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Managing uncertainty, ambiguity and ignorance in impact assessment by embedding evolutionary resilience, participatory modelling and adaptive management

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Abstract
In the context of continuing uncertainty, ambiguity and ignorance in impact assessment (IA) prediction, the case is made that existing IA processes are based on false ‘normal’ assumptions that science can solve problems and transfer knowledge into policy. Instead, a ‘post-normal science’ approach is needed that acknowledges the limits of current levels of scientific understanding. We argue that this can be achieved through embedding evolutionary resilience into IA; using participatory workshops; and emphasizing adaptive management. The goal is an IA process capable of informing policy choices in the face of uncertain influences acting on socio-ecological systems. We propose a specific set of process steps to operationalise this post-normal science approach which draws on work undertaken by the Resilience Alliance. This process differs significantly from current models of IA, as it has a far greater focus on avoidance of, or adaptation to (through incorporating adaptive management subsequent to decisions), unwanted future scenarios rather than a focus on the identification of the implications of a single preferred vision. Implementing such a process

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would represent a culture change in IA practice as a lack of knowledge is assumed and explicit, and forms the basis of future planning activity, rather than being ignored.

1. Introduction

This paper begins from the standpoint that the consideration of uncertainty (including ambiguity and ignorance) in impact assessment (IA) is a problem, leading to decisions which fail to accommodate the uncertain outcomes which may materialise as a result of planning and development decisions. The aim is to develop a process of IA which can better accommodate this uncertainty.

To meet this aim, we argue for the adaptation of IA processes to accommodate ‘post-normal science’ (which assumes science is neither value-free nor certain, in contrast to ‘normal science’ (Ravetz, 1999)), so that it can improve decision-making in contexts characterised by ambiguity, uncertainty and ignorance. We propose that embedding the concept of evolutionary resilience into IA through the use of participatory techniques combined with subsequent increased emphasis on adaptive management will provide an effective means of facilitating post-normal science.

Thus, the paper introduces a new combination of ideas drawn from existing literature. It also adds to the literature on post-normal science, uncertainty, and ambiguity and ignorance, by proposing a new process that moves beyond the theoretical deliberations which currently typify that literature, by translating the theory into practice.

We begin by explaining and justifying the problem statement (that uncertainty is inadequately accommodated in current IA process) in the remainder of this section, before introducing the structure of the paper, which is focussed around justifying, and then detailing, the new process proposal.

We define IA after the International Association for Impact Assessment (IAIA) as the “process of identifying the future consequences of a current or proposed action. The “impact” is the difference between what would happen with the action and what would happen without it” (International Association for Impact Assessment, 2009, p.1). We distinguish ambiguity, uncertainty and ignorance from risk after Stirling (2010) as illustrated in Figure 1, which also suggests appropriate qualitative and quantitative methods for identifying and/or managing these types of knowledge.

Stirling (2010) argues that a narrow focus on risk, which commonly informs many decision-making processes and often underpins IA processes in practice, inadequately considers incomplete knowledge and can therefore lead to decisions that ultimately prove to be poor. He recommends that attention be paid to more “neglected areas of uncertainty” (Stirling, 2010, p.1030) including ambiguity and ignorance (and this generic meaning for uncertainty, encompassing uncertainty, ambiguity and ignorance will be used in this paper); thus the focus of this paper will be on ambiguity, uncertainty and ignorance, and not on risk. In IA, uncertainty is a recognised problem (de Jongh, 1988; Geneletti et al., 2003; Liu et al., 2010),
although ambiguity and ignorance have received much less attention (a simple illustration is based on the number of results returned by the Scopus database at the time of writing considering the search terms “impact assessment” AND “uncertainty” (1,551), “ambiguity” (31) and “ignorance” (18) respectively), except where uncertainty is used as more of an umbrella term where ambiguity and ignorance are not distinguished.

![Uncertainty Matrix](image)

**Figure 1 Uncertainty matrix (Adapted from Stirling, 2010)**

The first decade of IA practice, following the introduction of the National Environmental Policy Act in the United States, largely ignored the issue of uncertainty (de Jongh, 1988) and the theoretical underpinning of IA at that time, rationalism (i.e. better information leads to better decisions based on ‘normal science’ whereby uncertainty is not present) was not questioned. More recently, however, there has been significant debate about the appropriate theoretical basis for IA, particularly in the light of uncertainty and different values of stakeholders (see, for example, Lawrence, 1997; Wallington *et al.*, 2007; Weston, 2010; Pope *et al.*, 2013). The argument is therefore that rational decision-making is neither typical of proposals subject to IA, nor appropriate (Kørnøv and Thissen, 2000). Furthermore, Petersen *et al.* (2011) describe a “scandal around uncertainty management in 1999” (p. 362) in the Netherlands Environmental Assessment Agency, whereby a senior statistician in the Agency published a national newspaper article criticising their approach of relying heavily on computer models without real measurements to back them up, providing unrealistic accuracy claims (i.e. hiding uncertainty). This threatened the Agency’s funding and resulted in them attempting to introduce a post-normal science approach to their work via guidance on
uncertainty assessment and communication, and guidance on stakeholder participation; albeit they conclude that changing the mind-sets of their staff is a longer-term prospect. This example typifies the field of IA which is traditionally very technocratic, embedded in a utopian rationalist view of the role of science in policy (Petersen et al., 2011) which argues that the assimilation of scientific, value-free information, should influence policy outcomes – despite the evidence to the contrary. This view of IA is institutionalised which, as the Netherlands Environmental Assessment Agency found, makes any redirection a ‘scandal’.

Within IA, attempts to manage uncertainty generally focus on transparent disclosure of acknowledged areas of uncertainty (see, for example, Tennøy et al., 2006). This approach, however, is typically based on an assumption that uncertainty is “identifiable, quantifiable and communicable” (Duncan, 2013, p.151). As such, there is universal agreement that uncertainty exists in IA, particularly in impact prediction (de Jongh, 1988), that uncertainty remains a key source of decision difficulty (Retief et al., 2013) and that it needs to be managed in some way, but no consensus exists on how to do this (Leung et al. 2014).

The remainder of the paper addresses the aim of the paper, to develop an IA process that better accommodates uncertainty. The next section of this paper examines the theoretical context for IA, generally, and the extent to which uncertainty, ambiguity and ignorance can properly be incorporated in a post-normal science framing of the IA process. Section 3 defines and investigates the concept of resilience, identified in Figure 1 as a useful concept in dealing with ignorance, and the extent to which it is compatible with a post-normal science IA process. In Section 4, the paper proposes a specific process of IA that incorporates resilience (more specifically, evolutionary resilience) and adaptive management more intensively than is currently typical in order to better consider and manage uncertainty, including ambiguity and ignorance. Finally reflections are presented on the practicability of the proposed post normal science IA process, and the extent to which the aims of the paper have been met.

2. Impact assessment theory and uncertainty

Impact assessment can be, and traditionally has been, framed in the context of rational decision making whereby better information leads to better decisions (Bartlett and Kurian, 1999; Cashmore, 2004). Inherent in this ‘positivist’ theory of decision making are the assumptions that: 1) decision makers behave rationally; and 2) IAs practice ‘normal’ science whereby the level of system understanding is sufficient to associate cause and effect (i.e. uncertainty, ambiguity and ignorance are assumed to be limited or non-existent). Taking the first of these assumptions, the evidence that objective information is transferred via IA into policy is somewhat limited (Wood and Jones, 1997; Cashmore et al., 2004; Cashmore et al., 2009; Elling, 2009; Van Buuren and Nooteboom, 2009; Eales and Sheate, 2011). More and more authors argue that decision-making is not rational and that IA, for example, has considerably more roles than simply information provision (see, for example, Lawrence, 2000; Leknes, 2001; Bond, 2003; Bekker et al., 2004; Cashmore, 2004; Owens et al., 2004).
Bartlett and Kurian (1999) detail six separate models explaining the role of environmental impact assessment in decision-making, in which the information processing (rational) model is just one end of the spectrum of influence; other models include the symbolic politics model, the political economy model, the organisational politics model, the pluralist politics model and the institutionalist model.

Despite the second assumption that current system understanding is sufficient to associate cause and effect and that uncertainty (including ambiguity and ignorance) is limited, a number of studies have demonstrated that impact predictions are poor at incorporating uncertainty (see, for example, Bennett et al., 2001) as existing understanding of systems is insufficiently clear to account for all the potential variation. This lack of complete system understanding can lead to predictions which are inaccurate (Dipper et al., 1998). In one example, a Gaussian plume model was compared against tracer data in two urban settings in the USA and found to both over- and under-predict concentrations at different receptors (Hanna and Baja, 2009). There is also evidence that complex prediction leads to a focus on smaller areas of certainty, at the expense of other issues that are no less important, but which cannot be predicted with any certainty; similarly, organisations might make simplifying assumptions that set inappropriately restricted boundaries around the issues to be investigated (Turner, 1976; Stirling, 2010). Duncan (2013) acknowledges the complexity of uncertainty and comments on the reality of IA practice whereby uncertainties are communicated by a range of actors drawing on different narratives of the potential consequences posed by uncertainties; he therefore suggests a constructivist perspective needs to be taken when dealing with uncertainty in IA, again calling into question the existing rationalist theoretical framings of impact assessment. Furthermore, and more fundamentally still, the psychologist Kahneman (2013) points out that individual humans inevitably rapidly arrive at simplistic understandings of complex situations as a direct function of how our brains work with respect to favouring intuition and easy or lazy answers. Other psychological characteristics of human decision-making and the implications for IA practice were summarised by Retief et al. (2013); in a nutshell, rational decision-making does not come naturally or simply to anyone, and as Kahneman (2013) shows, even trained experts can miss the key evidence in the face of complexity.

As such, there is cause for concern for both assumptions, with little evidence that the results of IAs are either rational, or used rationally in decision-making, and only limited evidence that science is certain. This means that the positivist theory of IA is not fit-for-purpose, meaning that it does not explain how IA works or influences decision makers, and it certainly does not facilitate the consideration of uncertainty, ambiguity or ignorance. Instead what is required is a process of IA which incorporates ‘post-normal’ science as a means to better reflect both lack of knowledge and differing values. Ravetz (1999) explains that ‘normal’ science is conceived as being straightforward scientific problem-solving, and that ‘normal’ policy-making is conceived as being the straightforward transfer of objective scientific knowledge into policy. He further defines post-normal science in diagrammatic terms as occupying a space where either system uncertainties (including ignorance and ambiguities), or decision stakes (or both) are high (Figure 2).
Figure 2  Post-normal science (after Ravetz, 1999)

The fundamental argument Funtowicz and Ravetz made almost two decades ago was that quantification is an inadequate approach for dealing with complexity and uncertainty because people will react to uncertainty in different ways (see, for example, Funtowicz and Ravetz, 1993; Funtowicz and Ravetz, 1994a; Funtowicz and Ravetz, 1994b; Funtowicz and Ravetz, 1994c). The argument for recourse to post-normal science is grounded in an assumption that current understanding of natural systems is so incomplete that any models developed are inadequate representations where the uncertainties are based on ignorance (Funtowicz and Ravetz, 1994b). Petersen et al. (2011, p.365) refer to three key elements in a post-normal science paradigm:

1) the management of uncertainty;
2) the management of a plurality of perspectives within and without science;
3) the internal and external extension of the peer community.

The arguments made thus far point strongly to the need to shift the dominant impact assessment paradigm, moving from an assumption of normal science to one of post-normal science which can better represent uncertainty, ambiguity and ignorance through inclusion of each of these three elements of post-normal science.
3. Resilience and post-normal science in impact assessment

In this section, we investigate the utility of the concept of resilience as a means of embedding post-normal science into IA processes, thereby developing an appropriate ex ante tool for considering uncertainty, ambiguity and ignorance. Hermans and Knippenberg (2006) also used resilience (and justice) as a key principle with which to evaluate sustainability assessment, while the potential of resilience thinking to contribute to strategic environmental assessment has also received attention (for example, Benson and Garmestani, 2011; Slootweg and Jones, 2011; Larsen et al., 2013).

Drawing on the pioneering work of Holling (1973), Davoudi et al. (2012, p.300) explain the difference between engineering resilience, which is defined as “the ability of a system to return to an equilibrium or steady-state after a disturbance” where the emphasis is on the time it takes a system to return to where it was (which might be defined as returning to ‘normal’), and ecological resilience, which is defined as “the magnitude of the disturbance that can be absorbed before the system changes its structure” where the emphasis is on the ability of the socio-ecological systems to persist and adapt. Davoudi et al. (2012) emphasise that both of these definitions embody the discourse of bounce-back ability, in that the end point in each case is a stable equilibrium state; this assumes that this state is worth returning to, and that it is sensible to return to.

This thinking aligns with the current model of IA predominantly practiced which is baseline-led. That is to say, that it takes the existing situation as being the preferred endpoint and examines the implications of change to this existing situation, proposing mitigation measures to perpetuate it. As (Hacking and Guthrie, 2006) put it: “[T]he established approach to impact assessment is baseline-led, whereby the conditions that are likely to prevail in the absence of a proposed initiative are used as the ‘benchmarks’ for determining the significance of impacts”. It is worth noting, however, that a change in emphasis of strategic IA towards the delivery of sustainable development as its goal is starting to change this prevailing practice (Sadler, 2011).

Davoudi et al. (2012, p.302) offer the alternative concept of evolutionary resilience, which they suggest “challenges the whole idea of equilibrium and advocates that the very nature of systems may change over time with or without an external disturbance”. In the context of uncertainty, this suggests that there is a possibility of the equilibrium state shifting subsequent to the implementation of a project, plan, etc., which is not necessarily something which can be avoided, and which in part is determined by fluctuation in natural conditions. They go on to stress the paradigm shift in thinking that this concept represents, whereby the past system behaviour is no longer a useful indication of the future system behaviour and that the socio-ecological system can suddenly change and never return to its past state.

Evolutionary resilience can be conceptually explored through the heuristic of the adaptive cycle, which is illustrated in Figure 3.
The adaptive cycle suggests that system behaviour often reflects a period of growth, $r$ (involving exploitation of resources) which is followed by more stability and an emphasis on conservation of the resources locked up in the system, $K$. After a tipping point is passed, the system collapses, releasing resources, $\Omega$. This phase can then lead to reorganisation and a new adaptive cycle, $\alpha$ – in a continual fashion – although the new cycle may represent an entirely different socio-ecological system.

Another useful and related concept is panarchy (Gunderson and Holling, 2002), which Slootweg and Jones (2011) have identified as having the potential to strengthen strategic IA. Panarchy is represented by a series of adaptive cycles operating at different geographical and temporal scales, although the cycles are connected and therefore have implications for each other. Whilst originally developed for purely ecological systems, the concept of resilience is now applied to socio-ecological systems, albeit with mixed success (Davidson, 2010) and so overlaps with the domain of IA, particularly when sustainability is invoked.

To summarise, a post-normal science perspective needs to be applied to IA to accommodate the ambiguity, ignorance and uncertainty inherent in IA. Thus, a form of ex ante assessment is required which embeds post-normal science. Evolutionary resilience seems to provide a potentially useful concept as it acknowledges that severe perturbation of systems can change them indefinitely. However, this is counter to the conventional way Governments operate which is founded on the normative assumption that the current state of the socio-ecological environment experienced by people is the one worth preserving. An example would be the requirement placed on European Union member states to preserve existing habitat designated
under the Habitats Directive (Council of the European Communities, 1992) in the face of climatic change moving the range of species northwards. It is also counter to the conventional way baseline-led IA is approached, which largely seeks to maintain baseline conditions. What resilience offers is a “structured way of looking at complexity, uncertainty and interrelatedness of systems and processes” (Slootweg and Jones, 2011, p.263) such that, rather than seeking to predict change in the face of uncertainty and ambiguity, it is better to seek to accept and accommodate that unpredictable change will occur. Such a change in philosophy can already be detected in climate change assessment where increasing focus is placed on adaptation rather than mitigation (Byer and Yeomans, 2007). A move towards managed retreat from coastal defences due to climate change might provide an example of such an adaptation strategy.

4. Combining the parts – impact assessment for building resilience to uncertainty

Continuing with our example around climate change, it is clear that consideration of climate change impacts, which are now already evident, calls into question a focus on maintaining the existing baseline and implementing mitigation measures (Walker et al., 2002). Canter and Atkinson (2010) focus on adaptive management to increase system resilience and Walker et al. (2002) propose resilience management as a means of preventing unwelcome system reconfigurations. Our approach is to embed elements of adaptive management and resilience management into the well-known stages of the IA process, recognising that attempting to understand systems is typically (although not universally) a strategic-level activity rather than project-level. We take the view that some level of change is inevitable, whether due to exogenous (external to the system) or endogenous (from within the system) forces. So we believe that IA should retain its traditional role of predicting what can be predicted and mitigating where possible, as long as the ambiguity, ignorance and uncertainty is acknowledged and managed through an increasing focus on adaptation, fostering socio-economic system resiliency, and acceptance of the inevitability of change.

Taking the early explanation of the strategic IA process published by Lee and Walsh (1992) as the basis for our step-wise IA approach, we try to envisage what a such a process would look like with adaptive management and resilience management reflecting the notion of evolutionary resilience embedded (thereby implementing approaches for dealing with ignorance according to Figure 1) considering the stages of screening; scoping; impact assessment (incorporating report production); decision-making (which incorporates public consultation on the report); and follow up (Lee and Walsh, 1992, p.132). In this context, we draw heavily on Walker et al. (2002) who, as part of the Resilience Alliance (see www.resalliance.org), have suggested an approach for managing resilience in socio-ecological systems. They recommend a four-stage approach including: 1) establishing important attributes of the study system through stakeholder engagement; 2) identifying predictable and unpredictable drivers and obtaining stakeholder visions of possible trajectories; 3) quantitative analysis of where resilience resides; and 4) integrated evaluation by a wide range of stakeholders of the management and policy implications. This approach is
consistent with the views of Hermans and Knippenberg (2006) who identified that participatory processes are key in a context where stakeholder views on potential outcomes are highly variable amidst high levels of uncertainty, and with the need for great pluralism espoused by Bond et al. (2013) when considering assessment of sustainability (participatory deliberation is identified as a suitable method for dealing with ambiguity in Figure 1). Such participatory approaches are also required for the achievement of legitimacy (Walker et al., 2002; Owens et al., 2004) and fit into the participatory discourse framing required for a post-normal science approach to IA.

Assuming screening requires strategic environmental assessment, the remaining four stages of the strategic environmental assessment process can be mapped against the Walker et al. (2002) stages for managing resilience for socio-ecological systems as shown in Table 1.

**Table 1. Mapping strategic environmental assessment against managing resilience for socio-ecological systems.**

<table>
<thead>
<tr>
<th>Strategic environmental assessment stages (after Lee and Walsh, 1992)</th>
<th>Stages for managing resilience for socio-ecological systems (after Walker et al., 2002)</th>
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<tr>
<td>1. Screening</td>
<td>1. Screening</td>
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<tr>
<td>2. Scoping, including types of impacts and alternatives to be considered</td>
<td>2.a. Establishing important study attributes; 2.b. Identifying drivers of change and alternative system response trajectories</td>
</tr>
<tr>
<td>4. Decision making</td>
<td>4. Decision making</td>
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<tr>
<td>5. Follow-up</td>
<td>5. Follow-up</td>
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Assuming a modified process to account for the stages proposed by Walker et al. (2002), the screening role (stage 1) remains largely unaltered although, as will be seen, the proposed process is resource intensive and would likely be suitable for fewer case applications than standard models of strategic environmental assessment. With this in mind, the following discussion focuses on stages 2-5.

For stage 2.a., *scoping - establish important study attributes*, for embedding evolutionary resilience, the parameters for the assessment would need to be different in that they would need to accommodate much longer time horizons. The very first stage requires identification of key stakeholders to establish a workable yet diverse group to follow the process through
and conduct visioning exercises to identify alternative trajectories in the next stage; such exercises are common in objectives-led assessments and advice on the approaches to take can be found based on guidance and learning taken from strategic environmental assessment and sustainability appraisal approaches (see, for example, Donnelly et al., 2006; Bond et al., 2011). Walker et al. (2002) also recommend a review of the historical profile of the system, as past changes can potentially be attributed to particular events and allow a greater understanding to be developed of the manner in which the system might react to future shocks (including disasters). An assessment also needs to be made to identify:

“Which factors are controllable (e.g., land use policy) and which are not (e.g., climate)? What are the ambiguities in the system, the uncertainties that can be neither controlled nor quantified?

How do the current institutional arrangements, property rights in particular, and the distribution of power and wealth influence formal and informal decision making and access to information?” (Walker et al., 2002, p.8)

Stage 2.b., scoping - identify drivers of change and alternative system response trajectories, as for any assessment process, this is key to a successful outcome. In the context of embedding evolutionary resilience, this exercise needs to focus on scenario building (which is a suitable technique for dealing with uncertainty as identified in Figure 1), with stakeholders aiming to identify, as well as internal influences, the key external influences that will have an effect on the socio-ecological system, but which cannot themselves be controlled. Walker et al. (2002, p.10) provide examples as being “variability resulting from climate change, technological innovation, and unforeseeable reactions of people to unfolding change in the social-ecological system”. The scenarios would be built taking into account the following three elements as suggested by Walker et al. (2002):

1) the stakeholder vision for the future – taken from stage 2 in terms of the constituents of human well-being;

2) uncontrollable external influences (physical, social, and economic) that would detrimentally affect some or all of the constituents of human well-being (for example, climate change, Tsunami, volcanic eruption, development of fusion technology);

3) possible policies controlling the elements of the socio-ecological system which are controllable (the internal influences).

Traditional scoping for strategic environmental assessment would examine external policy drivers and the current baseline situation in the context of draft plan policies in any case; however, this approach differs in focusing on visions of the future and a structured and systematic examination of natural and anthropogenic threats which are beyond control. Through consideration of these three elements, the stakeholder group can develop a series of scenarios reflecting different futures based on different types of interventions (planned and controllable, and unplanned and potentially uncontrollable). This sets the scope of the analysis as the set of alternative futures. The difference from the current practice of strategic
environmental assessment is that there needs to be acceptance that the plan or policy being assessed is unlikely to be able to guarantee one preferred future; rather it needs to accommodate the possibility of each of them where external influences cannot be controlled – thus adaptation has a far greater emphasis than in current assessment processes.

Stage 3.a., impact assessment - quantitative analysis of where resilience resides, and Stage 3.b., impact assessment - integrated evaluation by a wide range of stakeholders, revolve around decisions of significance based on a consideration of evidence, i.e. as for any IA process. However, the assessment would ideally be undertaken using a workshop-based analytic-deliberative approach (see, for example, Burgess et al., 2007; Fish et al., 2011; Karjalainen et al., 2013) that draws on modelling where possible. At this stage, the composition of the workshop team is critical as it needs to include representatives of affected communities, decision-makers, and also socio-ecological system experts who can be called upon to comment on the likely implication of interventions on particular scenarios, and to identify the key variables that are likely to control socio-ecological outcomes. Fish et al. (2011) provide specific advice on how to identify appropriate groupings of stakeholders. The analytic-deliberative approach can also be designed around a participatory modelling approach (Videira et al., 2003; Landström et al., 2011; Lane et al., 2011) whereby a series of workshops are held to sequentially agree upon deliverables and methods, and then allow deliberation based on model outputs either requested in real-time, or pre-requested where model complexity precludes real-time analysis.

The workshops should proceed on the basis of exploring scenarios and potential policy interventions, with experts and/or modelers called upon to highlight particular system uncertainties, and the implications on the socio-ecological system of both planned (internal) and unplanned (external) influences. A participatory modelling approach is likely to be appropriate here, whereby workshop participants can ask the modelers “what if” questions, and gain real-time answers to develop their scenario thinking; participatory modelling approaches have been successfully used in flood risk settings (see, for example, Landström et al., 2011; Lane et al., 2011) and are recommended in this context also. Through iterative development of ideas, the workshop participants would need to develop a set of proposed policies which are most resilient to external influences, and which will most likely and/or most closely achieve the preferred scenario. A lot of the work would be based on qualitative information, although some quantitative modelling could be undertaken if necessary and appropriate. The key to a successful outcome is to have anticipated that critical system variables could be threatened by external influences (like climate change) and to have planned some form of adaptation. They key to embedding evolutionary resilience is the acceptance that the socio-ecological environment is likely to have to adapt to accommodate uncertain events.

Stage 4., Decision making, is as for other forms of IA. Elected representatives, who would need to be part of the stakeholder groups developing and assessing the scenarios, would identify the appropriate policies to adopt on the basis of the estimated resilience of the subsequent outcomes. At this stage, any decision makers will still be subject to the political pressures associated with any decision, and there is no guarantee that workshop
recommendations will be implemented. However, we are not suggesting wholesale upheaval of political decision making in this paper, rather we are attempting to better incorporate and communicate uncertainty into an existing decision-support tool. In this event, the suggested IA adopts a post-normal science approach in terms of embedding uncertainty (including ambiguity and ignorance) in the analysis, but reverts to normal science in still expecting rational decision-making based on this process. As such, this stage would need to specifically acknowledge, and require, follow-up as detailed in the next stage.

Stage 5. *Follow-up* needs to take account of the fact that both uncertainties and future visions of human well-being are likely to change over time. As such, we would propose that a form of adaptive follow-up, as set out in (Morrison-Saunders et al., 2014) is practiced whereby there is frequent reflection on the suitability of the current pathway, and examination of the validity of the scenarios adopted, and the policies implemented to achieve the agreed vision. Over time, understanding of the socio-ecological system is likely to improve and this will warrant reassessment of the adopted policies. Also, the vision for the future may also change. In either case, the follow-up activities need to adapt to the changing circumstances, which sets adaptive follow-up apart from traditional follow-up.

5. Conclusions

In this paper we explained why uncertainty, ambiguity and ignorance are problematic in IA, and have developed a process whereby they can be better managed through embedding an evolutionary resilience approach, supported through participatory deliberation and adaptive management, into the process. Whilst designed for strategic IA in particular, there is no reason why such an approach cannot also be applied at the project level – subject to the resource constraints discussed below.

Specifically we have drawn on Stirling (2010) (see Figure 1) in using scenario methods to better manage uncertainty, interactive modelling and participatory deliberation to manage ambiguity, and adaptive management and resilience to manage ignorance.

The key changes from ‘business as usual’ IA are:

1) a move towards an objectives-led, visioning approach, rather than a baseline-led approach (although this already occurs in Sustainability Appraisal of land use plans in England, see Thérivel et al., 2009);

2) a focus on uncontrollable (external) threats that will change the future environment that the plan or policy is attempting to manage, leading to an emphasis on adaptation as well as mitigation, particularly during follow-up;

3) the use of analytic-deliberative techniques, possibly including participatory modelling, which are not common in existing IA practice;
4) a focus on embedding resilience in scenarios which goes beyond the objective of the project, plan or policy, and on mitigation and adaptation to uncertain events;

5) a recognition that the future is likely to be different from that planned, and that continual adaptation to changing circumstances is necessary.

The big difference here is that the focus needs to be on much longer timescales, although we have not specifically indicated what this means. Practice suggests that assessment timescales usually span the duration of a proposed plan or policy (Bond and Morrison-Saunders, 2011) whereas intergenerational needs to be looking at timescales measured at least in decades, and preferably in centuries. The focus also needs to be on the uncertainties and system shocks which cannot be predicted in an attempt to develop a more resilient future, and which are a considerable weakness of current IA practice. We have drawn very heavily on the work of Walker et al. (2002) in outlining an approach to embed resilience in IA; we would argue that it is necessary to do this given that IA is almost universally required across the world (Morgan, 2012). It is therefore an accepted decision-support tool and one which has greater traction with decision makers who are suspicious of adopting new approaches given the resource implications.

The extensive use of analytic-deliberative techniques would be resource intensive, both in terms of being expensive, but also demanding significant investment of expert time (Bond et al., 2011), particularly as the peer community is extended both internally and externally. Although necessary, such approaches would in all reality preclude the application of such a model of assessment to all but the most strategic decision-making contexts (including very large projects). However, this is in line with the application of the approach to the relevant context (as argued by Hilding-Rydevik and Bjarnadóttir, 2007) set out in Figure 2 – where the decisions stakes, or uncertainty, or both are very high. In the majority of cases, existing IA practices can continue to operate. There is increasing interest in the potential to embed resilience thinking in IA (Slootweg and Jones, 2011) which, up to now, has been conceptual in nature. We believe we have met our aim to develop a process of IA which can better accommodate uncertainty, but have not tested the approach in practice. We offer the process to others and encourage them to test and develop the approach so that it can evolve into a more cost-effective process that can be widely applied in the quest to anticipate and manage an uncertain future.

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