A problem structuring method for ecosystem-based management: The DPSIR modelling process

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Abstract

The purpose of this paper is to learn from Complex Adaptive Systems (CAS) theory to inform the development of Problem Structuring Methods (PSMs) both in general and in the specific context of marine management. The focus on marine management is important because it is concerned with a CAS (formed through the interconnection between natural systems, designed systems and social systems) which exemplifies their particularly 'wicked' nature. Recognition of this compels us to take seriously the need to develop tools for knowledge elicitation and structuring which meet the demands of CAS. In marine management, chief among those tools is the DPSIR (Drivers – Pressures – State Changes – Impacts – Responses) model and, although widely applied, the extent to which it is appropriate for dealing with the demands of a CAS is questionable. Such questioning is particularly pertinent in the context of the marine environment where there is a need to not only recognise a broad range of stakeholders (a question of boundary critique) but also to manage competing knowledge (economic, local and scientific) and value claims. Hence this paper emphasises how a CAS perspective might add impetus to the development of a critical perspective on DPSIR and PSM theory and practice to promote a more systemic view of decision-making and policy development.

Keywords: Problem structuring; Complex adaptive systems; OR in natural resources; DPSIR; The Ecosystem Approach; Sustainable development

1. Introduction

This paper is concerned with the Ecosystem Approach and the use of a particular knowledge elicitation and structuring approach, the DPSIR (Drivers – Pressures – State Changes – Impacts – Responses) model, within a particularly challenging context – namely the marine environment.

Management of the marine environment has been characterised in various ways and many point to its complexity. Jentoft and Chuenpagdee (2009) define fisheries and coastal governance to be a 'wicked problem', and others concerned with sustainable development, for example Espinosa et al. (2008), cite Patterson and Theobald (1999) and Young (1998), who regard this area to be 'characterised by a lack of autonomy at the local level and the absence of cross-disciplinary support and decision-making processes to ensure effective follow-through'. In the light of the above it would certainly seem that the marine environment is a prime candidate for the employment of Problem Structuring Methods. However, Bell and Morse (2007) argue that ''PSMs...are seen and experienced less often in areas of wide ranging and highly complex human activity – specifically those relating to sustainability, environment, democracy and conflict (or SEDC)'' and Paucar-Caceres and Espinosa (2011) find that interest in systemic approaches to environmental management is relatively new. Hence a concerted effort needs to be made to develop PSMs that enable a more holistic understanding and evaluation of multiple and interacting human uses of the marine environment, particularly as they inform decision-making relating to strategies, instruments, regulations and policies that will shape future use and sustainability. One of the key decision support tools that has emerged in recent years is the DPSIR model which is used to assess, manage and communicate the impact of environ- mental policy changes and associated problems (whether it can be claimed to be a PSM is tentatively addressed in this paper by questioning how both are realised in practice). It is complemented by a set of guiding principles, the Ecosystem Approach, and practices, Ecosystem-Based Management (EBM), and has widespread application (see for example its application to environmental indicators (EEA, 1999), offshore wind power (Elliott, 2002), sustainability in coastal zones (Bidone and Lacerda, 2004) and marine aggregates extraction (Atkins et al., 2011a)).

The aim of this paper is to contribute to the development of PSMs in general and for use in the marine management in particular by reviewing the characteristics of CAS and suggesting how intervention processes may be designed accordingly. One of the main features of CAS is that no one person within the CAS can have complete knowledge of it because it is too complex and dynamic hence the need for participation. Whilst the literature on PSMs emphasises participation in the knowledge elicitation and structuring process, with a focus on model building, guidance on how this might best be brought about is somewhat limited and a broad range of interpretations manifest in practice. In addressing what counts as participation there appear to be two key variables: breadth of participation, which is essentially a question of what and/or whom is or is not included, and depth of participation, which is essentially a question of managing knowledge and associated value claims. Such issues reflect a concern for what constitutes meaningful participation which resonates strongly with the multi-disciplinary writing team of this paper (comprising of a systems practitioner, an economist and two marine ecologists); each party bringing a different perspective and knowledge to bear. Hence the argument is established for a critical perspective on DPSIR as a PSM and a more systemic view of decision-making and policy development in the marine environment.

We start, though, by examining advancements in environmental management that gave rise to the DPSIR model and its further development. A case-study involving a multi-user coastal site, Flamborough Head, UK illustrates how such contexts exemplify the characteristics of a CAS and also demonstrates how DPSIR can be used to capture, in a simple manner, key indicators and effects.

1. The Ecosystem Approach, ecosystem-based management and the DPSIR model

Gibbs and Cole (2008) establish that the marine environment can be perceived to be a Complex Adaptive System (CAS) (Buckley, 1967; Holland, 1992) involving:

- a large numbers of parts undergoing an array of simultaneous nonlinear interactions;
- the behaviour of the whole feeding back to the individual parts, modifying their behaviour;
- the evolution of interactions over time as the parts adapt in an attempt to survive in the environment that is the other parts of the whole; and
- the ability to use internal models to anticipate and evaluate the consequences of actions, on the basis of past behaviour, without commitment.

Atkins et al. (2011a,b) regard marine management as being concerned with a CAS formed through the interconnection between natural systems (terrestrial, estuarine, coastal, and oceans), de- signed systems (extractive industries, tourism, transportation, power generation, etc.) and social systems (fishing communities, etc.). Thus recognising ‘‘a combination of social needs, ecological limits and quality of life, treating the natural and human social systems as co-evolving in a recurrent dance of interaction, each dependent on outputs from the other and providing inputs to it.’’ (Espinosa et al., 2008, pp. 637–638). Recognition that the marine environment can be taken to exhibit the defining characteristics of a CAS has led to the development of approaches that are more holistic in orientation such as the Ecosystem Approach (Kay et al., 1999).

The Ecosystem Approach can be regarded as a philosophy for summarising the means by which the natural functioning and structure of an ecosystem can be protected and maintained while still allowing and delivering sustainable use and development by society (Elliott et al., 2006; Elliott, 2011). The affect of such a philosophy has been to shift emphasis away from reductionism based single-species research, compartmentalised decision-making and narrow policy instruments to more systemic approaches which not only recognise scientific but also social, economic and other inherent features of such systems (see for example, Christensen et al., 1996; Daniels and Walker, 1996; Holling and Meffe, 1996; Hughes et al., 2005; Olsson et al., 2004; Olsson et al., 2008; Ruckelshaus et al., 2008); collectively such approaches are known as Ecosystem-Based Management (EBM). At the heart of EBM lies the DPSIR model, to manage the exploitation of the natural environment and any adverse effects of such activities. In the following, the Ecosystem Approach, EBM and DPSIR will be further defined.

2.1. The Ecosystem Approach: philosophical underpinnings

At its most comprehensive, the concept of The Ecosystem Approach has been defined by The Convention for Biological Diversity (CBD, 2000) as:

'*a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. The application of the Ecosystem Approach will help to reach a balance of the three objectives of the Convention: conservation, sustainable use and the fair and equitable sharing of the benefits arising out of the utilisation of genetic resources*'.

The Convention indicates that the implementation of The Eco- system Approach should be based on 12 guiding principles for the achievement of sustainable management, as outlined in Box 1.

2.2 Ecosystem-based management and the DPSIR model

If the Ecosystem Approach provides the guiding principles, then EBM represents practice. The challenge of developing management approaches for such complex systems, though, should not be underestimated; Gibbs and Cole (2008) argue that ''the very nature of oceanic and coastal ecosystems will prevent us from developing comprehensive forecasting abilities of marine ecosystems.'' (p. 75) and Levin et al. (2009) claim that 'little practical advice is available' on how to select specific management measures to achieve EBM goals.

Taking up the challenge, Levin et al. (2009) go on to propose a decision analysis based approach, Integrated Ecosystem Assessment (IEA), as 'a framework for organising science in order to in- form decisions in marine EBM'. IEA is defined as a five stage process involving:

1. *Scoping* – identification of critical ecosystem management drivers and specific pressures on ecosystems involving the investigation of stakeholder interests and agendas, and patterns of interaction among stakeholders;
2. *Indicator development* – specification and validation of quantitative indicators of ecosystem state enabling the assessment of status and emergent trends (as a means of

being able to deter- mine when the management has achieved the desired outcome);

3. *Risk analysis* – evaluation of changes to key indicators (but within the background of the inherent variability of the system) to determine the probability that an ecosystem indicator will reach or remain in an undesirable state;
4. *Management strategy development* – evaluation of management strategies based on their likely effect on key indicators; and
5. *Monitoring and evaluation* – learning about the effectiveness of management strategies through continued monitoring and assessment of key indicators and the performance of the management initiatives.

Curtin and Prellezo (2010) provide an account of EBM that is complementary to that of Levin et al. and advance thinking by linking indicator development and impact assessment to the DPSIR model. The DPSIR model, adopted by the European Environment Agency and others (EEA, 1999; Elliott, 2002; Gray and Elliott, 2009), serves to capture and represent the causes, consequences and responses to change in a systemic way. In the context of the marine environment, the over-arching Drivers of social and economic development change refers to the need for food, recreation, space for living, and other basic human needs (Gray and Elliott, 2009; Atkins et al., 2011a) which are delivered through fisheries, recreational sites, bioremediation of waste, and so forth. Unless mitigation is employed, each of these Drivers has the potential to create Pressures on the system, such as the exploitation of fisheries, removal of the seabed, demands for the conservation of coastal amenity and marine biodiversity, and the discharge of contaminated waters. As a result, the State of the system (e.g. the seabed structure or the water column) is changed and this may lead to actual or potential Impacts on society (e.g. degraded habitats, removal of species, reduction of food availability, loss of biodiversity, etc). To avoid any misunderstanding between impact on the natural system (State Change) and on society (Impact), the EU KnowSeas project has proposed that DPSIR becomes DPSWR where Impact on society has been replaced by Welfare (KnowSeas Website) and whilst the focus tends to be on adverse changes this does not necessarily have to be the case. Further, Impacts can be merely potential as this reflects the aforementioned CAS characteristic of being able to use models to anticipate and evaluate the consequences of actions. The human Responses to actual and potential Impacts are then needed to reduce, mitigate, or compensate for these created problems. For sustainable management these actions should meet 'the seven tenets for environmental management': environmentally/ecologically sustainable, technologically feasible, economically viable, socially desirable/tolerable, legally permissible, administratively achievable, and politically expedient (Elliott, 2011). Hence these aspects include aspects of governance (law, administration and politics), socio-economic demands and the ability to change and manage the system through mitigation and compensation technologies (McLusky and Elliott, 2004; Mee et al., 2008; Gray and Elliott, 2009). Fig. 1 illustrates the DPSIR model in this standard form, including feedback loops between Responses and Drivers and Pressures, and recognition that there are natural pressures (based on ecology, climate, and other dynamic conditions) on the ecosystem which can lead to State Changes (Berger and Hodge, 1998). Note that pressures on the sys- tem can be locally/regionally/internationally endogenic managed pressures (such as power generation, and fisheries) or exogenic unmanaged pressures (such as climate change, and volcanic eruptions) (see Elliott, 2011). The latter case, in contrast to the former, is one of bounded rationality (Simon, 1972) since their complexity is such that we do not yet have sufficient knowledge of how and why change occurs in such systems and so our response is not management of the pressure but of the consequences of that pressure. In the case of endogenic managed pressures, we can manage the causes as well as the consequences.

Next, an example of a marine management 'wicked' issue which not only illustrates how such contexts exemplify the characteristics of a CAS but also demonstrates how DPSIR can be used to capture key indicators and effects.

Example: The Management of Marine Biodiversity at a Multi-User Coastal Site: Flamborough Head, UK.

Flamborough Head is situated on the north-east coast of England between Bridlington and Filey Bay, within the East Riding of Yorkshire. Its headland represents the most southerly area of rocky coastline in the northern North Sea and the most northerly outcrop of coastal chalk in the British Isles. The marine communities found at the north and south cliff differ due to the Flamborough Front, which is the boundary of the change in water characteristics between the northern and southern North Sea during the summer. Additional mixing of water masses during this time creates a very productive environment, which results in a marine ecosystem comprising of many species of invertebrates, fish, marine mammals and seabirds.

Flamborough Head was identified as a candidate Special Area of Conservation (SAC) to the European Commission in January 1996. It has also been designated a Special Protection Area (SPA) under the EU Wild Birds Directive. The marine components of both sites qualify as a European Marine Site (EMS). The Flamborough Head EMS covers an area of approximately 6500 hectares, in which the main marine habitats are extensive littoral and sublittoral reefs and submerged/slightly submerged sea caves (English Nature, 2000). The majority of the designated habitats are located within about 1 kilometre of the coastline, with the sublittoral reefs extending further offshore to a distance of up to 6 kilometres from Flamborough Head. Its sub-interest features include sea caves, rocky shores, kelp forests and subtidal faunal turf communities.

These outstanding natural features associated with Flamborough Head in addition to its proximity to the towns of Flamborough, Bridlington, Filey and Scarborough, make for a range of Pressures upon the system. For example, there are currently nine inshore vessels registered at Flamborough, all with shellfish licences, which exploit populations of European lobster, edible crab, velvet crab and whelks. Sewage treatment works and industry also discharge into the area. In addition, the outstanding natural features associated with Flamborough Head and its proximity to tourist resorts, attracts over 56,000 visitors per year (East Riding News, 2006). The Pressures, in turn, can lead to State Changes in the environment. For example, if not managed correctly commercial fisheries may remove unsustainable levels of fish/shellfish species from the area, trawling activities may damage some of the subtidal habitats, and the industrial effluents may increase the level of pollutants in the water/sediments. State Changes in the environment are of importance if they lead to Impacts which affect society. For example, a loss of biodiversity and/ or habitat may have an impact on the local fish populations which use these for food and shelter; a loss in fish populations (for example sand eels) may also reduce both bird numbers at the local seabird reserve and wildlife watchers visiting the site; and a reduction in bathing water quality, as an effect of industrial discharges, may result in fewer tourists visiting the beaches.

In order to protect the integrity of the Flamborough Head EMS, the Flamborough Head Management Group (FHMG) was established. The FHMG consists of representatives of key stakeholder groups: East Riding of Yorkshire Council, Natural England, the Environment Agency, North Eastern Sea Fisheries Committee, North Yorkshire County Council, Scarborough Borough Council, The Trinity House, Yorkshire Water Services, and The Bridlington, Flamborough and North Landing Harbour Commissioners.

In 2000, the first Management Scheme was produced by the FHMG and it highlighted the requirement for the integrated management of the site (Evans, 2000). This led to the Flamborough Head Maritime Forum being established to provide user community involvement in the management of the site. The Forum is open to all stakeholders not present on the FHMG and consists of representatives from a range of interests. The role of the Forum is (Flamborough Head SAC website):

- to represent interests of the users of the site within the development of the management plan;
- to represent the conservation interests in the ongoing management of the site;
- to act as a forum for general discussion of issues relevant to the group;
- to advise the FHMG as necessary regarding issues relating to the site; and
- to report back to other groups within each area of interest.

The Management Scheme was reviewed in 2007 and stakeholders raised the following as activities of concern: marine aggregate development; offshore oil and gas terminals; housing; expansion of holiday parks and cottages; wind farms; development of wave power, and the impact of increased access on foreshore communities. Through the review process, stakeholders also raised the importance of applying the Ecosystem Approach for the integrated management of the site. The FHMP has therefore adopted a broad approach to wildlife, landscape and access resource at Flamborough and thus attempts to integrate this with the social and economic needs of stakeholders that use the site (FHMP, *Section 6.0 Sustainable development and the Ecosystem Approach*). The review provided the basis for the Flamborough Head Management Plan (FHMP) (Stockdale, 2007) which aims to '*ensure that human activities at Flamborough Head are managed in a way that is compatible with the natural assets of Flamborough, and to seek opportunities to improve these assets and the human activities that depend upon them*'. Thus the Management Plan plays a central role in determining types and level of activity and other interventions within the Flamborough Head EMS. Included within the FHMP is a comprehensive inventory of human activities which may potentially harm the wildlife features in and around the EMS, including: collection; energy industries; fishing; industrial activities and consented discharges to sea; land management; mineral extraction; planning and development; water quality; recreation and tourism; research and education; shipping, navigation and deposits at sea, and shore-line management. Whilst fishing was not raised as an activity of concern by stakeholders in the review process, its absence was perhaps notable and it is identified within the FHMP as an activity which has the potential to harm the wildlife features in and around the EMS whilst offering significant benefits: it was estimated that 'a single commercial fisherman provides direct employment for up to four individuals in associated industries' and that traditional fishing activities formed 'part of the local heritage'.

The authors of this paper, three of whom are stakeholders engaged with the Flamborough Head Maritime Forum, used the DPSIR model to structure their own understanding of commercial fishing (Fig. 2). The purpose of the model within the context of this paper is to provide a simple demonstration of the use of DPSIR; It is important to recognise that if the model were being developed to inform decision making in the Flamborough context then many other factors would be considered, such as 'level of subsidies to support the fishing industry', and 'cost of fishing/transport'. That said though, the narrow focus on the commercial fisheries sector caused the authors to give serious consideration to what was being regarded as within the scope of the model particularly in terms of spatial and temporal boundaries and the comment was made that 'the value was actually in the discussion about what should and should not be in the model rather than the model itself'.

The responses included in Fig. 2 can be related to the seven policies in the FHMP that specifically relate to the commercial fishing sector. These include:

1. Opportunities shall be taken to make more people aware of fisheries legislation and how it might affect their own use of the marine environment;
2. Promote and support sustainable fishing activity, which is consistent for the conservation objectives of the site;
3. Support the development of new sustainable fisheries where appropriate stocks exist;
4. Assess the impacts of fisheries on habitats and species;
5. Encourage environmentally sensitive fishing methods;
6. Apply the Habitats Regulations to ensure that all fishing methods are compliant with the EMS management objectives; and
7. Ensure close working between fishermen, fisheries managers and statutory nature conservation bodies.

The aim of the FHMP and its legal status provide an integrative basis for managing Pressures and determining Responses associated with the various activities. Under the central directives, the UK has to show that the area is in Favourable Conservation Status and determine whether any plan or project is affecting the conservation features for which the area was designated. For example, commercial fisheries activities are managed and monitored by the North Eastern Inshore Fisheries and Conservation Authority (NEI- FCA). Projects within the NEIFCA district which represent human Responses to Pressures on the system include:

- The establishment of three Prohibited Trawl Zones (PTZ) (see Allen, 2008) to protect static gear fisheries and to prevent conflict between mobile and static gear interests and potentially have wider benefits for marine diversity by contributing to resource management, conservation and habitat enhancement (Thomson et al., 2010).
- An agreement in April 2008 to designate an experimental No Take Zone (NTZ) to the south of the Flamborough Headland (Thomson et al., 2010).

The latter project is particularly significant given that it was, at the time, only the second NTZ to be established in the UK. NTZs provide the highest levels of protection for marine animals by excluding all extractive activities (e.g. fishing and aggregate extraction) with the aim of ensuring a range of benefits, such as:

- recovery of marine wildlife;
- improved scientific monitoring;
- tourism and education; and
- potential improvements in fish and shellfish populations out- side the NTZ.

It is emphasised, though, that 'the degree to which this type of Marine Protected Area will provide these benefits is still an area of debate and hence such sites should be seen as experimental' (Flamborough Head No Take Zone – update and minutes, 23/02/08). Indeed, whilst it was widely reported that fishermen had 'voluntarily' agreed to the NTZ (BBC News, 07/08/09) comments in the minutes of meetings indicate their expressed concerns: 'conservation causes displacement and displacement could seriously affect peoples' livelihoods'...'there are two boat clubs from Nottingham who have bought caravans and chalets over here and travel 100 miles to get here. If you ban fishing on this coast they will say ''Sod Bridlington'' and take their money somewhere else. So your proposals are going to damage the local economy'. The ongoing controversial nature of the NTZ is perhaps indicated by an on-line forum discussion in January 2010 concerning a 'leaked e-mail' about a proposal drafted by the Yorkshire Region of the Angling Trust (Flamborough Head No Take Zone - Leaked E-Mail Causes a Stir, 26/01/10). The proposal was about changes to the geographical boundary of the NTZ and caused the person that had posted the leaked e-mail to comment ''the draft was posted to me anonymous and I felt it need bringing to light as to what was happening with the no take zone (so why all the secrecy)''.

The controversial nature of the NTZ will be further discussed in a later section.

3. DPSIR as a problem structuring method for a complex adaptive system

It is important to recognise that the DPSIR model has been subject to much criticism and has evolved in response. In this paper, a form of DPSIR that is enhanced by techniques drawn from causal network modelling (following Niemeijer and de Groot, 2008) is presented as this addresses some of the criticisms that have been made. In order to assess how DPSIR has developed, it is worth summarising the critique here.

Svarstad et al. (2008) summarise the essential strength of the DPSIR model thus, ''it captures, in a simple manner, the key relationships between factors in society and the environment'' (p. 116). However, they balance an account of the various advantages of the DPSIR model with recognition of the criticisms that have been levelled against it by Berger and Hodge (1998), Rapport et al. (1998), and Rekolainen et al. (2003). In summary, DPSIR:

- cannot take into account the dynamics of the system it models;
- cannot handle cause-consequence relationships;
- suggests linear unidirectional causal chains; and
- ignores key non-human drivers of environment change.

The above criticisms emphasise DPSIR as being a snap-shot ta- ken at a particular moment in time that distorts reality through its simple and linear view. Indeed, recent thinking about the DPSIR model takes heed of these criticisms in order to make the approach more holistic and this enables the approach to be defined as a PSM for use in a particular applied context. Such a claim is supported by Mingers and Rosenhead's (2004) characterisation of PSMs as offering decision support when confronted by unstructured problem situations by enabling the situation to be represented in a model or models that enable participants to clarify their predicament, converge on a potentially actionable mutual problem or issue within it, and agree commitments that will at least partially resolve it. Largely founded on interpretivist or social constructivist epistemologies, PSMs should (Mingers and Rosenhead, 2004):

- enable alternative perspectives to be brought into conjunction;
- be cognitively accessible to participants from a range of back- grounds and without specialist training, so that the developing representation can inform a participative process of problem structuring (hence the value of conceptual and illustrative models);
- operate iteratively through the problem representation being adjusted to reflect the state and stage of discussion among the participants, and vice versa; and
- allow partial or local improvements rather than requiring a global solution, which would imply a merging of the various interests.

Importantly, as in many PSMs, in the DPSIR process ''The model representations are used to provide enough structure that those who must take responsibility for the consequences of the choices which are made, do so on a coherent basis and with sufficient confidence to make the necessary commitments.'' (Mingers and Rosenhead, 2004, p. 1). The notion of coherence and confidence is important particularly if we accept that, in dealing with CAS, there will be an inevitable lack of comprehensiveness in our designs and decision making. Keys (2007) contributed to the discussion of PSMs by viewing the use of PSMs as a design science enabling knowledge related processes to be revealed. Keys draws on Gibbons' et al. (1994) distinction between mode 1 (single paradigm, theoretically focussed) and mode 2 knowledge (multiparadigmatic, determined in the context of application), the latter particularly informing PSM practice. Rouwette et al. (2009) in- crease clarity on the PSM process by constructing a preliminary conceptual model. Despite the foregoing, the literature reveals a broad range of practice and interpretation of what counts as a PSM and the processes followed. However, it seems logical that if PSMs, such as DPSIR, are designed to enable us to make defendable decisions in the light of complexity then the process of operationalising and managing change within such systems should reflect the characteristics of CAS. Hence any model developed to support knowledge elicitation and structuring is required to not only represent the essential features of the systems of concern and their complexity, but also seek to respect, if not match, their variety (Ashby, 1956). Indeed, Tsoukas and Hatch (2001) suggest that 'if our approach is complex enough attention will be drawn to certain features of systems' behaviours which were hitherto unremarked'. Here we look to the work of Hammer et al. (2012) who draw from the work of Cilliers, Stacey and Mittleton Kelly a composite list of characteristics that comprise the CAS lens of four facets and 16 characteristics (there is overlap as characteristics 8 and 9 may also be seen to be People Factors and Self-Organisation is a facet in itself and underlies all of the other facets). From these characteristics a set of principles may be derived which may shape the process of intervening in CAS (Table 1).

In the light of the characteristics of CAS, in the next section the implications for management of the marine environment will be addressed and, where relevant, links to the principles from Table 1 made explicit. Much work has already been undertaken on developing DPSIR practice to deal with CAS features of Continuous Varying Interactions and Pattern Development whereas relatively less consideration has been given to considering the implications of People Factors and this is a serious omission given that they may be regarded an important prerequisite for Self-Organisation.

3.1. Continuous Varying Interactions (CVI)

Here it is important to reflect on the underpinning ontology and epistemology of the paradigm of work that has historically driven the development of DPSIR as this has implications for the status and role of modelling as part of a broader problem structuring process. The effort to enable the DPSIR model to better capture the complexity of an external reality fundamentally reflects a realist view of knowledge. Indeed, much of the critique levelled at this approach has been 'in paradigm' driving the refinement of modelling techniques to better capture external reality. Hence whilst in this paper a single narrowly bounded DPSIR is shown to portray the commercial fisheries sector at Flamborough (Fig. 2) it is recognised that to do so is a simplification and a more developed use of the approach suggests that the DPSIR is nested within a set of DPSIRs that encompass many sectors (i.e. marine aggregates, energy generation, aquaculture and so forth), with complex and non-linear linkages and feedback loops between the parts of the system with Responses to one set of Drivers and Pressures affecting others (Principles 1, 6). For example, the solution to overfishing may require a response which encourages aquaculture, if food needs are to be met, which in turn also creates problems which need to be solved. Recognition of this complexity requires us to make problematic the notion of causality (in particular the ability to differentiate between natural variability and other causes from State Changes resulting from the specific Pressure that is of interest) and to develop approaches for enabling us to capture and better understand the complex and dynamic nature of relationships. Furthermore, individual elements of the DPSIR model should be considered to have multiple interactions. This is recognised by Ness et al. (2010) whose approach to DPSIR is informed by Hägerstrand's (2001) work on multi-level dynamics, Niemeijer and de Groot's (2008) work on causal networks and Atkins et al.'s (2011a) further development of the idea of nested-DPSIR models (Principles 1, 2, 3). Also, as previously mentioned, DPSIR has also been developed to at least recognise if not explain exogenic unmanaged pressures as well as endogenic managed pressures (Principles 6, 10).

3.2. Patterns Development (PD)

Walters, cited in Karkkainen (2005), makes the important distinction between passive and active adaptive management. Passive adaptive management is a process involving heightened monitoring of key indicators leading to subsequent adjustments in policies in light of what may be learned through careful observation and data generation. Passive adaptive management contrasts with active adaptive management which focuses on a much more deliberate rather than reactive process involving integrative ecological modelling, generating hypotheses and testing these through simulations and field experimentation. Such an approach may embrace a wide range of approaches which may facilitate learning about and sensitivity to emerging system conditions and state changes (Principles 9, 10, 11, 12).

Indeed, despite the dominance of the realist paradigm, narratives are emerging that question the presentation of provable truths and facts that belie alternative interpretation; for example, Maxim et al. (2009) argue that DPSIR downplays uncertainty and complexity regarding environmental and socio-economic systems. Svarstad et al.'s social constructivist stance leads them to reflect that DPSIR can lead to ''a narrow and discourse-selective understanding of controversial issues'' (p. 117) and their commitment to epistemological relativism drives them to focus on the ''communicative processes through which social reality is created, reproduced and transformed'' (p. 118). Consequently, it can be argued that DPSIR has concerns common with PSMs as both focus on models as heuristic devices to facilitate engagement, explication of knowledge, communication and understanding between researchers from different disciplines as well as between researchers, policy makers and other stakeholders. Such a focus requires us to pay serious attention to sources of validity and whilst there is still the aim to develop a model that represents a shared conceptualisation of reality this is complemented by a concern for engagement in the model building process and how well different, possibly even competing, stakeholders' perceptions of reality are accommodated (Principles 4, 5, 6, 7, 13).

3.3. *People Factors (PF) and Self-Organisation (SO)*

In addressing People Factors and Self-Organisation there appears to be two key variables of particular significance (Principle 13): breadth of participation, which is essentially a question of what and/or whom is or is not included, and depth of participation, which is essentially a question of managing knowledge and associated value claims. We shall now address these in turn and, where relevant, widen the discussion beyond DPSIR to consideration of PSMs in general.

3.4. *Breadth of participation: a question of boundary critique*

As has been previously mentioned, PSMs are largely grounded in the interpretivist and social constructivist paradigms and, as a consequence, assume participation. Hence such approaches are subject to a similar, if not the same, set of criticisms as those advanced for soft systems approaches (see for example Jackson's critique of Soft Systems Methodology, 2003). Ackermann (2012) though, highlights how different PSMs 'ensure the socio-political requirements are attended to' and that this requires 'consideration of not only who to involve but also who to manage when considering outcomes'. Shaw et al. (2006) focus on participation in computer based PSM workshops which leads them to reflect on, among others, issues of participation validation of models developed, the agreement of achievable actions, anonymity, and equality and dominance. Despite this awareness of the participatory imperative, PSM researchers do not go as far as some systems researchers in explicating the implications of this (see for example Ulrich, 1983; Midgley, 2000). From a systems perspective, who is involved and how is a matter of where the boundary is placed and different boundary judgements affect who is involved and what values are privileged in defining 'good' decision making. Franco's (2009) recognition that PSMs tend to be employed within an overall frame- work of authority and accountability reflects this point.

The issue of participation and representation of different norms and values is certainly evident in the Flamborough case and illustrates the controversy that can arise when participation is limited. Indeed, ever since Arnstein's (1969) work it has been well recognised that 'participation' is a term that can mask a variety of options. This variety is certainly evident in the use of DPSIR, as Tscherning et al.'s (2012) assessment of 21 DPSIR studies published in peer-reviewed journals and books between 2003 and 2009 shows. Analysis of the studies reveals that the DPSIR elements were defined by a variety of methods or combination thereof, including literature review (77%), research team itself (23%) and expert (36%), stake- holder (27%) or legislative (governmental or non-governmental) consultation (23%). However 64% of the Response elements were defined only by researchers without the participation of policy makers and stakeholders (informal discussions with users of PSMs reveal a similar diversity and the need for a similar study on the use of PSMs is to be addressed in future research). That is not to say, though, that the question of participation and the specification of systems boundaries is not raised in the literature on DPSIR, Svarstad et al. (2008) recognise:

> ''The DPSIR framework embodies a systems perspective, implying the demarcation of a particular system of interest, with explicit or implicit boundaries. The system is bounded in

two ways. Firstly, it is bounded in terms of the scale at which the Impacts are defined, e.g. a single river up to worldwide. Secondly, it is bounded in terms of the scale of the Responses and Driving forces affecting this system, e.g. local economic changes up to global environmental agreements. The boundaries will not necessarily coincide; Impacts at one scale will often be determined by Responses and Driving forces that act at a different scale. The drawing of these boundaries depends on the particular issue of interest and its conceptualisation, which are strongly influenced by the perspective of those using the framework.'' (p. 117–118).

Whilst Svarstad et al. (2008) raise the issue of boundary definition they do not give serious consideration to the implications of its neglect nor do they go on to suggest how the issue of competing definitions and interests of those using the model might be resolved. Here, though, a useful link might be made to the systems literature for guidance.

One of Churchman's (1968,1971) greatest contributions to systems thinking was establishing the idea that the drawing of system boundaries is crucial for determining how improvement is to be defined and what action should be taken. He also saw it as the system designer's responsibility to redraw boundaries to 'sweep in' stakeholder views to ensure that the system comes to serve the interests of more than just the powerful. Midgley (2000) reflects on this in suggesting that you have to deal with power up-front because if you do not then its use may be hidden by the powerful in manipulating the definition of system boundaries to ensure that their interests are best served. Ulrich (1983), however, did not believe that this important task should just be left to the system designer but rather the question of determining where to draw the system's boundaries should be established through a dialogue between those involved and those affected by a system's design (referred to as the process of boundary critique).

Another notion that Ulrich draws from Churchman is the need for systems design to take on the whole system because localised action based on partial understanding can lead to unexpected con- sequences for the wider system. Of course, to attempt to understand the whole system is an impossible task. What is important therefore, is to accept an inevitable lack of comprehensiveness in our designs and planning but to make this transparent so that we can reflect critically on their limitations and the likely implications of boundary decisions (reflecting on the Flamborough case, as will be discussed later, we note with some irony that the level of engagement in the development of the DPSIR model in the Flamborough case was limited but recognise the need to make this transparent so that we can reflect critically on limitations and likely implications).

In terms of DPSIR, informing the process through a continual process of making problematic system boundaries (not only geographical but in other senses such as temporal) and questioning who is and who ought to be involved adds value by (drawing on Jackson, 2003):

- offering an 'inclusive' systems approach which emphasises the benefits of incorporating the values of a wide range of stakeholders in planning and decision-making or at least making explicit the logic of who is and who is not involved;
- not taking boundary definitions as given which highlights that drawing the boundary around the system in different ways critically impacts on how it is seen and what is done;
- requiring questions to be asked about whose values are actually being respected and whose interests are served by particular decision and policy making and whose ethically ought to be;

- demanding that attention be given to those affected by a design but not involved in it and who may be labelled disadvantaged in terms of their access to sources of power and resources; and
- undermining the notion of 'expertise' and in so doing empowering other stakeholders to fully participate in discussions and decisions about purposes.

In terms of the development and application of DPSIR and PSMs in general, the last point is somewhat controversial and it is to the issue of managing knowledge and value claims that we shall now turn.

3.5. Depth of participation: a question of managing knowledge and value claims

A large part of PSM practice is focussed on the development of models to elicit and structure knowledge about an issue of concern. Pidd (2010) defines four categories of model use: decision automation, routine decision support, investigation and improvement, and generating insights for debate. Hence the models used in PSMs are most likely to be for the purpose of the second two categories and as such model building is fundamental in most, if not all, PSMs. Whilst a level of participant engagement is generally assumed in such model building, a lack of specificity gives rise to a variety of options, including:

- Model built by facilitators or a small group of participants and then presented to a wider group as a stimulus for discussion;
- Model built by facilitators and then reworked by stakeholders; and
- Model built by a wide group of stakeholders in a participatory way.

Choice of the appropriate approach to model building in a given situation is largely the facilitator's and influenced by their assumptions about the abilities and experience of participants. White (2006) recognises that ''most proponents of PSMs assume that participants are similar in their ability to articulate problems and have an effect'' (p. 851) but such situations are the ideal rather than reality and Shaw and Blundell (2008) acknowledge the difficulty ''in turning expert knowledge about a situation into a structured model which is theoretically and contextually valid'' (p. 233). Given this difficulty, as has already been mentioned, a range of engagement strategies are evident in order to make the model building stage 'work' and as a consequence, decisions about the transparency of the model and extent of stakeholders engagement in the model building process, need to be made explicit. Reference here may usefully be made to Checkland and Scholes's (1990) distinction between mode 1 operation, being the explicit and sequential use of an approach to drive an intervention, and mode 2 operation, which occurs when an approach is internalised and used in a more situation-driven way. Jackson (2003) captures well the essence of mode 2 in stating that it is 'only occasionally breaking the surface to interact with ongoing ideas and events' (p. 196). The use of DPSIR in mode 2 is exemplified in the Flamborough case where the authors of this paper used the DPSIR model to structure their understanding of the situation and this undoubtedly affected their subsequent contributions as stakeholders engaged with the Flamborough Head Maritime Forum. Given the internalised nature of mode 2 operation, though, such cases tend not to be reported in the literature whereas mode 1 do. A good example of mode 1 operation is Bell and Morse's account of a set of projects by Plan Bleu for Mediterranean coastal zones in which local stakeholders actually built the models themselves (Bell and Morse, 2007). In terms of the current discussion Bell and Morse's case is an interesting one because, whilst they emphasise the need for participation and recognise that some stakeholders will privilege 'science in the positivist sense' and other 'learning', they do not explicitly take up the issue of how competing knowledge and value claims may be re- solved. Indeed although the participation of local stakeholders may appear superficially attractive it should also be seen to be potentially problematic. Firstly, it assumes the notion of an 'ideal speech situation' and consequently the need to design the situation to ensure that participants are able to contribute and engage in an appropriate way is given minimal attention. Whilst this may not always be problematic, the onus is on each and every participant to ensure that their contribution is understood and many, in particular scientists, are concerned for ensuring the usability of their ideas, it may necessitate working to the lowest common denominator which may negatively impact on the contribution of other stakeholders; in some areas this might be a good thing but it may not be so. For example, can it really be said that a lay person's view of eutrophication (the adverse consequences of excessive nutrients, Elliott and de Jonge, 2002) can be held equal to that of a marine scientist? To deny or limit the expression of expertise is surely to impose an unnecessary cost with local communities replicating work that has been done elsewhere (this is not to deny the uniqueness of each situation but rather to be resource prudent and recognise that certain cases may be similar and where they are relevant information should be drawn upon). It is also possible that agreement on a lowest common denominator, entails focussing on less-controversial options with more contentious and confrontational issues being ignored. Secondly, there is a boundary problem in that the view of the local community is likely to be restricted: geographically (they may be experiencing the symptoms of a problem but root causes may lie outside of the immediate location), temporally (long-term changes such as climate change may not have immediate impacts that would be picked up by local communities or the indicators they design) and politically (for example, a local community may not have the power or resources to tackle a multi-national business disposing of its waste products in their locale).

In the light of the above it is argued that participation is not merely about offering an opportunity to be involved but rather demands appropriate attention be given to the selection of approaches to ensure that participation is both appropriate and meaningful (Taket and White's work (2000) was a forerunner in highlighting the requirement to embrace diversity in a diversity of forms). To be clear, the argument here is not against the participation of local stakeholders but rather against approaches that do not explicitly take consideration of diversity and the consequent need to design knowledge elicitation and structuring processes accordingly. Waltner-Toews et al. (2004) recognise this need in drawing out the implication of a CAS approach (Principle 16) and suggest that ''The role of the scientist in decision making shifts from inferring what will happen – that is, making predictions which are the basis of decisions – to providing the decision makers and the community with an appreciation, through narrative descriptions, of how the future self-organisation of the socio-ecological systems might unfold.'' (p. 330). Approaches to using DPSIR in a critical way that seeks to accommodate a variety of knowledge claims – economic, local and scientific – are evident in the literature. For example, a process of researchers developing appropriate indicators, plotting/predicting changes and their consequences (scenarios), and then local communities assessing the implications of change in different scenarios and determining priorities seems most feasible (see for example, Atkins and Burdon, 2006). This approach recognises that it is not just about developing indicators of change but also about whether these changes matter (Principles 14, 15) and reference might well be made here to the literature on the social evaluation of the anthropocentric consequences of environmental change (see for example, Turner et al. (2001)).

Hence, deferring to local communities for a debate about appropriate indicators and parameters of change not only assumes significant insight and knowledge but may also waste resources by repeating existing research.

4. Evaluation and learning

In the light of the foregoing it might seem that an evaluation of 'what works, why and for whom' is called for but White (2006) recognises the inherent difficulty of evaluating PSMs and suggests a theory based approach (explicating how an intervention should work and comparing this with practice). Based on the foregoing it may be suggested that such an evaluation should include concern for: developing relationships that support the sharing of knowledge about the local and wider systems (Principles 1, 7, 8), developing modelling approaches of necessary complexity (Principles 2, 3, 4, 5, 6), use of models as heuristic devices to engage stake-holders in learning about patterns of behaviour (Principles 4, 5, 6, 7, 13, 15, 16), creating a space in which stories and histories can be shared (Principles 14, 15), acceptance of the ongoing nature of change and seeing it as a potentially good thing rather than a challenging threat (Principles 9, 10, 11) and, as a consequence of this, recognising the need to actively engage in the continual process of change (Principles 10, 11, 12, 16).

In addition, much important learning can be gleaned from cases on the development of PSMs that are specifically developed for use in a particular context. For example, Shaw and Blundell (2010) reflect on a methodology called Waste And Source-matter Analysis (WASAN) which is a facilitated methodology for structuring a waste minimisation problem in the nuclear industry. They define five issues of relevance for PSMs:

- The need for a quality audit trail that illuminates understanding in a diverse readership years later.
- Facilitators having sufficient contextual credibility and the PSM itself having credibility through built procedural rationality and alignment with existing approaches used in the particular context.
- Flexibility in the use of PSM techniques and the representation of knowledge thus derived in the form of tables rather than more systemic OR models.
- Use of keywords to structure analysis and enhance the rigour of the audit trail as all components are analysed similarly and the transparency of the analysis is strengthened.
- Use of sensitivity analysis to understand the interactions that are more/less important to manage to achieve optimal conditions.

White's recommendations and Shaw and Blundell's issues pro- vide a platform for further critical reflection not only on the DPSIR model but on the process of how the model is used. This reflection illustrates our commitment to an action research orientation that we hope will serve us well in our further application of the approach to not only generate understanding of given situations but also of the use of the DPSIR model itself.

5. Conclusions

Much has yet to be learnt about the use of PSMs not only in general but also context specific ones such as DPSIR. Honing PSM practice in 'wicked' contexts such as the marine environment compels us to take seriously the characteristics of CAS and suggest the need for a critical turn to not only recognise but also manage competing knowledge (economic, local and scientific) and value claims. The Flamborough case-study in providing an illustration of a CAS and how DPSIR might be used highlighted the need to give critical consideration to questions of breadth and depth of participation. In considering these questions, reference is made to relevant systems literature on the use of boundary critique and managing knowledge and value claims. Hence this paper emphasises how a CAS perspective might add impetus to the development of a critical perspective on DPSIR and PSM theory and practice.

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Box 1. The twelve principles of the Ecosystem Approach (CBD, 2000).

1. The objectives of management of land, water and living resources are a matter of societal choices.
2. Management should be decentralised to the lowest appropriate level.
3. Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems.
4. Recognising potential gains from management, there is usually a need to understand and manage the eco-system in an economic context. Any such ecosystem- management programme should: (a) Reduce those market distortions that adversely affect biological diversity; (b) Align incentives to promote biodiversity conservation and sustainable use; and (c) Internalise costs and benefits in the given ecosystem to the extent feasible.
5. Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the Ecosystem Approach.
6. Ecosystems must be managed within the limits of their functioning.
7. The Ecosystem Approach should be undertaken at the appropriate spatial and temporal scales.
8. Recognising the varying temporal scales and lag- effects that characterise ecosystem processes, objectives for ecosystem management should be set for the long term.
9. Management must recognise that change is inevitable.
10. The Ecosystem Approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity.
11. The Ecosystem Approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices.
12. The Ecosystem Approach should involve all relevant sectors of society and scientific disciplines.

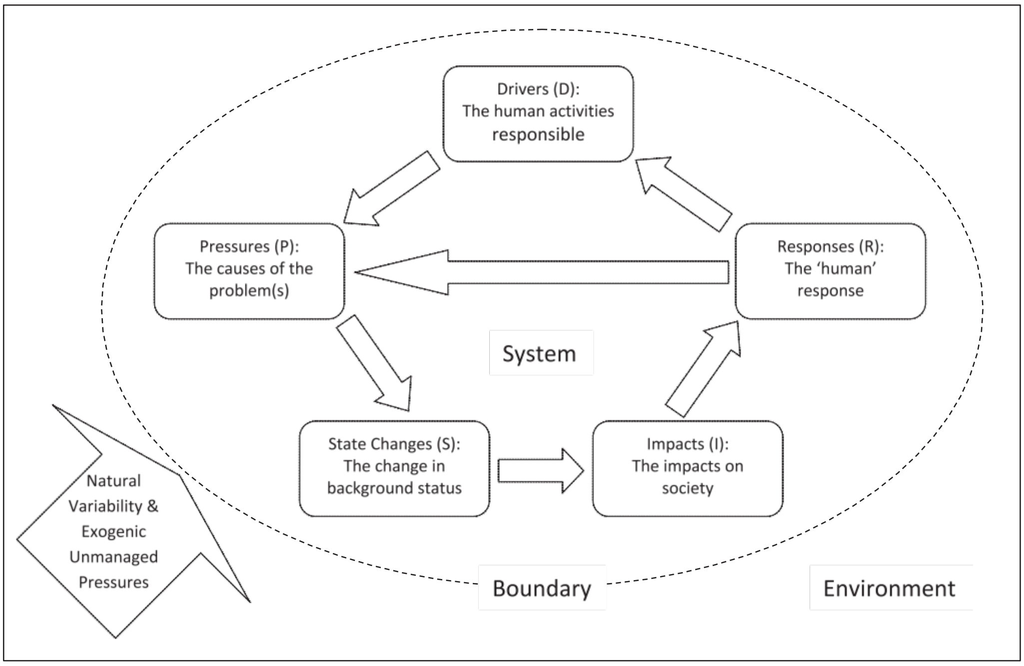
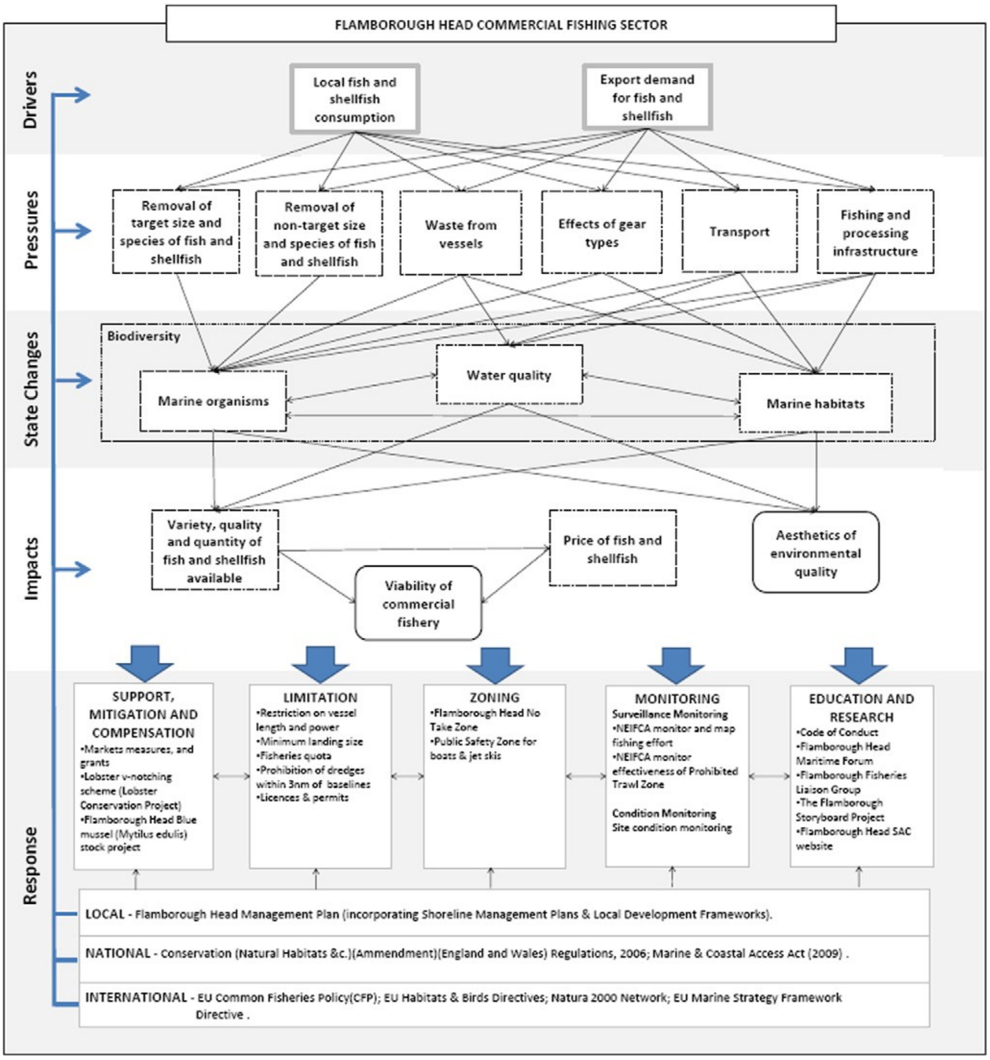
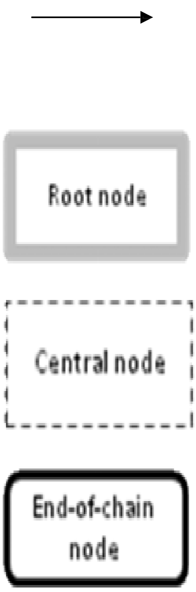


Fig. 1. A generic DPSIR model





An arc shows a linkage and the direction of the effect of one node on another.

Root nodes have many outgoing arcs and consequently may be the source of multiple effects.

Central nodes have many incoming/outgoing arcs and are influenced by a number of factors which in turn may be the source of multiple effects.

End-of-chain nodes have many incoming arcs and may be where the effects become visible.

Fig. 2. A DPSIR model for the Flamborough Head commercial fishing sector.

Table 1
PSM principles derived from CAS characteristics (based on Hammer et al., 2012).

	Characteristic	Principle
	Continuous Varying Interactions (CVIs)	
1.	*Local and remote*: the richest interactions between people usually occur locally within the relationship network of the organisation, but influences can be far reaching and remote connections may be important due to non-linearity.	Focus on relationships and networking within and between levels. Potential for cascading capacity building to all levels (also implying concern for stakeholder issues such as engagement) through the passing on of problem structuring and decision making techniques.
2.	*Non-linear interactions*: unpredictable cause/effect relationships. Small actions can have big effects, big actions can have minimal effects, and the scale of effects cannot be predicted.	Encourage experimentation and creativity as stakeholders cannot be sure what changes will take hold. Be alert to new ways of working/thinking ('attractors') and celebrating/reinforcing those deemed desirable.
3.	*Positive and negative feedbacks*: both developmental and restraining forces can exist within the system.	Be sensitive to the effects and sources of actions particularly how they are perceived either as developmental and/or restraining forces.
4.	*Large number of elements*: could be number of people or the relationships between them or both.	Recognise the requirement to roll-out boundaries or at least to be critical and to able to justify where boundaries are being placed. Seek to encourage widespread engagement of stakeholders as they are both constituting the CAS through their moment-to-moment interactions and observing it.
5.	*Continuous interaction*: endless, repeating and dynamic interaction between people through communication within and external to the organisation.	Respect the importance of communication as an ongoing process that is multi-faceted and diverse according to different participants needs.
6.	*Connected open systems*: active or passive interactions with other CAS which can be at various levels of integration within and external to the organisation.	Be aware of interconnections both at the same scale and across scale.
7.	*Rich interactions*: high to low quality, changing, developing, iterative and self-referential.	Be sensitive to changes in the quality and quantity of interactions.
8.	*Relationships co-evolve*: production of on-going variety in the rules (traditions, customs, etc.) of the relationship.	Recognise relationship rules at different system level and how they evolve over time.
	Patterns Development (PD)	
9.	*Patterns emerge*: coherent patterns of order emerge spontaneously and become 'attractors' which may develop the pattern further.	Monitor the situation for new emergent forms of behaviour and discussions about whether they are desirable or non-desirable.
10.	*Origins of patterns*: are unpredictable in time and place.	Be alert to spontaneous changes in behaviour.
11.	*Stable and far-from-equilibrium*: CAS can cope, adapt, survive and prosper in periods of turbulence so stability is not a requirement for progress and can lead to atrophy.	Embrace creative destruction and a capacity for coping with change, turbulence and uncertainty. Focus on letting go of the past as an indicator of present/future states and ways of being.
12.	*Patterns and 'attractors'*: can be stabilitising (orderly), de-stabilising (chaotic) or both simultaneously (chaordic).	Engage stakeholders in critical reflection and in an ongoing discussion about the desirability of different patterns and attractors of behaviour.
	People Factors (PFs)	
13.	*Whole system ignorance*: no one person within the CAS can have complete knowledge of the CAS because it is too complex and dynamic, which contributes to risks and uncertainties that affect people and organisations.	Encourage the widespread engagement of stakeholders in boundary critique, and reflection on limits to knowledge, the (un) acceptability of risk, and the justification for decisions made.
14.	*Histories*: origins and histories of development of both people and the CAS are very important because development options can be preferred, locked in or out, and influence options choices for future actions (path dependency).	Engage stakeholders in the telling of and reflecting on the meaning, causes and effects of stories of past system behaviours. Explore how past and current decision making either opens up options and possibilities or closes them down.
15.	*Space possibilities*: CAS can explore the 'space' and time possibilities into which they can develop by adapting existing conditions, because people can think, learn, imagine and make decisions.	Experiment and learn from the creative suggestion of alternative forms of being and acting.
	Self-Organisation (SO): as a result of the characteristics of a CAS they can self-organise spontaneiously	
16.	Emphasise active engagement and the creation of environments in which stakeholders can freely associate to develop their own plans and forms of future association/being.	