A Bibliographic Review of the Climate Change Adaptation Literature

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Abstract: This report attempts to develop a general, accessible doorway into climate change adaptation (CCA) literature which is indifferent to one's starting position and evolves with one's knowledge base. It is intended to provide an understanding of the major issues associated with the field, as well as tools to access its informational resources. This is accomplished in two parts: first, a rough overview of the IPCC AR4 Synthesis report is provided to introduce the reader to the major CCA topics; and second, a framework for organising the CCA information landscape is provided to aid researchers in keeping abreast of emerging trends. A broad overview of the CCA field is then presented along with a discussion of methodological issues, and options for further research.

Keywords: climate, climate change, adaptation, bibliometrics, literature review

1. Introduction

Newcomers to the science and policy of climate change[1] are immediately confronted by a field of study which has grown to include almost every aspect of human endeavour[2]. A simple web search quickly confirms just how expansive this landscape has become (e.g. a Google™ search on the key words "climate change," resulted in 101 million sites, and 1.67 million sites for "climate change adaptation" Oct. 16, 2007). Unfortunately, this information is unstructured and extremely difficult to navigate despite the best hopes of visionaries[3]. Even from within the formal environment of peer reviewed academic journals[4], researchers face a daunting task of staying informed and disseminating results not only to the public and policy makers, but amongst themselves as well (Bord *et al.,* 1999; Farbotko, 2005; Wall and Smit, 2006). The purpose of this report therefore, is to find a general, accessible doorway

1 The author includes himself in this group.

2 Even Formula 1 racing, is becoming conscious of the need to respond to the challenges of climate change. (**http://www.formula1.com/news/interviews/2007/5/6174.html, Accessed October 20, 2007**)

3 For example see the discussion of the future of the internet (Web 3.0) (Borland 2007; Tossell 2007).

4 Which some place at over 40,000 active peer-reviewed academic publications **http://www.libraryjournal.com/article/CA374956.html** (accessed October 20th, 2007)

into climate change adaptation (CCA) research, which is indifferent to one's starting position and evolves with one's knowledge base.

Numerous information sources and media formats exist to disseminate information regarding 'climate change' (CC), each with its own particular advantages and disadvantages. Aside from the web, the most obvious access points into this knowledge landscape are book length introductions\reviews (Weart, 2003; Coward and Weaver, 2004; Fagan, 2004; Flannery, 2005; McGuffie and Henderson-Sellers, 2005; Beerling, 2007; Strom, 2007; Cohen, 2007). While this is likely the best place to establish a foundation, this medium nevertheless has its limitations: books present subject matter that may be dated, they can be overly verbose given their content, and author bias may be over-stated given the lack of formal peer review (i.e. for example, see the work of Lomborg (2007) in the context of reviewers (Dasgupta, 2007; Mitchell, 2007). At the other end of the spectrum, the news media is a relatively immediate source of information, but is often fickle in terms of subject matter, shallow in terms of content, and has the potential to be systematically biased despite an implicit policy of 'balanced' reporting (Boykoff and Boykoff, 2004; Boykoff, 2007; Ward, 2007).

Proceeding through these various informational sources haphazardly (i.e. from books, to the web, to magazines, to research papers, to reports, etc.) is often the only way researchers can manage their information portfolios. For most scientists a periodic, all-inclusive overview of their chosen field and its effects upon human endeavour is simple fantasy. For climate change researchers though, this is precisely what happens. The 'Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)' was released in 2007. It is composed of three reports: a) The Physical Science Basis: Working Group I (IPCC, 2007); b) Impacts, Adaptation and Vulnerability: Working Group II (IPCC, 2007) which is the focus of this survey; and c) Mitigation of Climate Change: Working Group III (IPCC, 2007), and a Synthesis report (IPCC, 2007) which condenses results from the three working reports. Together this work is considered to be the most comprehensive and balanced assessment of climate change available.

The IPCC[5] was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) as a response to the problems accompanying global climate change. Its mandate is to collect and assess

5 Information regarding the IPCC can be found at their web page **http://www.ipcc.ch/about/about.htm** (accessed October 20, 2007).

scientific, technical and socio-economic information relevant for the understanding of climate change, and its potential impacts and options for adaptation and mitigation. It does not carry out research itself, but bases its assessments on peer reviewed and published scientific/technical literature. Its reports (released in 1990, 1997, 2001 and 2007) have been critical for informing climate change policy negotiations, directing research programs and agendas, and providing methodological input for developing mitigation and adaptation strategies.

In no other field has so encompassing a series of reviews been produced, making this the obvious starting point for informing oneself of climate change and a yardstick for any future research. Nevertheless, it is important to understand the manner in which these reports are created so as to recognise their limitations. Although the IPCC collects its information from peer reviewed journals, its' reports require consensus among members, which include government representatives. It has been suggested that this creates a conservative bias in IPCC reporting, as governments can unduly influence the process (Homer-Dixon, 2007). Additionally, the review process may also be open to bias given its' inherent methodological and structural preconceptions, which have historically favoured the physical over the social sciences (Cohen, Demeritt *et al.,* 1997). Finally, the process is a complex and cumbersome endeavour, the product of numerous authors, enormous datasets and thousands of reviewed articles. Not surprisingly, the reports are somewhat disjointed, and the reviewed literature dated (Homer-Dixon, 2007).

Despite such criticisms, no one would deny that the IPCC has been remarkably successful in raising awareness of the impacts of climate change and the potential for human response[6]. 'CCA for Neophytes' is not meant to compete with the IPCC AR4, but rather to complement it by providing new CCA researchers with an understanding of the major issues associated with the field, as well as tools to access its informational resources. This is accomplished in two parts: first, a rough overview of the AR4 Synthesis report is provided to inform the reader of the larger issues within the field at the time of AR4 publishing (Section 2.0); and second, a framework for managing one's access to the CCA information landscape is provided to keep researchers abreast of emerging issues (Section 3.0). In a sense we provide a snapshot

6 The IPCC received the Nobel Peace Prize in 2007: **http://nobelprize.org** in 2007.

of the CCA field from a given perspective (i.e. the IPCC AR4), and then provide an efficient means of critically evaluating that snapshot from alternate perspectives to reveal enduring and emerging trends.

2. Synthesis of the IPCC AR4 Synthesis

From a neophyte's perspective, the advantages of the IPCC reports are that they bring the lion's share of relevant climate change information together in one accessible location, they describe how the science has changed since the last report, and they provide a roadmap of where the field may go in the future. Before the release of each of the working groups' reports (i.e. WG I (IPCC, 2007), WGII (IPCC, 2007) and WGIII (IPCC, 2007) reports), a Summary for Policy Makers is released, which highlights the key findings of the individual working groups. Once all the reports have been released, a final synthesis report (IPCC, 2007) is published which brings all the information from the working groups together in an integrated fashion.

The Synthesis report delivers the 'big messages' of the IPCC review process and is composed of five major headings: the first section presents empirical evidence which supports the notion that human-induced climate change has actually occurred. The second section describes theory/modeling that explains how human behaviour has affected the atmosphere leading to a changing climate. Section three discusses potential impacts given various future possibilities, while section four describes ways of intentionally altering those possibilities through adaptation and/or mitigation. Finally section five discusses long term projections. Unfortunately, the reports taken together represent a large amount of information which can appear somewhat overwhelming if 'climate change' is not your primary research focus. The following is a brief overview of the key issues reported by the IPCC AR4 Synthesis, and is not meant to replace the reports, but rather give a flavour of what might be found there.

TOPIC 1 - Observed changes: The findings in Topic 1 describe empirical evidence (as opposed to modeling projections) in support of the contention that climate change has occurred. It recognises that atmospheric modeling is insufficient to establish the fact of global warming (McGuffie and Henderson-Sellers, 2005) and that projections of climate change must be verified (Weart, 2003). It employs strong wording, stating that the warming of the climate system is 'unequivocal.' Evidence includes an increase in global average temperatures (i.e. eleven of the last twelve years are among the warmest on record), an increase in observations of ocean temperatures, increased observations of rising precipitation levels in specific regions, as well as the widespread melting of snow and ice (i.e. arctic sea ice has shrunk by 2.7 % per decade) and rising global sea levels.

The report further states that specific systems are responding as expected (according to theory) in the face of global warming. For instance, the number and size of glacial lakes has increased, as has ground instability in mountainous and other permafrost regions. Hydrological systems have responded to warming with increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers. The warming temperatures have also affected the thermal structure and water quality of rivers and lakes. More specifically, evidence from over 29,000 observational data series of physical and biological systems are consistent (89% of the time) with the direction of change expected with climatic warming. These changes include: earlier timing of terrestrial spring events and poleward (upward) shifts in plant and animal ranges; shifts in ranges and changes in algal, plankton and fish abundance in marine and fresh water ecosystems; changes in ice cover, salinity, oxygen levels and circulation.

As well, changes in human environments are consistent with global warming (although this is confounded by additional factors). Examples drawn from agricultural and forestry management at Northern Hemisphere higher latitudes, include earlier spring planting, and alterations in disturbance regimes of forests due to fires and pests. Human health has also been affected by climatic changes, including: heat-related mortality in Europe; changes in infectious disease vectors in some areas; and allergenic pollen in Northern Hemisphere high and mid-latitudes. And human activities in the Arctic (e.g. hunting and travel over snow and ice) and in lower-elevation alpine areas (such as mountain sports) have been affected as well.

TOPIC 2 – Causes of change: This section of the report deals with the current scientific understanding of the causes of human-induced climate change. Determining the significance of issues raised within this section can be challenging if the reader is unfamiliar with the underlying theories of atmosphere weather and climate, and the current debates within that literature. Nevertheless, a number of primers can provide sufficient background to follow the discussion, including: popular accounts of atmospheric processes (Flannery, 2005; Cohen, 2007), introductory texts on atmospheric science (Barry and Chorley, 2003), or more specific reviews of the development (Weart, 2003) and technical aspects of climate modeling (McGuffie and Henderson-Sellers, 2005).

The section starts with the basic presumption that atmospheric concentrations in green gases (GHG), aerosols, land-cover and solar radiation have the affect of altering the energy balance of the climate system. The relative extent of these various drivers of the climate is established by first determining the historical changes in these various components of the climate systems: global human GHG emission increases of 70% between 1970 and 2004; concentrations of CO_2, methane (CH_4) and nitrous oxide (N_2O) have increased markedly since 1750; and concentrations of CO_2 and CH_4 in 2005 far in excess of the natural range over the last 650,000 years. CO_2 increases are primarily due to fossil fuel use, while CH_4 increases are predominantly due to agriculture and fossil fuel use.

Given these anthropogenic trends, the challenge for climate modellers has been to show the relative affect of these drivers upon the climate, in contrast to natural drivers. According to the literature, over the past 50 years, the sum of solar and volcanic forcings would likely have produced cooling, not warming. Additionally, increases in GHGs tend to warm the surface while the net effect of increases in aerosols tends to cool it. But the net effect due to human activities since the pre-industrial era is one of warming (+1.6 [+0.6 to +2.4]W/m^2), while solar irradiance are estimated to have caused only a small warming effect (+0.12 [+0.06 to +0.30]W/m^2). It is therefore concluded that the net effect of human activities since 1750 has been one of warming, changes in wind patterns, altered precipitation patterns and changes is extreme events.

TOPIC 3 – Climate change & impacts under different scenarios: The purpose of this section is to report on the projected impacts of human-induced climate change. As such, it represents one of the most critical sections of the IPCC reports given its direct relevance to decision and policy making. To determine these impacts, a number of subtleties associated with predicative modeling have to be taken into account. In an ideal sense, a single integrated model, itself the product of a thorough understanding of both natural and socio-economic systems, would produce a series of possibilities from which an optimal pathway for human agency could be determined. This perfect ideal would take into account all interactions and feedbacks between the natural and socio-economic systems, as well as value assessments of various outcomes.

In reality natural and socio-economic models are composed of numerous sub-systems, each of which is inherently incomplete, and typically modeled in isolation despite important feedbacks among systems. Results are produced by various research groups, each with their own competing theories and accompanying methodologies, as well as their own unique sets of initial and future input conditions. The more complex models are computationally heavy in the sense that they take large amounts of time and resources to run, implying that they can only perform a limited series of runs or simulations. Hence the ideal of optimality is typically abandoned in favour of producing a series of likely or contrasting scenarios for consideration. The problem for the IPCC has been the lack of consistency among the scenarios used by various research teams.

In the past modellers had used a range of emission scenarios as GCM inputs to examine the impacts of elevated GHGs (e.g. doubling of CO_2). Aside from the lack of consistency, this was not very revealing in terms of the conditions that would have produced a doubling of CO_2 in the first place, nor did it take into account the inherent circularity of the problem (i.e. humans affect the environment which in turn affects humans, etc.). Actual prediction of future anthropogenic GHG emissions would require consideration of very complex, ill-understood dynamic systems, driven by forces such as population growth, socio-economic development, technological progress (IPCC, 2001), and of course climate. Not only is such prediction impossible, but there are an infinite number of alternative futures to explore given the ranges of future emissions and driving forces (IPCC, 2001).

The solution has been to effectively freeze the relationship between the climate and society into plausible storylines by developing a standard set of alternative GHG emissions scenarios to analyze long-range developments of the socio-economic system and corresponding emission sources. SRES refers to these scenarios as described in the IPCC Special Report on Emission Scenarios (IPCC, 2000). Scenarios cover a wide range of the driving forces of future emissions, including demographics, land use change, technology, economy, energy, and agriculture. They encompass different future developments that might influence greenhouse gas (GHG) sources and sinks, such as alternative structures of energy systems and land-use changes. They do not address any future policy considerations (e.g. mitigation or adaptation) nor are they meant to infer policy preferences, or even suggest a business-as-usual scenario. They are based on an 'internally consistent and reproducible' set of assumptions about the key relationships and driving forces of change, derived from an understanding of history and the current situation (IPCC, 2001).

Using this framework as a foundation, projected impacts of the individual scenarios were gleaned from the literature. Some of the results suggest that across the entire range of SRES emissions scenarios we can expect a minimum warming of about 0.2°C per decade. In other words, without any active mitigative action, we are committed to climate warming. The report goes on to list the actual range of climate impacts for each of the SRES scenarios (e.g. in tabular and graphic form Figure SPM-5 and Table SPM.1). These ranges are consistent with the previous IPCC report (TAR), but upper ranges are larger due to the inclusion of stronger climate-carbon cycle feedbacks in some models (e.g. warming will reduce terrestrial and ocean uptake of atmospheric CO_2, increasing the fraction of anthropogenic emissions remaining in the atmosphere).

In terms of climatic changes warming will be greatest over land and most high northern latitudes. It will be least over the Southern Ocean and parts of the North Atlantic Ocean. The contraction in snow cover area will continue, including increases in thaw depth over most permafrost regions, and decrease in sea ice extent. Arctic late-summer sea ice may disappear almost entirely by the latter part of the 21st century. In other regions, there is a very likely increase in frequency of hot extremes, heat waves, and heavy precipitation. A likely increase in tropical cyclone intensity and a poleward shift of extra-tropical storm tracks. Precipitation is very likely to increase in high latitudes and likely decrease in most subtropical land regions, continuing observed recent trends. As such, annual river runoff and water availability are projected to increase at high latitudes (and in some tropical wet areas) and decrease in some dry regions in the mid-latitudes and tropics. Many semi-arid areas (e.g. Mediterranean basin, western United States, southern Africa and northeast Brazil) will suffer a decrease in water resources due to climate change.

Critical impacts are listed in tabular form for regions (Table SPM.2) and sectors (SPM.3). Table SPM.7 illustrates impacts to systems and sectors over an increasing global temperature, superimposed over the likelihood of those temperature increases under the different SRES scenarios. More specifically terrestrial ecosystems such as the tundra, boreal forest and mountain regions are likely to be affected by climate change, as are Mediterranean-type ecosystems and tropical rainforests. Coastal systems including mangroves and salt marshes, and marine systems including coral reefs, and sea ice are to be affected as well. In terms of human systems, agriculturalists in low-latitudes areas, and those who inhabit low-lying coastal systems (i.e. threat of sea level rise and increased risk from extreme weather events) are to be severely affected. Regions such as the Arctic, Africa, small oceanic islands and Asian and African mega-deltas are to be severely affected.

Finally, Figure SPM.8 describes estimated long term (multi-century) warming corresponding to the six AR4 WGIII stabilisation categories (Table SPM.3). Stabilisation targets are compared in terms of CO_2 concentrations and range from 445-490 ppm, all the way up to 855-1130 ppm. The graph shows the corresponding global temperature increases of 2-2.4°C up to 4.9-6.1°C. Table TS.2 shows as well the change in 2050 CO_2 concentrations in relation to year 2000 emissions. The timing of emission reductions depends on the stringency of the stabilization target. Stringent targets require an earlier peak in CO_2 emissions. In the majority of the scenarios in the most stringent stabilization category (I), emissions are required to decline before 2015 and be further reduced to less than 50% of today's emissions by 2050 (IPCC, 2007). In other words, this informs policy makers of the levels of emission reductions required to stabilise temperatures at the given levels.

TOPIC 4 – Adaptation, mitigation options and responses: This section deals with human responses in the form of mitigation and/or adaptation to climate change. It can read like a cookbook of ad hoc heuristics and lists describing either adaptation or mitigation actions. In terms of 'adaptation' this is partially due to the inherent difficulties in defining it, measuring it and/or projecting it. Comprehensive estimates of global costs and benefits of adaptation are very limited. Equally difficult is determining the ability or capacity to adapt. Adaptive capacity is intimately connected to social and economic development, unevenly distributed across and within societies, is dynamic and is influenced by a society's productive base including: natural and man-made capital assets, social networks and entitlements, human capital and institutions, governance, national income, health and technology.

The requirement of adaptation can be exacerbated by additional factors including current climate hazards, poverty and unequal access to resources, food insecurity, trends in economic globalisation, conflict and incidence of diseases such as HIV/AIDS. Though a wide array of adaptation options exists, more extensive adaptation will be required than is currently occurring to reduce vulnerability to climate change. Adaptation is not being implemented due to barriers, limits and costs that are not well understood. When implemented, it often occurs as a result of multiple drivers, such as economic development and poverty alleviation, which are embedded within broader development, sectoral, regional and local planning initiatives such as water resources planning, coastal defence and disaster risk reduction strategies. Thus a guiding principle of adaptation (i.e. a heuristic rule of thumb) is that it is more likely to be successful when it is embedded in broader sectoral initiatives.

Table SPM-4, describes some selected examples of planned sectoral adaptation (i.e. *Water, Agriculture, Infrastructure/settlement* (including coastal zones), *Human health, Tourism, Transport,* and *Energy*) in terms of: 1) adaptation options and strategies; 2) the relevant underlying policy framework; and 3) key constraints or opportunities to its implementation. If we examine *Infrastructure* as an example, adaptation options include: seawalls and storm surge barriers; dune reinforcement; land acquisition and creation of marshlands/wetlands as buffer against sea level rise and flooding; protection of existing natural; and relocation. The underlying policy framework it affects includes: standards and regulations that integrate climate change considerations into design; land use policies; building codes; insurance. And the key constraints and opportunities to implementation are: financial and technological barriers; availability of relocation space; integrated policies and managements; synergies with sustainable development goals.

Adaptation and mitigation are complementary responses to climate change, and we are entreated to consider them together, as well as in the context of sustainable development. Nevertheless, in the synthesis report, the two are largely treated separately. This distinction becomes even more pronounced as we consider the manner in which these two strategies are dealt with. As with adaptation, we are treated to heuristic rules of thumb to guide implementation of mitigation options, such as the fact no single technology can provide all of the mitigation potential in any sector, or *"A wide variety of policies and instruments are available to governments to create the incentives for mitigation action … [which] … depends on national circumstances and sectoral context."* We are also presented with a table of mitigation examples for key sectors. Table SPM.5 lists key sectoral mitigation technologies, policies and measures, constraints and opportunities for the Energy Supply, Transport, Buildings, Industry, Agriculture, Forestry, and Waste sectors.

If we use as our example the *Building* sector, we find under key mitigation technologies and practices: efficient lighting and daylighting; more efficient electrical appliances and heating and cooling devices; improved cook stoves, improved insulation; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycling of fluorinated gases; integrated design of commercial buildings including technologies, such as intelligent meters that provide feedback and control; and solar photovoltaics integrated in buildings. Examples of policies, measures and instruments for implementing these strategies include: appliance standards and labelling; building codes and certification; demand-side management programmes; public sector leadership programmes, including procurement; and Incentives for energy service companies (ESCOs). The key constraints or opportunities include: periodic revision of standards needed; attractive for new buildings. enforcement can be difficult; need for regulations so that utilities may profit; government purchasing can expand demand for energy efficient products; as well as access to third party financing.

But this is where the report's treatment of adaptation and mitigation diverge. While in the adaptation section there was mention of limited comprehensive estimates of global costs and benefits of adaptation, for mitigation strategies, actual numbers are attached to mitigation strategies by sector, as expressed through carbon prices. Mitigation potential is meant to assess the scale of GHG reductions that could be made, relative to emission baselines, for a given level of carbon price. Graph SPM.10 illustrates the economic mitigation potential by sector in 2030 derived from bottom-up studies, compared to the respective baselines assumed in the sector assessments for: *Energy Supply, Transport, Buildings, Industry, Agriculture, Forestry,* and *Waste* sectors. Given carbon prices of $20, $50 and $100 US$/tCO_2 eq – the Transport sector has a potential of between 1.5 and 2 GtCO_2 – eq/yr; the Buildings sector on the other hand had a potential of 5 to 6 GtCO_2 – eq/yr, while the Industry sector, Agricultural and Forestry sectors had much better response curves (e.g. Industry could sequester 1 to 4 GtCO_2 – eq/yr).

This important consideration of mitigation potential, has the advantage of offering policy makers guidance in terms of where to place their limited resources for the greatest return. It becomes readily apparent that the Transport sector not only has a much smaller affect upon carbon budgets than the Building sector, but that it would not respond as much to changes in carbon prices as would Industry or Agriculture. Such guidance is essential if limited resources are to be effectively applied to respond to climate change. Adaptation science would do well to attempt such monetarization of options and strategies as a similar offer of guidance.

TOPIC 5 – The long term perspective: In the final topic, the issues of long terms goals and prioritization are introduced, as well as a final word on the means and costs of meeting those goals. AR4 enlists the concept of 'key vulnerabilities' as derived from TAR to respond to IPCC's ultimate raison d'etre, that of avoiding "dangerous anthropogenic interference with the climate system" (Article 2 of the UNFCCC). Key vulnerabilities are associated with climate sensitive systems which include but not limited to: food supply, infrastructure, health, water resources, coastal systems, ecosystems, global biogeochemical cycles, ice sheets, and modes of oceanic and atmospheric circulation. They can be identified based upon a number of criteria including: magnitude, timing, persistence/reversibility, the potential for adaptation, distributional aspects, likelihood and 'importance' of the impacts.

There are five reasons for concern, regarding climate change and they include: 1) risks to unique and threatened systems; 2) Risks of extreme weather events; 3) Distribution of impacts and vulnerabilities; 4) Aggregate impacts; and 5) Risks of large-scale singularities. AR4 concludes that the reasons for concerns are assessed as 'stronger' than they were with TAR, in that many of the risks are identified with higher confidence, some are larger than projected or are to occur at lower temperatures. Additionally, understanding the relationship between impacts (the basis for "reasons for concern" in the TAR) and vulnerability (that includes the ability to adapt to impacts) has improved.

In terms of (1) risks to unique and vulnerable systems, there is new and stronger evidence of observed impacts on systems such as polar and high mountain communities and ecosystems. Also the risk of species extinction is projected to have increased; 20-30% of plant and animal species assessed so far are likely to be at increased risk of extinction if increases in global average temperature exceed 1.5-2.58°C over 1980-1999 levels. Society has been found to be more vulnerable to extreme weather events (2) than was revealed in TAR. There is also higher confidence in the projected increases in droughts, heatwaves, and floods as well as their adverse impacts.

There have been differences (3) across regions and their ability to respond to impacts. Those in the weakest economic positions, such as low-latitude and less-developed, or elderly or poor, in either developed or developing countries are found to be most vulnerable to climate change. In terms of (4) aggregate impacts, older estimates of net market-based benefits are now projected to peak at a lower magnitude of warming, while damages would be higher for larger magnitudes of warming. Finally, (5) there is new evidence of impacts from large scale singularities. Sea level rise is project with high confidence to increase from thermal expansion alone, with further risks coming from increases from the Greenland and possibly Antarctic ice sheets. Associated impacts are naturally expected to increase as a result.

Given this litany of potentially negative impacts, the authors of AR4 attempt to paint a picture of possibilities in this final Topic. In Table SPM.6 and Figure SPM.11, required emission levels are summarized for different groups of GHG stabilisation concentrations, and the accompanying equilibrium global warming temperatures and sea level rise. So for example (Table SPM-6), there are six categories of stabilisation that represent carbon concentrations, a stabilisation level of 485 – 570 ppm in the atmosphere (Category IV), is associated with a peaking year in terms of emissions around 2020 – 2060. This represents a 10 to 60% increase by year 2050 over year 2000 concentrations, and is associated with a global average temperature increase of 3.2 – 4.0°C, and a sea level rise of 0.6 – 2.4 m. Economic costs (Table SPM-7) of this category (categories are not perfectly consistent between the two tables) could be anywhere from 3 to 5% GDP with a reduction in average growth rates of less than 0.12%.

The IPCC conclusions appear self-evident: the sooner we attempt to achieve stabilisation, the easier it will be to achieve. Delayed emission reductions constrain the opportunities to achieve lower stabilisation levels and increase the risk of more severe climate change impacts. Stabilisation levels will be achieved through a portfolio of technologies that are either currently available or expected to be commercialised in coming decades. But this will require appropriate and effective incentives for their development, acquisition, deployment and diffusion and addressing related barriers. Any strategy will also include both adaptation and mitigation which can complement each other to reduce the risks of climate change. Such strategies must also take into account climate change damages, co-benefits, sustainability, equity, and attitudes to risk.

Summary of Synthesis: The IPCC report makes it clear that climate change has already occurred in the form of increased global warming, increased ocean temperatures, increased regional precipitation, widespread melting of snow and ice, and rising global sea levels. Alterations in human systems have been consistent with these climatic changes (i.e. in the form of adaptations), as are ecosystems responses (i.e. terrestrial, marine, hydrological and cryospheric alterations and species migrations). These modifications of the climate are also consistent with our theoretical understanding of how human activities have influenced the atmosphere (i.e. most notably through the emissions of green houses gases).

Projecting our theoretical understanding of atmospheric behaviour into the future over a standard set of socioeconomic scenarios (SRES) and accompanying emissions profiles, modellers suggest that we can expect a warming of about 0.2°C per decade, without any mitigative effort. Warming will be greatest over land and most high northern latitudes and least over the Southern and North Atlantic Ocean. There will continue to be a contraction of snow cover area, increases in thaw depth over most permafrost regions, and a decrease in sea ice extent. There will also be an increase in the frequency of hot extremes, heat waves, and heavy precipitation. The tundra, the boreal, the tropical rainforest, montane regions, mediterranean-type ecosystems, coastal and marine systems (the extent of sea-ice) will be most affected. In terms of human systems, those most affected will be agriculturalists in low-latitudes areas, inhabitants of low-lying coastal systems, and in regions such as the Arctic, Africa, small oceanic islands and Asian and African megadeltas.

Given what has already occurred and what may be possible, there is naturally much speculation and debate over what should be done. At the most general level, there are two basic responses: to mitigate or to adapt. Presumably the guiding rationale for the IPCC is to avoid *"dangerous anthropogenic interference with the climate system"* (Article 2 of the UNFCCC) which suggests a mitigation effort. Accordingly, the Synthesis lists examples of mitigation actions for key sectors including the policies, measures and instruments for implementing these strategies, and the constraints or barriers that prevent their implementation. Furthermore, it attempts to monetarize those options in a comparative framework and offer stabilisation strategies which are accompanied by timeframes for action.

Adaptation options are also listed and their accompanying policy implications, barriers and constraints, *but comparative frameworks appear lacking*. It is noted that adaptation is confounded by numerous factors, including current climate hazards, poverty and unequal access to resources, food insecurity, trends in economic globalisation, and conflict and incidence of diseases such as HIV/AIDS. *The best adaptation results appear to occur when strategies are associated with other initiatives.* A need is identified to discover systems that would allow the integration of adaptation and mitigation, in the context of sustainable development, but beyond individual examples it is difficult to ascertain how this would be accomplished. Nevertheless, the AR4 paints a clear picture of the need for immediate and simultaneous action on mitigation, and adaptation strategies.

The IPCC review process represents a monumental undertaking which has been successful in accumulating, interpreting and disseminating "greater knowledge about man-made climate change" as well as laying the foundations for *"measures that are needed to counteract such change[7]."* Nevertheless, AR4 cannot help but be a single snapshot of an extremely large and evolving field. AR4 gives some direction in terms of where the field may be heading, but is necessarily outdated even as it is published. It provides a heavily aggregated, implicitly biased perspective, leaving the reader with no sense of what was left out, or where speculative or innovative research may be found. It should be noted that this is not a flaw of the authors but rather inherent to the review process itself. This current review is meant to offer the researchers tools to access the CCA literature, and a framework(s) upon which to structure their mental models.

3. The CCA Information Landscape

Claude Levi-Strauss (1962) stated that humans are essentially a classifying animal; they make sense of the world around them by classifying like objects and processes to facilitate the creation of generalisations upon which their actions may be based (Berlin, Breedlove *et al.,* 1973). We will attempt to create a classification scheme of the CCA literature in the hope that patterns inherent to the field will become apparent so as to inform and guide our research activities. In our case, we wish to develop a framework for exploring the literature associated with CCA by ordering (categorising\ranking) the given articles in a manner suggested by the content and relationships within the literature, as well as the stated/implicit intentions of the field.

7 Quote from the declaration of the accomplishments of the IPCC and Al Gore for the Nobel Peace Prize **http://nobelprize.org/nobel_prizes/peace/laureates/2007**.

As such, the author, title, abstract and keywords will be used to categorise articles, and discern some sense of content, relevance and informational value. Key articles are identified by their relationship to their category, the importance of the category itself, the author's reputation, the journal's status, the article's overall ranking (as determined by its citation count), and ranking within the category. This should provide researchers with an awareness of relative occurrence of the critical climate change adaptation issues within scientific journals, which in conjunction with the AR4 synthesis, should provide a fundamental understanding of the field. To accomplish this we must first address the six questions of content analysis (Krippendorf, 2004):

1) Which data are analyzed?
2) How are they defined?
3) What is the population from which they are drawn?
4) What is the context relative to which the data are analyzed?
5) What are the boundaries of the analysis?
6) What is the target of the inferences?

We are fortunate in that we can easily define our data, the population it comes from, how it is defined, its limits, and for whom and to what end it is intended. The data is derived from the vast SCOPUS literature dataset which covers the physical sciences, life sciences, health sciences and social sciences. It is the largest abstract and citation database of research literature, with over 15,000 peer-reviewed journals from more than 4,000 publishers. Using this population of 33 million records, articles were sought that contained the terms *"climate change adaptation"* or *"climate change adapt"* in their title, abstract or keywords. As we are looking for trends in the CCA field, it is our assumption that the articles in this dataset reflect a representative sample of the intellectual activities occurring within the field itself. Clearly this assumption can be challenged because a large number of journals, non-reviewed articles, books and reports are not contained within the dataset; nevertheless a complete survey is logistically unattainable and our purpose is primarily exploratory. We further presume that the inter-disciplinary community of CCA researchers and professionals (Bodansky, 2005) is the target of the inferences derived, and that this community holds a common understanding of our search terms.

Our specific *"climate change adaptation"* search resulted in 2210 articles (Scopus Export date: September 20, 2007) which compares favourably with a SCOPUS search of *"climate change mitigation"* (1452 Articles, Scopus Export date: September 10, 2007) and yet is only a small portion of *"climate change"* articles (1,832,660 articles, Scopus Export date: October 16, 2007). These numbers represent datasets before they are 'cleaned' (i.e. checked for consistency and relevance). To aid in this process, we entered the SCOPUS dataset into an Endnote® bibliographic database manager (Version X1) and were able to easily identify and remove 168 duplicate articles. Endnote has various features that make it attractive for researchers, but other bibliographic managers would likely also suffice.

After reviewing each article's title and abstract, numerous irrelevant results were encountered (375 articles) likely due to the breadth of our search. Most of these articles were derived from a period before the 1990s, in disciplines as varied as sports medicine and human physiological response to cold climates. Clearly, the usage of the phrase 'climate change adaptation' has come to be dominated by climate change researchers over the last 10 to 15 years, as there are almost no references to these topics after this period. And though a rich literature exists concerning distant human evolutionary and cultural responses to climate change (Baker, 1984; Schule, 1992; Bobe and Behrensmeyer, 2004), 84 articles were removed for not aligning with our temporal scale of interest (i.e. the past\future 100 years). In addition, climate change adaptation is relevant for species other than *homo sapiens* (i.e. plant and animal species that are affected by climate change). Despite the relevance of such issues to human well being (i.e. through ecosystem services), 459 articles were also removed from our dataset for essentially misinterpreting our perspective of the concept of adaptation.

In the end, we were left with a climate change adaptation database of 1167 articles from which to work. Unfortunately, this is still an enormous dataset[8] to examine. We wish to devise a method for accessing this information as efficiently as possible, taking into account the differential value of each article in view of our interests. If we presume: 1) that a general, pragmatic purpose pervades the field (i.e. adapting society to human-induced climate change); 2) that an implicit structure underlies the field's knowledge landscape (see Toulmin and Goodwin (1965) for a discussion); and 3) that some papers\articles are more influential than others with respect to 1) and 2), we may begin to make sense of this dataset. To facilitate the construction of our

8 We can assume at the minimum 5,000 pages, not considering books length treatments or larger reports.

intellectual scaffolding, we start by determining some simple, yet revealing statistics of articles, journals and authors.

3.1 Dataset Statistics

It appears self-evident that not all articles are perceived, or valued, equally among researchers. Numerous explanations beyond the typical folk variety exist to describe this differential (e.g. see Kuhn (1962) for a start), yet it is not our purpose to enter into this discussion. The question confronting us is how to access this differential? Fortunately, SCOPUS provides us with one of the most direct means of determining the weight researchers deliberately attribute to individual articles: that of citing an article or paper within their own work. SCOPUS keeps track of an enormous number of individual articles and their accompanying references, enabling them to identify associations between articles (i.e. the cited article to the article citing it). It is simply a matter of adding up all the citations to a specific article to create a citation ranking among articles. This direct expression of social networks is currently the centre of much research which holds great potential for CCA (Watt, 2003).

When we rank CCA articles by the number of citations referring to them, we discover a dramatic disparity. Our top CCA article was cited 237 times, yet the next two articles are cited less than half that (111 & 110), after which the numbers drop off quickly. Fully 81% (950 articles) of the 1167 articles were cited ten times or less, 12% (142 articles) had only one citation, and 35% (410 articles) were not cited at all. A non-linear, relationship clearly exists between articles in terms of their citation numbers as seen in Figure 1.0 which illustrates the average number of citations for each sorted range of 25 articles. If we take this as representative of the differential value of articles, it means that relatively few articles have a strong influence upon the CCA field. This implies that we do not necessarily have to read every single CAA paper to get a sense of the major issues or trends in the field.

Unfortunately, the diversity of topics and sources associated with these articles suggests that this information is not necessarily coherent with respect to CCA as a general goal. The top articles in our ranking are from journals not typically devoted to climate change research; of the five most cited papers (Wilks, 1992; Walsh, Molyneux *et al.,* 1993; Hulme, Barrow *et al.,* 1999; DeMenocal, 2001; Hughes, Baird *et al.,* 2003), two are in the journal *Science*, one is from *Nature*, and one is from the medical journal *Parasitology.* Additionally, the articles are spread out temporally (i.e. over the 1990s

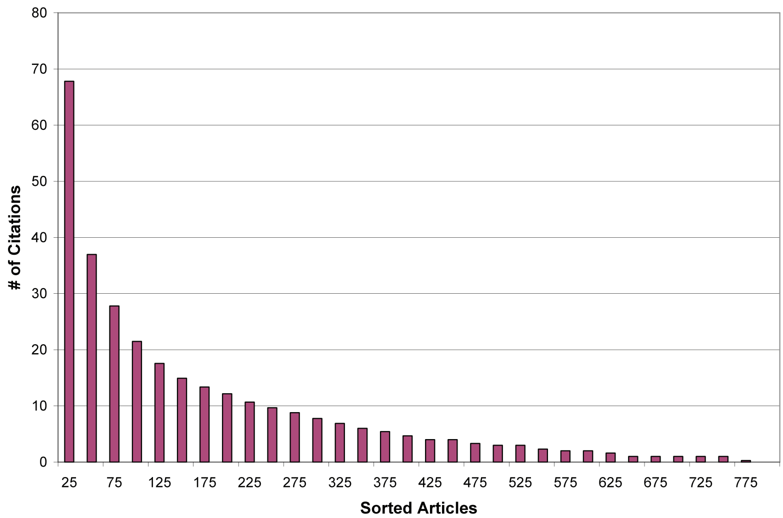

Figure 1 | The average number of citations for each range of 25, sorted articles. The most cited article was cited 237 times, but the range over the top 25 articles was 67.8. Clearly a non-linear, not quite negative exponential relation ship exists over article citations. Of the complete dataset (1167 articles) 35% were not cited even once, while 12% had only 1 citation, and 81% were cited ten times or less.

and early 2000s) making them difficult to compare. Not only does it take time to accumulate citations (recently published articles have had little time to disseminate), but the nature of the CCA field itself has evolved. As alluded to earlier, CCA has only recently emerged in its current form as a field of academic study. Figure 2.0 (CAA articles per year) illustrates the spectacular growth of interest in CCA beginning in the early 1990s as evidenced by the fact that four of the top five CCA journals were established after 1989 (Table 1).

This growth is inconsistently spread out among journals as well. Table 1 ranks journals by the cumulative number of CCA articles published within them, and Figure 3.0 compares these numbers for the top 30 journals (as ranked by number of articles). Not surprisingly, of the 373 journals that made it into our CCA database, the top five deal explicitly with the subject matter of 'climate change adaptation' accounting for 27% of all CCA articles. The top thirty journals (8% of the journals) account for

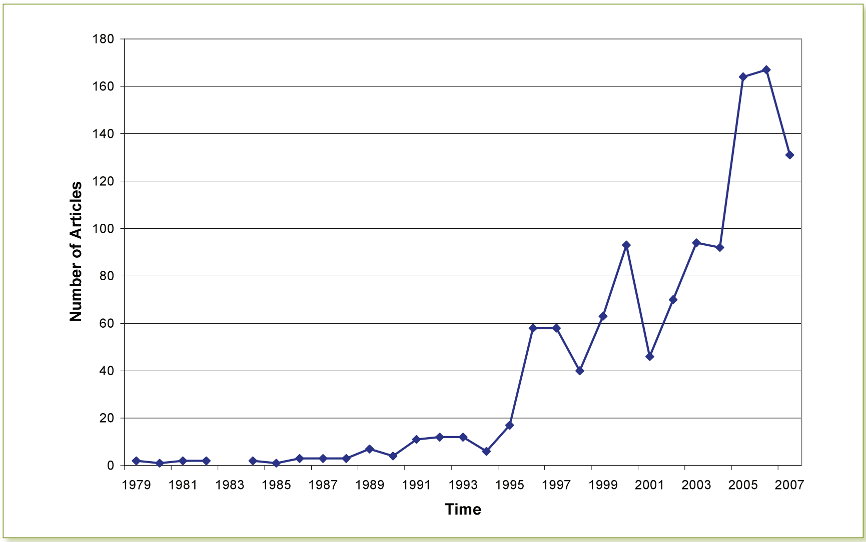

Figure 2 | The number of climate change adaptation articles within the SCOPUS database. Note, some articles published in 2007 have yet to make it into the SCOPUS dataset. Also note the years 1990, 1997, 2001, and 2007 are IPCC report years.

Table 1 | Number of climate change adaptation articles for the top ten journals in our SCOPUS search, the year the journal were founded and the Impact Factor. The impact factor is calculated by dividing the number of citations in the JCR year by the total number of articles published in the two previous years. An impact factor of 1.0 means that, on average, the articles published one or two year ago have been cited one time.

RANK	NUMBER CCA	JOURNAL NAME ARTICLES	JOURNAL YR. FOUNDED	IMPACT FACTOR
1	120	Climatic Change	Vol 1. - 1977	2.459
2	58	Mitigation and Adaptation Strategies for Global Change	Vol. 1 – 1996	NA
3	49	Climate Research	Vol. 1 - 1990	1.519
4	47	Global Environmental Change	Vol. 1 – 1990	2.6
5	26	Climate Policy	Vol. 1 – 2000	0.339
6	23	Building Research and Information	Vol. 1 – 1972	0.659
7	19	Environmental Monitoring and Assessment	Vol. 1 – 1981	0.793
8	17	IDS Bulletin	Vol. 1 – 1970	0.317
9	15	Forestry Chronicle	Vol. 1 – 1925	0.831
10	14	Agriculture, Ecosystems and Environment	Vol. 1 - 1979	1.832

approximately 50% of all articles. Again, most journals (228 journals or 60% of the total) have only one article about climate change adaptation. Although this broad allocation among journals may appear quite large, given the ubiquity of climate change impacts, it could be argued that the tail of this distribution (partially revealed in Figure 3) should be much longer.

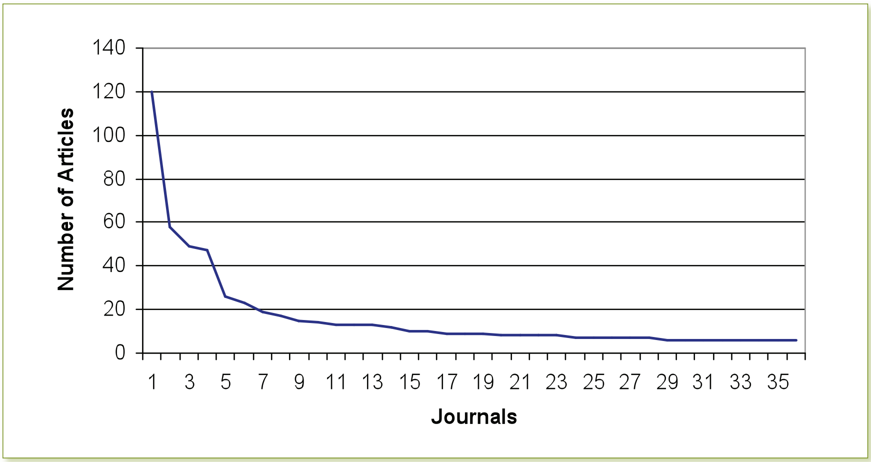

Figure 3 | The number of climate change adaptation (CCA) articles per journal, for the top 36 journals of 373 journals in total. Most journals (228 or 60%) have only one CCA article, while a small number publish a substantial portion of the total CCA landscape (the top 5 journals account for 27% of all articles).

We also sought to determine the importance of journals relative to each other. To do this we employed journal impact factors from the ISI Web of Knowledge® as listed in Table 2. We compared statistics for the top 20 journals in terms of overall articles in our database, with the addition of Science and Nature for comparative reasons. A journal impact factor is approximately the average number of times published papers are cited in the two calendar years following publication. Impacts factors can be controversial (Ball, 2006; Saha, Saint *et al.,* 2003): they cannot account for the differences in absolute number of researchers, the average number of authors on each paper, the nature of results in different research areas, and variations in citation habits between different disciplines. All these factors are relevant considerations for CCA which draws from numerous disciplines. Nevertheless, the calculation is an effective,

Table 2 | Impact factor and various statistics for the top 20 journals. The journals Science and Nature were added for comparative purposes.

No.	Total Citations	Impact Factor[10]	Immediacy Index[11]	Cited Half-Life[12]	Journal	No. CCA Articles
1	3306	2.459	0.327	6.7	Climatic Change	120
2	NA	NA	NA	NA	Mitigation and Adaptation Strategies for Global Change	58
3	1063	1.519	0.362	4.9	Climate Research	49
4	779	2.6	1.2	5.3	Global Environmental Change	47
5	186	0.339	0.6	4	Climate Policy	26
6	222	0.659	0.391	3.8	Building Research and Information	23
7	1839	0.793	0.067	6	Environmental Monitoring and Assessment	19
8	334	0.317	0.562	6.7	IDS Bulletin	17
9	869	0.831	0.127	7.8	Forestry Chronicle	15
10	4308	1.832	0.388	6.3	Agriculture, Ecosystems and Environment	14
11	1768	1.362	0.155	4.7	Energy Policy	13
12	415	1.052	0.452	3.9	Environmental Science and Policy	13
13	10445	1.839	0.356	5.8	Forest Ecology and Management	13
14	14434	5.861	0.994	5.6	Environmental Health Perspectives	12
15	5077	2.903	0.669	6.7	Agricultural and Forest Meteorology	10
16	NA	NA	NA	NA	IAHS-AISH Publication	10
17	2600	1.223	0.152	6.2	Ecological Economics	9
18	110	0.316	0.042	5.5	Natural Resources Forum	9
19	5703	1.205	0.09	9.1	Water, Air, and Soil Pollution	9
20	3937	0.737	0.197	6.2	Current Science	8
21	361389	30.028	5.555	7.7	Science	6
22	390690	26.681	6.789	7.8	Nature	1

10 The impact factor is calculated by dividing the number of citations in the JCR year by the total number of articles published in the two previous years. An impact factor of 1.0 means that, on average, the articles published one or two year ago have been cited one time.

11 The Immediacy Index The immediacy index is the average number of times an article is cited in the year it is published. The journal immediacy index indicates how quickly articles in a journal are cited.

12 The Cited Half-Life is Half of a journal's cited articles were published more recently than the cited half-life. For example, in JCR 2001 the journal Crystal Research and Technology has a cited half-life of 7.0. That means that articles published in Crystal Research and Technology between 1995-2001 (inclusive) account for 50% of all citations to articles from that journal in 2001.

consistent, and transparent means of comparing journals, given caveats. Figure 4 shows the relationship between the journals' relative impact factors and their ranking.

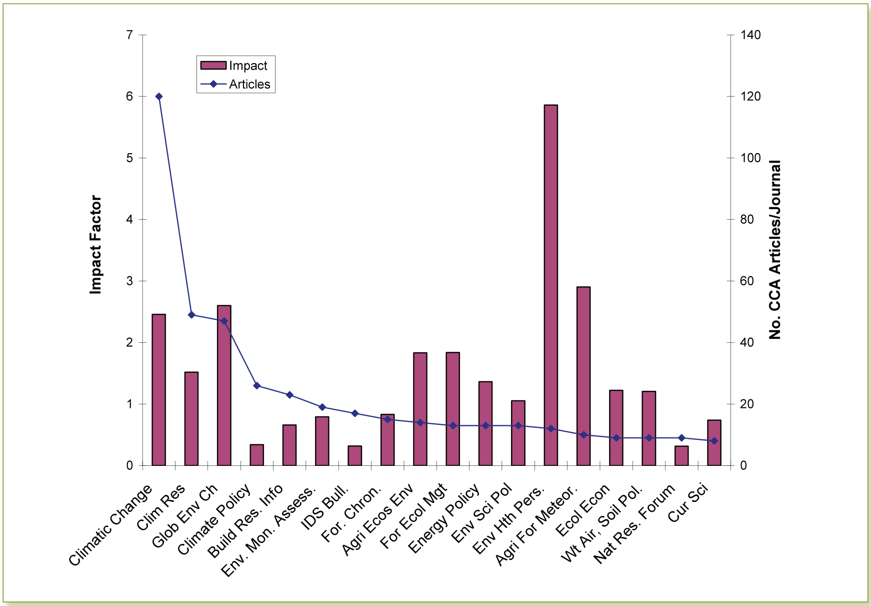

Figure 4 | Ranked Impact Factor of the top 18 journals. The journals Science and Nature were removed to facilitate comparison.

Aside from *Science* and *Nature*, it is clear that Environmental Health Perspectives dominates the field, with Agricultural and Forest Meteorology following not too far behind in terms of impact factor. Within the CCA community though, *Climatic Change* has a high impact as well as the greatest number of articles, with *Global Environmental Change* close behind. Unfortunately, we could not assess the relative importance of *Mitigation and Adaptation Strategies for Global Change,* since ISI does not rank the journal.

Finally, we can also assess who the key authors of the CCA field are by determining the number of articles that specific individuals publish (Table 3). Although these twenty authors represent only 0.8% of total author numbers, they are responsible

Table 3 | Authors of CCA articles with accompanying number of articles in SCOPUS, number of times the author was cited in the SCOPUS dataset irrespective of which of the author's articles are cited, and the ratio of # Articles to # times cited. List is sorted by the number of articles in the SCOPUS dataset.

#	Articles (A)	No. of Times Author Cited in CCA SCOPUS Dataset (B)	Ratio A to B	Author
1	15	122	8.13	Klein, R.J.
2	15	140	9.33	Smit, B.
3	14	133	9.50	Adger, W.N.
4	13	190	14.62	Tol, R.S.J.
5	12	20	1.67	Smith, J.B.
6	12	123	10.25	Easterling, W.
7	11	188	17.09	Rosenzweig,C.
8	9	101	11.22	Mendelsohn,R.
9	9	124	13.78	Yohe, G.
10	8	173	21.63	Burton, I.
11	8	70	8.75	Cohen, S.
12	8	121	15.13	Huq, S.
13	8	52	6.50	Strzepek, K.M.
14	7	57	8.14	Dowlatabadi,H.
15	7	86	12.29	Dixon, R.K.
16	7	75	10.71	Ebi, K.L.
17	6	18	3.00	Alexandrov, V.
18	6	39	6.50	Dessai, S.
19	6	72	12.00	Fankhauser, S.
20	6	82	13.67	Kane, S.

(with co-authors[9]), for 16% of the total number of papers in the field. We can further tease out an author's influence by examining the citation index of each of her papers within the database. Alternatively, we can determine how many papers in our database cite a specific author. Though somewhat imprecise this metric is easy to compute and gives a larger sense of the author's presence. Table 3 identifies the citation\paper ratio which is the number of articles that cite the author over the number of papers written

9 The average number of authors per paper was 2.06.

by the author in the CCA database. This ratio allows us to identify authors who may not write a great deal in the field, but still have a high number of citations (e.g. Holling, 2004, Nordhaus 1995). The only authors that make the top 20 of all three measures are: Tol, R.S.J.; Rosenzweig,C.; Burton, I.; Yohe, G.; Adger, W.N.; Easterling, W.; Huq, S.; Mendelsohn,R. ; Dixon, R.K.; Kane, S.; Ebi, K.L.; and Fankhauser, S.

3.2 Structural and Contextual Overview

The metrics from the previous section are quite useful in terms of identifying key articles, journals and authors but offer no guidance in terms of content. To facilitate a broader understanding of current trends, we offer two additional techniques for perceiving patterns within the literature. In the first section we examine the relative and temporal incidence of concepts by means of simple word counts. In the second we attempt to construct a structural scaffolding for the CCA literature, as guided by a systems perspective, and the occurrence of key topics in the literature.

3.2.1 Relative Concept Incidence

In this section, we employ simple counts (see Table 4) of specific words or phrases (i.e. as inferred by the literature) to roughly gauge their comparative utilisation in the field through time. A word count is the aggregate number of occurrences of specific words or combinations of words within the CCA dataset (i.e. a single occurrence represents the presence of a word/combination, one or more times, within the article's title, abstract or keywords). It can be used to determine when a word or phrase first appeared within the literature, and whether or not it was or has been adopted.

Two examples will offer a sense of the utility of this method. One of the major issues associated with CCA, is the conceptual and practical relationship between adaptation and mitigation as strategies for responding to climate change. The Working Group II report of the AR4 refers specifically to this issue throughout, and a special of Climate Policy (Johnson *et al.,* 2007) focuses entirely upon this issue. At its most simplified, this issue is about determining the optimal mix of mitigation and/or adaptation for responding to climate change (Kane and Shogren, 2000). If we search for articles in which adaptation and mitigation co-occur, we can obtain a rough sense of when these issues emerged, and how prevalent they have been since then. Referring to Table 4 we can see that the terms adaptation and mitigation occur in 37% of all articles and in 44 titles from as early as 1990. If we refer to Figure 5 we can observe the proportion of articles that refer to both adaptation and mitigation over time. Sometime after

1996, this issue became important enough to be referenced by between 30 and 45% of all articles in the field.

A further debate continues over the conceptual relationship of adaptation/ mitigation to sustainable development (Swart, Robinson *et al.,* 2003). If we search on 'sustainable development,' 'adaptation' and 'mitigation' we can see in Table 4 that 150 articles refer to all three concepts, and Figure 5 shows that the conceptual relationship between these three terms has been slowly growing in importance since the mid 1990s, accounting for up to 20% of all CCA articles. This is suggestive of the importance of the issue when compared to other terms and concepts (Table 4).

3.2.2 CCA Structure

The second tool offered, affords the ability to structure the informational content of the field. A loose scaffolding has been developed, based upon the pragmatic[13]

Table 4 | Word Occurrences in articles from the SCOPUS derived CCA database. An occurrence represents the presence of the word in an article, not the number of times the word occurs in articles. Unless otherwise noted, word counts relate to the fields: title; abstract; keywords. A word count in parenthesis indicates the number of times the word occurred in article titles.

Word(s)	Word Occurrence	Word	Word Occurrence
Adaptation;	1167	Biodiversity	146
Adaptation; & Mitigation	433 (44)	Complexity	23
Adaptation; & Mitigation; & Sustainable Dev.	150	Mainstreaming	26
Adaptive Capacity	123	Response Capacity	4
Vulnerability	564	Development pathway	7
Resilience	113	Risk	485
Scale	319 (13)	Uncertainty	309
Ecosystem	365	Emergence	22
Downscaling	16	Threshold	50
Security	129	Gender	9
Justice	40	Landuse	65
Ethic(s)	23	Optimal	25

13 In this case the term pragmatic is used in a philosophical sense (see James, 1907) wherein knowledge is at the service of practise.

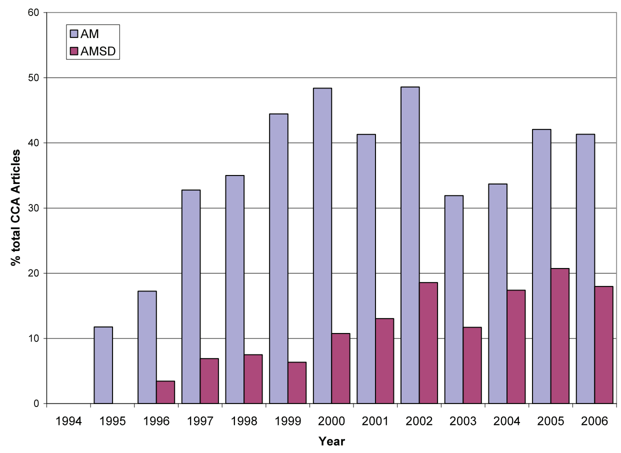

Figure 5 | The co-occurrence of the terms 'adaptation' and 'mitigation' in the CCA literature over time. This is compared with the co-occurrence of the terms 'adaptation' and 'mitigation' and 'sustainable development.'

assumption that CCA literature can be interpreted in terms of facilitating adaptation to human-induced climate change. As such, it is assumed that articles can be systematically classified into functional categories, starting with the most abstract or general topics and gradually leading towards more specific or particular topics and applications. Ideally, the categorization process is driven by the articles themselves and their relationship to one other. An initial set of categories is proposed, and then articles are sorted according to the content inferred by their title, abstract or keywords[14]. In the sorting process, inconsistencies are revealed, and a new categorization is proposed. The process continues iteratively until a satisfactory structure is determined, and the articles sorted accordingly. The final scheme is intended to reveal implicit relationships between, and among articles given the aforementioned pragmatic end (Table 5).

14 The keywords provided by journals can be misleading; while some articles provide a handful meaningful keywords, others may be overly zealous, offering extensive lists that are barely relevant.

Table 5 | CCA Literature Classification.

1.0 THEORY
- 1.1 'Adaptation' and Ancillary Terms
- 1.2 Other Theoretical Considerations

2.0 DISCIPLINES
- 2.1 Economics
- 2.2 Political Science
- 2.3 Sociology
- 2.6 Development
- 2.4 Ethics
- 2.5 Communication & Education
- 2.7 Law
- 2.8 Psychology
- 2.9 Anthropology

3.0 METHOD
- 3.1 DSS Systems Analysis
  - 3.1.1 Data
  - 3.1.2 Models
  - 3.1.3 Vetting
- 3.2 Scale
- 3.3 Integration

4.0 SECTORS/RESOURCES
- 4.1 Agriculture
- 4.2 Water
- 4.3 Forestry
- 4.6 Health
- 4.4 Infrastructure
- 4.5 Wildlife/Ecosystem Services
- 4.7 Tourism
- 4.8 Energy
- 4.9 Fisheries
- 4.10 Emergency Services
- 4.11 Transportation
- 4.12 Service Sector

5.0 GEOPOLITICAL PLACE
- 5.1 Land-use Policy Issues
- 5.2 Place
  - 5.2.1 Local
  - 5.2.2 Regional (National)
  - 5.2.3 National
  - 5.2.4 Regional (International)
  - 5.2.5 International/Global

Before continuing, it should be pointed out that: 1) the SCOPUS dataset represents only a small (albeit privileged) portion of the CCA literature; and 2) numerous other categorisation schemes are possible (although the literature likely follows established theoretical, disciplinary and methodological boundaries). Ideally readers should categorize the literature themselves as this encourages the development of the reader's own conceptual framework (i.e. accommodation in a constructivist sense), while tailoring the structural schema to meet their own needs. Categorisation is a continuous process: resources are regularly added from SCOPUS[15] and outside sources, and categories altered to meet the evolving needs and understanding of the researcher[16]. The metrics from Section 3.1 should aid in this process by identifying key journals and authors to initially focus upon. Ultimately, promising articles will have to be consulted directly to identify additional sources outside the SCOPUS domain, keeping in mind differential value.

Fundamental Categories: The following proposed structure of CCA literature (see Table 5) is based upon the simple premise that *theory* informs *method*, which in turn informs practise. Fundamental generalities (theory) about the way the world works (i.e. climatic and\or behavioural) are suggestive of various methodologies (e.g. modeled atmospheric relationships, rational economic decision making, etc.), which can be used to direct human practises (i.e. levels of mitigative and adaptive agency). Although science is not so linear (i.e. practise can inform theory, etc) this assumption is a reasonable starting position given the exploratory nature of this analysis. This premise was translated into the following five core classifications or themes: Theory, Disciplines, Method, Sectors\Resources, and Geopolitical Place, as seen in Table 5.

Theory and Method refer specifically to topics concerned with climate change adaptation (e.g. discussions of the concept of adaptation or integrated assessments methodologies) while Disciplines acts as an intermediary between these two. Disciplines provides additional information regarding the various fields that inform CCA theory and methodology (e.g. for instance there is a strong theoretical distinction between the social and physical sciences[17]). Delineating method and theory in this way facilitates greater interpretation, as most researchers are trained from within

15 Possibly using an RSS feed to be alerted to regular updates in the search.

16 A manifestation of this approach is embodied in certain visions of the semantic web (Borland, 2007; Tossell, 2007).

17 See MacLellan (2006), Chapters 3 and 4 for an extended discussion.

specific disciplinary fields. In a similar vein, Sectors\Resources, and Geopolitical Place, together represent the conditions for CAA *practise* which is concerned with increasing or maintaining human values (i.e. manifest as resources or affordances) associated with a specific place (i.e. as geopolitically defined) in the face of climate change. This format recognises that resources (i.e. economic, natural and social capital) are usually spoken of in terms of both sectors (i.e. agriculture) and geo-political distinctions (e.g. the agricultural sector in the Canadian prairies).

Given these categories and accompanying sub-categories (Table 5), individual articles are placed within those which most suit their content[18]. Though most will be assigned to a single category, multiple classifications are possible for articles that effectively span more than one topic. Once all articles have been sorted, it is possible to gauge the relative intellectual activity among topics, based upon the number of articles within the associated category. This is not intended as a measure of a topic's importance[19], it merely indicates the relative *attention paid by* members of the CCA community to the topic in question. Tables 6.1 to 6.4 provide the relative academic activity occurring in each category. Most articles (714 articles or approximately 61% of total CCA articles) specifically dealt with resource questions (i.e. Sectors\Resources) and associated Place distinctions (57%), while CCA Theory and Method accounted for 11% and 16% respectively, and the intermediary category Disciplines, accounted for 28% of all articles.

This focus upon *practise* is indicative of a field committed to assessing the impacts of, and responses to, climate change. In the following treatment, we attempt to further tease out such general insights as guided by the relative intellectual activity within different categories (see Tables 6.1 to 6.4). Some results will appear obvious as above, while others may only become apparent when their omission is recognised. In our analysis, greater attention will be paid to categories with higher article counts. Thus we begin with a short discussion of the major topics of Theory. This is followed by a discussion of Disciplines which will examine the contribution of the top three disciplines, as identified by article count, and how they might be integrated. We then discuss Method in terms of its essential components. And finish with a discussion of

18 This process utilized the custom grouping feature of ENDOTE XI which allows the user to define sub-categories and groupings of their bibliographic library.

19 In positing his Anna Karenina principle, Diamond (1997) reminds us that environmental adaptation must account for numerous factors simultaneously. In essence this makes all essential factors equally important; ignoring any single factor will result in the same overall failure. The principle is taken from the first sentence of Tolstoy's novel 'Anna Karenina': "Happy families are all alike; every unhappy family is unhappy in its own way."

Sectors\Resources and associated Place in terms of their top three sectors and associated geopolitical distinctions.

Table 6.1 | Article counts for given categories. The percentage reflects the number of articles in the given category as a portion of the total number of articles in the entire CCA SCOPUS dataset.

Section	Climate Change Adaptation Category	Number of Articles (%) per Category
1.0	Theories, Concepts, Generalities or Terms	130 (11 %)
2.0	Academic Distinctions	324 (28 %)
3.0	Methodology	182 (16 %)
4.0	Sectors/Resources	714 (61 %)
5.0	Place	670 (57%)

Category 1 (Theory): This category deals specifically with abstract issues or generalities surrounding the field of climate change adaptation (11% of all CCA articles). A short overview of this literature reveals a great deal of effort expended upon the concept of adaptation and its relationship to other terms. The category was divided into sub-sections dealing with the concepts of Adaptation (17% of all Theory articles), of *Adaptation and Mitigation* (22%), and *Adaptation, Mitigation and Sustainable Development* (11%). Ancillary terms such as 'vulnerability' and 'resilience' are strongly associated with the concept of adaptation, accounted for a further 17% of all theoretical articles. Thus, the dominant theoretical exercise in the field (two thirds of all theoretical papers) is concerned with defining and clarifying the concept of adaptation and its relationship to other concepts. The remaining third deals with topics such as *history, integration* and *scale*.

Table 6.2 | Article counts and percentages (of total CCA dataset) for given categories.

Section	Climate Change Adaptation Category	Number of Articles (%) per Category
2.1	Economics	105 (8.9 %)
2.2	Political Science	95 (8.1. %)
2.3	Sociology	56 (4.7. %)
2.6	Development	35 (2.9 %)
2.4	Ethics	27 (2.3 %)
2.5	Communication & Education	12 (1.0 %)
2.7	Psychology	5 (0.4 %)
2.8	Anthropology	5 (0.4 %)
2.9	Law	6 (0.5 %)

Category 2 (Disciplines): Table 6.2 gives some indication of the comparative makeup of the different disciplines within the field of climate change adaptation[20]. There appears little question regarding the privileged position of Economics within the field given the number of articles identified as such (8.6% of the CCA dataset), but Political Science and Sociology are also well represented with 7.5% and 4.1% of the total CCA articles respectively. The remaining disciplinary distinctions include International Development, Ethics, and Communications & Education. The discipline of Psychology (0.4%) can be interpreted in terms of the need to examine adaptation at the level of the individual. Likewise, Anthropology (0.4%) provides a methodological perspective on local phenomena, and an awareness of how cultures and societies have adapted in the past. Finally, the presence of Law seems self-evident given the many legal issues (i.e. international etc) involved in CCA.

How these various disciplines fit together is not readily apparent until the Political Science literature is considered. One of the main tasks of this field is the development of appropriate CCA policies that can effectively integrate key considerations (i.e. economic, sociological, ethical, etc.). A consequence of this purpose is an apparent, ideal typic article format that adheres to the following structure: 1) political science articles generally start with a review of current, past or proposed policy instruments (58% of Political Science articles); 2) then they discuss the implications or impacts of climate change for the aforementioned policy within a given geo-politically referenced sector, resource, or value (35%); and finally 3) they project the impacts of proposed policy options (strategies) based upon the given criteria (35%). Critiqued and proposed policy options are considered in terms of integration (16%), mainstreaming (9%), sustainable development (7%) and/or goal orientation (5%).

In this context, economics becomes an input in a process of climate change policy critique and formation. This assumption seems borne out by the fact that 23% of articles in the economics domain deal specifically with determining the financial impact of climate change. Other articles are also suggestive of this policy agenda: 9.5% of economics' articles concern the measurement of goods and services, 15.2%

20 There is some discussion in the literature as to how different disciplines should relate to one another (Schneider, S. H. (1997). "Integrated assessment modeling of global climate change: Transparent rational tool for policy making or opaque screen hiding value-laden assumptions?" *Environmental Modeling and Assessment* 2(4): 229-249.), including the sciences themselves (Lorenzoni, I., M. Jones, *et al.* (2007). "Climate change, human genetics, and post-normality in the UK." *Futures* 39(1): 65-82).

deal with risk and its avoidance, 13.3% examine the temporal aspects associated with the longer time scales relevant to climate change, and 8.6% deal with methodological questions involving choice. The field is rounded out by reviews (11.4%), methodology (12.4%), and international development (5.7%).

Sociology also focuses upon climate change impacts (47% of sociology articles), except it cannot rely upon a single metric to compare outcomes (i.e. the monetary standard). Sociology attempts to get beneath this economic simplification by measuring the actual drivers that facilitate or hinder adaptation. Thus a substantial portion of sociological discussion is concerned with determining metrics of vulnerability (11%), adaptive capacity (18%), social capital (4%) and the scales over which these metrics operate (11%). Climate change impacts and proposed solutions are discussed in terms of social networks (22%), institutions (42%), social capital (4%) and gender (15 %). Policy proposals are further discussed in terms of social learning (15%) and participatory approaches (9%). The topic is rounded off with reviews (22%).

Category 3 (Method): CCA methodology can be somewhat difficult to categorise given the multitude of approaches available. The reader is referred to Chapter 2 of Working Group II AR4, for a methodological overview reflecting current trends and emerging issues (IPCC, 2007). As per the previously discussed policy framework, it is presumed that CCA methodology is ultimately concerned with facilitating societal wellbeing in the face of climate change through the application of appropriate policy instruments (i.e. strategies). To do so, method must assess the impacts of various responses to climate change for specific sectors or resources, over specified geopolitical scales. From a systems perspective, this search for policy frameworks can be understood in the context of decision support.

An extremely simple framework is utilised here that captures the essence of a decision framework for CCA. Decision making includes: 1) the consideration of a defined set of alternatives through time; 2) and the likelihood or probability of their occurrence; 3) assignment of ‘preferences’ to the set of possible outcomes; given 4) a criteria such as maximal or optimal desirability of chosen alternatives with respect to the preference ranking (Doyle, 1999). This structure can be simplified further into three essential components: A) *Data*, B) *Predictive Modeling,* and C) *Choosing\Vetting Possibilities* (MacLellan and Innes, 2002; MacLellan and Fenech: Chapter 1).

Descriptive Data is information describing past atmospheric, biotic or abiotic environments including social and cultural conditions. In our case this category includes the choice of indicators, the scale over which data is relevant, whether data is probabilistic or spatially explicit, how data is collected, monitored, its relevance to other indicators, and to modeled processes, etc. This category accounts for 2.8% of all CCA articles. From these representational elements, dynamic relationships among elements can be inferred (i.e. modeled), and ultimately projected to describe future environmental conditions. The dominant *Predictive Models* (2.0%) in the CCA literature are obviously climate models, although their presence is often implicit. CCA is largely concerned with interpreting their results for other processes by utilising: hazard models, energy models, demographic models, industrial output models and/or hydrological models, productivity models, forest successional models, etc[21].

Once these projections have been defined (i.e. as output of the data\modeling relationship), it becomes a matter of choosing the future(s) that best suits society or a subset therein[22]. Various factors confound this aspect of decision making such as the uncertainty associated with modeling future conditions, the inability to represent all future states (most problems are unbounded or open), and the inability to successfully search through projections for solutions[23]. *Choice\Vetting Possibilities* (4.8% of CCA dataset) represents any process that allows the decision maker to find\reveal a favoured solution or set of solutions that can be implemented. Many such activities are implicit in a decision framework including the selection of models and methodologies, the selection scenarios (see Topic 3 in Section 2.1), the choice of technique to search the projected human possibilities (i.e. optimization methods), and methods to determine choice (i.e. democratic forums) (MacLellan and Fenech, Chapter 1).

Aside from these three essential factors (data, models, vetting), other aspects of environmental decision making must also be taken into account when constructing methodology. These include questions of *Scale* (1.5%), *System Integration\Testing* (3.8%) (including the utilisation of case studies), and *Uncertainties and Risk* (1.1%). Finally the output of this process (i.e. a strategy for CCA) must be turned into a prescription (i.e. the implementation of that strategy). This consideration also includes monitoring and adaptive learning.

21 Though forecasting often utilises computer simulation models, it should be remembered that Predictive Models also include knowledge-based systems (individual human cognition) where lies the vast majority of what we 'know'.

22 Or disqualifying those that are not acceptable.

23 See MacLellan, J. I. (2006). Ecologic Agency: Human Behavior within the Boreal Forest. *Faculty of Forestry*. Toronto, University of Toronto. PhD: 368., Chapter 1 for an overview of the limitations of modeling.

Category 4 (Sectors/Resources): Ultimately we want to know how climate change will affect natural, social and economic capital in local, regional, national and international communities, through time. Most importantly, we want to know what we can do to alter our developmental pathways towards possibilities that are closer to our individual and collective preferences (i.e. towards economically prudent, socially and ethically responsible development). As such, all the previous topics come together to guide our relationships to specific forms of capital in specific, geo-politically referenced 'places.' An essential relationship exists therefore, between Category 4.0 and Category 5.0 which can be hard to dissect. In many instances it is difficult to assess the impact to a specific resource or sector (i.e. its production or utilisation) without reference to a specific place. Nevertheless, we have divided the literature on practise, into two categories because it provides additional, useful information to researchers.

With this in mind, we observe from Table 6.3 that *Agriculture* was clearly the dominant subject matter of CCA literature (almost 20% of all CCA articles). *Water* (16.6%) placed second, *Forestry* (7.4%) third and *Human Health* (5.1%) fourth. After this were *Infrastructure* (4.3%) and *Ecosystem Services* (2.7%). And all other categories came in at under 2%: Tourism (1.5%), Energy (1.5%), Fisheries (1.0%), Emergency Services (0.7%), Transportation (0.3%) and finally the Service Sector (0.1%).

Table 6.3 | Article counts and percentages (of total CCA dataset) for given categories.

Section	Climate Change Adaptation Category	Number of Articles (%) per Category
4.1	Agriculture	233 (19.9 %)
4.2	Water	194 (16.6 %)
4.3	Forestry	87 (7.4 %)
4.6	Health	59 (5.1 %)
4.4	Infrastructure	50 (4.3 %)
4.5	Wildlife\Ecosystem Services	31 (2.7 %)
4.7	Tourism	18 (1.5 %)
4.8	Energy	17 (1.5 %)
4.9	Fisheries	12 (1.0 %)
4.10	Emergency Services	8 (0.7 %)
4.11	Transportation	4 (0.3 %)
4.12	Service Sector	1 (0.1 %)

In terms of content, we will examine the top three sectors to offer an indication of the sort of analysis that is undertaken. The *Agriculture* category is predominately comprised of climate change impact assessments for a specific geopolitical place. Analysis is typically undertaken by estimating species specific responses (mostly plants but 5.2% of the agriculture category was livestock) to climate change and/or carbon fertilisation (14.7%), as derived either empirically (13%) or through simulations (30.7%), for a specific region or locality (42% mention a location). Almost a quarter of the articles examine how to manage these changes (22.5%), including consideration of soils (3.5%), pests (2.6%), carbon sequestering, agrobiodiversity (Kotschi 2006), wildlife affects, pollution etc. Analysis often includes some form of economic assessment (14.7%) and or policy implications (13.4%) such as food security (3.4%). Finally, agriculture reviews (16.4%) discussed knowledge domains, knowledge dissemination, methodology and future research.

The *Water* category is bisected along two lines: one line deals with ocean systems (29.4% of Water articles) the other with terrestrial hydrological systems (40.2%). Sea level rise is the dominant concerns for oceans systems, while terrestrial hydrological systems are considered in terms of flooding, drought, water delivery, water quality, energy, etc. In either case, methodology is dominated by climate change impact assessments for specific geopolitical locations (69.6%). Assessments are typically undertaken by applying some form of hydrological simulation model (29%) to predict water behaviour under climate change conditions, with proposed management solutions (41.2%). Socio-economic analysis comprises 14.9% of the articles and policy considerations are covered in 8.2% of the articles. Unique aspects of *Water* include a discussion of hydrological systems on ecosystems (2.6%) and energy in the form of hydropower (1.5%). Another key aspect of the category is its relationship to both agriculture (8.7%) and urban environments (8.7%). Finally, reviews (13.4%) included discussions of impacts, knowledge domains and their dissemination, method and future research.

Forestry as a category was somewhat incoherent. As with the other sectors, many of the articles referred to specific impacts on specific places (56% of the category refers to a specific place). But the assessments (28%) did not appear to be explicitly devoted to climate change per se. There appeared to be less concern in defining the actual climate change impacts over time, than there was highlighting new techniques, etc. Forestry models were mentioned explicitly in 36% of the total number of articles.

And 17% of the articles were of an economic or sociological nature. 15% of the articles were specifically about policy implications, while 29% focused on management or adaptation options. A large number of articles, focused on species specific responses to climate change (28%). While specific forestry issues included: fire (7%), pests (3%), ecosystem impacts (9%), and carbon sequestration (6%). 21% of the articles dealt specifically with reviews or information dissemination.

Category 5 (Geopolitical Place): Category 5.0 is divided into two major parts: the first section deals with place sensitive policy and land-use issues (4% of all CCA articles), while the second section is a discussion of the impacts\possibilities associated with climate change and their affect in the context of various geo-political hierarchical distinctions (53.4% of all CCA articles) (see Table 6.4). As mentioned earlier, much of the research undertaken in CCA is identified as place specific (i.e. enlists some geo-political distinction). Hierarchical distinctions were adopted that were consistent with the literature: Local, Regional (National), National, Regional (International) and International or Global. Local is meant to represent any settlement, community, town, urban centre, or municipality (9% of total CCA articles). Regional (National) (18%) is understood as being between the National and Local designations (i.e. a province, state, etc.). The National designation is self-evident (20%), and the Regional (International) (10%) represents any collections of nations or a region that crosses borders (i.e. South East Asia, developing countries, the south Pacific, etc.). Finally International or Global is meant to represent the entire world (2%).

Table 6.4 | Article counts and percentages (of total CCA dataset) for given categories.

Section	Climate Change Adaptation Category	Number of Articles (%) per Category
5.1	Land-use Policy Issues	47 (4%)
5.2.1	Local	110 (9.4%)
5.2.2	Regional (National)	212 (18.2%)
5.2.3	National	229 (19.6%)
5.2.4	Regional (International)	114 (9.8%)
5.2.5	International\Global	20 (1.7%)

Those articles designated as National can be further delineated by specific countries. An examination of the literature reveals that certain nations appear more often as subject matter. And though these trends must be taken with caution (i.e. totals are low) they can be quite revealing in a comparative sense. In terms of total articles, the USA and Canada are similar in number, with the UK about half of that and China half again. In terms of trends, the USA has shown a steady increase in articles numbers and then seems to have levelled out after 2003. Canada has steadily increased from 1996 onward, UK has increased steadily from 2002 onward and China has been sporadic with a general increase from 2003 onward. Australia also seems to have a fair number of articles (i.e. a quick search suggests numbers slightly less than the UK).

Summary: We have created a simple means of structuring our data given the objectives of our research. The structure not only offers a mental model for logically organising the information in the CCA domain, but suggests what is not in the literature, and where to look for new insights (i.e. theoretical papers and outliers). Though it is tempting to take this further and create some meta-theory regarding the necessary relationship between these parts, we should not forget that this structure is only a heuristic aid. *"The 'world of ideas' is self-contained, cogent, and certain, just because we fashion it deliberately so that our minds can move freely and confidently within it."* (Toulmin and Goodfield, 1965). A silver, integrative bullet is unlikely for such a diverse field. In the following section we will attempt to utilise the results from the previous sections, and provide some general insights regarding the CCA field.

4. Discussion & Conclusion

Despite explosive growth of the CCA field since the mid 1990s (Figure 3), successful completion of IPCC AR4[24], a Nobel peace prize for the IPCC[25], presumed field maturation (i.e. towards development studies and disaster risk reduction (IPCC, 2007; Klein, Huq *et al.,* 2007)) and increasing requests for assistance to develop local adaptation strategies[26], some authors feel that now is time for a collective re-evaluation of the field (Pielke, Prins *et al.*, 2007)[27]. Though the 'taboo' of CCA has been lifted, it is not a matter of simply embracing adaptation as it has come to be known. "New ways of thinking about, talking about and acting on climate change are necessary if a changing society is to adapt to a changing climate" (Pielke, Prins *et al.,* 2007).

24 **http://www.ipcc.ch/**

25 **http://nobelprize.org/**

26 Witness the recent activity by US urban centres to develop adaptation plans despite the lack of US Federal support. (The Economist, 2006. A survey of climate change: Dismal Calculations: Sept 7, 2006.).

27 Oppenheimer, M., O'Neill, B.C., Webster, M. & Agrawala, S. *Science* 317, 1505–1506 (2007). The Limits of Consensus. and Hagg, 2007 "What's next for the IPCC?

At some level, this will require dealing with the core issues of the field: CCA's relationship to the physical sciences (Cohen, Demeritt *et al.,* 1998); its relationship to the 'sustainable development' community (i.e. as a single instance of sustainable development); and the strategic trade-offs between mitigation and adaptation. Though such issues are readily apparent from our review of the IPPC Synthesis (Section 2.0), word/phrase counts (Table 4 and Figure 5) and articles counts (Section 3.2.2, Category 1), their solutions are not. Such issues reflect policy biases (Cohen, Demeritt *et al.,* 1998), inertia (Pielke, Prins *et al.,* 2007), and planning concerns that resist formal analysis (i.e. wicked problems (Rittel and Webber, 1973).

This report has been undertaken with the conviction that solutions will require more openness to change, greater participation from other fields (i.e. more neophytes), and greater accessibility to the CCA information domain. Understanding the domain of the field is the first step in any innovative process (Wallas, 1926)[28] and is our focus here. Csikszentmihalyi (1996) suggests that creativity can be understood as a confluence of three factors: the domain which consists of a set of rules, practises and knowledge; an individual who makes a novel variation in the contents of the domain[29]; and a field which consists of experts who act as gatekeepers to the domain, and decide which novel idea is worth adding to the field. And though individuals lie at the heart of the creative process, a great deal can be accomplished by making domain knowledge more readily accessible (Csikszentmihalyi, 1999).

In Section 3.1 we attempted to develop simple bibliometric tools to facilitate access to the knowledge domain. Using the data management features of ENDNOTE, and the citation metrics offered by SCOPUS, articles were examined in terms of the number of citations referring to them, their authors, and where and when they were published. Journals were also examined in terms of the number of CCA articles they had published, as well as their impact factor. Key authors were identified in terms of the number of publications they had written, their citation ranking, and the number of references made to the author. In all cases, non-linear, preferential attention by the CCA community was given to specific articles, journals and authors, leading one to

28 According to Wallas (1926) any creative process lists five steps in the creative process: 1) preparation (immersing oneself in the knowledge domain); 2) incubation; 3) insight; 4) evaluation; and 5) elaboration.

29 In many cases, even the problems which dominate a field may not be clearly defined; it is easy to find a solution to a well defined problem, yet much harder to formulate a problem that no one has previously recognized (Csikszentmihalyi, 1999).

speculate that a great deal of informational value can be accessed with little effort if the means to identify those papers are available and caveats kept in mind. A simple program of bibliographic library maintenance is suggested to sustain a current awareness of the information domain.

Bibliometric statistics are useful but offer little guidance in terms of domain content and structure. To acquire a better sense of the field, we therefore offered two additional techniques, which despite their crudeness, were quite helpful. The first technique (Section 3.2.1) utilises the search features of ENDNOTE to derive simple word counts. This method is useful only in a comparative sense, and for determining how concepts emerge and dissipate. For example the term 'resilience' is often utilised in the literature as a counterpart to terms 'adaptation' and 'vulnerability,' and yet it is far less prevalent. Moreover, the lead proponent of the 'resilience' concept C.S. Holling has only one publication in the CCA database (Holling, 2004), yet his name appears 60 times in the dataset (i.e. referred to by other articles). This perplexing set of statistics, is nicely elaborated upon by Janssen, Schoon *et al.*, (2006) revealing a fundamental limitation of our dataset (i.e. its disregard of an entire field of enquiry directly relevant to CCA).

The second technique attempts to structure the literature around the assumption that a general, pragmatic purpose (i.e. adapting society to human-induced climate change), pervades the field, which results in a specific structure of the CCA knowledge landscape. In reality numerous perspectives and structures are possible; IPCC reports are based upon one such structure which some believe is biased against adaptation (Cohen, Demeritt *et al.,* 1998). The purpose here was twofold: 1) to formalise a CCA information framework focused primarily upon climate change adaptation (as opposed to mitigation); and 2) to demonstrate a methodology. No grand scheme to integrate all information relevant to CCA is offered, just a given perspective and the means to organise data.

In this technique, the author, title, abstract and keywords are be used to categorise articles, and discern some sense of content, relevance and informational value. Key articles are identified by their relationship to their category, the importance of the category itself, the author's reputation, the journal's status, the article's overall ranking (as determined by its citation count), and ranking within the category. The articles are systematically classified into functional categories with the most abstract or general topics gradually leading towards the most specific, particular or applied topics. The structure reflects the idea that method and theory from various disciplines is ultimately directed towards actual decisions or actions within a specific geopolitical arena.

There are five fundamental categories of the literature: general theories and concepts, academic distinctions, methodological issues, sectors and resources and assessments as defined by their geopolitical place. Most theoretical issues concern the concept of 'adaptation' and its relationship to ancillary terms/concepts such as mitigation, sustainable development, vulnerability, adaptive capacity, etc. Economics appeared to be the dominant disciplinary source of information, methodology and decision criteria. Sociology and Political Science were also quite important. Not surprisingly, most articles dealt with resource or sector issues within a specific geopolitical place. Agriculture and Water resource questions dominated the field, with Forestry and Health issues not far behind. Surprisingly Fisheries and Ecosystem Services appeared to be under-represented.

Explanations could easily be promulgated as to why or why not, certain sectors are over, or under represented. For example, it appeared somewhat surprising that *Fisheries* is relatively under-represented given the incredible importance of fisheries to global food security and the strong evidence of marine species migrations (IPCC, 2007). It was also unexpected, that only 2.7% of the articles could be classified as Wildlife/Ecosystem Services given the overwhelming importance of ecosystem services to society's wellbeing. Why? The easy answer is that we removed such articles from the database when we discounted the behavioural and evolutionary adaptations of other species to climate change. But by doing so, we have effectively eliminated a discussion of ecology from our literature (in Category 2: *Disciplines*). The ambiguity this has created suggests that more attention will have to be paid to incorporating such distinctions in the future.

Another aspect of this omission may be that the phrase 'climate change adaptation' is specific to the disciplines associated with the IPCC process. 'Resilience' is a term utilised to convey a similar meaning by those concerned with ecosystem studies. This idea is explored more fully by Janseen *et al.* (2006) as noted above. They use bibliometric analysis to examine the 'knowledge domains' associated with these terms. Their results suggest that the 'resilience' knowledge domain is only weakly connected with the adaptation domain in terms of co-authorships and citations. 'Resilience' researchers typically have a background in ecology and mathematics, while adaptation researchers possess a background in geography and natural hazards with a focus on case studies and climate change research. It is not a simple matter of bringing the two fields together as strong theoretical disputes exist between the two fields[30]. The lesson here is that we must recognise the limitations of our methodology, the language that it uses, and compensate by expanding our level enquiry.

Finally, a categorisation that divides *Methodology* topics into: *Data, Predictive Modeling,* and *Choosing\Vetting Possibilities* appeared helpful in resolving the basic relationships between topics in the field (see Chapter 1). It was based upon the notion that a general purpose pervades the field and a systems approach can be utilised to order or structure information so that inferences can be made about key relationships. If a researcher accepts the goals and intent of the perspective offered here, the structure may give some indication of where their research fits into an overall scheme, or it may generate new ideas for future research. The inter-relationship of the three factors (data, models, choice) also implies that other formulations may be possible which may then open new doors to analysis. Many perspectives are possible.

In conclusion, adaptation is one of those omnipresent processes that are difficult to pin down. On the one hand we are all intimately familiar with adaptation (i.e. we all adapt daily to weather), yet there is a growing realisation that responses based upon past climatic experience will be far from adequate given what awaits us. An underlying assumption of this report is that we possess the capacity to creatively adapt[31] given that we are provided with the correct tools, environment and attitude (Csikszentmihalyi, 1999). An attempt has been made here to provide the tools to understand the CCA information landscape. Clearly much more needs to be done to move from static, dated, sporadic reviews (i.e. IPCC assessment reports) to more dynamic approaches that incorporate real time bibliometric analysis of climate change articles. Larger datasets, extended analysis, and more user friendly tools would certainly facilitate the migration of neophytes into the field which would facilitate a more extensive debate on climate change adaptation. And given the nature of the core CCA issues, this cannot but help.

30 Roe's book "Taking Complexity Seriously" generated a strong debate with authors such as C.S.Holling, as witnessed in the journal *Ecology and Society* Vol. 4, Issue 2 (2000).

31 Although see Homer-Dixon, T. (2000). *The Ingenuity Gap: Can We Solve the Problems of the Future?* Knopf, Toronto.

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