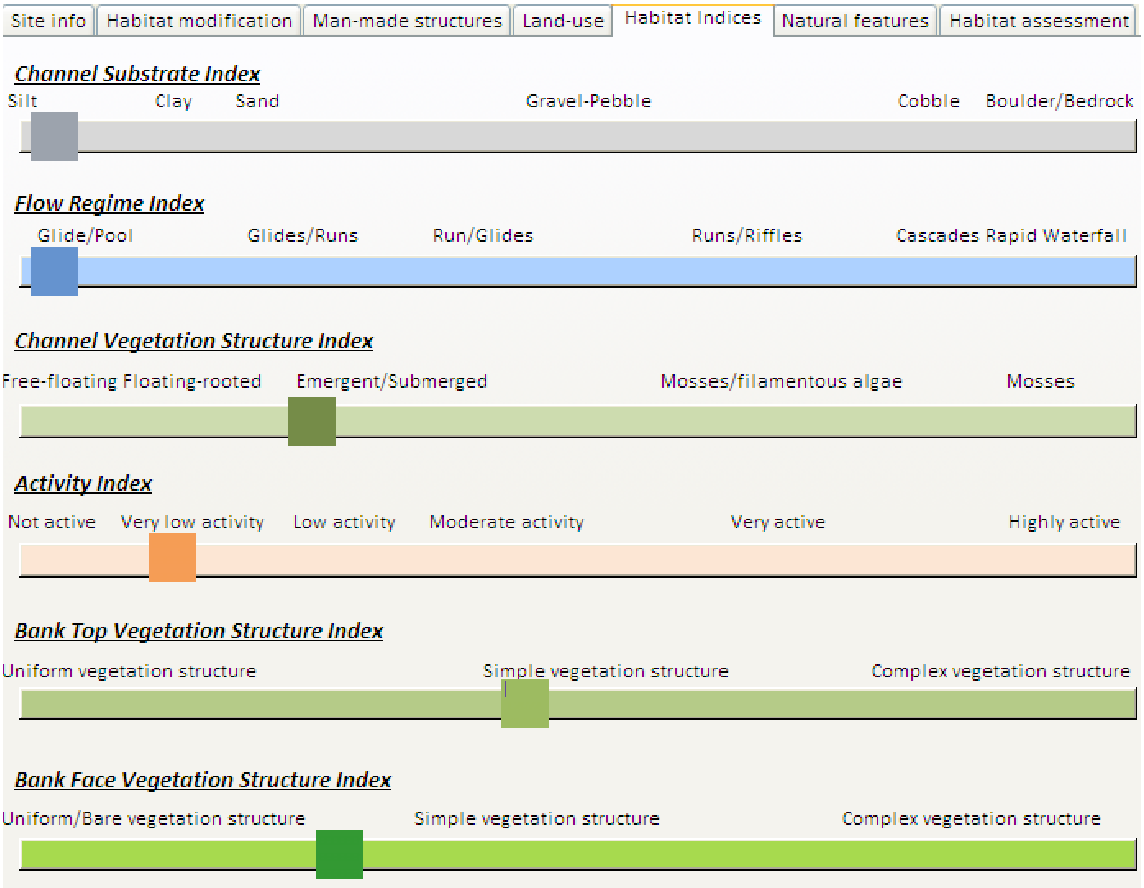
Each scale is labeled according to the feature(s) dominating at key points along its gradient. For example, the Channel Substrate Index represents a gradient between sites dominated by fine substrate on the left of the scale (silt, clay and sand) to sites dominated by coarser substrates (cobbles and boulders). This gradient represents the typical transition between headwater - upland and lowland streams. Similarly, the Flow Regime Index represents a gradient between sites dominated by slow-flowing features (glides and pool) towards sites dominated by faster-flowing habitats such as riffles and rapids.

The 6 scales enable a quick visual assessment of the character of the reach. The values displayed are the average value of the RHS sites on the selected reach.

For each scale, a marker indicates the location of the reach on the scale. In our case we can quickly assess that our reach is dominated by silt substrate and has slow-flowing features, emergent/submerged channel vegetation and uniform/simple bank vegetation structure. The reach displays very low levels of activity (erosion or deposition).

Combined with previous data on habitat modification and land use, these indices give us some insights into the potential impacts of engineering structures and land management on river habitats.

Channel and bank resectioning are generally associated with an increase in channel depth and width resulting in slower flow types and lower levels of activity. Trees are also removed to let machinery access the channel to perform the work. Banks are regularly mowed and trees are cut down to reduce frictions and potential flooding risks. It is possible that the silt and low flow velocities observed are the direct impact of bank and channel resectioning. Channel vegetation and bank vegetation structure could also be affected by the modifications as vegetation is related to flow, and trees and bank vegetation structure will be affected by the management regime (mowing, tree cutting etc).

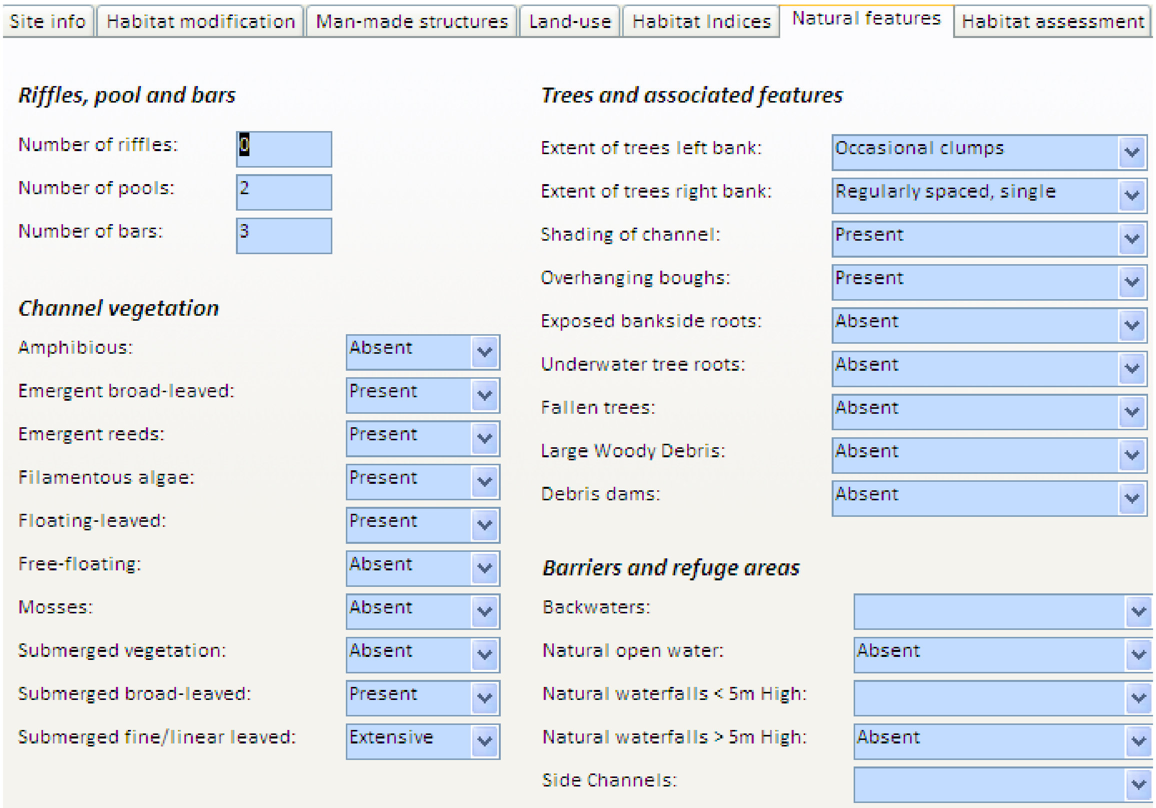

Site info
Habitat modification
Man-made structures
Land-use
Habitat Indices
Natural features
Habitat assessment
Channel Substrate Index
Silt
Clay
Sand
Gravel-Pebble
Cobble
Boulder/Bedrock
Flow Regime Index
Glide/Pool
Glides/Runs
Run/Glides
Runs/Riffles
Cascades Rapid Waterfall
Channel Vegetation Structure Index
Free-floating Floating-rooted
Emergent/Submerged
Mosses/filamentous algae
Mosses
Activity Index
Not active
Very low activity
Low activity
Moderate activity
Very active
Highly active
Bank Top Vegetation Structure Index
Uniform vegetation structure
Simple vegetation structure
Complex vegetation structure
Bank Face Vegetation Structure Index
Uniform/Bare vegetation structure
Simple vegetation structure
Complex vegetation structure

Take a quick tour

Natural features

This sections contains information on the average extent of natural features recorded in RHS. Features include the average number of riffles, pools and bars and the extent of trees and related features. Channel vegetation extent is also recorded in a broad-brush manner as simple, absent/present/extensive indices.

The reach considered has little vegetation in channel apart from submerged vegetation and few trees on the banks. The absence of trees could be explained by the management regime and the presence of resectioning.



Take a quick tour

Habitat assessment tool

The habitat assessment tool is based on RHS, water quality and land use data combined. It uses the conceptual models derived by experts (see 'knowledge resources') and turns them into predictive models using available data.

Expert fisheries officers from the Environment Agency were gathered to identify build simple conceptual models of fish habitat for 3 life stages (spawning, juveniles and adults). The models were combined and tested on existing fish and habitat data on a total of 2500 sites. The resulting model was then applied to all existing RHS sites and presented here in a graphical way for trout (more species will be added in the future).

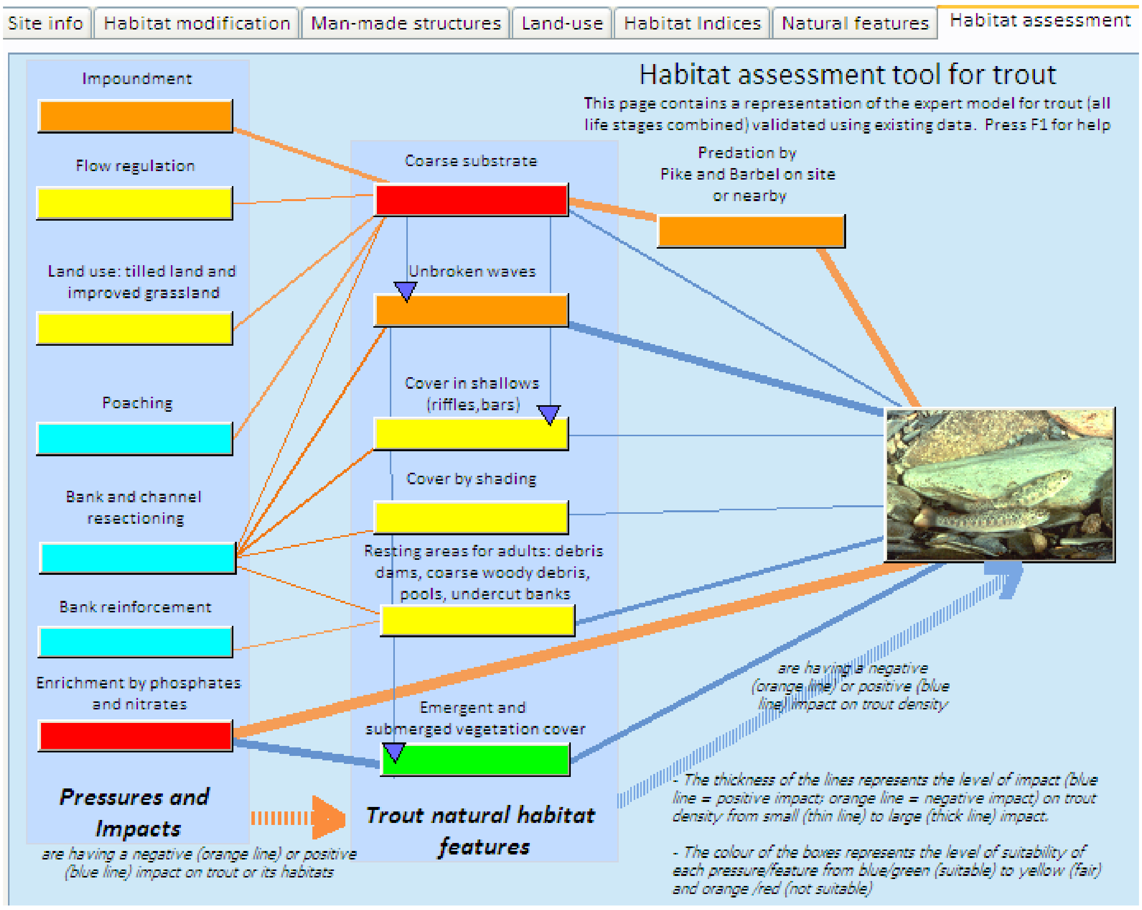
The factors affecting trout habitat can be split into 2 broad groups:

- Natural habitat features;
- Pressures and impacts.

On the figure below, all pressures and natural habitat feature have been grouped into 2 columns. Predation/competition was displayed separately.

The figure is 'read' from left to right using colour-coded boxes and lines.

The average suitability of each pressure/feature for the reach is assessed using the



colour of its box.

The colour code is as follow:

- Blue: the observed pressure level/feature is suitable and very favourable to trout
- Green: the observed pressure level/feature is suitable and favourable to trout
- Yellow: the observed pressure level/feature is fair and somewhat favourable to trout
- Orange: the observed pressure level/feature is not suitable and unfavourable to trout
- Red: the observed pressure level/feature is not suitable and very unfavourable to trout

The coloured lined represent the average impact of habitat features and pressures on each other and on trout.

The colour of the lines indicates the nature of the impact:

- blue is for positive impacts (e.g. coarse substrate impact positively on the presence of unbroken waves);
- orange is for negative impacts (e.g. tilled land-use will impact negatively on coarse substrate - by inputting fines).

The thickness of the line represents the average level of observed impact from low (thin line) to high (thick line)

All values have been averaged for all RHS sites on the selected reach

Example:

The figure above suggests that the habitats of the river reach are not very favourable to trout.

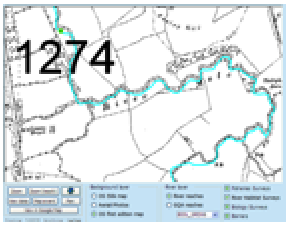
Natural habitat features normally associated with trout are either 'somewhat favourable' (cover in shallows or by shading, channel vegetation) or not favourable (channel substrate and flow type).

The model suggests that the level of pressures on habitats are having an overall low to moderate impact on trout (blue and yellow boxes) and a moderate impact on associated natural features. The highest and probably most significant impact according to the model is water quality. The levels of phosphates and nitrates are very high and are likely to have a large impact on trout populations. The presence of impoundments is also perceived as having a moderate to high impact. Surprisingly, channel bank and channel resectioning do not seem to impact on trout habitat. The reason is that bank resectioning has probably been under-estimated by surveyors. It is likely that bank and channel resectioning are having a significant impact on trout habitats.

This assumes, however, that trout would naturally occur on the reach. The assessment using the fish population and FCS2 tools is that the likelihood of finding trout on such reach at reference condition is 42%. It also suggests that, despite the observable modifications and potential impacts on natural habitat features, the fish populations are close to reference condition.

Models and surveys have limitations and only provide a 'snapshot' of 'what could be' in time and space. No single model will predict 100% of the variability. In this case, we can clearly see that important modifications have been missed out by surveyors. Considering the position of the reach in the catchment, we may want to challenge the results of the models and use other datasets such as long term monitoring data and local expert opinion to come to a conclusion.

We may want, for example to look at historical maps to see how the river has changed since the 1900s. Below is a snapshot of the 1897 OS maps around RHS site 1274, just downstream of Gatwick airport. As can be seen, the river has not changed its course much since the beginning of the 20th century. This suggest that the modifications observed either pre-date the 20th century or they have been carried out without modifying the planform of the river (i.e. without realigning it).



Catchment Decision Support tool

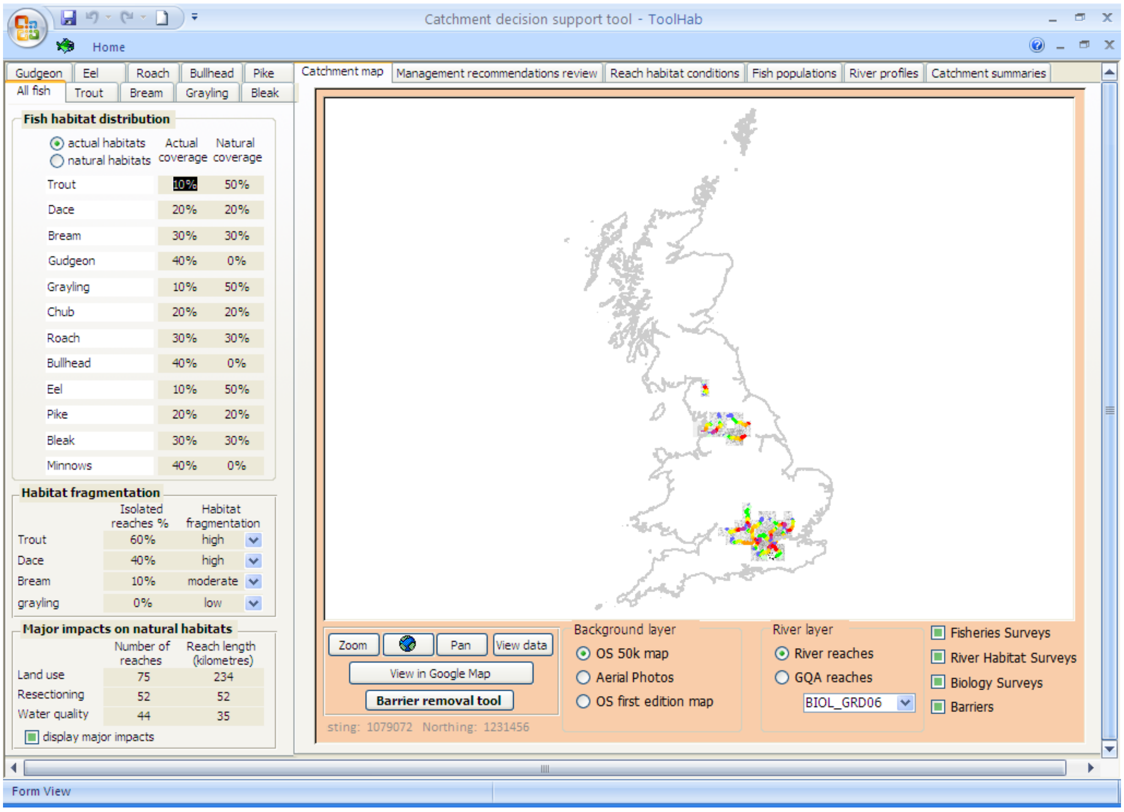
Catchment Decision Support Tool

This tool provides an interface to view and summarise the reach habitat assessment information entered by catchment officers using the reach assessment tool.

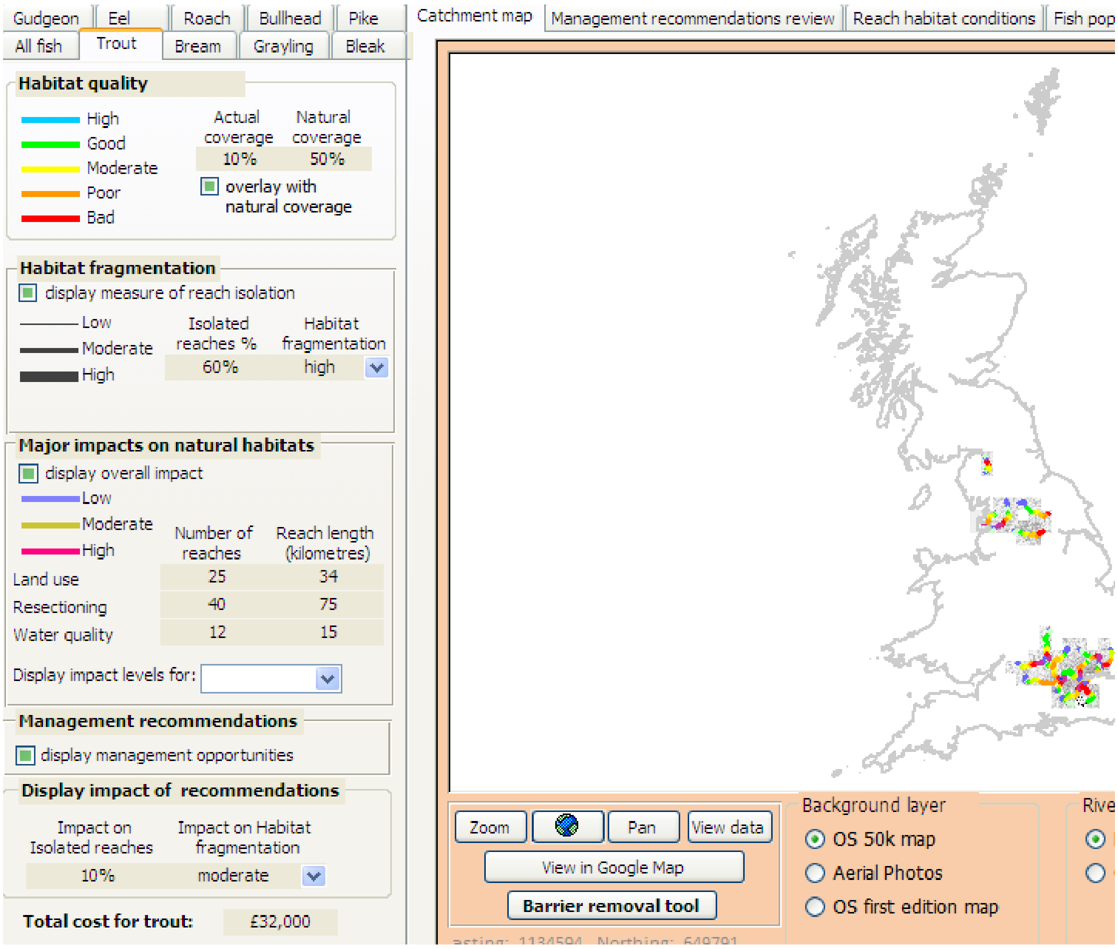
The aim is to use this tools to develop strategies for improving habitats at catchment scale and prioritise sites/reaches for habitat improvement work.

The interface displays summary statistics on

- habitat suitability for fish as observed and in reference conditions;
- pressures and impacts;
- habitat fragmentation.



Summary statistics can also be viewed using maps and tables for each species.



Users will also be given access to assessment forms for individual reaches.

This should help build an overall pictures of habitat quality at river/catchment scale and the pressures affecting those habitats.

For example, we may find that a particular catchment has lost habitats 50% of its habitats for trout potentially due to engineering and land use pressures.

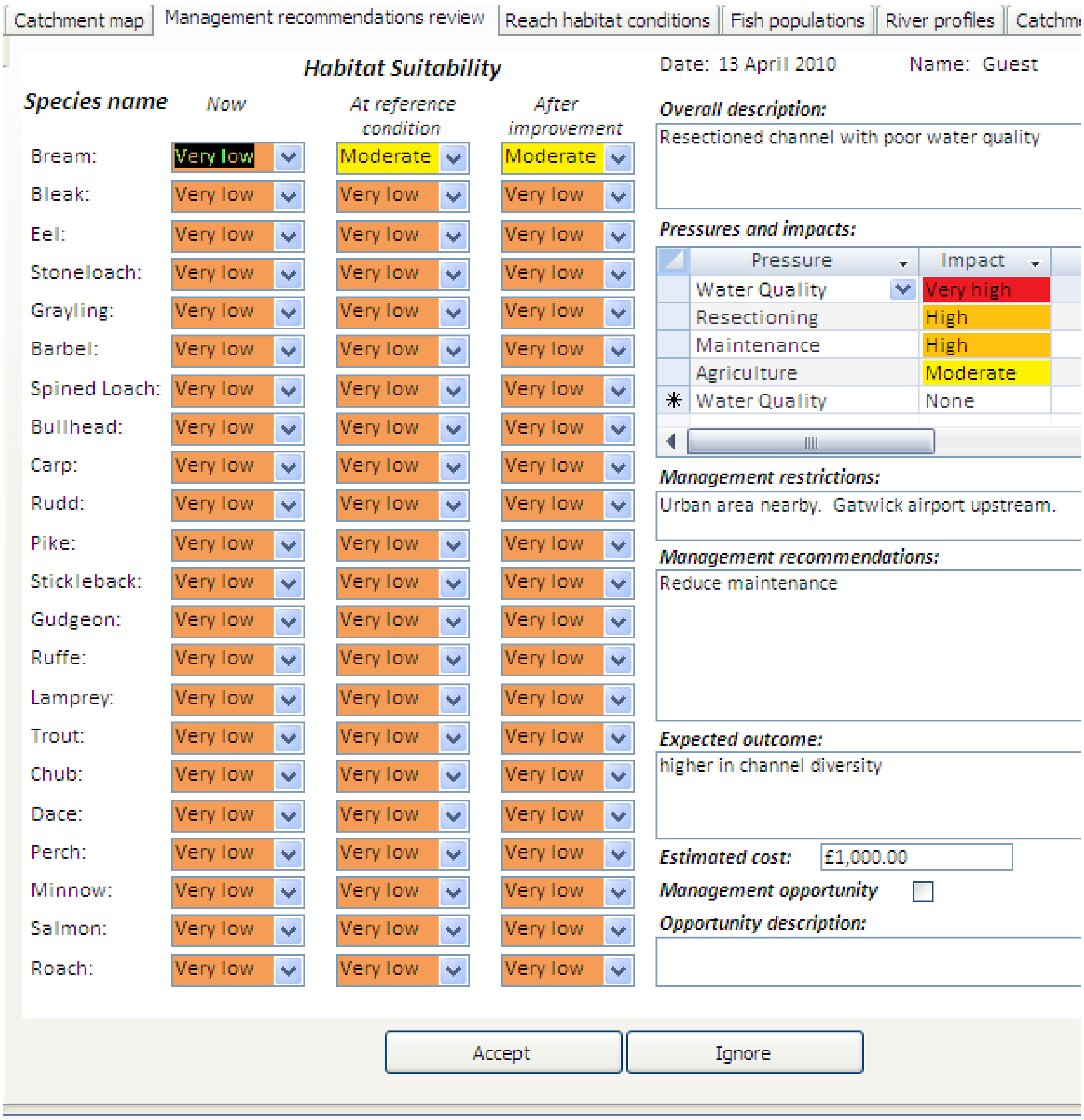
The tool may also tell us how fragmented remaining habitats are and design a strategy for improving habitat quality and connectivity for trout at catchment scale.

To do so, users can access all the information and knowledge inputted by catchment officers and interact with them in the development of potential strategies.They can also consult existing data and modelling tools and views maps and photos using the map interface.

As ToolHab contains the Environment Agency Fisheries Barriers database, it should be possible to develop a tool to assess the impact of removing barriers on river connectivity. The 'Barrier removal tool' button on the interface is not functional but it illustrate the kind of analyses that could be carried out using the available data.

Altogether, this should facilitate the development of strategies based on existing knowledge (expert, local and scientific) and data.

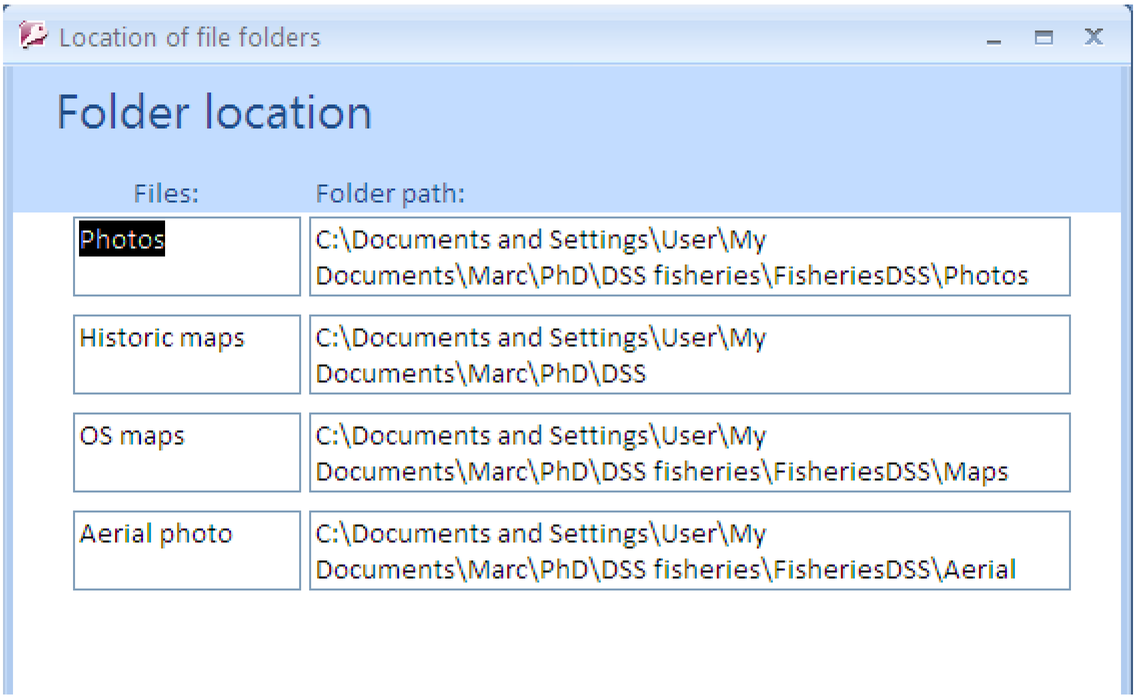
At present the interface is not functional and is for demonstration purposes only.



File location

File location menu

You can change the path to the folder containing maps and photos. This can be useful if you are using large map/photo files that have to be stored on an external or network drive.



Contact us and feedback

Contact Us

Please contact us for any feedback, comments or bugs at marc.naura@mnaura.freeserve.co.uk

Alternatively, post your comments on the project website forum page: www.riverhabitatsurvey.org

ToolHab Appendices

Appendices

Appendix 1: Environment Agency General Quality Assessment (GQA) Scheme

Appendix 2: Environment Agency Biological Indices

Appendix 3: Technical information

ToolHab Appendices

Appendix 1:
Environment Agency
General Quality Assessment (GQA) Scheme

The EA has developed a General Quality Assessment scheme (GQA) which provides a consistent method for classifying water quality in rivers and canals across the UK. The scheme provides a way of comparing river quality from one river to another and for looking at changes through time.

The scheme uses four main parameters of measurement which include:

- chemical content;
- biological content;
- nutrient content; and
- aesthetics.

Table 1.1 Classification: Chemistry

Classification	likely uses and CHARACTERISTICS*
A – Very good	All abstractions Very good salmonid fisheries Cyprinid[1] fisheries Natural ecosystems
B - Good	All abstractions Salmonid fisheries Cyprinid fisheries Ecosystems at or close to natural
C - Fairly good	Potable supply after advanced treatment Other abstractions Good cyprinid fisheries Natural ecosystems, or those corresponding to good cyprinid fisheries
D - Fair	Potable supply after advanced treatment Other abstractions Fair cyprinid fisheries Impacted ecosystems
E - Poor	Low grade abstraction for industry Fish absent or sporadically present, vulnerable to pollution ** Impoverished ecosystems **
F - Bad	Very polluted rivers which may cause nuisance Severely restricted ecosystems
* Provided other standards are met ** Where the grade is caused by discharges of organic pollution	

Chemistry

Samples are analysed for three determinands of organic pollution: ammonia, biochemical oxygen demand (BOD), and dissolved oxygen. The results for a site are averaged and percentiles are calculated. These are compared with limits set for each of six grades as shown in the Table 1.1. A grade is assigned to the length of river (which the sampling site represents) according to the lowest grade achieved by any of the three determinands. For example, if a site is grade A for dissolved oxygen and ammonia but only grade B for BOD, then the grade assigned is B.

Biology

The macro-invertebrates (small animals that can be seen with the naked eye) found in the kick-samples taken are identified by the EA. The range of species found is compared with the range that would be expected in the river if it was not polluted or physically damaged. This takes account of natural differences expected due to different types of geology and flow, for example. One of six grades is allocated to each river length, as shown in Table 1.2.

Table 1.2: Classification: Biology

classification	description
A – Very good	Biology similar to that expected for an unpolluted river
B – Good	Biology is a little short of an unpolluted river
C – Fairly good	Biology worse than expected for unpolluted river
D – Fair	A range of pollution tolerant species present
E – Poor	Biology restricted to pollution tolerant species
F – Bad	Biology limited to a small number of species very tolerant of pollution

Nutrients

Samples are analysed for nitrate and phosphate. A grade is assigned for each of these nutrients according to the Table 1.3 and Table 1.4.

Table 1.3 Classification: Nutrients - Phosphates

classification	grade limit (mgP/l)	Description
1	0.02	Very low
2	0.06	Low
3	0.1	Moderate
4	0.2	High
5	1.0	Very high
6	>1.0	Excessively high

Table 1.4 Classification: Nutrients – Nitrates

classification	grade limit (mgno³/i)	Description
1	5	Very low
2	10	Low
3	20	Moderately low
4	30	Moderate
5	40	High
6	>40	Very High

Nitrate levels in many English surface waters are increasing. Nitrate pollution is of concern because it has to be removed before water can be supplied to consumers and may result in detrimental environmental impacts. The Nitrates Directive requires all known areas of land draining into nitrate polluted waters to be identified for designation as Nitrate Vulnerable Zones (NVZs). Therefore, if an area of land drains into one or more of the above categories of polluted water, it will be located within a NVZ. Farmers located within these NVZs are required to adhere to an Action Programme of measures to reduce the amount of nitrate lost from their land to the polluted waters

Source: http://www.environment-agency.gov.uk/

ToolHab Appendices

Appendix 2:

Environment Agency Biological Indices

This is based on groups of macro-invertebrates (small animals including mayfly nymphs, snails, shrimps and true worms) that are found on the riverbed.

Macro-invertebrates are used because they:

- do not move far
- have reasonably long life cycles
- respond to the physical and chemical characteristics of the river
- are affected by pollutants which may occur infrequently
- provide a picture of water quality and quantity integrated over time

Samples are collected using a standard method of 3 minutes active sampling with a pond net, plus a 1 minute visual search for animals living on the water surface, or attached to rocks, logs or vegetation. Other features of the sampling area are recorded (substrate type, sampling depth, watercourse width, channel depth, aquatic vegetation, fish, land use, shade, evidence of weed management, pollution, turbidity, etc). In the laboratory, the macro-invertebrates are identified to family level, as a minimum requirement, and to species level (where possible) and their relative abundances estimated, according to the following scheme:

Abundance category	Interpretation
A	1 to 9 specimens in sample
B	10 to 99 specimens in sample
C	100 to 999 specimens in sample
D	1000 to 9999 specimens in sample
E	>10, 000 specimens in sample

Terms used in routine reporting of biology data.

BMWP – Biological Monitoring Working Party Score

Scores are assigned to invertebrate families depending on their tolerance of organic pollution. The individual family scores are added together to give a sample BMWP score, higher scores indicate cleaner conditions. BMWP scores can vary from 0 (grossly polluted) to 150+ (excellent quality).

TAXA

This is the number of BMWP scoring families found in the sample. There may be additional non-scoring taxa in the sample which are not recorded here.

ASPT – Average Score Per Taxon

This is the total BMWP score divided by the number of BMWP scoring taxa and is therefore independent of sample size. ASPT can vary from 0.00 (grossly polluted) to 6.00+ (excellent quality).

LIFE (Family)/ LIFE (Species) – Lotic-invertebrate Index for Flow Evaluation

A flow score is derived for each species/family using the species/family abundance and ecological association with different flows (see conversion table below). An overall LIFE score is calculated for the sample from the sum of the individual species/family flow scores divided by the number of scoring species/families. LIFE scores less than 6.00 generally indicate sluggish or still water conditions. As current velocity increases, so do LIFE scores. LIFE values greater than 7.5 indicate very fast flows.

	Abundance categories			
Flow group	A (1-9)	B (10-99)	C (100-999)	D/E (1000+)
I Rapid	9	10	11	12
II Moderate/fast	8	9	10	11
III Slow/sluggish	7	7	7	7
IV Flowing/standing	6	5	4	3
V Standing	5	4	3	2
VI Drought resistant	4	3	2	1

Reference

Extence C., Balbi DM. and Chadd RP. 1999. *River flow indexing using British benthic macro-invertebrates: a framework for setting hydro-ecological objectives.* Regulated Rivers Research and Management **15**: 543-574.

For more information on these indices contact the Biology team at the Environment Agency, Spalding.

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Appendix 3: Technical information

Technical specifications for the ToolHab Decision Support System:

- Pentium PC with Windows XP or Windows 7 with at least 1 Gig of RAM
- Microsoft Access 2007 or 2010 or runtime version (available for free on Microsoft website http://www.microsoft.com/download/en/details.aspx?id=4438)
- Setup of MapWindows ActiveX 4.7 (http://www.mapwindow.org/)

References

Adelman, L. (1992) *Evaluating decision support and expert systems.* Wiley, New York.

Agnew, N.M., Ford, K.M. & Hayes, P.J. (1997) Expertise in context: personally constructed, socially selected and reality-relevant? *Expertise in context* (eds P.J. Feltovich, K.M. Ford & R.R. Hoffman), pp. 219-244. AAAI Press / The MIT Press.

Aguinis, H. & Henle, C.A. (2003) The search for universals in cross-cultural organisational behaviour. *Organisational behaviour. The state of the science. (2nd edition)* (ed. J. Greenberg), pp. 379-410. Lawrence Erlbaum Associates, Mahwah.

Akcakaya, H.R. (2000) Viability analyses with habitat-based metapopulation models. *Population Ecology,* **42,** 45-53.

Akcakaya, H.R. (2002) RAMAS GIS: linking spatial data with Population Viability Analysis (version 4.0). *Applied Biomathematics.*

Alho, J.M. & Kangas, J. (1997) Analyzing uncertainties in experts' opinions of forest plan performance. *Forest Science,* **43,** 521-528.

Alho, J.M., Kangas, J. & Kolehmainen, O. (1996) Uncertainty in expert predictions of the ecological consequences of forest plans. *Applied Statistics-Journal of the Royal Statistical Society Series C,* **45,** 1-14.

Ames, D. (2006) MapWindow GIS Open Source projects: Mapwindows ActiveX version 4.7.

Angehrn, A.A. & Jelassi, T. (1994) DSS research and practice in perspective. *Decision Support Systems,* **12,** 267-275.

Anonymous (2007) The great divide. *Nature,* **450,** 135-136.

Argent, R.M. & Grayson, R.B. (2001) Design of information systems for environmental managers: an example using interface prototyping. *Environmental Modelling & Software,* **16,** 433-438.

Argent, R.M., Grayson, R.B. & Ewing, S.A. (1999) Integrated models for environmental management: Issues of process and design. *Environment International,* **25,** 693-699.

Ariely, D. (2008) *Predictably irrational. The hidden forces that shape our decisions.* HarperCollins Publishers.

Arnott, D. & Pervan, G. (2008) Eight key issues for the decision support systems discipline. *Decision Support Systems,* **44,** 657-672.

Ashkanazi, N.M., Broadfoot, L.E. & Falkus, S. (2000) Questionnaire measures of organizational culture. *Handbook of organizational culture and climate* (eds N.M. Ashkanazi, C.P.M. Wilderom & M.F. Peterson), pp. 131-146. Sage Publications, London.

Austin, M. (2007) Species distribution models and ecological theory: A critical assessment and some possible new approaches. *Ecological Modelling,* **200,** 1-19.

Ayton, P. (1992) On the competence and incompetence of experts. *Expertise and decision support* (eds G. Wright & F. Bolger), pp. 77-106. Plenum Press, New York.

Baron, J. (2004) Normative models of judgement and decision making. *Blackwell Handbook of Judgement and Decision Making* (eds D.J. Koehler & N. Harvey), pp. 19-36. Blackwell publishing, Malden, Oxford, Carlton.

Beach, L.R. (1992) Epistemic strategies: causal thinking in expert and non-expert judgement. *Expertise and decision support* (eds G. Wright & F. Bolger), pp. 107-128. Plenum Press, New York.

Beach, L.R. & Connolly, T. (2005) *The Psychology of Decision Making. People in Organisations.,* Second edition edn. Sage Publications, Thousand Oaks, London, New Delhi.

Beissinger, S.R. & Westphal, M.I. (1998) On the use of demographic models of population viability in endangered species management. *Journal of Wildlife Management,* **62,** 821-841.

Ben Ayed, M., Ltifi, H., Kolski, C. & Alimi, A.M. (2010) A user-centered approach for the design and implementation of KDD-based DSS: A case study in the healthcare domain. *Decision Support Systems,* **50,** 64-78.

Benamati, J.S. & Lederer, A.L. (2008) Decision support systems infrastructure: The root problems of the management of changing IT. *Decision Support Systems,* **45,** 833-844.

BenDavid, M., Bowyer, R.T. & Faro, J.B. (1996) Niche separation by mink and river otters: Coexistence in a marine environment. *Oikos,* **75,** 41-48.

Berthoz, A. (2003) *Emotion and reason. The cognitive neuroscience of decision-making.* Oxford University Press, Oxford.

Bhatt, G.D. & Zaveri, J. (2002) The enabling role of decision support systems in organizational learning. *Decision Support Systems,* **32,** 297-309.

Bojorquez-Tapia, L.A., Brower, L.P., Castilleja, G., Sanchez-Colon, S., Hernandez, M., Calvert, W., Diaz, S., Gomez-Priego, P., Alcantar, G., Melgarejo, E.D., Solares, M.J., Gutierrez, L. & Juarez, M.D. (2003) Mapping expert knowledge: Redesigning the Monarch Butterfly Biosphere Reserve. *Conservation Biology,* **17,** 367-379.

Bolger, F. & Wright, G. (1992) Reliability and validity in expert judgement. *Expertise and decision support* (eds G. Wright & F. Bolger), pp. 47-76. Plenum Press, New York.

Bonesi, L., Rushton, S. & Macdonald, D. (2002) The combined effect of environmental factors and neighbouring populations on the distribution and abundance of Arvicola terrestris. An approach using rule-based models. *Oikos,* **99,** 220-230.

Bouveresse, J. (1979) La théorie et l'observation dans la philosophie des sciences du positivisme logique. *La philosophie au XXe siècle* (ed. F. Châtelet), pp. 70-128. Marabout.

Boyce, M.S. (1992) Population Viability Analysis. *Annual Review of Ecology and Systematics,* **23,** 481-506.

Brenden, T.O., Wang, L., Seelbach, P.W., Clark Jr, R.D., Wiley, M.J. & Sparks-Jackson, B.L. (2008) A spatially constrained clustering program for river valley segment delineation from GIS digital river networks. *Environmental Modelling & Software,* **23,** 638-649.

Bruce-Burgess, L. & Skinner, K. (2002) Appraisal: River Restoration's Missing Link. pp. 25. The River Restoaration Centre.

Bruinderink, G.G., Van Der Sluis, T., Lammertsma, D., Opdam, P. & Pouwels, R. (2003) Designing a Coherent Ecological Network for Large Mammals in Northwestern Europe. *Conservation Biology,* **17,** 549-557.

Buetow, S., Upshur, R., Miles, A. & Loughlin, M. (2006) Taking stock of evidence-based medicine: opportunities for its continuing evolution. *Journal of Evaluation in Clinical Practice,* **12,** 399-404.

Bunch, M.J. (2003) Soft systems methodology and the ecosystem approach: A system study of the Cooum River and environs in Chennai, India. *Environmental Management,* **31,** 182-197.

Bunch, M.J. & Dudycha, D.J. (2004) Linking conceptual and simulation models of the Cooum River: collaborative development of a GIS-based DSS for environmental management. *Computers, Environment and Urban Systems,* **28,** 247-264.

Burnham, K.P. & Anderson, D.R. (2002) *Model selection and multimodel inference.* Springer.

Burns, C. & Hewitt-Dundas, N. (2009) *Implementation of Discrete and Integrated IT: the Role of Organisational Structure and Culture*. Academic Conferences Ltd, Nr Reading.

Bywater, J. (2005) Ecology Skills Survey Project Phase 2. pp. 35. Environment Agency.

Carroll, C., Marsden, P., Soden, P., Naylor, E., New, J. & Dornan, T. (2002) Involving users in the design and usability evaluation of a clinical decision support system. *Computer Methods and Programs in Biomedicine,* **69,** 123-135.

Chalmers, A.F. (1999) *What is this thing called Science?,* Third edn. Open University Press, Glasgow.

Chalos, P. (1985) Financial Distress: A Comparative Study of Individual, Model, and Committee Assessments. *Journal of Accounting Research,* **23,** 527-543.

Châtelet, F. (1992) *Une histoire de la raison. Entretiens avec Émile Noël.* Éditions du seuil.

Checkland, K.H. (2005) Understanding general practice: an exploration of bureaucratic initiatives in general practices in the UK. PHD, University of Manchester.

Checkland, P.B. & Scholes, J. (1990) *Soft system methodology in action*. John Wiley & Sons, Toronto.

Chenoweth, T., Dowling, K.L. & St. Louis, R.D. (2004) Convincing DSS users that complex models are worth the effort. *Decision Support Systems,* **37,** 71-82.

Chi, M.T.H. (2006) Two approaches to the study of experts' characteristics. *The Cambridge Handbook of expertise and expert performance* (eds K.A. Ericsson, N. Charness, P.J. Feltovich & R.R. Hoffman), pp. 21-30. Cambridge University Press, Cambridge.

Cianciolo, A.T., Matthew, C., Sternberg, R.J. & Wagner (2006) Tacit knowledge, practical intelligence, and expertise. *The Cambridge Handbook of expertise and expert performance* (eds K.A. Ericsson, N. Charness, P.J. Feltovich & R.R. Hoffman), pp. 613-632. Cambridge University Press, Cambridge.

Clark, M.J. (2002) Dealing with uncertainty: adaptive approaches to sustainable river management. *Aquatic Conservation: Marine and Freshwater Ecosystems [Aquat. Conserv.: Mar. Freshwat. Ecosyst.].* **12,** 347-363.

Collins (1993) *Collins Cobuild English language dictionary*. Harper Collins Publishers.

Cournot, A. (1875) *Matérialisme, vitalisme, rationalism.*

Cowardin, L.M., Carter, V., Golet, F.C. & LaRoe, E.T. (1979) Classification of Wetlands and Deepwater Habitats of the United States. US Fish and Wildlife. pp. 131. U.S. Fish and Wildlife Service.

Cowling, R.M., Pressey, R.L., Rouget, M. & Lombard, A.T. (2003) A conservation plan for a global biodiversity hotspot--the Cape Floristic Region, South Africa. *Biological Conservation,* **112,** 191-216.

Cox, C. & Madramootoo, C. (1998) Application of geographic information systems in watershed management planning in St. Lucia. *Computers and Electronics in Agriculture,* **20,** 229-250.

Csuti, B., Polasky, S., Williams, P.H., Pressey, R.L., Camm, J.D., Kershaw, M., Kiester, A.R., Downs, B., Hamilton, R., Huso, M. & Sahr, K. (1997) A comparison of reserve selection algorithms using data on terrestrial vertebrates in Oregon. *Biological Conservation,* **80,** 83-97.

Damasio, A.R. (1996) *Descartes*' *Error. Emotion, reason and the human brain.* Papermac, London.

Davenport, T. & Prusak, L. (1998) *Working Knowledge*. Harvard Business School, Boston.

Davey, K.M. & Symon, G. (2001) Recent approaches to the qualitative analysis of organizational culture. *The international handbook of organizational culture and climate* (eds C.L. Cooper, S. Cartwright & P.C. Earley), pp. 123-142. John Wiley & Sons, Chichester.

Dawes, R.M., Faust, D. & Meehl, P.E. (2002) Clinical versus actuarial judgement. *Heuristics and biases. The psychology of intuitive judgement* (eds T. Gilovich, D. Griffin & D. Kahneman), pp. 716-729. Cambridge University Press, Cambridge.

Daya, S. (2005) The Cochrane Collaboration - a decade of progress. *Evidence-based Obstetrics and Gynecology,* **7,** 1-2.

De Dombal, F.T. (1993) The development of knowledge-based decision support from 1955 to 2005. *Theoretical Surgery,* **8,** 213-220.

De Lange, W.J., Luiten, J.P.A. & Blind, M. (2002) Description of Work of HarmoniCA (Harmonised Modelling Tools for Integrated Basin Management). pp. 46.

Denison, D.R., Janovics, J., Young, J. & Cho, H.J. (2005) Diagnosing organizational cultures: Validating a model and method.

Denzin, N.K. & Lincoln, Y.S. (2005) The discipline and practice of qualitative research. *The Sage Handbook of Qualitative Research. Third edition.* (eds N.K. Denzin & Y.S. Lincoln), pp. 1- 32. Sage Publications, Oaks.

Descartes (1637) Discourse on the method. *Descartes. Key philosophical writings* (ed. E. Chavez-Arvizo), pp. 71-122. Wordsworth Editions.

Doherty & Perry (2001) The Cultural Impact of Workflow Management Systems in the Financial Services Sector. *The Service Industries Journal,* **21,** 147 - 166.

Doherty, N.F. & Doig, G. (2003) An analysis of the anticipated cultural impacts of the implementation of data warehouses. *IEEE Transactions on Engineering Management,* **50,** 78-88.

Donnelly, J.H., Gibson, J.L. & Ivancevich, J.M. (1995) Fundamentals of Management. pp. 127-128. Irwing, Chicago.

Environment Agency (1997) A strategy for implementing the Environment Agency's contribution to the UK Biodiversity Action Plan. The Environment Agency England and Wales, Bristol.

Environment Agency (1998) An action plan for Conservation. The Environment Agency England and Wales, Bristol.

Environment Agency (2000) Focus on Biodiversity. pp. 112. The Environment Agency England and Wales, Bristol.

Environment Agency (2003a) Corporate Plan 2003-06. pp. 64. The Environment Agency England and Wales, Bristol.

Environment Agency (2003b) Guidebook of applied fluvial geomorphology. pp. 233. The Environment Agency England and Wales.

Environment Agency (2004) Solving environmental problems using science. pp. 28. The Environment Agency England and Wales, Bristol.

Eom, S.B. (1998) The intellectual development and structure of decision support systems (1991-1995). *Omega-International Journal of Management Science,* **26,** 639-657.

Eom, S.B., Lee, S.M., Kim, E.B. & Somarajan, C. (1998) A survey of decision support system applications (1988-1994). *Journal of the Operational Research Society,* **49,** 109-120.

Ericsson, K.A. & Charness, N. (1997) Cognitive and developmental factors in expert performance. *Expertise in context* (eds P.J. Feltovich, K.M. Ford & R.R. Hoffman), pp. 3-41. AAAI Press / The MIT Press.

European Union (1992) *Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora.*

European Union (1997) *Council Directive 97/11/EC of 3 March 1997 amending Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment*

European Union (2000a) *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy*.

European Union (2000b) *Strategic Environmental Impact Assessment Directive*.

European Union (2004) *Environmental Liability Directive*.

Fahrig, L. & Merriam, G. (1994) Conservation of Fragmented Populations. *Conservation Biology,* **8,** 50-59.

FAME Consortium (2004) Manual for the application of the European Fish Index - EFI. A fish-based method to assess the ecological status of European rivers in support of the Water Framework Directive.Version 1.1, January 2005.

Fedriani, J.M., Delibes, M., Ferreras, P. & Roman, J. (2002) Local and landscape habitat determinants of water vole distribution in a patchy Mediterranean environment. *Ecoscience,* **9,** 12-19.

Feltovich, P.J., Prietula, M.J. & Ericsson, K.A. (2006) Studies of expertise from psychological perspectives. *The Cambridge Handbook of expertise and expert performance* (eds K.A. Ericsson, N. Charness, P.J. Feltovich & R.R. Hoffman), pp. 41-67. Cambridge University Press, Cambridge.

Fenouil, E. & Chaix, J.C. (1992) Development of a Theoretical-Model of the Population-Dynamics of Austropotamobius-Pallipes after Reintroduction in Running Water. *Crustaceana,* **62,** 65-70.

Ferrier, S., Pressey, R.L. & Barrett, T.W. (2000) A new predictor of the irreplaceability of areas for achieving a conservation goal, its application to real-world planning, and a research agenda for further refinement. *Biological Conservation,* **93,** 303-325.

Finlay, P.N. & Forghani, M. (1998) A classification of success factors for decision support systems. *Journal of Strategic Information Systems,* **7,** 53-70.

Fischhoff, B. (2002) Heuristic and biases in application. *Heuristics and biases. The psychology of intuitive judgement* (eds T. Gilovich, D. Griffin & D. Kahneman), pp. 730-748. Cambridge University Press, Cambridge.

Fontana, A. & Frey, J.H. (2005) The interview: from neutral stance to political involvement. *The Sage Handbook of Qualitative Research. Third edition.* (eds N.K. Denzin & Y.S. Lincoln), pp. 695-728. Sage Publications, Oaks.

Forestry, N.C.o.S.f.S. (2004) Decision Support System for Biodiversity, evaluation of current systems and future needs.

Fuller, S. (2006) The constitutively social character of expertise. *The philosophy of expertise* (eds E. Selinger & R.P. Crease), pp. 342-357. Columbia University Press, New York.

Garcia-Quijano, J.F., Deckmyn, G., Moons, E., Proost, S., Ceulemans, R. & Muys, A. (2005) An integrated decision support framework for the prediction and evaluation of efficiency, environmental impact and total social cost of domestic and international forestry projects for greenhouse gas mitigation: description and case studies. *Forest Ecology and Management,* **207,** 245-262.

Garg, A.X., Adhikari, N.K.J., McDonald, H., Rosas-Arellano, M.P., Devereaux, P.J., Beyene, J., Sam, J. & Haynes, R.B. (2005) Effects of computerized clinical decision support systems on practitioner performance and patient outcomes - A systematic review. *Jama-Journal of the American Medical Association,* **293,** 1223-1238.

Geertz, F. (1973) *Thick Description: Toward an Interpretive Theory of Culture. In The Interpretation of Cultures.* Basic Books, New York.

Geraghty, P.J. (1993) Environmental Assessment and the Application of Expert-Systems - an Overview. *Journal of Environmental Management,* **39,** 27-38.

Gharaibeh, N., Abu-Soud, S.M., Bdour, W., Gharaibeh, I. & Ieee (2009) *Agile Development Methodologies: Are they suitable for developing Decision Support Systems*. Ieee, New York.

Gigerenzer, G. (2004) Fast and frugal heuristics. *Blackwell Handbook of Judgement and Decision Making* (eds D.J. Koehler & N. Harvey), pp. 62-88. Blackwell publishing, Malden, Oxford, Carlton.

Gilovich, T., Griffin, D. & Kahneman, D. (2002) Heuristics and biases. The psychology of intuitive judgement. pp. 857. Cambridge University Press, Cambridge.

Giraudoux, P., Pradier, B., Delattre, P., Deblay, S., Salvi, D. & Defaut, R. (1995) Estimation of water vole abundance by using surface indexes. *Acta Theriologica,* **40,** 77-96.

Giupponi, C., Mysiak, J., Depietri, Y. & Tamaro, M. (2005) Harmoni-CA Synthesis Report. Decision Support Systems for water resources management: current state and guidelines for tool development., pp. 75.

Gkaraveli, A., Good, J.E.G. & Williams, J.H. (2004) Determining priority areas for native woodland expansion and restoration in Snowdonia National Park, Wales. *Biological Conservation,* **115,** 395-402.

Glaser, S.R., Zamanou, S. & Hacker, K. (1987) Measuring and Interpreting Organizational Culture. *Management Communication Quarterly,* **1,** 173-198.

Goldenberg, M.J. (2006) On evidence and evidence-based medicine: Lessons from the philosophy of science. *Social Science & Medicine,* **62,** 2621-2632.

Gorry, G.A. & Morton, M.S.S. (1989) A Framework for Management Information-Systems. *Sloan Management Review,* **30,** 49-61.

Grimm, V., Lorek, H., Finke, J., Koester, F., Malachinski, M., Sonnenschein, M., Moilanen, A., Storch, I., Singer, A., Wissel, C. & Frank, K. (2004) META-X: generic software for metapopulation viability analysis. *Biodiversity and Conservation,* **13,** 165-188.

Guba, E.G. (1990) The alternative paradigm dialog. *The paradigme dialog* (ed. E.G. Guba), pp. 17-30. Sage, Newbury Park.

Guba, E.G. & Lincoln, Y.S. (2005) Paradigmatic controversies, contradictions, and emerging conferences. *The Sage Handbook of Qualitative Research. Third edition.* (eds N.K. Denzin & Y.S. Lincoln), pp. 191-215. Sage Publications, Oaks.

Hall, K. (2005) A Data and Information Acquisition Plan (DIAP) for Environment Agency Category One and Two UK BAP Scpecies and Habitats. Environment Agency, England and Wales.

Harris, R.B., Metzgar, L.H. & Bevins, C.D. (1986) GAPPS: generalized animal population projection system. Version 3.0. Montana Cooperative Wildlife Research Unit, University of Montana, Missoula.

Harrison, S.S.C., Pretty, J.L., Shepherd, D., Hildrew, A.G., Smith, C. & Hey, R.D. (2004) The effect of instream rehabilitation structures on macroinvertebrates in lowland rivers. *Journal of Applied Ecology,* **41,** 1140-1154.

Hartono, E., Santhanam, R. & Holsapple, C.W. (2007) Factors that contribute to management support system success: An analysis of field studies. *Decis. Support Syst.,* **43,** 256-268.

Hatch, M.J. & Cunliffe, A.L. (2006) *Organization theory. Modern, symbolic, and post-modern perspectives.,* Second edn. Oxford University Press, Oxford.

Hedberg, B. & Mumford, E. (1974) The design of computer systems: man's vision of man as an integral part of the system design process. *IFIP Conference on Human Choice and Computers* (eds E. Mumford & H. Sackmann), pp. 31-59. Amsterdam.

Heylighen, F. & Joslyn, C. (2001) Cybernetics and second-order Cybernetics. *Encyclopedia of Physical Science and Technology* (ed. R.A. Meyers), pp. 155-170. Academic Press, New York.

Hirzel, A.H., Hausser, J., Chessel, D. & Perrin, N. (2002) Ecological-niche factor analysis: How to compute habitat- suitability maps without absence data? *Ecology,* **83,** 2027-2036.

HMSO (1994) *Biodiversity. The UK action plan.* HMSO, London.

Hoctor, T.S., Carr, M.H. & Zwick, P.D. (2000) Identifying a linked reserve system using a regional landscape approach: The Florida ecological network. *Conservation Biology,* **14,** 984-1000.

Hofstede, G. (2001) *Culture's consequences. Comparing values, behaviours, institutions, and organisations across nations.,* second edn. Sage Publications, London.

Hofstede, G., Neuijen, B., Daval Ohayv, D. & Sanders, G. (1990) Measuring organisational cultures: a qualitative and quantitative survey across 20 cases. *Administrative Science Quarterly,* **35,** 286-316.

Hogarth, R.M. & Makridakis, S. (1981) Forecasting and planning: An evaluation. *Management Science,* **27,** 115-138.

Holling, C.S. (1978) *Adaptive environmental assessment and management*. Wiley, New York.

Holsapple, C.W. (2008) Decisions and knowledge. *Handbook on Decision Support Systems* (eds F. Burstein & C.W. Holsapple), pp. 21-54. Springer.

Hom, J. (1996) The Usability Methods Toolbox.

Hughes, J., Jewson, N. & Unwin, L. (2007) Communities of practice: a contested concept in flux. *Communities of practice: critical perspectives* (eds J. Hughes, N. Jewson & L. Unwin), pp. 1-16. Routledge, Oxon.

Iivari, J. & Abrahamsson, P. (2002) The interaction between organizational subcultures and User Centred Design -a case study of an implementation effort. *35th Hawaii International Conference on System Sciences.* Hawaii.

Jackson, S. (2011) Organizational culture and information systems adoption: A three-perspective approach. *Information and Organization,* **21,** 57-83.

Johnson, C.J. & Gillingham, M.P. (2004) Mapping uncertainty: sensitivity of wildlife habitat ratings to expert opinion. *Journal of Applied Ecology,* **41,** 1032-1041.

Johnson, P. & Lachman, B. (2001) Rapid scan of decision support system tools for land-use related decision making. Arlington.

Jones, M.C., Cline, M. & Ryan, S. (2006) Exploring knowledge sharing in ERP implementation: an organizational culture framework. *Decision Support Systems,* **41,** 411-434.

Kankanhalli, A., Tan, B.C.Y., Wei, K.-K. & Holmes, M.C. (2004) Cross-cultural differences and information systems developer values. *Decision Support Systems,* **38,** 183-195.

Kaplan, B. (2001a) Evaluating informatics applications - clinical decision support systems literature review. *International Journal of Medical Informatics,* **64,** 15-37.

Kaplan, B. (2001b) Evaluating informatics applications - some alternative approaches: theory, social interactionism, and call for methodological pluralism. *International Journal of Medical Informatics,* **64,** 39-55.

Kappos, A. & Rivard, S. (2008) A three-perspective model of culture, information systems, and their development and use. *Mis Quarterly,* **32,** 601-634.

Kay, J.J., Regier, H.A., Boyle, M. & Francis, G. (1999) An ecosystem approach for sustainability: addressing the challenge of complexity. *Futures,* **31,** 721-742.

Keen, P.G.W. & Morton, M.S.S. (1978) *Decisión support systems: an organizational perspective.* Addison-Wesley Pub. Co.

Keeney, L.K. (1988) Value-focused thinking and the study of values. *Decision-making. Descriptive, normative, and prescriptive interactions.* (eds D.E. Bell, H. Raiffa & A. Tversky), pp. 465-494. Cambridge University Press, Cambridge.

Keil, M., Beranek, P.M. & Konsynski, B.R. (1995) Usefulness and ease of use: field study evidence regarding task considerations. *Decision Support Systems,* **13,** 75-91.

Keren, G. (1992) Improving decisions and judgements: the desirable versus the feasible. *Expertise and decision support* (eds G. Wright & F. Bolger), pp. 25-46. Plenum Press, New York.

Klein, M.R. & Methlie, L.B. (1995) *Knowledge-based Decision Support Systems with applications in business,* second edition edn. John Wiley & Sons Ltd, Chichester.

Kristensen, K. & Rasmussen, I.A. (2002) The use of a Bayesian network in the design of a decision support system for growing malting barley without use of pesticides. *Computers and Electronics in Agriculture,* **33,** 197-217.

Kuhn, T.S. (1996) *The structure of scientific revolutions,* Third edition edn. The University of Chicago Press, Chicago.

Lacy, R.C. (1993) Vortex - a Computer-Simulation Model for Population Viability Analysis. *Wildlife Research,* **20,** 45-65.

Larson, B.D. & Sengupta, R.R. (2004) A spatial decision support system to identify species-specific critical habitats based on size and accessibility using US GAP data. *Environmental Modelling & Software,* **19,** 7-18.

Latour, B. (1987) *Science in action*. Harvard University Press, Cambridge Massachusetts.

Lave, J. & Wenger, E. (1991) *Situated Learning:Legitimate Peripheral Participation*. Cambridge University Press, Cambridge.

Lee, A.S. (1999) Rigor and Relevance in MIS Research: Beyond the Approach of Positivism Alone. *Mis Quarterly,* **23,** 29-33.

Lee, D., Newman, P. & Price, R. (1999) *Decision making in organisations*. Financial Times Prentice Hall, Harlow.

Lehmann, A., Overton, J.M. & Leathwick, J.R. (2003) GRASP: generalized regression analysis and spatial prediction. *Ecological Modelling,* **160,** 165-183.

Lehrer, K. (2000) *Theory of Knowledge,* Second edn. Westview Press, Oxford.

Leidner, D.E. & Kayworth, T. (2006) Review: A review of culture in information systems research: Toward a theory of information technology culture conflict. *Mis Quarterly,* **30,** 357-399.

Lemon, M. & Sahota, P.S. (2004) Organizational culture as a knowledge repository for increased innovative capacity. *Technovation,* **24,** 483-498.

Lerch, F.J., Prietula, M.J. & Kulik, C.T. (1997) The Turing effect: the nature of trust in expert system advice. *Expertise in context* (eds P.J. Feltovich, K.M. Ford & R.R. Hoffman), pp. 417-448. AAAI Press / The MIT Press.

Lindenmayer, D.B. & Possingham, H.P. (1996) Ranking conservation and timber management options for Leadbeater's possum in southeastern Australia using population viabililty analysis. *Conservation Biology,* **10,** 235-251.

Lindstrom, L. & Jeffries, R. (2004) Extreme programming and agile software development methodologies. *Information Systems Management,* **21,** 41-52.

Llewellyn, D.W., Shaffer, G.P., Craig, N.J., Creasman, L., Pashley, D., Swan, M. & Brown, C. (1996) A decision-support system for prioritizing restoration sites on the Mississippi River Alluvial Plain. *Conservation Biology,* **10,** 1446-1455.

Loiselle, B.A., Howell, C.A., Graham, C.H., Goerck, J.M., Brooks, T., Smith, K.G. & Williams, P.H. (2003) Avoiding pitfalls of using species distribution models in conservation planning. *Conservation Biology,* **17,** 1591-1600.

Lopez-Nicolas, C. & Merono-Cerdan, A.L. (2009) The impact of organizational culture on the use of ICT for knowledge management. *Electronic Markets,* **19,** 211-219.

Macdonald, D.W. & Rushton, S. (2003) Modelling space use and dispersal of mammals in real landscapes: a tool for conservation. *Journal of Biogeography,* **30,** 607-620.

Madsen, A.B. & Prang, A. (2001) Habitat factors and the presence or absence of otters Lutra lutra in Denmark. *Acta Theriologica,* **46,** 171-179.

Marcia Barbosa, A., Real, R., Olivero, J. & Mario Vargas, J. (2003) Otter (Lutra lutra) distribution modeling at two resolution scales suited to conservation planning in the Iberian Peninsula. *Biological Conservation,* **114,** 377-387.

Martin, J. (2002) *Organizational culture. Mapping the terrain*. Sage Publications, Oaks.

Memmott, J., Cadotte, M., Hulme, P.E., Kerby, G., Milner-Gulland, E.J. & Whittingham, M.J. (2010) Putting applied ecology into practice. *Journal of Applied Ecology,* **47,** 1-4.

Mieg, H.A. (2006) Social and sociological factors in the development of expertise. *The Cambridge Handbook of expertise and expert performance* (eds K.A. Ericsson, N. Charness, P.J. Feltovich & R.R. Hoffman), pp. 743-760. Cambridge University Press, Cambridge.

Mills, L.S. & Smouse, P.E. (1994) Demographic consequences of inbreeding in remnant populations. *American Naturalist,* **144,** 412-431.

Milner, N., Wyatt, R.J. & Scott, M.D. (1993) Variability in the distribution and abundance of stream salmonids, and the associated use of habitat models. *Journal of Fish Biology,* **43,** 103-109.

Mocan, H.N. & Azad, S. (1995) Accuracy and rationality of state general fund revenue forecasts: evidence from panel data. *International Journal Forecasting,* **11,** 417-427.

Montazemi, A.R., Wang, F., Khalid Nainar, S.M. & Bart, C.K. (1996) On the effectiveness of decisional guidance. *Decision Support Systems,* **18,** 181-198.

Morton, M.S.S. (1971) *Management decision systems: computer-based support for decision making*. Division of Research, Graduate School of Business Administration, Harvard University.

Mullett, C.J., Evans, R.S., Christenson, J.C. & Dean, J.M. (2001) Development and impact of a computerised paediatric anti-infective decision support programme. *Paediatrics,* **108,** 75.

Naura, M. (2005a) Decision support tools for biodiversity Phase I. pp. 70. Environment Agency.

Naura, M. (2005b) Decision support tools for biodiversity. A review of methods for the assessment of habitat suitability within Decision Support Systems for the delivery of biodiversity duties. pp. 40. Environment Agency.

Naura, M. (2006) Designing Decision Support Systems in a Conservation organisation: lessons from a feasibillity study.

Naura, M. & Robinson, M. (1998) Principles of using River Habitat Survey to predict the distribution of aquatic species: an example applied to the native white-clawed crayfish Austropotamobius pallipes. *Aquatic Conservation-Marine and Freshwater Ecosystems,* **8,** 515-527.

Nemati, H.R., Steiger, D.M., Iyer, L.S. & Herschel, R.T. (2002) Knowledge warehouse: an architectural integration of knowledge management, decision support, artificial intelligence and data warehousing. *Decision Support Systems,* **33,** 143-161.

Nielsen, J. (1993) What is usability? *Usability Engineering* (ed. J. Nielsen), pp. Chapter 2. Academic Press.

Nikolakaki, P. (2004) A GIS site-selection process for habitat creation: estimating connectivity of habitat patches. *Landscape and Urban Planning,* **68,** 77-94.

Nonaka, I. & Takeuchi, H. (1995) *The Knowledge-Creating Company*. Oxford Univ. Press, New York.

NPWS (2001) *C-Plan Conservation Planning Software. User Manual version3.06*. New South Wales National Parks and Wildlife Services.

O'Reilly, C.A., Chatman, J. & Caldwell, D.F. (1991) People and Organizational Culture: A Profile Comparison Approach to Assessing Person-Organization Fit. *The Academy of Management Journal,* **34,** 487-516.

Ortigosa, G.R., De Leo, G.A. & Gatto, M. (2000) VVF: integrating modelling and GIS in a software tool for habitat suitability assessment. *Environmental Modelling and Software,* **15,** 1-12.

Over, D. (2004) Rationality and the normative/descriptive distinction. *Blackwell Handbook of Judgement and Decision Making* (eds D.J. Koehler & N. Harvey), pp. 3-18. Blackwell publishing, Malden, Oxford, Carlton.

Parker, C. (2001) An approach to requirements analysis for decision support systems. *International Journal of Human-Computer Studies,* **55,** 423-433.

Parker, C. & Sinclair, M. (2001) User-centred design does make a difference. The case of decision support systems in crop production. *Behaviour & Information Technology,* **20,** 449-460.

Parsons, H. (2001) A review of the use of River Habitat Survey within Conservation in the Environment Agency. Environment Agency.

Pearce, J.L., Cherry, K., Drielsma, M., Ferrier, S. & Whish, G. (2001) Incorporating expert opinion and fine-scale vegetation mapping into statistical models of faunal distribution. *Journal of Applied Ecology,* **38,** 412-424.

Pearce, P.H. & Walters, C.J. (1987) Perspectives on the application of economic-ecological models. *Economic-ecological modeling* (eds L.C. Braat & W.F.J. Van Lierop), pp. 269-281. Elsevier Science Publishers B.V (North Holland).

Pearson, S.A., Moxey, A., Robertson, J., Hains, I., Williamson, M., Reeve, J. & Newby, D. (2009) Do computerised clinical decision support systems for prescribing change practice? A systematic review of the literature (1990-2007). *Bmc Health Services Research,* **9**.

Phillips, J.K., Klein, G. & Sieck, W.R. (2004) Expertise in judgement and decision making: a case for training intuitive decision skills. *Blackwell Handbook of Judgement and Decision Making* (eds D.J. Koehler & N. Harvey), pp. 297-315. Blackwell publishing, Malden, Oxford, Carlton.

Pliskin, N., Romm, T., Lee, A.S. & Weber, Y. (1993) Presumed Versus Actual Organizational Culture - Managerial Implications for Implementation of Information-Systems. *Computer Journal,* **36,** 143-152.

Possingham, H.P. & Davies, I. (1995) Alex - a Model for the Viability Analysis of Spatially Structured Populations. *Biological Conservation,* **73,** 143-150.

Pretty, J.L., Harrison, S.S.C., Shepherd, D.J., Smith, C., Hildrew, A.G. & Hey, R.D. (2003) River rehabilitation and fish populations: assessing the benefit of instream structures. *Journal of Applied Ecology,* **40,** 251-265.

Pullin, A.S. & Knight, T.M. (2001) Effectiveness in conservation practice: Pointers from medicine and public health. *Conservation Biology,* **15,** 50-54.

Pullin, A.S. & Knight, T.M. (2003) Support for decision making in conservation practice: an evidence-based approach. *Journal for Nature Conservation,* **11,** 83-90(88).

Pullin, A.S. & Knight, T.M. (2005) Assessing conservation management's evidence base: a survey of management-plan compilers in the United Kingdom and Australia. *Conservation Biology,* **19,** 1989-1996.

Pullin, A.S., Knight, T.M., Stone, D.A. & Charman, K. (2004) Do conservation managers use scientific evidence to support their decision-making? *Biological Conservation,* **119,** 245-252.

Ramamurthy, K., Sen, A. & Sinha, A.P. (2008) An empirical investigation of the key determinants of data warehouse adoption. *Decision Support Systems,* **44,** 817-841.

Rauscher, H.M. (1999) Ecosystem management decision support for federal forests in the United States: A review. *Forest Ecology and Management,* **114,** 173-197.

Raven, P.J., Fox, P., Everard, M., Holmes, N.T.H. & Dawson, F.H. (1997) River habitat survey: A new system for classifying rivers according to their habitat quality. *Freshwater Quality: Defining the Indefinable?*, 215-234.

Raven, P.J., Holmes, N.T.H., Dawson, F.H., Fox, P.J.A., Everard, M., Fozzard, I.R. & Rouen, K.J. (1998) River Habitat Quality. The physical character of rivers and streams in the UK and Isle of Man. pp. 86. Environment Agency, Bristol.

Remus, W., O'Conner, M. & Griggs, K. (1996) Does Feedback Improve the Accuracy of Recurrent Judgmental Forecasts? *Organizational Behavior and Human Decision Processes,* **66,** 22-30.

Reynolds, K.M., Jensen, M., Andreasen, J. & Goodman, I. (2000) Knowledge-based assessment of watershed condition. *Computers and Electronics in Agriculture,* **27,** 315-334.

Richards, K.J. (2000) Redefining the concept of sustainable development; upland rural river corridor management in England and Wales. PhD, University of Southampton.

Ringle, C.M., Wende, S. & Will, A. (2005) SmartPLS. Hamburg, Germany.

Rivard, S., Lapointe, L. & Kappos, A. (2011) An Organizational Culture-Based Theory of Clinical Information Systems Implementation in Hospitals. *Journal of the Association for Information Systems,* **12,** 123-162.

Rottenstreich, Y. & Shu, S. (2004) The connections between affect and decision making. *Blackwell Handbook of Judgement and Decision Making* (eds D.J. Koehler & N. Harvey), pp. 444-463. Blackwell publishing, Malden, Oxford, Carlton.

Rouget, M. (2003) Measuring conservation value at fine and broad scales: implications for a diverse and fragmented region, the Agulhas Plain. *Biological Conservation,* **112,** 217-232.

Rushton, S.P., Ormerod, S.J. & Kerby, G. (2004) New paradigms for modelling species distribution? *Journal of Applied Ecology,* **41,** 193-200.

Sackmann, S. (2001) Cultural complexity in organizations: the value and limitations of qualitative methodology and approaches. *The international handbook of organizational culture and climate* (eds C.L. Cooper, S. Cartwright & P.C. Earley), pp. 143-164. John Wiley & Sons, Chichester.

Saldaña, J. (2009) *The coding manual for qualitative researchers*. Sage, London.

Sarros, J.C., Gray, J., Densten, I.L. & Cooper, B. (2005) The Organizational Culture Profile Revisited and Revised: An Australian Perspective. *Australian Journal of Management,* **30,** 159-182.

Sauter, V.L. (1997) *Decision Support Systems: an applied managerial approach*. John Wiley & Sons, New York.

Schein, E.H. (2004) *Organisational culture and leadership,* Third edition edn. Jossey-Bass, San Francisco.

Schumaker, R.G.L. (2004) *A beginners guide to structural equation modelling. Second edition*. Lawrence Erlbaum Associates, London

Scott, T., Mannion, R., Davies, H. & Marshall, M. (2003) The Quantitative Measurement of Organizational Culture in Health Care: A Review of the Available Instruments. *Health Services Research,* **38,** 923-945.

Sear, D. & Newson, M. (2004) The hydraulic impact and performance of a lowland rehabilitation scheme based on pool-riffle installation: the River Waveney, Scole, Suffolk, UK. *River Research and Applications,* **20,** 847-863.

Selinger, E. & Crease, R.P. (2006) The philosophy of expertise. Columbia University Press, New York.

Shannon, C.E. (1948) A mathematical theory of communication. *The Bell System Technical Journal,* **27,** 379-423 623-656.

Shanteau, J. (1992) The psychology of experts: an alternative view. *Expertise and decision support* (eds G. Wright & F. Bolger), pp. 11-24. Plenum Press, New York.

Shih, Y. (1994) Neuralyst. User's guide. Cheshire Engineering Corporation.

Shim, J.P., Warkentin, M., Courtney, J.F., Power, D.J., Sharda, R. & Carlsson, C. (2002) Past, present, and future of decision support technology. *Decision Support Systems,* **33,** 111-126.

Silverman, D. (2005) *Doing qualitative research,* Second edition edn. Sage, London.

Simon, H. (1955) A behavioural model of rational choice. *The Quarterly Journal of Economics,* **69,** 99-118.

Simon, H. (1956) Rational choice and the structure of the environment. *Psychological review,* **63,** 129-138.

Simon, H. (1960) *The New Science Of Management Decision*. Harper & Row, New York.

Smith, G.R.T., Learner, M.A., Slater, F.M. & Foster, J. (1996) Habitat features important for the conservation of the native crayfish Austropotamobius pallipes in Britain. *Biological Conservation,* **75,** 239-246.

Smith, M.Y., Depue, J.D. & Rini, C. (2007) Computerized decision-support systems for chronic pain management in primary care. *Pain Medicine,* **8,** S155-S166.

Soman, D. (2004) Framing, loss aversion and mental accounting. *Blackwell Handbook of Judgement and Decision Making* (eds D.J. Koehler & N. Harvey), pp. 379-398. Blackwell publishing, Malden, Oxford, Carlton.

South, M.C. (1998) GAFFER: Genetic Algorithm For Finding Existing Relationships.

Sprague, R.H.J. (1989) A framework for the development of Decision Support Systems. *Decision Support Systems. Putting theory into practice* (eds R.H.J. Sprague & H.J. Watson), pp. 9-35. Prentice-Hall.

Sprague, R.H.J. & Carlson, E.D. (1982) *Building Effective Decision Support Systems*. Prentice-Hall, Englewood Cliffs, NJ.

Stasser, G. & Titus, W. (1985) Pooling of unshared information in group decision-making: biased information sampling during discussion. *Journal of Personality and Social Psychology,* **48,** 1467-1478.

Stein, E.W. (1997) A look at expertise from a social perspective. *Expertise in context* (eds P.J. Feltovich, K.M. Ford & R.R. Hoffman), pp. 181-194. AAAI Press / The MIT Press.

Stockwell, D.R.B. (1999) The GARP modelling system: Problems and solutions to automated spatial predictions. *International Journal of Geographical Information Systems,* **13,** 143-158.

Sturdy, A., Newman, I. & Nicholls, P. (1992) Sociological perspectives on the nature of expertise. *Expertise and decision support* (eds G. Wright & F. Bolger), pp. 129-151. Plenum Press, New York.

Stuth, J.W., Hamilton, W.T. & Conner, R. (2002) Insights in development and deployment of the GLA and NUTBAL decision support systems for grazinglands. *Agricultural Systems,* **74,** 99-113.

Sutherland, W.J., Pullin, A.S., Dolman, P.M. & Knight, T.M. (2004) The need for evidence-based conservation. *Trends in Ecology & Evolution,* **19,** 305-308.

Telfer, S., Holt, A., Donaldson, R. & Lambin, X. (2001) Metapopulation processes and persistence in remnant water vole populations. *Oikos,* **95,** 31-42.

Tenenhaus, M., Vinzi, V.E., Chatelin, Y.M. & Lauro, C. (2005) PLS path modeling. *Computational Statistics & Data Analysis,* **48,** 159-205.

Thompson, S., Larcom, A. & Lee, J.T. (1999) Restoring and enhancing rare and threatened habitats under agri-environment agreements: a case study of the chiltern Hills Area of Outstanding Natural Beauty, UK. *Land Use Policy,* **16,** 93-105.

Tian, J., Wang, Y., Li, H., Li, L. & Wang, K. (2007) DSS development and applications in China. *Decision Support Systems,* **42,** 2060-2077.

Todd, P. & Benbasat, I. (1994) The Influence of decision aids on choice strategies under conditions of high cognitive load. *IEEE Transactions on Systems, Man, and Cybernetics,* **24,** 537-547.

Turban, E., Aronson, J.E. & Liang, T.P. (2005) *Decision Support Systems and Intelligent Systems,* Seventh edition - International edition edn. Pearson Prentice Hall.

Turchin, V. (1993) On Cybernetic Epistemology. *Systems Research,* **10,** 1-28.

Tversky, A. & Kahneman, D. (1974) Judgement and uncertainty: heuristics and biases. *Science,* **185,** 1124-1131.

Tversky, A. & Kahneman, D. (1988) Rational choice and the framing of decisions. *Decision-making. Descriptive, normative, and prescriptive interactions.* (eds D.E. Bell, H. Raiffa & A. Tversky), pp. 167-192. Cambridge University Press, Cambridge.

Uran, O. & Janssen, R. (2003) Why are spatial decision support systems not used? Some experiences from the Netherlands. *Computers, Environment and Urban Systems,* **27,** 511-526.

US EPA (2004) Decision tools for sustainability. United States Environmental Protection Agency.

Vanoirbeek, C., Rekik, Y.A., Karacapilidis, N., Aboukhaled, O., Ebel, N. & Vader, J.P. (2000) A web-based information and decision support system for appropriateness in medicine. *Knowledge-Based Systems,* **13,** 11-19.

Villanueva-Russell, Y. (2005) Evidence-based medicine and its implications for the profession of chiropractic. *Social Science & Medicine,* **60,** 545-561.

Vivash, R. & Janes, M. (2002) *Manual of river restoration techniques,* Second edition edn. The River Restoration Centre, Beford.

Von Glasersfeld, E. (2002) Cybernetics and the Theory of Knowledge. *UNESCO Encyclopedia* (ed. UNESCO).

Walker, J., Diamond, M. & Naura, M. (2002) The Development of Physical Habitat Objectives. *Aquatic Conservation: Marine and Freshwater Ecosystems [Aquat. Conserv.: Mar. Freshwat. Ecosyst.].* **12,** 381-390.

Wang, S. & Yeoh, W. (2009) *How does Organizational Culture Affect IS Effectiveness: A Culture-Information System Fit Framework*. Ieee Computer Soc, Los Alamitos.

Watson, H.J., Fuller, C. & Ariyachandra, T. (2004) Data warehouse governance: best practices at Blue Cross and Blue Shield of North Carolina. *Decision Support Systems,* **38,** 435-450.

Westmacott, S. (2001) Developing decision support systems for integrated coastal management in the tropics: Is the ICM decision-making environment too complex for the development of a useable and useful DSS? *Journal of Environmental Management,* **62,** 55-74.

Wheeldon, J. (2003) The river Avon cSAC conservation strategy. English nature, Peterborough.

White, P.C.L., McClean, C.J. & Woodroffe, G.L. (2003) Factors affecting the success of an otter (Lutra lutra) reinforcement programme, as identified by post-translocation monitoring. *Biological Conservation,* **112,** 363-371.

Wong, I.W., McNicol, D.K., Fong, P., Fillman, D., Neysmith, J. & Russell, R. (2003) The wildspace decision support system. *Environmental Modelling and Software,* **18,** 521-530.

Woodhouse, S., Lovett, A., Dolman, P. & Fuller, R. (2000) Using a GIS to select priority areas for conservation. *Computers, Environment and Urban Systems,* **24,** 79-93.

Wright, J.F., Moss, D., Armitage, P.D. & Furse, M.T. (1984) A preliminary classification of running water sites in Great Britain based on macro-invertebrate species and prediction of community type using environmental data. *Freshwater Biology,* **14,** 221-256.

Wu, J.H., Shen, W.S., Lin, L.M., Greenes, R.A. & Bates, D.W. (2008) Testing the technology acceptance model for evaluating healthcare professionals' intention to use an adverse event reporting system. *International Journal for Quality in Health Care,* **20,** 123-129.

Wurster, C.J., Lichtenstein, B.B. & Hogeboom, T. (2009) Strategic, Political, and Cultural Aspects of IT Implementation: Improving the Efficacy of an IT System in a Large Hospital. *Journal of Healthcare Management,* **54,** 191-206.

Wyatt, R.J. (2004) Development of river fish habitat inventory. Phase II. Methodology development for juveniles salmonids., pp. 44. Environment Agency.

Yamada, K., Elith, J., McCarthy, M. & Zerger, A. (2003) Eliciting and integrating expert knowledge for wildlife habitat modelling. *Ecological Modelling,* **165,** 251-264.

Young, W.J., Lam, D.C.L., Ressel, V. & Wong, I.W. (2000) Development of an environmental flows decision support system. *Environmental Modelling & Software,* **15,** 257-265.

Yu, T.-K., Lu, L.-C. & Liu, T.-F. (2010) Exploring factors that influence knowledge sharing behavior via weblogs. *Computers in Human Behavior,* **26,** 32-41.

Zeleznikow, J. & Nolan, J.R. (2001) Using soft computing to build real world intelligent decision support systems in uncertain domains. *Decision Support Systems,* **31,** 263-285.