Human conflict and ecosystem services: finding the environmental price of warfare

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Warfare is a uniquely human endeavour, and has been central to human culture and civilization for many thousands of years. Early forms of intergroup conflict were conducted by our hominid ancestors over one million years ago,[1] while the development of larger-scale, organized conflict is recorded by early civilizations in Mesopotamia and China almost 5,000 years ago.[2] The impetuses for warfare, being a complex mix of genetics, psychology, culture, politics, technology and resource availability,[3] are unlikely to disappear in the future, as long as our species survives. Though the nature of warfare is changing, from its most devastating twentieth-century form of industrial 'total' warfare to the geographically and politically complex 'everywhere war' that is beginning to define conflict in the twenty-first century,[4] violent conflict is certain to remain a defining part of the human story.

Warfare may be defined in different ways, from Clausewitz's 1832 conception of war as 'continuation of State policy by other means' to Machlis and Hanson's establishment of a taxonomy of warfare wherein the term incorporates preparations for warfare, acts of violent conflict and post-conflict activities.[5] Much debate and analysis of warfare has, quite rightly, focused on the moral dimensions of war in all its forms. More recently, increasing investigation of the environmental impacts of warfare, both positive and negative, has featured in public debate and scholarly analysis.[6] The environmental impacts of violent conflict have been recognized for millennia, with the intentional destruction or degradation of natural resources such as forests, crops and water sources being particularly common.[7] More recently, increasing pressures on the natural environment, combined with

[1] George R. Pitman, 'The evolution of human warfare', *Philosophy of the Social Sciences* 41: 3, 2011, pp. 352–79.
[2] Claudio Cioffi-Revilla, 'Origins and evolution of warfare and politics', *International Studies Quarterly* 40: 1, March 1996, pp. 1–22.
[3] Pitman, 'The evolution of human warfare'.
[4] Derek Gregory, 'War and peace', *Transactions of the Institute of British Geographers* 35: 2, April 2010, pp. 154–86.
[5] Carl von Clausewitz, *Vom Kriege* [On war] (Berlin: Dümmlers Verlag, 1832; English version from 1874 translation by J. J. Graham, 2008 printing by Digireads.com Publishing, p. 17); Gary E. Machlis and Thor Hanson, 'Warfare ecology', *BioScience* 58: 8, Sept. 2008, pp. 729–36.
[6] For examples see Machlis and Hanson, 'Warfare ecology'; Robert A. Francis, 'The impacts of modern warfare on freshwater ecosystems', *Environmental Management* 48: 5, Nov. 2011, pp. 985–99; Giacomo Certini, Riccardo Scalenghe and William I. Woods, 'The impact of warfare on the soil environment', *Earth-Science Reviews*, vol. 127, Dec. 2013, pp. 1–15.
[7] For a focus on woodland resources in particular, see J. R. McNeill, 'Woods and warfare in world history', *Environmental History* 9: 3, July 2004, pp. 388–410.

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a greater environmental awareness and changes in the character of warfare itself, have raised the stakes in respect of both intentional and collateral environmental damage, making more rigorous and scientific investigation of the links between warfare and environment increasingly important.

Human development has inadvertently created a situation in which high populations and unprecedented resource consumption are having significant, indeed potentially catastrophic, impacts on local, regional and global environments. Rockström and colleagues have highlighted nine planetary 'systems' that are required for the integral functioning of the global environment and the survival of the human species, and have evaluated the thresholds or boundaries beyond which the systems become dangerously unstable and may effectively collapse.[8] Three systems have already exceeded their thresholds: biodiversity loss, interruption of the nitrogen cycle,[9] and climate change. Two further systems remain to be quantified (atmospheric aerosol loading and chemical pollution), while five systems (phosphorus cycle, stratospheric ozone depletion, ocean acidification, global freshwater use and change in land use) have not yet crossed their thresholds. This summary illustrates global impacts and universal environmental trends; and of course even for those systems that have not yet been heavily degraded, localized systems will have been heavily compromised, putting individual societies under stress for environmental resources such as fresh water.[10] In many cases, such resource dependence has led to increased cooperation, though conflict has arisen in some situations.[11] Abundance of environmental resources has been linked to greater frequency of warfare, with Hanson and colleagues noting that over 80 per cent of wars between 1950 and 2000 took place in areas of high biodiversity.[12] The high incidence of war in biodiversity hotspots arises from the increasing need for natural resources alongside political instability in many of the states within these areas, which fosters conditions conducive to exploitation and therefore increases tensions and inequities within and among national and international communities. The ultimate result is armed conflict. Increases in the global population, which is projected to continue growing to a peak of between 8 billion and 10 billion people around the mid-twenty-first century,[13] will further increase resource utilization and, potentially, the chances of conflict—chances that may be the greater given

[8] Johan Rockström, Will Steffen, Kevin Noone, Asa Persson, Stuart F. Chapin III, Eric F. Lambin, Timothy M. Lenton, Marten Scheffer, Carl Folke and Hans Joachim Schellnhuber, 'A safe operating space for humanity', *Nature* 461: 7263, Sept. 2009, pp. 472–5.

[9] The nitrogen and phosphorus cycles form part of a single 'biogeochemical flow' boundary, and so nine planetary boundaries are listed by Rockström and colleagues.

[10] C. J. Vörösmarty, P. B. McIntyre, M. O. Gessner, D. Dudgeon, A. Prusevich, P. Green, S. Glidden, S. E. Bunn, C. A. Sullivan, C. Reidy Liermann and P. M. Davies, 'Global threats to human water security and river biodiversity', *Nature* 467: 7315, Sept. 2010, pp. 555–61.

[11] See e.g. Peter H. Gleick, *The world's water* (Washington DC: Island Press/Center for Resource Economics, 2014).

[12] Thor Hanson, Thomas M. Brooks, Gustavo A. B. Da Fonseca, Michael Hoffmann, John F. Lamoreux, Gary Machlis, Cristina G. Mittermeier, Russell A. Mittermeier and John D. Pilgrim, 'Warfare in biodiversity hotspots', *Conservation Biology* 23: 3, June 2009, pp. 578–87.

[13] Wolfgang Lutz and K. C. Samir, 'Dimensions of global population projections: what do we know about future population trends and structures?', *Philosophical Transactions of the Royal Society B: Biological Sciences* 365: 1554, Sept. 2010, pp. 2779–91.

that population growth is predicted to be most dramatic in those regions that are less developed and more politically unstable.

The loss or concentration of environmental resources within smaller areas (e.g. shrinking areal extent of ecologically important ecosystems such as wetlands or tropical forests, or fresh water stored in reservoirs) also means that environmental damage, whether intentional or collateral, has the potential for particularly dramatic consequences not just for the environment but for the human societies that are a part of that environment.[14] Essentially, the environment provides important resources and processes that benefit humankind: these are referred to collectively as 'ecosystem services', and there is an increasing focus on them to inform environmental management efforts around the world.[15]

The Millennium Ecosystem Assessment groups these services into a fourfold classification:

- provisioning services: products obtained from ecosystems (food, fibre, fuel, natural medicines);
- regulating services: benefits obtained from regulation of ecosystems, including air quality, climate regulation, water purification and natural hazard regulation;
- cultural services: non-material services obtained through spiritual enrichment, artistic inspiration, and recreation;
- supporting services: services that are necessary for the production of other ecosystem functions, such as soil formation, photosynthesis and nutrient cycling.[16]

All of these services may be damaged or compromised, either temporarily or permanently, by the impacts of warfare on the environment. The loss of ecosystem services has a significant cost to humankind, but this cost is difficult to quantify and has yet to be factored into many potential applications, and in particular into warfare. Here we explore the potential of utilizing the ecosystem services framework to more firmly ground the environment in modern warfare.

Alongside increasing environmental pressures, the character of warfare itself is changing. Though conflict between states is generally held to be declining,[17] the incidence of intrastate violence, including 'grey area' warfare,[18] is both increasing (particularly in developing and least developed countries) and becoming more widely spread across geographical boundaries.[19] This development is facilitated by advances in technology (e.g. the use of unmanned aerial vehicles: UAVs or 'drones') that allow more precise military actions (e.g. strikes) to be taken, and yet may also lead to disengagement between the acts of warfare and their local

[14] Elizabeth L. Chalecki, 'A new vigilance: identifying and reducing the risks of environmental terrorism', *Global Environmental Politics* 2: 1, Feb. 2002, pp. 46–64.

[15] Paul Ferraro, 'The future of payments for environmental services', *Conservation Biology* 25: 6, Nov. 2011, pp. 1134–8.

[16] Millennium Ecosystem Assessment, *Ecosystems and human well-being* (Washington DC, 2001).

[17] Azar Gat, 'Is war declining—and why?', *Journal of Peace Research* 50: 2, March 2013, pp. 149–57.

[18] 'Grey area' warfare involves elements of organized crime, and may be exemplified by the violent conflict associated with the ongoing 'drug wars' in Mexico.

[19] See e.g. Steven Metz, *Armed conflict in the 21st century: the information revolution and post-modern warfare* (Carlisle: Strategic Studies Institute, United States Army War College, 2000); Derek Gregory, 'The everywhere war', *Geographical Journal* 117: 3, Sept. 2011, pp. 238–50.

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repercussions. All of these factors, from the lack of 'regulation' in civil war to the growing capacity for destruction associated with modern weaponry, increase the potential for intentional or collateral environmental damage. Local factors further complicate relationships among militaries, societies and the environment. As the incidence of civil war increases, so does the complexity of assessing, preventing, mitigating and reversing environmental impacts.

Recognition of this, alongside the greater environmental awareness that has characterized the last five decades in particular, has revitalized the debate on the environmental impacts of warfare. Machlis and Hanson have suggested a taxonomy of warfare that includes preparatory phases (training, construction of infrastructure and materiel), engagement (physical acts of aggression and defence) and post-conflict (weapons disposal and decommissioning, peacekeeping, reconstruction of infrastructure, etc.), and have called for greater investigation of ecological impacts across this broad spectrum of activities.[20] There remains, however, a gap in the translation of environmental understanding into the practice of warfare. In an ideal situation, ecological systems and their services would be well understood, impacts would be quantifiable, and legislation would be put in place to ensure that those impacts did not occur or, where they did, that suitable reparations or restitution were put in place. Environmental legislation in relation to warfare has existed for some time, in recognition of its environmental impacts, but remains largely ineffective, at least in part because of insufficient understanding of ecosystems and the ecological impacts that may result from warfare, and ineffective mechanisms for both valuing and restoring damaged ecosystems. These remain difficult obstacles to overcome.

This article now reflects on the current state of environmental legislation in relation to warfare, before considering the ecosystem services framework in a warfare context and highlighting both the potential benefits and the challenges that may accompany adoption of such a framework by the international community.

Environmental legislation and warfare

In response to environmental concerns, several legislative instruments and treaties have been put in place with the aim of preventing excessive environmental damage during warfare; there are also instruments that are not primarily intended to protect the environment, but may be considered to do so in an ancillary fashion, and some international environmental laws that should still apply during periods of warfare.[21]

Several authors have criticized these legal provisions, concluding that (1) the terminology used is often so vague that satisfying a court of law that the conditions have been breached would be very problematic; (2) they were put in place for situations which are not clearly represented in their wording (e.g. the UN Convention on the Prohibition of Military or Any Other Use of Environmental

[20] Machlis and Hanson, 'Warfare ecology'.
[21] United Nations Environment Programme (UNEP), *Protecting the environment during armed conflict: an inventory and analysis of international law* (Nairobi, 2009), pp. 1–88.

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Modification Techniques, as discussed below); (3) they are aimed at preventing interstate warfare, which is in decline; (4) they require states to sign up to them and are therefore self-selecting; and (5) they have never been enforced and so are effectively defunct.[22] The one successful application of environmental law in a warfare context to date was that relating to the environmental damage caused by Iraq in the 1990–1991 Gulf War.[23] Alongside this, it is unclear whether international environmental agreements also apply during periods of warfare. This has led to several calls for a Fifth Geneva Convention that would consider the environment in warfare more specifically,[24] though this proposal remains undeveloped.

In 2009 the United Nations Environment Programme (UNEP) conducted a review of environmental legislation in relation to warfare.[25] It noted that current legal frameworks do not sufficiently address environmental issues during armed conflict for several reasons:

- The relevant articles do not provide adequate protection to the environment due to the stringent criteria used to demonstrate damage.
- Some provisions in humanitarian law that protect civilian property offer indirect protection of the environment, but this remains vague.
- Most legal provisions protecting the environment were designed for international rather than internal conflict.
- There is a lack of case law on protecting the environment during warfare due to the limited number of cases brought to court.
- There is no permanent international mechanism to monitor and address environmental damage during armed conflict.
- The general principles of humanitarianism are not sufficient to limit damage to the environment.
- There is no standard definition of what constitutes a 'conflict resource' and when sanctions should be applied to prevent the utilization of such resources.

The Programme found, however, that environmental damage that contributes to war crimes, crimes against humanity and genocide is considered a criminal offence under international law; that international environmental law applies during armed conflicts and could be used as a basis for protection; and that commissions and tribunals could be used to investigate environmental damage as a result of international and internal armed conflict. Acting on each of these conclusions is difficult, however, and requires sufficient evidence of environmental impacts.

As a result of UNEP's review, several recommendations were made, including clarification of key terms ('widespread', 'long-term', 'severe'); an update of legislation related to protection of the environment during armed conflict; and development of an evidence base in the courts of law for addressing the impact of

[22] See e.g. Michael Bothe, Carl Bruch, Jordan Diamond and David Jensen, 'International law protecting the environment during armed conflict: gaps and opportunities', *International Review of the Red Cross* 92: 879, Sept. 2010, pp. 569–92.

[23] UNEP, *Protecting the environment during armed conflict*, p. 27.

[24] For an early example see Hans-Peter Gasser, 'For better protection of the natural environment in armed conflict: a proposal for action', *American Journal of International Law* 89: 3, July 1995, pp. 637–44.

[25] UNEP, *Protecting the environment during armed conflict*.

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conflict on the environment. These recommendations are summarized in table 1. Rather than the creation of new legislation to protect the environment and environmental resources during warfare, UNEP primarily suggested that existing legislation be strengthened.[26] A particular problem remains quantifying ecological systems and their degradation sufficiently to satisfy the legal criteria used. The most relevant clarifications hang on the definitions of 'widespread', 'long-term' and 'severe', which are crucial terms defining levels of impact that are prohibited during warfare, but are used in different ways in different legal instruments.

Table 1: Recommendations from the United Nations Environment Programme to better protect the environment during armed conflict

Type of recommendation	*Specific recommendation*
Recommendations related to legal language and terminology	The terms 'widespread', 'long-term' and 'severe' within articles 35 and 55 of Additional Protocol I to the 1949 Geneva Conventions should be clearly defined.
	The United Nations should define 'conflict resources', articulate triggers for sanctions and monitor their enforcement.
Recommendations related to updating legal structures	The International Committee of the Red Cross Guidelines on the Protection of the Environment during Armed Conflict (1994) require updating and subsequent consideration by the UN General Assembly for adoption, as appropriate.
	Legal agreements covering natural resources issued by conflict parties often lack legitimacy and should be reviewed at the outset of the post-conflict period.
	Environmental protection should be considered during the First Review Conference of the International Criminal Court (ICC) Statute in 2010.
Recommendations related to stronger institutions and mechanisms	A permanent UN body to monitor violations and address compensation for environmental damage should be considered.
	A new legal instrument is needed for place-based protection of critical natural resources and areas of ecological importance during armed conflicts.
	The international community should consider strengthening the role of the Permanent Court of Arbitration to address disputes related to environmental damage during armed conflict.
	Countries that wish to protect the environment during armed conflict should consider reflecting the relevant provisions of international law in national legislation.
Recommendations related to developing the evidence base	The International Law Commission should examine the existing international law for protecting the environment during armed conflict and recommend how it can be clarified, codified and expanded.

[26] UNEP, *Protecting the environment during armed conflict*, p. 51.

They first occur in the UN Convention on the Prohibition of Military or Any Other Use of Environmental Modification Techniques (ENMOD) (1976). In this case, 'widespread' refers to 'a spatial area of several hundred square kilometres'; 'long-term' is 'a period of months, or approximately a season'; and 'severe' refers to 'serious or significant disruption or harm to human life, natural economic resources or other assets'.[27]

These terms are also used in the Additional Protocol I to the 1949 Geneva Conventions (1977), articles 35(3) and 55(1), and in the Convention on Prohibitions or Restrictions on Use of Certain Conventional Weapons which May Be Deemed to Be Excessively Injurious or to Have Indiscriminate Effects (CCW), and its Protocol III on Prohibitions or Restrictions on the Use of Incendiary Weapons (1980); but with some important differences. First, the wording of the latter two conventions is 'widespread, long-term and severe damage to the natural environment'. This is what UNEP refers to as the 'triple cumulative standard':[28] that is, the prohibition applies only to impacts that meet the criteria for widespread, long-term *and* severe—a standard that in reality represents a very high threshold and one that would prove difficult to demonstrate in many cases. It is also possible to debate the use of the term 'natural environment', with regard to the extent to which globally ubiquitous anthropogenic landscapes qualify as the 'natural environment'—particularly given that these landscapes are the main focus for warfare.[29] The spirit of the instruments probably lies within 'natural environment' as an incorporation of physical and biological elements regardless of human influence, but altogether the terms need to be better defined. Second, 'long-term' in the latter two conventions refers to impacts that last for decades, while the original ENMOD interpretation was much shorter (months or a season).

These definitions were originally created for ENMOD, which was established to prevent weather modification techniques being used for warfare, before the limitations of weather modification and geo-engineering became apparent. ENMOD was founded on an overly optimistic prediction of what would be possible, and indeed is now largely irrelevant. It is possible that the 'standard' of prohibited impact for the latter conventions was increased to ensure that devastation would reach a sufficient magnitude before the laws came into effect. Nevertheless, although UNEP recommends that at a minimum such definitions should be applied to other legislation and more rigorously worded, they remain limited in potential application.

While it is appropriate to define impacts on the basis of space and time scales, and intensity of degradation, the implementation of such definitions is crude at best. Is the pollution of a small lake in a semi-arid area negligible because it is less than several hundred square kilometres? Is a short-term disruption at a key point in species phenology not relevant because it does not last for a season or several decades? Conversely, is a bombing episode that alters the vegetation community

[27] UNEP, *Protecting the environment during armed conflict*, p. 52.
[28] UNEP, *Protecting the environment during armed conflict*, p. 12.
[29] With much warfare being conducted within urban and agricultural landscapes, for example.

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for years or decades eligible, even though such disturbances may not have any real long-term ecological impact (though they may have socio-economic implications)? Likewise, the focus on 'natural economic resources' and the rather vague 'other assets' (what constitutes an 'asset'?) reflects a time before the origin of awareness of biodiversity and of the services biodiversity and other elements of the natural world provide to our societies. The Rio Summit was 16 years away. Notwithstanding UNEP's recommendations, these definitions are not fit for purpose.

It is clear that these definitions and the relevant legal instruments should be revisited, but also that a framework for quantification of impacts needs to be developed. Quantification is always difficult in ecosystems, which are complex adaptive systems and therefore defy easy explanation and prediction.[30] The use of the ecosystem services framework, within the broader remit of ecological economics, may represent the best way forward for estimating and quantifying impacts in ways that may be understood by experts in a variety of disciplinary contexts, and may be most useful for satisfying legal criteria. In conditions of war it is especially important to establish culpability, given the potentially extreme consequences for the environment. We now consider this framework in more detail in a warfare context.

Valuation of ecosystem services in a warfare context

The environmental consequences of war have been well documented in terms of hazardous impact and resource depletion.[31] Examples include radiation from nuclear explosions (Hiroshima and Nagasaki in the Second World War), forest degradation through use of defoliants (Vietnam War), and exhaustion of important minerals such as nickel and copper (especially in civil conflicts in sub-Saharan Africa). However, the cost of war to the environment is not equally well understood and documented.[32]

Recent years have seen an increasing interest in quantifying the services provided by ecosystems, due to a growing receptivity among donors and policymakers to the use of financial incentives to achieve desirable social and environmental outcomes. This growth is reflected in the emergence of global initiatives to standardize the economic valuation of ecosystems, such as the 'Economics of

[30] Complex adaptive systems are characterized by (1) complex physical and biological structures that are nested over space and time; (2) self-organized patterns and processes; (3) dynamic flows of matter, energy and information; (4) change in system structure/organization/configuration and individual components over time (e.g. due to processes of succession and natural selection); and (5) non-linearity in patterns and processes, including the existence of thresholds and feedbacks.

[31] For examples, see Clionadh Raleigh and Henrik Urdal, 'Climate change, environmental degradation and armed conflict', *Political Geography* 26: 6, Aug. 2007, pp. 674–94; Kara Stevens, Lindsay Campbell, Gerlad Urquhart, Dan Kramer and Jiaguo Qi, 'Examining complexities of forest cover change during armed conflict on Nicaragua's Atlantic coast', *Biodiversity and Conservation* 20: 12, Nov. 2011, pp. 2597–613; Ana-Maria Sanchez-Cuervo and Mitchell Aide, 'Consequences of the armed conflict, forced human displacement, and land abandonment on forest cover change in Colombia: a multi-scaled analysis', *Ecosystems* 16: 6, Sept. 2013, pp. 1052–70.

[32] See discussion in Francis, 'The impacts of modern warfare on freshwater ecosystems', and Certini et al., 'The impact of warfare on the soil environment'.

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Ecosystems and Biodiversity' Initiative.[33] Similarly, the increase in the number of publications on the topic highlights increasing demand for scientific approaches to valuation of services: Ferraro estimates that in the period 1996–8 only around a dozen publications included the phrase 'payment for environmental services' (or 'payment for ecosystem services'), compared to over 500 between 2006 and 2008.[34] In the context of warfare, valuation of ecosystem services can be applied in order to evaluate damage caused to the environment, bring responsible parties to justice, and quantify reparations that reflect some of the broader effects of war in a way that is relevant to society.

Given the complex implications of war for environmental, physical, economic and social factors, assessment of ecosystem services loss remains 'an art rather than a science'.[35] Factors such as the magnitude of impact on ecosystem services, when the impacts may be felt, and the spatial distribution of the impact are extremely difficult to quantify and predict. Due to this complexity, assessment of ecosystem services in the context of war will inevitably depend on expert opinion. Significant questions then arise. Who are the experts who evaluate the environmental cost of a specific war, and how objective are they? Who gets to make decisions once the assessments have been made? What legal mechanisms, beyond the instruments discussed above, exist to ensure that the decisions are not influenced by special interests? Such questions are particularly important in a post-conflict context where the stakes are high and failure to achieve a satisfactory result may lead to further impacts, including sparking further conflict.

An appropriate approach to determining impacts and responses is that of post-normal science.[36] Post-normal science is a method of approaching scientific enquiry that explicitly encourages the integration of a wide range of stakeholders beyond the traditional remit of the 'scientific expert', as there are several forms of knowledge that may help in addressing large, complex and uncertain issues that need urgent attention and that the usual forms of scientific enquiry may not be able to address in isolation. This wider group is termed the 'extended peer community', and may involve stakeholders with different expertise, knowledge and perceptions relevant to the environmental system to be managed. Usually there is an important balance to be struck between more formalized 'external' expertise that might contribute (for example) theoretical or empirical knowledge of ecological or environmental systems, methods of survey and analysis, and understanding of legislation, policy and restorative action; and 'internal' expertise that may come from local ecological knowledge of the impacted systems. Put simply, local people are better able than outsiders to describe and express the values (economic or otherwise) that they attach to particular species or ecological processes (changes to hydrology that reduce soil moisture in agricultural systems, for example). This

[33] http://www.teebweb.org/, accessed 24 May 2014.

[34] Ferraro, 'The future of payments for environmental services'.

[35] Asit K. Biswas, 'Scientific assessment of the long-term environmental consequences of war', in Jay E. Austin and Carl E. Bruch, eds, *The environmental consequences of war* (Cambridge: Cambridge University Press, 2010), p. 310.

[36] Developed by Silvio O. Funtowicz and Jerome R. Ravetz, 'Science for the post-normal age', *Futures* 25: 7, Sept. 1993, pp. 739–55.

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is particularly the case in areas where ecological data are scarce and social tensions high, including some of the developing countries that are both prone to conflict and ecologically rich.[37]

Post-normal thinking has been applied to issues such as biological conservation,[38] climate change,[39] and sustainable development.[40] It entails a recognition that there is no single 'right' answer to many of the environmental challenges that the world currently faces, and that multiple future environmental scenarios and management responses are possible, with different (and sometimes conflicting) levels of desirability for different stakeholders. The post-normal approach is consequently very suitable for examining impacts on services. It is imperative that the 'extended peer community' includes a representative selection of stakeholders who may be able to contribute to understanding and addressing the environmental problem in question, without acting at cross-purposes and causing conflict.

The provision of expert and local knowledge is only part of the battle, however. Valuing ecosystem services in a warfare context is intrinsically complicated due to the uncertainties and controversies inherent in the enterprise. In particular, measurement of 'ecosystem services' is difficult. The environment is nebulous and services provided by ecosystems are rarely understood well enough to be quantified—particularly for those communities that are most vulnerable to the impacts of warfare. This in turn means that it is often exceedingly difficult to quantify how a change in ecosystem condition or function will translate into changes in the ecosystem services that are provided.[41] Indeed, establishing impact and its causes is the first of the major challenges posed by the attempt to build the ecosystem services framework into warfare.

Measurements of environmental conditions are difficult to arrive at, and there is often a lack of data enabling scientists to establish a 'pre-conflict' baseline against which to evaluate damage. Even where environmental data may be available for a prewar context, the quality of the data in many of the main conflict-affected areas around the world is mediocre.[42] Postwar evaluations of environmental conditions are also challenging, due to security concerns. Remote sensing techniques can play a critical role in evaluating ecosystem services where access is difficult—but this may be insufficient and may even result in controversial or invalid results.[43]

[37] Hanson et al., 'Warfare in biodiversity hotspots'.

[38] Robert A. Francis and Michael K. Goodman, 'Post-normal science and the art of nature conservation', *Journal for Nature Conservation* 18: 2, May 2010, pp. 89–105.

[39] John Turnpenny, Mavis Jones and Irene Lorenzoni, 'Where now for post-normal science? A critical review of its development, definitions, and uses', *Science, Technology and Human Values* 36: 3, May 2011, pp. 287–306.

[40] Bob Frame and Judy Brown, 'Developing post-normal technologies for sustainability', *Ecological Economics* 65: 2, April 2008, pp. 225–41.

[41] Unai Pascual, Roldan Muradian, Luis Rodriguez and Anantha Duraippah, 'Exploring the links between equity and efficiency in payments for environmental services: a conceptual approach', *Ecological Economics* 69: 6, April 2010, pp. 1237–44.

[42] Cf. FAO, 'Conflict, agriculture and food security', in *The state of food and agriculture 2000* (Rome, 2001).

[43] For examples of applications of remote sensing to map ecosystem services, see: Austin Troy and Matthew Wilson, 'Mapping ecosystem services: practical challenges and opportunities in linking GIS and value transfer', *Ecological Economics* 60: 2, Dec. 2006, pp. 435–49; Virginia Dale and Stephen Polasky, 'Measures of the effects of agricultural practices on ecosystem services', *Ecological Economics* 64: 2, Dec. 2007, pp. 286–96; Robin Naidoo, Andrew Balmford, Robert Costanza, Brendan Fisher, Rhys E. Green, B. Lehner, T. R. Malcolm and Taylor H. Ricketts, 'Global mapping of ecosystem services and conservation priorities', *Proceedings of the National*

Lack of sufficient relevant know-how to assess damage to ecosystem services is another critical challenge. Expertise is needed alike in taxonomy, environmental economics and social science to evaluate the total costs of war on the environment. However, the number of people specializing in taxonomy appears to be in the decline,[44] posing significant obstacles to scientific (as opposed to purely economic or social) assessments of environmental impact in the future. This decline is of concern given that the majority of conflicts are now occurring in areas with very high biodiversity.[45]

Assessment of future impact is important in order to ascertain 'long-lasting' damage. However, methods to forecast future impacts are subject to significant methodological constraints. Several of the techniques proposed to forecast environmental impact have remained unchanged since the early 1970s, but there is no single study that objectively examines the comparative effectiveness of environmental impact assessments in predicting and managing environmental impact.[46]

There is an urgent need to update methods to effectively address emerging and future environmental challenges, in such a way that they may be useful for establishing culpability and quantifying the total environmental cost of war on the environment. This enterprise may become increasingly relevant in the context of long-term or widespread environmental change. For example, pollution in the form of carbon dioxide or other greenhouse gas emissions from military activity would contribute to anthropogenic climate change; in such contexts, the estimated damage from warfare becomes intergenerational and highly contentious.

Different environmental aspects are sensitive to warfare in unique ways. Much depends on the developmental history of the particular ecosystem under consideration, such as the level of degradation experienced prior to the conflict, and the ecosystem's current ecological quality or health. Empirical evidence supports this idea of differential sensitivity, and there are even some examples demonstrating that war may benefit some aspects of the environment[47]—for example, by resulting in the disruption or permanent destruction of environmentally damaging activities,[48] as reflected in the spontaneous reforestation seen in postwar Puerto Rico,[49] and

Academy of Sciences 105: 28, July 2008, pp. 9495–500; Jason Scullion, Craig Thoman, Kristina Vogt, Octavio Perez-Maqueo and Miles Logsdon, 'Evaluating the environmental impact of payments of ecosystem services in Coatepec (Mexico) using remote sensing and on-site interviews', *Environmental Conservation* 38: 4, Dec. 2011, pp. 426–34; Virginia Gorsevski, Eric Kasischke, Jan Dempewolf, Tatiana Loboodo and Falk Grossmann, 'Analysis of the impacts of armed conflict on the Eastern Afromontane forest region on the South Sudan–Uganda border using multitemporal Landsat imagery', *Remote Sensing of Environment*, vol. 118, March 2012, pp. 10–20.

[44] Quentin D. Wheeler and Joel Cracraft, 'Taxonomic preparedness: are we ready to meet the biodiversity challenge?', in Marjorie L. Reaka-Kudla, Don. E. Wilson and Edward O. Wilson, eds, *Biodiversity II: understanding and protecting our biological resources* (Washington DC: John Henry Press, 1997); Ana S. L. Rodriguez, Claudia L. Gray, Ben J. Crowter, Robert M. Ewers, Simon N. Stuart, Tony Whitten and Andrea Manica, 'A global assessment of amphibian taxonomic effort and expertise', *Bioscience* 60: 10, Nov. 2010, pp. 798–806; Mark J. Costello, Marta Coll, Roberto Donavaro, Pat Halpin, Henn Ojaveer and Patricia Miloslavich, 'A census of marine biodiversity knowledge, resources, and future challenges', *PLOS ONE* 5: 8, Aug. 2010, p. e12110.

[45] Hanson et al., 'Warfare in biodiversity hotspots'.

[46] Biswas, 'Scientific assessment of the long-term environmental consequences of war'.

[47] Francis, 'The impacts of modern warfare on freshwater ecosystems'.

[48] Rafael Reuveny, Andreea S. Mihalache-O'Keef and Quan Li, 'The effect of warfare on the environment', *Journal of Peace Research* 47: 6, Nov. 2010, pp. 749–61.

[49] Thomas K. Rudel, Marla Perez-Lugo and Heather Zichal, 'When fields revert to forest: development and spontaneous reforestation in post-war Puerto Rico', *Professional Geographer* 52: 3, Sept. 2010, pp. 386–97.

the preservation of relatively unimpacted ecosystems and ecological communities in the demilitarized zone separating North and South Korea. The potential environmental benefits of war must be taken with a grain of salt, however, and should not be used to justify a war with social costs that would far outweigh any possible environmental benefit. Instances of warfare benefiting environmental outcomes are limited and are an exception rather than the norm.

Attribution of impacts directly to warfare can be difficult—for example, if military operations occur in a context of increasing climate extremes, it may be impossible to separate the effects of warfare from those of extreme weather, or to attribute culpability proportionately.[50] While the argument can be made that military interventions would exacerbate damage, it is extremely difficult to determine the extent to which military operations are responsible for damage incurred.

By necessity, discussions on the environmental cost of warfare focus on economic aspects. Quantification along monetary lines is potentially more likely to establish a solid case for justifiable reparations than criteria relating to loss of biodiversity or ecosystem health, which are more difficult for society and governments to place specific values on. It is easier to understand losses in terms of crop yields than it is to quantify the cost of the destruction of a wetland, because placing an economic value on 'forgone' crop production is much simpler than placing a monetary value on 'forgone' biodiversity or air quality.

Different methods have been proposed to estimate the monetary value of ecosystems, usually expressed in US dollars for global comparability. The two main categories of these are revealed preferences and stated preferences methods.[51] Methods based on revealed preference rely on direct, observable market interactions. Areas experiencing or recovering from conflict are unlikely to have stable, functioning markets. Even where markets are re-emerging, prices are likely to be distorted due to difficulty of access, security concerns or scarcity of products. Owners of scarce resources may also take advantage of the conflict situation to artificially inflate prices.

Where markets for a specific good are non-existent, information about the economic value of ecosystem services can be derived from surrogate markets.[52] The most common surrogates used are property and labour. Again, in a war context, both property and labour prices are likely to be too distorted to provide useful information for decision-making. An unusual scenario of extremely low property prices and extremely high wages—to incentivize people to resettle in an area where conflict has ended—may occur after a war, providing conflicting information about the true cost of ecosystem services.[53]

Some of the most valuable ecosystem services may occur in areas where there is no market activity at all, either because there are no, or few, people living in that area or because market activity is restricted. Non-market-based (stated preferences)

[50] UK Ministry of Defence, *Future character of conflict* (London, 2010).
[51] David Pearce and Edward B. Barbier, *Blueprint 6: for a sustainable economy* (London: Earthscan, 2000).
[52] Pearce and Barbier, *Blueprint 6*.
[53] See e.g. Marita Eastmond, 'Transnational returns and reconstruction in post-war Bosnia and Herzegovina', *International Migration* 44: 3, July 2006, pp. 141–66.

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approaches can be used in these contexts to estimate economic value. These methods depend on primary information collected from surveys, interviews and experiments. This method is unlikely to be applied in warfare contexts, where key informants and potential local experts may be too traumatized to contribute, or may place more immediate value on the social cost of war. Other experts who are not directly affected by a specific conflict can provide information but the results could be highly controversial or uninterpretable without local input, as noted above.

Applications of valuation tools in warfare contexts have been limited.[54] Inevitably, available methods for attributing economic value to the environment focus on 'provisioning services' and resources, partly because these tend to be more akin to economic goods and are therefore easier to monetize, and partly because providing a market value for services that are currently not in a market can be controversial. However, this trend does not fully capture impact.

Recent years have seen an increase in attempts to value the environment and the non-marketable services it provides. These analyses focus on species,[55] river basins,[56] and even global ecosystems as a whole.[57] Estimates of value are usually extremely high, often to the extent of being meaningless for decision-making, unrealistic in practical terms and difficult to operationalize. In their seminal paper of 1997, Costanza and colleagues estimate the global value of ecosystem services to be approximately US$33 trillion[58]—twice the global gross product at the time. Such valuation provides another significant challenge in the context of war. Where estimated losses exceed the annual economic output of a responsible party, reparations that cover environmental damage may be unfeasible and may not be paid on time, if at all:[59] former Soviet countries are today still trying to pay for the costs of cleaning up arising from military activities carried out during the Cold War.[60] As conflicts occur increasingly in countries with fragile economies, the financial burden of repaying the environmental cost may lead to bankruptcy. Moreover, if countries are unable (or unwilling) to compensate for environmental damage, there is currently no legal framework to punish responsible parties for delays. In

[54] Biswas, 'Scientific assessment of the long-term environmental consequences of war', p. 310.

[55] Daniel G. Wenny, Tavis L. DeVault, Matthew D. Johnson, Dave Kelly, Cagan H. Sekecioglu, Diana F. Tomback and Christopher J. Whelan, 'The need to quantify ecosystem services provided by birds', *The Auk* 128: 1, Jan. 2011, pp. 1–14.

[56] Patrick J. Dugan, Chris Barlow, Angelo A. Agostinho, Eric Baran, Glenn. F. Cada, Daqing Chen, Ian G. Cowx, John W. Ferguson, Tuantong Jutagate, Martin Mallen-Cooper, Gerd Marmulla, John Nestler, Miguel Petrer, Robin L. Welcomme and Kirk O. Winemiller, 'Fish migration, dams, and loss of ecosystem services in the Mekong Basin', *Ambio* 39: 4, Feb. 2010, pp. 344–8.

[57] Robert Costanza, Ralph d'Arge, Rudolf de Groot, Stephen Farber, Monica Grasso, Bruce Hannon, Karin Limburg, Shahid Naeem, Robert V. O'Neill, Jose Paruelo, Robert G. Raskin, Paul Sutton and Marjan van den Belt, 'The value of the world's ecosystem services and natural capital', *Nature* 387: 6630, May 1997, pp. 253–60.

[58] Costanza et al., 'The value of the world's ecosystem services and natural capital'.

[59] For comparative purposes, the cost of clean-up of military-related sites has been estimated at over US$500 billion (International Peace Bureau, *The military's impact on the environment: a neglected aspect of the sustainable development debate*, Geneva: International Peace Bureau, 2002). This is 545 times the annual economic output of Somalia (one of the countries with longest-running conflicts), and even higher than the annual GDP of countries such as Poland (US$498.8 billion) and Norway (US$499.7 billion).

[60] International Peace Bureau, *The military's impact on the environment*.

this context, there may be a significant role for stronger legislative frameworks that protect the environment and allow for alternative non-economic reparations.

All aspects of warfare have detrimental effects on the environment: in addition to direct military strikes, strategic counter-action, collateral damage and preparatory military operations also affect ecosystems in complex ways.[61] For instance, in Afghanistan the presence of anti-personnel landmines and the use of ammunition containing uranium are likely to have long-term environmental and health impacts.[62] Similarly, the introduction of invasive species in military bases can have long-term environmental costs—the accidental introduction of the brown tree snake (*Boiga irregularis*) into Guam as US overseas military bases were being established has resulted in dramatic reductions of native bird (only three of 13 native species currently survive), mammal and lizard populations.[63] Other important questions then follow. Which costs should be considered? If there are no direct military interventions but other operations do occur, should the responsible party compensate affected areas? If so, would this concession apply to non-environmental costs of war?

Ecosystem services also have a potentially important role to play in postwar recovery. In most cases, research into recovery has focused on the ethical, political, legal and socio-economic aspects of post-conflict communities rather than the environment, despite the importance of the latter. The importance of ecosystem services has begun to be recognized, however. Milburn has recently emphasized the importance of managing natural resources such as water and biodiversity, in a process he terms 'ecological development', alongside the post-conflict improvement of humanitarian conditions, in establishing sustainable and durable conditions for recovery.[64]

The future of environment in warfare

It is apparent that there is a need to more fully incorporate consideration of environmental impacts into warfare, and that the current legal instruments that seek to prevent or mitigate impacts require an acceptable level of quantification of these impacts, if the environmental impacts of war are to be brought out from the shadows of more overtly human impacts. That this should be achieved is particularly important given the increasingly recognized close links between environment and society, and also because environmental degradation, while a different form of impact from loss of life and physical and emotional trauma, can nevertheless reduce natural capital and disrupt people's livelihoods and quality of life for generations. The most effective way of quantification probably lies within the ecosystem services framework, which has been foregrounded in environmental

[61] Biswas, 'Scientific assessment of the long-term environmental consequences of war'.
[62] International Peace Bureau, *The military's impact on the environment*.
[63] David Pimental, Rodolfo Zuniga and Doug Morrison, 'Update on the environmental and economic costs associated with alien-invasive species in the United States', *Ecological Economics* 52: 3, Feb. 2005, pp. 273–88.
[64] Richard Milburn, 'Mainstreaming the environment into postwar recovery: the case for "ecological development"', *International Affairs* 88: 5, Sept. 2012, pp. 1083–1100.

thinking following the development of ecological economics and the Millennium Ecosystem Assessment. Though controversial, the framework has some traction with environmental scientists, politicians, managers and policy-makers, and is a useful interdisciplinary tool for achieving progress. As pressures on the environment increase, there is likely to be increasing demand for ecosystem services to be used to help account for environmental degradation associated with all aspects of warfare, and in particular for post-conflict reparations and recovery.

Regardless of method, significant challenges remain. As our scientific understanding of environmental processes improves, so will our capacity to better attribute damage to particular war-related activities. However, consideration of the environment in the context of warfare is likely to remain predominantly a political and legal issue, and decisions made may not always follow a scientific rationale. A substantial evidence base is required to ensure that management decisions made are appropriate. Adoption of the ecosystem services framework may be useful, however, as while human life is priceless—though not valueless—prices can be fixed for ecosystem services, and these may act to give second thoughts to militaries and governments. This may especially be true in those situations where war is being waged remotely or indirectly, though it is perhaps less relevant to informal warfare.

There is certainly a case to be made that ecosystem services should be included in the UNEP recommendations for incorporating environmental concerns into warfare. Ways in which this may be done, using the structure of 'revealed preferences' and 'stated preferences' outlined above, are suggested in table 2. More general possibilities include:

- inclusion of ecosystem services alongside initial reviews of the natural resources on which conflict may have impacts, both in the early stages of warfare and post-conflict;
- inclusion of ecosystem services within any new legal frameworks that are set up to safeguard key environmental resources;
- ensuring that international legal practitioners have an understanding of ecosystem services in relation to environmental law and policy, which may be facilitated by policy guidelines on their application in different situations;
- ensuring that expert advisory panels include ecological economists and those familiar with the ecosystem services framework;
- construction of an evidence base to determine whether the application of ecosystem services as a form of quantification of impact is feasible, whether it can satisfy the requirements of legislation and policy, and what level of resource investment is required to achieve this;

As the environmental implications of warfare become increasingly mainstreamed in economic and legal discussions, it will be important to understand how ecosystem functions and services are affected. Despite the challenges highlighted in this article, the emergence of new technologies and methods of valuing the environment will provide alternative ways of effectively assessing the true cost of war for the environment. While methods based on stated preferences are flexible and can

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Table 2: Examples of valuation of ecosystem services in the context of warfare

Method		*Potential application in warfare*	*Advantage*	*Disadvantage*
Revealed preferences	*Market-based*			
	Factor of production	Quantify the loss of output, in terms of lower productivity of timber and non-timber forest products, due to declines in forest health after a war.	Data may be available from communities living in the affected area, or from companies who have economic interests in the area.	Data may not always be available, and it may be difficult to objectively separate loss in output from non-war-related activities.
	Producer/ consumer surplus	The destruction of a freshwater habitat can lead to reduced populations of fish. Fisherfolk would spend more resources for every unit of fish caught, leading to higher production cost. Consumers may respond by not buying the more expensive fish. The producer and consumer surpluses can be quantified based on this behaviour.	If data are available, they are based on consumer behaviour in the market and are therefore likely to be more accepted and easily understood by society.	Markets may be distorted by a wide range of socio-political conditions, including monopolistic markets, especially in a postwar context.
	Defensive expenditure	Evaluate the total cost of postwar recovery interventions, including the cost of setting up water purification tanks, landscape rehabilitation schemes, and planting of trees.	As several humanitarian and development organizations may be involved in postwar recovery, data on the cost of different operations may be available.	A war-affected area may be abandoned with no intention of reconstruction for several decades, and therefore no data may be available to value the damage done to environmental services.
	Surrogate market			
	Hedonic pricing	Monitor property prices in an area recently affected by conflict where the key differentiating factor is the availability of an environmental service from which people can derive a livelihood (e.g. a lake for fishing).	Where housing is re-established quickly after a conflict, it is possible to monitor housing prices over time to establish the value of the environment over a given period.	Areas that are abandoned altogether may no longer have surrogate markets.
	Travel cost	The economic costs of some environmental services may be quantified by adding the amount of money spent by tourists to visit some sites of environmental significance. For example, a large number of tourists visited the Nyamuragira volcano in 2011 in the Democratic Republic of Congo despite security concerns.	Data are likely to be easily available from tour agencies, tourists and airline companies.	It may be extremely difficult to separate environmentally related tourism from 'war-zone' tourism.

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Method		***Potential application in warfare***	***Advantage***	***Disadvantage***
Stated preference	Contingent valuation	Surveys may be distributed to stakeholders (indigenous populations, biologists, economic and legal experts) to value environmental conditions before, during and after a war to estimate the total damage caused by violent conflict.	This method is extremely flexible and can be used to estimate the value of most environmental services.	May not yield accurate results due to biases that may be introduced in the survey or through respondents' behaviours.
	Choice experiments	Different stakeholders (including indigenous populations, biologists and economic experts) may be given a range of environmental services to rank according to perceived importance, and the types of interventions (and associated costs) to restore them after a war.	This method is extremely flexible and can provide an overview of different priorities for reconstruction in a postwar context.	May not yield accurate results due to biases that may be introduced in the survey or through respondents' behaviours.

Source: Categorization drawn from NOAA CSC, *Methods for environmental valuation*, http://www.csc.noaa. gov/archived/coastal/economics/methodsenvvaluation.htm, accessed 23 May 2014.

be used in a variety of contexts, the results may not be meaningful; conversely, methods based on revealed preferences in situations where market data are available can provide a credible and practical response, and are more likely to result in reparations. Even if actual repayments are unlikely to be made, other agreements where states decide to provide goods and services to equivalent values may be appropriate.