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Review Paper

Integrating health and environmental impact analysis[☆]

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ABSTRACT

Scientific investigations have progressively refined our understanding of the influence of the environment on human health, and the many adverse impacts that human activities exert on the environment, from the local to the planetary level. Nonetheless, throughout the modern public health era, health has been pursued as though our lives and lifestyles are disconnected from ecosystems and their component organisms. The inadequacy of the societal and public health response to obesity, health inequities, and especially global environmental and climate change now calls for an ecological approach which addresses human activity in all its social, economic and cultural complexity. The new approach must be integral to, and interactive, with the natural environment.

We see the continuing failure to truly integrate human health and environmental impact analysis as deeply damaging, and we propose a new conceptual model, the *ecosystems-enriched Drivers, Pressures, State, Exposure, Effects, Actions* or 'eDPSEEA' model, to address this shortcoming. The model recognizes convergence between the concept of ecosystems services which provides a human health and well-being slant to the value of ecosystems while equally emphasizing the health of the environment, and the growing calls for 'ecological public health' as a response to global environmental concerns now suffusing the discourse in public health.

More revolution than evolution, ecological public health will demand new perspectives regarding the interconnections among society, the economy, the environment and our health and well-being. Success must be built on collaborations between the disparate scientific communities of the environmental sciences and public health as well as interactions with social scientists, economists and the legal profession. It will require

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outreach to political and other stakeholders including a currently largely disengaged general public.

The need for an effective and robust science-policy interface has never been more pressing. Conceptual models can facilitate this by providing theoretical frameworks and supporting stakeholder engagement process simplifications for inherently complex situations involving environment and human health and well-being. They can be tools to think with, to engage, to communicate and to help navigate in a sea of complexity. We believe models such as eDPSEEA can help frame many of the issues which have become the challenges of the new public health era and can provide the essential platforms necessary for progress.

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Introduction

Aims and scope of this paper

In discussing different models of public health, Lang and Rayner¹ introduce *Ecological Public Health (EPH)* as a new environmental conceptualization. EPH focuses on the interactions between the biological and the material world while fully recognizing the complexity of these links and influences. Their passionate argument for a better integration of these worlds is timely, and as we will argue here, is indispensable for addressing the challenges facing human and environmental health of global environmental and climate change. This paper and indeed the evolution of Ecological Public Health as a concept have emerged from attempts to better integrate environmental and health impact assessment for which the publication of the book *Health and Environmental Impact Assessment – An Integrated Approach* by the British Medical Association² laid the groundwork in the late 1990s.

To pursue public health improvements taking into account ecological principles, has led us to review the evolution of the field of environmental impact assessment, including improvements in understanding and valuing ecosystems, especially conceptual modelling. Such knowledge can then be used to operationalize the ecological public health approach as we move forward.

In this paper, we use the terms *conceptual model* specifically to refer to the core formulations of decision support methodologies (e.g. the Driver-Pressure-State-Impact-Response, or DPSIR model), while we refer to *conceptual framework* to identify the comprehensive set of data and models applied.

Evolution of conceptual models for environment and health

In the past, there has been little or no interaction between scientists from the public health and ecosystems services communities. The typical public health perspective on the environment is marked by a ‘pollution-driven’ concept of environmental effects on human health. The *Driver-Pressure-State-Impact-Response (DPSIR)*³ and the *Driver-Pressure-State-Exposure-Effect-Action (DPSEEA)*^{4,5} frameworks for instance have been developed and widely applied in an environmental and health impact assessment context. More recent views of the environment in health research and practice embrace a

socio-ecological dimension, and recognize the more subtle influence of the environment on health.^{4,5} For example, we now recognize the potential for aspects of individual’s physical surroundings to encourage or impede participation in physical activity; or for substandard housing to combine with other life circumstances to engender stress and isolation with implications for both mental and physical well-being. In a similar way, the main objective of the ecosystem services concept was initially framed rather narrowly as determining the (measurable, economic) services that ecosystems provide to humanity, while tending to underestimate the importance of humans as integral components of the ecosystem and their intimate links to biodiversity and to biological and biophysical processes.

A number of richer conceptual models for ecosystem services have been proposed in recent years. The Millennium Ecosystem Assessment⁶ (MEA) prompted increasing efforts to formalize and operationalize models of ecosystem services. The MEA focussed on the linkage between ecosystem services and human well-being, and so forms a useful resource for framing assessment of ecological public health. The MEA broadly defined four categories of ecosystem services:

1. **Provisioning Services** cover products obtained from the ecosystem e.g. fresh water, food, timber, fibres pharmaceuticals etc.;
2. **Regulating Services** govern issues like climate, rainfall, pollination, the spread of disease, the purification of water and the filtration and breakdown of organic waste;
3. **Cultural Services** encompass a diverse set of non-material ways in which people benefit from ecosystems; and
4. **Supporting Services** underpin the production of all other ecosystems services. Key supporting services are *soil formation* (which supports many of the provisioning services), *photosynthesis* and *primary production* (assimilation or accumulation of energy and nutrients by organisms) and *nutrient cycling* (notably the cycling of nitrogen and phosphorous through ecosystems).

In terms of more recent conceptual models of ecosystem services, *The Economics of Ecosystems and Biodiversity*⁷ (TEEB) framework and the approach taken for the UK *National Ecosystem Assessment*⁸ (UK NEA) are derived from the MEA framework. These approaches both largely omit, in terms of

the DPSIR type approach, the *Pressure* variable (subsuming it within the *Driver* variable) and focus more on the detail of the relationships between structural and process components of ecosystems and the different services and benefits they deliver to society. Other efforts include the *Framework for Ecosystem Service Provision*⁹ (FESP), based explicitly on the DPSIR framework, and the *Integrated Science for Society and the Environment (ISSE)* framework¹⁰ which is more loosely based on DPSIR and uses a narrative approach. The *Ecosystem Properties, Potentials and Service*¹¹ (EPPS) framework differentiates between the potential and real supply of ecosystem goods and services and the biophysical prerequisites underpinning these.

For the purpose of this paper, we focus on ecosystem services that are directly related to human health. We particularly emphasize the limited representation of public health and well-being in current ecosystem services research. For example, the UK NEA only considered a very limited subset of the health benefits of ecosystem services. For the purposes of ecological public health, it is necessary for the wider implications of changes in ecosystem service provision for public health be considered.

Whilst applauding improved opportunities for integration of thinking and working across disciplines and sectors already provided (e.g. by Strategic Environmental Assessment (SEA), Health Impact Assessment (HIA) and Environmental Impact Assessment (EIA) protocols) and for evidence synthesis (e.g. through realist approaches), we question whether this is sufficient. In the following sections through reference to specific conceptual models, we seek to demonstrate the need for and benefit of a comprehensive and consistent integration of human and environmental health impact analysis. We discuss how the enhanced conceptual model we propose can foster dialogue across different disciplines by illustrating both the interconnection and dependency of causes and effects, thus improving the capture of synergies and trade-offs between policy measures. We argue for the power of a simple conceptual model to bridge professional, institutional, and policy boundaries; and recommend it as having potential significance for international agenda setting.

The scope and potential of conceptual models

Conceptual models are extremely useful for issue framing and for communicating complex relationships to a wider non-specialist audience. While such models are by design simplified representations of complex real-world relationships, the complexity of the underlying issues described often creates difficulty in agreeing the most appropriate model to address specific issues.¹² Difficulties are further compounded when developing models to bridge scientific and professional disciplines and/or policy areas. Differences in specialist vocabularies and conceptual understanding of the 'issue' often act as barriers to establishing a generally accepted framing of the issues. This is regrettable given the utility of conceptual frameworks as 'Tools to think with'¹³ in a variety of situations.

An abundance of conceptual models exists; those most relevant here have been introduced and discussed in more detail by Reis et al.¹⁴ These range from the comparatively simple to those which embrace complexity such as the

Foresight obesity systems model¹⁵ which seeks to integrate all levels from the physiological response to environmental influences.

Depending on their characteristics, conceptual models and frameworks such as those developed in ecosystem services, DPSIR, and modified DPSEEA (mDPSEEA¹⁶) have a variety of uses including: a) as conceptual frameworks for problem framing and elicitation; b) as scientific tools for understanding and predicting complex human-environment and ecosystem interactions; c) as tools to guide management and policy decision making and responses; and d) as communication tools for interaction with stakeholders.

Here we focus on the integration of ecosystems services frameworks with the mDPSEEA model. We show how the integrated approach can be developed and consistently applied to represent, in a policy-relevant way, the dynamic interaction of human activity (including the pursuit of population health) with natural global systems.

The environment in public health

Public health owes many of its most celebrated triumphs to action on the environment. Scientific and technological advances have consistently driven interventions to dramatically reduce numbers exposed to toxic, infectious and physical hazards in the key environmental compartments of air, soil and water, and through the food chain. These improvements and their positive implications for prosperity and the burden of morbidity and disease have often been unequally shared between countries and across society. However, the effectiveness of population-specific interventions to address environmental hazards is undeniable. In a survey of over eleven thousand readers of the *British Medical Journal* in 2007, most believed the provision of piped water supplies and sewerage systems – the so-called 'sanitary revolution' – to be the most important medical milestone since the journal was first published in 1840.

Yet in the developed world during the latter half of the twentieth century, a belief that the threat to health from the environment was largely contained, coupled with an improved understanding of pathological mechanisms at the cellular and molecular levels, saw public health priorities shift away from the environment towards individual behaviours and lifestyle choices. More enlightened thinking emerging in the 1970s – partly driven by spiralling healthcare costs – recognized that even if they were effective, policies directly targeting unhealthy behaviours frequently increased social inequalities in health.

Advocates of the 'socio-ecological' perspective posited that health and disease were always products of a complex mixture of factors at individual and societal levels and should be tackled accordingly. Thus environment (in all its aspects: physical, social, economic, cultural, historical, and political) would always be an important, if sometimes subtle, determinant of health status.

Unfortunately, translating such insights into policy has generally proved challenging. Public health has understandably struggled with complexity. It has often failed to catalyse broader multisector collaborations necessary to react

appropriately (e.g. to growing understanding of a psychosocial dimension¹⁷ to the relationship between people and place; or indeed mounting evidence on the health-nurturing potential of high quality environments, especially green, blue and natural spaces^{18–20}).

In parallel with the changing discourse in public health, a new awareness of environment pollution was developing from the seminal insights offered by, for example, Rachel Carson's 'Silent Spring'.²¹ Both the public and politicians became increasingly concerned about exposure of animals and plants, as well as humans, to pollutants ranging from pesticides and metals (such as mercury and cadmium); to radioactive materials. This concern became manifest in the establishment of environment agencies such as the United States Environmental Protection Agency (EPA), charged with protecting both ecosystems and the public from emerging environmental threats. A more sophisticated view of how human activities might adversely affect ecosystems and their component organisms began to take root.

Ecologists also made progress in understanding that ecosystems are not static but progress through a succession states with different species mixes over time. Such work culminated in the development of a model which encapsulated how both natural and anthropogenic drivers can exert pressures on ecosystems, thereby influencing their progression through ecological succession and giving rise to a series of impacts which in turn provoke responses. This was presented as the 'DPSIR' model in the late 1990s, and has since been widely adopted and used, for instance by the European Environment Agency (EEA).

More recently, the utility of conceptual models to help navigate socio-ecological complexity in environmental public health has been recognized. In 2008, the Scottish Government introduced a new policy initiative on environment and human health – *Good Places Better Health*²² – which used the mDPSEEA model.¹⁶ Populated initially for selected child health outcomes, it offered a policy-relevant way of considering the higher level cultural, economic, demographic, and other drivers which shape environment as well as those social, demographic and other factors which influence exposure and health outcomes (positive or negative) in the individual. mDPSEEA also proved a useful 'tool to think with' and in the process of populating the model facilitated stakeholder engagement and consensus building. The populated models in turn informed structured literature reviews, the assembly of a wider range of evidence, acted as a framework for data gathering, and as a basis for quantification. The overall approach allowed health-relevant messages to be distilled for a broad policy constituency.²³

The capacity of the model to simplify complex issues has helped elucidate the environmental contribution to health inequalities. Indeed, there is real potential to apply the approach to other issues in health and environment, e.g. identify environmental action which could help address the social and public health challenges of an ageing population. Despite proving useful in a policy context, mDPSEEA was conceived primarily to address proximal environmental health issues and now seems limited in the face of the 21st century threats to human health and well-being, and long term survival in the face of anthropogenic damage to planetary systems.²⁴

Proposal for a new conceptual model

The application of DPSIR and the practical application of the ecosystem services concept have been widely discussed.^{25,26} A major challenge for the deployment of any conceptual framework is to account for complexity with regards to feedback loops across the whole system or individual components within it. This complexity is one reason for the emergence of different frameworks over time.

Conceptually, the model we propose is based on previous interdisciplinary experiences. It also draws on applications with different foci, for instance, models addressing remediation/removal of adverse effects (as in the case of classical *pollution-damage-to-health* relationships) and those taking a more proactive approach (such as those relating to the provisioning of beneficial effects on human health and well-being). Another aspect is that in the same way as human influence can adversely affect ecosystems, negative effects or 'dis-services' of ecosystems (such as transmitting vector-borne diseases or flooding) should be accounted for in a comprehensive impact assessment framework. The frameworks which would emerge from embracing these wider considerations would include dynamic feedbacks (both positive and negative), and may be considered 'a bridge too far,' until a consolidated view has been established in both the research and policy communities.

We identify convergence between the emerging field of *Ecological Public Health* (with its calls for an acknowledgement in policy and action of the integration of social and natural ecology) and the concept of ecosystem services. We agree that there are close relationships between ecosystem services and the four determinants of human health and well-being, as identified by the *Millennium Ecosystem Assessment*.⁶ Based on the experience both in using mDPSEEA and applying the ecosystem service frameworks, we suggest that there is a need to integrate social and ecological perspectives within both environmental and public health policy in order to frame complex issues in a policy-relevant way and to support stakeholder engagement. This implies that a new conceptual framework is required that can provide an underpinning theoretical model, and also help communicate and operationalize *Ecological Public Health* for the development of integrated policies.

We propose the integration of aspects of ecosystem services into the mDPSEEA framework, extending the representation of *State* beyond simply that of a physical environment with particular physical, chemical, biological, or aesthetic etc. characteristics. This allows different pathways from pressures via ecosystem services to *Exposure* to be reflected. This model, termed '*ecosystem enriched*' or eDPSEEA (Fig. 1), will provide a platform for a cross-disciplinary integration of approaches to jointly assess impacts of environmental pressures on human health and well-being as well as ecosystem health and the resulting ecosystem services provided.

The eDPSEEA framework explicitly acknowledges that the actions of humans can operate at several points in the system leading to 'knock-on' effects, that can lead to trade-offs and synergies of policy actions directed at specific intervention points throughout the model and process 'pathway.' This

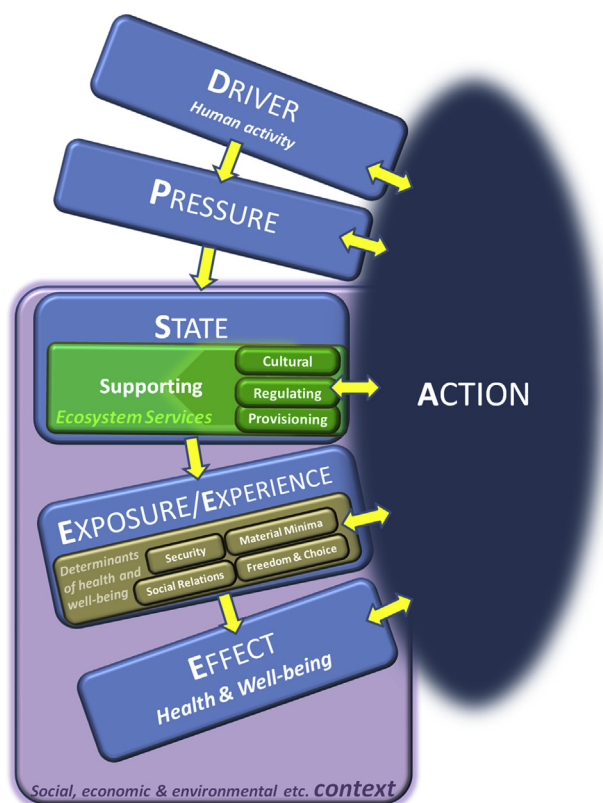


Fig. 1 – Ecosystem-enriched DPSEEA (eDPSEEA) – a conceptual framework for an integrated assessment of human and ecosystem health and ecosystem service provision.

reflects a more realistic approach than typically represented in both the mDPSEEA framework and the ecosystems services frameworks which tend to assume a single unidirectional flow of influence.

In reality, interactions between ecosystems services and human health and well-being will not be as clear-cut as Fig. 1 suggests, as ecosystems services can directly affect humans via *Exposure/Experience* and *Effect* through a more subjective experience of well-being and environment.²⁷ Fig. 2 depicts this network of complex relationships, while not attempting to be comprehensive. As ecosystem services are inherently context dependent, the original contextual approach of mDPSEEA provided a robust basis for the development of eDPSEEA.

Practical application of the eDPSEEA model requires intensive engagement with stakeholders. The authors have developed and delivered a workshop³¹ using the approach to discuss the issues associated with the application of nitrogen fertilizers at an international conference of ecological toxicologists. The need to consider both the benefits of fertilizer use to human health (e.g. improved capacity to feed an ever growing global population) against the risks to ecosystem services and human health were identified and discussed. The use of the model drew out a discussion of wider potential impacts, highlighting the strengths of eDPSEEA in capturing the complexity of the relationships and in identifying wider implications: for instance considering the impacts of loss of

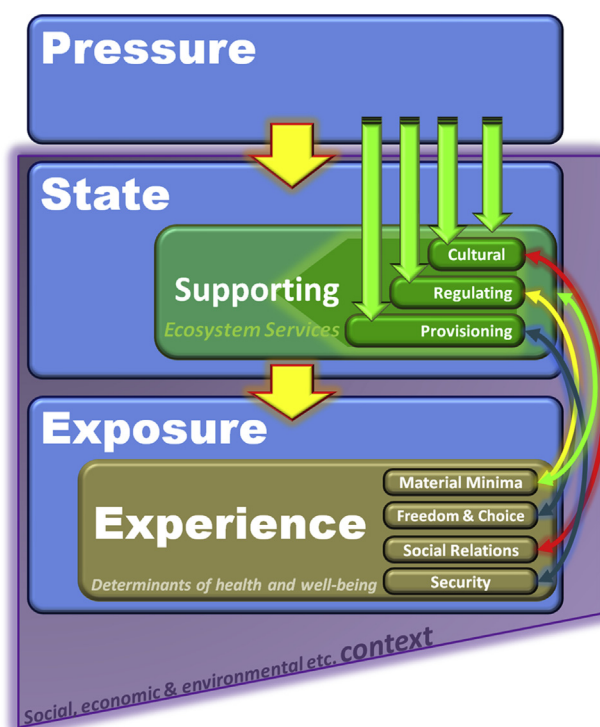


Fig. 2 – Illustrating the potential for feedback loops between Pressure, State and Exposure/Experience which is manifest when considering relationships between ecosystem services and determinants of human health and well-being. Feedbacks are depicted by two-directional arrows, but it should be noted that both positive and negative feedback effects may occur between a wide range of components of the eDPSEEA model.

amenity (via cultural services, e.g. recreational fishing or swimming) on human well-being. Further applications to test and refine eDPSEEA in a variety of contexts and with different audiences are scheduled and will provide the basis for an in depth evaluation of the conceptual model.

Discussion

Currently, the daunting challenge of maintaining and improving public health in the face of rapidly accelerating environmental change at the local, but especially the planetary level, is not being adequately met. This in part reflects the changing nature of public health. In the 1800s there were only about one billion people on the planet and the major public health challenge related to the introduction of sanitation. Today, with a global population of more than seven billion, the majority of whom live in urban environments, new challenges have emerged beyond infectious disease. They include climate-change related flooding, heat waves, severe storms, pollution of air and water, the spread of antibiotic resistance, food security and safety. Obesity and mental health problems are now in epidemic proportions on a global scale. The different communities represented by public health and

ecosystems services, need to come together to take on these challenges and protect the health of both humans and our ecosystems. The situation can be improved by adopting an integrated, coherent approach, based on sound conceptual models and stakeholder engagement tools. In the foregoing account we have highlighted the value of integrating human and environmental risk assessments and have offered a model, eDPSEEA, to enhance our capability to make real progress. We see this as the start of a journey towards a more integrated and holistic approach to assess human and ecosystem health as two sides of the same coin.

As we have seen, *Ecological Public Health* has been conceived as 'a new environmental conceptualization of public health'.²⁸ Rayner and Lang²⁸ built on the core idea that human activity in all its social, economic, and cultural dimensions must be seen as integral to, and in dynamic interaction with, the ecosystems on whose functionality humans depend. It is important to be clear that the term 'ecological' is used in the sense of something which is both complex and has many elements which if disturbed have widespread ramifications.

The challenge of operationalizing ecological public health is that of integrating socio-ecological complexity with a concern for the changing environment, both local and planetary. Success may be defined as learning to navigate within this complexity to identify sensible policies, rather than achieve complete understanding. There is a pressing need for tools to help people think and interact with. There is obvious convergence between *Ecological Public Health* (with its calls for the acknowledgement in policy and action of the integration of social and natural ecology) and the concept of ecosystems services (with its origins in the desire of environmentalists to integrate the natural and the physical especially with economic concerns, but also social, infrastructural, and other anthropocentric concerns¹²).

The urgent need for action to counter grave threats to planetary and human health is widely though not universally recognized. There are many hearts and minds yet to be won in creating the conditions for the necessary societal change. Importantly, the idea that future health and well-being can only be built on ecological principles must move rapidly from the periphery to the heart of the public policy discourse. All professional bodies with a locus in ecological public health – there are many, – can mainstream ecological perspectives and reinforce their relevance to their members by incorporating the principles and application of tools like eDPSEEA as common elements in their training and Continuing Professional Development schemes. In particular, environmental practitioners and public health doctors, and professional constituencies more specifically concerned with the environment could acquire similar perspectives and a common language.

Furthermore, international bodies such as the World Health Organization²⁹ and European Environment Agency³⁰ who already unquestionably embrace the ecological message could use approaches based on eDPSEEA to help dissolve policy and professional silos which currently impede them in their aspirations. Finally, experience of using the earlier modified DPSEEA as a tool to think, engage, and communicate at community and neighbourhood level with stakeholders implies a capacity for eDPSEEA to introduce more ecological perspectives here as well.

Conclusions

Initial applications of the eDPSEEA model in stakeholder workshops have shown it to be a useful tool for engagement.³¹ The eDPSEEA model has particular strengths in capturing the complexity of relationships and in identifying wider impacts of changes in ecosystems. Further refinements are needed to use the model for policy making, but we argue that eDPSEEA represents an important development in operationalizing the concepts of ecological public health.

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Competing interests

None declared.

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