Socio-Ecological Accounting: DPSWR, a Modified DPSIR Framework, and its Application to Marine Ecosystems

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Abstract

In contrast to institutionally focussed environmental accounting, socio-ecological accounting frameworks organise information concerned with human-environment interactions at scales relevant to ecosystem change and thus encapsulate information more relevant to ecosystem-based management. The DPSIR (Driver-Pressure-State Impact-Response) framework has been used to identify relevant information in a number of ecosystem contexts but suffers limitations in terms of its definitional clarity and conceptual foundations, which undermine comparability between studies. These limitations are addressed in the DPSWR (Driver-Pressure-State-Welfare-Response) framework, which defines information categories based on a synthesis of concepts in DPSIR and its predecessors so as to more clearly identify the object of measurement in each category and isolate information relating to social systems. Consequently, its categories dealing with social systems are better suited to assessing anthropocentric trade-offs in environmental decision-making, such as through cost-benefit analysis. A conceptual input-output analysis is used to highlight measurement issues connected with the inter-relations between information categories, particularly as regards scale, and the application of the framework is illustrated by reference to issues affecting marine ecosystems included in a Europe-wide study for the European Commission. However, DPSWR's definitions are designed to be sufficiently general as to support application in other ecosystem contexts.

Keywords: socio-ecological accounting; environmental accounting; ecosystem approach; marine ecosystems

1. Introduction

Environmental accounting involves organising and presenting information on interactions between the economy and the environment in a standardised way to support policy development and decision making (UNSD, 2012) and, in the case of corporate entities, as a basis for social accountability (Gray et al., 1995). This practice is generally associated with institutional accounting frameworks, where the scope of accounting is determined by the attribution of environmental resources to socially defined entities. However, indicator-based frameworks which integrate information on associated changes in social (human) and ecological systems with a scope relevant to ecological change constitute the basis for socio-ecological accounting frameworks (Table 1). Thus, they are more appropriate to fulfilling the information needs of integrated management (Grumbine, 1994; McFadden and Barnes, 2009) as embodied in the ecosystem approach (see, for example, CBD, 2000; Environment Canada, 2012; EU, 2008).

[Table 1 about here]

In the simplest conceivable cases, analysis can be confined to a single ecosystem change with a unique anthropogenic cause at a given location. More generally, socio-ecological accounting requires information categorised so as to capture multiple causes of ecosystem change, the nature of that change and the range of effects on social systems in a manner that supports the analysis of the complex interactions among those categories. The DPSIR (Driver-Pressure-State-Impact-Response) accounting framework comprises information categories based on a chain of causal relations that together encompass these phenomena and has been widely adopted in a variety of ecosystem contexts, for example: soil erosion (Gobin *et al.*, 2004); biodiversity loss (Maxim *et al.*, 2009); and, marine and coastal systems (Bowen and Riley, 2003; Cave *et al.*, 2003). However, as explained below, the definitions of this framework's information categories are subject to interpretation and they are not well aligned conceptually with the economic analysis of interactions between social and ecological systems.

Some flexibility in the interpretation of information categories allows users to adapt the framework to their particular needs but this flexibility needs to be limited to ensure comparability between studies, making the accumulation of knowledge about specific social-ecological interactions more efficient. This issue was highlighted in a recent European Commission-funded project, ELME (European Lifestyles and Marine Ecosystems), which motivated the study reported here. The project involved multidisciplinary teams analyzing a range of ecosystem changes in European seas making it necessary to adopt a standard set of information category definitions that could be uniformly applied in each case, regardless of the type of ecosystem change or sea under investigation, and supporting common indicator measures so that the results could be aggregated. For this purpose, a modified DPSIR framework (DPSWR, Driver-Pressure-State-Welfare-Response) was designed to improve definitional clarity and the alignment of social system categories with the needs of economic analysis. While the DPSWR framework was thus inspired by the needs of the ELME project, and its application is illustrated here in the context of marine ecosystem degradation, the definition of terms is sufficiently general for it to be utilised in other contexts.

This paper describes the derivation of the DPSWR framework in two stages. First, it critically reviews the DPSIR category definitions to identify definitional and conceptual limitations, supported by comparison with predecessor frameworks which have a common conceptual heritage - DPSIR may be seen as the latest generation in an evolutionary process. In doing so, the paper provides a historical perspective on the origins of current practice, highlighting the risks of conceptual confusion that have arisen. Second, the results of the review are synthesised through modifications to DPSIR that result in the DPSWR framework. A spatial input-output representation of the causal relationships among information categories is employed to discuss measurement issues in the application of the DPSWR definitions. In these sections, eutrophication, primarily from agricultural run-off, is used to illustrate certain points; the subsequent section uses results from a survey of natural scientists in the ELME project to illustrate other applications. Finally, concluding remarks deal with the advantages of the DPSWR framework, how its scope can be reconciled with that of institutional accounting frameworks and aspects of the framework requiring further development.

2. Review of DPSIR and Predecessor Frameworks

The review is structured around the DPSIR information categories as originally defined by the European Environment Agency (EEA, 1999) or as subsequently modified in its glossary (EEA, 2012), as summarised in Table 2.[1] This table aligns, as far as possible, these categories with those employed in predecessor frameworks extending back to the Stress-Response Environmental Statistical System (S-RESS) proposed by Friend (1979); no earlier frameworks could be identified in the literature.

[Table 2 about here]

[1] The European Environment Agency is considered an authoritative source as it or its parent body, the European Commission, have been cited as the source for the framework (e.g. Bowen and Riley, 2003) and the framework has been widely applied by the EEA itself (e.g. EEA, 2007) and in projects for the Commission (e.g. Eurostat, 1999).

2.1 Overview

The summary in Table 2 demonstrates the shared heritage of core concepts in terms of the characteristics of social and ecological systems of relevance, but highlights omissions in certain categories, most notably the restriction to environmental effects in the FDES (Framework for the Development of Environment Statistics) and PSR (Pressure-State-Response) frameworks, and a sub-division of its pressure category in the PSR/E (Pressure-State-Response/Effect) framework. Nevertheless, a wide variation in terminology and subtle variations in the precise definition of information categories are apparent. For example, the S-RESS "stressor" and the PSR "indirect pressure" categories both refer to human activities, but they most closely align with the Driver concept reflected in DPSIR which refers to large-scale social "developments". Thus, there is a common reference to "what people do" but a distinction between specific activities in S-RESS and PSR, and a more summary representation based on trends in DPSIR.

Certain of the frameworks are not characterised solely by the definitions of the constituent information categories but also by a structuring property: an orientation towards a motivating object of analysis. S-RESS is additionally structured around "stressor activities", e.g. generation of waste residuals, harvesting activity, while affected systems provide the orientation for FDES, which uses a media, or environmental component, approach (e.g. atmosphere, water) based on an international survey (UN, 1977). Similarly, PSR is orientated around "issues" associated with particular environmental media, e.g. climate change, water resources. However, such structuring properties are more in the nature of guidance for application of the framework rather than integral to the definition of informational categories. The following sub-sections consider each of the DPSIR categories in turn.

2.2 Driver Category

Common to the frameworks summarised in Table 2 is the concept that environmental status or change is ultimately the result of, or driven by, humans.[2] However, there is little consensus around how this force should be defined and measured.

The EEA definition represents Drivers as "developments" in fundamental, broad-scale aspects of social systems. While this scope is appropriate to some forms of analysis, it does not allow for the concept of some constant aspect of social systems exerting an influence on ecosystems and, moreover, involves information that may be too highly aggregated to elucidate the interactions between social and ecological systems, e.g. in terms of the extent to which they are coupled. To illustrate in the context of eutrophication, in the EAA scheme one of the relevant "developments", and so a Driver, might be an increasing demand for agricultural output with an associated Pressure being an increased release of eutrophying agents (nitrogen, phosphorus, potassium), i.e. assuming increased use of man-made fertilisers to meet the increased demand. This approach would then fail to capture information on the effect of fertiliser use where there is a constant rate of such use, or indeed varying rates of use where there is no change in demand for agricultural output, and ignores the potential for decoupling in the relationship between fundamental economic forces and pressures. For example, changes in price or technology, or policy measures, may result in decoupling between fertiliser inputs and agricultural output.

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[2] While the EEA glossary refers to "driving force(s)" as opposed to "driver(s)" as used elsewhere (e.g. Cave *et al.*, 2003), there appears to be no conceptual distinction since the EEA uses the terms interchangeably (EEA, 1999; EEA, 2000).

Applications and reviews of the framework in practice, see for example, Cave *et al.* (2003), Turner *et al.* (2000) and Wieringa (1999), broadly follow the EEA definition and the above interpretation, although Cave *et al.* (2003) and Turner *et al.* (2000) expand on the nature of drivers by specifying types of change or processes (e.g. urbanisation, agricultural intensification). However, the predecessors of DPSIR (Table 2) reinforce the concern that the framework as defined by the EEA focuses the Driver category at too broad a scale. While different terms are employed, a common theme in the definition of "stressor" (S-RESS), "action" (FDES) and "indirect pressures" (PSR and PSR/E) is that they refer to "activities" – the use of fertilisers in the eutrophication example. Thus, they envisage specific actions as giving rise to environmental effects. Furthermore, the PSR/E framework draws a distinction between "underlying" and "indirect" pressures which reconciles the scope of the DPSIR Driver category to those of other frameworks in that "underlying" pressures correspond to broad-scale changes in social system as envisaged in the DPSIR Driver category while "indirect" pressures correspond to specific activities at the source of environmental change as envisaged in these other frameworks: respectively, the demand for agricultural output and the use of man-made fertilisers in the eutrophication case.

2.3 Pressure Category

Consistent with its definition of Driver, the definition of Pressure in the EEA scheme refers to "developments", again suggesting the need for some change in rate to constitute a pressure although, for example, a constant rate of emission can equally well be seen as a pressure on the assimilative capacity of ecosystems.

This category is problematical in terms of detecting a common theme in the other frameworks that might act as a guiding precedent. S-RESS uses the concept of "stress" but defines this in terms of pressures and FDES does not explicitly include a category corresponding to DPSIR's Pressure. However, both PSR and PSR/E regard a pressure as being a manifestation of human activities that directly acts on the environment (i.e. as "proximate" or "direct" pressures respectively), the simplest example being emissions. This notion is implicit in the PSIR and DPSIR pressure categories but by their reference to resource and land use also encompasses human activities that are elsewhere treated as the equivalent of drivers, creating a potential conflict between the categories.

2.4 State Category

Distinct from the definitions of other categories, EEA's definition of State refers to measurement (indicators) rather than simply what is the object of measurement but it is unclear whether this has any significance. Furthermore, it is unclear whether its reference to the "condition of *different* environmental compartments and systems" (emphasis added) envisages that a measure of State must summarise various aspects of the environment related to a given issue. Together, these observations indicate the need to define State in terms of the object of measurement (rather than a particular measure) while allowing this object to be that most relevant to the analysis in hand (rather than to "different … compartments").

As regards what is to be measured, the EEA definition of State refers to "condition", suggesting that relevant information in this category is concerned with status at a given point in time. Similarly, the PSR/E and PSR frameworks envisage a static measure reflecting the stock of the quantity or quality of environmental resources. Such measures may be useful in conveying readily accessible messages about trends over time. However, in terms of relating this category to others in the framework, information on change in State would be needed. Indeed, the PSIR and FDES frameworks are concerned with such change (and in this sense resource flows) in the environment, although FDES allows for other perspectives given its recognition that there may be a direct link between changes in stocks and environmental impacts (UN, 1984, paras. 46 & 47), while the relevant S-RESS category encompasses both "effects" on the natural environment and to stock of available resources.

2.5 Impact category

In DPSIR, impacts are expressed in terms of the effects of "environmental quality" on both social and ecological systems. Thus, in Cave *et al.* (2003) and Turner *et al.* (1998) impacts include both ecosystem and human welfare effects, although in the former case they focus on ecosystem effects such as "reduced water quality".

The inclusion of effects on ecosystems obscures the boundary between this category and the State category. Referring to the eutrophication example, the envisaged distinction in DPSIR could be between eutrophication as the relevant State and its consequences, such as the effects of hypoxia on particular species, as the Impact. However, this division would introduce an artificial distinction since ecosystem changes attributable to eutrophication would also fall in the State category since they reflect the "condition of different environmental compartments and systems". Thus, ecosystem changes attributable to eutrophication could be treated as a manifestation of Impact or an aspect of State. Alternatively, if State is taken to represent the availability of eutrophying agents, then Impact would embrace both the extent of eutrophication and its consequences, and thus would be seeking to encapsulate a wide range of information, particularly given its inclusion of consequences for social systems.

A further issue arises from including effects on social and ecological systems in the same category. This conflates distinct concepts, with their own systems of measurement, and potentially disguises the relationships between them. Moreover, defining the ultimate consequences of anthropogenic ecosystem change in this way complicates comparison with the human activities that gave rise to them and can thus hamper Response decisions. Separating the two forms of Impact to isolate the effects on social systems would make information in this new category comparable with that in the Driver category. With appropriate economic measurement in these categories there is thus direct correspondence with the elements required for cost-benefit analysis. To illustrate with the eutrophication example, say that the use of fertilisers increases agricultural yields and so welfare by A but leads to ecosystem Impacts, measured in biophysical terms as B, which generate external welfare costs of C. Only A and C are directly commensurable and respectively represent the benefits and costs of fertiliser use.

Support for the notion of isolating impacts on social systems in a separate information category can be drawn from predecessor frameworks that recognise effects on social systems: PSR/E and PSIR provide separate categories for such effects. Similarly, in their applications of DPSIR, both Bowen and Riley (2003) and Atkins et al. (2011) recognise the need for separate recognition of welfare effects.

2.6 Response Category

This category is the most uncontroversial in that the frameworks summarised in Table 2 share a common conception of information dealing with human reaction to environmental status/change. Furthermore, none confines the category to management action at a particular level represented by the other categories. Throughout, categories corresponding to Response include, for example, policy measures to reduce Drivers as much as to remediate or mitigate Impacts.

2.7 Omitted Categories

Having considered each of the categories included in DPSIR, the question arises as to whether these omit types of information covered in the other frameworks. In this context, the FDES framework includes “natural events” in its “action” category but this is on the basis that human activities can contribute to certain such events (UN, 1984, para. 41). The relation between these activities and events can be catered for through DPSIR’s Driver and State categories; a separate category is unnecessary. Nevertheless, this concept of “natural events” highlights the broader issue that relationships within ecosystems may be moderated or exacerbated by natural conditions or their variability that are exogenous to DPSIR categories, i.e. not the result of human activity. While S-RESS allows recognition of “natural forces” as a source of stress on the environment, alone or in conjunction with anthropogenic stresses (Friend, 1979, p.76), none of the frameworks allocates a category to information on such conditions/variability. Rather, it is implied that these forces are manifested through changes in the relationships between categories, i.e. in the application of the accounting framework. They do not constitute a separate factor in the chain of causal relationships that set the scope of the information categories.

3. Modifying DPSIR – the DPSWR Framework

The modifications of the DPSIR framework respond to the definitional and conceptual limitations, and incorporate lessons learned from the examination of precedents, as discussed above. In overview, the number of categories is retained to ensure they are the minimum necessary for representing relevant information and their scope is aligned with social or ecological systems. Table 3 summarises the resulting information category definitions employed in the DPSWR framework and the relationships between them are depicted in Figure 1. This figure also highlights their configuration as regards social or ecological systems, reflecting the distinction between phenomena associated with human agency and those associated with conditions or processes in ecosystems. Thus, the framework isolates categories of information relating to social systems.[3]

Each of the DPSWR categories is discussed below within a spatially-framed conceptual framework involving serial input-output relationships represented by notional coefficients. It is emphasised that this is a means of making explanations more concrete and conveying conceptual relationships in a more formalised setting so as to highlight issues in measurement; it does not purport to constitute a model. In reality, the relation between two categories may be non-monotonic (e.g. exhibiting threshold effects) and/or dependent on a variable from another category Nevertheless, this form of description may be used as a basis for identifying elements relevant to specifying models and inform decisions on relevant scales and the selection of variables appropriate to specific applications of the framework.

[3] The form of measurement for each information category is not prescribed by the framework but the system division denotes a broad distinction between types of available measurement. Categories associated with ecological systems involve the objective observation of nature; those associated with social systems may be represented by physical measures or socially constructed measures of ‘value’. However, a common criterion in the selection of measures is that they be appropriate to the objective of the analysis for which the framework is employed – in accounting theoretic terms, the framework is a means of processing information, which entails a purpose orientation (Chambers, 1966: 162).

Furthermore, the specific application will influence for which categories information is required; not all categories will necessarily be pertinent for every analysis.

3.1 Driver - Pressure

The key modification in the Driver category is to focus it on human activities that give rise to Pressure on natural systems. Thus, the relation between the two is made more direct, overcoming DPSIR's apparent concentration on large scale and potentially long-term changes in social systems which are at some remove from specific activities that precipitate ecosystem change. However, scope is offered for recognising these broader changes as well as the immediate activities associated with Pressures to facilitate studies concerned with trends in fundamental factor such as population and consumer choice that influence the level and nature of activities giving rise to Pressure. This is achieved by focussing the definition of a Driver in the modified framework on an activity or process within the social system but, where necessary to accommodate broader scale analysis, allows separation between "immediate Drivers" (those proximate to Pressures) and "underlying Drivers" (more closely corresponding to the Driver category in DPSIR). This is similar to the approach of the PSR/E framework in its definition of "pressures" (Table 2).

[Table 3 and Figure 1 about here]

In applications involving multiple Drivers, organising information on an economic-sectoral basis can help direct attention to which parts of the economy are most salient in respect of the environmental issue at stake. This may be useful in the scoping or prioritisation of analysis in practice, or in highlighting critical areas for policy development. Similarly, where the analysis is concerned with long-term social trends, organising immediate Drivers in this way can highlight where such trends are having most effect. A further benefit of sectoral classification arises where the application is motivated by understanding the range of impacts that given Drivers have. The sectoral scheme is not prescribed as part of the framework as the most appropriate level of detail is dependent on the application. In the ELME project, for example, a high level scheme with nine sectors derived from Eurostat (1999), as shown at the foot of Table 3, was adequate.

In DPSWR, the Pressure category takes on a broad meaning, representing the mechanism or process that intermediates between human action (Driver) and the relevant ecosystem State. As such, the category has a more abstract definition than in DPSIR and allows various uses dependent on the analytical context. This flexibility aids the applicability of the DPSWR framework to a range of contexts within the constraint of the Driver and State category definitions being more firmly fixed. Indeed, in certain cases the category may be redundant. For example, in the case of an emission from some human activity, it is the resulting increase in concentration of the pollutant in the environment that constitutes the Pressure on the ecosystem measured in the State category. By contrast, if the human activity directly affects the ecosystem of interest, e.g. loss of habitat due to dredging activities, there is no need to specify a Pressure measure. In such cases, the Driver category can still be used to examine alternative actions, e.g. different methods of dredging and disposal of spoil.

To examine the implications for measurement in DPSWR's Driver-Pressure relationship, consider measures of a range of human activities, a_{xi}, indexed by the suffix x ($x = 1, 2, \ldots, X$) at location i ($i = 1, 2, \ldots, I$), the set of which is represented by the column vector $\mathbf{A}_i$ of order $X \times 1$. Given the set of activities, $\mathbf{A}_i$, the resulting exploitation of environmental resources, e.g.

emissions, e_{yi}, can be connected through notional coefficients, α_{yxi}, where y indexes the type of exploitation. Thus, for location i, the set of exploitations may be represented as:

$$\boldsymbol{\alpha}_i \mathbf{A}_i = \mathbf{E}_i \qquad \text{……………………. (1)}$$

where $\boldsymbol{\alpha}_i$ is a Y x X matrix the elements of which are the respective coefficients and $\mathbf{E}_i$ is a column vector of order Y x 1, the elements of which are the measures of total environmental exploitation of type y from activities in location i, e_{yi}. For example, if $y = 1$ represents the emission of nitrogen species to water and $x = 1$ represents the amount of fertiliser used for a given period, α_{11i} represents the rate at which this pollutant is produced by this activity at location i. Furthermore, the first element in $\mathbf{E}_i$ is the total emission of nitrogen species to water from activities at location i in that period, which would also include, for example, atmospheric deposition of nitrogen from activities involving combustion at this location. Thus, equation (1) encapsulates the essential features of the Driver-Pressure relationship and highlights the significance of the coefficients, α_{yxi}, which can be used to represent various aspects of the relationship. Variation in a given coefficient across locations, i, may be used to represent differences in natural transport processes, i.e. the extent to which a given Driver activity results in Pressure over a given period, while variation over time at a given location could be used to represent information on decoupling between Driver activities and Pressures, for example due to management practices, or a closer coupling due to exogenous changes.

The scale selected to define location and the measures of activity depend on the application. For example, a national government may restrict its attention to activities within its territory or jurisdiction while a regional environmental authority, transcending national boundaries, is more likely to be concerned with activities at a geographical scale appropriate to a specific ecosystem change and thus, potentially, with activities in various countries.

3.2 Pressure - State

In common with other frameworks, State is defined in general terms by reference to "attributes" (see Table 3) to allow flexibility in application but is most directly comparable to the S-RESS and FDES frameworks scope in explicitly providing for both static and dynamic measures of environmental conditions. To illustrate by reference to the input-output analysis, consider static measures of the relevant conditions at location j, c_{zj}, where z (z = 1, …, Z) indexes the type of environmental condition. As noted above, such static measures may be compared at different points in time to identify trends but by themselves they do not generally support analysis of the relationships between State and its adjacent categories, which involve measurement of change over periods of time. Therefore, where the application involves relating information across categories, measures of change in conditions, d_{zj}, across periods comparable with those used for measurement in other categories, are required. Where the elements of $\mathbf{D}_{ij}$ (a Z x 1 vector) are the measures of change in different types of condition d_{zj}, and $\boldsymbol{\beta}_{ij}$ is a Z x Y matrix, the elements of which are coefficients linking respective Pressures arising from activities at i to change in environmental conditions at j, the relationship between the Pressure and State categories can be represented by:

$$\boldsymbol{\beta}_{ij}\, \mathbf{E}_i = \mathbf{D}_{ij} \qquad \text{……………………. (2)}$$

For example, if $z = 1$ is taken to represent eutrophication then d_{1j} as the first element in $\mathbf{D}_{ij}$ is a measure of the change in eutrophication at location j attributable to Pressures from human activities at location i.

While the coefficients $\boldsymbol{\beta}_{ij}$ in equation (2) represent purely natural processes, they also represent information on human-ecosystem interactions in that they reflect to what extent a unit of Pressure from Driver activities at a given location, i, is translated into State change at j. Comparing coefficients across different locations j indicates the physical distribution of environmental consequences from those activities. This is an anthropocentric orientation and applications motivated by State change at a specified location $\mathbf{D}_j$ resulting from activities at multiple locations can be represented by (notional) summation:

$$\mathbf{D}_j = \sum_i \mathbf{D}_{ij} \qquad \text{(3)}$$

Indeed, in practice, it is the values in $\mathbf{D}_j$ that are most likely to be observed initially, and analysis is required to identify which Driver locations, i, are most material in terms of relative values of e_{yi} and $\boldsymbol{\beta}_{ij}$ coefficients across locations.

3.3 State - Impact/Welfare

Modifications of DPSIR's State and Impact categories are interrelated. The underlying motive is to isolate the effects of ecosystem change in terms of social systems from the ecosystem changes resulting from Pressures. Thus, the Impact category is redefined in DPSWR to cover only information relating to social system effects (see Table 3) and the ecosystem changes which DPSIR would have treated as Impacts are dealt with in the State category so that this category encompasses all ecosystem changes other than those which constitute Pressures; where the boundary lies between them depends on the application context, as discussed in section 4 below. The renaming of the Impact category as Welfare signifies this change in scope and improves communication with natural scientists who can find it challenging to employ the word "impact" as exclusively relating to social systems and instinctively use it to also encompass ecosystem change.[4] The DPSWR nomenclature supports this usage in that "impact" can refer to State and/or Welfare changes.

By designating a separate category for information relevant to assessing Welfare effects of ecosystem change, the DPSWR framework draws a clear distinction that makes the relationship between them more explicit and highlights the need for human agency in linking State to Response, since Response is contingent on human perception of values associated with State. Moreover, this distinction supports comparison of the human causes and effects of environmental change: the Driver category identifies activities the economic benefit of which can be assessed next to the costs in the Welfare category. Furthermore, the distribution of benefits and costs can be revealed in the measurement scheme. Continuing the input-output representation above, the change environmental conditions at location j can be notionally translated into welfare effects at location k, w_k, through the K x Z coefficient matrix, $\boldsymbol{\gamma}_{jk}$ to yield a vector of welfare effects, $\mathbf{W}_k$:

$$\boldsymbol{\gamma}_{jk}\,\mathbf{D}_j = \mathbf{W}_k \qquad \text{……………………. (4)}$$

The locations, k, thus represent where the costs of environmental degradation are borne, while the locations, i (equation 1) represent those where the activities giving rise to that change took place and thus where benefits arise. Any mismatch between the two reflects different

[4] I am grateful to Laurence Mee for this insight.

distributions of benefits and costs and where these cross institutional, e.g. national, boundaries this raises the question of equity.

Welfare effects encompass a range of human values as regards environmental change, including non-use value motivated by bequest, existence or ‘anthropocentric intrinsic’ values, that are potentially capable of representation with a common (monetary) metric (Turner, 1999). Such monetary representation enables lost benefits, or costs, to be aggregated across types of environmental change and their location, and to be compared with monetary representation of the benefits associated with the Driver activities from which the Welfare effects derive, i.e. cost-benefit analysis. Similarly, such analysis might be applied in assessing the cost of Response actions against the benefit of environmental improvement. However, in common with the other DPSWR categories, the Welfare category is defined conceptually rather than in terms of its measurement base. Consequently, in applications where there is a lack of reliable valuation data, indicator-based measures of relevant criteria, e.g. an increase in morbidity or reduction in employment attributable to State change, may be used to represent the Welfare category. With appropriate weightings, such indicators can be combined to represent multiple criteria in a single measure (i.e. multi-criteria analysis, OECD, 1989: 19) that can substitute for an aggregate monetary value for those criteria.

Through its use of the welfare concept, the DPSWR framework gives a primary role to assessing changes in ecosystem services in terms of the effects on humans, thus aligning it with the information needs of various decision making contexts (Fisher et al., 2009) and policies such as the Marine Strategy Framework Directive (EU, 2008:29). However, the content of the Welfare category can be adapted to other decision-frames such that ‘welfare’ is given a broader meaning as ‘what matters’ through human instrumentality, i.e. human agency in defining decision criteria. For example, where cost-benefit analysis is rejected on economic-theoretic grounds (Gowdy, 2004), under conditions of uncertainty (Perrings, 1991), or, more generally, as an inappropriate basis for environmental decision-making (O'Neill, 1997; Sagoff, 2004), the category could be used to encapsulate information on minimum acceptable levels of ecosystem provision in accordance with the precautionary principle or an ethically motivated desire to maintain such a level 'for its own sake' (i.e. 'anthropocentric intrinsic value' in the classification scheme of Turner, 1999:35).

4. Illustration in Marine Ecosystems

To test the feasibility of the DPSWR framework, natural science teams working in the ELME project were requested to apply the framework in identifying key Drivers and Pressures for the environmental issues with which they were concerned, using the definitions and a slightly extended version of the notes shown in Table 3. Examples derived from their responses are presented in Tables 4 and 5 to illustrate the application of the framework in the marine context. These examples are selected as they involve differing treatments of the same class of item: seagrass loss in the Mediterranean (Table 4) includes various forms of pollution as Pressures while that of chemical pollution in the Northeast Atlantic (Table 5) takes pollution, rather than its consequences for ecosystems, as the State of interest. This reflects the scope of work of the respective teams and illustrates that the treatment of an item as a Pressure or a State variable depends on the application context. A similar flexibility is apparent in policy. The EU's Marine Strategy Framework Directive (EU, 2008) prescribes descriptors of "good environmental status" (in Annex I). Some of these directly correspond to State (e.g. no.1 "biological diversity is maintained"), while others may be seen more generally as Pressures (e.g. no.11 “introduction of energy … is at levels that do not adversely affect the marine environment”).

[Tables 4 and 5 about here]

Despite the difference in the role of pollution in these cases, both are able to align biophysical phenomena relevant to their scope with Diver and Pressure categories. However, this involves different approaches to the classification of Pressures. In the seagrass case there is a range of types of Pressure (physical, chemical and biological), while for the chemical pollution case this category is used to organise Drivers according to the route of transmission of the pollutants to the marine environment, reflecting the significance of different transport processes as contributors to State change.

The identification of Drivers and their sectoral classification by the respondents were consistent with the concepts used in the design of the framework despite the relatively simple definition of Driver. Indeed, there is evidence of a flexible interpretation in the responses in that static physical structures such as shipping infrastructure were seen as Drivers although the “activity or process” with which they are associated is their presence, i.e. “being there”.

5. Concluding Remarks

The DPSWR framework involves a number of modifications to DPSIR which seek to improve the clarity of information category definitions and establish a conceptual foundation for each category that supports its linkage with other categories. By defining Drivers in terms of human activities, a direct link to Pressures is enabled; by expanding the State category to encompass changes in conditions establishes a link between Pressures and changes in human Welfare over a period of time; and by separating such Welfare changes from State changes the boundary between social and ecological systems and the interaction between them are clearly marked. As a result, the DPSWR information categories relating to social systems highlight the link between the human activities that give rise to environmental change, whether as a result of actions in the Driver or Response categories, and the effect of such change on humans. Thus, the framework isolates information relevant to the requirements of cost-benefit analysis and other decision frames insofar as these reflect human, rather than intrinsic, values.

Modifying DPSIR in the ways embodied in the DPSWR framework was found to be feasible in the project that motivated this study and imports advantages to applications in terms of supporting the identification of representative variables for each category and comparability across studies. Furthermore, the conceptual input-output analysis employed here to represent relationships between categories indicates types of information needed to fully account for interactions between human and ecological systems.

In common with previous socio-ecological accounting frameworks, DPSWR is less prescriptive than institutional accounting frameworks in its definition of information to be provided but is more comprehensive in its scope. This allows flexibility in its application but results in a richer, more integrated portrayal of human-ecosystem interactions, as is apparent in reconciling this framework with those employed in institutional accounting (Table 1). In the case of macroeconomic accounting, the primary link with DPSWR is through limiting the State category to a scale in accordance with national boundaries, for example UNSD (2012) defines the scope of “environmental assets” by reference to “the economic territory over which a country has control … including waters and sea-beds within a country's Exclusive Economic Zone" (p.124). Thus, scope is restricted in accordance with anthropocentric criteria which may not correspond to the scales required to fully capture information on ecological change as envisaged in DPSWR. In corporate level accounting, the current practice (as illustrated by the examples in Table 1) is to limit accountability in reporting and management information systems to the immediate results of the entity's Driver activities, its emissions or resource use, corresponding to Pressures in DPSWR. However, where the entity operates at multiple locations, information on Pressures aggregated at the corporate level may be of limited usefulness.

While socio-ecological accounting frameworks such as DPSWR offer the potential for more detailed policy-relevant information than institutional frameworks, they have thus far been concerned primarily with the definition of relevant types of information. Their further development requires consideration of how to incorporate information on the temporal lags between measures of different categories (e.g. *when* Drivers are manifested in Welfare changes) and the degree of uncertainty in the relationship between information categories, as well as how these relationships may be affected by other changes in future (the importance of which is noted by Heal, 2007, in the context of national accounting). These factors could be material to decisions based on applications of the DPSWR framework.

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Table 1: A typology of environmental accounting frameworks

Perspective	Economic scope/ Accounting entity	Environmental scope	Measurement	Examples
Institutional	Macroeconomic/ Geo-political entity (typically a country)	Attributable (national) resource stocks and flows	Monetary, e.g. environmentally adjusted national income, "environmental asset" values[a]	Satellite national accounts (UNSD, 2003: 450, 2012) Sustainability indicators (Hamilton and Clemens, 1999; Pearce and Atkinson, 1993)
			Physical units, e.g. physical flows between economy and environment	Satellite national accounts (UNSD, 2012)
		Total resource use	Geographical area required to meet entity's needs	Ecological footprint (Wackernagel et al., 1999)[b]
	Microeconomic/ Corporate entities (e.g. firms)	Attributable natural resource use (as source or sink)	Physical units[c]	Sustainability reporting guidelines (GRI, 2011) Internal ecological accounting (Schaltegger and Burritt, 2000: Ch.11)
Socio-ecological	"Mesoeconomic"/ Scope required to account for social system interactions relevant to the environmental scope	As specified for the purpose of the analysis	Indicators representing status or change by information category	DPSIR (EEA, 2007)

[a] For an overview, see Lawn, 2007.
[b] Ecological footprinting has been applied to sub-national entities, e.g. Greater London (BFF, 2002).
[c] The use of monetary measures in corporate environmental information systems and reporting (e.g. applying external damage estimates to emissions or costing replacement/amelioration) is conceivable but has not been widely taken up in practice.

Table 2: Summary of socio-ecological accounting framework information categories and their content

Framework	**Information Categories**				
	Driver	**Pressure**	**State**	**Impact**	**Response**
DPSIR (EEA, 2012)* (EEA, 1999)**	Driving force** *social, demographic and economic developments in societies and the corresponding changes in life styles, overall levels of consumption and production patterns*	Pressure** *developments in* (the) *release of substances (emissions), physical and biological agents, the use of resources and the use of land*	State (indicator)* *indicator of condition of different environmental compartments and systems in physical, chemical or biological variables*	(Environmental) impact* *impacts on human beings, ecosystems and man-made capital resulting from changes in environmental quality*	Response** *responses by groups (and individuals) in society, as well as government attempts to prevent, compensate, ameliorate or adapt to changes in the state of the environment*
PSIR (Turner 2000; Turner et al., 1998)	Socio-economic drivers *urbanisation and transport/trade, agricultural intensification/land-use change, tourism and recreation demand* etc.	Environmental pressures *land conversions and reclamation, dredging, aggregates and oil and gas extraction, waste disposal* etc.	Environmental "state" changes *changes in … fluxes across coastal zones, loss of habitats and biodiversity* etc.	Impacts *consequential impacts on human welfare via productivity, health, amenity and existence value changes*	Policy response options -
PSR/E (Schulze and Colby, 1994)	Pressures Underlying: *social and technological forces that … drive economic activity* Indirect[a]: *human activities related to … improvement of human welfare*	Direct pressures *biophysical inputs and outputs that may exert immediate stress on ecosystems*	State *Ambient conditions and trends* *Valued environmental attributes*	*Human health and welfare: Longevity, morbidity, value of ecological goods & services, other non-use values*	Societal response *purposeful actions to address … ecological, human health or welfare changes or impacts that are considered undesirable*
	Effects *Relationships between two or more variables within any of the pressure, state and response categories*				
PSR (OECD, 2003; 1993)	Pressure Indirect *human activities which lead to proximate pressures*	Proximate *pressures directly exerted on the environment e.g. emissions*	State *quality of the environment and the quality and quantity of natural resources*		Response *actions to mitigate, adapt to or prevent human-induced negative impacts on the environment*
FDES (UN, 1991; 1984)	Action *social and economic activities, natural events*		Impact *environmental impacts of activities/events* Stock *of natural resources*		Reaction *responses to environmental impacts*
S-RESS	Stressor	Stress	Environmental response		Collective and individual

(Friend, 1979)	*activities with the potential to degrade the quality of the natural environment, to effect* (sic) *the health of man, to threaten the survival of species, to place pressure on non-renewable resources, and to deteriorate the quality of human settlement*	*elements that place pressures on, and contribute to the breakdown of, the natural and man-made environment*	*observed effects of stress upon natural and man-made environments* Stock *available resource (cf. flows in other measures)*		responses *man's reaction to environmental changes*

[a] Also includes "natural processes and factors" which may act alone or together with human actions to create biophysical pressures.

Table 3: Definition of DPSWR information categories

Information Category	Definition	Commentary
Driver	An activity or process intended to enhance human welfare.	▪ Organising activities into economic sectors assists in directing attention to the most salient areas of the economy.[a] ▪ Where necessary the category can be split between: - Immediate Drivers: activities proximal to at least one Pressure. - Underlying Driver: population, economic, social and technological factors that influence the level/nature of Immediate Drivers.
Pressure	A means by which at least one Driver causes or contributes to a change in State.	Thus a pressure is a link between a Driver and a change in environmental State, effectively therefore the agent of change. Generally, it is a by-product or an unintended consequence of the Driver activity/process.
State (change)	An attribute or set of attributes of the natural environment that reflect its integrity as regards a specified issue (or change therein).	This definition allows flexibility so that the information or measure used can be tailored to the precise circumstances that are relevant. However, often the most useful information will: ▪ relate to the extent to which a system has been subject to disturbance, particularly in terms of ecosystem functionality, and ▪ reflect changes in State over time. Natural (i.e. non-anthropogenic) variability may influence the effect of Pressures on State or change in State.
Welfare	A change in human welfare attributable to a change in State.	▪ “Change” allows for enhancement but generally we are concerned with diminution in welfare. ▪ Welfare is not only affected by changes in use values; it can be affected by changes in nonuse values that people hold (e.g. in respect of general ecosystem functionality or the viability of particular species).
Response	An initiative intended to reduce at least one Impact (State or Welfare change).	In this sense “initiative” is an action that would not have been taken in the absence of an effect on Welfare. It may operate through influencing any of the above but with the intention to ultimately reduce such an effect.

[a] For example, the following sectors were used in the ELME project (based on Eurostat, 1999): Agriculture, Energy, Fisheries & Aquaculture (including extraction of biological resources), Household (individual consumption), Industry, Tourism & Recreation, Transport, Urbanisation & Coastal Development.

Table 4: Summary of drivers and pressures resulting in loss or degradation of seagrass beds in the Mediterranean

Pressure	**Driver**	**Sector**[a]
Nutrient (nitrogen & phosphorus) release	Fertiliser use; Intensive livestock management	Agriculture
	Release of sewage after low level treatment; Use of inadequate sewage systems (resulting in leakage and storm water overflows)	Urbanisation
	Aquaculture (discharge of waste food, faecal and dead animal waste)	Fisheries
Mechanical disturbance	Dredging and spoil disposal; Propeller and anchor damage from shipping	Transport
	Laying of submarine pipelines and cables; Land claim	Urbanisation
	Use of mobile gears (e.g. trawling and dredging)	Fisheries
	Aggregate extraction	Resource Extraction
	Anchoring of pleasure craft	Tourism & Recreation
Introduced organisms	Accidental release of organisms from aquaria (e.g. *Caulerpa taxifolia*)	Tourism & Recreation
	Use of mobile fishing gears (leading to spread of *Caulerpa*)	Fisheries
Contaminants	Land claim using contaminated landfill; Sewage sources, as above	Urbanisation
	Industrial processes (discharge of untreated wastes)	Industry
	Dredging/spoil disposal; Shipping waste disposal (e.g. oil and fuel)	Transport
Physical oceanographic change (increase in turbidity)	Aggregate extraction	Resource Extraction
	Beach replenishment using terrigenous material	Tourism & Recreation
	Land claim; Coastal defence construction/modification; Discharge of sewage particulates	Urbanisation
	Land management, e.g. deforestation (increased deposition of sediment)	Agriculture
	Aquaculture (discharge of waste food, faecal and dead animal waste)	Fisheries
Direct removal	Harvesting for use in agricultural fertiliser production	Fisheries
	Removal to “improve” aesthetics of tourist beaches.	Tourism & Recreation
Anthropogenic structures (producing shading)	Shipping infrastructure: ports, harbours, jetties	Transport
	Land claim; Protection of urban areas/infrastructure through coastal defences	Urbanisation
Chemical oceanographic change	Water abstraction	Extraction
	Untreated waste discharge (increasing chemical oxygen demand)	Industry
	Untreated sewage discharge (increasing chemical and biological oxygen demand)	Urbanisation
Deposition of physical material	Laying of submarine pipelines and cables; Sewage sludge disposal	Urbanisation
	Construction/maintenance of artificial reefs	Tourism & Recreation

[a] “Fisheries” includes biological resource utilisation and aquaculture; “Transport” includes maritime traffic and construction/preservation of navigable routes

Table 5: Summary of drivers and pressures resulting in chemical pollution in the Northeast Atlantic

Pressure	**Driver**	**Sector**
Chemical products discharged into rivers, coastal waters or offshore	Disposal of urban waste; Release of sewage after low level treatment; Use of inadequate sewage systems (resulting in leakage and storm water overflows); Coverage of land with urban space and roads (producing run-off water)	Urbanisation
	Use of domestic chemicals and pharmaceuticals (including hormones) present in wastewater	Household
	Industrial processes	Industry
	Aquaculture (leading to release of chemotherapeutics, hormones)	Fisheries
	Shipping waste disposal; Release of antifouling agents	Transport
	Use of pesticides/herbicides (contaminating run-off water)	Agriculture
Atmospheric emissions deposited in rivers, coastal waters or offshore	Industrial processes	Industry
	Operation of terrestrial vehicle and ship engines	Transport
	Combustion for electricity generation	Energy
	Oil and gas refinery processes; Flaring by oil and gas production platforms	Energy
	Use of pesticides/herbicides	Agriculture
Chemicals accidentally released into rivers, coastal waters or offshore	Industrial processes	Industry
	Transport of oil/chemicals	Transport
	Oil production processes	Energy

Figure 1: Summary of DPSWR definitions and relationships