Better science for forestry: could evidence-based forestry work?

Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy
University of Oxford

Gillian Susan Petrokofsky
Green Templeton College, Oxford

Trinity Term 2011

Supervisors

Dr Nick D. Brown
Principal of Linacre College and
University Lecturer in Forestry, Department of Plant Sciences,
University of Oxford

Dr Paul Jepson
Senior Research Fellow in Conservation Practice
Environmental Change Institute
University of Oxford

Dr. Gabriel E. Hemery
Chief Executive of the Sylva Foundation
Little Wittenham
Oxford

Better science for forestry: could evidence-based forestry work?

Gillian Petrokofsky
Green Templeton College, Oxford
Doctor of Philosophy, Trinity Term 2011

ABSTRACT: As society's demands for goods and services from forests increase, there is a corresponding increase in demand for high quality science which can help shape forestry policies for the sustainable management of natural resources. Forestry research is now undertaken in a very diverse range of institutions. The increased outputs from researchers in domains other than traditional forestry schools have not been matched by systematic methods of utilising new or existing information for policy or to identify future research needs that reflect the priorities of people in forestry's extended networks. An analysis of academic papers and informal articles indicated that the term 'evidence-based' is widely used in environmental literature, matching the rates of popularity of the term 'evidence-based medicine', but without the rigorous methodological processes that medicine has adopted to justify the phrase. Two strands of participatory research were undertaken to examine the potential for adopting rigorous evidence-based frameworks for forestry. The first focussed on a process for identifying important questions for policy-focussed forestry research. Using a combination of internet-based surveys and a workshop, some 480 people representing broad interests in the UK forestry sector set out a priority list of research questions. In the second, a group of international researchers and policy makers explored the possibility of using systematic reviews for validating the evidence base for carbon stock assessment under the REDD (Reducing Emissions from Deforestation and forest Degradation) process. The results indicate that there is capacity to collaborate to frame questions and critically appraise evidence for important policy issues. The longer-term benefits of adopting gold-standard systematic reviews are clear, however, there are also short-term advantages to be gained from moving incrementally towards this goal. In the aftermath of society's concerns about possible manipulation of science by experts (in the climate science arena), it would be folly for the forestry sector to ignore the benefits that would accrue from adopting genuinely evidence-based procedures for matters of global significance.

Under the greenwood tree
Who loves to lie with me,
And turn his merry note
Unto the sweet bird's throat,
Come hither, come hither, come hither:
Here shall he see
No enemy
But winter and rough weather.

Who doth ambition shun,
And loves to live i' the sun,
Seeking the food he eats,
And pleas'd with what he gets,
Come hither, come hither, come hither:
Here shall he see
No enemy
But winter and rough weather.

As you Like It Act 2, sc 5 Shakespeare, 1623

For Carl, Max and Leo

Acknowledgements

I owe many people a huge debt of gratitude for supporting my work on this project.

My supervisors Dr Nick Brown, Dr Paul Jepson and Dr Gabriel Hemery were enthusiastic about the project from before day one and gave me encouragement, inspiration and sound advice mixed in with a lot of fun. I am grateful to Dr John Holmes, Department of Earth Sciences, University of Oxford, for being my examiner for transfer and confirmation of status, and for acting as a very valuable fourth supervisor. Professor Hugh Dickinson and Professor Liam Dolan were extremely supportive and kind as Directors of Graduate Studies in Plant Sciences.

I am indebted to the Sylva Foundation, the Forestry Commission, the Natural Environment Research Council, Natural England, the Woodland Trust, the Institute of Chartered Foresters, the Food and Agriculture Organisation of the United Nations (FAO), the Department of Plant Sciences, and Green Templeton College for assistance with funding for my research and travel to conferences.

Julie Smith, Kit Bailey and Andrew Liddell were the Dream Team from IT and I am thankful that they were here to dig me out of many technical holes. Julie and Andrew were invaluable for the online survey work I did as part of the research. Bridget Biggs and Everild Haynes from CABI gave me helpful advice and assisted greatly with coding the survey. Roger Mills, Judith Pinfold, Sue Bird and all the librarians I encountered in the departmental and College libraries of Oxford were immensely helpful, calm and effective. They are amongst the real hidden treasures of Oxford, providing more than just cataloguing expertise in Oxford's wonderful libraries. I am grateful, too, for the kindly support of their US counterparts in the lovely Moorestown library, New Jersey.

Peter Freer-Smith, Jim Lynch, Helen McKay, Gary Kerr, Anna Lawrence, and Marcus Sangster from the Forestry Commission offered robust criticism and valuable support for my work with the British forestry sector, and Andrew Pullin provided helpful advice on systematic reviews in conservation.

Iain Chalmers was a huge source of inspiration: I am grateful to him for sharing some of his personal experiences of the uphill battles in the early years establishing the Cochrane Collaboration for a sceptical medical community. Professor Jeff Burley's early interest in systematic reviews for forestry was central to my desire to research this particular area. I am grateful for his guidance and support during my time as a student at Green Templeton College; I am also grateful to Jean Burley for her friendship and support. Jerry Ravetz and Sam Randalls opened my eyes to the world of science philosophy and discourse. The hours spent in their company were amongst the most stimulating during my years as a graduate student.

Team mates in Oxford Hawks Hockey club have kept me more or less sane and fit. Hilly Hinks was not only a great friend in the high hills but an invaluable researcher, enlisting diners at Eddy's mobile breakfast truck in the New Forest to pilot test my first survey.

Rebecca Ross, Christina Vinson, Chris Dixon, Graham Muir, Will Hawthorne, Steven Heathcote, Katie Ridout, Nodoka Nakamura, David Boshier and Tudor Jones have been valued friends, helping me drink more beer than is strictly necessary, but lightening the learning load considerably. Tonya Lander has combined solid academic advice with fun and friendship. Sandy West, Sam Mullee and Jasen Bustin were invaluable, supplying food and drink, and dispensing solid good advice in the Department and in College.

My Father Dennis taught me the fun of argument, which has stood me in good stead for this work. He and my Father-in-law, Sam, would have been kindly critics of this thesis; I valued their insights and practical knowledge. My Mother Joan and Mother-in-Law Rose are kindly non-critics, and I thank them both for that, together with sisters Denise, Jan, and Joan, who have teased me into finishing.

Most especially, thank you to Carl, Max and Leo, who have put up with a great deal of neglect and given in return practical and academic help… and warmth and humour and love.

Table of Contents

ABSTRACT i

Acknowledgements iv

Chapter 1. Introduction 1

1.1 The aims of this study 7

1.2 Framework for examining the hypotheses 7

1.3 Participatory approaches 10

1.4 Outline of the thesis 12

1.5 Summary of the chapters 13

Chapter 2. What does it mean to be “Evidence-based? Towards a model for evidence-based forestry. 18

2.1 Evidence-based medicine: the original ‘evidence-based’ concept 18

2.2 Evidence based policy and public acceptability 22

2.3 Growth of the term ‘evidence-based’ 24

2.4 Results 36

2.5 Discussion 41

2.6 Conclusions 43

Chapter 3. Identifying high priority questions for policy-relevant research using a participatory process 45

3.1 Introduction to chapter 3 45

3.2 Background 49

3.3 Method 55

3.4 Results 61

3.5 Discussion 67

3.6 Conclusions 70

Chapter 4. Linking the existing knowledge base with research priorities identified in a participatory stakeholder process. 72

4.1 Science for policy questions – where are the knowledge gaps? 72

4.2 Methods 74

4.3 Results 81

4.4 Discussion 86

4.5 Conclusions 90

Chapter 5. Applying an evidence-based framework to validate the science for a key policy issue within the UN-REDD programme 92

5.1 Introduction 92

Section A. Scoping the potential for a systematic review 98

5.2 Background 98

5.3 Evidence based frameworks 103

5.4 Applying an evidence-based approach to carbon assessment 105

5.5 A conceptual framework for measuring forest carbon 106

5.6 The existing evidence base on forest carbon monitoring 109

5.7 A systematic review of methods of carbon measurement and assessment 113

5.8 Discussion 116

5.9 Conclusions 118

Section B. Protocol for a systematic review comparing methods for measuring and assessing carbon stocks in terrestrial carbon pools. 119

5.10 Background to carbon assessments in REDD 121

5.11 Object of the systematic review of carbon assessment methods 141

5.12 Systematic review methods 144

Chapter 6. Knowledge management for evidence-based forestry 184

6.1 New problems, more information 184

6.2 Robust scientific analysis and effective knowledge management 186

6.3 Information access and overload 189

6.4 Collaborating to share resources and expertise 193

6.5 Conclusions 195

Chapter 7. Conclusions and reflections: the way forward 197

7.1 From serendipity to systematic 197

7.2 Experts on tap not on top 200

7.3 The way forward 206

7.4 Final statements 210

References 212

List of Acronyms used in the thesis 233

Statement of authorship for multi-authored papers in chapter 5 235

List of tables

Table 1 Numbers of papers containing key phrases in bibliographic databases 34

Table 2 Numbers of web pages indexed with key phrases in Google 35

Table 3 Sector of T10Q participants in survey and Workshop 61

Table 4 Questions in themes by sector of participants. 64

Table 5 The Top Ten Questions for Forestry 66

Table 6 T10Q project: the top ten questions 76

Table 7 Search strategies used to determine the number of papers of potential relevance to each of the T10Q questions andfor EU countries. 78

Table 8 Number of publications for each of the ten questionsfor forestry 80

Table 9 Actual and predicted number of articles for each question in each region 83

List of Figures

Chapter 1. Introduction 1

Figure 1 Conceptual framework for evidence-based forestry 8

Figure 2 Elements of an evidence framework for a systematic use of science for policy 12

Chapter 2. What does it mean to be “Evidence-based? Towards a model for evidence-based forestry. 18

Figure 3 Boolean logic illustrated for search string 4 below 26

Figure 4 MeSH Thesaurus extract showing hierarchy for 'evidence based medicine' 28

Figure 5 Articles containing the phrase evidence-based medicine in MEDLINE 36

Figure 6 Evidence based medicine compared with phrase Evidence-based in ‘environment’ literature 37

Figure 7 Evidence based medicine compared with comparator phrase "small sample" 38

Figure 8 Evidence based medicine compared with comparator phrase "acid rain", shown at same scale and finer scale to illustrate detail for acid rain trend 38

Figure 9 Number of articles with key phrases as a percentage of all environment articles 39

Figure 10 Log numbers of web pages for selected phrases in Google 39

Figure 11 Log numbers of web pages for selected phrases in Google Blogs 40

Figure 12 Evidence-based forestry, based on a definition of evidence-based medicine in Sackett & McKibbon,1998) 44

Chapter 3. Identifying high priority questions for policy-relevant research using a participatory process. 45

Figure 13 Stages in the T10Q process 57

Figure 14 Number of participants in the T10Q survey by sector 62

Figure 15 Number of participants in the T10Q survey by country of residence 62

Figure 16 Number of participants in the T10Q survey from England by region 62

Chapter 4. Linking the existing knowledge base with research priorities identified in a participatory stakeholder process. 72

Figure 17 Size of scientific knowledge base for each T10Q question as a percentage of the scientific knowledge base for all T10Q questions 81

Figure 18 Actual vs. Expected numbers of publications for each T10Q question, from all EU countries 84

Figure 19 Actual vs. Expected numbers of publications for each T10Q question, from the UK 84

Figure 20 Recent publications as a percentage of the total number of publications for each T10Q question. The horizontal black line shows the database average for all publications in the period 2005-2009 as a percentage of the total number of publications in the database. 85

Chapter 5. Applying an evidence-based framework to validate the science for a key policy issue within the UN-REDD programme 92

Figure 21 Projected global market for forest carbon offsets from forest preservation..... 101

Figure 22 A hierarchy of evidence showing increasing reliability of evidence in a progression from anecdotal evidence as generally the least reliable to systematic reviews as generally the most reliable 102

Figure 23 Evidence framework for decision-making..... 104

Figure 24 Process for assessing carbon stock for an area *a* at time *t* 107

Figure 25 Number of articles of relevance to carbon in forest indexed in three major databases 110

Figure 26 Major carbon pools and fluxes of the global carbon balance in Giga tons of carbon (GtC) (FAO, 2004)..... 124

Figure 27 The saturation problem (after Hofstad, 2005), by permission Hofstad. 131

Figure 28 Calculated minimum detectable difference (MDD) in soil organic carbon inventory as a function of variance ($\sigma 2$) and sample size (n). The MDD is the smallest difference that can be detected ($\alpha = 0.05$) between two mean soil organic carbon inventories with 90% confidence ($1 - \beta$) given the average variance (mean square error from ANOVA) and the sample size (Garten and Wullschleger, 1999). Used with permission, from *Journal of Environmental Quality* 28:1359-1365 134

Chapter 6. Knowledge management for evidence-based forestry..... 184

Figure 29 Growth in published forestry information (Pasiecznik and Petrokofsky 2005)..... 192

Figure 30 Stages in a typical Cochrane-style systematic review 194

Chapter 7. Conclusions and reflections: the way forward..... 197

Figure 31 Steps for improving the quality of science reviews for policy questions 209

Figure 32 Knowledge-use challenge: adapted from Defra website (undated), accessed 2007 210

Chapter 1. Introduction

> *"Forestry… may be called the younger sister and the servant of Agriculture. Each of these arts is essential to the welfare of nations, and no people can be said to be wise, politic, or economic which does not pay attention to the advancement of both"*
>
> *(Nisbet 1905)*

The value of forestry in shaping landscapes is as important now as it was over a century ago when Nisbet was working as a professional forester. However, he would have been surprised by the dramatic shifts in the services and products that woodlands of the 21st Century are expected to deliver. There are new challenges too with rapid environmental change, new pests and diseases and novel economic and social conditions to consider.

Many of these new directions and uncertainties require fresh forest policies and new research to guide decisions and achieve beneficial outcomes for society. This places heavy demands on science to provide the information to form sound, evidence-based policy. Often this requires new approaches to research and will even involve entirely new disciplines in contributing to the forest knowledge base. Broadening the scope of forestry, however, creates a further problem. With research funding in very short supply and ever increasing demands for research from a widening group of players there is a real need for focussed priority setting and careful utilisation of the existing knowledge base.

Public involvement in environmental decision-making was one of the central themes of the 1992 United Nations Conference on Environment and Development (UNCED), the 'Earth Summit'[1]. Although UNCED's focus is on poverty alleviation, public involvement also accords with current thinking on governance and democracy. It is expected now that people's views on a variety of policy issues are sought through open and well-informed debate. The International Union of Forestry

[1] http://www.un.org/geninfo/bp/enviro.html

Research Organizations (IUFRO), the oldest international organisation devoted to forests and 2related science, recognised a lack of connection between the research carried out by scientists in its member organisations (some 700 organisations in over 100 countries) and policies being developed in their countries. In 1998, IUFRO established a Task Force on the Forest Science-Policy interface to:

> *"…develop a better understanding about the ways that forest research results have influenced the development and implementation of policies to protect, manage, and utilize forest resources."* (Gamborg *et al*. 2004**)**

Implicit in this mission, was to learn from past failures as well as successes, why research results did or did not influence natural resource policies. Evidence was gathered using case studies from a variety of geographic scales (from local to national and regional) that dealt with complex sets of forest resources and competing public demands for them. The resulting Guidelines contained a number of recommendations under four broad categories (Guldin *et al*. 2005):

- Focus research on questions relevant to policy issues
- Conduct research in a communicative, collaborative manner
- Encourage researchers to engage with and understand policy processes
- Create capacity and culture for research at the science-policy interface

Whilst these recommendations are clearly important in terms of improving the dialogue between researchers and policy-makers, they do not of themselves guarantee that science will be more influential, or even more widely used. As Jackie Burgess points out:

> *"The learning that accrues from a public-science-policy dialogue is all very well, but people want to get things done too!"*(British Science Association 2002)

There is no one single reason why this does not lead to better-informed policy or better-directed action, but the sheer volume of science and the cost and difficulty of reading through it to gain understanding of complex, often conflicting, messages are daunting for policy-makers.

It is hardly surprising if cherry-picking science becomes routine:

> *"The scientific enterprise is diverse enough to offer information that can be used to support a diversity of perspectives on just about any subject…deciding a course of action and then finding information to support it is common across the political spectrum"* (Pielke 2007)

It is not just the policy community who find are guilty of drawing on information that supports a position, or at least only citing information that supports a particular position. Latour (1987) illustrates how technical papers attract 'friends' and 'dissenters', particularly where there are scientific controversies, and how the patterns of citations amongst these two groups influences the arguments proposed in the original paper, but there are benign reasons, that are more pragmatic and less overtly personal or political, that explain why some scientific pronouncements may be favoured over others. Sheer volume of published science and access to it are significant factors which limit what is available for scientists and policy-makers. The knowledge base continues to grow, year on year, for all science, not just forestry, but it is highly doubtful that people have the capacity to understand, assimilate, evaluate and summarise a growing knowledge base. Institutional resources, do not even allow people to access most of it, a point which will be discussed in Chapter 6.

It is understandable that the general public, landowners and even policy makers, do not know, or have access to, the full spectrum of scientific advice that is available; however, it is altogether more worrying that forestry professionals and academics are mostly aware of only a fraction of the evidence base underpinning practice, and are therefore not well placed to assess the likely shortcomings in the evidence base. A range of tools and techniques used in other disciplines to increase the power of the evidence base, minimise bias, and ensure that selective use of the evidence is eliminated when planning research or constructing policy advice (for example, Dubben and Beck-Bornholdt 2005, Egger *et al.* 1997 in medicine) is almost universally unknown in the forestry sector. Binkley and Menyailo (2005) suggested that forest science should:

> *"embrace standards of evidence established for other scientific fields"*

They included in their paper a brief section titled

"*a case for evidence based forest science*"

apparently using the term 'forest science' to mean decision-making in forestry. None of the subsequent authors who cited their chapter, however, made reference to this valuable suggestion and the idea lay dormant.

My personal involvement over many years with published global research in forestry led me to question this apparent 'isolation' of the extensive research knowledge base from the communities of practitioners, policy-makers and even researchers themselves who would most benefit from using it and who appeared to 'dip into it' rather than interrogate it systematically. In an age where the internet was supposedly democratizing access to information and where publications were increasing exponentially, there were strange knowledge gaps opening up. Senior researchers I met at conferences had very limited access to publications which required subscriptions; people did not know about research taking place in other institutions; papers on almost identical topics were being published with so few common citations that they could have come from entirely different disciplines.

Finally, a literature review of the causes of tropical deforestation, universally recognised, from the News of the World to the journal Nature as one of the biggest environmental threats facing the world, was published so obscurely (Rudel *et al*. 2000) , and with so few references that were common to an earlier review (Kaimowitz and Angelsen 1998), which itself had a puzzling number of missing references, that I felt that the apparent pattern of disregard of existing research was extremely worrying for forestry. These reviews, and many others like them, were commissioned as part of wider initiatives with policy implications. Decision-making, it was clear, was being made in spite of, not because of, the available evidence. It was not that the decisions being taken were necessarily 'wrong' or that new research being undertaken was 'unnecessary' – I am in no position to judge across such a wide field - but that there was no way of knowing; there were no obvious links between the actors in the different parts of the forestry network; no transparent accounts of how these

authoritative accounts of anything and everything had come about. Scientific experiments, field trials, social research projects all use rigorous methods to undertake primary research; methods are usually carefully written in peer-reviewed (and other) publications. Rigour counts. But literature reviews, which underpin so much policy are written with no details of the methods used to find and analyse the research which they summarise. This means that they are unrepeatable, which undermines the cornerstone of scientific enquiry. I would go so far to say that they are not scientific. And yet they carry as much authority as carefully documented research. They are arguably more influential: the first port of call for any new project or policy area is usually an existing literature review.

Looking to other fields, the necessity for transparency and a systematic approach to research has a long history. For example, this has long been a concern for the medical profession: Sidney Burwell, the Dean of Harvard Medical School commented in the 1950s that:

> *'the rate and magnitude of change is such that the contents of a medical student, like the contents of a text-book, are partly out of date at the time of publication. Indeed, I've made a little speech to fourth year students that runs like this: "your teachers have tried to give you a good opportunity to learn and to offer you information which the evidence indicated to be accurate. Nevertheless, probably half of what you know is no longer true. This troubles me, but what troubles me more is that I don't know which half it is."'(*Pickering 1956*).*

Medicine introduced not only a systematic approach to its scientific knowledge base, with varying degrees of success and acceptability (Chalmers 2005, Chalmers and Altman 1995) but a new way of engaging the key actors –scientists, experts (clinicians, physicians, etc.) and patients and their carers - in decision-making in the context of high-quality science and other evidence that is available for all the actors (Sackett *et al*. 1996).

Forestry has not embraced this approach to evidence-based policy making. Given the growing interest in linking research with policy and practice, exemplified by the IUFRO work, and the increasing use of the phrase 'evidence-based', with no associated definition within the forestry context, I believed that it was timely to look at how closely the research agenda is linked with what

the ‘community’ of foresters think is important, and how fit for purpose the knowledge base is to answer important questions in a way that could justify the term ‘evidence-based’.

1.1 The aims of this study

Hypothesis

Despite the widespread calls for better use to be made of evidence and research in policy making, the forestry science base is not fit for purpose and could be improved by the adoption of evidence-based frameworks.

Sub-hypotheses

Science could be more effective for policy if:

- it is systematically evaluated;
- there is a dynamic mechanism for ensuring that there is a match between the needs of policy makers and the research activities and outputs of the research communities;
- the research agenda for forestry is constructed with regard to the needs of the wider forestry sector.

1.2 Framework for examining the hypotheses

I developed a framework to help conceptualise the current context in which science in used for policy and decision-making, and a future context in which issues examined in the hypotheses had been addressed (Figure 1).

The thesis examines the possibility of moving from the current 'haphazard' situation in forestry, described for medicine by Petticrew and Roberts (2006), that is characterised by non-transparent methods of finding and analysing research from the total body of relevant research available for any given policy question, to the situation of evidence-based forestry, in which systematic, repeatable methods outline how research is used.

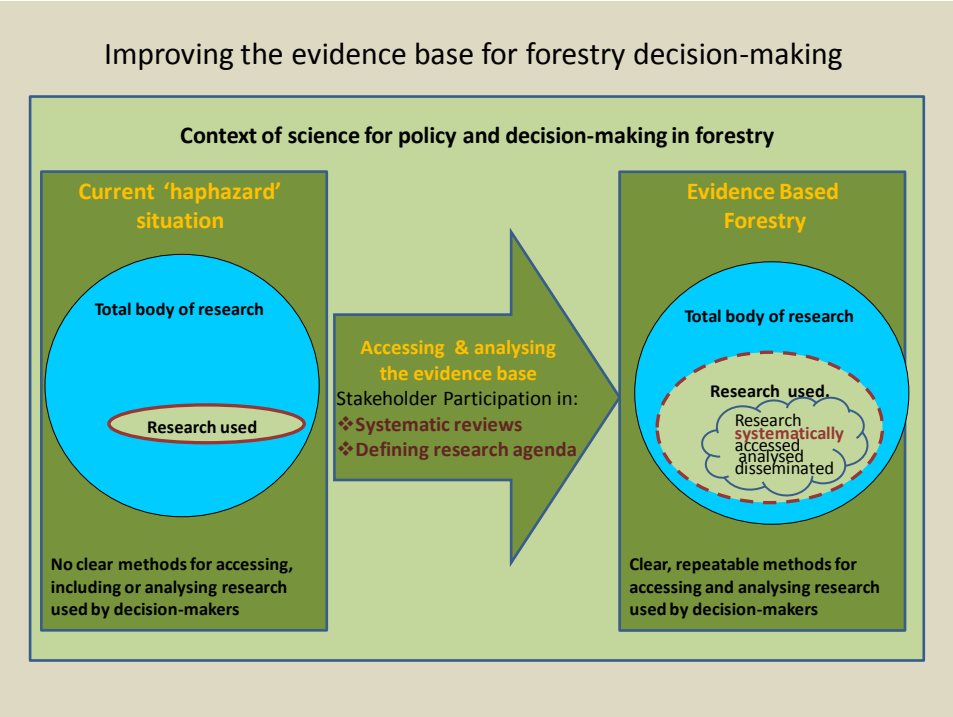


Figure 1 Conceptual framework for evidence-based forestry

The aim of evidence-based forestry would be twofold: an increase not only in the volume of research accessed by decision-makers, but an increase in the quality and relevance of scientific evidence, achieved through systematic analysis and stakeholder involvement. The boundaries of both these bodies are indicated as fluid in Figure 1; the more that research is accessed and analysed systematically, the more research will be utilised. Introducing and increasing stakeholder participation in two key areas of science – agenda setting and evidence evaluation – has the potential to increase both of these bodies of research.

The thesis has not set out to measure the impact of introducing an evidence-based framework for forestry decision-making, the time frame of this study was far too short to allow a new idea to penetrate even a small part of this broad sector, but a set of steps for improving the quality of science for policy is proposed that could be used in due course to design a rudimentary evaluation model.

The third strand of the model is the dissemination of the results of science evaluations in appropriate formats which ensures that knowledge circulates through the system, promoting further improvements in agenda setting and evidence evaluation and, ultimately, a better evidence base. In medicine, dissemination of findings is an integral part of the systematic review process and fundamental to ensuring that the essential messages from the review reach the appropriate audiences. Strategies for dissemination are considered at an early stage to allow adequate time for planning and development and to ensure that the proposed activities are properly resourced (Centre for Reviews and Dissemination 2008).

Disseminating forestry information has been highlighted as an essential component for effective international forestry for many years (Finlayson *et al*. 1978), and the availability of vast amounts of information via the internet and the possibility of very rapid communication has not brought an end to the problems of ineffective knowledge exchange. Kleinschmit and Real (2009) recently highlighted poor communication as a hindrance to good forestry policy after an extensive international survey of academics and decision-makers who are active in forestry and related fields.

The focus of this thesis is on the quality of the scientific evidence base as a resource for use by policy-makers, decision-makers, researchers, or indeed, any other stakeholders. The assumption is made that good policy-making relies on effective use of high quality research (and other) evidence. Evaluating the success of policies and the impact of the scientific inputs, though enormously important from the perspective of improving policy-making, is outside the scope of this thesis.

1.3 Participatory approaches

The pressure to adopt a more participatory approach to the development of forest policies has been growing steadily (Innes and Hoen 2005). Public involvement in environmental decision-making was one of the central themes of the 1992 United Nations Conference on Environment and Development (UNCED), the 'Earth Summit'. Although participatory methods in natural resource work were initially investigated in developing countries (e.g. Buchy and Hoverman (2000) , Côté and Bouthillier (2002), Pagdee *et al.* (2006),Van Herzele *et al*. (2005), Leach (2006) and DesRoches (2007)), participation and 'citizen engagement' now accord with current thinking on policy-making in developed countries (Carnegie United Kingdom Trust, 2008). The EU Forestry Strategy was developed in 2004 using a participatory and transparent approach (European Commission, 2005), which is now mainstream for developing national forest policies in EU countries.

Participatory methods are used for the two principal case studies which form the basis for my current research. Participation is now widely accepted as an essential principle for policy framework development in forestry. The general trend towards more attention for strengthening stakeholder participation in policy processes gained momentum in the forestry sector following endorsement by the Intergovernmental Panel on Forests (IPF) of national forest programmes (NFPs) as a means improving forest policy processes. The IPF principles stressed the need for participation of, and partnerships with, all stakeholders in a shared effort to promote sustainable forest management.

Although there had been a tendency to carry out superficial participatory processes in order to 'tick the box' requiring participation (FAO 2003), progress was made following establishment by FAO and the National Forest Programme of a Community of Practice on 'Enhancing stakeholder participation in national forest programmes'. The logical step from having stakeholder participation in NFPs, is to widen participation in the production and utilisation of evidence, including,

importantly but not exclusively science. Chapter 3 discusses participation in the context of setting a research agenda and framing research questions of relevance to forestry policy.

Cooper *et al*. (2007) described a continuum of community science research models that involve the public, from 'Science Shops' (the Scientific Consulting Research model developed in the Netherlands in the 1970s) through the 'Citizen Science' model, which uses a network of volunteers to work mainly on data collection with professional researchers using methodologies that have been developed by (or increasingly in collaboration with) these researchers on research questions posed by the researchers in response to policy issues, exemplified by the work of Earthwatch (Bebber 2010), to the 'Participatory Action Research' model that starts with the interests of participants, who work collaboratively with professional researchers through all steps of the scientific process to find solutions to problems of community relevance.

The methods explored in this thesis may not fit Cooper's classification of citizen science models, unless one considers that data collection includes collecting ideas for research questions (arguably it does). Although the 'general public' have not specifically been included in the group of participants, the method adopted for the project does contain Finn's (1994) three key elements of participatory research, at least for a broadly defined community of forestry professionals (which includes woodland owners):

(1) it responds to the experiences and needs of the community,

(2) it fosters collaboration between researchers and community in research activities,

(3) it promotes common knowledge and increases community awareness.

It would be stretching definitions rather too widely to argue that systematic reviewing is citizen science, but I have described it in this work as 'participatory' because it is clearly a process that draws on the elements elaborated by Finn and others.

1.4 Outline of the thesis

A version of the evidence framework developed in chapter 5 serves as a route map for the thesis. The chapters follow the elements of an evidence-based framework (Figure 2).

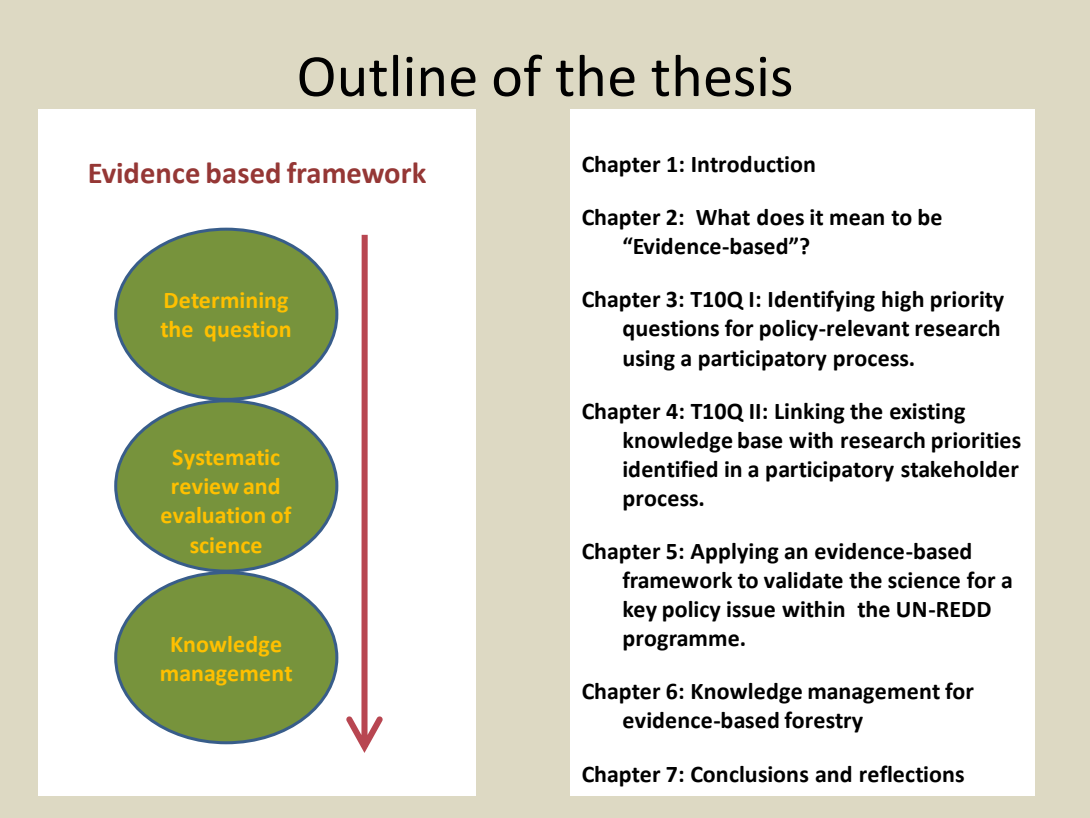


Figure 2 Elements of an evidence framework for a systematic use of science for policy

1.5 Summary of the chapters

Chapter 2: What does it mean to be "Evidence-based"?

The growth of the term 'evidence-based' in forestry is examined empirically by examining occurrences of the term in academic publications, blogs and in web pages generally. The increasing usage of the term is compared with that of the term 'evidence based medicine', for which a robust definition has been in existence for over a decade. The history of evidence based medicine is discussed, with particular reference to systematic reviews, which have been developed as tools for ensuring that the science which supports policy is compiled with minimum bias and is analysed within a participatory setting, with opportunities for engagement by stakeholders in setting the review question, finding the evidence, analysing the findings, disseminating the results and suggesting further research. The lack of systematic reviews in forestry, or any formal framework which defines an evidence based approach to the science used for decision-making, suggests that 'evidence-based' is attached to work as a borrowed quality mark, but with no universally understood minimum standard. A definition of 'evidence based forestry' is proposed.

Chapter 3: Identifying high priority questions for policy-relevant research using a participatory process.

There is growing interest in widening public participation in research and practice in environmental decision-making and an awareness of the importance of framing research questions which reflect policy needs. Building on the need for greater stakeholder involvement in the question-framing element of evidence-based frameworks for forestry, the T10Q (Top Ten Questions for Forestry) project was undertaken to investigate a process for compiling and prioritising a meaningful set of policy-relevant research questions using a collaborative, bottom-up approach that involved professionals from a wide set of disciplines of relevance to modern forestry. Details are presented of the process which involved an online survey and a workshop for participants in the United Kingdom and Republic of Ireland. Survey responses were received from 481 researchers, policymakers and

woodland owners, who contributed 1594 research questions. These were debated and prioritised by 51 people attending the workshop. The project engaged people who were outside the traditional boundaries of the discipline, a trend likely to be more important in the future, particularly in the light of complex problems connected with climate change, bio-energy provision or health and well-being, for example, which require multidisciplinary partnerships within the research and policy communities.

Chapter 4: Linking the existing knowledge base with research priorities identified in a participatory stakeholder process: the T10Q project as a case study for forestry

The Top Ten Questions for Forestry research (T10Q) project was developed further to explore the global knowledge base of science which currently exists for these questions. The ten questions emerged from a large-scale stakeholder consultation. The threats posed by invasive species, pests and diseases emerged as the top-ranked priority. The volume of published European literature for this topic was somewhat lower than expected, compared with the other nine questions and overall database figures. Fostering understanding between society and the forestry community, improving knowledge transfer, assessing links between forest and human well-being, and understanding ownership of private forest were high-priority social research questions. Ecosystem responses to climate change, understanding variations in carbon pools and the impacts of land uses on forest fragmentation were considered to be high-priority ecological questions. Choosing provenances to plant for climate adaptation and expanding woodfuel production were the main silvicultural concerns. Analysing the published scientific literature of relevance to the top ten questions demonstrates a novel way of using bibliometrics to link stakeholder priorities with the existing knowledge base to provide a richer picture of the state of scientific evidence available for decision-making.

Chapter 5: Undertaking a systematic review: a case study of a multidisciplinary approach to terrestrial carbon assessment methods under the UN-REDD Programme.

The case study was conceived under the UN-REDD programme[2] as a project to investigate the potential for conducting a systematic review of the global literature on monitoring and assessment methods for carbon stocks using an evidence-based frameworks to shed further light on the scientific validity of the knowledge base in this area. Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD) was a good candidate for a contemporary policy area in which to test the possibility of conducting a systematic review, given its high prominence in national and international discussions, and the wealth of relevant forestry research that is available to evaluate. Amongst the areas of REDD which are the subject of active discussion and research are arguments over forest carbon measurement accounting, and trading. These include the technical aspects of monitoring and verifying change in forest cover, and criteria for establishing credible deforestation baselines.

Despite the wide range research on methods and data sources for assessing carbon, and a concomitant proliferation of scientific and technical papers, there was a perceived lack of rigour in reviewing these methods. A collaborative project was undertaken analyse this literature using evidence-based frameworks of the type widely used in medicine and other policy areas which require scientifically-grounded decision-making. The aims of the project were to lend scientific credibility to the guidance given to countries participating in a future REDD mechanism, and to provide scientific underpinning of the many approaches which exist. The chapter is in two parts: Section A is an outline of the approach taken to establish a group of people with no previous knowledge of systematic review to the point of writing a Protocol for the review. Section B is the Protocol written in collaboration with the group, which emerged as an output of the scoping phase of the project.

[2] http://www.fao.org/climatechange/unredd/en/

Chapter 6: Knowledge management evidence-based forestry

To ensure that the best evidence is available to guide decision-making in forestry, effective mechanisms are necessary for analysing and communicating the results of research. In medicine, an evidence based approach, developed in Canada in the early 1990s to assist doctors in applying good science when treating patients, has grown rapidly and globally and has widespread support amongst practitioners, policy-makers and the public. The approach has required the development of new methodological tools for systematically reviewing research.

There are a number of features of the systematic review process which should recommend it to the field of forestry. The volume of research is increasing exponentially, which makes it increasingly difficult for scientists, policy makers and research funders to review the existing body of knowledge in a way that eliminates bias associated with traditional narrative reviews. Librarians have a role to play in the steps identified for successful evidence-based practice, notably in gathering the best evidence with which to answer the review question, critically appraising it for its relevance to the problem, summarising the evidence, distributing the findings, and facilitating feedback on the findings to improve future research or practice.

Librarians have the skills and tools, practiced daily, for these tasks and a long tradition of networking, which is at the heart of the systematic reviewing process. In forestry there are networks of librarians and other information professionals who already work closely with forestry researchers and practitioners.

Evidence-based forestry does not currently exist in the form understood in medicine or practiced in fields such as education, justice and even librarianship itself, and there are fewer than a dozen systematic reviews which would meet the exacting standards set by medicine through the Cochrane Collaboration, for example. There is therefore real scope for involving librarians at a very early stage in the development of Cochrane-style review groups to make better use of the existing evidence base in forestry and to identify significant knowledge gaps.

Chapter 7: Conclusions and reflections: the way forward

There is no reason why forestry should not follow medicine, social policy, education and nature conservation in embracing a genuine evidence-based approach for policy questions which impact on society. The experiences of collaborative work in framing a research agenda which responds to key concerns were highly positive and could be further developed. Experiences in adopting a systematic approach to review the science for a key policy question of global importance revealed the full range of responses from highly sceptical to evangelically enthusiastic. There are benefits of collaboration for question framing, accessing sources of evidence, critical evaluation of the science and knowledge management and dissemination.

Chapter 2. What does it mean to be "Evidence-based? Towards a model for evidence-based forestry.

"Writing texts that withstand the assaults of a hostile environment"

(Latour 1987)

The growth of the term 'evidence-based' in forestry is examined empirically by analysing occurrences of the term in academic publications, blogs and in web pages generally. The increasing usage of the term is compared with that of the phrase 'evidence based medicine', for which a robust definition has been in existence for over a decade. The history of evidence based medicine is discussed, with particular reference to systematic reviews. These have been developed as tools for ensuring that the science which supports policy is compiled with minimum bias and is analysed within a participatory setting, with opportunities for engagement by stakeholders in setting the review question, finding the evidence, analysing the findings, disseminating the results and suggesting further research. The lack of systematic reviews in forestry, or any formal framework which defines an evidence based approach to the science used for decision-making, suggests that 'evidence-based' is attached to work as a borrowed quality mark, but with no universally understood minimum standard. A definition of 'evidence based forestry' is proposed.

2.1 Evidence-based medicine: the original 'evidence-based' concept

A Google search for the phrase "evidence based" returns over seven million web pages, of which almost 700,000 were added or re-indexed in 2010 from UK domains alone, and 2.5 million from domains in the USA. It is a phrase routinely used in newspaper articles, from the Westmorland Gazette, a small regional newspaper in the UK, once read avidly by William Wordsworth and Beatrix Potter, to the Times of India, the world's largest English-language circulation daily newspaper, read by over 13 million people. But what does the term mean to these readers, or, indeed to the growing number of academics who use the phrase? Do they mean what the originators of the concept in medicine mean? Have they defined a different meaning? Are they perhaps using it to attach

additional legitimacy to their work, or is it now impossible *not* to claim to be evidence-based, in the same way that it became difficult *not* to write about 'sustainable forestry' once the Second Ministerial Conference on the Protection of Forests in Europe (MCPFE), in Helsinki in 1993, had defined "sustainable forest management"[3]?

The roots of the phrase 'evidence based' are in medicine. Almost forty years ago, Professor A.L. (Archie) Cochrane, who has been called the 'Father of Evidence-Based Medicine' described:

> *"ineffective, unproved, and occasionally harmful medical treatments"*

and presented a picture of medicine characterised by widely varying practice where 'a not insubstantial amount of practice had not been well evaluated' (Cochrane 1972). Perhaps even more worryingly, new medical treatments and techniques were influenced by:

> *"a complex interplay of professional, commercial and public pressures"*

rather than a:

> *"coherent policy for assessing the relative value of different technologies",*

which gave rise to widely differing practice within and between countries (Jennett 1992).

Disquiet about the lack of critical evaluation of evidence in medical practice grew until the term 'evidence based medicine' was coined in the 1980s to label a clinical learning strategy, which the medical school at McMaster University, Canada had been developing for over a decade (Rosenberg and Donald 1995). This strategy involved four steps:

---

[3] Resolution H1: General Guidelines for the Sustainable Management of Forests in Europe, Second Ministerial Conference on the Protection of Forests in Europe, 16-17 June 1993, Helsinki, Finland. http://foresteurope.org/filestore/foresteurope/Conferences/Helsinki/helsinki_resolution_h1.pdf

1. formulate a clear clinical question from a patient's problem;
2. search the literature for relevant clinical articles;
3. evaluate (critically appraise) the evidence for its validity and usefulness;
4. implement useful findings in clinical practice.

The first published use of the term was in a paper produced by a large working group chaired by Gordon Guyatt at McMaster in 1992. Their paper expounded on what they termed a "new paradigm for medical practice" which "de-emphasizes intuition [and] unsystematic clinical experience… as sufficient grounds for clinical decision-making" and instead, stresses the necessity of evaluating evidence from research. Among the new skills they insisted were necessary for physicians was the ability to conduct efficient literature searches and the application of formal rules of evidence evaluation of the clinical literature (Evidence-Based Medicine Working Group1992).

Since then, there have been many different definitions articulated in journals, books, training materials and on websites. They all share core elements, but they place emphasis subtly differently, to some extent in response to criticisms or as a result of misunderstandings which have arisen over time about what evidence based medicine means. David Sackett (1996), who was the first Director of the Centre for Evidence Based Medicine, Oxford defined it as the:

> *"conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients"*

Greenhalgh (1998, 2001), who has written extensively about the importance of narrative and discourse in health care, noted that:

> *"Evidence based medicine requires you not only to read the right papers at the right time but then to alter your behaviour (and, what is often more difficult, the behaviour of other people) in the light of what you have found"*

Muir Gray (1997) refuted criticisms that evidence based medicine is only a scientific application of knowledge by an 'expert' to a problem, by defining evidence based clinical practice as:

> *"an approach to decision making in which the clinician uses the best evidence available, in consultation with the patient, to decide upon the option which suits that patient best."*

Finally, McKibbon (1998), returning again to the theme after some years' experience evaluating evidence-based practice and writing for the medical library association came up with a comprehensive definition of evidence-based practice (EBP) as:

> *"an approach to health care wherein health professionals use the best evidence possible, i.e. the most appropriate information available, to make clinical decisions for individual patients. It involves complex and conscientious decision-making based not only on the available evidence but also on patient characteristics, situations, and preferences. It recognizes that health care is individualized and ever changing and involves uncertainties and probabilities."*

This very measured definition has resonance with natural resources management and, in particular, forestry, with its long time-frames and complex interactions of physical and human elements. Evidence based forestry has not yet been defined, but it is clear from the literature that there has been a growing tendency to use the term 'evidence-based' in environmental literature, including forestry. This chapter explores the growth of the phrase outside medicine and proposes a definition that would be applicable to forestry.

2.2 Evidence based policy and public acceptability

The 1999 Government White Paper, Modernising Government makes the following commitment: 'government must be willing constantly to re-evaluate what it is doing so as to produce policies that really deal with problems; that are forward-looking and shaped by the evidence rather than a response to short-term pressures; that tackle causes not symptoms; that are measured by results rather than activity; that are flexible and innovative rather than closed and bureaucratic; and that promote compliance rather than avoidance or fraud. To meet people's rising expectations, policy making must also be a process of continuous learning and improvement' (Cabinet Office 1999).

The phrase 'evidence based policy', though not used in this White Paper, began to be used shortly after its publication to describe the approach taken by the UK Government as a contribution, at least in part, towards building public trust in policy-making following the BSE crisis. Whether this was a new approach, or a new phrase for an existing approach somewhat adapted, is not certain but it is clear that the media were not using the phrase in a way that presupposed public understanding of the concept prior to the White Paper, though there was a steady increase in its appearance from mid 1999 on the back, perhaps, of this and another 1999 White Paper (on statistics) and a feeling that a new approach was being set out by a Government intent on responding to a new set of criteria.

A search of LexisNexis for the phrase 'evidence based policy' in British broadsheet newspapers brings up only 2 articles prior to 1 March 1999, the earlier, in the Guardian, opining that

> *"Evidence-based medicine is not paralleled by evidence-based policy or management"*

in an article discussing GP's fears that changes in the NHS were happening too fast and that the radical policy agenda had not been matched by the rapid dissemination of information, advice and guidance (Guardian (London) May 20, 1998). The second article to use the phrase was urging 'government commitment to more explicit evidence-based policy and practice [in education] supported by a crucial mediation infrastructure to help interpret research' (The Independent (London)

October 29, 1998). By contrast, there are 98 articles using the phrase ‘evidence based medicine’ prior to March 1999.

A complete track of the development of the phrase to something fully embedded in public consciousness is outside the scope of this review, but it is clear from an examination of the broadsheets at least that it moved very quickly after March 1999 into general use. Tim Holt, director of the Office for National Statistics, appears to be the first to have been quoted in the national press using the phrase in relation to an identifiable Government approach with which readers were expected to be moderately familiar. The newspaper article contains the comment ‘Mr Holt is convinced that the increased focus on evidence-based policy means that "the outlook for statistics is incredibly positive"’ (Financial Times (London Edition) April 3, 1999). Shortly afterwards, the Government is being termed ‘an advocate of evidence-based policy’ in an article in May 1999 (Guardian (London) May 12, 1999).

Adoption of the phrase was not met with universal approval. Within weeks of the release of the White Paper on modernizing government, Chris Holme, writing in the Glasgow Herald has this to say about the phrase:

> *“Beware new buzzwords floating around Holyrood. Muir Russell, chief civil servant at the Scottish Office, says legislation will be anchored on "evidence -based" policy. This is, presumably, a change from existing law-making which is made on whim, ignorance, or spousal instruction. The concept is, of course, a lift from the current trend of evidence-based medicine, which, it has to be said, doesn't inspire universal slavish adherence among practicing doctors. It gets the evidence bit from mass randomised controlled trials which means we should be in for a bit of interesting social policy engineering from the Holyrood 129”* (The Herald (Glasgow) April 14, 1999).

The Herald’s distrust of the term lingered long – an article in 2002 spoke of Members of the Scottish Parliament:

> *“descending into management-speak with cries of ‘evidence-based policy development’”* (The Herald (Glasgow) Dec. 19, 2002).

but by July 2004 the Herald was noting that the Chancellor of the Exchequer, Gordon Brown,

> *'demonstrably lives evidence-based policy'*
>
> (The Herald (Glasgow) March 19, 2004).

Proof perhaps that acceptability of the concept of evidence based policy had moved from the mouths of 'policy wonks' in London to society in general.

2.3 Growth of the term 'evidence-based'

I took an empirical approach to examining how extensive the concept 'evidence-based' is in the scientific environmental literature and in the less formal content available through Google on the web.

Method

Bibliographic databases of academic publications and Google Search were used to search for references to the phrase "evidence based" in the environmental literature. The trends over time in the occurrence were compared with trends for the phrases "evidence-based medicine" and four comparator phrases with similar numbers of articles in bibliographic databases. Thomson Reuters' ISI Web of Knowledge (WoK)[4] indexes two significant bibliographic databases which are relevant for these searches: MEDLINE[5] (the United States National Library of Medicine's bibliographic database covering the fields of medicine, nursing, dentistry, veterinary medicine, the health care system, and the preclinical sciences) and Web of Science (WoS). Experiences searching WoK are not the same for all users – different institutions subscribe to different databases within the suite of resources available. WoS searching can also vary between institutions, depending on subscriptions;

[4] http://www.isiwebofknowledge.com

[5] http://www.nlm.nih.gov/databases/databases_medline.html

Conference Proceedings Citation Indexes, for example, are a separate subscription, but because the search operates seamlessly within WoS, this can be a source of confusion where different results are obtained in different institutions.

Elsevier's SciVerse Scopus[6] is equally comprehensive for this area of work (see Chapter 5) and has some significant advantages for bibliometric work (Ball and Tunger 2006), notably it is possible to search stop words in phrases, which is useful in the present investigation. Stop words are common, frequently-used words, which rarely have significance in a search strategy. Examples include:

- some articles (such as "*the"*, "*an"*)
- some conjunctions (such as "*as"*, "*because"*, "*if"*, "*when"*)
- most personal pronouns (such as "*he"*, "*she"*, "*we"*)
- some prepositions (such as "at", "for", "on")

Although Scopus is also available only on subscription, the content does not vary between institutions, which makes working with groups across institutions slightly more transparent.

References to training courses, workshops, seminars and reports generate large sources of information in addition to the scientific articles indexed in MEDLINE, WoK, Scopus and other bibliographic databases and these are valuable sources of 'grey literature (discussed in more detail in Chapter 5). Common usage of phrases in newspapers, magazines, and online content such as blogs, is also a useful way of tracking how ideas spread from research into general use. Google is not the only web search engine, but it amongst the largest and since September 21, 1999, when it launched officially, it has grown considerably in size, from 560 million pages in June 2000 to over 5 billion by September 2005. After this time the company stopped advertising the number of pages on their website (Notess 2006). The main advantage Google has over other web search engines, however, is

[6] http://www.info.sciverse.com/scopus/

the search features that make it suitable for use in bibliometric analysis: phrase searching, data range searching, Boolean operators (AND, OR, NOT), which are illustrated in Figure 3, using a search string which is described below.

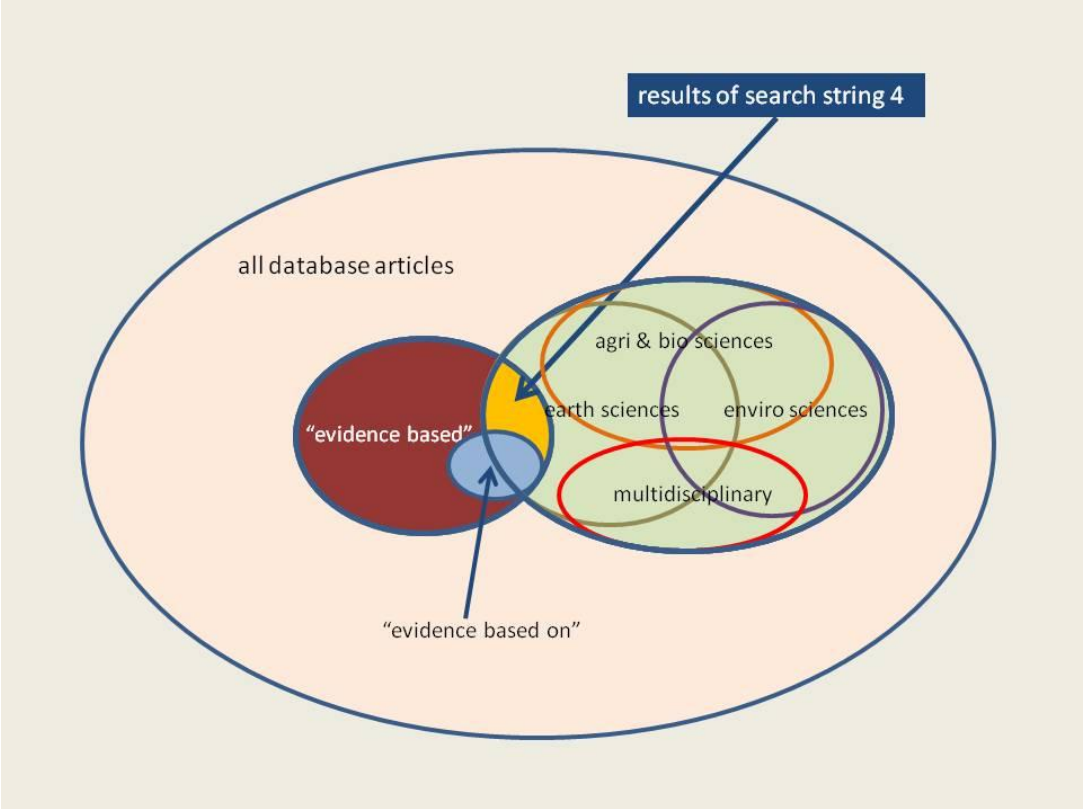


Figure 3 Boolean logic illustrated for search string 4 below

Academic articles

a) Evidence based medicine

MEDLINE was searched on 8 March, 2011 using the following search strategy:

search string 1: TI=("evidence based medicine") OR AB=("evidence based medicine") OR MH=(evidence based medicine)

where TI=title; AB=Abstract; MH=MESH (Medical Subject Headings)

MeSH is the National Library of Medicine's controlled vocabulary thesaurus. It consists of sets of terms naming descriptors in a hierarchical structure that permits searching at various levels of specificity (http://www.nlm.nih.gov/pubs/factsheets/mesh.html)

In order to determine the extent to which there had been a general increase in publications, the numbers of papers included in the category in which the term "evidence based medicine" is placed within the MeSH thesaurus hierarchy was searched on 8 March, 2011 using the following search strategy:

search string 2: MH=(Health Occupations)

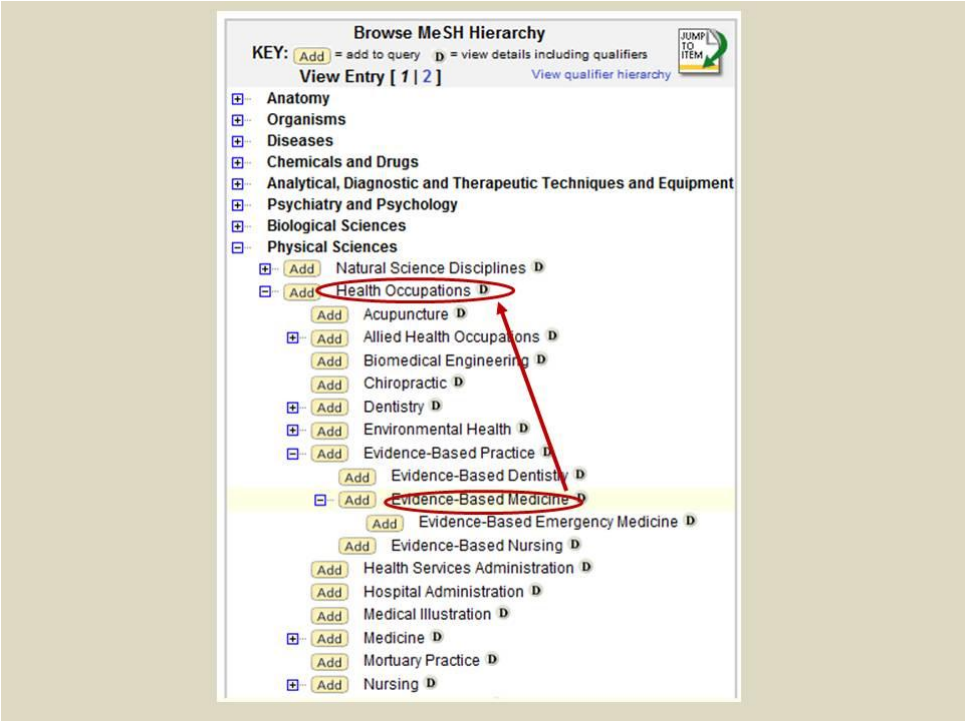


Figure 4 MeSH Thesaurus extract showing hierarchy for 'evidence based medicine'

Figure 4 shows the relevant portion of the MeSH hierarchy, with "Health occupation" indicated as the 'parent' category for 'evidence-based medicine'

The results of the searches were sorted by year from 1995 to 2010.

b) Evidence-based 'environment'

Using similar logic, Scopus was searched on April 21, 2011 for the phrase "evidence-based" within the subject areas which contain most scientific articles about environmental issues:

- Agricultural and Biological Sciences
- Earth and Planetary Sciences
- Environmental Science
- Multidisciplinary (also chosen to include articles in publications which have a broad subject coverage)

Preliminary results of searches in WoS conducted on March 8, 2011, indicated a potential problem with the phrase "…evidence based on…" in contexts which were not referencing "evidence-based medicine" or "evidence based policy". Examples were:

> *"Renewable energy policies and technological innovation: Evidence based on patent counts"*
>
> *"Our changing atmosphere: Evidence based on long-term infrared solar observations at the Jungfraujoch since 1950"*

For this reason, the searches were carried out in Scopus, using their work-around solution for searching stop words. Enclosing a phrase containing a stop word in double quotes enables the software to retrieve occurrences of the phrase. Searching for the phrase "evidence based" and eliminating articles with the phrase "evidence based on" gave a more accurate result.

> *search string 3: (TITLE-ABS-KEY("evidence based")) and not (TITLE-ABS-KEY("evidence based on"))AND (LIMIT-TO(SUBJAREA,"AGRI") OR LIMIT-TO(SUBJAREA,"ENVI") OR LIMIT-TO(SUBJAREA,"EART") OR LIMIT-TO(SUBJAREA,"MULT")*

The results of the searches were sorted by year from 1995 to 2010.

In order to assess the extent to which there had been a general increase in publications, the total number of papers included in the subject areas was determined. In common with WoS, Scopus does not allow a search of all publications, or even all publications within a year, or a subject area. The software demands a search term or author name. A work-around was devised, whereby common stop words ("a", "and", "or", "the") were searched, on the assumption that most papers would include these words somewhere in their title, abstracts or keywords.

> *search string 4: ((TITLE-ABS-KEY("a"))) or ((TITLE-ABS-KEY("or"))) or ((TITLE-ABS-KEY("and"))) or ((TITLE-ABS-KEY("the"))) AND (LIMIT-TO(SUBJAREA,"AGRI") OR LIMIT-TO(SUBJAREA,"ENVI") OR LIMIT-TO(SUBJAREA,"EART") OR LIMIT-TO(SUBJAREA,"MULT"))*

c) Comparator phrases

The search strategies outlined in (b) were repeated for four phrases with similar results set sizes in Scopus. Two were chosen to represent phrases likely to have remained consistent over time since 1995 ("small sample" and "tropical rain forest"), and two were chosen as examples of phrases which

may have been subjected to changing levels of interest over time ("acid rain" and "deforestation", the former an example of an environmental concern which was, perhaps, the "global warming" of the 1980s (Pasiecznik and Petrokofsky 2005), and the latter receiving a great deal of attention following developments post-Kyoto, particularly in negotiations for Reduced Emissions from Deforestation and forest Degradation (REDD)[7] (see Chapter 5).

search strings 5/6/7 : (TITLE-ABS-KEY("small sample"/ acid rain"/"deforestation")) AND (LIMIT-TO(SUBJAREA,"AGRI") OR LIMIT-TO(SUBJAREA,"ENVI") OR LIMIT-TO(SUBJAREA,"EART") OR LIMIT-TO(SUBJAREA,"MULT"))

General content available through a Google search

a) Evidence based medicine

The phrase "evidence based medicine" (which also retrieves incidences of the hyphenated phrase "evidence-based medicine"), was searched in Google for the date range 1/1/1995- 31/12/2010:

search string 8:
http://www.google.co.uk/search?q=%22evidence+based+medicine%22&hl=en&lr=&sa=X&ei=mJOuTbSpK5GwhAeD3_TdAw&ved=0CAwQpwUoBg&source=lnt&tbs=cdr%3A1%2Ccd_min%3A1%2F1%2F1995%2Ccd_max%3A31%2F12%2F2010&tbm=

Altering the dates highlighted in search string 3 gives results for different years, e.g. for 2002:

search string 8(for the year 2002, as an example):
http://www.google.co.uk/search?q=%22evidence+based+medicine%22&hl=en&lr=&prmd=ivnsb&sa=X&ei=M5iuTbDYHMaShAfktuXdAw&ved=0CBkQpwUoBg&source=lnt&tbs=cdr%3A1%2Ccd_min%3A1%2F1%2F2002%2Ccd_max%3A31%2F12%2F2002&tbm=

[7] See UN-REDD Programme http://www.un-redd.org/

b) Evidence-based ‘environment’

Using the same search strategy, Google was searched for incidences of the phrase “evidence based” in a subset created broadly to represent ‘environmental’ interest. In contrast to searching in bibliographic databases, complex searches in Google are limited. There is a limit for the number of characters in any search string. After experimenting with various phrases, a simple string was adopted: ‘natural resource’ plus ‘forestry’ plus ‘ecology’ plus ‘ecosystem’.

This does not attempt to capture all records of environmental interest, but it allowed some comparisons to be made between key phrases to track trends in content in web pages and on blogs. Many of the web pages retrieved were primarily about evidence-based medicine, the words ecology, ecosystem, etc. appeared in the pages without being a focus of the content. Eliminating records which included the word ‘medicine’ provided a simple, if somewhat blunt, solution.

Well-constructed searches in more complex databases (such as MEDLINE, Scopus, WoS, etc.) would not normally use the Boolean operator ‘NOT’ (which is the equivalent of Google’s minus sign preceding a term) in this way, because it would eliminate genuinely interesting articles, whose primary focus was on environmental issues, and medicine was mentioned in a secondary capacity. However, as previously discussed, Google does not allow this level of sophistication, and the object of the method was to highlight trends, rather than attempt to analyse the numbers closely.

The search strategy for ((("evidence based") AND ("natural resource" OR forestry OR ecology OR ecosystem)) NOT medicine) limited to each year from 1995 to 2010 (using the year 2000 to illustrate) is shown in search string 9.

search string 9:
http://www.google.co.uk/search?q=%28%28%22evidence+based%22%29+AND+%28%22natural+resource%22+OR+forestry+OR+ecology+OR+ecosystem%29%29+%E2%80%93medicine&hl=en&sa=X&ei=bj2zTabPMcqi8QOnovWVDA&ved=0CAwQpwUoBg&source=lnt&tbs=cdr%3A1%2Ccd_min%3A1%2F1%2F2000%2Ccd_max%3A31%2F12%2F2000&tbm=#q=((%22evidence+based%22)+AND+(%22natural+resource%22+OR+forestry+OR+ecology+OR+ecosystem))+%E2%80%93medicine&hl=en&prmd=ivns&sa=X&ei=jz2zTdmbHZKs8QP32eyVDA&ved=0CBIQpwUoBg&source=lnt&tbs=cdr:1%2Ccd_min%3A1%2F1%2F2000%2Ccd_max%3A31%2F12%2F2000&tbm=&fp=4287dfd63891046d

c) Comparator phrases

The comparator phrases 'acid rain', 'small sample', and 'deforestation' replaced the phrase "evidence based" in search string 9.

Content searched through Google Blogs

In addition to these information resources, there is a rapidly-expanding collection of blogs that contain items of varied quality and usefulness, but are nonetheless indicative of issues of current interest to non-academic audiences as well as researchers (Hewitt 2005).

a) Evidence based medicine

Google Blogs was searched for posts containing the phrase "evidence based medicine" created or modified in each year from 2000 to 2010. The search can be limited to blogs by selecting the option Blogs from the menu, which generates "tbm=blg" in the search string. (Other options for searching particular Google content include 'Discussions' (tbm=dsc), and 'Videos' (tbm=vid), which were not used for the present study.)

search string 10:
http://www.google.co.uk/search?q=%22evidence+based+medicine%22&hl=en&lr=&biw=1440&bih=689&prmd=ivnsb&sa=X&ei=aZuTZiuG4KLhQeZvujdAw&ved=0CBMQpwUoBw&source=lnt&tbs=cdr%3A1%2Ccd_min%3A1%2F1%2F1995%2Ccd_max%3A31%2F12%2F2010&tbm=blg

b) Evidence-based 'environment'

The same strategy was used as before to define the set of environmental content. In this case, however, the term 'medicine' was not excluded from the search string. Preliminary examination of the blogs revealed that a large number were comparing evidence based practices with those in medicine. Over-selecting in the blog searches was considered useful, in contrast with the deliberate under-selection for the general Google search.

> *Search string 11 (publication year 2005 to illustrate):*
> *http://www.google.co.uk/search?q=%28%28%22evidence+based%22%29+AND+%28%22natural+resource%22+OR+forestry+OR+ecology+OR+ecosystem%29%29+%E2%80%93medicine&hl=en&sa=X&ei=bj2zTabPMcqi8QOnovWVDA&ved=0CAwQpwUoBg&source=lnt&tbs=cdr%3A1%2Ccd_min%3A1%2F1%2F2000%2Ccd_max%3A31%2F12%2F2000&tbm=#q=((%22evidence+based%22)+AND+(%22natural+resource%22+OR+forestry+OR+ecology+OR+ecosystem))+%E2%80%93medicine&hl=en&prmdo=1&prmd=ivns&sa=X&ei=2kSzTdzMHYSx8QOjnoWWDA&ved=0CBYQpwUoBw&source=lnt&tbs=cdr:1%2Ccd_min%3A1%2F1%2F2005%2Ccd_max%3A31%2F12%2F2005&tbm=blg&fp=4287dfd63891046d*

c) Comparator phrases

The comparator phrases 'acid rain', 'small sample', and 'deforestation' replaced the phrase "evidence based" in search string 11.

Tables of results for searches in bibliographic databases and Google

Table 1 Numbers of papers containing key phrases in bibliographic databases (MEDLINE or Scopus)

Year of publication	Record Count	Cumulative records	Record count	Record Count	Cumulative records	Record Count	Cumulative records	Record Count	Cumulative records	Record Count	Cumulative records	Record count
	Evidence-based medicine (EBM)		Broader 'Health Occupation' category	"evidence-based" environment (EBE)		"small sample"		"acid rain"		"deforestation"		Broader environmental sciences category
1995	77	97	22,102	1	1	84	84	436	436	204	204	124,306
1996	243	340	22,647	2	3	149	233	180	616	234	438	166,232
1997	674	1,014	24,647	16	19	152	385	130	746	229	667	168,825
1998	1,091	2,105	25,086	19	38	171	556	171	917	221	888	170,947
1999	1,646	3,751	26,376	37	75	166	722	133	1,050	246	1,134	170,078
2000	1,952	5,703	27,201	42	117	156	878	151	1,201	258	1,392	177,525
2001	2,606	8,309	28,317	89	206	160	1,038	232	1,433	292	1,684	180,371
2002	2,807	11,116	28,854	116	322	177	1,215	137	1,570	340	2,024	186,586
2003	2,919	14,035	30,363	199	521	167	1,382	141	1,711	319	2,343	195,765
2004	3,378	17,413	32,761	172	693	191	1,573	106	1,817	406	2,749	206,667
2005	3,595	21,008	34,728	287	980	223	1,796	149	1,966	410	3,159	224,158
2006	4,057	25,065	36,391	284	1,264	250	2,046	107	2,073	451	3,610	249,025
2007	4,476	29,541	37,526	287	1,551	279	2,325	123	2,196	469	4,079	264,822
2008	4,785	34,326	39,572	271	1,822	261	2,586	125	2,321	599	4,678	279,059
2009	4,379	38,705	38,669	173	1,995	280	2,866	89	2,410	705	5,383	290,105
2010	4,167	42,872	37,731	200	2,195	291	3,157	147	2,557	754	6,137	293,701

Table 2 Numbers of web pages indexed with key phrases in Google

	All Google resources					Google Blogs				
Year of publication	EBM	EBE	acid rain	deforestation	All 'environmental'	EBM	EBE	deforestation	acid rain	All 'environmental'
1995	192,000	4	87,300	176,000	12,000,000					
1996	190,000	10,300	86,900	176,000	12,100,000					
1997	191,000	10,000	86,900	175,000	12,000,000					
1998	191,000	9,880	86,900	174,000	12,000,000					
1999	191,000	10,100	86,900	175,000	12,000,000					
2000	190,000	9,990	86,600	175,000	12,000,000	5	0	4	4	4,940
2001	281,000	14,400	111,000	238,000	14,100,000	61	5	89	48	6,550
2002	191,000	10,100	45,400	122,000	8,160,000	35	2	32	14	4,080
2003	151,000	11,300	31,500	75,800	6,750,000	26	4	24	7	6,080
2004	237,000	13,800	33,500	107,000	8,360,000	234	98	111	46	18,400
2005	246,000	17,500	52,000	132,000	10,800,000	1,980	391	716	345	91,700
2006	511,000	27,800	69,900	182,000	13,800,000	4,700	321	1,770	728	221,000
2007	592,000	34,100	69,500	247,000	13,000,000	7,970	459	5,400	1,570	1,070,000
2008	830,000	49,400	107,000	384,000	16,500,000	12,400	1,070	12,000	2,550	2,010,000
2009	1,680,000	80,600	126,000	491,000	20,800,000	18,000	1,390	16,600	3,320	3,030,000
2010	2,390,000	126,000	176,000	678,000	24,500,000	21,400	2,290	26,700	6,230	6,150,000

2.4 Results

Table 1 shows the results of searches for key phrases and categories in bibliographic databases (MEDLINE and Scopus). Figures 4 to 9 illustrate the increase in articles containing the key phrases and comparators in the bibliographic databases.

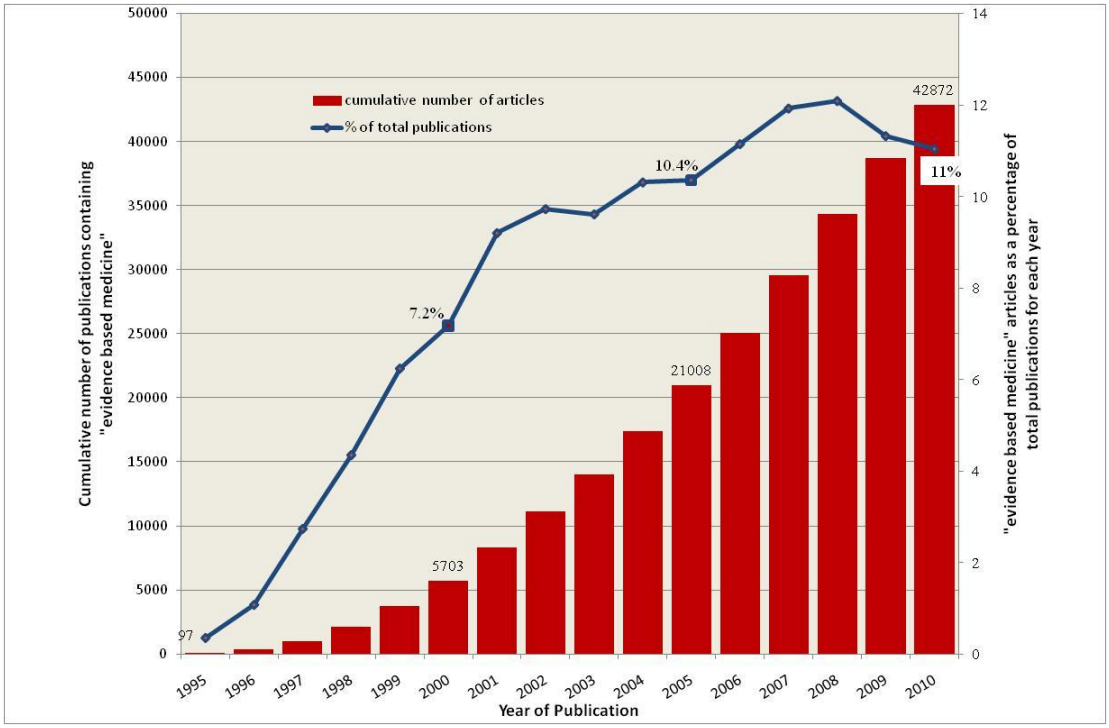


Figure 5 Articles containing the phrase evidence-based medicine in MEDLINE

Strauss (2005) reported that the number of articles on MEDLINE that used the term 'evidence based medicine' had grown since 1992 to 13,000 in [sic] Feb. 2004. Strauss does not give details of the search strategy used to obtain this result, which means that it is impossible precisely to replicate the findings, particularly as additional papers from earlier years are continuously added to the database as backfiles of journals are added to the list of those indexed on MEDLINE and changes are made to the structure of the database (Glanville *et al.* 2006). The present research shows that by the end of 2004 the figure was 14,035, and had reached 42,872 by the end of 2010 (Figure 5). During this time,

MEDLINE itself had been growing, but the proportion of articles on evidence-based medicine increased sharply between 1996 and 2002, and continued to increase until 2008.The numbers of articles containing the phrase “evidence based” in the environment literature articles similarly increased relatively steeply between 2000 and 2005 (Figure 6). This contrasts with articles containing the phrase “small sample”, which show a more modest increase in keeping with the year on year increase in literature in Scopus (Figure 7).

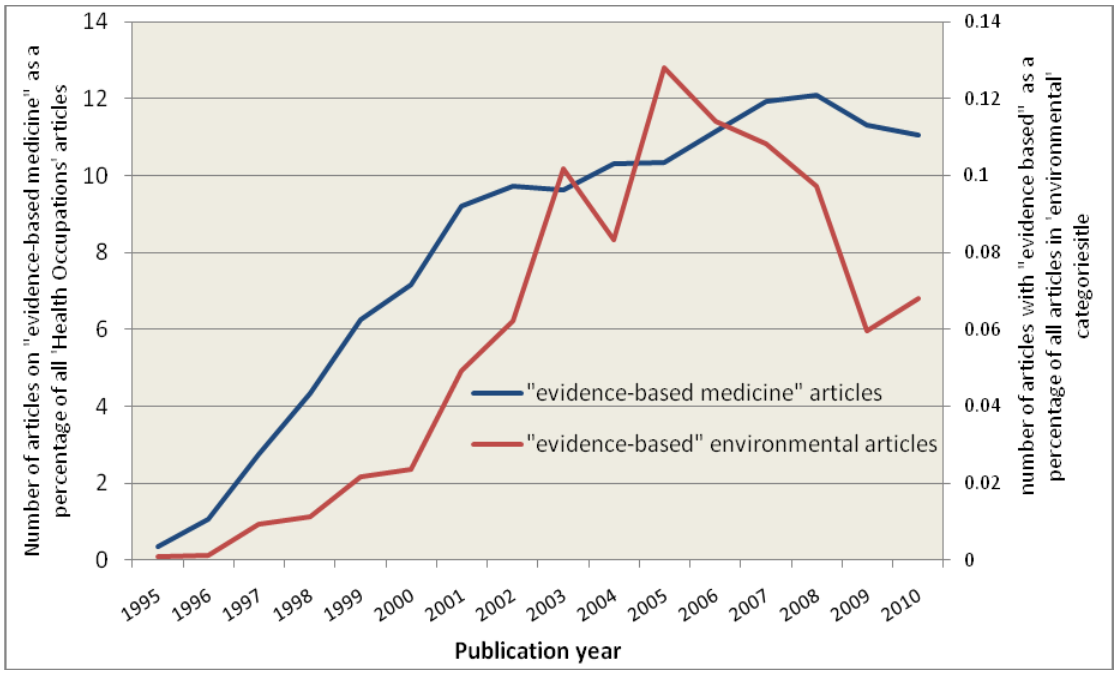


Figure 6 Evidence based medicine compared with phrase Evidence-based in ‘environment’ literature

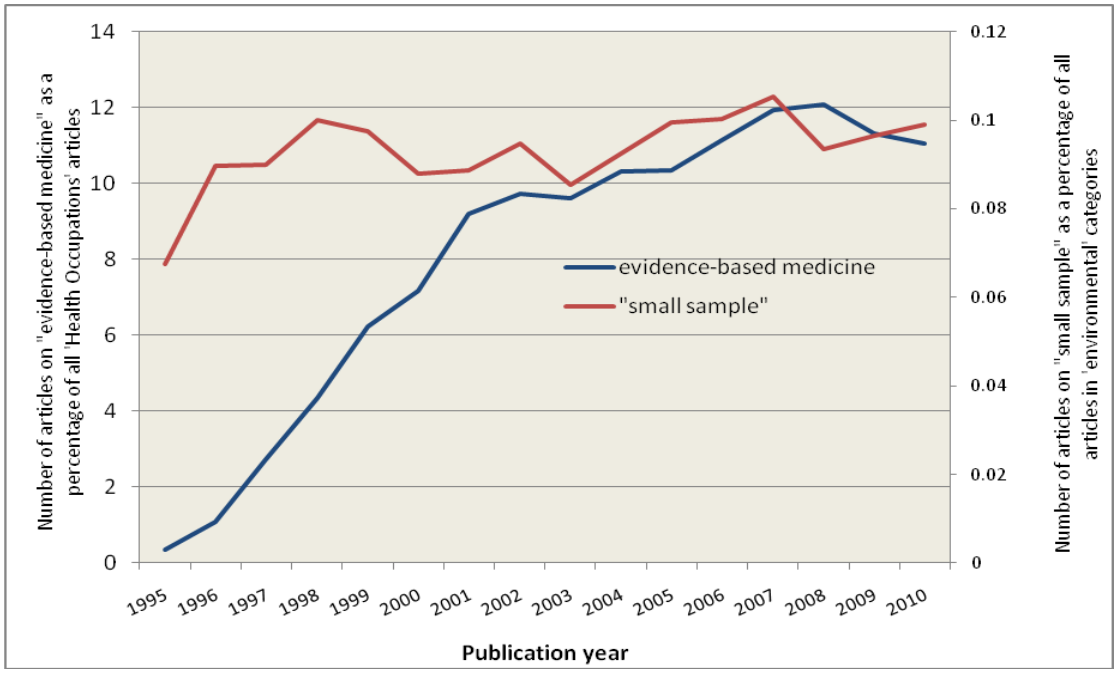


Figure 7 Evidence based medicine compared with comparator phrase "small sample"

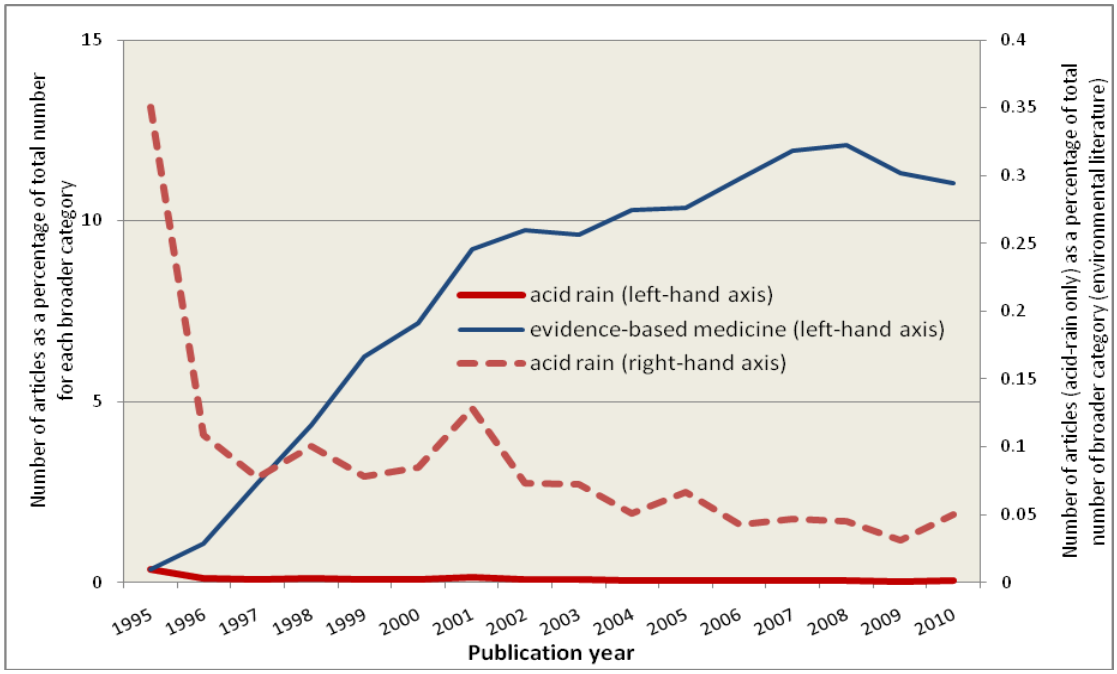


Figure 8 Evidence based medicine compared with comparator phrase "acid rain", shown at same scale and finer scale to illustrate detail for acid rain trend

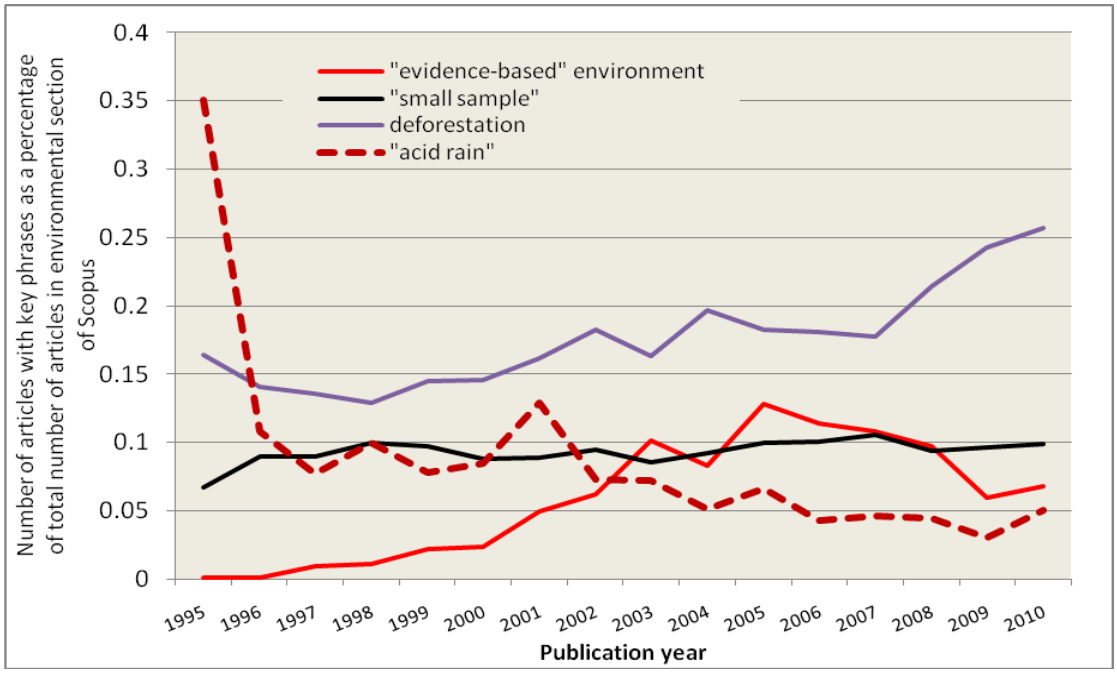


Figure 9 Number of articles with key phrases as a percentage of all environment articles

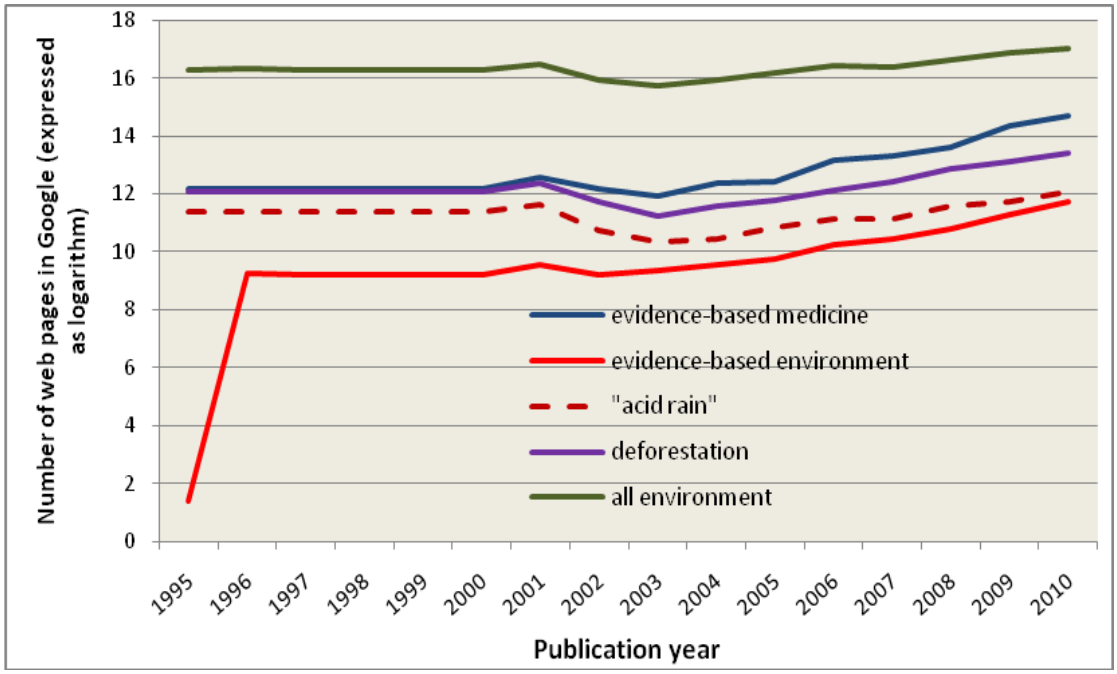


Figure 10 Log numbers of web pages for selected phrases in Google

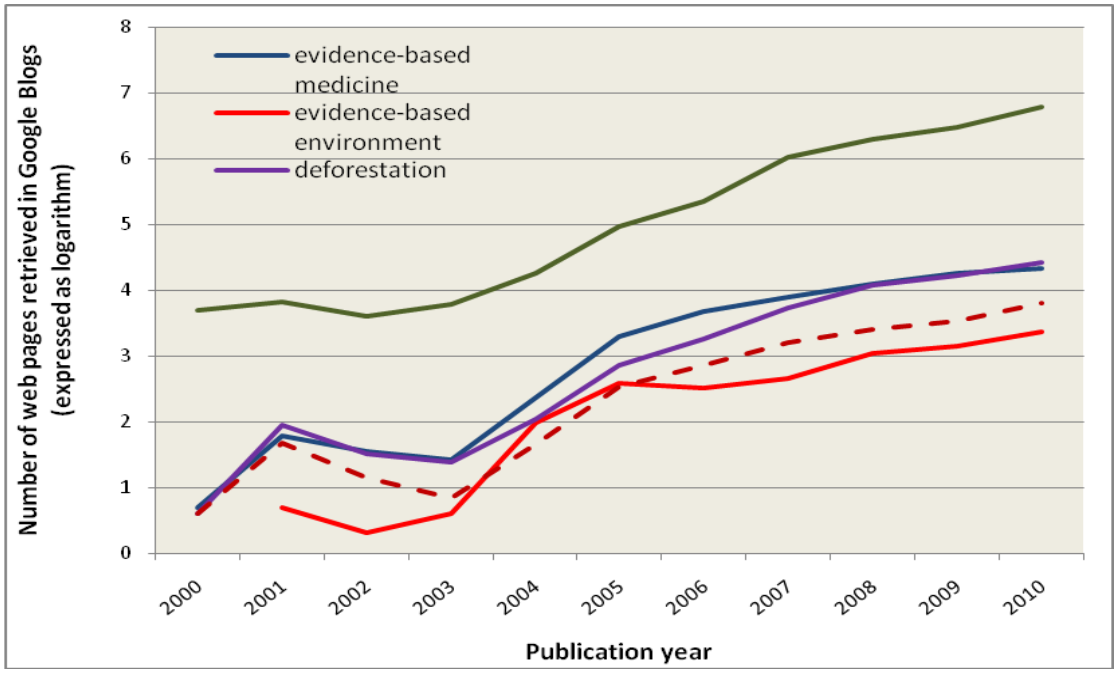


Figure 11 Log numbers of web pages for selected phrases in Google Blogs

2.5 Discussion

The rapidly increasing publishing activity, whether Web 2.0 (Google web pages and blogs) or traditional publishing (bibliographic databases), for the phrase "evidence based medicine" followed general professional acceptance of the validity of the concept of and over a decade of work on methods of evidence evaluation as an essential component for evidence-based medicine. There is some evidence to support the view that the environmental field was influenced by this new term and started to use it, which is reflected in the rapid rise in its occurrence in academic articles and in web pages retrieved through Google. Academic articles, in particular, show that other phrases increased at different rates, as might be expected from a knowledge of research interests in the environment during this period – acid rain having risen and then fallen as a 'hot topic', and deforestation showing some declines in interest followed by a more recent period of great interest and corresponding publication proliferation.

A phrase like 'small scale' simply kept pace with the increasing volume of publications being produced each year. Acid rain and deforestation are very well understood concepts, however, but there been very little discussion in the academic literature about what 'evidence-based' might mean in environmental research. The exception is the work reported by Pullin *et al*. (2003, 2004) and Sutherland *et al.* (2004) on evidence-based conservation.

Although systematic reviews have been promoted since 2002 in the field of nature conservation, the library of reviews maintained since 2007 by The Collaboration for Environmental Evidence (CEE)[8] is still small (32 completed reviews in August 2010) and the concept of systematic review is largely unknown internationally in environmental and forestry professional and research communities. The long-term objectives of evidence-based conservation according to CEE are to allow "better prediction

[8] http://www.environmentalevidence.org

of the effects of different management actions by: (i) encouraging the accumulation of information on the consequences of management; (ii) carrying out systematic reviews of the available evidence; and (iii) providing means of disseminating this information to practitioners".

For the set of "evidence-based" environment records extracted from Scopus (Table 1), once articles with a medical focus have been excluded from the set, only 17 articles include the phrase "systematic review". These 17 have all had an association with CEE and have used a Cochrane-style systematic review to evaluate the current evidence of relevance to their research question; these 17, therefore, can be said to be 'evidence-based' by the standard defined by the medical community. That leaves a great many other papers which are using a concept whose definition is still comparatively unknown. A sample of those papers was read; none defined 'evidence-based'.

The forestry community has very recently started to look at the possibility of using systematic reviews to underpin science for key policy issues (see Chapter 5). Evidence-based forestry would entail more than the use of systematic reviews – or at least the adoption of more transparent and robust methods of using science to inform policy.

There is a large body of literature on what evidence means in the context of evidence-based policy making and, indeed, in whether the term should be "evidence-based" at all. Nutley (2003) argues that "evidence-informed" or "evidence-aware" are more appropriate. Chalmers claims (pers comm.) never to have used the term "evidence-based medicine" and refers always to "evidence-informed medicine (see, for example, Chalmers 2005). A spirited exchange of views between Chalmers and Hammersley (2005) debated the impact of the terminology, amongst other points of disagreement. Holmes and Clark (2008) review the different terms suggested in the literature and argue for a "pragmatic and realistic" aspiration to strengthen the use of science (and evidence generally) in environmental policy-making

2.6 Conclusions

Environmental decision-making is now undertaken in an atmosphere of intense public scrutiny of science and, in the current financial crisis, value for money to ensure an effective and efficient use of limited funds for research. Society's demands of forests are increasingly complex and require multidisciplinary approaches.

The community of those with an interest in forestry need to draw on a wide range of sources for data and information. The volume of information, both in academic publications and available generally on the Internet through search engines such as Google, is growing exponentially. The volume of research in almost every area has become so large that it is impossible for most people to assess it and be able to demonstrate that their decisions have been taken on the basis of rigorous and robust analysis of the science.

Governments in Europe and elsewhere are aware of these problems and promote evidence-based policy. At the heart of this approach is a methodology for the synthesis of new analysis of large volumes of information from existing research. Medicine pioneered the approach, which has been adopted for the areas of crime and justice, education and welfare and nature conservation.

The field of environmental sciences, generally, and forestry in particular, have been slow to adopt these methods of selection and analysis of research, despite using the term 'evidence-based' freely. Consequently, the sector has limited capacity to reassure funders of research or the general public that the best use of evidence, including science, has informed decision-making. Promoting meaningful evidence-based forestry is a priority for the sector nationally and internationally.

I propose the following definition as a work-in-progress:

> "*Evidence-based forestry is the conscientious, explicit, and judicious use of current best evidence in making decisions to enhance provision of products and services from forest resources. It recognizes that forest resource management is context specific, ever-changing, and involves uncertainties, and that the best evidence is derived from a systematic process which aims to minimise bias.*"
>
> (after Sackett 1996 & McKibbon 1998)

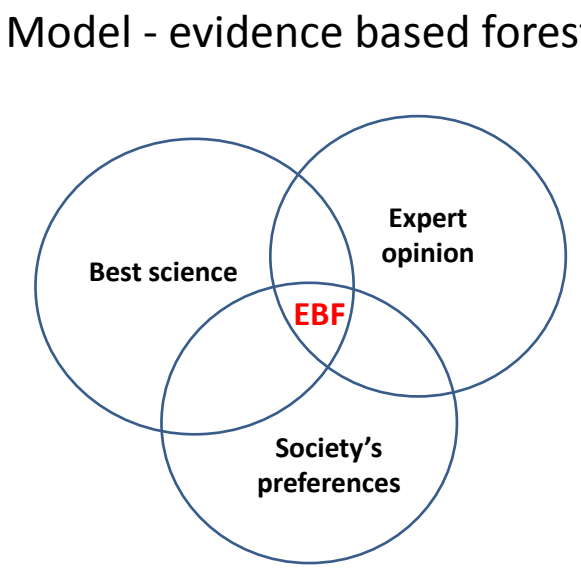


Figure 12 Evidence-based forestry, based on a definition of evidence-based medicine in Sackett & McKibbon,1998)

Chapter 3. Identifying high priority questions for policy-relevant research using a participatory process.

3.1 Introduction to chapter 3

The UK has a long-established tradition of research in forestry, not only focused on British woodlands but also overseas forests, initially for their timber exporting potential, but more recently for their importance to global climate and biodiversity. The forestry sector has diversified in recent years and is under increasing pressure to respond to the rapidly developing policy arena. Research is now undertaken in a more diverse range of institutions, with a trend away from dominance by traditional forestry schools towards involvement by a wider range of actors.

The traditional network of forestry professionals and academics who advised governments not only on forestry policy but on research policy for forestry may have been effective and efficient when forestry was expected to deliver a narrower range of products and services, but it may not serve the purposes of modern requirements. Importantly, perhaps, the narrow networks may not be perceived as being responsive enough to new requirements which embrace wider societal demands and concerns. The current research was devised to examine new ways of engaging with a wider network of actors with an interest in forestry to determine collectively a research agenda for policy-relevant research in the sector. Two difficulties are immediately apparent in setting out on this particular journey: 'forestry' and 'policy' are easy to understand, but difficult to define.

The definitions of forest and forestry are the subject of heated debate in international circles as changing public perceptions and environmental and social realities impact on debates on forest resources, deforestation and, more recently, payments for avoided deforestation to mitigate climate change.

Burley, citing Stewart (1997) traces the origins of the problem with the word, at least in English, to its linkage with an unpopular activity:

> "*The [ancient] forest law was very harsh and was enforced by a hated body of men called foresters, whose activities were called forestry…When the scientific study of forests began in France, a distinction was made between the body of knowledge, science forestière, and the corresponding economic activity,* économie forestière. *Similarly, in German,* Forstwissenschaft *was distinguished from* Forstwirtschaft*... It is unfortunate that no such distinction was made in English; instead, the old term* forestry *was used to cover both the body of knowledge and the economic activity, and the practitioners of both were given the name of foresters. English remains the only language in which the science and the activity are confused.*"

Like the definition of 'forestry', the word 'policy' is one that most people would claim to understand, but would be reluctant to define, and may often link with the word 'politics', something practiced, if not by Stewart's 'hated body of men', but by a group who do not always enjoy deep public affection.

> *'Defining policy is rather like the elephant - you know it when you see it but you cannot easily define it'* (Cunningham 1963, cited in Keeley and Scoones 1999*).*

Heclo (1972) reviewed a number of existing definitions of policy and suggested a broad definition of his own:

> *"policy is usually considered to apply to something 'bigger' than particular decisions, but 'smaller' than general social movements'*

Hogwood and Gunn (1984) propose considering the uses of the term 'policy' in ten categories: policy as a label for a field of activity; policy as an expression of general purpose or desired state of affairs; policy as specific proposals; policy as decisions of Government; policy as formal authorisation; policy as a programme; policy as output; policy as outcome; policy as a theory or model; and policy as process.

The present research used a broad definition of 'forestry' to try to engage with as many people as possible who might have an interest in participating in the work, but no attempt was made to limit their views on what constituted 'policy-relevant forestry research'.

There is growing interest in widening public participation in research and practice in environmental decision-making and an awareness of the importance of framing research questions which reflect policy needs. Building on the need for greater stakeholder involvement in the question-framing element of evidence-based frameworks for forestry, the T10Q (Top Ten Questions for Forestry) project was undertaken to investigate a process for compiling and prioritising a meaningful set of policy-relevant research questions using a collaborative, bottom-up approach that involved professionals from a wide set of disciplines of relevance to modern forestry.

The project engaged people who were outside the traditional boundaries of the discipline, a trend likely to be more important in the future, particularly in the light of complex problems connected with climate change, bio-energy provision or health and well-being, for example, which require multidisciplinary inputs and ideas.

A version of the main body of the remainder of this chapter was published as:

Petrokofsky, G., N.D. Brown, G.E. Hemery, *et al.*, 2010. A participatory process for identifying and prioritizing policy-relevant research questions in natural resource management: a case study from the UK forestry sector. *Forestry, 83*(4), 357-367.

Author contributions:

Gillian Petrokofsky: I suggested the paper, devised its structure and content and wrote it.

Nick Brown: is Principal of Linacre College and University Lecturer in Forestry in the Department of Plant Sciences. He helped shape the structure of the paper and provided valuable feedback during the drafting stages.

Gabriel E. Hemery is Chief Executive of the Sylva Foundation. He helped shape the structure of the paper and provided valuable feedback during the drafting stages.

The following contributors made comments on drafts prior to publication:

Steve Woodward, Department of Plant and Soil Sciences, Institute of Biological and Environmental Sciences, University of Aberdeen.
Ted Wilson, The Medical School, University of Sheffield.
Andrew Weatherall, National School of Forestry, University of Cumbria, Newton Rigg Campus
Victoria Stokes, Forest Research, Alice Holt Lodge
Richard J. Smithers, Woodland Trust
Marcus Sangster, Forestry Commission, Edinburgh
Karen Russell, Lockhart Garratt
Andrew S. Pullin, Professor of Evidence-based Conservation, School of the Environment, Natural Resources and Geography, Bangor University
Colin Price, Professor of Environmental & Forestry Economics, School of the Environment, Natural Resources and Geography, Bangor University
Michael Morecroft, Principal Climate Change Specialist in the Evidence Team, Natural England.
Mark Malins, Department of Social & Policy Sciences, University of Bath.
Anna Lawrence, Head of the Social and Economic Research Group, Forest Research,
Keith Kirby, Natural England
Douglas Godbold, Professor of Forest Sciences, School of the Environment, Natural Resources and Geography, Bangor University
Elisabeth Charman, Royal Society for the Protection of Birds.
David Boshier, Department of Plant Sciences, University of Oxford.
Sasha Bosbeer, Sylvan Consulting Ecologists, Galway, Irish Republic.
J.E. Michael Arnold, formerly Department of Plant Sciences, University of Oxford

3.2 Background

Environmental policy making in Europe is focussed strongly on increasing public engagement with science (European Commission, 2007b). The UK is supportive of an approach that engages the public 'upstream' in science and technology developments (i.e. at the start of the process of designing research and technology programmes, rather than at the end, providing feedback). This would include end-user involvement in programmes operated by the research councils, an initiative strongly endorsed by the British Science Association (Wilsdon and Willis 2004, Whitmarsh *et al*. 2005). Greater public participation in setting research priorities and framing research questions might enhance the integration between environmental policy and science (Holmes and Savgård 2009). However, the diversity of stakeholders with specialised interest in forests presents challenges if a more participatory approach is to be adopted.

This chapter describes the Top Ten Questions for Forestry (T10Q) project and the process developed to engage forestry professionals in participatory exercises to prioritise an agenda for policy-relevant research. The aim was not simply to respond to current policy, nor to suggest new policy, but to explore a novel way of identifying research which the forestry sector considers important to inform policy and practice.

In the T10Q project, the term 'forestry' was defined very broadly to include any aspect of trees and wooded landscapes and products and services derived from forest and woodland. The definition used here is based on one published after extensive consultation by the Food and Agriculture Organization (2006): '"Forestry" is broadly defined to include livelihoods, social aspects, environmental services, forestry policies and institutions and economic considerations.

In addition to traditional aspects of forest management, production, health and protection, forestry considers the broad landscape of trees outside forests, including urban forestry and agroforestry. Forestry includes the management of wildlife and protected areas. Forestry considers the impacts of

other sectors on the forest, as well as the impact of the forest on other sectors. The project did not attempt to engage the 'lay public': the target group were woodland owners and managers, researchers and those with policy interest working in the broadly defined field of forestry in the UK and the Irish Republic.

Co-ordination of forestry research priorities

The Forestry Research Coordination Committee (FRCC) was established in 1982 as a forum for the main funders of forestry and forest products research in the UK to discuss research priorities, encourage effective funding and avoid duplication of effort. Co-ordination of forestry research was felt to be necessary because of the increasing diversity of research and the large number of bodies funding it (Evans, 1992). The key sponsoring agencies funding forestry research were Government ministries and departments, the Forestry Commission, nature conservation bodies, research councils and universities. Some members of the committee represented particular constituencies, for example one member represented all UK universities offering forestry degrees and another represented forestry charities. Among its original terms of reference was 'to identify and define forestry research needs and opportunities' (Burdekin, 1989). 'Defining research needs' was removed as a specific objective after a review of FRCC activities in 1997, but it retained a specific brief to "identify gaps or overlaps and encourage the co-ordination of research programmes in forestry".

The FRCC remained, until its demise in 2007, the only body which systematically examined forestry research across disciplines in the UK and made its findings public through an annual collation of forestry and tree-related research which summarised expenditure by subject and organisation. The summaries provide information about trends in research and funding activities (Evans 1992, Lawson and Hemery 2007) but no information about the process of decision making that had been used to set research priorities. It is difficult to assess the extent to which representatives on the committee liaised with their constituents except for the purpose of compiling the annual research summaries or

included information from individuals or organisations that engaged in activities not traditionally defined as forestry but nevertheless of broader forestry importance.

Currently, most of the functions of the FRCC are taken by The Environment Research Funders' Forum (ERFF), which was established in 2002 'to make the best use of public funding for environmental research' (Environmental research is defined by ERFF to be research and associated monitoring, survey, policy, regulation and training in traditional environmental sciences and in areas of economic, social and engineering research concerned with the interaction of people with the environment.). Forum membership is drawn from UK public bodies that fund or use environmental research. There are three tiers of membership, which are based on subscription (2008 subscriptions were £5k, £15k and £25k per year) and entitle members to different levels of governance representation.

Forestry research that is funded by ERFF members is co-ordinated by the ERFF. The Forestry Commission is represented on the main ERFF board, though not on the research co-ordination group, which is tasked with 'driving forward the Forum's core purpose of fostering collaboration between public funders of 'environmental research' in its broadest sense'. Unlike the FRCC, universities are not separately represented in the ERFF, nor are charities.

In common with the FRCC, the ERFF does not routinely engage individuals; the mode of operation is by committee, membership of which is restricted to public bodies.

Participation in research priority setting

Public involvement in environmental decision making was one of the central themes of the 1992 United Nations Conference on Environment and Development, the 'Earth Summit'. Public involvement also accords with current thinking on governance and democracy; 'participation' and 'citizen engagement' being now part of the political lexicon, even though consultation is clearly not a 'magic bullet' that guarantees policy change (Carnegie United Kingdom Trust 2008).

In the past two decades, a large body of literature has emerged on public engagement and participatory processes, with much of the early literature growing out of theoretical development work or political science research on citizenship and democracy (Jasanoff 2003, Rayner 2003), and work in developing countries on equitable access to natural resources (e.g. Côté and Bouthillier 1999, Buchy and Hoverman 2000, Van Herzele *et al*. 2005, Leach 2006, Pagdee *et al*. 2006, Des Roches 2007).

Even though the virtues of using participatory methods to engage stakeholders with important decision making have been vigorously extolled, and well funded, by development agencies in developed countries for use in developing countries, these practices have not been systematically applied domestically in developed countries. One example of a participatory process pioneered in a developing country and subsequently adapted for a developed country has been work on mental health in the UK (Rose *et al*. 2008) and pulmonary disease in The Netherlands (Caron-Flinterman *et al*. 2006), which both built on work with small-scale farmers in developing countries (Broerse and Bunders 2000). There are a very large number of forestry professionals in Europe and North America, who have worked on participatory decision-making projects in developing countries who have practical experience which could supplement the body of published literature.

In Great Britain, government departments were required to engage with stakeholders to develop research and innovation strategies and to include statements in their strategies about mechanisms for stakeholder involvement. The Science and Innovation Strategy for British Forestry was one of these outputs (Forestry Commission 2005). Details of the stakeholder processes in the separate countries of the UK and the steps taken to weigh the evidence received have not been published, however, making it difficult to evaluate how useful this was considered to be by the sector generally. The most recent Science and Innovation Strategy for British Forestry (Forestry Commission 2010) did not involve formal stakeholder engagement; however, the strategy endorses the importance of "regular contact with diverse stakeholders in order to identify research questions and needs", and it seems likely that broader consultation will be a feature of future strategy development. This type of

consultative approach is now mainstream for developing national forest policies in European Union countries. The pan-European Union Forestry Strategy was also developed using a participatory and transparent approach that recognised the importance of engaging with individuals, an estimated 16 million private forest owners, who together own some 60 per cent of the European Union's forest and wooded land, mostly in small holdings (European Commission 2005).

In the UK, the concept that 'communities of interest' should be involved in agenda setting sits well with the fact that some 35 per cent of the nation's forests and woodlands are publicly owned. The development of separate forestry strategies for England, Wales, Scotland and Northern Ireland, which included substantial consultative elements and allowed stronger stakeholder representation, ushered in an era of greater public participation in the national forestry debates (O'Brien and Claridge 2001). The more recent forestry strategies of England (2007, updating the 1998 strategy), Scotland (2005, updating the 2000 strategy), Wales (2009, updating the 2001 strategy) and Northern Ireland (2006) were all produced after public consultation (Forest Service 2006, Forestry Commission Scotland 2006, Department for Environment, Food and Rural Affairs 2007, Forestry Commission Wales 2009).

There is, however, a much less tangible sense of broad stakeholder engagement with the research process. The Carnegie Trust suggests that a robust evidence base is necessary, though not sufficient, for effective involvement of civil society in policy-making decisions (Carnegie United Kingdom Trust 2008). For effective engagement, the public should be actively involved in setting the research agenda because they need to participate in the creation of the evidence base. This accords with Fischer's (2003) view that by transforming citizen's ways of knowing and acting, participatory deliberation can extend decision-making capabilities and reduce the tension between democracy and science.

Holmes and Clark (2008) identified a need for closer collaboration between scientists and policy makers at the stage of 'setting research questions and agendas' in the area of environmental science. The problem of planning, managing and communicating research to inform environmental policy making was further investigated by Holmes and Savgård (2009) in an empirical study involving 95 people from 33 organisations in 11 European countries. Two of the good practice guidelines developed from this research were:

1. Engage researchers and potential users to ensure their perspectives are appropriately reflected in the framing of the research question and

2. Specify research questions and project deliverables at a level of detail sufficient to ensure outputs do actually meet user needs.

Two principal methodologies have been used in the fields of medicine and public health to enable public participation in setting research agendas (Oliver *et al*. 2004): collaboration (involving patient representation on decision-making bodies) and consultation (involving questionnaires, focus groups and consensus conferences).

A model for prioritizing specific policy-relevant ecological research questions was undertaken in 2005: a group of policy makers, advisers and lobbyists from 28 organisations and researchers from 10 UK universities and research institutes participated in a workshop to determine the 100 most important ecological questions of relevance to policy in the UK (Sutherland *et al*. 2006). Just over 1000 candidate questions were collected in advance from the organisations represented at the workshop. Academics at the workshop were involved in suggesting questions and facilitating discussion, while the final set of questions were selected and composed entirely by policy specialists drawn from a range of governmental institutions and non-governmental organisations (NGOs) that were either creating policy or were involved in influencing policy in the UK. The strength of the process was the very large number of research questions collected from different stakeholders; the weakness was perhaps the tendency for those questions to be framed in somewhat general terms, rather than as specific research topics.

This chapter describes a two-phase participatory process adopted in the project titled T10Q, which built on Sutherland's model and related work on horizon scanning (Sutherland and Woodroof 2009; Sutherland *et al*. 2009, 2010), to engage stakeholders in the process of refining a short list of high-priority research questions for forestry.

3.3 Method

T10Q involved two phases. First (Phase 1), questions were submitted using an online survey from individuals across the forestry sector. The survey ran from May until September 2008. Second (Phase 2), a 2-day workshop with 51 people, involved professionally in UK or Irish forestry, was held on 25 and 26 September 2008 to discuss the questions gathered under the Phase 1 and to arrive at a list of 10 high-priority questions for forestry research using a process of discussion and voting. Figure 13 summarises the steps taken to reach a final list of ten questions and the numbers of people involved at each stage of the process.

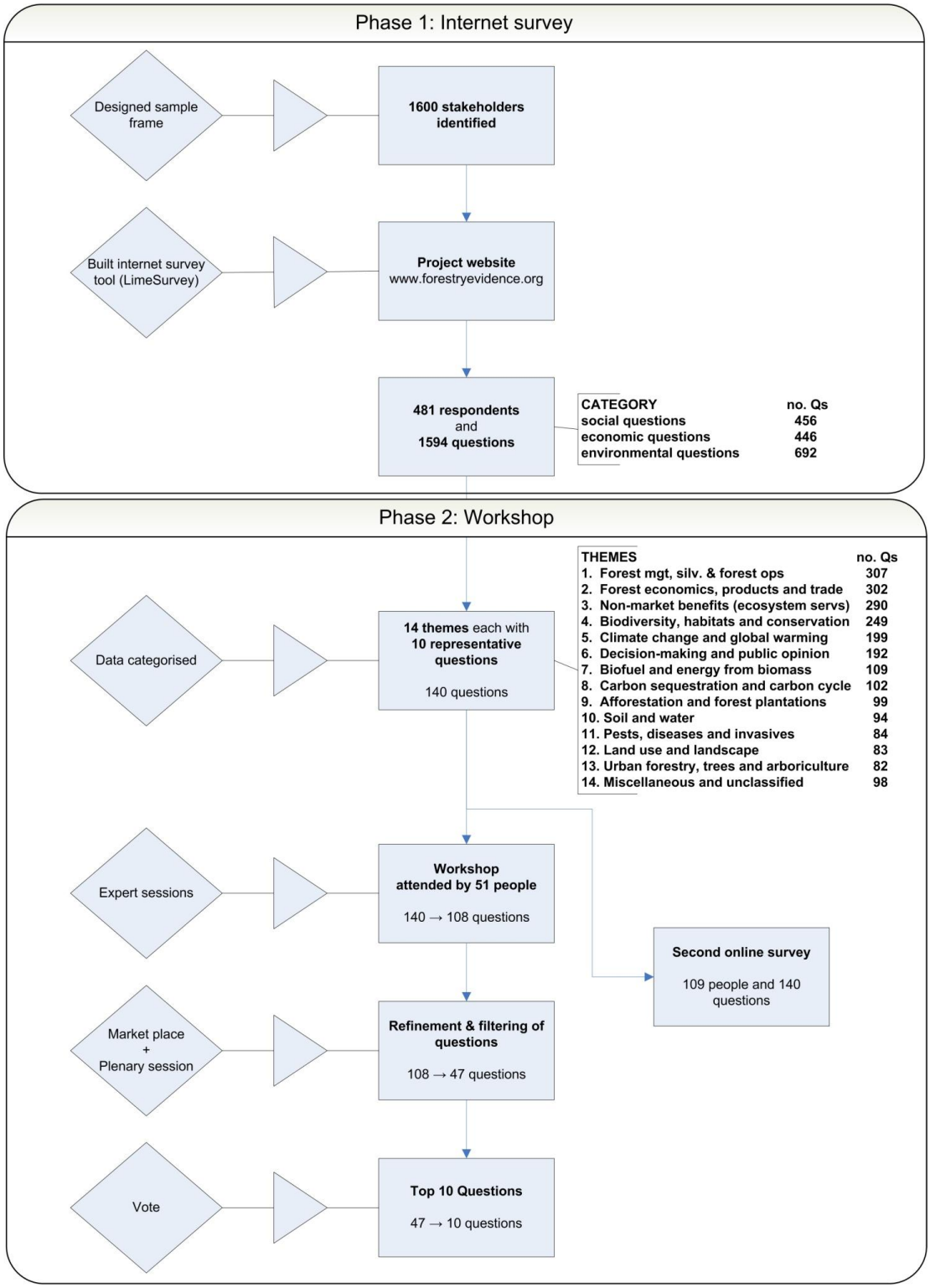


Figure 13 Stages in the T10Q process

Phase 1: Internet-based survey

Survey participants

A total of 1600 individuals were invited to participate in a structured online survey, using LimeSurvey (Version 1.71+, Build 5147), which is a multilingual open-source survey tool (www.limesurvey.org).

Participants were identified in a number of ways:

- They had participated in forestry meetings or consultations organised by four of the partner organisations who funded the T10Q project (Forestry Commission, Natural England, University of Oxford and Woodland Trust).
- They responded to a call for participants published in UK newsletters and automated electronic mailing lists aimed at an audience of people with an interest in environmental sciences, forestry (including agroforestry) and forest policy, and on the project website (www.forestryevidence.org).
- They were members of the Forest Research Co-ordination Committee or the Environment Research Funders Forum.
- They were academics either working in the UK or Irish Republic, or whose work was focussed on forestry in the UK or Irish Republic, who had published scientific articles within the previous five years.[9]

The survey posed a total of 45 questions arranged across seven sections (Woodland ownership & management, Attitudes to the environment, Attitudes to research, Ability to influence policy, Access

[9] Authors were identified from email addresses indexed in ForestScience.info (published by CAB International) between 2004 and 2008.

to information, Organisational profile and Personal profile). Questions were presented as variables that could be selected by participants through the use of multiple choice options or Likert scales (A psychometric scale commonly used in questionnaires in which respondents express their strength of agreement with each of several statements, typically with an odd number of response options varying from 'strongly disagree' to 'strongly agree' (de Vaus, 2002).) that assessed the extent of agreement/disagreement with statements. The questionnaire contained 274 variables (Variables are defined as characteristics which have more than one category (de Vaus, 2002), which can be thought of in the present survey as the response options available for each question. For example, the question asking 'In which country (or region of England) do you live?' had 14 variables from which to select (9 regions of England, Wales, Scotland, Northern Ireland, Irish Republic and country other than UK or Ireland) generated from multiple choice elements of the 45 questions.

There were also sections that enabled free text responses. Only two questions were mandatory, and these were inserted to route certain participants through relevant questions that were not applicable to everyone (for example, the set of questions about aspects of woodland ownership was only available to those who had indicated that they owned woodland; a similar set of questions about aspects of research was only available to people who described themselves as researchers).

One of the key objectives of the survey was to collect a series of policy-relevant research questions of high importance to individuals. Participants in the survey were invited to submit up to five policy-relevant research questions in each of three categories: environment, people and society and economics (Figure 13), the three 'pillars' of sustainable development.

Coding the questions

Submitted questions were coded by three independent people using a specialised thesaurus of forestry and applied life sciences terms, which is used by Intute (which ceased operations in July 2011, although the information resources are maintained under an agreement with JISC [formerly the

Joint Information Systems Committee]) and other international documentation services (Ahsan-ul Morshed and Sini 2009). Coders applied up to three keyword terms for each question.

All the questions submitted were sorted into one or more of 14 themes (Figure 13), which were determined on the basis of the most commonly occurring keywords. Ten questions were selected for each theme as representatives of the most frequently occurring topics within the themes. These 140 representative questions were presented on the Website in their themes, together with the complete list of 1594 questions.

A Delphi-style approach was taken to cycle the results of Phase 1 back to the same set of 1600 people to gauge their views on the comments submitted by other stakeholders. Delphi methods have been used with some success in forestry, notably for issues where detailed data are lacking, uncertainty is large and informal judgements are a fundamental source of information (Mendoza and Martins 2006). Results from this phase of T10Q will be analysed separately. In parallel, the workshop was organised to discuss the questions submitted in Phase 1 and to arrive at a set of 10 policy-relevant research questions for forestry.

Phase 2: Workshop

Invitations to attend a 2-day workshop to discuss the research questions submitted in Phase 1 of the project were sent to people who had registered an interest in attending a workshop after completing one or both online surveys or after reading about it on the project Website or in promotional articles (e.g. Petrokofsky et al. 2008).

The aim of the workshop was to arrive at a list of 10 research questions by a process of repeated filtering through discussion and finally voting. This was achieved by parallel facilitated discussions on separate themes, focussed drafting sessions, two whole-group sessions (that considered, revised or rejected the outputs of the drafting sessions) and, finally, a confidential vote.

3.4 Results

Phase 1: Internet-based survey

A total of 481 people responded to the survey, of whom 21 provided no information. Of those who provided information on gender, 59 (21%) selected 'Female' and 217 (79%) 'Male'. Table 3 shows the sector participants selected from a menu of 15 options to describe their current work or their principal work before retirement. Figures 14, 15 and 16 illustrate the sectors and regions participants came from.

Table 3 Sector of T10Q participants in survey and Workshop

Sector	Responses from participants			
	Online survey		Workshop	
	%	n	%	n
Forest industry/woodland management	18	57	19	8
International organisation	5	17	0	0
NGO/community organisation	12	38	19	8
Public sector – central/devolved government	17	54	7	3
Public sector – local authority	4	11	0	0
Research institute	15	48	12	5
University research	22	70	35	15
Other	6	18	9	4
Total		313		43

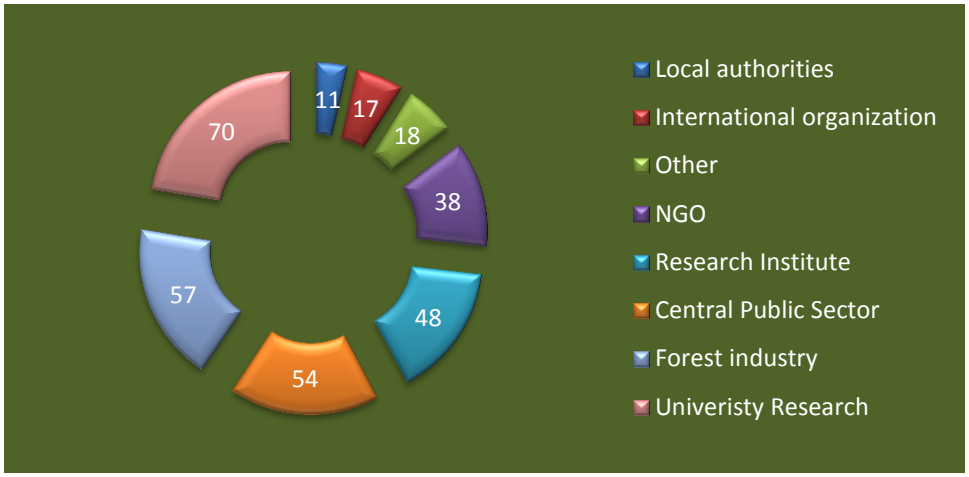


Figure 14 Number of participants in the T10Q survey by sector

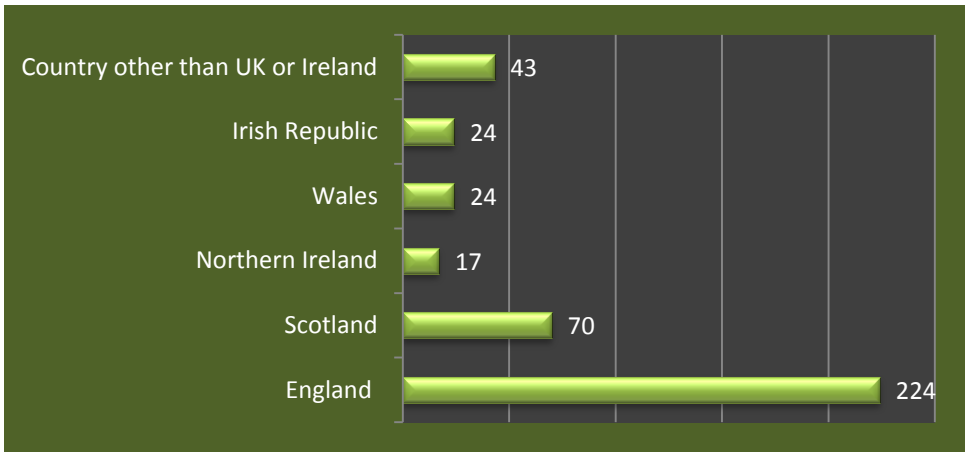


Figure 15 Number of participants in the T10Q survey by country of residence

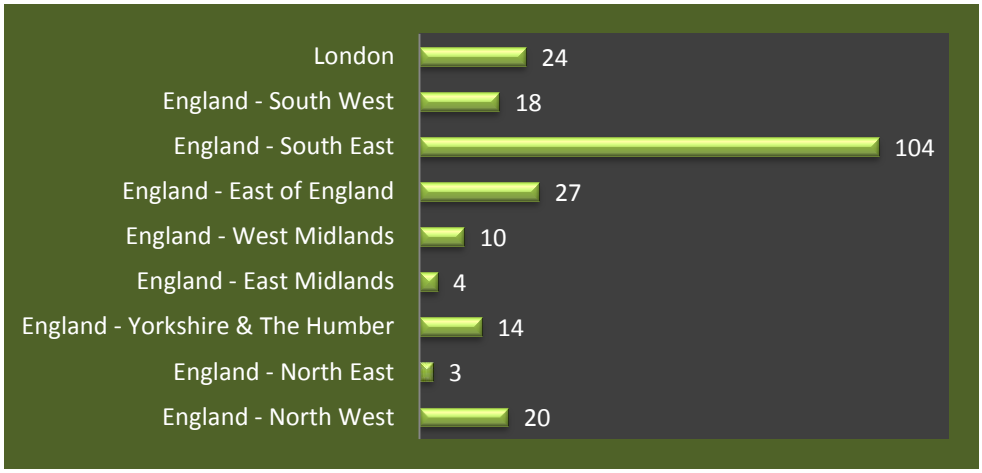


Figure 16 Number of participants in the T10Q survey from England by region

Responses to the survey questions yielded a total of 37 585 separate pieces of information (multiple options within questions generated a large volume of data) from the 481 respondents, with an average of 78 per person (the range was 1-167). Analyses of responses to all sections of the survey are outside the remit of this chapter which focuses primarily on the 1594 separate research questions that were submitted by respondents.

Preliminary tests showed a high degree of uniformity in term selection by the three coders. A total of 2819 unique keywords and keyword phrases were used, 187 of which were used once only. These terms were not used in subsequent stages of sorting the questions into themes and topics. Questions were sorted into one or more of 14 themes on the basis of the most commonly occurring issues identified during coding. The number of questions in each theme was not equal (see Figure 13) and 629 were listed in more than one theme (534 in two themes, 90 in three and 5 in four).

Important sources of potential bias in survey-based work are the coding and data analysis methods used. Therefore, experienced external indexers were used to add keywords to all the original questions submitted in Phase 1. These keywords were used to group the questions into themes. The themes emerged from the keyword groupings; they were not set up a priori. By this mechanism, questions could be listed under more than one theme. This process enabled questions to be viewed from different perspectives. Although the process created replication for survey participants, the effect of subjective judgements by the lead author in allocating questions to particular topics was thereby reduced.

Table 4 Questions in themes by sector of participant submitting the question. Cells with dark shading indicate higher than expected values; cells with light shading indicate lower than expected values (determined by chi square test).

sector	EC	MG	NM	BI	CC	OP	BF	CS	AF	SW	PD	UR	LU	Misc	total	total unique questions	sector n
Forest industry	70	57	38	34	29	30	19	16	13	9	17	16	12	11	371	281	52
International organisations	7	11	4	10	7	8	0	4	4	7	2	2	2	4	72	62	12
NGO	29	43	36	23	22	29	14	12	10	16	9	9	13	12	277	207	37
Central Public sector	49	37	48	33	31	28	25	18	19	21	18	19	22	16	384	259	52
Local Authorities	14	8	14	9	15	9	3	5	2	3	2	7	2	2	95	58	11
Research Institutes	46	58	56	54	36	37	14	14	15	13	17	3	16	25	404	283	47
University Research	69	69	73	68	49	28	22	23	28	14	15	21	13	21	513	361	70
Other	18	24	21	18	10	23	12	10	8	11	4	5	3	7	174	83	31
total	302	307	290	249	199	192	109	102	99	94	84	82	83	98	2290	1594	312

Key to themes

EC	Forest Economics, Products and Trade	CS	Carbon Sequestration and Carbon Cycle
MG	Forest Management, Silviculture and Forest Operations	AF	Afforestation and Forest Plantations
NM	Non-Market Benefits (Ecosystem Services)	SW	Soil and Water
BI	Biodiversity, Habitats and Conservation	PD	Pests, Diseases and Invasives
CC	Climate Change and Global Warming	UR	Urban Forestry, Urban Trees & Arboriculture
OP	Decision-Making and Public Opinion	LU	Land Use and Landscape
BF	Biofuel And Energy From Biomass	MISC	Miscellaneous & Unclassified

Phase 2: Workshop

A total of 51 people attended one or both days of the workshop, 43 of whom took part in the final online vote (Figure 13). Participants came from England, Scotland, Wales and the Irish Republic and included people working in all three 'pillar' areas of sustainability. There were proportionally more university researchers and fewer people working in the public sector or for NGOs than there had been in the online survey (Table 3). Two groups were not represented at the workshop: public sector–local authority and international organisations, though several of the participants had worked for international organisations at some time during their careers. The workshop participants included people who owned woodland and/or had practical experience of forest management. The university researchers worked on widely different aspects of forestry, with research interests spread across the three pillar areas.

The facilitated themed discussion sessions were organised in a way that maximised mixing among participants. The 10 representative questions for each theme were presented for each theme group to discuss, amend and prioritise. The complete set of 1594 questions was also available for consideration. At the end of these sessions, parallel drafting sessions for each theme considered the prioritised list of questions that emerged from the discussions and produced a set of five questions of high priority. These 70 questions were further reduced to 47 after parallel facilitated small-group discussions that aimed to consolidate similar questions and remove duplication. The final list of 47 questions was presented to the participants in the form of a very short survey using the LimeSurvey tool. Participants were invited to select the 10 questions that they considered most important from the list of 47 and provide details of the sector in which they work. The survey was assembled soon after the short list of 47 questions had been agreed and participants voted online at computer terminals provided at the workshop. LimeSurvey allows very rapid export of results and these were analysed to determine the questions receiving the highest number of votes and to classify the sectors of those voting.

Top Ten Questions for Forestry

Table 5 shows the final ten questions that attracted the most votes from participants voting at the workshop, with percentage of votes cast. Table 5 Final Top Ten Questions

Table 5 The Top Ten Questions for Forestry selected by participants at the T10Q workshop from a shortlist of questions submitted during the T10Q survey

Question	Percentage of votes cast
What are the most technically and financially effective ways of identifying, monitoring and controlling invasive species, pests and disease?	45
How can we achieve better understanding between foresters and other parts of society?	42
What are the most effective landscape planting schemes to ensure connectivity between woodland fragments while maintaining connectivity between other land use types?	39
How will climate change affect both natural forest ecosystems and forestry and how should management be adapted to minimise adverse impacts and optimise benefits?	34
What is the value of forestry to human health and well-being?	34
Who are the private woodland owners and how can they be engaged and influenced? What are their concerns?	34
Which parts of forest ecosystems form the largest and most stable carbon pools and how are these impacted by forest management and climate change?	32
How can we address the economic, environmental, social and institutional constraints of expanding woodfuel [in the UK]?	32
What species or provenances should we be considering in relation to a range of forestry systems including urban and agroforestry, in the light of climate change?	32
What are the barriers to knowledge transfer in forestry from research to practice and how can they be removed?	32

The remaining 37 questions on the short list were selected by fewer than 30% of voting participants. All 47 questions gained at least one vote.

Clearly, not all workshop participants felt that the final set of ten questions reflected their own personal views. However, more than half of those who voted chose at least four of the top ten questions and every voter chose at least one of the top ten questions, which supports the view that the Workshop process gave rise to more agreement in choosing ten questions than would have arisen by random voting by 43 people choosing from 47 questions.

The variance in the frequencies with which each question was chosen will be higher where there is agreement between respondents. In order to test for agreement between respondents,

therefore, we calculated the variance in the frequencies with which our 47 questions were chosen, and compared it to the distribution of the variance assuming no agreement between respondents. We simulated 10,000 rounds in which 43 respondents randomly chose 10 out of 47 possible responses. The 95% confidence interval of this variance was (0.002824, 0.006514); the observed variance of 0.0122 lies far outside this confidence interval, allowing us to reject the null hypothesis of no agreement between respondents.

3.5 Discussion

The 1594 questions submitted in Phase 1 of T10Q were distributed across a broad spectrum of forestry interest: 13 key subject themes were identified. Of these, the largest two themes, containing over 300 questions each, were traditional core issues of forest management, silviculture, forest economics, products and trade. Ecosystem services and non-market benefits were almost as well represented, with just under 300 questions, followed by biodiversity, habitats and conservation, climate change, then decision making and public opinion, all ranging between 190 and 250 questions. The final top 10 questions were also drawn from the smaller themes, so there is no evidence that weight of numbers dictated the final top 10 choices.

The process was well supported and compared favourably with the level of responses in stakeholder consultations for national forestry strategies in the UK: 221 written responses (plus 187 participants at two workshops) in England in 2006 (Department for Environment, Food and Rural Affairs 2007), 231 responses in Wales in 2009 (Forestry Commission Wales 2009) and 189 and 149 in the two rounds of the 2006 Scottish strategy (Forestry Commission Scotland 2006). Janse (2006, 2008) reported similar response rates (average 32 per cent) in recent European surveys of forest policy makers and scientists (using much lower sample sizes) and an international online survey on science communication by researchers by the International Union of Forestry Research Organisations in 2006 attracted 340 responses in an open survey with an unknown population size (Kleinschmit and Real

2009). Response rates were of a similar size for the consultation on creating a unified European Research Area (681 responses to an open online questionnaire (European Commission 2007a)).

There has been very little systematic evaluation of the effectiveness of participation for environmental decision making (Newig and Fritsch 2009) but increasing participation in decision making is a central element in European environmental policy (European Commission 2007b). The European Strategic Research Agenda for the Forest-Based Sector, drawn up after a stakeholder consultation in all European Union countries, recommended greater engagement of scientists from all relevant disciplines with the process of developing research priorities across five forest-based value chains (Forest-Based Sector Technology Platform 2006). In attempting to remove the actual bias or the perception of bias inherent to closed decision making by experts, new sources of bias are potentially created by giving unequal and potentially unrepresentative weight to contributions from certain stakeholders. Price (2000) expressed poetically what many view as a real weakness of the practice, namely that the 'idealised sweet reasonableness of participatory discussion is not always found in real-world debate, where decisions may favour not the most deserving, but the most obstinate'.

The workshop format, using facilitators, changing groups of delegates and a final secret ballot, was designed to reduce the effects of obstinate voices dominating debates as far as possible. The most important source of potential bias in any survey is undoubtedly the people who participate. T10Q employed purposive sampling, a type of non-probability sampling in which the 'population' of 'those with a professional interest in forestry' is not known precisely. The issue of non-response bias is impossible to quantify in a non-probabilistic survey (de Vaus 2002). However, Table 3 categorises survey respondents and workshop participants and Table 4 provides a more detailed breakdown of the topics of questions submitted by the different sectors. Although not a tool for removing bias, it enables some sectoral comparisons to be made and provides a check against dominance of the process by one sector. This would be an essential element in using this methodology more widely or in, for example, a European context to gather inputs for international research agendas of the type

undertaken in conservation (Sutherland *et al* 2010). It is particularly noticeable that the NGO sector, which was well represented, displayed no particular leaning in the topics of questions it submitted. Submissions by participants from NGOs were divided among the 14 themes in numbers which were not statistically different from expected, the only sector for which this was true. Greatest variance was from the forest industry sector, who not surprisingly contributed more questions to the theme 'Economics, products and trade'.

Though a small group, local authority participants favoured questions on climate change and, again not surprisingly, urban forestry. It should be noted that even within sectors, participants came from different areas of interest. Researchers in particular, both in the survey and workshop, had widely differing research fields and certainly did not constitute a 'unified voice' in terms of identifying priority research topics. Similarly, members of NGO organisations, that were relatively over-represented at the workshop compared with the survey population, expressed widely different views during group discussions; their voting patterns were equally varied.

Within the UK context, forestry policy is heavily influenced by the devolved governments in Wales, Northern Ireland and Scotland. These governments were not represented officially at the workshop, although individuals from all three had participated in the online surveys submitting research questions. It would be interesting to investigate further the extent to which the questions submitted had a regional or national 'flavour' given the differences between the different forestry strategies.

The themes that emerged from the T10Q project align very closely with the eight strategic research priority areas identified in the Science and Innovation Strategy for British Forestry (Forestry Commission 2005): social and economic research, monitoring and evaluation, **climate change***, **soil & water management***, **forest products***, **changing silviculture***, **biodiversity & habitat restoration*** and **plant health***. These priorities describe almost the entire range of forestry activity in the UK; they are not so much 'priorities' as broad categories of interest. It is of little surprise, therefore, that the themes that emerged in the T10Q project fall within the compass of six of these priority categories (indicated by an asterisk above) (compare themes in Figure 13).

Our T10Q themes emerged as clusters of interest from the questions submitted and were not deliberately designed to be coherent with these established categories. The researchable questions submitted within these themes are a potentially rich resource that could be analysed and considered further in the context of discussing a forestry research agenda that was responsive to perceived knowledge needs from a broad section of the forestry sector.

According to Taylor (2005) the first rule in the process of making science more influential is to win the argument about what the problem is, before trying to win the argument about the solution. Collectively framing research questions that relate to what a broad spectrum of stakeholders view as the important policy challenges of the 21st Century will be fundamental to commissioning relevant research that makes the best use of the limited funding resources likely to be available for a rapidly diversifying forestry research sector.

3.6 Conclusions

Using combined online and face-to-face participation, a diverse group of people with a professional involvement in forestry engaged in a process that produced a set of 10 questions, from close to 1600 suggested by stakeholders, which were felt to warrant further research in forestry. The T10Q project demonstrated that it was possible to compile and prioritise a meaningful set of research questions using a collaborative 'bottom-up' approach that involved professionals from a wide set of disciplines of relevance to modern forestry.

Within the UK, the ERFF, which is the body currently co-ordinating publicly funded forestry research, offers a framework for identifying research that matches national policies and priorities in forestry and environmental science. The method described in this chapter could complement this activity by readily engaging a large number of people and stakeholder groups, in a process of framing research questions highly relevant to their sector. The process itself is scalable and could be readily adapted for local, regional or international consultations that aim to determine research priorities in natural resources management.

The T10Q project engaged people who were outside the traditional boundaries of the discipline, a trend likely to be more important in the future, particularly in the light of complex problems connected with climate change, bioenergy provision or health and well-being, for example, which require multidisciplinary partnerships within the research and policy communities.

There is no particular significance to the fact that the project aimed to prioritise 10 questions. Top 10 lists are ubiquitous across all subjects and countries. The key message is that the process can be adapted to achieve lists of research questions that can be analysed and prioritised collectively in a variety of appropriate ways.

Through the T10Q project an effective method for reaching a large number of stakeholders engaged in forestry research and policy in the UK was developed. The process demonstrably delivered a precise and detailed roadmap of use to researchers and policy makers in assisting responses and adjustments to current research priorities over coming years.

Chapter 4. Linking the existing knowledge base with research priorities identified in a participatory stakeholder process.

A version of this chapter was submitted on 13 December, 2010 to *Forest Policy and Economics*

Accepted with revisions.

Petrokofsky, G., G.E. Hemery, N.D. Brown, 2010. Linking the existing knowledge base with research priorities identified in a participatory stakeholder process: the T10Q project as a case study for forestry.

Author contributions:

Gillian Petrokofsky: I suggested the paper, devised its structure and content and wrote it.

Nick Brown: helped shape the structure of the paper and provided valuable feedback during the drafting stages.

Gabriel E. Hemery: helped shape the structure of the paper and provided valuable feedback during the drafting stages.

4.1 Science for policy questions – where are the knowledge gaps?

European science academies view science as being not only central to many aspects of modern life, but a pre-requisite to wise policy-making (EASAC, 2010). The Fifth Ministerial Conference on Environment and Health called for greater use to be made of existing scientific information for policy-making (World Health Organization 2009), and the Warsaw Declaration specifically committed European governments to improving understanding between policy makers, practitioners and the scientific community so that better use is made of "scientific knowledge and research results relevant to forests and the forest sector as a sound basis for decision making" (Forest Europe 2007). The existing body of information, which lies largely unused after publication, could justly be considered the 'unknown knowns', to paraphrase Donald Rumsfeld (Ravetz, pers com; Ravetz,

1987). Alongside calls for greater use of existing science, there is also growing demand for so-called 'evidence-based policies' in Europe and elsewhere (European Commission 2010), though scant actual evidence of what this means in practice outside the field of medicine. One of the barriers limiting the implementation and adoption of evidence-based frameworks, however, is the notion that scientific research activities are not focused on issues of relevance to decision makers or to policies, at least in the field of natural resource management (Pullin *et al*. 2004, Pullin and Knight 2005), and there is no reason to believe the situation is better in forestry.

To overcome this problem, Sutherland (2006) pioneered an approach for generating a list of important research questions. This '100 questions' model has been repeated and adapted a few times since then in ecological fields (Morton *et al*. 2009, Sutherland *et al*. 2009, and in forestry by Petrokofsky *et al*. (2010). Cooke (2010) has introduced the idea to the fisheries community and reports that two other groups are undertaking 100-questions exercises in Canada and the USA. There has been considerable interest in these projects and the questions generated have been used by governmental and non-governmental organisations to refine their own research agendas (Sutherland 2009) or to highlight important priorities (see, for example, Lawrence 2008). However, apart from Cooke, who critically evaluated the global 100 questions exercise (Sutherland *et al*. 2009) to identify those of relevance to aquatic and fisheries professionals, there has been very little further work on the questions generated by stakeholders. Given the growing importance of using existing knowledge to improve decision-making and the necessity of finding practical ways of identifying knowledge gaps, a useful secondary exercise would appear to be looking at the knowledge base which exists for questions generated by these exercises.

Utilizing the knowledge base is a critical component of evidence-based medicine, and the small number of other disciplines that use systematic reviews to inform decision-making. The amount of existing literature is scoped at an early stage to assess the size and potential relevance of the knowledge base to provide evidence for the review question (Chalmers 2003, Davies and Boruch 2001, Pullin and Knight 2009). There are only a handful of systematic reviews of relevance to forest

and forestry professionals (Petrokofsky and Mills 2009), but there is a growing interest in adopting them for global problems, such as deforestation and forest degradation, which require collaborative, multi-disciplinary efforts to make the best use of the available evidence. The 'T10Q - Top Ten Questions for Forestry' project, adapted in 2008 from Sutherland's '100 questions' approach, did not set out specifically to generate potential systematic review questions, but it was undertaken in the expectation that it could provide useful inputs to develop an evidence-based approach in forestry (Petrokofsky *et al*. 2010).

The aim of the current paper is to examine the research base underpinning the ten priority questions determined in the T10Q project to gain a better understanding of the quantity of research which is available currently to stakeholders to take forward these questions. Although the questions were generated by UK and Irish stakeholders, the literature was examined from a global perspective to gain greater understanding of how research outputs differ between countries and over time.

4.2 Methods

The T10Q project

The detailed methodology for the T10Q project is described in Petrokofsky *et al*. (2010). Briefly, the project involved two distinct phases:

1. First, questions were submitted by 481 individuals with a professional interest in 'forestry' (defined broadly to include the whole forest-based sector, and involving academic researchers, policy-makers, NGO personnel, and owners and managers of woodland).
2. Second, a two-day workshop with 51 people, from 29 different organisations or consultancies, who are involved professionally in UK or Irish forestry, was held on 25th and 26th September 2008 to review the questions submitted and to arrive at the ten most important research questions for forestry using a process of discussion and voting (see Fig 1).

Analysing the knowledge base for the T10Q questions

An assessment was made of the volume of academic articles on topics closely related to the subject covered by each of the ten questions that emerged as the most important at the end of the stakeholder engagement process. The analysis was not an exhaustive review of the literature for each question but an indicative assessment using a search strategy to interrogate the forest science subset of CAB Abstracts, a bibliographic database published by CAB International (CABI), a not-for-profit international (http://www.cabi.org/). The principal author devised the search strategy in consultation with members of CABI's staff who are responsible for the structure and content of the bibliographic database. Details of the search strategy are in Table 7. This database was chosen in preference to other similarly large bibliographic databases (e.g. Scopus, Web of Knowledge) for two principal reasons:

- CAB's records have been coded and indexed using a widely-used specialist Thesaurus of controlled keyword terms (Ahsan-ul-Morshed and Sini 2009) and coding schedules that have been retrospectively applied to older records in the database, which enables bibliometric comparisons to be made over time (McDonald and Lassoie1996);

- CAB includes in their database 'grey' literature (conference papers, book chapters, working papers, practice papers, etc.) in addition to articles from academic journals. This grey literature is of great importance to policy-relevant questions in natural resource management in general and in forestry in particular.

Table 6 The Top Ten Questions for Forestry selected by participants at the T10Q workshop from a shortlist of questions submitted during the T10Q survey (see Chapter 3)

	Question
1	What are the most technically and financially effective ways of identifying, monitoring and controlling invasive species, pests and disease?
2	How can we achieve better understanding between foresters and other parts of society?
3	What are the most effective landscape planting schemes to ensure connectivity between woodland fragments while maintaining connectivity between other land use types?
4	How will climate change affect both natural forest ecosystems and forestry and how should management be adapted to minimise adverse impacts and optimise benefits?
5	What is the value of forestry to human health and well-being?
6	Who are the private woodland owners and how can they be engaged and influenced? What are their concerns?
7	Which parts of forest ecosystems form the largest and most stable carbon pools and how are these impacted by forest management and climate change?
8	How can we address the economic, environmental, social and institutional constraints of expanding woodfuel [in the UK]?
9	What species or provenances should we be considering in relation to a range of forestry systems including urban and agroforestry, in the light of climate change?
10	What are the barriers to knowledge transfer in forestry from research to practice and how can they be removed?

The following analyses were performed for each of the ten literature searches:

The literature search strategy for each question was applied over seven time periods:

2005-2009; 2000-2004; 1995-1999; 1990-1994; 1985-1989; 1980-1984; before 1980.

Results were analysed for three time periods (2005-2009, 2000-2004, < 2000) in three geographical sets:

- global ;
- all European Union countries;
- UK only

The regional subsets were created by selecting papers of research carried out in the relevant countries determined by lead author's home institute, or by the geographical location of the field research. This captured not only European field work but also work carried out in, for example, tropical countries by researchers based in European institutions. Present and historical names of countries currently in the EU were used in the search strategy, e.g. German Federal Republic, Czechoslovakia (see Table 7).The regional data were compared with overall trends within the whole database.

In order to look at recent trends in the literature for different topics, the proportion of papers published in the last five years (2005-2009) was calculated for each question as a percentage of the total publications in the database for each question.

In order to get an indication of how the volume of literature for each individual question in the two regions compared with the overall database proportions for EU and UK literature, the data were analysed on the assumption that 'expected' proportions of literature would not be significantly different for each question than regional proportions for the entire database. Where there are no other factors that influence publication output, it would be expected that the volume of literature for each question represents a subset of the entire database, with identical characteristics. Where differences occur, it is reasonable to assume that these may reflect, amongst other factors, differences in interest in a topic, which results in different volumes of published outputs between regions or at different times. No assessment of the quality or level of direct relevance of the literature retrieved through the searches was made.

Table 7 Search strategies used to determine the number of papers of potential relevance to each of the T10Q questions and to create the set of EU countries.

T10Q question	search strategy
1	Descriptor: introduced AND Descriptor: species OR Descriptor: invasions AND Descriptor: pests OR Descriptor: plant AND Descriptor: diseases OR Descriptor: weeds OR Descriptor: "invasive alien species" OR Descriptor: "invasive species" AND CABI electronic journal code: tr
2	title: forest AND title: management OR title: forestry OR title: forester OR title: foresters OR abstract: forestry OR abstract: forester OR abstract: foresters AND "public opinion" OR "public relations" OR attitude AND attitudes
3	Descriptor: "land use" OR title: fragmentation OR Abstract: fragmentation OR Descriptor: fragmentation OR title: landscape OR Abstract: landscape OR Descriptor: landscape AND title: connectivity OR Abstract: connectivity OR Descriptor: connectivity
4	title: ecosystem* OR Descriptor: ecosystems OR Descriptor: "forest ecology" OR Descriptor: "forest management" OR title: forestry OR Descriptor: forestry OR Subject Category (CABICODE): kk100 OR Subject Category (CABICODE): kk110 OR Subject Category (CABICODE): pp720 AND title: "climate change" OR Abstract: "climate change" OR Descriptor: "climatic change"
5	Subject Category (CABICODE): PP720 AND title: woodland OR title: woodlands OR title: forest OR title: forests OR Subject Category (CABICODE): KK100 OR Subject Category (CABICODE): KK110 AND "public health" OR "mental health" OR "community health" OR "health protection" OR illness OR "health beliefs"
6	title: woodland* OR Abstract: woodland* OR title: forest* OR Abstract: forest* AND "land ownership" OR landowners OR ownership OR "public ownership" OR "forest ownership"
7	"carbon sequestration" OR title: carbon OR carbon AND pools AND Descriptor: forest AND Descriptor: management OR title: climate AND title: change OR Abstract: climate AND Abstract: change OR Descriptor: climatic AND Descriptor: change OR Descriptor: forest AND Descriptor: management AND "carbon sequestration" OR title: carbon OR carbon AND pools
8	title: fuel AND title: wood OR Descriptor: fuelwood
9	Descriptor: geographical AND Descriptor: distribution OR Descriptor: biogeography OR Descriptor: choice AND Descriptor: of AND Descriptor: species AND Specific Topic: "choice of species" OR Descriptor: provenance OR title: provenance AND Abstract: "climate change" OR Descriptor: climatic AND Descriptor: change OR title: global AND title: warming OR title: climate AND title: change
10	Subject Category (CABICODE): pp720 OR Subject Category (CABICODE): kk600 OR Subject Category (CABICODE): kk140 OR Subject Category (CABICODE): kk120 OR Subject Category (CABICODE): kk110 OR Subject Category (CABICODE): kk100 AND Abstract: "research into practice" OR Abstract: "research TO practice" OR title: "research TO practice" OR "research TO practice" OR title: "information dissemination" OR Abstract: "information dissemination" OR Descriptor: "diffusion of information" OR Descriptor: "diffusion of research" OR Abstract: knowledge AND Abstract: transfer OR title: knowledge AND title: transfer

Country	
EU	aa:(Austria) OR aa:(Belgium) OR aa:(Bulgaria) OR aa:(Cyprus) OR aa:("Czech Republic") OR aa:(Czechoslovakia) OR aa:(Denmark) OR aa:(Estonia) OR aa:(Finland) OR aa:(France) OR aa:(Germany) OR aa:("German Federal Republic") OR aa:("German Democratic Republic") OR aa:(Greece) OR aa:(Hungary) OR aa:("Irish Republic") OR aa:(Italy) OR aa:(Latvia) OR aa:(Lithuania) OR aa:(Luxembourg) OR aa:(Malta) OR aa:(Netherlands) OR aa:(Poland) OR aa:(Portugal) OR aa:(Romania) OR aa:(Slovakia) OR aa:(Slovenia) OR aa:(Spain) OR aa:(Sweden) OR aa:(UK) OR aa:(Yugoslavia) OR gl:(Austria) OR gl:(Belgium) OR gl:(Bulgaria) OR gl:(Cyprus) OR gl:("Czech Republic") OR gl:(Czechoslovakia) OR gl:(Denmark) OR gl:(Estonia) OR gl:(Finland) OR gl:(France) OR gl:(Germany) OR gl:("German Federal Republic") OR gl:("German Democratic Republic") OR gl:(Greece) OR gl:(Hungary) OR gl:("Irish Republic") OR gl:(Italy) OR gl:(Latvia) OR gl:(Lithuania) OR gl:(Luxembourg) OR gl:(Malta) OR gl:(Netherlands) OR gl:(Poland) OR gl:(Portugal) OR gl:(Romania) OR gl:(Slovakia) OR gl:(Slovenia) OR gl:(Spain) OR gl:(Sweden) OR gl:(UK) OR gl:(Yugoslavia)
UK	Author affiliation: uk OR Location: uk

Table 8 Number of publications for each of the ten questions from the T10Q workshop by year and region

T10Q question	region	<1980	1980-1984	1985-1989	1990-1994	1995-1999		<2000	2000-2004	2005-2009	total
1. invasive, pests, disease	global	105	100	123	249	366		943	568	1,557	3,068
	EU	10	10	9	20	59		108	107	330	545
	UK	3	5	3	3	12		26	22	41	89
2. improved understanding	global	138	69	100	161	360		828	448	441	1,717
	EU	38	24	26	44	166		298	161	141	600
	UK	17	8	6	11	36		78	27	21	126
3. landscape connectivity	global	206	69	75	163	500		1,013	1,154	1,716	3,883
	EU	87	39	38	63	151		378	482	652	1,512
	UK	22	16	9	12	18		83	93	125	301
4. climate change effects	global	198	41	91	580	1,619		2,529	2,407	4,519	9,455
	EU	14	6	22	171	890		1,103	999	1,989	4,091
	UK	2	2	10	42	204		260	211	373	844
5. forest & human health	global	339	53	47	69	128		636	290	348	1,274
	EU	90	28	20	18	41		197	80	104	381
	UK	14	4	11	7	9		45	21	19	85
6. who owns woodland?	global	1,074	235	328	529	1,021		3,187	1,461	1,416	6,064
	EU	429	124	128	192	369		1,242	518	477	2,237
	UK	45	29	29	34	65		202	74	44	320
7. carbon pools	global	5	4	4	59	339		411	750	1,084	2,245
	EU	1	1	1	16	151		170	256	414	840
	UK	0	0	0	1	36		37	58	71	166
8. Expanding woodfuel	global	1,074	418	573	555	893		3,513	888	854	5,255
	EU	274	103	120	126	352		975	390	386	1,751
	UK	21	20	35	31	61		168	24	38	230
9. provenances for climate change	global	6	1	3	35	160		205	168	242	615
	EU	3	0	2	17	75		97	83	125	305
	UK	0	0	0	3	14		17	19	19	55
10. Knowledge transfer	global	34	7	15	50	98		204	185	183	572
	EU	11	4	5	15	50		85	57	64	206
	UK	3	0	0	5	16		24	12	9	45
All T10Q questions	global	3179	997	1359	2450	5484		13,469	8,319	12,360	34,148
	EU	957	339	371	682	2304		4,653	3,133	4,682	12,468
	UK	124	84	103	144	455		940	561	760	2,261
Total for all database	global	249230	60,494	70,530	78,890	109993		569,137	135,580	173,083	877,800
	EU	39,032	21,093	24,634	29,486	41,912		156,157	43,157	51,719	251,033
	UK	7,337	3,492	4,385	4,249	1,941		21,404	4,887	4,882	31,173

4.3 Results

The existing knowledge base for each of the top ten questions

The number of publications retrieved from CAB Abstracts using the search strategy devised for each of the top ten questions is shown in Table 8.

The knowledge base supporting each question varies widely largely because the breadth of each question is quite different. The absolute values are of less interest in the current paper than relative values between geographical regions and changes over time. Figure 17 shows how the number of publications differed between questions, by showing the number as a percent of the total number of publications for all ten questions.

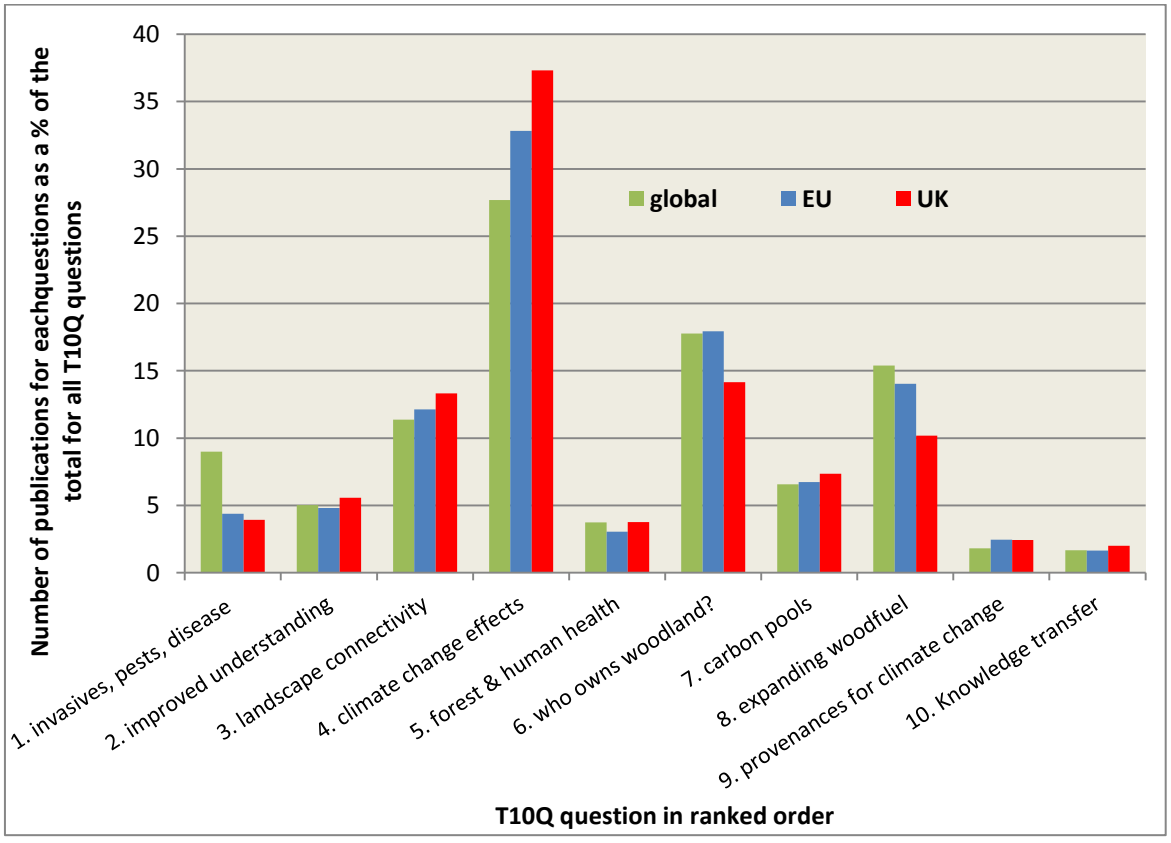


Figure 17 Size of scientific knowledge base for each T10Q question as a percentage of the scientific knowledge base for all T10Q questions

Publication trends in the EU and the UK for the T10Q knowledge base

The overall proportion of papers from all EU countries in the database is 28.6%; the figure for UK research is 3.6% (12% of the EU total), with slight variations between the different time periods considered in the analysis in Table 8. These proportions were applied to the global figures for each question, so that each question is treated as a subset of the entire database, with a predicted breakdown into similar proportions of literature from different regions. So, for example, for question 1, there were 3,068 relevant publications in the whole database; applying the database average of 28.6% for EU papers would yield an expected 877 publications. The actual search produced 545 publications. Similarly, for UK papers, the expected yield is 109 publications; the actual number was 89. Table9 gives the actual and predicted figures for each of the ten questions.

Table 9 Actual and predicted number of articles for each question in each region a = proportion of T10Q global total, b = proportion global total for whole database

T10Q question	region	actual	predicted
1.invasive, pests, disease	global	3,068	
	EU	545	877
	UK	89	109
2.improved understanding	global	1,717	
	EU	600	491
	UK	126	61
3.landscape connectivity	global	3,883	
	EU	1,512	1110
	UK	301	138
4.climate change effects	global	9,455	
	EU	4,091	2704
	UK	844	336
5. forest & human health	global	1,274	
	EU	381	364
	UK	85	45
6. who owns woodland?	global	6,064	
	EU	2,237	1734
	UK	320	215
7.carbon pools	global	2,245	
	EU	840	642
	UK	166	80
8.Expanding woodfuel	global	5,255	
	EU	1,751	1503
	UK	230	187
9.provenances for climate change	global	615	
	EU	305	176
	UK	55	22
10.Knowledge transfer	global	572	
	EU	206	164
	UK	45	20
All T10Q questions	global	34,148	
	EU	12,468	0.37[a]
	UK	2,261	0.07[a]
Total for all database	global	877,800	
	EU	251,033	0.286[b]
	UK	31,173	0.036[b]

Figures 18 and 19 show differences between the numbers of publications that could be predicted from database average values and the actual figures for EU (Figure 18) and UK (Figure 19) publications in each of the 10 question subsets.

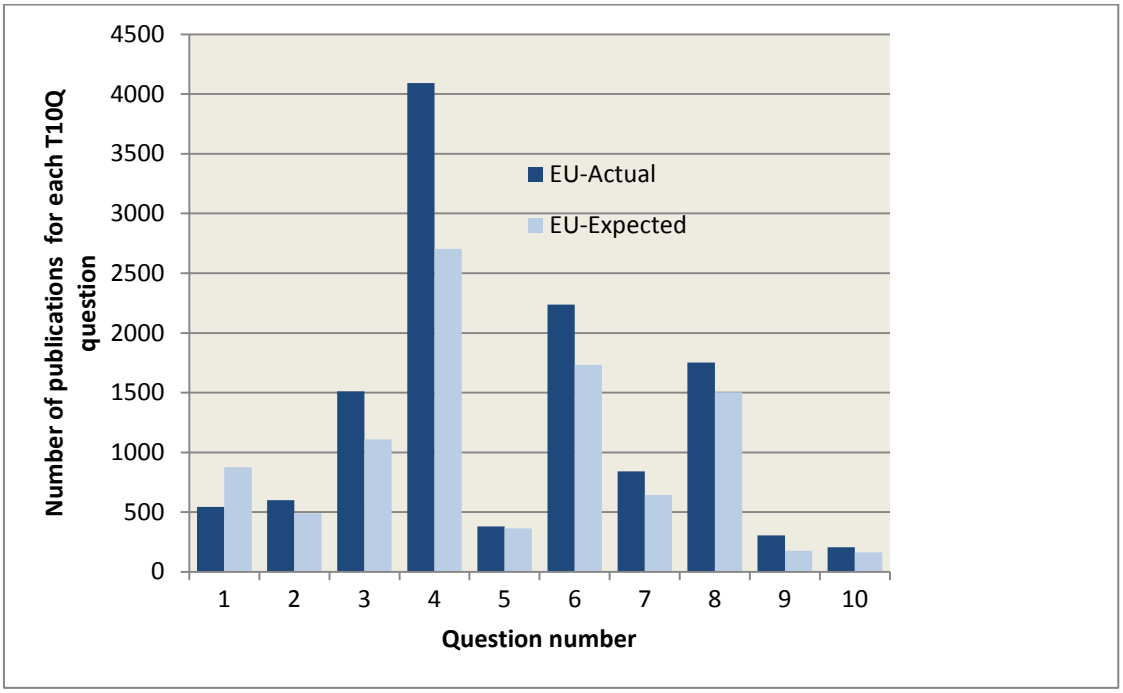


Figure 18 Actual vs. Expected numbers of publications for each T10Q question, from all EU countries

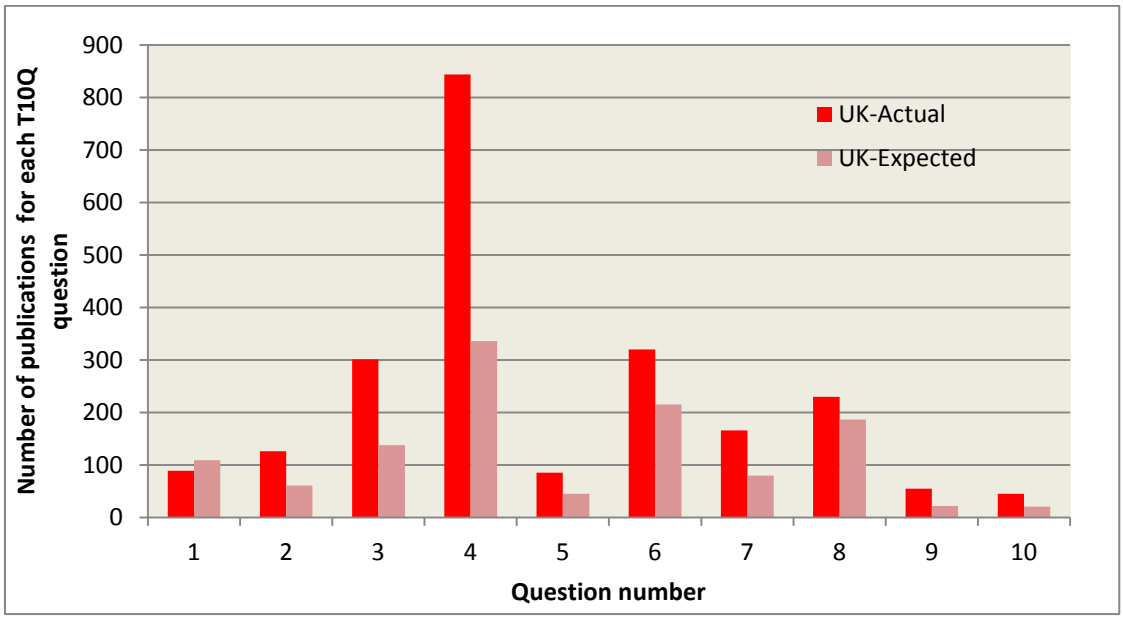


Figure 19 Actual vs. Expected numbers of publications for each T10Q question, from the UK

Publications of the most recent five years

Figure 20 shows data from the last five-year period (2005-2009) plotted as a percentage of the whole dataset available for each question, which gives an indication of topics which are growing most rapidly in terms of publications

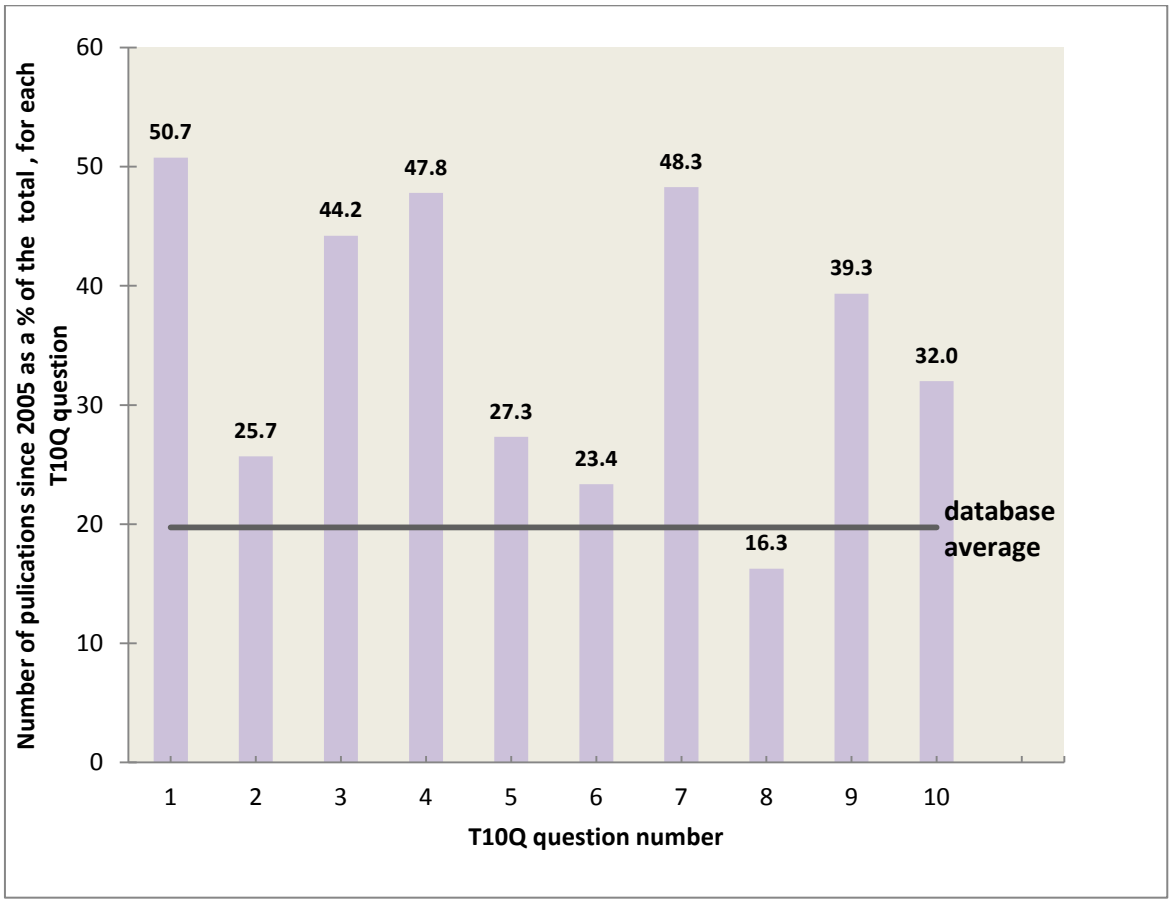


Figure 20 Recent publications as a percentage of the total number of publications for each T10Q question. The horizontal black line shows the database average for all publications in the period 2005-2009 as a percentage of the total number of publications in the database.

4.4 Discussion

Criticisms of public consultations and other stakeholder engagements have often focussed on the representativeness, or otherwise, of those participating. Few of the participants in T10Q claimed to be 'representing' the views of their organisations. Participants had, in any case, to balance their representative 'mandates', with 'independence of judgement' (Dombrowski 2010), because T10Q used a Delphi approach to amend and refine submissions, rather than a rigid process of mandated voting with no discussion.

A philosophical discussion of representativeness of participants in participatory exercises in general, and T10Q in particular, is outside the scope of this paper. However, it is important to establish whether, collectively, the stakeholders' decisions can be considered broadly representative of the sector or not. One of the key objectives of this phase of the project was to find a practical way of gauging whether the T10Q process resulted in a set of questions which could be viewed as meaningful for the broad range of people who consider themselves to have an active interest in forestry issues, or whether the resulting questions were indicative of over-prominence of people following a narrow agenda.

The earlier paper found that the top ten questions from the T10Q project mapped very closely onto existing national research priority themes, and could therefore justly be considered at least broadly representative of contemporary thinking (Petrokofsky *et al*. 2010). Looking at the number of existing research publications which have relevance to these questions enabled a more detailed level – below that of 'theme' – to be analysed. The results of the literature analysis showed that no question had fewer than 570 articles of potential relevance, and most questions had well over 1000. The issues raised were therefore clearly not so narrowly framed that they could be considered pressure-group topics.

Another possible outcome of this type of participatory process was that stakeholders would submit and prioritise only topics which had received recent coverage in the media. The results of the first phase of the project showed that a very wide set of questions were submitted and that these contained examples of topics rather rarely reported in the newspapers or on television.

There was some speculation before the workshop phase of the project that the issue of climate change was so central, in the research literature, the media and policy arenas, that discussions would be dominated by the subject, as it was in Morton's work in Australia (Morton *et al*. 2009). Three of the top ten questions (numbers 4,7 and 9) did relate to aspects of climate change, from a total of 294 questions (ca. 18%) submitted, that were classified as 'climate change' or 'carbon sequestration' (topics which are intimately connected in current debates in forestry) (Figure 1), which does reflect a heightened concern with this research area. Not surprisingly, perhaps, the knowledge base for at least one of these climate change questions (number 4) was very much larger than for any of the other questions (Table 8), with a particularly high proportion of articles published in the last five years (ca. 48% for questions 4 and 7, compared with a database average of ca. 20%).

There has to be caution in making direct comparisons between the figures obtained for the knowledge sets supporting each question, given that the scope of the questions varies widely and the search strategies (Table 8) cannot therefore be standardised so as to be equally efficient for each question. The searches, compiled by a former senior forestry database editor at CABI, provide indications of potentially interesting publications within the CABI database. The searches will inevitably have retrieved publications which would be of little use in answering the questions posed. However, differences in the volume of research literature published in this extensive database are evident and observations on these differences are almost certainly indicative of trends in the wider knowledge base which lies outside the scope of the CABI database. Questions 4, 6 and 8 all had an extensive volume of literature, with over 5,000 publications (from 1939 to 2009) of potential relevance each (Table 8). Questions 9 and 10 were very much smaller, with fewer than 1000

publications in total, and fewer than 100 each from the UK, reflecting the much narrower scope of these two questions, compared with the broader scope of other questions.

Looking at the most recent five-year period (Figure 20), all the top ten questions, apart from number eight about woodfuel, had higher than expected values compared with the database as a whole. Just over half the available literature for the top question to emerge from the workshop was published in the past five years: well above the 19% database average. In terms of a rapid assessment of the validity of the method, it does appear that a question of very high importance at present did emerge from the rigorous process of question submission, refinement and prioritisation and is supported by a large body of research, which could bear greater analysis and review. It may be a matter of concern, for example, that the proportion of European (and UK) based research in this area has not kept pace with global research on invasive pests and diseases. At the other end of the spectrum, it is interesting to note how the topic of woodfuel has had a resurgence recently. There is a large body of research in this field, but much of it is from previous decades, which points to a need to review what is known already before embarking on new research.

That climate change emerges as a high priority and is supported by a large, and growing, knowledge base, will come as no surprise to anyone who has followed debates in forestry over the last few years. Looking at the set of ten questions as a whole, however, other, less predictable, findings emerge. The question on invasive pests and diseases, that emerged with the most number of votes from Workshop delegates and is considered the 'top' question in the final T10Q list, was the only one of the ten whose knowledge base was smaller for both EU and UK research than expected on the basis of database proportions for these two regions. The knowledge base for all other questions showed higher numbers for EU and UK than could have been predicted from database average figures applied to each question. The research base for the topic of invasive pests is dominated by the USA. Research from or focussed on the USA comprises 16% of the database on average but for this topic it is 55%. The EU tends to produce twice as many research papers as the US but there were almost

three times as many US papers as EU papers on invasives, pests and diseases. It would appear to be a strong candidate topic for greater EU and UK research.

Analysis of the literature supporting the top ten questions shows that there are no major differences between relative outputs from the UK and those from the EU or elsewhere. Where differences do exist, these could be further explored to determine whether research effort is falling behind. There is not a very large pool of research literature emanating from the UK for any of the questions, with the exception of question 4 - on climate change effects on forestry- where there were 844 potentially relevant papers, compared with fewer than 100 papers each for four of the ten questions. However, the potentially less well-known articles from non-UK institutions form a sizeable body of knowledge to consult when considering where knowledge gaps exist and subsequently constructing research agendas.

The policy cycle is not a linear process, where good science is fed in at one end and good policy comes out at the other, but rather a cycle of events, with science contributing at all stages and, importantly, knowledge gaps emerging as pointers for new research. For forestry, particularly, this process can take decades, with issues gaining in and falling from prominence, and research following these trends (Pasiecznik and Petrokofsky 2005). These are strong reasons to look at long-term trends in published scientific research when constructing agendas for policy-relevant research. The best way to maximise the impact of scientific input in the policy process is through "continuous, routine engagement … in the context of long-term, mutually beneficial partnerships with decision makers, policy analysts, and program implementers" (Pouyat *et al*. 2010). They point to the case of acid rain, where the issues were framed and reframed over years as the public debate changed and the science base continued to expand until finally a workable policy was implemented. Overcoming the research implementation gap and improving practice requires collaboration between researchers and practitioners during the 'long and often messy process of research, strategy development, and implementation' (Sayer and Campbell 2004). T10Q demonstrates a practical way of constructing a

meaningful list of high-priority research questions, which can be further explored in terms of existing knowledge and prominent knowledge gaps.

This project did not explore the quality of the literature extracted for each question, nor did the project seek to determine what research papers (or other forms of evidence) were influencing stakeholders' decisions at any stage of the process. Neither did it seek to determine what evidence is being used selectively or non-selectively in a non-biased manner to answer or frame policy questions of the type discussed during the project. These will be important topics to explore in future work which examines how research outputs can best contribute to robust evidence of the sort needed for systematic reviews, which are commonplace gold standards for evidence in medicine, social policy and, increasingly, environmental conservation((Chalmers, 2003), Davies and Boruch, 2001; Pullin and Knight, 2009) and much needed in forestry.

4.5 Conclusions

The T10Q project successfully developed a collaborative, 'bottom up' process in which a diverse group of people with a professional involvement in forestry prioritised questions which they considered to have relevance to a modern research agenda, and which subsequent bibliometric analysis revealed to be of high global interest.

There is no particular significance to the fact that the project aimed to prioritise ten questions. Top ten lists are ubiquitous across all subjects and countries. The method can readily be adapted to produce a different number of high priority questions, according to need and available resources.

Bibliometrics provided a rapid assessment method for examining the prioritised questions in the light of current published scientific knowledge. Literature analysis, even at this rather broad level of detail, provides a back-stop to validate the likely level of real interest in the topics and also enables geographical comparisons to be made, which offers the possibility of looking at national research priorities in the context of global or European research. Analysing trends over time and between

regions gives some indications about where knowledge gaps may occur and where topics are receiving attention in different regions.

Recent global economic pressures affecting science funding in Europe and elsewhere make it imperative to ensure that funded research is meeting the needs of stakeholders and, moreover that the quality of that research is of sufficient calibre to allow policy decisions to be taken on that basis. A recent speech by the UK Secretary of State for Business, Innovation and Skills set out a "challenge to the science and business communities" (http://www.bis.gov.uk/ministers/vince-cable) to

> "*come together, work together and plan a future together that makes the most of this country's competitive advantages in financially difficult circumstances for the benefit of us all."*

In other words, to "do more with less". The approach presented in this paper offers a model for doing more with what we have, by exploring novel ways of stakeholder participation in helping to prioritise key areas for research, and by examining research priorities in conjunction with existing published research, offers the prospect of working towards an improvement of the knowledge base which underpins decision-making in forestry.

Chapter 5. Applying an evidence-based framework to validate the science for a key policy issue within the UN-REDD programme

5.1 Introduction

This chapter describes a case study that was conceived under the UN-REDD programme[10] as a project to investigate the potential for conducting a systematic review of the global literature on monitoring and assessment methods for carbon stocks using an evidence-based frameworks to shed further light on the scientific validity of the knowledge base in this area.

The choice of REDD as a topic

Reducing Emissions from Deforestation and forest Degradation in developing countries (REDD) was a good candidate are from which to choose a current policy topic on which to test the possibility of conducting a systematic review, given its high prominence in national and international discussions, and the wealth of relevant forestry research that is available to evaluate. The basic idea behind REDD is that countries should be financially compensated for reducing carbon dioxide emissions from deforestation. Approaches to reducing global deforestation have never been successful and the hope is that REDD provides a new framework that will enable countries with high rates of tropical deforestation to break this trend without suffering financially.

Linking deforestation with global climate change enabled REDD to be pursued internationally at the highest level, and under the spotlight of the world's media, whose interest in climate change was increasing. In 2005, the Coalition for Rainforest Nations (through negotiators from Papua New Guinea and Costa Rica) presented a draft proposal at

[10] http://www.fao.org/climatechange/unredd/en/

the first Meeting of the Parties to the Kyoto Protocol in Montreal, which was held in conjunction with the eleventh session of the Conference of the Parties to the Climate Change Convention (COP11).[11]

> *"Reducing emissions from deforestation in developing countries: approaches to stimulate action"*

Two years later, REDD was presented as a key climate change mitigation tool at the Conference of Parties to the United Nations Framework Convention on Climate Change (UNFCCC – COP13) and the Parties to the Kyoto Protocol (CMP3) which met in Bali in December 2007. (Clémençon 2008) summarised the event:

> *"After some high-stakes poker about emission reduction frameworks and the role of emerging economies, participants settled on a road map for negotiating a new climate agreement by the end of 2009…A properly designed REDD mechanism is widely seen as a cost-effective approach to simultaneously conserve forests, slow climate change, protect biodiversity, foster sustainable development, and maintain important ecological services provided by healthy forest ecosystems. The concept of REDD has won support from a wide range of interests, including conservationists, big business, scientists, governments, development agencies, and some environmental and indigenous rights groups. Opponents of REDD anticipate problems with implementation and question whether benefits will be fairly shared between stakeholders."*

Cementing the idea that deforestation should be framed within the global warming debate, the Stern report (2006) cited figures for greenhouse gas (GHG) emissions from tropical deforestation that were greater than emissions from all the world's cars, lorries, ships, planes, and trains combined. His recommendation that tackling the problem of deforestation was a relatively cheap solution to climate change mitigation was a pivotal moment in focussing attention on forestry activities. The UN Intergovernmental Panel on Climate Change (IPCC)

[11] http://unfccc.int/meetings/cop_11/items/3394.php

report (2007) produced figures which estimated that the forest sector (and other sectors that affect landuse through deforestation, forest degradation and other changes in forests) was responsible for some 17% of global greenhouse gas emissions (GHG) from human activity[12,] or approximately 5.8 Gt of carbon dioxide equivalent (CO2-e), per year. Later work estimated that a 25% reduction in annual global deforestation rates could be achieved by 2015 if financing of US$22-38 billion were made available from 2010-2015 for results-based incentives and capacity building, complementing other bilateral and multilateral REDD+ efforts[13].

REDD+[14] gained important momentum at COP-15 in Copenhagen, at which a large number of governmental and non-governmental proposals for reducing emissions from deforestation and degradation were discussed (Parker *et al.* 2009). The conference, widely regarded as a disappointing failure generally, successfully framed REDD+ as an issue for which agreement was attainable (UNFCCC 2007).

---

[12] IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp. http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml [accessed 29/3/2011]

[13] Report of the Informal Working Group on Interim Finance for REDD+. Discussion Document. (October, 2009) http://www.rainforestsos.org/report-of-the-working-group-on-finance-for-redd/ [accessed 29/3/2011]

[14] REDD + is defined here as "policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries" (UNFCCC 2007).

COP-16 in Cancún agreed on the REDD+ policy approaches and positive incentives, including guidance on activities and safeguards to be promoted and supported[15]. Many countries have called for immediate and significantly scaled-up action to build capacity and readiness to address the multiple challenges associated with reducing emissions from deforestation and forest degradation as well as addressing conservation, sustainable management of forests and enhancement of forest carbon stocks.

Key REDD issues

The UN-REDD Programme was launched in September 2008 to assist developing countries prepare and implement national REDD+ strategies. It is a collaboration of three United Nations agencies - the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP) and the United Nations Environment Programme (UNEP).

The interim and country-led REDD+ Partnership was established in May 2010, to ensure that momentum and support for REDD+ continues to grow while the mechanism is negotiated under the UNFCCC. In this context, over US$4 billion was pledged as early finance to implement REDD+.

Important areas of REDD+ which are the subject of active discussion and research include:

- governance, equity, land tenure, ownership, participation of forest-dependent communities structures and illegal logging;
- 'leakage', whereby forest conservation in one place causes deforestation in another;

[15] http://unfccc.int/2860.php

- financing to support the mechanism and provide sufficient economic incentives to stop deforestation, and controversies over carbon offsets and forest carbon in market-based trading schemes;
- technical aspects of monitoring and verifying change in forest cover, and criteria for establishing credible deforestation baselines;
- scale of implementation ('national' vs. 'sub-national' projects);
- understanding the drivers of deforestation;
- sustainable forest management (protection of intact forest ecosystems vs. reduced impact logging);
- protection of biodiversity and environmental services in non-carbon-rich ecosystems

Science underpinning the assessment of carbon

During the pilot phase of the UN-REDD Programme, one area of focus was reviewing and evaluating approaches to Measurement, Assessment, Reporting and Verification (MARV), as a cornerstone for future accounting of carbon credits. It was acknowledged that although there had been a very wide range of efforts undertaken in public and corporate research to provide for optional methods and data sources for MARV, and a concomitant proliferation of scientific and technical papers, but a lack of rigour in reviewing methods used to assess forest carbon storage (Holmgren and Marklund 2007):

"current monitoring of forests seems insufficiently accurate or precise for an international protocol that would administer finances based on monitoring results of forest area or forest carbon storage."

While it has been argued that a REDD+ system must be flexible to allow and account for variability in methodologies and accuracy (Olander, L.P. *et al.*. 2008), flexibility must come

with knowledge of the limits of confidence in these variable approaches if REDD is to be credible, transparent and fair. A collaborative project was conceived that would systematically analyse MARV literature using evidence-based frameworks of the type widely used in medicine and other policy areas which require scientifically-grounded decision-making. The aims of the project were to lend scientific credibility to the guidance given to countries participating in a future REDD mechanism, and to provide scientific underpinning of the many approaches which exist.

Chapter 5 outlines the approach taken to the project in Section A, and presents the Systematic Review Protocol which emerged as an output of the scoping phase of the project in Section B.

Section A. Scoping the potential for a systematic review

A version of Section A was published as: G. Petrokofsky, P. Holmgren, N.D. Brown, 2011. Reliable forest carbon monitoring – systematic reviews as a tool for validating the knowledge base. *International Forestry Review 13* (1), 56-66

Author contributions:

Gillian Petrokofsky: I suggested the paper, devised its structure and content and wrote it.

Peter Holmgren: is Director of the Climate, Energy and Tenure Division of the Food & Agriculture Organisation of the United Nations. He devised the framework for analysing carbon in forests and contributed insights from international initiatives in addition to valuable feedback on the drafts [see Holmgren email confirmation in Appendix XX]

Nick Brown: is Principal of Linacre College and University Lecturer in Forestry in the Department of Plant Sciences. He helped shape the structure of the paper and provided valuable feedback during the drafting stages.

5.2 Background

Tropical forests cover about 15% of the world's land surface (FAO 2006) and contain some 25% of the carbon in the terrestrial biosphere (Bonan 2008). Deforestation and forest degradation are estimated to be responsible for almost 20% of the world's total greenhouse gas emissions (Gullison *et al.* 2007, Van der Werf 2009). Although emitting substantially less carbon dioxide than electricity and heat generation and transport, which together account for two-thirds of global carbon dioxide emissions (OECD, 2010), agriculture, forestry, and land use changes represent a significant source of atmospheric CO2.

In his Review of the economics of climate change Lord Nicholas Stern said,

> *"without prompt action emissions from deforestation between 2008 and 2012 are expected to total 40Gt CO2, which alone [is] greater than the cumulative total of aviation emissions from the invention of the flying machine until at least 2025."*

Some 13 million hectares of forest are converted to other land uses each year (FAO 2006). Current deforestation in Indonesia and Brazil releases carbon equal to four-fifths of the annual reduction target for Annex I countries of the Kyoto Protocol (Santilli *et al.*. 2005). Forests, carbon emission and climate change are all firmly linked in the public's eye.

Although the 1997 Kyoto Protocol permitted emissions trading it did not sanction the use of reduced deforestation as a carbon emission reduction project in non-Annex I countries. It was not until the 15th Conference of the Parties at Copenhagen in December 2009 that details of a mechanism for Reduced Emissions from Deforestation and Degradation (REDD) were defined within the United Nations Framework Convention on Climate Change (UNFCCC). For developing countries, REDD and REDD+[16] could include mitigation actions through reduced rates of deforestation or forest degradation, but also through sustainable forest management, conservation of forest ecosystems and enhancement of forest carbon stock, for example on degraded land. The REDD+ instrument, as agreed in Cancún, Mexico at COP-16 of the UNFCCC in December 2010[17], will alter the situation for developing countries. It includes the implementation of five mitigation actions:

---

[16] REDD + is understood to be: "policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries" (UNFCCC 2007).

[17] http://unfccc.int/2860.php

1. Reducing emissions from deforestation;
2. Reducing emissions from forest degradation;
3. Conservation of forest carbon stocks;
4. Sustainable management of forest;
5. Enhancement of forest carbon stocks.

All forest resources in developing countries are potentially subject to accountable mitigation actions. Such actions would be rewarded to their value of tons of carbon mitigated. The Cancún Agreements also stipulate that robust and transparent national monitoring systems of these mitigation activities should be developed. In order to implement REDD+ successfully, it will be crucial to determine the spatio-temporal variation of carbon stocks. Obtaining field measurements and developing estimation models to do so is an expensive and time-consuming task.

With credits globally valued at US$126 billion in 2008 (up from $31 billion in 2006) (Capoor and Ambrosi 2009) and the global forest carbon offset market projected to grow from $42.0 million in 2010 to $65.1 million in 2015 (Figure 21), carbon credit accounting under REDD brings into sharp focus the current poor performance of national forest monitoring systems (Holmgren and Marklund 2007) and the necessity of adopting carbon monitoring and assessment methods that are reliable and based on sound science.

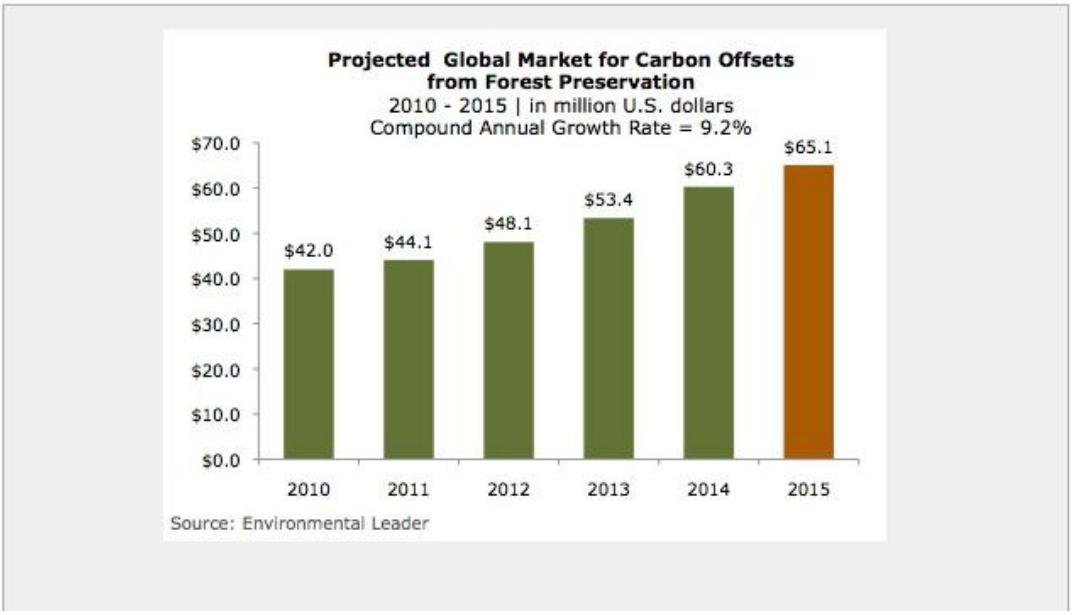


Figure 21 Projected global market for forest carbon offsets from forest preservation

.

There has been no systematic analysis of the relative levels of accuracy, precision or comparability of the wide range of methods used to assess and measure forest carbon. There are now over 600 scientific papers published each year on topics of relevance to measuring carbon in forests, too many for even subject specialists to be able to read and understand. Contradictory results and questionable methods threaten to delay or damage the credibility of attempts to negotiate a workable REDD mechanism.

When confronted with the twin challenges of a large volume of evidence and conflicting findings, the worlds of medicine and social policy use robust reviewing tools to bring order to the chaos. Medicine pioneered the use of systematic reviews over a decade ago as an essential component of evidence based medicine (Sackett *et al.* 1996); they are now considered to be the 'gold standard' for evidence (Figure 22) not only in medicine and public health, but also in many areas of social science, notably education, crime and justice and social welfare

(Petticrew and Roberts 2006) and, more recently, nature conservation (Pullin and Knight 2009).

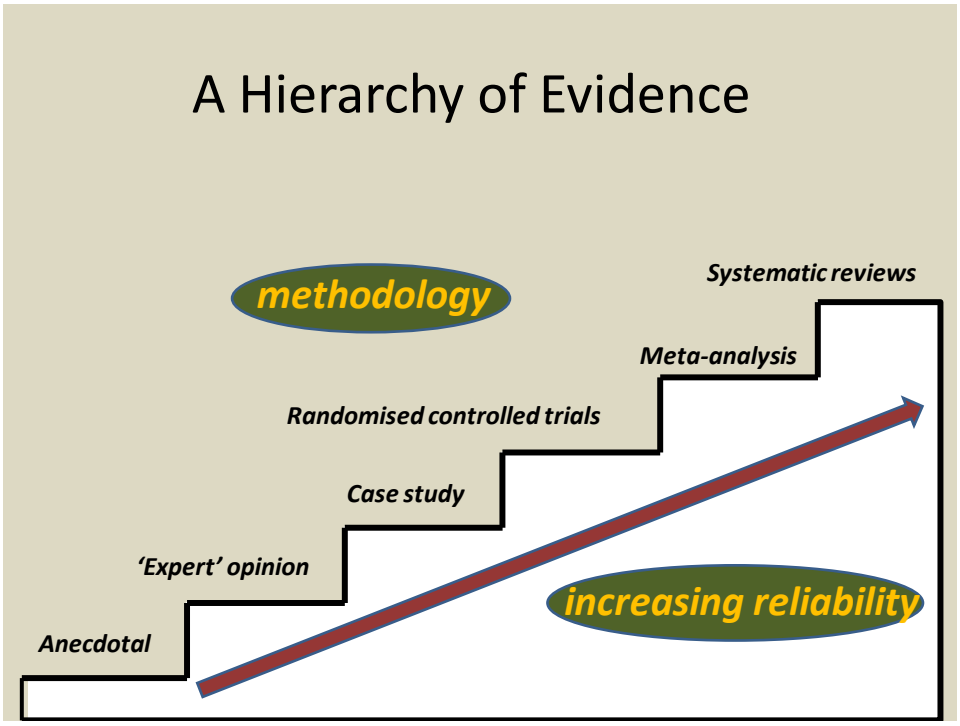


Figure 22 A hierarchy of evidence showing increasing reliability of evidence in a progression from anecdotal evidence as generally the least reliable to systematic reviews as generally the most reliable

This paper describes a methodological and analytical framework for developing an evidence-based approach to the issue of forest carbon monitoring, which can serve as a model for wider use in forestry and natural resource management where decision-making must take account of diverse scientific findings.

5.3 Evidence based frameworks

Evidence-based frameworks evolved from evidence-based medicine and have three key elements: the question; the systematic review of evidence; and active dissemination of results (Figure 23). The participatory nature of these frameworks for all phases from question framing to active distribution of results in appropriate formats for different audiences is highly relevant to the issue of forest carbon monitoring under a REDD+ scheme.

The role of systematic reviewing as a potentially powerful tool to aid good decision-making is poorly understood in the forestry community and there have been very few reviews completed. However, the call for evidence-based policy continues to grow and terms like 'evidence-based policy' are used freely, largely without definition, in the literature. The number of peer-reviewed environmental science papers containing the phrase 'evidence-based' in the title or abstract of the paper grew from fewer than 50 in 2000 to over 350 in 2008 (Petrokofsky and Mills 2009). With the exception of a small number of papers published in association with the Collaboration for Environmental Evidence, which promotes Cochrane-style systematic reviews[18], none of these publications employed a transparent method of weighing evidence, which is a pre-requisite for a study to be termed 'evidence-based' in medicine.

[18] http://www.environmentalevidence.org/

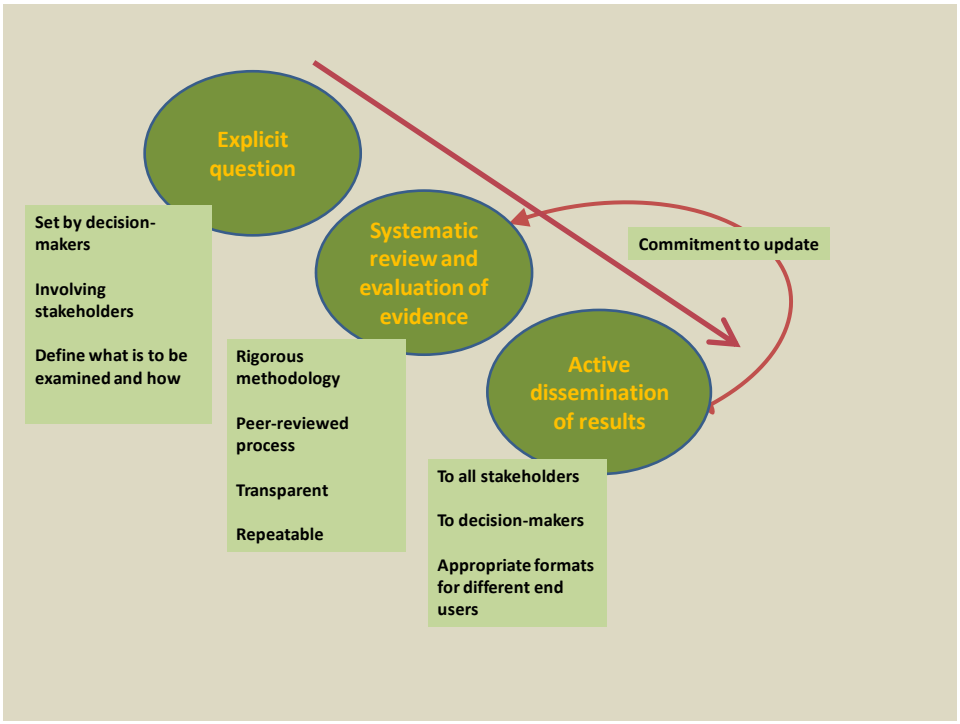


Figure 23 Evidence framework for decision-making

Without unbiased evaluation of the best available evidence, there cannot be genuine evidence based practice. Given that very few systematic reviews exist in forestry, there is a real danger that talk of 'evidence-based decision making' is a gross deception. This has potentially serious implications for acceptance by the wider public, particularly where science is invoked as a justification for policy action.

Public loss of trust in science is a subject which periodically comes to the fore and has deep roots and a long history (Wynne 2006). The issue has resurfaced recently with widespread commentaries on the IPCC and its handling of science (Nature 2010, IPCC 2007). It could be argued that some of the weaknesses of the IPCC processes identified by the five climate scientists who discuss possible reforms could be addressed by the adoption of evidence-based frameworks for an issue for which, like forest carbon monitoring, "facts are uncertain, values in dispute, stakes high and decisions urgent" (Funtowicz and Ravetz 1990).

Two of the five excerpts serve to illustrate this:

> *"Rather than comprehensive reports every six years, this panel [Global Science Panel – one of suggested groups to replace the IPCC] would commission, on a rolling basis, a larger number of smaller, sharply focussed syntheses of knowledge on fast-moving topics that have great scientific or policy salience"* (Hulme 2010);
>
> *"ICA [International Climate Agency – a suggested stronger, more independent version of the IPCC] reports should be independently reviewed in a transparent process, draw only on established, peer-reviewed literature, and highlight research gaps."* (Zorita 2010).

5.4 Applying an evidence-based approach to carbon assessment

REDD finance based on accurate and verifiable carbon assessment is highly likely to be the subject of a great deal of public scrutiny not only of governance but also of the science behind the figures.

At an initial Workshop held in FAO headquarters in March 2009, it was agreed that an international participatory initiative should be undertaken to scope the potential for using an evidence-based approach to validate the knowledge base on carbon monitoring methods. A project contact group of 50 people was chosen to represent a range of organisations with academic, policy, consultancy and/or training focus in different countries.

The contact group participated in iterative discussions (mostly by email and telephone) to develop a shared understanding of the problems which need to be addressed and to develop a series of possible review topics. In addition to discussions the group shared knowledge, mainly published papers but also 'grey literature' (project reports and discussion documents), which contributed to an understanding of the potential scope of the review. The review topics were further developed by two scoping groups (one meeting in person and the other via a teleconference) during the Bonn climate change meetings in June 2009.

Outputs from this first phase of the project were the development of explicit review questions, and a preliminary evaluation of the existing evidence base that could provide scientific underpinning for these questions. In order to frame review questions precisely, a clear understanding of all the components of forest carbon assessment was developed.

5.5 A conceptual framework for measuring forest carbon

This framework defines components of forest carbon measurements, as a starting point for an investigation into reliable carbon monitoring. It builds on experiences from national forest inventories (Ranneby *et al.* 1987) and remote sensing technology (Foody and Cutler 2003; Goetz *et al.*. 2009) and takes into account the suggestions in the IPCC Good Practice Guidance for Land Use, Landuse change and Forestry (Penman *et al.* 2003).

The framework defines the components of a national assessment of carbon stock, then extends this to change-assessment between two points in time.

1. Assessment of C within area *a* at time *t* (C*at*)

For efficiency and non-destructive reasons, direct measurements must be made on proxy variables, such as tree diameter and height, that are applied in conversion models to estimate the carbon stock at the measured location, for the set of carbon pools considered, in this case the five terrestrial pools[19] identified by the IPCC (Penman *et al.* 2003). For efficiency reasons, measurements are normally made at sample locations and not for the entire area in question.

[19] Above-ground biomass, Below-ground biomass, Deadwood, Litter, Soil (including peat).

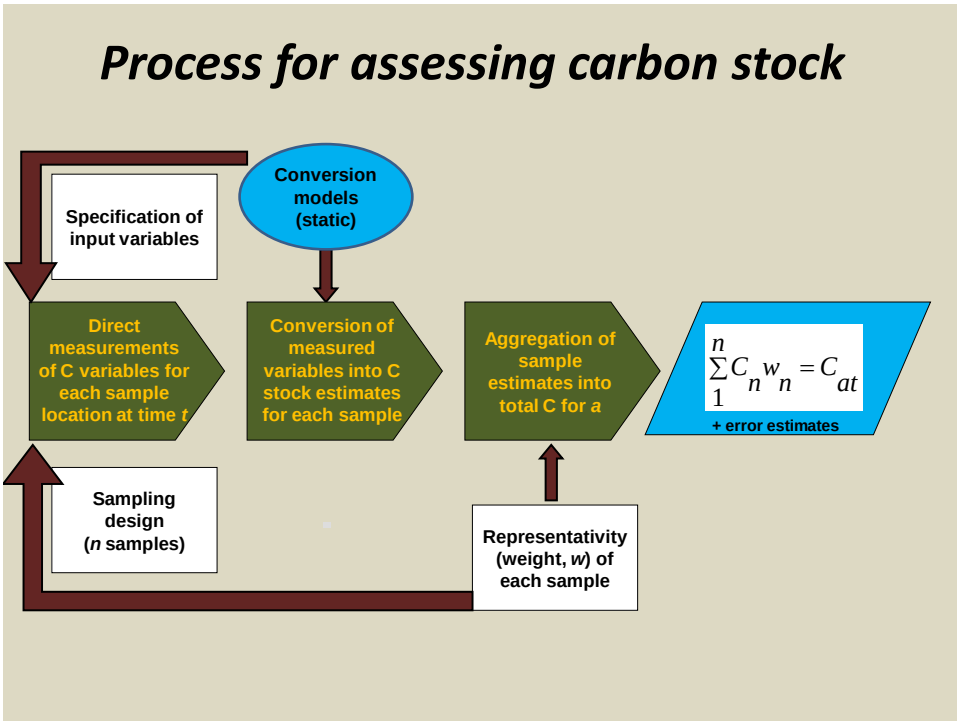


Figure 24 Process for assessing carbon stock for an area *a* at time *t*

The measurement process can therefore be described by three independent but interlinked components (Figure 24):

- Actual (direct) measurements
- conversion models
- statistical representation

Each of these components contributes to assessment errors, and also incurs costs. Further to the direct measurement costs, the cost (and time) required to establish conversion models and design the measurement sample must be considered.

2. Change assessment within area *a* between t_1 *and* t_2 ($\Delta C_{at_{1,2}}$)

Measuring change introduces additional challenges. Two generic alternatives are :

i. to measure at two points in time and calculate the difference

ii. to measure once and use modelling to estimate the change

(i) Changes between independent measurements

Building on (1), the change of C can be expressed simply as the difference between independent assessments at t_2 and t_1 , i.e. $C_{at_2} - C_{at_1}$ **.** This will provide the net change of the carbon pool in question for *a* as a whole.

However, there may be requirements for determining 'gross changes' between carbon pools, i.e. the overall gains and losses from/to each pool, resulting in a change matrix. Further, there may be demand for measuring carbon changes in a spatially explicit manner, i.e., the gains and losses for defined area fractions over the overall territory. These approaches are similar in the sense that changes need to be assessed individually for a number (*n*) of sub-areas (samples) that constitute a complete and non-overlapping representation of *a*, such that:

$$\Delta C_{at_{1,2}} = \sum_{1}^{n} (C_{a_n t_2} - C_{a_n t_1})$$

Noting that:

- n=1 is a special case expressing net change for *a* as a whole;
- very large *n* can be exemplified by a set of permanent national forest inventory plots, a complete set of land properties in a country, or a 'wall-to-wall' set of remote sensing observations, for which time series of carbon assessments can be provided and added up to totals for *a* ;
- the concept of 'gross changes' is related to the scale of measurement, i.e. the sizes of a_n. For large sized a_n, internal losses and gains may occur, but would not be recorded. Consequently, recorded gross changes will be larger when smaller units are considered in the assessment.

(ii) **Modelling changes based on one carbon stock assessment**

An alternative to independent measurements over time builds on having only one measurement of carbon stock at t_1, and then applying a dynamic model to estimate the stock at t_2. The estimate can be for past as well as future changes.

Direct measurement or observation of change may also improve assessment of $\Delta C_{at_{1,2}}$ also without adding new assessment of the carbon stock *per se***.**

This includes in particular remote sensing options for

- estimating changes in signals that can be directly correlated to biomass/carbon pools,
- reassigning weights to individual measurements through post-stratification approaches.

Developing this detailed conceptual framework provided a very robust means of 'unpacking' broad questions about carbon assessment and clarifying precisely what evidence in the published literature would need to be reviewed to provide Reliable forest carbon monitoring scientific underpinning for the development of credible national systems of monitoring and assessment.

5.6 The existing evidence base on forest carbon monitoring

There is a growing body of scientific and technical information on ground-based and remote sensing methods of forest carbon monitoring. Figure 25 shows the growth of literature reporting on topics of relevance to elements of the processes outlined in the framework for carbon measurement illustrated in Figure 24.

Three bibliographic database which systematically index academic articles on natural resources research are:

1. Web of Science (http://isiwebofknowledge.com),
2. Scopus (http://www.info.scopus.com)
3. CAB Abstracts (http://www.cabi.org).

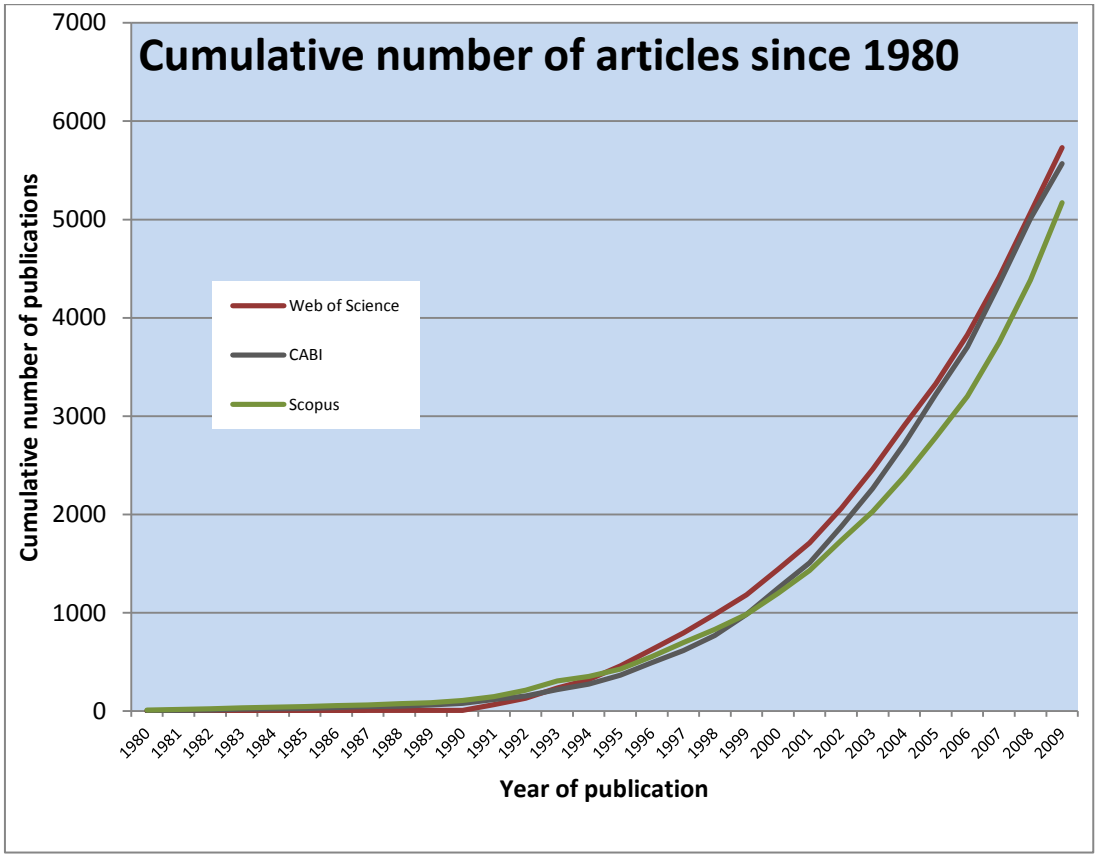


Figure 25 Number of articles of relevance to carbon in forest indexed in three major databases

There is a large amount of duplication between the databases, but they have different strengths for applied natural resources research and operate independent selection policies. A preliminary search was conducted in each of these databases to determine the volume of literature that could potentially be included in the knowledge base which supports decision-making for carbon stock monitoring in REDD. Table 10 shows details of the search strategies. All three databases show a knowledge base currently containing over 5000 articles, which has been growing at the rate of over 600 articles per year since 2007, and shows no sign of abating.

Table 10 Search strategies used for each bibliographic database

DATABASE	SUBJECT SCOPE SELECTED	SEARCH STRATEGY
Scopus	Subject coverage: limited to Agriculture and Environment subsections of Scopus.	((TITLE-ABS-KEY(carbon W/5 sink*)) OR ((TITLE-ABS-KEY(carbon W/5 emi*)) OR (((TITLE-ABS-KEY(carbonW/5 assess*)) OR (TITLE-ABS-KEY(carbon W/5 measur*))) OR (TITLE-ABS-KEY(carbon W/5 sequest*))))) AND (TITLE-ABS-KEY(forest* OR wood* OR scrub* OR browse)) AND (LIMIT-TO(SUBJAREA, "ENVI") OR LIMIT-TO (SUBJAREA, "AGRI") OR LIMIT-TO(SUBJAREA, "MULT"))
CAB Abstracts	Subject coverage: This is a database specializing in agriculture, natural resources and forestry, which defines the subject coverage. No further filters were necessary for the search.	((carbon adj5 assess*).ti,ab OR (carbon adj5 emi*).ti,ab OR (carbon adj5 sequest*).ti,ab OR (carbon adj5 sink).ti,ab) OR ((carbon sequestration).de OR ((carbon).de AND (measurement),de OR (assessment).de OR (emission).de)) AND ((forest* OR wood* OR scrub* OR browse OR agroforest* OR rainforest* OR tree*)),ti,ab,de)
Web of Science	Subject coverage: Subject Areas=(environmental sciences or ecology or forestry or meteorology & atmospheric sciences or soil science or geosciences, multidisciplinary or plant sciences or agronomy or biodiversity conservation or energy & fuels or environmental studies or multidisciplinary sciences or remote sensing or agriculture, multidisciplinary or agricultural engineering or imaging science & photographic technology or biology or geography).	(TS=(carbon SAME assess*) OR TS=(carbon SAME measur*) OR TS=(carbon SAME sink*) OR TS=(carbon SAME emi*) OR TS=(carbon SAME sequest*)) AND TS=(forest*) OR TS=(wood*) OR TS=(scrub*) OR TS=(browse) OR TS=(tree*) OR TS=(agroforest*) OR TS=(rainforest*)

Notes

title: TITLE (Scopus); /.ti (CABI) ; abstract: ABS (Scopus); /.ab (CABI); Keywords: KEY (Scopus); /.de (CABI); TS (topic search) – searches in title, abstract and keyword fields in Web of Science; Search logic The operator 'W' in Scopus is 'Adj' in CAB. W/5= search for the two terms up to 5 words apart, in either order. The number 5 is suggested to limit occurrence to words in a phrase. Adj5 operates in the same way CABAbstracts. In Web of Science, the operator 'SAME' searches for occurrence of two words in one sentence. This is the closest equivalent to the W or ADJ operators in the other two databases. The search strategies have taken account of the different ways searches operate within each database.

In addition to the large volume of scientific literature which already exists and the growing volume which is being added each year, there are conflicting findings and discrepancies in methodologies which add to the difficulties of interpretation and consensus-building.

A prime example of these problems is the lack of consensus on how much carbon is being emitted by tropical land use changes (Malhi and Grace 2000, Malhi *et al.*. 2002, Fearnside and Laurance 2003, Achard *et al.* 2004, De Fries *et al*. 2007, Van der Werf *et al.* 2009). It is rarely clear what the source of such discrepancies and inconsistencies is. It could be attributable to uncertainties about the amount of carbon in tropical forests or uncertainties in deforestation rates (Houghton 2005).

There is substantial variation in published estimates of the total carbon content of tropical forest (Ramankutty *et al*. 2007). These variations are attributed to a number of factors, which can be considered in terms of the three independent but interlinked components defined in the framework for carbon measurement (Figure 24):

1. Problems of direct measurements of biomass variables including difficulties of access and limited number of ecological studies that measure biomass directly (Brown *et al*. 1989, Baker *et al.* 2004a, Malhi *et al*. 2004).
2. Problems converting biomass estimates into C stock estimates including the large number of published biomass equations (Baker *et al*. 2004b) and the spatial extent of tropical forests (Malhi *et al.* 2004, Hansen *et al*. 2008). Grainger (2008) points to uncertainties in values derived from remote sensing for extent of forest area and rates of deforestation. These values significantly affect estimations of carbon stocks.
3. Problems of scale and extrapolation. Laumonier *et al.* (2010) caution against calculating carbon stocks in a given forest type or a region by extrapolating data from small plots to larger spatial scales and demonstrate considerable variation in values obtained sometimes

from very small sample plots and replicated in reports with no regard for applicability. The same study specifically highlights considerable variance from the IPCC biome default value for 'tropical wet forest' (Eggleston *et al.* 2006) reported in their results and in the literature, but the point is a general one: using values derived for one ecological or landscape type and applying them to another is likely to result in errors.

Difficulties in comparing results of carbon estimates are not confined to research in tropical areas. Bradshaw *et al.* (2009) describe a situation of considerable uncertainty in boreal forest zones, pointing out discrepancies between methodologies of estimating biomass and applying carbon modelling projections.

The scoping project produced clear evidence of a large knowledge base that had not been subjected to systematic or transparent synthesis. The group concluded that greater rigour could be brought to a review of reliable forest carbon monitoring methods through adoption of an evidence-based framework of the type widely used in medicine.

5.7 A systematic review of methods of carbon measurement and assessment

The final output of the first phase of the project to scope an evidence-based approach to carbon monitoring was a collaborative document produced as a draft systematic review 'Protocol'. This was posted in July 2009 for peer-review on the website of the Collaboration for Environmental Evidence[20]

These protocols describe the set of steps to be followed in systematic reviews: the rationale for the review, the objective(s), and the methods that will be used to locate, select and

[20] (http://www.environmentalevidence.org/SR77.html).

critically appraise studies, and to collect and analyse data from the included studies. They are written collaboratively with a considerable element of iteration and peer-reviewed in order to reduce bias of the final systematic review, which is also peer-reviewed. The concept for peer-review developed by the Cochrane Collaboration and followed in this project, involves direct approaches to expert reviewers (mirroring practice in many academic journals), and inviting feedback from interested parties through direct emailing and, more 'informally', using internet discussion groups and fora to draw attention to the work as it progresses. The Protocol remained open for review until the end of 2010. Twenty-two people reviewed the protocol and provided feedback. The level of detail varied greatly among reviewers, as is not uncommon with peer-review in academic journals, but was generally well-informed and useful.

The scoping exercise had considerably widened the extent of the review to include carbon pools in all terrestrial biomes and not just those connected with forest. The draft protocol having received no adverse feedback, the decision was taken to fund a full-scale systematic review using review authors with expertise in the terrain and topic areas identified by the scoping project: forest, soil and peat land, agricultural land, remote sensing technology for carbon assessment. The review authors met in November 2009 for three days to frame the review questions with very precisely defined terms and start a discussion to agree the basis on which evidence from the literature would be included in the review and how findings from these papers would be analysed in accordance with 'Cochrane-style' systematic review methodology (http://www.cochrane.org). Those discussions are ongoing and will be reported in due course when the systematic review has been completed.

The review question

After extensive discussion, a question was agreed as a strong candidate for a systematic review, which commenced in December 2009. The scope of the question is extremely broad

and it has been broken down into three sub-questions, which will be the focus of the reviewed literature. Several competing suggestions had emerged during the group discussions, notably a suggestion to limit the scope of the review to forest carbon only, which had been the starting point of the project, or to concern the review only with economic comparators of methods, or to abandon the idea of assessing above-ground carbon altogether in favour of the much less well researched below-ground carbon, which all had validity, but were rejected finally on two principal grounds. Firstly, it is clear that a review of studies on carbon stocks within one biome type or one carbon pool would suffer from precisely the sort of methodological bias the review was aiming to overcome. Second, the scope of REDD+ is broad and requires an equally broad evidence base of robust science, which was one of the driving forces behind the project to validate the evidence base in the area of carbon monitoring.

The framework for measuring forest carbon discussed above, was key to framing the wording of these questions, and will inform the inclusion criteria for the literature under review.

Primary question

> *How do current methodologies compare in their ability to measure and assess terrestrial carbon stocks and changes in carbon stocks with accuracy, precision and repeatability?*

'methodologies' is defined to include methods (direct measurements, sampling design, remote sensing and Reliable forest carbon monitoring models) and systems that aggregate methods to measure and assess carbon stocks.

Sub-questions

1. *How accurate, precise and repeatable are methodologies used for the conversion of in situ measurements into carbon stock estimates at the site level?*

reviews direct measurements in the field (in situ)and methodologies that convert them into carbon stock estimates at the site level. Also reviews the geographical validity of

methodologies developed at the site-level and examines the applicability of methodologies to different land use categories in different environments, ecosystems and countries.

2. *How accurate, precise and repeatable are methodologies for generating carbon stock estimates for larger geographical areas (landscape level) from site-level data?*

'landscape level' encompasses the spatial scales from site to national levels through forest inventories, stratification, other sampling schemes and modelling.

3. *How accurate, precise and repeatable are direct remote sensing methodologies for estimating carbon stocks?*

reviews direct carbon stock estimates from measurements by remote sensing instruments, coupled with field measurements and methodologies to convert measurements into stock estimates.

The challenge of defining, a priori, which studies to include in the review to answer each question has necessitated extensive discussions about the diverse terminology which is used in the literature to describe concepts of direct relevance to the study. These terms will be used to construct a transparent literature search strategy, which can be replicated by other researchers. This clarity of content is one the most important facets of the systematic reviews that contributes to reduced bias compared with traditional, 'narrative' reviews. Chalmers (2003) discusses 'bluntly' clear evidence of bias in narrative reviews which have used different methods to review the literature and arrived at different conclusions.

5.8 Discussion

It is too early for a scholarly analysis of the Cancun Agreement on REDD+ taken at COP16 in December 2010, but what is certain is that there will now be progress towards mechanisms which can reward carbon mitigation and that this will drive demand for high quality carbon monitoring systems. REDD+ can potentially act as the elusive catalyst for sustainable forest management by providing what could be unprecedented financial opportunities for

developing countries for mitigating climate change through sound natural resources management. The very substantial amount of money that will be available for REDD+ implementation will focus attention on the need to adopt monitoring and assessment systems that are underpinned by good science.

Although there is a very large, and growing, body of scientific and technical information on methods of carbon measurement, there has been no systematic review of the literature which would meet the high standards of evidence review which are demanded as prerequisites for decision making by disciplines such as medicine and social policy. This does not mean that current decisions on methods are wrong, simply that they cannot be said to have been taken on the basis of evidence which has been analysed in a manner that is readily repeatable and as free from bias as possible. These criteria are the minimum for original scientific work but they have not been widely adopted in forestry or natural resource management as minimum standards for analysing the knowledge base prior to taking key decisions of global importance. Researchers are very familiar with the discipline of designing robust experiments, often in international teams of collaborators, from which high quality data can be generated. Systematic reviews utilise the same discipline, and encourage international, multidisciplinary teams of scientists, information professionals and decision-makers to work collaboratively on providing a high-quality evidence base. Collaboration is recognised as an important element in systematic reviewing, building partnerships between researchers and promoting stronger linkage between the science and policy communities (Turner, pers comm., Turner and Nye 2007).

The earlier scoping phase of the carbon assessment project and early results of the ongoing systematic review have demonstrated the strength of working in a multidisciplinary group to reach a shared understanding of the precise nature of the questions which need to be answered and to define very precisely a method of interrogating and analysing the existing evidence in the knowledge base.

5.9 Conclusions

Measuring forest carbon accurately and reliably is an absolute requirement if REDD+ is to be accepted and implemented successfully. At present, however, there is insufficient capacity in almost all potential REDD+ countries and potentially costly investments will need to be made in national forest monitoring systems. But which systems should impoverished countries invest in and are recommendations for these systems based on sound science? For REDD to be credible, the methods used by different national systems for forest carbon measurement need to be evidence based.

It is clear from the preliminary scoping work described in this paper that the underpinning science for measuring forest carbon has not been systematically reviewed using the sort of robust evidence-based frameworks which are considered to be essential in other science-informed areas which develop evidence-based policy and practice.

Working towards the development of a systematic review for forest carbon measurement has successfully engaged members of the science community in a process which has clear benefits for other policy problems that require analysis of complex and often contradictory science.

REDD+ is at a critical stage of development which coincides with a time of increased public scepticism in science. A systematic review of carbon measurements, using the standards set in medicine, will provide a transparent and readily-repeatable evidence base which can support decision-making in an important area of climate mitigation.

Section B. Protocol for a systematic review comparing methods for measuring and assessing carbon stocks in terrestrial carbon pools.

Published as Systematic Review No. 09-016 (previously SR77) Protocol, Collaboration for Environmental Evidence.

Draft Protocol published 27 July 2009. Final Protocol published following peer-review on 21 December 2010.

Authors:

Gillian Petrokofsky (University of Oxford), Scott Goetz (Woods Hole Research Center), Frédéric Achard (Joint Research Centre for the European Commission), Hans Joosten (Greifswald University), Hideki Kanamaru (FAO), Aleksi Lehtonen (Finnish Forest Research Institute), Mary Menton (Center for International Forestry Research (CIFOR)), Andrew Pullin (Bangor University), Martin Wattenbach (Freie Universität Berlin)

Author contributions:

Gillian Petrokofsky: I devised the systematic review project during extensive discussions with the Director, Climate, Energy & Tenure Division of the Food & Agriculture Organisation of the United Nations, who is providing Overall project leadership. I wrote the Protocol and coordinated amendments to it, following peer review, which have not been extensive. Protocols for the CEE follow a strict set of procedures, including naming the lead systematic review author as the principal author of the Protocol, as an aid to clarity [this version currently appears on the CEE website, as of 21 December, 2010]. I consider that I am responsible for most of the content of the document, which is also shaping the final review (work in progress). [see Holmgren email confirmation in Appendix XX].

Scott Goetz: is Senior Scientist at the Woods Hole Research Center. He is acting as Lead author for the systematic review, which is progressing according to the steps laid out in the Protocol.

Frédéric Achard: works at the Joint Research Centre of the European Commission. He provided feedback on aspect of remote sensing in forest.

Hans Joosten: is a Professor at Greiswald University, Germany. He provided feedback and inputs on soil and peatlands.

Hideki Kanamaru: works in the Natural Resources Management and Environment Department, FAO. He was principal contact for FAO personnel during the first phase of the project, and is now coordinating the systematic review.

Aleksi Lehtonen: works at the Finnish Forest Research Institute. He provided feedback on issues related to gas exchange and biomass assessment in forest.

Mary Menton: now works at the Center for International Forestry Research in Peru, and was formerly a researcher in the University of Oxford. She provided feedback on deadwood and fire in forest, and on biomass assessment in forest generally.

Andrew Pullin: is a Professor at the Centre for Evidence-Based Conservation, Bangor University, UK. He provided guidance on standards for systematic review and protocol development.

Martin Wattenbach: now works at the Freie Universität Berlin, and was formerly a researcher in the University of Aberdeen, UK. He provided feedback and input on carbon assessment in soil and agricultural land.

5.10 Background to carbon assessments in REDD

Land use and land cover changes, including legal and illegal deforestation, are amongst the most important factors that contribute to the social and environmental challenges facing mankind in the 21st century. Deforestation alone is responsible for about 12% of the world's anthropogenic greenhouse gas (GHG) emissions, whereas another 6% stems from peat oxidation and fires on degraded peatland areas (Van der Werf *et al.*. 2009). The combined effects of logging and forest regrowth on abandoned land are responsible for 10-25% of global human-induced emissions (Achard *et al.* 2002, Gullison *et al.* 2007). Annual emissions from deforestation in Indonesia and Brazil equal four-fifths of the annual reduction target of the Kyoto Protocol (Santilli *et al.* 2005).

Under the United Nations Framework Convention on Climate Change (UNFCCC), the REDD+ 21 instrument (Reducing Emissions from Deforestation and Forest Degradation), as agreed at COP-16 of the UNFCCC in December 201022, will alter the situation for developing countries. REDD+ includes the implementation of five main mitigation actions.

---

[21] The thirteen Conference of the Parties to the UNFCCC addressed in the Bali Action Plan consideration of policy approaches and positive incentives on issues relating "to reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries", actions now referred collectively as REDD+ (Decision 1/CP.13; UNFCCC 2007).

[22] see http://unfccc.int/files/meetings/cop_16/application/pdf/cop16_lca.pdf (version as of 13 December, 2010)

The main mitigation actions are:

(a) Reducing emissions from deforestation;

(b) Reducing emissions from forest degradation;

(c) Conservation of forest carbon stocks;

(d) Sustainable management of forest; and

(e) Enhancement of forest carbon stocks.

This means that, potentially, all forest resources in developing countries are subject to accountable mitigation actions. The Cancun agreement also stipulates that robust and transparent national monitoring systems of the above mitigation activities shall be developed. As a consequence, for the implementation of REDD+, it is crucial to determine the spatio-temporal variation of carbon stocks. Obtaining field measurements and developing estimation models to do so is an expensive and time-consuming task.

This systematic review will compare methods of measuring carbon stocks and carbon stock changes in all primarily vegetated land use and land cover types, e.g., forest, croplands, wetlands, pastures, agroforestry systems (FAO 2005), and all major terrestrial carbon pools (soil including peat, deadwood, litter, above and below-ground biomass). The review is not designed to provide technical guidance, such as those outlined in the Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance and Guidelines (IPCC 2003, IPCC 2006), or to be a sourcebook of methods, such as GOFC-GOLD (2009), but is aimed at providing an exhaustive comparative literature review in this field, including the provision of published data on uncertainties.

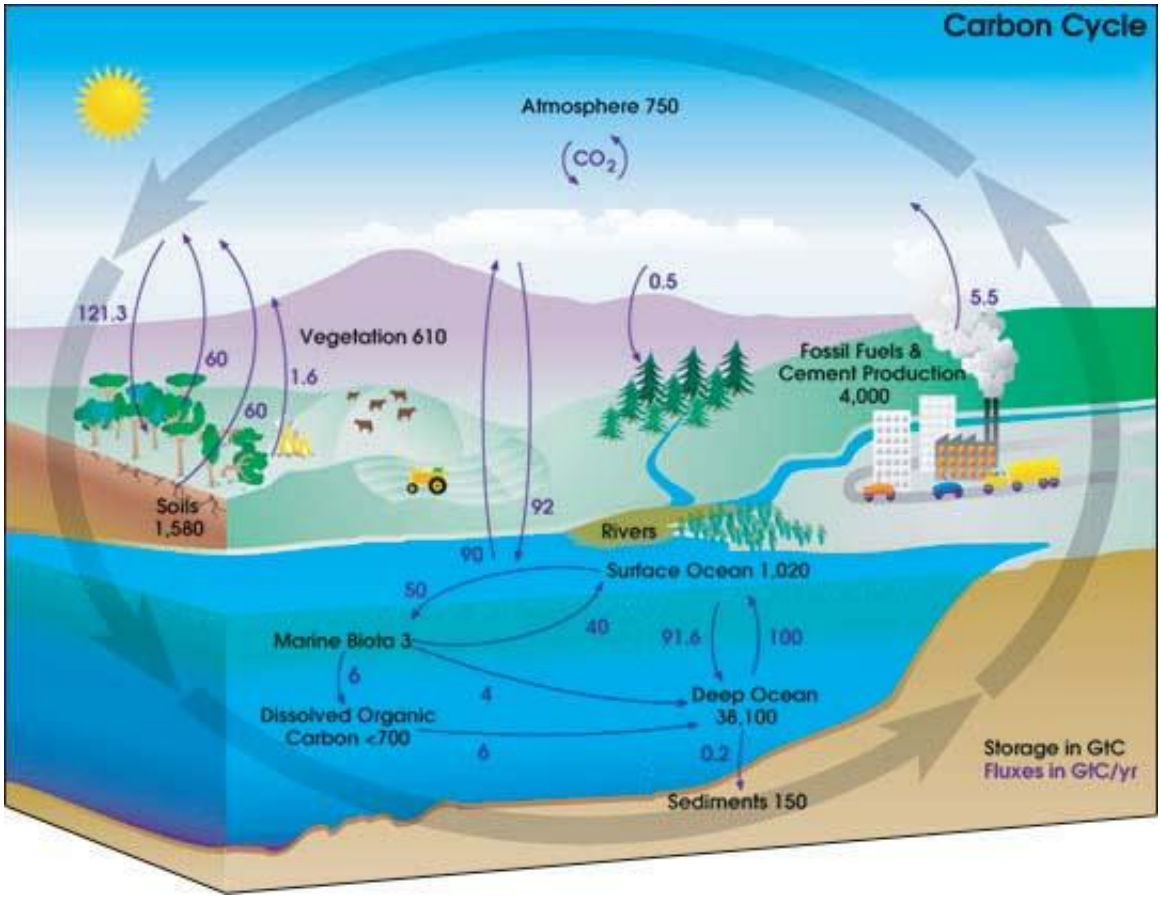


Figure 26 Major carbon pools and fluxes of the global carbon balance in Giga tons of carbon (GtC) (FAO, 2004)

Forests and biomass

The discussion below has a focus on tropical forests to highlight current methodological issues that are pertinent to forest science in general. It should be stressed that this systematic review covers all forest types.

A key challenge for successfully implementing REDD+ and similar mechanisms is the reliable estimation of biomass carbon stocks in tropical forests. Biomass consists of approximately 50% carbon (Brown and Lugo, 1982, Malhi *et al.* 2004). Uncertain estimates of biomass carbon stocks of tropical forests (resulting from difficult access, limited inventory and their enormous extent, Baker *et al..*, 2004a; Hansen *et al..*, 2008; Malhi *et al..*, 2004)

prohibit the accurate assessment of carbon emissions as much as uncertainties in deforestation rates (Houghton 2005).

A reliable estimation of above-ground biomass (AGB) has to take account of spatial variability, forest allometry and wood density (wood specific gravity or WSG). Many studies have been published on AGB estimates in tropical forests around the world (e.g. Brown *et al.* 1999, Chave *et al.* 2001; Gaveau *et al.* 2003, DeWalt and Chave, 2004; Segura and Kanninen 2005, Saatchi *et al.* 2007, Sales *et al.* 2007, Baccini *et al.* 2008; Fox *et al.* 2010), whereas the volume of literature on below-ground biomass estimates in tropical areas is relatively small (e.g. Cannell, 1982, Castellanos *et al.* 1991; Vance and Nadkarni,1992; Cairns *et al.* 1997, Komiyama *et al.* 2000, Jaramillo *et al.* 2003, Green *et al*. 2005,Pande 2005, Saint-André *et al.* 2005, Kenzo *et al.* 2009, 2010). Indeed, because root systems have particular features and require highly specific procedures (Danjon and Reubens 2008), measurements are very often time consuming and costly, qualitative, focussed only on one specific application and often not representative of large areas, as they generally involve a small number of root systems.

In some cases, however, new methods (e.g. three-dimensional root architecture data analysis) can be used to compute the continuous spatial distribution of coarse root volume, biomass, external surface and specific root length (Danjon and Reubens 2008).

Several databases provide harmonised above-ground and below-ground biomass information: for example, the World Forest Biomass and Primary Production Database (Cannell 1982), the database and geography of Forest Biomass of Northern Eurasia (Usoltsev 2001) and the Biomass Compartment Database of the European Commission Joint Research Centre23. Similar databases for tropical areas would be extremely valuable.

[23] http://afoludata.jrc.ec.europa.eu/index.php/public_area/biomass_compartments

Most studies on tropical forest AGB have been conducted in the Brazilian Amazon and in Southeast Asia. Few studies have reported on AGB for forests in Africa (but see Baccini *et al.*. 2008). The large number of published biomass equations (Baker *et al.* 2004b) indicates that there is a substantial variation in tropical forest biomass (Ramankutty *et al.* 2007). There are four types of uncertainty associated with AGB estimates of tropical forests (adapted from Chave *et al.* 2004):

1. Inaccurate measurements of variables, including instrument and calibration errors
2. Wrong allometric models
3. Sampling uncertainty (related to the size of the study sample area and the sampling design)
4. Poor representativeness of the sampling network.

Vieira *et al.* (2008) demonstrated the effect of inaccurate height measurement. A stem with a diameter at breast height (DBH) of 20 cm and a height of 13 m gave an AGB of 153.0 and 127.0 kg, respectively, when using models of Chave *et al*. 2005 and Scatena *et al.* 1993.

With the same DBH but one metre more height, the estimated AGB values become 164.1 and 136.6 Kg, i.e. an increase of around 7% and 5%, respectively. Large footprint LiDAR (Light Detection And Ranging) data (e.g. Geoscience Laser Altimeter System - GLAS) and small footprint LiDAR data (e.g. airborne laser scanner - ALS) can be used to retrieve indirect tree height estimates, however the elevation differences that are present within the footprint, especially for large footprint LiDAR data, can be substantial in comparison with the predominant tree height and make it difficult to estimate accurately tree height (Van Leeuwen and Nieuwenhuis 2010). Terrestrial laser scanning can also be used to estimate indirectly tree height at plot level; however as tree height, branching frequency and stand density increase the quality of the information obtained from the terrestrial laser scanner decreases as a result of the inherent occlusion effects and increasing point spacing, and the

related uncertainly as to whether the highest returns are echoes from the tree tops or echoes from inside the tree canopy. Because of these data quality problems, using small footprint LiDAR data to retrieve tree height would therefore be preferable (Van Leeuwen and Nieuwenhuis 2010).

Another important error is the wrong choice of allometric model, which is related to the representativeness of biomass sampling. Allometric equations relate easily-measured variables of an organism (such as diameter and height) to attributes that are more difficult to assess (such as volume, leaf area, and biomass).

They aim at facilitating large scale estimation of complex parameters (Zianis 2008), by, for example, providing ground reference for remote sensing or for estimating regional biomass.

Height and diameter are the most common dependent variables for assessing tree biomass, but as height of individual trees has been difficult to measure, most allometric models for tropical forests are based only on tree diameter (Williams and Schreuder 2000, Alder and van Kuijk 2009).

Although there are cases where height is the key independent variable for explaining variations in biomass (e.g. in palms), measurements of DBH, which is typically used for trees, explains more than 95% of the variation in tree biomass even in highly species rich tropical forests (Brown 2002).

Currently, allometric equations are almost entirely based on Southeast Asian and South American measurements. Some equations are available for African tree species or forest vegetation types (Hofstad 2005), but there are no allometries based on destructively sampled trees for Central Africa (Chave *et al.* 2005). Biomass equations for North America are listed in Ter-Mikaelian and Korzukhin (1997), and for Europe in Zianis *et al.* (2005). Similar databases for other parts of the world would be of high value.

The accuracy of biomass estimation ultimately depends on the accuracy of the original measurements used to develop biomass assessment tools, such as allometric models, biomass expansion factors (BEFs), generic equations (Wirth *et al.* 2004, Wutzler *et al.* 2008) and species group specific volume-to-biomass models (Smith *et al.* 2003).

It is time consuming and costly to sample sufficient trees to acquire information on species and size distribution in a forest (particularly in a highly diverse tropical forest) ; grouping all species, even in species-rich tropical forests, produces regression equations with high r2 (generally greater than 0.95) (Brown 2002) and therefore except in those cases where unique plant forms occur (e.g. species of palms and early colonisers) and developing of local regression equations is recommended, using generic regression equations stratified by, for example, ecological zone or species group (broadleaf or conifer) might increase the accuracy and precision of the equations, because they tend to be based on a large number of trees and span a wider range of diameters (Brown 2002). There is thus a clear need for country- and region-specific studies to address the validity and reliability of allometric models.

Ideally, such studies would utilise good ecological plot data, but these are often of poor quality or lacking completely. Commercial inventory data gathered by private companies are therefore used as an alternative and rich source of site-specific data. These are necessary for improving methods for estimating forest carbon, but are generally not available in the published literature or readily accessible from those who hold the data.

Guidelines for measuring WSG in the field exist, but for tropical regions published WSG data are limited to a few commercial timber species that represent only a fraction of the forest biomass. WSG data on other species are scarce or lacking.

BEFs, for example, strongly depend on stand structure (Lehtonen *et al.* 2004, Lehtonen *et al.*.2007) and site characteristics (Wirth *et al.*.2004; Teobaldelli *et al.* 2009) and extrapolation

with BEFs may lead to biased results when compared with local biomass equations (Jalkanen *et al.*2005), indicating the importance of representativeness and the risks of extrapolation.

Furthermore the biomass stock of tropical forests and its distribution remain poorly resolved at the regional scale (Fearnside 1996, Houghton *et al.*2001, Houghton 2005). Consensus has also yet to be reached on how much carbon is being emitted by changes in tropical land use (see, for example, Malhi and Grace 2000, Malhi *et al.* 2002, Fearnside and Laurance 2003, Achard *et al.* 2004, De Fries *et al.* 2007, Ramankutty *et al.* 2007, Van der Werf *et al.* 2009). There is thus an urgent need for calibrating and improving the methods for determining tropical forest biomass and its spatial distribution (Goetz *et al.* 2009).

Remote sensing

Remote sensing has considerable potential as a source of derived biomass data (Foody and Cutler 2003, Goetz *et al.* 2009). Remote sensing (space-borne or air-borne) usually provides continuous spatial information over landscape-size areas (size depends on sensor characteristics) in contrast to field inventory where information is generally limited to plots or small areas. Carbon stocks can be estimated by applying carbon density values from ground data or national forest inventories across land cover/vegetation maps obtained by remotely-sensed data. Spatial vegetation information from optical satellite sensors can be related to ground-based measurements to estimate carbon stocks. Direct measurements of AGB are limited to small forest areas, because site-specific allometric equations cannot be generalised for a forest or region and space-borne instruments cannot measure tropical forest biomass directly. The use of space-borne radar backscatter data is becoming popular as a method for estimating woody biomass over large areas in the tropics because of its capability of penetrating through the forest canopy and all-weather acquisition.

Published studies very often use national forest inventory data to verify results of remote sensing estimates of carbon. Many claim to show strong correlation. However, limitations are reported in the literature, in particular the weak, or absent, relationship between radar backscatter and AGB associated with saturation, and errors in geo-location: for example, old Global Positioning System (GPS) instruments used in constructing inventories may introduce uncertainty in establishing the 'centre of plot' location, compass direction, etc. (Alder and van Kuijk 2009).

The spatial extrapolation of biomass density measurements from ground sample plots can be improved by (satellite-based) radar and (airborne) laser assessments. The latter can cover complete areas or transects. Radar can penetrate clouds while laser (LiDAR) cannot.

Radar measurements saturate at biomass densities around 100 tons per hectare, whereas LiDAR shows no evidence of saturation (Figure 27).

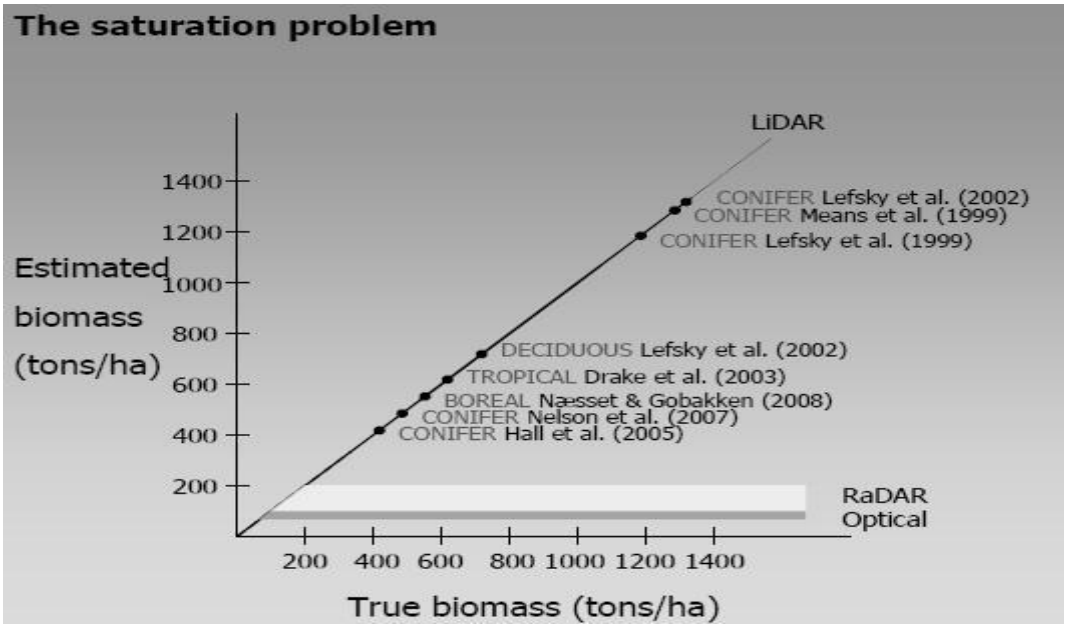


Figure 27 The saturation problem (after Hofstad, 2005), by permission Hofstad.

There are a number of approaches to estimating AGB at larger spatial scales with remote sensing data by extrapolating those obtained from field plots.

Such methods include multi-stage sampling, multiple regression analysis, nonparametric k-nearest neighbour technique (k-NN), neural networks, or indirect relationships between forest attributes, determined by remote sensing, and biomass. An increasing number of studies use fine resolution imagery such as QuickBird, a high-resolution commercial earth observation satellite, launched in 2001, aerial photographs or IKONOS, a commercial earth observation satellite, which launched in 1999 to collect publicly available high-resolution imagery at 1- and 4-metre resolution, for modelling tree parameters or forest canopy structures, though these are not applied to large areas owing to cost and technical demand. Medium spatial resolution imagery such as Landsat has been widely in use since 1972.

Where optical sensors have limitation, radio detection and ranging (radar) and light detection and ranging (LiDAR) data are being used.

Most studies on AGB estimates have not provided accuracy or precision assessments with respect to ground data (Lu 2006). Rosenqvist *et al.* (2003) undertook a qualitative review of remote sensing techniques for use under the Kyoto Protocol but did not provide an assessment of their operational status for use at national scales. For the UK and countries with similar reporting requirements, Patenaude *et al.* (2005) made quantitative assessments of the accuracy and comparative costs of optical, radar and LiDAR techniques for reporting deforestation through land-cover classification analyses and quantification of forest above-ground carbon stocks.

The accurate assessment of above-ground forest biomass and carbon stock over large areas requires a grid of ground sample plots (with very precise location or a nested sampling) together with a map of vegetation types and/or cover classes. Classification and mapping can be done either from ground sampling or on the basis of satellite imagery or aerial photography. More precise vegetation classification and a denser network of sample plots would give more precise estimates at higher costs.

There is clearly a need to critically review the accuracy, precision and cost of various remote sensing techniques against ground observation and among methods, and their applicability in geographically varied regions.

Carbon stocks in soils

Soils are the largest carbon reservoir of the terrestrial carbon cycle. Worldwide they contain three/four times more organic carbon (1500 Gt to 1 m depth, 2500 Gt to 2 m) than vegetation (610 Gt) and twice or three times as much carbon as the atmosphere (750 Gt, see Figure 26) (Batjes and Sombroek 1997). Carbon storage in soils is the balance between the input of dead plant material (leaf, root litter, and decaying wood) and losses from decomposition and

mineralisation of organic matter ('heterotrophic respiration'). Under aerobic conditions, most of the carbon entering the soil returns to the atmosphere by autotrophic root respiration and heterotrophic respiration (together called 'soil respiration' or 'soil CO2 efflux'). The mineralisation rate is a function of moisture levels and chemical environment with factors such as temperature, pH, Eh, nitrogen level and the cation exchange capacity of the minerals in the soil affecting the mineralisation rate of soil organic carbon (SOC) (Li *et al.* 1994, Kätterer *et al.* 1998, Reichstein *et al.* 2000, 2003, 2005, Heimann and Reichstein 2008). Under anaerobic conditions, resulting from constantly high water levels, part of the carbon entering the soil is not fully mineralised and accumulates as peat.

Guo and Gifford (2002) conducted a meta-analysis of 74 publications on the influence of land use changes on soil carbon stocks (See also a follow-up study by Laganière *et al.* (2009). They acknowledge the possible bias in their findings as most data drew from only four countries (Australia, Brazil, New Zealand, and USA) and a limited number of studies. They point to the need for a more comprehensive analysis of some hypotheses generated in their study: soil carbon stocks decline after land use changes from pasture to plantation (-10%), native forest to plantation (-13%), native forest to crop (-42%), and pasture to crop (-59%). Soil carbon stocks increase after land use changes from native forest to pasture (+ 8%), crop to pasture (+ 19%), crop to plantation (+ 18%), and crop to secondary forest (+ 53%). Most land use on peat soils requires drainage and is associated with a continuous loss of soil carbon stock.

One of the limitations of many of these studies of the effect of land use change on soil carbon levels is that often the plots were established to study other parameters, such as soil fertility, and early experimental protocols did not consider extensive measurements of soil carbon throughout the soil profile. Many studies only measure the carbon change in the top 20 to 30cm of the soil profile and therefore do not show the effect of leaching and activity by earthworms, etc, on the movement of carbon down the profile. In addition temporal sampling

of SOC measurements tend to be sparse and insufficient in number and interval to estimate SOC decomposition rates and final equilibrium (Post *et. al*. 2001). Eddy covariance measurement of CO2 flux is valuable in this regard.

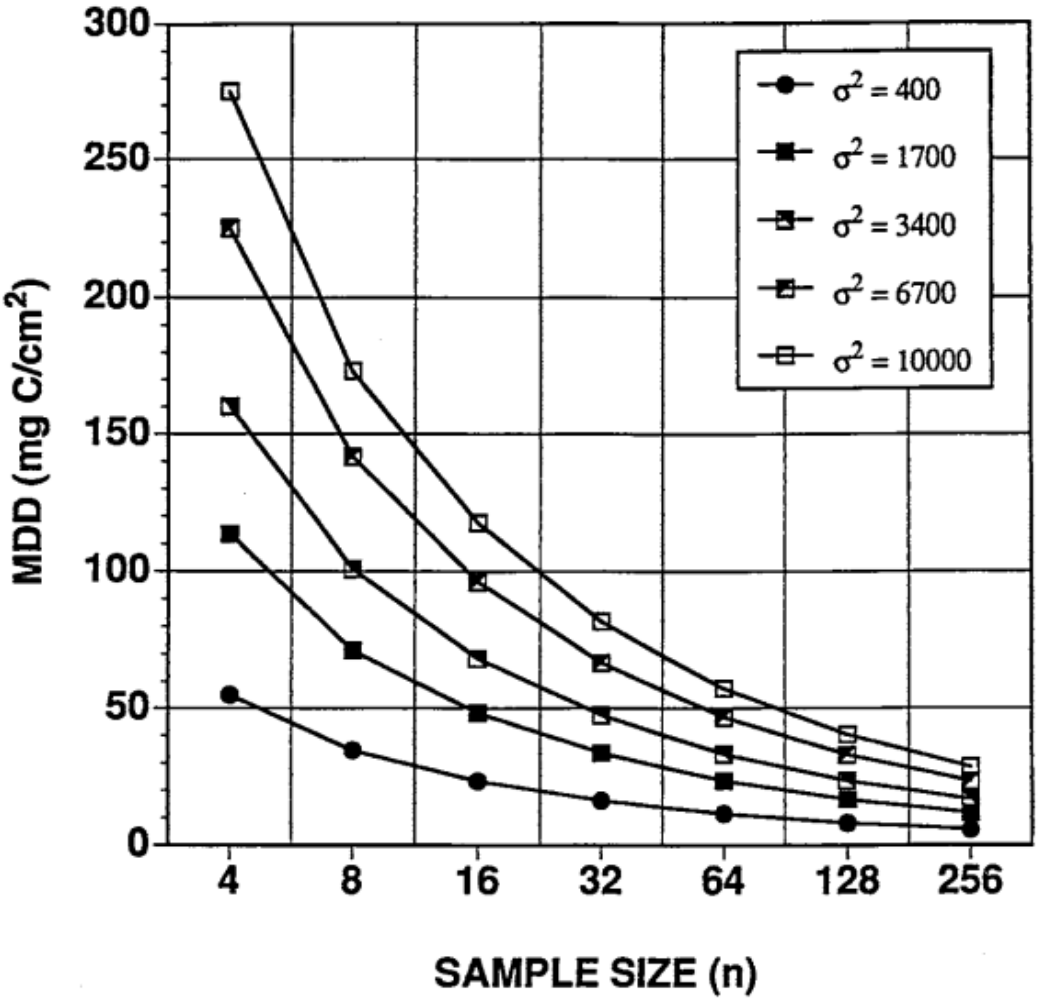


Figure 28 Calculated minimum detectable difference (MDD) in soil organic carbon inventory as a function of variance (σ2) and sample size (n). The MDD is the smallest difference that can be detected (α = 0.05) between two mean soil organic carbon inventories with 90% confidence (1 − β) given the average variance (mean square error from ANOVA) and the sample size (Garten and Wullschleger, 1999). Used with permission, from *Journal of Environmental Quality* 28:1359-1365

Mineral soils

Estimates of soil organic carbon (SOC) stock changes are applied to determine long-term carbon fluxes and to design carbon sequestration strategies. Several approaches to estimating these stock changes are currently in use and may provide conflicting results.

On the plot scale there are a number of methods to detect changes in soil organic carbon stocks. Repeated soil samples over a range of years to decades have been noted above, but, in addition, long term flux measurements covering comparable time periods, either by soil chambers or eddy covariance systems, can provide estimates of stock changes. Eddy covariance plays an important role in this context because, depending on its footprint area, it is able to give an integrated picture of the ecosystem under consideration (Post *et al.* 2001).

In comparison to chamber measurements which are at the point scale, eddy flux measurements therefore provide a direct link to a higher spatial level and allow integrative analysis. However, there are a range of uncertainties associated with the method, such as u* correction, gap filling, outlier filtering, advection and flux partitioning etc. (Hollinger and Richardson 2005, Reichstein *et al.* 2005, Richardson and Hollinger 2005). For the estimation of soil carbon stock changes only, systematic uncertainty components are of relevance, such as those outlined in, for example, Lasslop *et al.* (2008).

In order to scale-up plot estimates to the landscape, country or continental scale, additional information about the spatial arrangement of soil types and land cover/land use needs to be considered, which introduces additional sources of uncertainties (Post *et al.* 2001). One method for estimating SOC stocks of different ecosystems is a regression approach in which regional SOC densities (mass SOC/area) are related to a number of auxiliary variables like temperature, precipitation, age class, and land-use history. An updated methodology applies a geographic information system (GIS) to calculate SOC densities for each forest type within a region from soil databases and satellite-derived land cover information. Campbell *et al.*

(2008) showed large differences in the outcomes of both approaches and identified the need to use direct measurements of SOC in order to determine absolute errors in both approaches. The fact that the methods have been used interchangeably in the past indicates that errors will have been perpetuated in the literature. Both methods are valuable for estimating soil carbon stocks but not for carbon stock changes, because the predictors of both parameters are different.

According to Mäkipää *et al.* (2008) a reliable carbon stock change inventory for Finland with repeated soil carbon sampling would take 10 years and cost 8 million Euros. This high cost would almost certainly prevent more than a few countries from investing in soil carbon inventories; the reality is that a combination of models and additional measurements is needed. Regardless of the methodology applied there is a clear need to identify the uncertainties associated with current understanding of SOC stocks and stock changes (Peltoniemi *et al.* 2006). It is important to pay particular attention to changes in soil carbon stock through direct measurements and soil carbon modelling (Peltoniemi *et al.* 2007), as well as to regional variation of soil carbon stock.

Soil carbon models can be used for estimating carbon stocks and stock change estimation but they need to be parameterised and validated for each land use, vegetation cover, climatic condition and soil type. This requires measurements of the soil carbon in the soil profile as well as spatially. In addition models divide the soil carbon into theoretical pools with different decay rates and their validation requires measurements of soil carbon types that can be related to these pools (Zimmerman *et al.* 2007, Dondini *et al.* 2009). Soil carbon models also face the initialisation problem due to the model partitioning the soil carbon into pools with different decay rates.

To model soil carbon changes associated with land use or land management change, the initial proportion of these partitions needs to be known for the first land use. For change from a long term land use such as savannah or forest to cropland, soil carbon models assume that at the beginning of the simulation period equilibrium conditions apply, i.e., that plant input and soil carbon stock are in balance given the local climatic conditions. In order to simulate land cover or land use change under constant or changing climatic conditions the model needs a so-called 'spin up' period to reach equilibrium condition before any transition takes place. For cases where the prior land use is less than 100 years the land use history must be known in order for this spin-up to be made, accounting for all the historical land use changes. Alternatively the initial pools can be estimated from actual measurements of the soil carbon pools (Zimmerman *et al.* 2007). There are a number of problems and uncertainties related to this assumption and alternative methods are discussed. It is therefore essential to quantify these effects in any soil carbon accounting (Peltoniemi *et al.* 2006, Wutzler and Reichstein 2007, Zimmermann *et al.* 2007, Yeluripati *et al.* 2009).

Organic (peat) soils

Only recently has science recognised the importance of organic (peat) soils for greenhouse gas emissions and climate change. With some 500 Gt of carbon stored on only 4 million km2 (= 3 %) of land, peatlands constitute the world's most dense terrestrial carbon stocks (Joosten and Couwenberg 2008). In the case of peat swamp forest, emissions from peat oxidation and peat fires following drainage may be significantly larger and longer lasting than above-ground emissions from clearing or burning forest vegetation. Peat oxidation currently leads to worldwide emissions of some 1.3 Gt CO2 per year, whereas peat fires contribute another 0.6 Gt CO2 per year on average (Joosten 2009). During the 1997-1998 El Niño drought peat fires in Southeast Asia emitted some 1.8 Gt CO2 (Page *et al.* 2002, Van der Werf *et al.* 2008, Couwenberg *et al.* 2009), which is equivalent to 10% of the total global anthropogenic emissions for the same year.

Many variables linked to peat oxidation are not well understood and few reliable measurements exist for many of them. Uncertainty begins with the extent of peatlands worldwide and especially in the tropics and with the amount of carbon stored in the peat layer. The degree of peat humification has strong influence on the mass of peat and carbon per volume, the hydraulic conductivity and the moisture retention capacity. Knowledge of the 3D topology of peatlands is important for hydrology and modelling, but peat depth and peatland shape have been measured only in a few locations (e.g., mapping by petroleum exploration companies in Borneo forests). Sampling sufficient locations to allow for spatial modelling is a time-consuming and costly exercise. New technologies may be capable of reducing time and effort.

Even less is known about emissions factors, which are essential for reliably estimating GHG emissions. Emission estimates from peat fires have large uncertainties, because of the highly variable mass of peat combusted and the various gases emitted depending on fire severity, water table, peat moisture and fire history. Data on most of these parameters are scarce or lacking. Long-term GHG emissions from biological oxidation of peat are even more significant than the emissions from peatland fires (Couwenberg *et al.* 2009, Joosten 2009). Very few long term (> 1 year) measurements exist to assess emission rates under different water management regimes. A recent review shows that drained peatlands emit in the range of 9 CO2 t/ha/yr from peat oxidation for each 10 cm of additional drainage depth (Couwenberg *et al.* 2009). The role of tropical peat swamps is crucial not only in terms of GHG emissions but also for REDD+, as their peat carbon stock is on average 10 times larger than their above-ground biomass stock (Joosten and Couwenberg 2008) and significant amounts of carbon are released by fire and bacterial decomposition. Emissions from drained peatland occur worldwide. The largest emitters include Indonesia, the European Union, Russia, China, USA, Malaysia, Mongolia, Belarus and Uganda (Joosten 2009).

Deadwood and litter

Biomass of deadwood and litter could be as large as above-ground biomass. A variety of methods to measure deadwood and litter needs to be reviewed. Deadwood pools, including standing dead trees, fallen woody debris, and decaying and burned wood, are of particular interest in projecting carbon losses from decomposition. They are also often used as an indicator of carbon losses from degradation due to logging (Palace *et al.* 2007) or fire (Barlow 2003). Data collection regarding standing dead trees frequently follow the same protocols as those for AGB inventories but ideally should also include data on levels of decay. Woody debris is most often estimated using the line-intercept method which measures only debris which crosses a transect (e.g., Palace *et al.* 2007) or through rectangular plots wherein the dimensions of each piece of debris is measured (e.g., Rice *et al.* 2004). Although some studies have addressed the densities of woody debris of different decay classes (Keller *et al.* 2004, Palace *et al.* 2007), more regionally and biome specific studies would help refine estimates of carbon content of this pool (e.g., Mäkinen *et al.* 2006).

Litter is another pool that must be taken into consideration when estimating carbon losses and movement between pools (litter -> soil) (Ostertag *et al.* 2008). This is important for the parameterisation of soil carbon models. Litter includes leaves and other fallen plant material (including fine woody debris of diameter < 2cm). Litter may be equivalent to only a small fraction of AGB in some ecosystems (e.g. 2% for montane forests in Mexico (Ordóñez *et al.* 2008)) whereas it can be substantially higher in others (e.g. 30% in sugarcane fields). Some estimates of the litter pool in forests use quadrats to assess the litter mass per unit area at a given point in time (Ordóñez *et al.* 2008). However, this method may suffer from imprecision due to the difficulty of distinguishing between litter and soil organic matter. Litterfall traps, which can monitor the input of litter falling over time, may be more accurate in distinguishing between pools.

Many studies are available which address decomposition rates and the implications for carbon cycles (Tuomi *et al.* 2009, Wieder *et al.* 2009).

Agriculture and croplands

According to the Fourth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC), agriculture, forestry and other land uses (AFOLU) account for approximately 30% of the total anthropogenic GHG emissions (IPCC 2007). Of these, agriculture accounts for about 60% of N2O and 50% of CH4 emissions, whereas deforestation and land use change are responsible for most of the CO2 emissions (IPCC 2007). It is recognised that the relationship between agricultural practices that affect CO2, CH4, and N2O can be especially complex in cropping and grazing systems. This systematic review, however, will focus on carbon measurements and make recommendations that future systematic reviews should look at assessment methods for other GHG emissions. Agriculture has the potential to mitigate between 5.5 and 6 GtCO2e/yr (IPCC 2007), which means that there will be a need to assess carbon accurately and reliably to comply with international monitoring requirements or trading schemes.

Smith *et al.* (2010) review current methods available for measuring components of the carbon budget in croplands, and examine some of the tools used for scaling the carbon budget of croplands from ecosystem to continental levels. They highlight the complex nature of the evidence that needs to be gathered at each site before a full carbon budget can be made. They also point at the "impossibility" of up-scaling results from sites to the continental level (Europe is the focus in their synthesis), even with an extensive network of sites, because of the lack of spatially explicit information on management and soil for agricultural systems. However, they point out the value of such site-specific data for calibrating and validating ecosystem models for continental projections.

The necessity of synthesising studies from different disciplines

It is clear that a wide range of efforts have been and are being undertaken in public and corporate research to provide methods and data for carbon stock assessments in different pools. There is a huge body of knowledge collected over decades. There has been a proliferation of scientific and technical papers. But still monitoring of forests is 'insufficiently accurate or precise for an international protocol that would administer finances based on monitoring results of forest area or forest carbon storage' (Holmgren and Marklund 2007) and there is no reason to suppose that the situation for other pools is any better. The adequacy of current or potential systems for reliably assessing carbon stocks at national, regional or local levels (under the REDD+ framework or elsewhere) has not been systematically evaluated, nor has the scientific underpinning of these approaches been properly examined. It has been argued that a REDD+ system must allow and account for variability in methodologies and accuracy. The latter is inevitable with such wide differences between countries and assessment methods. But flexibility must come with knowledge of the limits of confidence in these variable approaches if REDD+ is to be credible, transparent and fair. It is timely to undertake a systematic review of methods and approaches to carbon stock assessments.

5.11 Object of the systematic review of carbon assessment methods

Primary question

How do current methodologies compare in their ability to measure and assess terrestrial carbon stocks and changes in carbon stocks with accuracy, precision and repeatability?

Accuracy is a relative measure of the exactness of an estimate against true values. Precision is the inverse of uncertainty with a measurement or estimate (e.g., the standard error of the sample mean).

Sub-questions

- How accurate, precise and repeatable are methodologies used for the conversion of in situ measurements into carbon stock estimates at the plot or site level?
- How accurate, precise and repeatable are methodologies for generating carbon stock estimates for larger geographical areas (landscape level) from site-level data?
- How accurate, precise and repeatable are direct remote sensing methodologies for estimating carbon stocks?

The term "methodologies" is used to include methods (including direct measurements, sampling design, remote sensing and models) and systems that aggregate methods to measure and assess carbon stocks.

Sub-question one reviews direct measurements of variables in the field (in situ) and methodologies that convert them into carbon stock estimates at the site level. "Site" refers to sample or assessment plot. Sub-question one also looks at the geographical validity of methodologies developed at the site-level and examines the applicability of methodologies to different land use categories in different environments, ecosystems and countries.

The term "landscape level" in sub-question two encompasses the spatial scales from site to sub-national and national levels through forest inventories, stratification, other sampling schemes and modelling. Sampling and stratification by remote sensing are also dealt with under sub-question two. Sub-question two also looks at methodologies to assess changes in soil carbon with land use conversion.

Sub-question three includes carbon stock estimates from direct measurements of variables by remote sensing instruments, coupled with field measurements and methodologies to convert measurements into stock estimates. Ground-based measurements such as terrestrial LiDAR

will be included, and field biomass components will be identified when available from the source material.

Components of the questions

The subject for all sub-questions will be the 5 terrestrial carbon pools identified by the Intergovernmental Panel on Climate Change (IPCC 2006):

- Above-ground biomass
- Below-ground biomass
- Deadwood
- Litter
- Soil (including peat)

Applicable spatial and temporal scales of methodologies will be explicitly reviewed for each question. For soil, depth and mass will be taken into consideration.

Land-cover categories will include the following:

- Forest (including agroforestry)
- Cropland, pasture and grassland
- Wetland

Peatland is a carbon pool and can be found under any land-cover categories.

Outcomes

Outcomes will assess accuracy, precision and repeatability against gold standard methodologies that are generally agreed to have the highest accuracy, precision and repeatability. Recognizing that there may not be a single gold standard for any of the carbon pools and land types, the methodologies that convert in situ measurements into carbon stock

estimates at the site level, reviewed under sub-question 1, will be treated as the gold standard for sub-questions 2 and 3.

Consideration will be taken of the frequency requirements built into the methods and systems (e.g. necessity for annual measurements, etc.)

5.12 Systematic review methods

Search strategy and resources

Published material

The following computerised information resources will be searched for published studies and resources in organisational libraries:

CAB Abstracts http://www.cabi.org

Google Scholar http://scholar.google.com

ISI Web of Knowledge (including Web of Knowledge with Conference Proceedings, BIOSIS Previews) http://apps.isiknowledge.com

Scopus http://www.scopus.com

SCIRUS http://www.scirus.com/

AGRICOLA http://agricola.nal.usda.gov

Scielo http://www.scielo.org

GeoRef database http://www.ovid.com/

ScienceDirect http://www.sciencedirect.com

ProQuest Dissertations and Theses http://www.il.proquest.com/

Science.gov http://www.science.gov

US Department of Agriculture Forest Service Treesearch

http://www.treesearch.fs.fed.us/

Australian Government Department of Climate Change website

http://www.climatechange.gov.au/index.html

Tropical forest conservation and development database

http://forestry.lib.umn.edu/bib/trps.html

EuroForest portal http://forestportal.efi.int/

EDIS (Electronic Data Information Source) http://edis.ifas.ufl.edu/

Forests in flux http://www.unep-wcmc.org/forest/flux/index.htm

ATROFI-UK ; Archive of Tropical Forestry Inventory

http://www.rdg.ac.uk/ssc/atrofi/

NRCAN Library Catalogue http://catalogue.nrcan.gc.ca

World Environment Library http://www.nzdl.org/fast-cgi-bin/library?a=p&p=about&c=envl

CGVlibrary http://vlibrary.cgiar.org

UNFCCC REDD Web Platform

http://unfccc.int/methods_science/redd/items/4531.php

FAO Online Catalogues http://www4.fao.org/faobib

CIFOR Publications http://www.cifor.cgiar.org/Publications

ISRIC http://www.isric.org/

UNEP Publications http://www.unep.org/publications

World Agroforestry Centre Publications http://www.worldagroforestry.org

Columbia Earth Institute – International Research Institute for Climate and Society - http://portal.iri.columbia.edu/portal/server.pt

European Space Agency Earth Observation Projects Department http://www.esa.int

Tropical Soil Biology and Fertility Institute of CIAT (TSBF-CIAT): Conservation and Sustainable Management of Below-Ground Biomass project http://www.bgbd.net

Global Forest Resources Assessment (FRA) 2005 of FAO and its country reports http://www.fao.org/forestry/fra

National Forest Monitoring and Assessment (NFMA) of FAO and its reports http://www.fao.org/forestry/nfms/en/

Centre de coopération internationale en recherche agronomique pour le développement (CIRAD) http://www.cirad.fr

Tropenbos International http://www.tropenbos.org/

CATIE http://www.catie.ac.cr (Spanish)

Carbo Europe-IP http://www.carboeurope.org

Nitro Europe IP http://www.nitroeurope.eu

CARBO-Extreme http://www.carbo-extreme.eu

Greenhouse gas management in European land use systems http://cordis.europa.eu/search/index.cfm?fuseaction=proj.document&PJ_LANG=DE&PJ_RCN=11092864&type=pro

Unpublished and grey literature

As a large proportion of material has not been digitised and requires hand searching through organisational resources, the search strategy and list of searchable resources will be further

developed iteratively during the early phases of the review. A large volume of work on systems and methods of measurement and assessment has not been published formally. Recognised experts, authors and people who have used these techniques as practitioners will be contacted to contribute further ideas on resource identification and invited to share relevant publications or data. A large database of potential contacts has already been established in the scoping phase of this project and will be made available to the reviewers for this systematic review. The review will utilise the expertise of members of the International Directory of Forest Information Services (Libraries, Documentation Centres, and Subject Specialists), launched by IUFRO in 2002 and hosted by Forintek in Canada, which contains details of 152 forestry libraries and information centres in 49 countries (http://iufro.forintek.ca).

Collaboration with agricultural information professionals and librarians will be canvassed through the International Association of Agricultural Information Specialists (http://www.iaald.org), whose members are drawn from research and development institutes, international agencies, universities and colleges, government departments, information providers, non-governmental organisations and the private sector. Logging companies with significant inventory resources will be pursued during the early stages of the review for information resources of relevance to the review questions. For peat the members of the International Peat Society and the International Mire Conservation Group will be consulted.

Search terms and strategies[24]

1. (Carbon near/2 stock*) AND (aboveground OR 'above ground' OR above-ground OR belowground OR 'below ground' OR below-ground OR forest OR forests OR terrestrial OR land OR soil OR peat OR yield OR harvest OR crop OR grass* OR meadow)
2. Carbon AND (forest near/2 inventor*)
3. Biomass AND (aboveground OR 'above ground' OR above-ground OR belowground OR 'below ground' OR below-ground OR forest OR forests OR terrestrial OR land OR yield OR harvest OR crop OR grass* OR meadow)
4. Carbon and (deadwood OR dead wood OR necromass OR litter OR litterfall OR residue OR stubble* OR humus OR soil* OR peat OR peatland*)
5. (estimate* OR asses* OR measure* OR monitor* OR method*)
6. Carbon and (Remote near/2 sens* OR Aerial near photo* OR LiDAR OR AVHRR OR MODIS OR MERIS OR VGT OR Landsat- OR ASTER, OR LISS OR AwiFs OR CBERS OR PALSAR OR IKONOS OR QuickBird OR radar OR SAR OR ALOS OR ERS-1 OR JERS-1)
7. **((1 OR 2 OR 3 OR 4) AND 5) OR 6 [combine sets above]**

A wide range of papers that address the main question will be captured by the search terms above but too large a number of hits suggested by preliminary searches on major databases may prevent reviewers from conducting an effective review from a practical point of view. There are several tiers of search terms as summarised below and the best strategy to combine

[24] Search terms were combined with slight variations, depending on the databases being interrogated. Precise details of the search strategies for each database will be added to the Protocol on an ongoing basis.

these terms will be determined in iterative processes at the literature search phase. We aim to have a standardised search approach across all sub-questions but there can be multiple sets of search terms for each sub-question to carry out an efficient search.

Subject for measurement:

8. carbon or biomass
9. “peat depth” or “peat thickness” or “peat bulk density” or “carbon density”

Land type:

10. *forest* or *wood* or *tree* [for forest]
11. crop* or pasture* or graz* or grass* or savanna* [for cropland and grassland]
12. wet* or peat* or swamp* or marsh* [for wetland and peatland]

Carbon pool:

13. (aboveground or "above ground" or above-ground) or (belowground or "below ground" or below-ground) or (deadwood or "dead wood" or dead-wood) or (litter or root* or shoot* or necromass* or AGB* or BGB*

    or live or dead or branch* or leaf* or leaves) [for forest biomass]

14. (*soil* and *organic*) and (stock or pool or storage or mass or content) [for soil carbon]
15. (yield or harvest or residue or fodder or silage or straw or hay or stubble or litter) [for croplands]

Methods utilised in the studies

16. (method* or technique* or approach* or model* or simulat* or estimat* or assess* or *measure* or calculat* or allometr* or biometr* or "expansion factor*" or "conversion factor*" or BEF* or formula*) [for methodologies in forest except for remote sensing]
17. (method* or technique* or approach* or model* or simulat* or estimat* or assess* or *measure* or calculat* or allometr* or biometr* or formula*) [for methodologies in cropland and grassland]
18. (method* or technique* or approach* or model* or simulat* or estimat* or assess* or *measure* or calculat* or formula*) [for methodologies in peatland and wetland]
19. (remote near/2 sens*) OR (aerial near photo*) OR LiDAR OR AVHRR OR MODIS OR MERIS OR VGT OR Landsat- OR ASTER, OR LISS OR AwiFs OR CBERS OR PALSAR OR IKONOS OR QuickBird or Radar or SAR or ALOS or ERS-1 or JERS-1 [for remote sensing]
20. "basal area*"or "wood volume*" or "diameter at breast height*" or DBH* or "growing stock*" or stem* or diameter* or densit* or height* or crown* or trunk* or "specific gravit*" or (structure near/5 tree) or (stand* near/5 tree) or timber [for direct measurements]

Comparison of methodologies

(accura* or uncertaint* or precis* or repeat* or confiden* or cost* or variat* or reliabl* or better or best or worse or worst or statist* or robust* or discrepanc* or error* or deviat* or

compar* or improve* or capab* or trasparen* or timel* or credib* or practical or *consisten* or sensitiv* or *appropriat* or *agree* or evaluat* or "metaanaly" or "meta-analy" or "meta analy")

In a separate exercise, language experts familiar with the subject will be used to advise on the extent to which it will be practical to retrieve documents in other languages using searches comprising translated terms from the list above. If this is considered practical and beneficial for the review as a whole, and if the means at our disposal for carrying out this exercise will not add additional bias into the process, it is envisaged that important collections of literature will be retrieved from French, Spanish, and Portuguese, and possibly Malaysian Malay and Bahasa Indonesia, sources of forestry information, and, additionally for peat, German, Finnish, Swedish, Russian, Polish and Czech. The review team will consider the advice of language experts before the stage of data extraction and synthesis and will update the Protocol accordingly.

Knowledge management

The bibliographic details of all studies retrieved by this search strategy will be captured in a RefWorks bibliographic library. Studies will be coded to indicate which of the sub-questions they have been retrieved for. Many studies will be relevant to more than one sub-question. In order to reduce replication of effort retrieved studies will be coded for all sub-questions before being entered in the bibliographic library. Full texts will be retained on a secure site and will be coded with the unique ID taken from the RefWorks bibliography.

Study inclusion criteria

Studies will first be assessed for inclusion on the basis of title only, followed by assessment on the basis of abstract, and finally, full-text. Preliminary studies during the scoping phase have revealed the difficulty of assessing relevant studies on the basis of either title or abstract alone; studies will be included unless there is clear information to justify exclusion.

To reduce the effects of between-reviewer bias, two reviewers will apply the inclusion criteria for a random sample of 20% of the studies retrieved (up to a maximum of 200 studies) to assess repeatability of the selection criteria. Kappa analysis will be performed, with a rating of substantial (0.6 or above) being required to pass the assessment (Cohen 1960). Disagreement regarding inclusion or exclusion of studies will be resolved by consensus, or following assessment by a third reviewer. If the Kappa value is low, the reference list will be reassessed against adjusted inclusion and exclusion criteria. The same subset of references will be re-assessed by a second reviewer with Kappa analysis. Reviewers will then consider articles viewed at full text for relevance, either excluding them from, or admitting them to, the review.

Relevant studies are required to discuss all three elements: X [name of method] method to measure Y [what is measured] in Z [where].

Relevant subjects

The list of methods to assess carbon stocks/changes (across all 3 sub-questions) that are considered relevant for the review, i.e., X [name of method], is provided in Annex A.

Relevant papers must also present methods to assess carbon stocks/changes in the following land uses, types, and terrestrial ecosystem components, i.e., Z [where]:

All land uses and types (forest, wood, woodland, woodlot, park land, terrestrial system, agricultural land, cropland, pasture, grazing land, savanna (woody and herbaceous), grassland, wetland, meadow, swamp, marsh, agroforestry, agroecosystem, bog, shrubs, trees, biomes, peatland, fen, and all other land) in the form of:

- Above-ground biomass
- Below-ground biomass
- Deadwood
- Litter
- Soil (incl. peat)

including necromass, litterfall, decaying and burned wood, residue, stubble, humus, harvest, , yield, grain, harvest, tuber, live roots, roots, shoot, branch, leaves, fodder, silage, straw, hay, timber, lumber, stands, stem wood, stem bark, living and dead branches, woody debris, fallen trees, fallen braches, fragmented wood, standing dead trees (snags), needles, stump, foliage, downed wood, woodlot, plantations, biomes, dissolved organic matter, dissolved gases.

Types of outcome

All types of outcome measures that relevant papers should contain, i.e., Y [what is measured], are listed in Annex B. This could also contain measures of processes (if this is relevant), such as litter decomposition rates, etc.

Comparators

Studies comparing either one methodology of carbon stock/carbon stock change measurement or assessment over time or space or one methodology against another methodology. It is possible there will be a prohibitively large number of single methodology papers. At the study quality assessment stage it will be determined whether it is feasible to include single methodology papers in the review.

Types of studies

Any primary study that compares methods of assessment or estimation or attempts to assess the effectiveness of the method against clear criteria.

Studies on short-term CO2 fluxes such as those that use chamber or eddy flux measurements are considered not relevant for this systematic review, unless the paper reports carbon stocks or stock changes for a time scale longer than one year. However, studies looking at systematic uncertainties in these measurements that will reflect on stock estimates and are below the one year threshold are considered suitable candidates for analysis in this review.

Studies reporting soil carbon model comparison with data are only considered if the data are from an independent source (different plot, site or region), which was not used to calibrate model parameters. This specifically excludes studies where data of one plot/site or region are split into validation and calibration. These measures have been adopted in order to reduce bias in the systematic review analysis.

Potential for heterogeneity in outcomes

Differences in terrain/vegetation, spatial scale, temporal scale, technical and/or personnel limitations.

Study quality assessment

To assess the possible systematic errors or bias, each study will be assessed at full-text using a simple list of desirable study characteristics based on a hierarchy of evidence developed for other systematic reviews in medicine and conservation.

Data extraction strategy

The volume and quality of information available to address the systematic review sub-questions (2.2) are not known at this stage of the review work. During the quality assessment stage (3.4), papers will be assessed to determine whether the study reported collected data that would be necessary for basic statistical analysis in this systematic review; the possibility of conducing meta-analysis to answer the sub-questions will therefore be assessed at this stage. At the same time, a matrix of comparator and alternative methods will be composed to extract sets of homogeneous studies. If there are a sufficient number of papers with potential for meta-analysis in a set of homogeneous studies, data will be extracted from them, and a meta-analysis, or other quantitative analysis, will be performed for the set to provide a summary of quantified differences in methods. If information is too limited for a meaningful meta-analysis of methodology comparisons, studies will be categorised according to subject,

comparator and outcome, and a detailed qualitative summary will be produced. The Protocol will be amended accordingly to reflect decisions and methods.

Annex A.

List of methods to assess carbon stocks/changes (across all three sub-questions):

X [name of method]

Broad methods:

Remote sensing, modelling, survey, inventories, conversion, field sampling, measurements

All approaches within these broad methods:

aerial photography
airborne laser scanning, ALS
airborne mapping
decision tree approach
earth observations
full waveform
GLAS
hyperspectral
infrared imagery
Laser Scanner (terrestrial, ground-based)
Lidar (light detection and ranging)
microwave radiation
neural networks
optical
Radar (radio detection and ranging)
regression tree model
Remote sensing
satellite imagery
satellite laser altimetry
spaceborne laser scanning
SRTM
support vector machines

Modelling

Bayesian
CANDY model
CENTURY
CERES model
Crop growth model
Crop yield model
DGVM, digital global vegetation models
digital canopy height model, DCHM
DNDC
ecosystem demography model (height structured ecosystem model)
ecosystem flux techniques
eddy correlation
footprint modelling
gap filling strategies
GIS
grassland ecosystem model
Monte Carlo
peat accumulation model
peat decomposition model
peat growth model
pedotransfer function
pedotransfer model
pipe model theory
Probability distribution function
process based model
process based simulations
Q model
RothC (a soil carbon model)
soil organic matter models,
surface energy exchange models
Up-scaling
Yasso

Survey

cluster
inventory
line
plot shape
plot size
plotless
point
random forest
sampling
statistical design and analysis
stock
strip
survey
transect

Inventories

biomass classification approach
inventory plots

Conversion

allometric equations
allometric regression equations
allometric relationship
ARCA (Actual Rate of Carbon Accumulation)
biomass assessment
Biomass conversion against volume
biomass equations
biomass expansion factors, BEF
biomass functions
biometric approach
biometric equations (function)
continuous biomass expansion factor method, CBM
conversion factor
LORCA or LARCA (LOng term Rate of Carbon Accumulation)
mean biomass density method, MBM
mean ratio method, MRM
RERCA (REcent Rate of Carbon Accumulation)

Field sampling

diameter relascope sampling of CWD, DRS
fixed area sampling (plots) of CWD
line intersect sampling (method) of CWD
point relascope sampling of CWD
prism sweeps
soil organic carbon sampling
soil organic matter sampling
soil sampling
vertical intercept sampling

Measurements

AIR-based estimation
bulk density correction
carbon accounting
closed dynamic chambers
dendrometers
FACE – free air carbon enrichment
flask-based estimation
flux chamber techniques
FLUXNET
gas analyzers
Litter traps
Litterbags
litterfall traps
Marcocosm experiment
mesocosm experiment
microcosm experiment
network theories
soil cores
SOMNET
tower eddy flux network

Annex B.

List of types of outcome measures that relevant papers should contain:

Y [what is measured].

All types – outcome measures

biomass
biomass accumulation
biomass density
biomass increment
biomass saturation values
biomass stock
biomass turnover rates
C pool
C stock
carbon
carbon accumulation
carbon balance
carbon credits
carbon cycling – *if it is in remote sensing papers, not relevant*
carbon density
carbon emission
carbon estimate
carbon flux – *[if it is in remote sensing papers, not relevant]*
carbon monitoring
carbon pool
carbon sequestration
carbon sink
carbon source
carbon stock
carbon stock change
carbon storage
carbon surface flux
carbon uptake
emission factors
gross ecosystem production
gross primary production, GPP
implied emission factor
net biome production, NBP
net ecosystem exchange, NEE
net ecosystem production, NEP
net primary production, NPP
terrestrial organic carbon
volume as surrogate for biomass

Soil – outcome measures

bomb carbon
carbon age
CH4 efflux
CO2 efflux
CO2 exchange
DIC (dissolved inorganic carbon *[includes dissolved CO2])*
DOC (dissolved organic carbon)
Humic
labile
labile carbon
peat bulk density
peat depth
peat thickness
peat volume
POC (particulate organic carbon)
protected carbon
recalcitrant
recalcitrant carbon
soil carbon
soil carbon transit times and age distribution
soil organic carbon
soil organic carbon, SOC
soil organic matter, SOM
soil profile

Soil – measures of processes

decomposition
Decomposition rate
DOC/DIC/POC loss
heterotrophic respiration
litter input
Microbial activity
Q10 temperature sensitivity
soil autotrophic respiration
soil heterotrophic respiration
wetting

Forest – outcome measures

forest cover, canopy area *[not an inclusion keyword for forestry subgroup but it is one for remote sensing subgroup*]
root [*not an inclusion keyword for forestry subgroup but it is one for remote sensing subgroup*]
root biomass (density)
root:shoot ratios (R/S)
stem biomass
stem density
stem volume [*an inclusion keyword for remote sensing subgroup as it is a proxy for carbon but not used as an inclusion keyword for forestry subgroup*]
total forest plant mass
wood density
wood specific gravity

176Deadwood and Litter – outcome measures

coarse woody debris, CWD
dead organic matter (DOM)
down and dead woody (DDW) materials
litterfall
transect length

Deadwood and Litter – measures of processes

decomposition
litter decomposition
litter input
litterfall / litter fall
respiration

Crop and grassland – outcome measures

cut
fodder
foliage
forage
grain
grass
leaf
litter
manure
residue
root
seeds
silage
slurry
straw
stubble
tuber
yield

Crop and grassland – measures of processes

aboveground autotrophic respiration rate
biomass decay rates
crop growth rate
ecosystem respiration rate
rate of photosynthesis
senescence rate

Chapter 6. Knowledge management for evidence-based forestry

A version of this chapter was peer-reviewed and published as: Petrokofsky, G., R.A. Mills, 2009. The role of librarians and information specialists in evidence-based forestry Proceedings of the XIII World Forestry Congress, Buenos Aires, Argentina, 18-23 October, 2009.

Author contributions:

Gillian Petrokofsky: I suggested the paper, devised its structure and content and wrote it.

Roger Mills: Head of Science Liaison and Specialist Services, Bodleian Libraries of the University of Oxford, provided feedback on the draft, and clarified IUFRO's structure.

6.1 New problems, more information

Forestry in the 21st Century faces two unprecedented and substantial challenges. The first is the elevated rate of change in the wider social, economic and environmental context for forests and forestry. In particular, climate change and global economic recession, with their associated social and environmental consequences, are dominant global themes. The second is the changing expectations about the services and products that forest should deliver and how they are valued. New policies will inevitably be needed to meet these challenges. Forestry research must provide relevant and credible information to inform the policy process. This process will involve using existing research more effectively as well as developing new research. A wider set of disciplines, beyond those traditionally associated with forestry, must account for a substantial part of the knowledge base if it is to serve society's information needs in the future. It is rare to listen to a popular news or public interest report on forests these days without a significant focus of the report being about the forests' carbon sequestering potential. Such questions were hardly raised by scientists

themselves a decade ago, much less the general public. A new set of professionals and disciplines has thus begun to become active in foresters' traditional domain of the forest – with a resulting explosion of knowledge and pressures on national research budgets. This expansion in the remit of forestry research can create unrealistic demands for increased research investment. In recent years, despite a general trend towards increased funding for research, traditional forest research in many countries has declined relative to other disciplines (Seppälä 2006). This trend is unlikely to be reversed, particularly while most countries are in a recession, an economic situation that is expected to continue for many years. The additional information and data generated from the expanded research has not been matched with more consistent or accessible management of this knowledge (Grainger and Obersteiner 2011).

There is a clear need to prioritise what research is undertaken in the future and to consolidate published evidence which is growing exponentially. Consolidation through meta-analysis of many primary studies was introduced over 30 years ago (Glass 1976). It is a powerful means of reducing bias in evidence-based decision making. There is a case to be made, also, that this approach of pooling smaller studies and looking for treatment or intervention effects is an efficient way of sharing resources and expertise.

Lee (2004) concluded that the key solution for challenges in the forestry sector is the establishment of information networking within collaborative partnerships that can enhance e-dialogue and interactive participation. Forestry libraries are already well networked through the International Union of Forestry Research Organizations (IUFRO). A key thread running through this chapter argues that with their extensive collections of local and international publications and well-trained information specialists, forestry libraries have a clear role to play in collaborative systematic reviews which lie at the heart of evidence-based medicine (Petticrew 2001) and could be central to evidence-based forestry, as discussed in earlier chapters.

6.2 Robust scientific analysis and effective knowledge management

The present chapter is not a discourse on the theory of knowledge management. A broad working definition is offered by O'Dell and Grayson (1997):

> *"Knowledge management is…a conscious strategy for moving the right knowledge to the right people at the right time and helping people share and put information into action in ways that strive to improve organizational performance"*

A systematic approach to knowledge management of the science which is needed for policy-making in forestry, therefore, involves a network of people who are involved in any of the five stages described by Grainger and Obersteiner (2011):

1. Collecting data
2. Constructing information.
3. Reporting information.
4. Verifying information.
5. Synthesising verified information to construct knowledge.

Gray (2003) has been at the forefront of research and practice for managing knowledge for evidence-based medicine, and his much-repeated quote would serve equally well for forestry as for medicine:

> *"knowledge is the enemy of disease and, by getting what we know into practice, we will have a bigger impact on health and disease than any drug or technology likely to be developed in the next decade".*

Chapter 5 set out reasons for scoping the potential for systematic reviews to answer key policy questions in forestry. Use of systematic reviews must therefore be viewed as a key component of the wider development of improved knowledge management in forestry more

generally. Without unbiased evaluation of the best available evidence, there cannot be evidence based practice. Policy makers need to consider where the balance of evidence lies on any given issue. Single studies can be misleading and they can be subject to bias. Policy makers cannot be expected to have good scientific knowledge of the range of questions they must consider (Nutley *et al*. 2007) and the sheer volume of literature which exists makes it very difficult to produce robust syntheses of evidence. Given the very few systematic reviews which exist in forestry, there is a real danger that talk of 'evidence-based decision making' in forestry is a somewhat empty concept.

Detailed descriptions of systematic reviews have been written about extensively and a series of guidelines exist for compiling systematic reviews for different fields, notably the Cochrane and Campbell Collaborations (Clarke *et al*. 2007).

The definition used by the more recently established Centre for Evidence Based Conservation is reproduced here with permission[25].

> *"Systematic review is a tool used to summarise, appraise and communicate the results and implications of a large quantity of research and information. It is particularly valuable as it can be used to synthesise results of many separate studies examining the same question, which may have conflicting findings. The purpose of a systematic review is to provide the best available evidence on the likely outcomes of various actions and, if the evidence is unavailable, to highlight areas where further original research is required. It is, therefore, a tool to support decision-making by providing independent, unbiased and objective assessment of evidence; it is not designed to make decisions on behalf of the user-community"*

[25] http://www.cebc.bangor.ac.uk/

Systematic reviews have been described as ‘critical links in the great chain of evidence’ which are not satisfied with finding part of the truth, but look for ‘the whole truth’ (Mulrow 1994)

Systematic review methodology therefore aims to overcome problems inherent in single studies, randomly selected from a huge body of literature, by looking at a large body of literature which is selected and analysed according to strict, transparent protocols and methods. They are invariably conducted collaboratively, with as much effort going into setting the question and agreeing the search criteria as analysing the studies and drawing the conclusions. These features make them eminently suited as tools in the effort to bring rigour and order to the large body of research knowledge which exists for forestry.

They are not simply bigger, more comprehensive, literature reviews, utilizing a wider set of bibliographic databases; they may even be smaller than traditional literature reviews because of the strict criteria used to select studies for review (Petticrew 2001). Whereas systematic reviews use a highly formal approach, traditional ‘narrative’ reviews use an informal approach which is mostly far from transparent to the reader, and almost invariably not possible to replicate. Table 11 summarises the key differences.

Both types of review are retrospective, observational research studies whose quality depends on the extent to which scientific review methods have been used to minimise error and bias. However, the lack of reproducibility of traditional literature reviews renders them fundamentally unscientific.

Table 11. Difference between narrative and systematic reviews (adapted from Nutley et al. 2007)

Feature	Systematic review	Narrative review
Question	Often a focused clinical question	Often broad in scope
Sources and search	Comprehensive sources and explicit search strategy	Not usually specified, *potentially biased*
Selection	Criterion-based selection, uniformly applied	Not usually specified, *potentially biased*
Appraisal	Rigorous critical appraisal	Variable
Synthesis	Quantitative summary (may be a meta-analysis if it includes a statistical synthesis)	Often a qualitative summary
Inferences	Usually evidence-based	Sometimes evidence-based

6.3 Information access and overload

Chapters 3 and 4 discuss the Top Ten Questions (T10Q) project, which included an extensive online survey. Responses were received from 480 people in the UK and Ireland with a professional interest in forestry in its broadest sense (including forest owners, policy-makers, researchers and those working for Non Governmental Organisations (NGO) with forestry interest. Amongst the questions asked in the survey, opinion was sought on a range of issues relating to participants' experiences of information provision and knowledge management at their institutions.

Not surprisingly, perhaps, a large number of respondents reported that keeping up to date with science was difficult. Results of responses to this survey question are shown in

Table 12. Keeping abreast of science

Do you feel that you are able to keep abreast of the forestry-related science in your area of work?	Yes (%)	No (%)	No response (%)
All respondents	50	37	13
Researchers	56	36	8

Interestingly, researchers who responded reported as much difficulty keeping abreast of science as the general survey population. This group has greater access to published forestry information than any other group sampled because of their affiliation to universities or government research centres with library subscriptions to specialised print and online publications.

Table 13 shows that lack of time was, predictably, the reason given by the largest number of respondents for failing to keep abreast of relevant science. Lack of access to publications was a problem for some research institute respondents and non academics, though not University researchers, none of whom cited lack of access to publications as a limiting factor. 'Information overload' was noted as a problem by some respondents who submitted general comments on the topic of information access.

Table 13. Reasons cited for failing to keep up with science.

Reasons for failing to keep up with science	% respondents
Time constraints	88
Insufficient access to scientific articles	22
Cannot afford to access journals or databases	17
Keeping abreast of science is not perceived as important by my organisation	9

Responses to questions about the importance of different sources of information were broadly in line with those reported in a very extensive survey of information provision in the forest industry in South Africa (Lamoral 2001). Table 14 shows responses received in the T10Q survey. In terms of keeping abreast of science, there was still great reliance on 'traditional' library-based sources of information and various forms of personal contact. Web 2.0 sources (blogs, wikis, etc.) have so far failed to make a significant impact on this group of people.

Table 14. Sources of information and their value

Sources of information	Regularly use (%)	Useful or very useful (%)	Of little or no use (%)
Academic journals (print or online);Books, published reports; Technical reports, pamphlets, practice notes, etc.	89	89	5
Conferences, meetings; Professional personal contact; Informal personal contact; Scientific papers circulated by email or on Internet discussion lists	90	90	3
Blogs, Wikis, and other user-generated web content	13	27	47

Pasiecznik and Petrokofsky (2005) reported a long-term trend towards increased numbers of scientific publications and increased volume of published literature in forestry (Figure 29) and this increase has continued exponentially not only in the academic literature but, at a greater rate, in web-published content, and, increasingly, Web2 content. This puts an enormous strain on library budgets which have not kept pace, in the UK at least, with the growth in publication volume (Sconul/LISU 2009). It seems likely, therefore, that even those researchers who report no problem with keeping up to date with the literature are not, in reality accessing the full range of research which is available. There is great potential for bias if reviewers are selecting studies from a relatively limited range of publications.

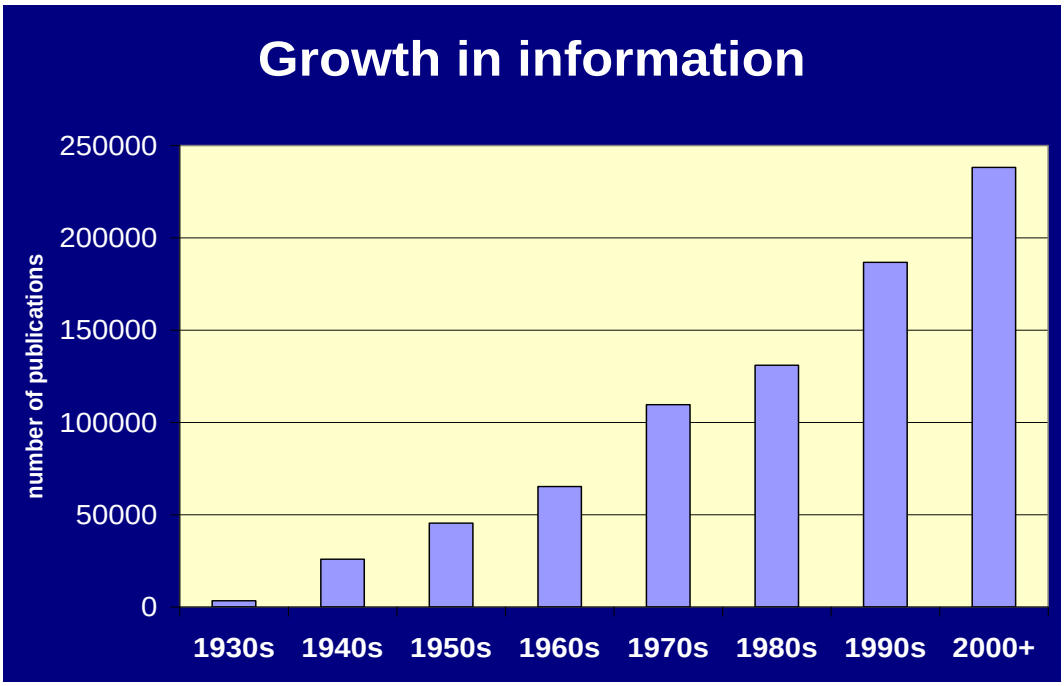


Figure 29 Growth in published forestry information (Pasiecznik and Petrokofsky 2005)

6.4 Collaborating to share resources and expertise

There is a well-developed tradition of sharing resources amongst libraries; inter-library loans are factored into library and research budgets to supplement literature available locally. However, locating literature is only one difficulty; a greater problem is perhaps knowing what exists, particularly in other subject domains. Increasingly, forestry is multidisciplinary and needs to draw on evidence generated in a wide range of fields. Collaboration will be essential if the widest possible range of evidence is to be accessed. Lee (2004) expressed the view that partnership acts as a catalyst towards successful communication of forestry information among users and that partnership can be strengthened via networking. These are strong attributes of the systematic review process.

The International Directory of Forest Information Services: Libraries, Documentation Centres, and Subject Specialists, launched by IUFRO in 2002 and hosted by Forintek in Canada, contains details of 152 forestry libraries and information centres in 49 countries.[26]The multilingual collections of publications residing in their collections and the subject specialists who work with the collections represent a potentially highly valuable collective resource for systematic review groups.

The guidelines for systematic reviews produced by the Cochrane Collaboration, the Campbell Collaboration and the Centre for Evidence Based Conservation all advocate working with librarians and information specialists to develop effective literature search strategies. Each of Cochrane's more than 50 Review Groups, which specialise in particular areas of medicine or

[26] http://iufro.forintek.ca).

public health[27], have on their Editorial Team a Trials Search Coordinator (TSC), who is usually a professional librarian or information specialist. Many TSCs have also co-authored reviews (Swinkels 2006).

Figure 30 shows the stages of a Cochrane-style systematic review. Forestry librarians and information specialists have a clear role to play in all stages of the systematic review process in addition to their important role as resource locators, particularly of the unpublished and 'grey' literature which is a key resource for evaluation.

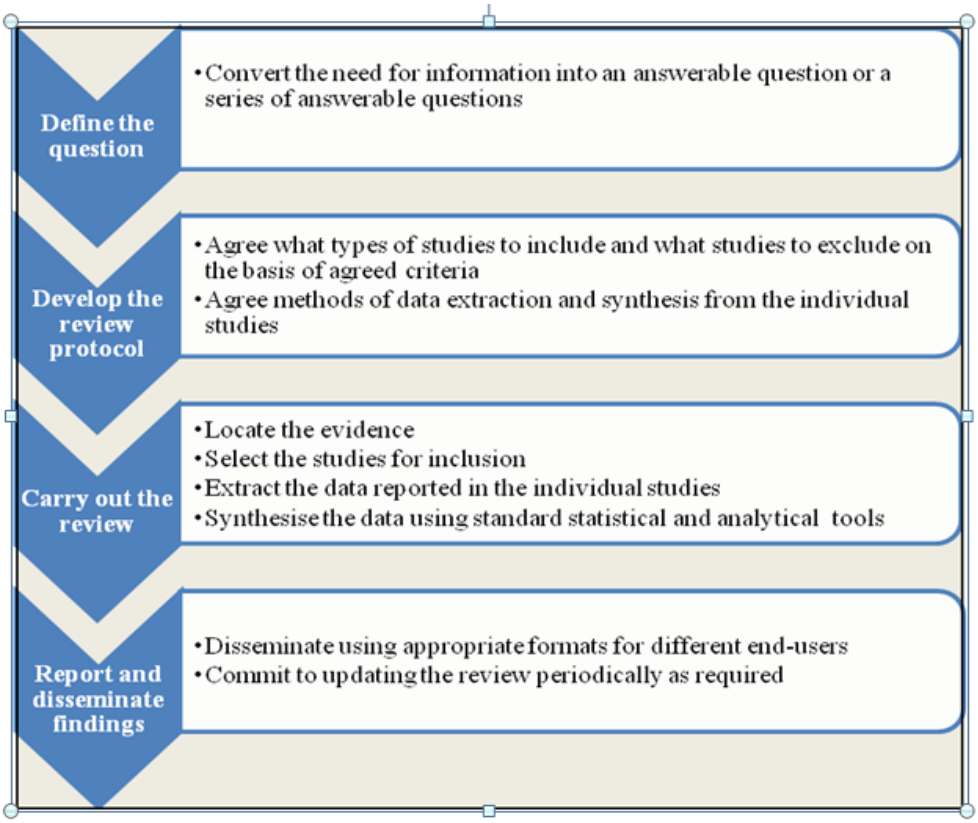


Figure 30 Stages in a typical Cochrane-style systematic review

[27] http://www.cochrane.org/contact/entities.htm#CRGLIST

6.5 Conclusions

There is a need for skilled knowledge managers who can help other professionals ensure that both primary research and applied research in practice and policy is based on the firmest scientific foundation which has systematically collated, assessed and analysed the available research. While medicine and social policy have adopted robust methods for synthesizing research in multi-disciplinary, international groups, this is not happening on anything like the scale which it could be in forestry. Systematic reviews are widely recognised as powerful tools for making sense of the enormous volume of published and unpublished literature. Their role in reducing the bias inherent in reviews or primary studies is well documented. There is an opportunity for professional librarians and information specialists to lead the way in forestry to ensure that researchers, practitioners and policy makers are taking decisions based on the best available, *systematically* collected evidence from primary research. There is a need to ensure that the skills of academic librarians working in fields relevant to modern forestry are equal to those which are being exercised by the best in other disciplines and, moreover, that these skills and methodologies are understood by the wider forestry community in order to establish a more rigorous dialogue between them. Basic skills in evidence-based forestry should be taught by librarians so that researchers and practitioners have an understanding of the bias which will inadvertently, but inevitably, creep into their work if the experiences of practice in other spheres such as medicine serves as a guide.

A forum is needed to discuss the practicalities of this approach and set up a pilot; this role is well suited to the International Union of Forest Research Organization's unit 6.03, *Information Services and Knowledge Organization*, and could be taken forward at the IUFRO Congress in 2010. The role of librarians is changing in many fields, and the advantage of embedding information professionals in research teams is increasingly widely recognised (Schumacher 2007**)**, particularly in the biosciences and particularly in the USA. The massive amounts of new data which many projects accumulate present huge challenges both in

curation and exploitation (Brown and Turnbull 2006), and need to be linked to existing knowledge in reliable and accessible ways that will be of practical use in decision making. Embedded librarians can bring both technical understanding and knowledge of the existing literature to the research management process, and by working alongside research staff on specific projects will gain enhanced understanding of the day-to-day challenges actually faced by researchers and help to develop targeted solutions that are relevant and cost-effective. This in turn can influence software designers and database providers to ensure that their products are closely matched to needs (Schuck 2007).

This evolving role for information specialists will require specialist training and library school curricula will in due course need to be adapted to provide that. A corpus of knowledge needs first to be established on how librarians can most usefully serve the research process, which will itself come from experiment. We recommend that forestry research projects give serious consideration to the inclusion of a librarian in each research team from the outset, building the funding of such positions into the project budget, and requiring publication of the methods used and outcomes of the librarian's contributions to the project as part of standard project outputs. This would lead to a body of literature that can itself be systematically reviewed, thus allowing the spread of good practice.

Chapter 7. Conclusions and reflections: the way forward

7.1 From serendipity to systematic

> *"as their Highnesses [the three Princes of Serendip] travelled, they were always making discoveries, by accidents and sagacity, of things which they were not in quest of"*[28]

Serendipity is a highly valued component of scientific discovery. Merton and Barber (2004) document the long history of the word since its coinage by Walpole, and devote a chapter to a discussion of how the scientific community has embraced the term: "The diverse significance of serendipity in science".

The benefits of serendipity are often cited when researchers are asked to justify their work, particularly work which has no immediate 'benefit' to society: Alexander Fleming's discovery of penicillin, Alfred Nobel's discovery of dynamite and Jocelyn Bell-Burnell's discovery of pulsars, for example. The UK Government's decision to include metrics for "the economic and social impact of research, as well as impact upon public policy" as part of assessment of the overall assessment of quality of research (HEFCE 2009) drew criticism that expressed concern about losing this cherished aspect of scientific enquiry.

[28] In a letter from Horace Walpole to Horace Mann dated January 28, 1754, cited in Merton & Barber (2004) and in most dictionary entries of the origin of the word 'serendipity'.

The summary of responses received during the second consultation on the Research Excellence Framework contained the following comment (with my emphasis):

> *"A minority of responses, notably the University and College Union (UCU), some of the academic associations, individual departments, individual researchers and others, opposed or objected to assessing the impact of research in the REF, even with a lower weighting. The UCU submitted a petition to withdraw the impact proposals, signed by 17,500 people, although the petition presented the proposals as seeking to predict* ***the impact of research before it is carried out****, rather than assessing 'historical' impacts as we had proposed… Their key concerns were that the REF would harm long-term,* ***curiosity-driven research****…*

Opposition to evidence-based medicine (EBM) has often drawn from the same well in the sense that there is a belief that it is an 'ivory tower' concept that imposes restrictions on what information should inform clinicians when deciding on treatments, and would limit their ability to use their own experiences and instincts to tailor treatments to individual patients. Straus and McAlister (2000) reviewed common criticisms of EBM systematically (47 published papers) and concluded that they fell into two groups: misconceptions stemming from misperceptions of EBM (the critics had not understood the principles); and criticisms that were misrepresentations of EBM (the critics were wrongly reporting the principles). They found no evidence of criticisms which addressed any limitation of the practice.

Similar criticisms have been levelled at the elevation of systematic reviews to be the gold standard of evidence in medicine, education and other areas of social policy, with critics expressing scepticism about the highly structured way in which evidence is chosen a priori; the very antithesis of serendipity. Chalmers (2003, 2005) and Petticrew (2001, 2006) have provided robust defences of systematic reviews and challenged critics to propose alternative models which reduce bias as effectively as systematic review methodology does.

Serendipity *in* research and systematic reviews *of* research can coexist comfortably within science. Serendipity in reviewing research, however, has no advantages and carries a high risk of bias. The dearth of systematic reviews or meta-analysis of aspects of forest

management, even for issues of such high global importance as tropical forest deforestation or illegal logging, means that serendipity is reigning supreme in literature reviews which are available for decision-makers.

Even where meta-analyses are available, if they are not referenced in 'accessible' reports, they are unlikely to be picked up by time-constrained policy-makers who may not have deep scientific knowledge of the area of study. For this reason, systematic reviews published by the Cochrane Collaboration always contain a 'plain language summary', whose primary audience is policy-makers and the general public.

A very recent (2011) case in forestry illustrates how opportunities for promulgating robust research through semi-popular publications are commonly missed in forestry. Two rigorous meta analyses of the causes of deforestation and the impacts of landuse change by Rudel (2007, 2008) were not referenced in the first UN-REDD Report (a highly accessible publication given prominence on the FAO and UN-REDD websites in February and March, 2011 and picked up by media services covering REDD). It was published to coincide with the 6th UN-REDD Policy Board meeting in Vietnam[29] and also appeared as part of a set of resource materials on the collaborative online workspace for people working with or for the UN-REDD programme. A considerable number of policy-makers and representatives of country forestry delegations with responsibility for international negotiations of REDD would therefore have read this report.

The English version of the report had received 1113 hits in the seven weeks since it was uploaded on the REDD collaborative workspace on 21/2/2011 until 11/4/2011 (when I accessed the site). There were also190 hits for the Spanish version and 123 for the French

[29] http://www.un-redd.org/PolicyBoard/6thPolicyBoard/tabid/6893/Default.aspx

version in the same period. The hit rate for the English publication is one of the highest for any document on the site and some four times higher than other documents labelled 'hot'.

This document, commissioned by decision-makers who are grappling with a highly divisive, globally important problem, which has huge potential influence, drew on a very limited evidence base and is a critical example of the very problem which stimulated this research.

7.2 Experts on tap not on top

Boshier *et al.* (2009) combined a meta analysis with participatory workshops in a project which examined and weighed evidence from more than 100 participatory surveys to determine what farmers in Central America considered 'important trees' for planting and compared their findings with those of the more conventional projects which suggest suitable species based on experts' views.

Of the 150 species rated most highly by farmers in their survey, 62% had not been covered in the international CABI Forestry Compendium[30], of over 20,000 trees compiled by technical experts.

The value of utilising existing evidence sources and combining qualitative and quantitative information from surveys and workshops rather than relying on expert opinion was demonstrated comprehensively for this particular policy question in this region.

Their stakeholder group, local famers, was not different essentially from the stakeholder group involved in our T10Q project. They are both groups for whom the outputs of the investigation were of great importance and whose inputs shaped the outcome almost entirely. Where 'expert' (i.e. *external* expert) intervention was utilised – for a sensitivity analysis in

[30] http://www.cabi.org/fc/

the case of the Central American farmers, and to group the research questions into themes, in the case of the T10Q project – it was to organise the information in a way that facilitated further deliberation by stakeholders. In other words, having experts not *on top* , but *on tap* to provide analysis or overview, with the problems that may arise from missing essential bottom-up input (Laski 1930).

The T10Q project (Chapters 3 and 4) provides a model for doing 'more with less', by combining stakeholder participation in suggesting high-priority areas for research, with a bibliometric study of the existing published research in the areas deemed most important. The T10Q participants, who were self-selected and drawn from a broad base of the UK forestry community, generated a meaningful set of policy-relevant research questions that compared favourably with other expert-driven methods of deciding what is important for forestry and for forestry research.

The process itself is scalable and could be adapted readily for local, regional or international consultations that aim to determine research priorities in other areas of natural resources management. One of the benefits of facilitating broad stakeholder input is that the whole process can be transparent and can be improved over time iteratively. Another very important benefit is that the stakeholders feel a sense of ownership over the research agenda and are therefore much more likely to be interested in considering and possibly using its results.

Nationally, the Living with Environmental Change Partners (LWEC) Partnership, which has merged with the Environment Research Funders' Forum (see Chapter 3), could embrace this approach to investigate and establish future research needs of the sector. Internationally, IUFRO has the organisational structure to facilitate the sort of multi-disciplinary participation needed for questions of global importance across the breadth of the sector.

Moving from an expert-driven approach to one which engages a wider network of actors who have a shared interest in forestry not only follows the recommendations of national

governments, but also accords well with the popular movement towards social networking to participate in and shape particular policy discussions.

The huge advantage of enabling a 'Linked-In' approach is that people who have an interest in the issue can become active in the decision-making processes which affect them, without having to be 'sponsored' by an existing player and without fear of being excluded by groups within the network who have a vested interest in keeping out contrary opinions.

Forestry policy will continue to evolve and decisions will need to involve people who are outside the traditional boundaries of the discipline. It is likely that this trend will be more important in the future, particularly in the light of complex problems connected with climate change, bio-energy provision or health and well-being, for example, which require multidisciplinary partnerships within the research and policy communities. Few would have predicted ten years ago, perhaps, that research funding would be directed at projects on governance of deforestation, or the benefits of green-spaces on well-being. A participatory approach to defining the research agenda provides the necessary flexibility to respond to unforeseen challenges without the constraints of conventional research disciplines

The scoping project on the potential for a systematic review of carbon assessment methods discussed in Chapter 5, raised a number of important questions that are relevant to any similar study:

- Were stakeholders sufficiently engaged by the subject of the investigation?
- Were stakeholders convinced of the value of using an evidence-based framework to review the subject?
- Were the right stakeholders engaged?

A significant conceptual hurdle which emerged early in the stakeholder engagement process was the division between those who felt that the orthodoxy (of carbon assessment methods) should be challenged and those who did not. The early champions of evidence-based medicine did so in order to create a 'new paradigm' for medicine precisely to break the stranglehold of 'experts', whose knowledge of and use of the best scientific research was highly questionable.

Embarking on the REDD project, it was to be expected that this division would reveal itself. Reactions to this attempt to evaluate the science systematically can be characterised by three typical responses, paraphrasing some of Rogers' (1962) adopter categories:

> **Early rejecter**: The person/organisation who strongly believes that the current way is the best one because they have a vested interest (intellectual or economic) in promoting the method (the analogy with health here is the drug company which currently has the contract for supplying an effective medicine);
>
> **Over-eager adopter**: The person/organisation who strongly believes that the current way is not the best one because they have a vested interest

(intellectual or economic) in promoting an alternative method - often their own - (the medical analogy is a competing drug company wanting to break into the market);

Methodological sceptic: The person/organisation who has an open mind about the current way and wants to test it.

These are gross over-simplifications, and many subtle variations exist. It could be argued with some justification that all proponents of evidence-based frameworks or systematic reviews as tools for guiding decision-making have a vested interest in challenging orthodoxy. However, the critical difference between "over-eager adopters" and "methodical sceptics", using the above characterisation, is that the latter, accept *a priori* that a systematic review is equally capable of demonstrating unequivocally that the current way is the best way. Systematic reviews are not therefore instruments to be used to unseat unpopular policies; they will only do that if the science justifies a conclusion that the current way is not the best way.

Certainly, early reactions to the project proposal from the large stakeholder group who were contacted drew out examples of people who had absolute belief in the IPCC methodologies for assessing and measuring carbon as well as those who felt the IPCC guidelines did not offer robust methodologies backed up by sound science. However, there was sufficient support from stakeholders who had a genuine interest in looking at the science in a systematic way to enable the project to progress more or less as planned.

A systematic review Protocol was produced collectively (Chapter 5) and the review is currently underway with a group of reviewers with no previous knowledge of systematic reviews methodologies. This represents a successful acceptance by these stakeholders at least that the subject of the review is valid and necessary, and that a systematic review will be an effective tool for uncovering the science underpinning different methodological options for carbon stock assessment.

Proof, of a more tangible sort, that the project succeeded in convincing those in the policy community who dispense funds for international work, is that the 6th UN-REDD Programme Policy Board proposed accepting the draft Global Programme Framework (UN-REDD Programme 2011a), which contained the following plan to embed systematic reviewing in the framework:

> *"Science analysis and systematic reviews of science for measurement and monitoring are key elements for appropriate advice to countries. Knowledge and techniques applied in monitoring systems must be well documented and tested. …This activity will apply established approaches to systematic reviews to key policy questions related to REDD+ monitoring, to guide policy makers and REDD+ practitioners through transparent processes backed by stakeholders. This activity also covers the dissemination of the results through knowledge dissemination applications, side events and workshops."*

This plan includes a budget allocation of US $1,800,000 over three years. This sum is modest, perhaps, within the overall budget of $81,657,362, but a significant allocation for a new information/ knowledge management activity (UN-REDD Programme Board 2011b). The UN-REDD programme qualifies for Rogers' (1962) term "early adopter" of the practice of using a systematic approach to review science for policy within the forestry community.

Reflecting on the hypotheses I set out to examine, it has become clear that there is very little systematic evaluation of science for policy in the forestry field. There is an appetite amongst key people at international level to adopt systematic methods in order to make decisions that are demonstrably evidence-based. There is clear evidence of enthusiasm amongst people in the broad forestry sector in the UK to engage in a collaborative process of prioritising research for policy.

7.3 The way forward

On the basis of the participatory work discussed in the previous chapters, I propose a10-step approach that could be implemented as a starting point for moving towards a fully developed system of evidence-based forestry that incorporates the elements outlined in detail in chapters 3, 5 and 6. This approach draws heavily on the basic steps which form the work flow for any systematic review. My proposal is not that all science-policy engagement must involve a full systematic review, rather that adopting similar rigorous, iterative approach can greatly improve the quality of the science and also the dialogue.

I concluded from my experience with scoping the possibility of a systematic review for REDD that the discipline imposed by an evidence-based framework added greatly to the quality of discussions about the information which would inform the policy question. Most of the researchers who participated were enthusiastic about the benefits of treating a literature review with the same rigour as any other scientific experiment, where discussions between colleagues during development stages, and repeated trials to improve the method are the norm.

Elements in red indicate those which have the potential to improve quality of the review of scientific evidence; those in green have the potential to increase the uptake and use of the information, by widening the base of those who will be aware of the findings of the review.

Ten steps to improve the quality of science for policy

Where science is needed for policy - as identified by the science community, requested by policy-makers, or collaboratively recognised by policy-makers, scientists, professional groups, and others.

1. FRAME THE QUESTION

   involve stakeholders (at a minimum, scientists and the relevant policy-makers with an interest in the question) early to frame the question precisely and ensure that the boundaries of what is to be considered are clearly stated. These can be amended on later iterations

2. SELECT AND ANALYSE THE EVIDENCE

   involve stakeholders to decide:

   where to look for key evidence (databases, organisational websites, libraries, etc.);

   how to find it (keywords, search strategy, access to relevant studies in journals, archives, etc.)

   why individual studies will be selected for review (inclusion criteria)

   what analysis will be performed on the selected items

3. DOCUMENT THE DECISIONS AND STRATEGIES

   to ensure transparency and repeatability

4. PEER-REVIEW THE METHOD

   involve stakeholders in extended peer-review of strategies proposed for finding the evidence

5. AMEND THE METHOD

6. WRITE THE COMPLETE REVIEW

   according to strategies in Stage 2

7. PEER-REVIEW THE REVIEW

   involve stakeholders in extended peer-review

8. AMEND THE REVIEW

9. ADOPT A DISSEMINATION STRATEGY

   involve stakeholders in identifying audiences for the review and formats appropriate for these different audiences (can be done at time of Stage 2)

10. ACTIVELY DISSEMINATE THE REVIEW

    involve stakeholders to disseminate the review and summaries

The benefits of this systematic approach (which borrows from systematic review methods, but is some way short of a full "gold-standard" systematic review) are:

The possibility of gaining broader insights into the question, particularly of boundary issues in multidisciplinary research – silo breaking

Greater access to published information (wider range of journal subscriptions, journals in different languages)

Greater access to grey literature (institutional reports, working papers, unpublished surveys, etc.) and data

Greater access to funding for summaries in different formats (policy-briefs, guidelines and training materials, podcasts, semi-popular articles, etc.)

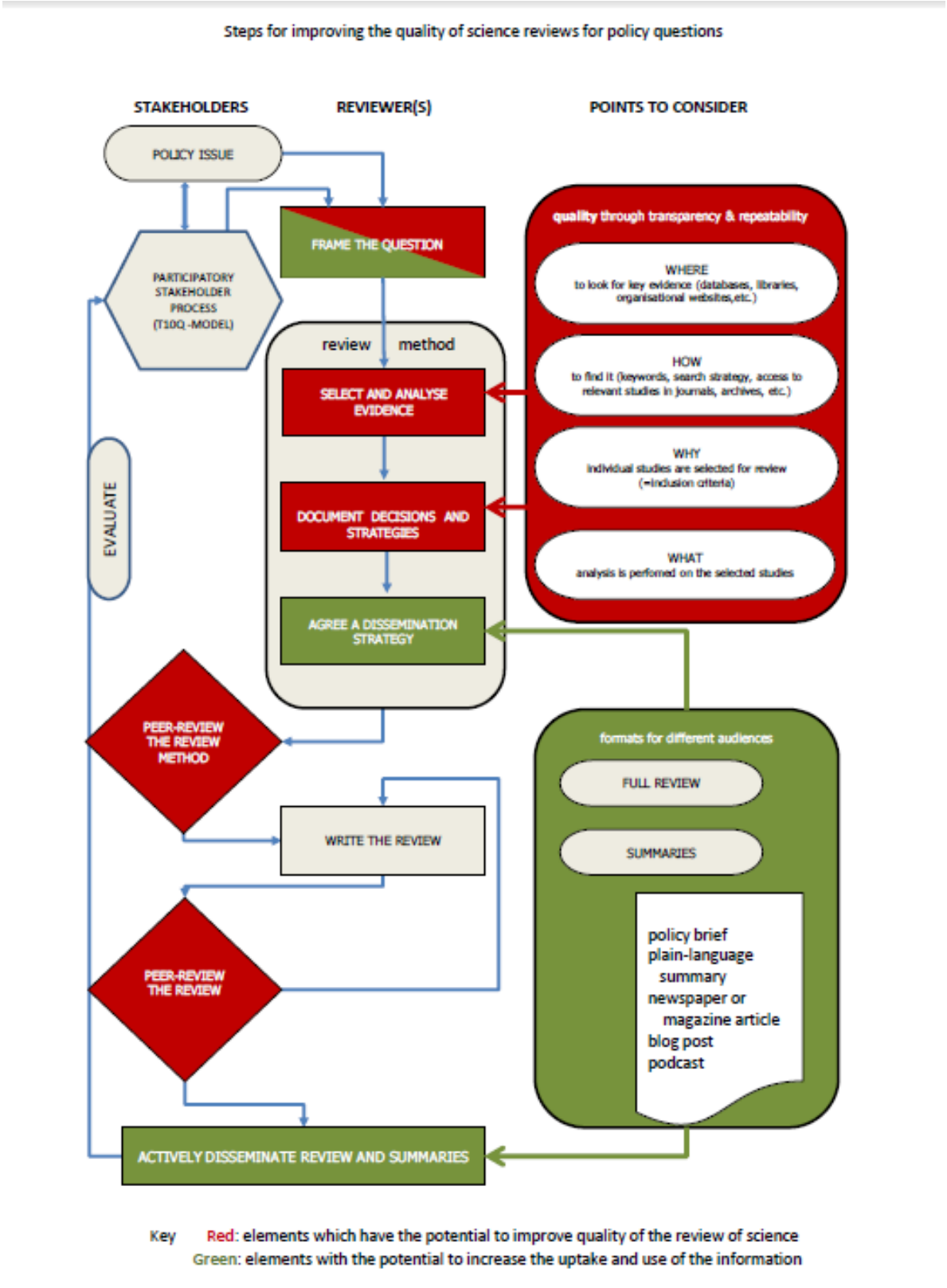


Figure 31 Steps for improving the quality of science reviews for policy questions

7.4 Final statements

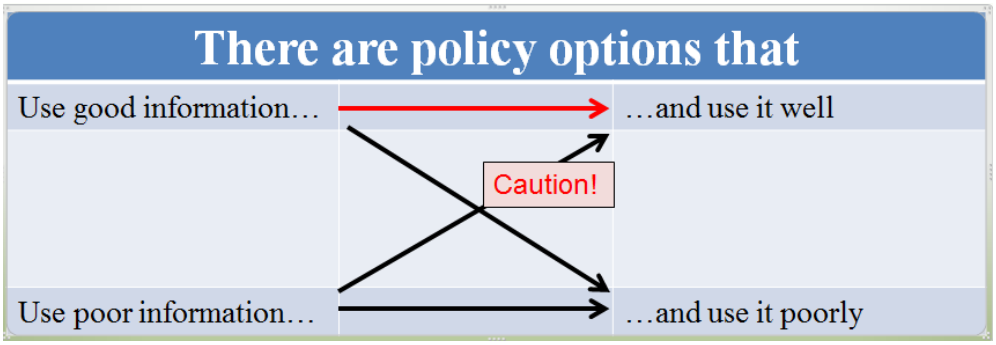


Figure 32 Knowledge-use challenge: adapted from Defra website (undated), accessed 2007

Defra's matrix of options for using information in policy sums up perfectly the current situation for use of science in forestry. There is undoubtedly a great deal of excellent science and a great deal of exemplary decision-making. "Good people are doing good things", to coin Ravetz's comment on the 'ClimateGate' affair that put public scepticism in the use of scientific evidence on the front pages of newspapers around the world.[31]

However, where claims of scientific knowledge provide the basis of critically important public policies, such as those of REDD, demands for extended peer review and the democratisation of science become overwhelming. It cannot be assumed that the top line of Defra's matrix is being applied, but neither should it be assumed that the bottom line is the norm, despite some evidence for public scepticism about the use of science in policy.

Perhaps most worrying of all options in the matrix is the one resulting from poor information having been used 'well', meaning that a happy chance has given us a good, workable policy, which happens to have been based on no robust evidence at all. The current situation in forestry is that it is very difficult to know where on the matrix any policy or decision lies. Policy evaluation could provide information about the success or otherwise of individual

[31] A short commentary of ClimateGate by Ravetz and Hulme is at http://news.bbc.co.uk/1/hi/sci/tech/8388485.stm (Page last updated at 14:56 GMT, Tuesday, 1 December 2009)

policies, and these should be encouraged and funded. They are by necessity historical analyses, however, and a shorter-term solution exists for evaluating the strength of science for policy in the form of evidence-based frameworks of the sort described in the current work.

Involving more people in deciding what the important questions are does not lead to a partial research agenda. Insisting on transparency in selecting and analysing science for policy questions does not impose undue burdens on scientists or policy-makers; it upholds the very foundation of science. Collaboration adds intellectual richness from different fields of research and promotes active mixing of ideas through wider networks. While moving towards fully developed mechanisms for evidence-based forestry, small steps should be taken to improve the critical appraisal of science for policy using transparent, participatory methods to strengthen the evidence base and make it 'fit for purpose'.

References

Achard, F., H.D. Eva, H.J. Stibig, P. Mayaux, J. Gallego, T. Richards, J. Malingreau, 2002. Determination of deforestation rates of the world's humid tropical forests. *Science* **297**, 999-1002.

Achard, F., H. D. Eva, P. Mayaux, H.J. Stibig, A. Belward, 2004. Improved estimates of net carbon emissions from land cover change in the tropics for the 1990s. *Global Biogeochemical Cycles* **18**, GB2008, doi:10.1029/2003GB002142.

Ahsan-ul Morshed, M. Sini, 2009. Creating and aligning controlled vocabularies. In: Proceedings of the Workshop on Advanced Technologies for Digital Libraries 2009 (AT4DL 2009), 8th September 2009, Trento, Italy. Bernardi, R., S. Chambers, B. Gottfried (Eds). Bozen-Bolzano University Press, Italy. ISBN: 978-88-6046-030-1 50-53.

Alder, D., M. van Kuijk, 2009. *A baseline assessment of forest carbon in Guyana*. Report prepared for Guyana Forestry Commission.

Baccini, A., N. T. Laporte, S. J. Goetz, and M. Sun, 2008. A first map of tropical Africa's above-ground biomass derived from satellite imagery. *Environmental Research Letters* 045011 (open access online) doi: 10.1088/1748-9326/3/4/045011.

Baker, T.R., O.L. Phillips, Y. Malhi, S. Almeida, L. Arroyo, A. Di Fiore, T. Erwin, T.J. Killeen, S.G. Laurance, W.F. Laurance, *et al*., 2004a. Variation in wood density determines spatial patterns in Amazonian forest biomass. *Global Change Biology* **10**: 545-562. doi:10.1111/j.1365-2486.2004.00751.x.

Baker, T.R., O.L. Phillips, Y. Malhi, S. Almeida, L. Arroyo, A. Di Fiore, T. Erwin, N. Higuchi, T.J. Killeen, S.G. Laurance, *et al*., 2004b. Increasing biomass in Amazonian forest plots. *Philosophical Transactions of the Royal Society B Biological Sciences* **359**: 353-365. doi:10.1098/rstb.2003.1422

Ball, R., D. Tunger, 2006. Science indicators revisited - Science citation index versus SCOPUS: a bibliometric comparison of both citation databases. *Information Services and Use* **26**(4), 293-301.

Barlow, J., C.A. Peres, B.O. Lagan, T. Haugaasen, 2003, Large tree mortality and the decline of forest biomass following Amazonian wildfires. *Ecology Letters* **6**, 6-8.

Batjes, N.H., Sombroek, W.G., 1997. Possibilities for carbon sequestration in tropical and subtropical soils. *Global Change Biology* **3**, 161-173.

Bebber, D., 2010. 'There is much more work to be done post Cancun'. *Science News, Earthwatch Institute (Europe)*, Tuesday 21, December, 2010. http://www.earthwatch.org/europe/newsroom/science/news-3-postcancun.html [accessed 6/3/2011]

Binkley, D. , Menyailo, O. , 2005. Gaining insights on the effects of tree species on soils. In: Tree species effects on soils: implications for global change. Proceedings of the NATO Advanced Research Workshop on Trees and Soil Interactions, Implications to Global Climate Change, August 2004, Krasnoyarsk, Russia. Binkley, D. , O. Menyailo [Editors]. NATO science series. Series IV: Earth and environmental sciences. Vol. 55, ISBN: 9-781-4020344-59, 1-16.

Bonan, G.B., 2008. Forests and climate change: Forcings, feedbacks, and the climate benefits of forests. *Science* **320(**5882): 1444-1449.

Boshier, D., J. Cordero, G. Detlefsen, J. Beer, 2009. Indigenous trees for farmers. Information transfer for sustainable management in Central America and the Caribbean. In: *Ecosystèmes forestiers des Caraïbes*. Joseph, P. (Editor), Martinique, Editions Karthala, Conseil Général de la Martinique ISBN: 978-2-8111-0090-2. 397-410.

Bradshaw, C.J.A., I.G. Warkentin, N. S. Sodhi., 2009. Urgent preservation of boreal carbon stocks and biodiversity. *Trends in Ecology & Evolution* **24**(10): 541-548. doi:10.1016/j.tree.2009.03.019

British Science Association , 2002. Report of the Science Communication Conference organised by the BA [British Science Association] in association with Copus – the Science Communication Partnership, held at the Institute of Electrical Engineers, May 30-31, 2002. http://www.britishscienceassociation.org [accessed 30/3/2011]

Broerse, J.E.W., J.F.G. Bunders, 2000. Requirements for biotechnology development: the necessity for an interactive and participatory innovation process. *International Journal of Biotechnology* **2**, 275-296.

Brown, A. G., J.W. Turnbull, 2006. Information resources for forest researchers and managers: strengths, weaknesses, threats and opportunities. *Issues in Science and Technology Librarianship* Spring 2006 Supplement. http://www.istl.org/46-supp/index.html

Brown, S., A.E. Lugo, 1982. The storage and production of organic matter in tropical forests and their role in the global carbon cycle. *Biotropica* **14**, 161-187.

Brown, S., A J. R. Gillespie, A.E. Lugo,1989. Biomass estimation methods for tropical forests with applications to forest inventory data. *Forest Science* **35** (4), 881-902.

Buchy, M., S. Hoverman, 2000. Understanding public participation in forest planning: a review. *Forest Policy & Economics* **1**, 15-25.

Burdekin, D. A., 1989. Trends in forestry research 1982-1988. *Occasional Paper, Forestry Commission, UK.* No. 23,10 pp.

Burley, J., 1997. What's in a word? *IUFRO News***26** (2), 1,3.

Cabinet Office. *Modernising Government*. 1999.

Cabinet Office. Professional Policy Making for the Twenty First Century. 1999.

Campbell, J.E., J.C. Moen, R.A. Ney, J.L. Schnoor, 2008. Comparison of regression coefficient and GIS-based methodologies for regional estimates of forest soil carbon stocks. *Environmental Pollution* **152**, 267-273.

Capoor K., P. Ambrosi, 2009. *State and Trends of the Carbon Market 2009* World Bank and International Emissions Trading Association, Washington, DC, USA.

Carnegie United Kingdom Trust, 2008 *Power moves : exploring power and influence in the UK*. Carnegie UK Trust, Dunfermline, UK.

Caron-Flinterman, J.F., J.E.W. Broerse, J. van Teerling, J. M.L.Y. Alst, S. Klaasen, L.E. Swart, *et al*., 2006 Stakeholder participation in health research agenda setting: the case of asthma and COPD research in the Netherlands. *Sci. Public Policy* **33,** 291-364.

Centre for Reviews and Dissemination, University of York, 2008. *Systematic Reviews. CRD's guidance for undertaking reviews in health care*. University of York, CRD, ISBN:978-1-900640-47-3.

Chalmers, I., 2003. Trying to do more good than harm in policy and practice: the role of rigorous, transparent, up-to-date evaluations. *Annals of the American Academy of Political and Social Science* **589**, 22-40.

Chalmers, I., 2005. If evidence-informed policy works in practice, does it matter if it doesn't work in theory? *Evidence & Policy: A Journal of Research, Debate and Practice* **1** (2), 227-242.

Chalmers, I., D. G. Altman, 1995. *Systematic Reviews.* London: British Medical Journal Publishing.

Chalmers, I., D.L. Sackett, C. Silagy, 1997. The Cochrane Collaboration. In: *Non-random reflections on health services research*. (Maynard, A., I. Chalmers, eds.) London: British Medical Journal Publishing.

Chave, J., C. Andalo, S. Brown, M.A. Cairns *et al.*, 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia* **145**, 87-99.

Chave, J., B. Riéra, M.A. Dubois, 2001. Estimation of biomass in a neotropical forest of French Guiana: Spatial and temporal variability. *J. Trop. Ecol*. **17**, 79-96.

Chave, J., R. Condit, S. Aguilar, *et al*., 2004. Error propagation and sealing for tropical forest biomass estimates. Philos. Trans. R. Soc. B Biol. Sci. 359, 409-420.

Clarke, M., S. Hopewell, I. Chalmers, 2007. Reports of clinical trials should begin and end with up-to-date systematic reviews of other relevant evidence: a status report. *Journal of the Royal Society of Medicine* **100**(4), 187-190.

Clémençon, R., 2008. The Bali road map: a first step on the difficult journey to a post-Kyoto Protocol agreement. *Journal of Environment & Development* **17**, 70-94.

Cochrane, A.L., 1972. Effectiveness and efficiency: random reflections on health services. London, UK: RSM Press Ltd.

Cochrane, A. L., A. Maynard, I. Chalmers, 1997. Non-random reflections on health services research: on the 25th anniversary of Archie Cochrane's Effectiveness and Efficiency. London, UK: British Medical Journal Books.

Cohen, J., 1960. A coefficient of agreement for nominal scales. *Educational and Psychological Measurement* **20**, 37-46.

Cooke, S.J., A.J. Danylchuk, M.J. Kaiser, M.A. Rudd,, 2010. Is there a need for a '100 questions exercise' to enhance fisheries and aquatic conservation, policy, management and research? Lessons from a global 100 questions exercise on conservation of biodiversity. *Journal of Fish Biology*, 2261-2286.

Cooper, C. B., J. Dickinson, T. Phillips, R. Bonney, 2007. Citizen science as a tool for conservation in residential ecosystems. *Ecology and Society* **12**(2), 11 [online] http://www.ecologyandsociety.org/vol12/iss2/art11/

Côté, M., L. Bouthillier, 1999. Analysis of the relationship among stakeholders affected by sustainable forest management and forest certification. *Forestry Chronicle* **75**, 961-965.

Couwenberg, J., R. Dommain, H. Joosten, 2009. Greenhouse gas fluxes from tropical peatlands in Southeast Asia. Global Change Biol. Accepted Article. doi: 10.1111/j.1365-2486.2009.02016.x.

Davies, P., R. Boruch, 2001. The Campbell Collaboration. *British Medical Journal* **323**, 294-295.

De Fries R, F. Achard, S. Brown, M. Herold, D. Murdiyars, B. Schlamadinger, C. Souza, 2007. Earth observations for estimating greenhouse gas emissions from deforestation in developing countries. *Environmental Science and Policy* **10:** 385–394.

De Vaus, D.A., 2002. *Surveys in social research, 5th Edition*. ISBN: 978-0-415-26858-5. Abingdon, UK: Routledge.

Department for Environment, Food and Rural Affairs (Defra), 2007. *A strategy for England's trees, woods and forests (ETWF)*.

Des Roches, C.T., 2007. Policy advice for public participation in British Columbia forest management. *Forestry Chronicle* **83**, 672-681.

DeWalt, S.J., J. Chave, 2004. Structure and biomass of four lowland neotropical forests. *Biotropica* **36,** 7-19.

Dombrowski, K., 2010. Filling the gap? An analysis of non-governmental organizations responses to participation and representation deficits in global climate governance. *International Environmental Agreements: Politics, Law and Economics* **10** (4): 397-416.

Dubben H.H, H.P. Beck-Bornholdt, 2005. Systematic review of publication bias in studies on publication bias. *British Medical Journal* **331**, 433–434.

Egger M, T. Zellweger-Zahner, M. Schneider *et al*.,1997. Language bias in randomised controlled trials published in English and German. *Lancet* **350**, 326–329.

Eggleston, H.S., L. Buendia, K. Miwa, T. Ngara, K. Tanabe (Eds.), 2006. *IPCC Guidelines for National Greenhouse Gas Inventories. Vol.4. Agriculture, Forestry and Other Land Use*. Intergovernmental Panel on Climate Change, National Greenhouse Gas Inventories Programme, Institute for Global Environmental Strategies, Kanagawa, Japan. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html.

European Commission, 2005. Report from the Stakeholder Consultation on the Draft Commission Staff Working Document on the Implementation of the EU Forestry Strategy. http://ec.europa.eu/agriculture/consultations/forestry/report_en.pdf [accessed 30/3/2011]

European Commission, 2007. *Green Paper: The European Research Area: new perspectives.* Brussels, Belgium http://ec.europa.eu/research/era/consultation-era_en.html [accessed 30/3/2011]

European Commission, 2007a. Taking European knowledge society seriously. Report of the Expert Group on Science and Governance to the Science, Economy and Society Directorate, Directorate-General for Research, European Commission. Directorate-General for Research, European Communities, Luxembourg.

European Commission, 2007b. Taking European knowledge society seriously. Report of the Expert Group on Science and Governance to the Science, Economy and Society Directorate, ISBN: 978-92-79-04826-5 Directorate-General for Research, European Commission.

European Commission, 2010. Evidence-based policy versus policy-biased evidence: the challenge of feeding scientific advice into policy-making. Conclusions of the High-Level Trans-Atlantic Science for Policy Workshop, October 2009, Ispra, Italy. http://ec.europa.eu/dgs/jrc/downloads/jrc_aaas2010_dialogue_en.pdf. downloaded from website on 3/12/1020

Evans, J.,1992. Ten years of forestry research: an account of the work of the Forestry Research Co-ordination Committee, 1982-1992. Edinburgh, UK: Forestry Commission. ISBN: 0 85538 247 3

Evidence-Based Medicine Working Group, 1992. Evidence-based medicine. A new approach to teaching the practice of medicine. *JAMA - Journal of the American Medical Association* **268** (17), 2420-2425.

FAO, 2003. Enhancing stakeholder participation in national forest programmes. *Proceedings of the second technical meeting of the Community of Practice, 24-25 November 2003, Rome*. http://www.fao.org/DOCREP/MEETING/007/AC922E/AC922E00.htm#TOC [accessed 05/03/2011]

FAO, 2004. Carbon sequestration in dryland soils. *World Soil Resources Reports* No.108.

FAO, 2005. Land Cover Classification System: classification concepts and user manual.

FAO, 2006. Global forest resources assessment 2005: progress towards sustainable forest management. *FAO Forestry Paper* No. 147, 320pp.

Fearnside, P.M., 1996. Amazonian deforestation and global warming: Carbon stocks in vegetation replacing Brazil's Amazon forest. *Forest Ecology & Management* **80**, 21-34.

Fearnside, P.M., Laurance, W.F., 2003. Comment on 'Determination of deforestation rates of the world's humid tropical forests'. *Science* **299**, 1015

Financial Times (London Edition), 1999. (April 3).

Finlayson, W., E.F. Hemmings, B. Biggs, C. Davis, C.A. Elbourn, A.H. Hyde, 1978. Forestry Information Services from Oxford. *Journal of Forestry* **76**(2), 97-99.

Finn, J. L., 1994. The promise of participatory research. *Journal of Progressive Human Services*, **5**(2), 25-42.

Fischer, F., 2003 *Reframing public policy. Discursive politics and deliberative practices*. ISBN: 0-19-924263-1 Oxford, UK: Oxford University Press, Inc.

Foody, G.M., M.E.J. Cutler, 2003. Tree biodiversity in protected and logged Bornean tropical rain forests and its measurement by satellite remote sensing. *J. Biogeogr*. **30**, 1053-1066.

Forest Europe, 2007. Warsaw declaration. Fifth Ministerial Conference on the Protection of Forest in Europe 5-7 November, 2007, Warsaw, Poland.

Forest Service, 2006. *Northern Ireland forestry. a strategy for sustainability and growth.* http://www.forestserviceni.gov.uk/index/publications/policy-and-standards/a-strategy-for-sustainability-and-growth.htm. [accessed 12/2/2009]

Forest-Based Sector Technology Platform (FTP), 2006. *A strategic research agenda for innovation, competitiveness and quality of life. Brussels, Belgium: FTP* http://www.forestplatform.org/index.php?mid=102 [accessed 12/2/2009]

Forestry Commission Scotland, 2006. The Scottish Forestry Strategy. SE/2006/155. Edinburgh, UK: Scottish Executive. http://www.forestry.gov.uk/forestry/INFD-6AGGZW [accessed 12/2/2009]

Forestry Commission Wales, 2009. *Woodlands for Wales. The Welsh Assembly Government's Strategy for Woodlands and Trees.* CMK-22-01-146. ISBN: Number: 978 0 7504 5034 8. http://www.forestry.gov.uk/forestry/INFD-7GDE7A [accessed 12/2/2009]

Forestry Commission, 2005. *Science and innovation strategy for British forestry*. Edinburgh, UK: Forestry Commission. www.forestresearch.gov.uk [accessed 12/2/2009]

Funtowicz, S.O., J.R. Ravetz, 1990. *Uncertainty and quality in science for policy*. Kluwer Academic Publishers, Netherlands. ISBN: 0-7923-0799-2. 229 pp.

Gamborg, C.H., J.A. Parrotta, B.J. Thorsen (Guest Editors), 2004. The forest science/policy interface: building bridges to a sustainable future. *Scandinavian Journal of Forest Research* **19**, (Suppl. No. 4), 1-176.

Gaveau, D.L.A., H. Balzter, S. Plummer, 2003. Forest woody biomass classification with satellite-based radar coherence over 900 000 km^2 in Central Siberia. *Forest Ecology &Management* **174**, 65-75.

Glanville, J.M., C. Lefebvre, J.N.V. Miles, J. Camosso-Stefinovic, 2006. How to identify randomized controlled trials in MEDLINE: ten years on. *J Med Libr Assoc.*, **94** (2),130-136.

Glass, G., 1976. Primary, secondary, metaanalysis of research. *Educational Research* **10**, 3-8.

Goetz, S.J., A. Baccini, N. Laporte, T. Johns, W.S. Walker, J.M. Kellndorfer, R.A. Houghton, M. Sun, 2009. Mapping and monitoring carbon stocks with satellite observations: a comparison of methods. *Carbon Balance and Management* [online journal] doi:10.1186/1750-0680-1184-1182

Grainger, A., 2008. Difficulties in tracking the long-term global trend in tropical forest area. *Proceedings of the National Academy of Sciences of the United States of America* **105,** 818-823.

Grainger, A., M. Obersteiner, 2011. A framework for structuring the global forest monitoring landscape in the REDD+ era. *Environmental Science and Policy* **14** (2), 127-139.

Gray, J. A.M., 2003. *Knowledge is the enemy of disease*. The Health Care Blog. http://thehealthcareblog.com/blog/2008/04/07/knowledge-like-clear-clean-water-muir-gray-on-health-cares-progress/ [accessed 30/3/2011]

Gray, J.A.M. 1997. E*vidence-based healthcare*. New York, USA; London, UK: Churchill Livingstone.

Greenhalgh, T., 2001. *How to read a paper: the basics of evidence based medicine*. 2nd ed. London, UK: British Medical Journal Books.

Greenhalgh, T., B. Hurwitz, 1998. *Narrative based medicine: dialogue and discourse in clinical practice*. London, UK: British Medical Journal Books.

Guardian (London). 1998. (May 20)

Guardian (London). 1999. (May 12)

Guldin, R.W., J.A. Parrotta, E. Hellström, 2005. Working effectively at the interface of forest science and forest policy - guidance for scientists and research organizations. *IUFRO Occasional Paper* No. 17, 29 pp.

Gullison, R.E., P.C. Frumhoff, J.G. Canadell, *et al*., 2007. Tropical forests and climate policy. *Science* **316 (5827)**, 985-986.

Guo, L.B., R.M. Gifford, 2002. Soil carbon stocks and land use change: a meta analysis. *Global Change Biology* **8**, 345-360. doi:10.1046/j.1354-1013.2002.00486.x.

Hammersley, M. 2005. Is the evidence-based practice movement doing more good than harm? reflections on Iain Chalmers' case for research-based policy making and practice. *Evidence & Policy* **1**(1)**,** 85-100.

Hansen, M.C., S.V. Stehman, P.V. Potapov, *et al*. 2008. Humid tropical forest clearing from 2000 to 2005 quantified by using multitemporal and multiresolution remotely sensed data. *Proceedings of the National Academy of Sciences*, **105**(27): 9439-9444. doi: 10.1073/pnas.0804042105

Heclo, H. H. 1972. Policy Analysis. *British Journal of Political Science.* **2** (1), 83-108.

Hewitt, H., 2005. Blog: understanding the information reformation that's changing your world. Nashville, Tenn., USA: T. Nelson Publishers.

Higher Education Funding Council for England, 2009. *Research Excellence Framework: Second consultation on the assessment and funding of research.* HEFCE 2009/38 http://www.hefce.ac.uk/pubs/consult/outcomes/ref2.asp [accessed 5/4/2011]

Hofstad, O., 2005. Review of biomass and volume functions for individual trees and shrubs in Southeast Africa. *J. Trop. for. Sci.* **17**, 151-162.

Hogwood, B. W., L.A. Gunn, 1991 *Policy Analysis for the Real World.* Oxford: ELBS with Oxford University Press.

Holmes, J., J. Savgård, 2009. The planning, management and communication of research to inform environmental policy making and regulation: an empirical study of current practices in Europe. *Sci. Public Policy* **36**, 709-721.

Holmes, J., J. Savgård, 2009. The planning, management and communication of research to inform environmental policy making and regulation: An empirical study of current practices in Europe. *Science and Public Policy* **36**, 709-721.

Holmes, J., R. Clark, 2008. Enhancing the use of science in environmental policy-making and regulation. *Environmental Science & Policy* **11**, 702-711.

Holmgren, P., L.G. Marklund, 2007. National forest monitoring systems: purposes, options and status. In : *Forestry and Climate Change*, Freer-Smith P.H., M.S.J. Broadmeadow, J.M. Lynch (Eds), Wallingford, UK: CAB International, 163-173.

Houghton, R.A. D. Butman, A.G. Bunn, O.N.Krankina, P. Schlesinger, T.A. Stone, 2007. Mapping Russian forest biomass with data from satellites and forest inventories, *Environmental Research Letters* **2** Article number 045032, doi:10.1088/1748-9326/2/4/045032: 7 pp.

Houghton, R.A., 2005. Aboveground forest biomass and the global carbon balance. *Global Change Biol.* **11**, 945-958. doi:10.1111/j.1365-2486.2005.00955.x.

Houghton, R.A., Lawrence, K.T., Hackler, J.L., Brown, S., 2001. The spatial distribution of forest biomass in the Brazilian Amazon: A comparison of estimates. *Global Change Biol*. **7**, 731-746. doi:10.1046/j.1365-2486.2001.00426.x.

Hulme, M., 2010. Split into three panels. In: "IPCC: cherish it, tweak it or scrap it?" Nature 463 (7282): 730-731.

Informal Working Group on Interim Finance for REDD+, 2009. *Discussion Document* http://www.rainforestsos.org/report-of-the-working-group-on-finance-for-redd/ [accessed 29/3/2011]

Innes, J.L., H.F. Hoen, 2005. The changing context of forestry. *IUFRO Research Series No. 11*. Wallingford, UK: CABI Publishing, 1-14.

IPCC, 2006. Guidelines for National Greenhouse Gas Inventories – Volume 4: Agriculture, Land Use and Forestry (GL-AFOLU). Intergovernmental Panel on Climate Change. Institute for Global Environmental Strategies, Kanagawa, Japan. http://www.ipcc-nggip.iges.or.jp/

IPCC, 2007a. IPCC Fourth Assessment Report: Climate Change. Geneva, Switzerland: IPCC.

IPCC, 2007b. Agriculture in Climate change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate

Change. Cambridge, United Kingdom and New York, NY, U.S.A., Cambridge University Press.

Jalkanen, A., Mäkipää, R., Ståhl, G., Lehtonen, A., Petersson, H., 2005. Estimation of the biomass stock of trees in Sweden: comparison of biomass equations and age-dependent biomass expansion factors. *Annals of Forest Science*, **62** (8), 845-851.

Janse, G., 2006 Information search behaviour of European forest policy decision-makers. *Forest Policy & Economics* **8**, 579-592.

Janse, G., 2008. Communication between forest scientists and forest policy-makers in Europe - a survey on both sides of the science/policy interface. *Forest Policy & Economics* **10**, 183-194.

Jasanoff, S., 2003 Technologies of humility: citizen participation in governing science. *Minerva* **41**, 223-244.

Jennett, B. 1992. Health technology assessment. *British Medical Journal* **305,** 67–68.

Joosten, H. J. Couwenberg, 2008. Peatlands and carbon. In: Assessment on peatlands, biodiversity and climate change. Parish, F., A. Sirin, D. Charman, H. Joosten, T. Minaeva, M. Silvius (eds) Global Environment Centre, Kuala Lumpur and Wetlands International Wageningen, pp. 99-117.

Joosten, H. 2009. The Global Peatland CO^2 Picture. Peatland status and emissions in all countries of the World. Wetlands International, Ede

Kaimowitz, D., A. Angelsen, 1998**.** *Economic models of tropical deforestation: a review***.** Jakarta, Indonesia: Center for International Forestry Research (CIFOR), 139pp.

Keeley, J. S., I. Scoones, 1999. Understanding Environmental Policy Processes: a review. *Institute of Development Studies Working Paper*. 89.

Keller, M., M. Palace, G.P. Asner, R. Pereira Jr., J.N.M. Silva, 2004, Coarse woody debris in undisturbed and logged forests in the eastern Brazilian Amazon. *Global Change Biology* **10**, 784-795.

Kleinschmit, D., A. Real, 2009. *Communicating forest science communicating forest science*. Proceedings of the XIII World Forestry Congress, Buenos Aires, 18-23 October, 2009.

Lamoral, D., 2001. An evaluation of information provision at the Institute for Commercial Forestry Research, South Africa: the findings of an information audit. *Journal of Librarianship and Information Science*, **33**(4), 177-190.

Laski, H. 1930. *Harper's Magazine (December*)**,** 101-110.

Latour, B., 1987. *Science in action: how to follow scientists and engineers through society*. ISBN: 0-674-79290-4. Cambridge Mass., USA: Harvard University Press. 288 pp.

Laumonier, Y., A. Edin, M. Kanninen, M. Agung, W. Munandar, 2010. Landscape-scale variation in the structure and biomass of the hill dipterocarp forest of Sumatra: implications for carbon stock assessments. *Forest Ecology and Management* **259** (2010), 505–513.

Lawrence, A., 2008. *Continuous cover forestry: opinion and evidence*. Presentation given at the CCFG workshop on 'Silvicultural Systems for Tomorrow!' in Llanidloes, Wales in October 2008. http://www.forestry.gov.uk/fr/INFD-7KEDYE

Lawson, G.J., G.E. Hemery, 2007. *World timber trade and implementing sustainable forest management in the United Kingdom*. *A report to the Woodland Policy Group*. Exeter, UK: The Land Use Policy Group,

Leach, W.D., 2006. Public involvement in USDA forest service policymaking: a literature review. *Journal of Forestry* **104**, 43-49.

Lee, D. K., 2004. Information networking for new partnerships in forestry. *Journal of Forest Research* **9**(4): 299-305.

Lehtonen, A., E. Cienciala, F. Tatarinov, R. Mäkipää, R. 2007. Uncertainty estimation of biomass expansion factors for Norway spruce in the Czech Republic. *Annals of Forest Science* **64**(2), 133-140.

Lehtonen, A., R. Mäkipää, J. Heikkinen, R. Sievänen, J. Liski, 2004. Biomass expansion factors (BEF) for Scots pine, Norway spruce and birch according to stand age for boreal forests. *Forest Ecology and Management*, **188**, 211-224.

Lu, D., 2006. The potential and challenge of remote sensing-based biomass estimation. *Int. J. Remote Sens.* **27**, 1297-1328.

Mäkipää, R., M. Häkkinen, P. Muukkonen, M. Peltoniemi, 2008. The costs of monitoring changes in forest soil carbon stocks. *Boreal Environment Research* **13** (suppl. B)(1-2), 120.

Malhi, Y., T.R. Baker, O.L. Phillips, *et al*., 2004. The above-ground coarse wood productivity of 104 neotropical forest plots. *Global Change Biol*ogy **10**, 563-591.

Malhi, Y., J. Grace, 2000. Tropical forests and atmospheric carbon dioxide. *Trends Ecol. Evol*. **15**, 332-337.

Malhi, Y., P. Meir, S. Brown, 2002. Forests, carbon and global climate. *Philosophical Transactions A: Mathematical, Physical and Engineering Science* **360** (1797), 1567-1591.

Malhi, Y., T.R. Baker, O.L. Phillips, S. Almeida, E. Alvarez, L. Arroyo, J. Chave, C.I. Czimczik, A. Fiore, N. Higuchi, *et al*., 2004. The above-ground coarse wood productivity of 104 neotropical forest plots. *Global Change Biol*ogy **10**, 563-591.

McDonald, P., J.P. Lassoie, 1996. *The literature of forestry and agroforestry*. Ithaca, USA: Cornell University Press.

Mckibbon, K.A., 1998. Evidence-based practice. *Bulletin of the Medical Library Association* **86** (3), 396-401.

Mendoza, G.A. H. Martins, 2006. Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. *Forest Ecology and Managemen*t **230** (1-3), 1-22.

Merton, R.K., E. Barber, 2004. *The travels and adventures of serendipity: a study in historical semantics and the sociology of science.* Princeton, N.J, USA: Princeton University Press. ISBN: 0-691-11754-3

Morton, S.R., Hoegh-Guldberg, O., Lindenmayer, D.B., *et al*., 2009. The big ecological questions inhibiting effective environmental management in Australia. *Austral Ecology* **34**, 1-9.

Mulrow, C. D. ,1994. Systematic reviews: rationale for systematic reviews. *British Medical Journal* **309**(6954), 597-599.

Nature, 2010. IPCC: cherish it, tweak it or scrap it? Nature **463** (7282): 730-732.

Newig, J., O. Fritsch, 2009. Environmental governance: participatory, multi-level - and effective? *Environmental Policy and Governance* **19**, 197-214.

Nisbet, J., 1905.*The forester*. [2 Volumes] UK: William Blackwood and Sons.

Notess, G.R., 2006. *Review of Google*. In: Search engine showdown: the users' guide to web searching. http://www.searchengineshowdown.com/features/google/index.shtml. [accessed 06/03/2011]

Nutley, S. M., I. Walter, H.T.O. Davies, 2007. *Using evidence: how research can inform public services*. Bristol, UK: Policy Press.

O'Brien, E.A. J.N. Claridge, 2002. Trees are company: social science research into woodlands and the natural environment. In *Proceedings of the Forestry Research Co-ordination Committee Conference convened by Forest Research on 19–20 June 2001 at Glamorgan Building, Cardiff University, Cardiff.* O'Brien, E and Claridge, J. (Eds). Edinburgh, UK: Forestry Commission.

O'Dell, C., J. Grayson, 1998. *If we only knew what we know: Identification and transfer of internal best practices*. New York, USA: The Free Press. ISBN: 0-684-84474-5.

Olander, L.P., H.K. Gibbs, M. Steininger, J.J. Swenson, B.C. Murray, 2008. Reference scenarios for deforestation and forest degradation in support of REDD: a review of data and methods. *Environmental Research Letters* **3** (2) 025011.

Oliver, S., L. Clarke-Jones, R. Rees, R., *et al*., 2004. Involving consumers in research and development agenda setting for the NHS: developing an evidence-based approach. *Health technology assessment (Winchester, England)* No. 8, 1-148, III.

Ordóñez, J.A.B., B.H.J. de Jong, F. Garcia-Oliva, F.L *et al*., 2008, Carbon content in vegetation, litter, and soil under 10 different land-use and land-cover classes in the Central Highlands of Michoacan, Mexico. *Forest Ecology and Management*, **255**, 2074-2084.

Ostertag, R., E. Marín-Spiotta, W.L. Silver, J. Schulten, 2008, Litterfall and decomposition in relation to soil carbon pools along a secondary forest chronosequence in Puerto Rico. *Ecosystems*, **11**, 701-714.

Pagdee, A., Y. Kim, P.J. Daugherty, 2006. What makes community forest management successful: a meta-study from community forests throughout the world. *Soc. Nat. Res***. 19**, 33-52.

Page, S.E., F. Siegert, J.O. Rieley, *et al.*, 2002. The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature* **420**, 61-65.

Palace, M., M. Keller, G.P. Asner, J.N.M. Silva, C. Passos, 2007, Necromass in undisturbed and logged forests in the Brazilian Amazon. *Forest Ecology and Management*, **238**, 309-318.

Parker, C., A. Mitchell, M. Trivedi, N. Mardas, 2009. *The Little REDD+ Book*. http://www.globalcanopy.org/ [accessed 28/3/2011]

Pasiecznik, N.M. , G. Petrokofsky, 2005. *Forestry research in the balance? Trends in the published literature 1939–2005*. Proceedings of the XXII IUFRO World Congress, 8-13 August 2005, Brisbane, Australia.

Patenaude, G., R. Milne, T.P. Dawson, 2005. Synthesis of remote sensing approaches for forest carbon estimation: reporting to the Kyoto Protocol. *Environ. Sci. & Policy* **8**, 161-178.

Peltoniemi, M. et al., 2007. Models in country scale carbon accounting of forest soils. *Silva Fennica* **41**, 575-602.

Peltoniemi, M., T. Palosuo, S. Monni, S., R. Mäkipää, 2006. Factors affecting the uncertainty of sinks and stocks of carbon in Finnish forests soils and vegetation. *Forest Ecology and Management*, **232**, 75-85.

Penman, J., M. Gytarsky, T. Hiraishi. et al. (Eds.), 2003. *Good Practice Guidance for Land Use, Landuse Change, and Forestry*. Intergovernmental Panel on Climate Change, National Greenhouse Gas Inventories Programme, Institute for Global Environmental Strategies, Kanagawa, Japan. www.ipcc-ggip.iges.or.jp/public/gpglulucf/gpglulucf_contents.htm [accessed 30/3/2011]

Petrokofsky, G., G.E. Hemery, N.D. Brown, 2008. Knowledge feeds decision making. The people's say in UK forestry. *Quarterly Journal of Forestry* **102,** 221-225.

Petrokofsky, G., R. Mills, 2009. The role of librarians and information specialists in evidence-based forestry. *Proceedings of CFM 2009, 13th World Forestry Congress, Buenos Aires, Argentina.*

Petrokofsky, G., N.D. Brown, G.E. Hemery, *et al*., 2010. A participatory process for identifying and prioritizing policy-relevant research questions in natural resource management: a case study from the UK forestry sector. *Forestry* **83**, 357-367.

Petticrew, M., 2001. Systematic reviews from astronomy to zoology: myths , misconceptions. *British Medical Journal* 322(7278), 98-101.

Petticrew M., H. Roberts, 2006. *Systematic reviews in the social sciences: a practical guide*. Blackwell Publishing, Oxford, UK. 336 pp.

Pickering, G. W. ,1956. The purpose of medical information. *British Medical Journal* **2**, 113.

Pielke, R.A.,Jr., 2007. *The honest broker: making sense of science in policy and politics.* Cambridge, UK: Cambridge University Press. ISBN: 978-0-521-87320-8. 198 pp.

Pouyat, R.V., K.C. Weathers, R. Hauber, A. Lovett, *et al*., 2010. The role of federal agencies in the application of scientific knowledge. *Frontiers in Ecology and the Environment* **8**, 322-328.

Price, C., 2000 Valuation of unpriced products: contingent valuation, cost-benefit analysis and participatory democracy. *Land Use Policy* **17,** 187-196.

Pullin, A.S., T.M. Knight, 2003. Support for decision making in conservation practice: An evidence-based approach. *Journal for Nature Conservation* **11**(2), 83-90.

Pullin, A.S., T.M. Knight, 2009. Doing more good than harm - building an evidence-base for conservation , environmental management. *Biological Conservation*, **142** (5): 931-934.

Pullin, A. S., T. M. Knight, D. A. Stone, K. Charman, 2004. Do conservation managers use scientific evidence to support their decision-making? *Biological Conservation* **119**(2), 245-252.

Ramankutty, N., H.K. Gibbs, F. Achard, F., R. De Fries, J.A. Foley, R.A. Houghton, 2007. Challenges to estimating carbon emissions from tropical deforestation. *Global Change Biology* **13**, 51-66.

Ranneby, B., T. Cruse, B. Hägglund, H. Jonasson, J. Swärd, 1987. Designing a new national forest survey for Sweden. *Studia Forestalia Suecica No.177*.

Ravetz, J., 1987. Usable knowledge, usable ignorance: incomplete science with policy implications. *Knowledge* **9**, 87-116

Rayner, S., 2003 Democracy in the age of assessment: Reflections on the roles of expertise and democracy in public-sector decision making. *Sci. Public Policy* **30,** 163-170.

Rice, A.H., E.H. Pyle, S.R. Saleska, *et al.*, 2004, Carbon balance and vegetation dynamics in an old-growth Amazonian forest. *Ecological Applications*, **14**

Roberts, P.D., A.S. Pullin, 2008. The effectiveness of management interventions for the control of *Spartina* species: a systematic review and meta-analysis. *Aquatic Conservation: Marine and Freshwater Ecosystems* **18**, 592-618.

Rogers, E.M., 1962. *Diffusion of Innovations*. Glencoe, UK: Free Press.

Rose, D., P. Fleischman, T. Wykes, 2008. What are mental health service users' priorities for research in the UK? *Journal of Mental Health* **17**, 520-530.

Rosenberg, W., A. Donald, 1995. Evidence based medicine: an approach to clinical problem-solving. *British Medical Journal* **310** (6987): 1122-1126.

Rosenqvist, Å., A. Milne, R. Lucas, M. Imhoff, C. Dobson, 2003. A review of remote sensing technology in support of the Kyoto Protocol. *Environ. Sci. Policy* **6**, 441-455.

Rudel, T. K.; K. Flesher, D. Bates, S. Baptista, P. Holmgren, 2000. Tropical deforestation literature: geographical and historical patterns. *Unasylva* (*English ed*.) **51** (203), 11-18.

Rudel, T.K., 2007. Changing agents of deforestation: From state-initiated to enterprise driven processes, 1970-2000. *Land Use Policy,* **24** (1), 35-41.

Rudel, T.K., 2008. Meta-analyses of case studies: A method for studying regional and global environmental change. *Global Environmental Change-Human and Policy Dimensions,* **18**(1), 18-25.

Rudel, T.K., K. Flesher, D. Bates, S. Baptista, 2000. Tropical deforestation literature: geographical and historical patterns in the availability of information and the analysis of causes. *FAO Forest Resources Assessment Programme Working Paper No. 27.*

Saatchi, S., R.A. Houghton, R.C. dos Santos Alvalá, J.V. Soares, Y. Yu, 2007. Distribution of aboveground live biomass in the Amazon basin. *Global Change Biol*ogy **13**, 816-837.

Sackett, D. L., W.M.C. Rosenberg, J.A.M. Gray, R.B. Haynes, W.S. Richardson, 1996. Evidence based medicine: what it is and what it isn't. It's about integrating individual clinical expertise and the best external evidence. *British Medical Journal* **312**(7023), 71-72.

Sales, M.H., C.M. Souza Júnior, P.C. Kyriakidis, D.A. Roberts, E. Vidal, 2007. Improving spatial distribution estimation of forest biomass with geostatistics: a case study for Rondônia, *Brazil. Ecol. Model*. **205**, 221-230.

Santilli, M.; P. Moutinho, S. Schwartzman, D. Nepstad, L. Curran, C. Nobre, 2005. Tropical deforestation and the Kyoto Protocol. *Climate Change* **71** (3), 267-276.

Sayer, J. A., B.M. Campbell, 2004. *The science of sustainable development. Local livelihoods and the global environment*. Cambridge, UK: Cambridge University Press.

Scatena, F.N., W. Silver, T. Siccama, A. Johnson, M.J. Sanchez, 1993. Biomass and nutrient content of the Bisley experimental watersheds, Luquillo Experimental Forest, Puerto Rico, before and after Hurricane Hugo, 1989. *Biotropica* **25**, 15-27.

Schuck, A., *et al*., 2007. Towards a European Forest Information System. *European Forest Institute Research Report* No. 20. Leiden: Brill, ISBN: 978 90 0416150 4.

Schumacher, D. , L.A. Tyler, 2007. *Embedded library services: an initial inquiry into practices for their development, management, and delivery*. A contributed paper for the Special Libraries Association Annual Conference, Denver, Colorado, June 6, 2007. http://www.sla.org/pdfs/sla2007/ShumakerEmbeddedLibSvcs.pdf

SCONUL. 2009. A*nnual Statistics*. London, UK: SCONUL. http://www.lboro.ac.uk/departments/ls/lisu/lampost.html

Segura, M., M. Kanninen, 2005. Allometric models for tree volume and total aboveground biomass in a tropical humid forest in Costa Rica. *Biotropica* **37**, 2-8.

Seppälä, R. 2006. Global trends and issues in the forest sector and challenges to forest research. *Allg.Forst- Jagdztg*. **177**(8-9)**,** 138-141.

Smith, J. E., L.S. Heath, J.C. Jenkins, 2003. Forest volume-to-biomass models and estimates of mass for live and standing dead trees of U.S. forests. *General Technical Report NE-298*, USDA Forest Service, Northeastern Research Station.

Stern, N., Cabinet Office, HM Treasury, 2006. The *economics of climate change: the Stern review*. Cambridge, UK: Cambridge University Press. ISBN: 9780521700801 712 pp.

Straus, S. E., F.A. McAlister, 2000. Evidence-based medicine: a commentary on common criticisms. *CMAJ* **163** (7), 837-841.

Straus, S.E., 2005. *Evidence-based medicine: how to practice and teach EBM*. 3rd ed. Edinburgh, UK: Elsevier/Churchill Livingstone.

Sutherland, W. J., A. S. Pullin, P. M. Dolman, T. M. Knight, 2004. The need for evidence-based conservation. *Trends in Ecology and Evolution* **19**(6), 305-308.

Sutherland, W.J., S. Armstrong-Brown, P.R. Armsworth, *et al*., 2006. The identification of 100 ecological questions of high policy relevance in the UK. *Journal of Applied Ecology* **43**, 617-627.

Sutherland, W.J. and Woodroof, H.J. 2009. The need for environmental horizon scanning. *Trends in Ecology and Evolution* **24**, 523-527.

Sutherland, W.J., M. Clout, I.M. Côté, P. *et al*., 2010. A horizon scan of global conservation issues for 2010. *Trends in Ecology and Evolution* **25**, 1-7

Sutherland, W.J., W.M. Adams, R.B. Aronson, *et al*., 2009. One hundred questions of importance to the conservation of global biological diversity. *Conservation Biology* **23**, 557-567.

Swinkels, A., J. Briddon, J. Hall, 2006. Two physiotherapists, one librarian and a systematic literature review: collaboration in action. *Health Information and Libraries Journal* **23**, 248–256.

Taylor, M., 2005. Bridging research and policy: a UK perspective. *Journal of International Development* **17**, 747-757.

Ter-Mikaelian, M. T., M.D. Korzukhin, 1997. Biomass equations for sixty-five North American tree species. *Forest Ecology and Management*, **97**(1), 1-24.

The Herald (Glasgow). 1999. (April 14)

The Herald (Glasgow). 2002. (December 19)

The Herald (Glasgow). 2004. (March 19)

The Independent (London). 1998. (October 29)

Tuomi, M., T. Thum, H. Jarvinen, *et al*., 2009, Leaf litter decomposition-Estimates of global variability based on Yasso07 model. *Ecological Modelling*, **220**, 3362-3371.

Turner, H.M., III, C. Nye, 2007. The Campbell Collaboration: systematic reviews and implications for evidence-based practice. *Focus Technical Brief, National Center for the Dissemination of Disability Research (NCDDR). No. 16.* NCDDR, Austin, Texas, USA.

United Nations Framework Convention On Climate Change (UNFCCC), 2007. *Report of the Conference of the Parties on its thirteenth session, held in Bali from 3 to 15 December 2007. Addendum Part Two: Action taken by the Conference of the Parties at its thirteenth session.* FCCC/CP/2007/6/Add.1. 14 March 2008. http://unfccc.int/resource/docs/2007/cop13/eng/06a01.pdf#page=3

UN-REDD Programme, 2011a. *Report of the sixth Policy Board Meeting*, 21-22 March 2011, Da Lat, Viet Nam http://www.unredd.net/index.php?option=com_docman&task=cat_view&gid=1005&Itemid=53 [accessed 21/4/2011]

UN-REDD Programme, 2011b. *Support to National REDD+ Action - Global Programme Framework 2011-2015, submitted to the sixth Policy Board Meeting, 21-22 March 2011, Da Lat, Viet Nam* UNREDD/PB6/2011/IV/2. http://www.un-redd.org/PolicyBoard/ 6thPolicyBoard/ tabid/6893/Default.aspx [accessed 21/4/2011]

Van der Werf, G. R., D. C. Morton, R. S. De Fries, *et al*., 2009. CO2 emissions from forest loss. *Nature Geoscience* **2**:737-738.

Van der Werf, G.R., Dempewolf, J., Trigg, S.N. *et al*., 2008. Climate regulation of fire emissions and deforestation in equatorial Asia. *Proceedings of National Academy of Sciences USA*, **105**, 20350–20355.

Van Herzele, A., K. Collins, L. Tyrväinen, 2005. involving people in urban forestry — a discussion of participatory practices throughout Europe. In: *Urban Forests and Trees, a reference*. Konijnendijk, C.C., K. Nilsson, T.B. Randrup, J. Schipperijn, (Eds.) Springer. ISBN: 978-3-540-25126-2 . 207-228.

Vieira, S.A., L.F. Alves, M. Aidar, *et al*., 2008. Estimation of biomass and carbon stocks: The case of the Atlantic Forest. *Biota Neotropica* **8**, 21-29.

Whitmarsh, L., S. Kean, C. Russell, M. Peacock, R. Hatala, 2005. *Connecting science: what we know and what we don't know about science in society*. London, UK: British Association for the Advancement of Science. http://www.britishscienceassociation.org. [accessed 30/2/2011]

Wieder, R.K., K.D. Scott, K. Kamminga, *et al*., 2009. Postfire carbon balance in boreal bogs of Alberta, Canada. *Global Change Biology*, **15**, 63-81.

Williams, M.S., H.T. Schreuder, 2000. Guidelines for choosing volume equations in the presence of measurement error in height. *Canadian Journal of Forest Research*, **30**, 306-310.

Wilsdon, J., R. Willis, 2004. *See-through science. Why public engagement needs to move upstream.* London, UK: Demos. ISBN: 0-84180130-5.

Wirth, C., J. Schumacher, E. D. Schulze, 2004. Generic biomass functions for Norway spruce in Central Europe—a meta-analysis approach toward prediction and uncertainty estimation. *Tree Physiology*, **24**(2), 121-139.

Wolf, K.L., L.E. Kruger, 2010. Urban forestry research needs: a participatory assessment process. *Journal of Forestry* **108**, 39-44.

World Health Organization, 2009. *Report of the International Public Health Symposium on Environment and Health Research Science for Policy, Policy for Science: Bridging the Gap. Madrid, Spain, 20–22 October 200*8, 1-28.

Wutzler, T., M. Reichstein, 2007. Soils apart from equilibrium; consequences for soil carbon balance modelling. *Biogeosciences*, **4**, 125-136.

Wutzler, T., C. Wirth, J. Schumacher, 2008. Generic biomass functions for Common beech (Fagus sylvatica) in Central Europe: predictions and components of uncertainty. *Canadian Journal of Forest Research*, **38** (6), 1661-1675.

Wynne, B., 2006. Public engagement as a means of restoring public trust in science – hitting the notes, but missing the music? *Community Genetics* **9,** 211–220.

Yeluripati, J. B., M. van Oijen, M. Wattenbach, *et al*., 2009. Bayesian calibration as a tool for initialising the carbon pools of dynamic soil models. *Soil Biology and Biochemistry***, 41**, 2579-2583.

Zianis, D., 2008. Predicting mean aboveground forest biomass and its associated variance. *Forest Ecology and Management*, **256**, 1400-1407.

Zianis, D., P. Muukkonen, R. Mäkipää, M. Mencuccini, 2005. Biomass and stem volume equations for tree species in Europe, *Silva Fennica Monographs*, **4**, 1-63.

Zimmermann, M., J. Leifeld, M. W. I. Schmidt, P. Smith, and J. Fuhrer., 2007. Measured soil organic matter fractions can be related to pools in the RothC model. *European Journal of Soil Science*, **58**, 658-667.

Zorita, E., 2010. *Independent agency needed*. In: IPCC: cherish it, tweak it or scrap it? *Nature*, **463** (7282), 731.

List of Acronyms used in the thesis

AFOLU	Agriculture, Forestry and Land Use
AGB	Above-ground biomass
CABI	CAB International (formerly Commonwealth Agricultural Bureaux)
CEE	Collaboration for Environmental Evidence
CRD	Centre for Reviews and Dissemination
DBH	Diameter at Breast Height
Defra	Department for Environment, Food and Rural Affairs
EBM	Evidence-based medicine
EBP	Evidence-based practice
EC	European Commission
ERFF	Environment Research Funders' Forum
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
FC	Forestry Commission
FRCC	Forestry Research Coordination Committee
GHG	Greenhouse gasses
GIS	Global Information Systems
GOFC-GOLD	Global Observation of Forest and Land Cover Dynamics
IPCC	Intergovernmental Panel on Climate Change
IPF	Intergovernmental Panel on Forests
IUFRO	International Union of Forest Research Organizations
JISC	Joint Information Systems Committee
MARV	Measurement, Assessment, Reporting and Verification
MRV	Measurement, Reporting and Verification
MCPFE	Ministerial Conference on the Protection of Forests in Europe
MEDLINE	Medical Literature Analysis and Retrieval System Online
MESH	Medical Subject Headings
NFP	National Forest Programmes
NGO	Non-governmental Organization
OECD	Organisation for Economic Co-operation and Development
REDD	Reducing Emissions from Deforestation and Forest Degradation
T10Q	Top Ten Questions for Forestry
TSC	Trials Search Co-ordinator
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WoK	Web of Knowledge

WoS	Web of Science

Statement of authorship for multi-authored papers in chapter 5

From: Nick Brown [mailto:nick.brown@linacre.ox.ac.uk]
Sent: 09 February 2011 15:21
To: Holmgren, Peter (NRC)
Cc: Gill Petrokofsky
Subject: RE: Thesis

Dear Peter,

Many thanks for your assistance with this formal requirement of the Oxford DPhil thesis examination process. I very much enjoyed working with you on our co-authored paper.

Best wishes,

Nick

From: Holmgren, Peter (NRC) [mailto:Peter.Holmgren@fao.org]
Sent: 09 February 2011 14:13
To: 'Nick Brown'
Cc: 'Gill Petrokofsky'
Subject: FW: Thesis

Dear Nick,

Gill asked me to review the attached author contributions text for her thesis. Besides the recently changed name of my division (see amendment in attached), I agree with and confirm the statements from my side.

Best regards,,

Peter Holmgren

Peter Holmgren
Director
Climate, Energy and Tenure Division
Natural Resources Management and Environment Department
Food and Agriculture Organization of the United Nations (FAO)
Rome, Italy

Chapter 5 Section A **Reliable forest carbon monitoring - applying a participatory evidence-based framework to validate the knowledge base. A case study of the systematic review process for a current policy issue.** [Petrokofsky, G., P. Holmgren[1], N.D. Brown[2], 2011 International Forestry Review Vol.13(1)]

I suggested the paper, devised its structure and content and wrote it.

Author contributions:

1. Peter Holmgren is Director of the Climate, Energy and Tenure Division of the Food & Agriculture Organisation of the United Nations. He devised the framework for analysing carbon in forests and contributed insights from international initiatives in addition to valuable feedback on the drafts.
2. Nick Brown is Principal of Linacre College and University Lecturer in Forestry in the Department of Plant Sciences. He helped shape the structure of the paper and provided valuable feedback during the drafting stages.

Chapter 5 Section B: **Comparison of methods for measuring and assessing carbon stocks and carbon stock changes in terrestrial carbon pools. Protocol**. Collaboration for Environmental Evidence (CEE) Systematic Review No. 09-016 (previously SR77) Authors: Scott Goetz[1] (Woods Hole Research Center), Frédéric Achard[2] (Joint Research Centre for the European Commission), Hans Joosten[3] (Greifswald University), Hideki Kanamaru[4](FAO), Aleksi Lehtonen[5] (Finnish Forest Research Institute), Mary Menton[6] (Center for International Forestry Research), Gillian Petrokofsky (University of Oxford), Andrew Pullin[7] (Bangor University), Martin Wattenbach[8] (Freie Universität Berlin)

I devised the systematic review project during extensive discussions with Peter Holmgren, who is providing Overall project leadership. I wrote the Protocol and co-ordinated amendments to it, following peer review, which have not been extensive. Protocols for the CEE follow a strict set of procedures, including naming the lead systematic review author as the principal author of the Protocol, as an aid to clarity. I consider that I am responsible for most of the content of the document, which is also shaping the final review (work in progress).

Author contributions:

1. Scott Goetz is Senior Scientist at the Woods Hole Research Center. He is acting as Lead author for the systematic review, which is progressing according to the steps laid out in the Protocol.
2. Frédéric Achard works at the Joint Research Centre of the European Commission. He provided feedback on aspect of remote sensing in forest.
3. Hans Joosten is a Professor at Greiswald University, Germany. He provided feedback and inputs on soil and peatlands.
4. Hideki Kanamaru works in the Natural Resources Management and Environment Department, FAO. He was principal contact for FAO personnel during the first phase of the project, and is now coordinating the systematic review.
5. Aleksi Lehtonen, works at the Finnish Forest Research Institute. He provided feedback on issues related to gas exchange and biomass assessment in forest.
6. Mary Menton now works at the Center for International Forestry Research in Peru, and was formerly a researcher in the University of Oxford. She provided feedback on deadwood and fire in forest, and on biomass assessment in forest generally.
7. Andrew Pullin is a Professor at the Centre for Evidence-Based Conservation, Bangor University, UK. He provided guidance on standards for systematic review and protocol development.
8. Martin Wattenbach now works at the Freie Universität Berlin, and was formerly a researcher in the University of Aberdeen, UK. He provided feedback and input on carbon assessment in soil and agricultural land.