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ECOSYSTEM FUNCTIONS AND SERVICES

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FUNKCJE I ŚWIADCZENIA EKOSYSTEMÓW

STRESZCZENIE: W niektórych sytuacjach występują kolizje pomiędzy pożytkami z funkcjonowania układów przyrodniczych a innymi czynnikami wpływającymi na dobrobyt ludzi. W okolicznościach, gdy trzeba podejmować tego typu nieuniknione, choć trudne do rozstrzygnięcia decyzje, wsparciem może być wycena świadczeń ekosystemów. Niniejsza praca wyjaśnia niektóre kontrowersje związane z definiowaniem pozytywnego wpływu procesów w ekosystemach na ludzki dobrobyt, bez względu na to, czy ludzie uświadamiają sobie ten wpływ, czy też nie. Sklasyfikowano i opisano obszary problemowe, w których zastosowanie mają różne metody szacowania korzyści płynących ze świadczeń ekosystemów. Przedstawiono też kilka najnowszych studiów przypadku oraz rozwój badań nad wyceną świadczeń ekosystemów.

SŁOWA KLUCZOWE: wycena, dobrobyt ludzi, kapitał przyrodniczy, świadczenia ekosystemów, podejście transdyscyplinarne

Ecosystem Services

"Ecosystem services" (ES) are the ecological characteristics, functions, or processes that directly or indirectly contribute to human well-being – the benefits people derive from functioning ecosystems[1]. Ecosystem processes and functions may contribute to ecosystem services but they are not synonymous. Ecosystem processes and functions describe biophysical relationships and exist regardless of whether or not humans benefit[2]. Ecosystem services, on the other hand, only exist if they contribute to human well-being and cannot be defined independently.

The ecosystems that provide the services are sometimes referred to as "natural capital," using the general definition of capital as a stock that yields a flow of services over time[3]. In order for these benefits to be realized, natural capital (which does not require human activity to build or maintain) must be combined with other forms of capital that *do* require human agency to build and maintain. These include: (1) built or manufactured capital; (2) human capital; and (3) social or cultural capital[4].

These four general types of capital are all required in complex combinations to produce any and all human benefits. Ecosystem services thus refer to the relative contribution of natural capital to the production of various human benefits, in combination with the three other forms of capital. These benefits can involve the use, non-use, option to use, or mere appreciation of the existence of natural capital.

The following categorization of ecosystem services has been used by the Millennium Ecosystem Assessment[5].

1. Provisioning services – ecosystem services that combine with built, human, and social capital to produce food, timber, fiber, or other "provisioning" benefits. For example, fish delivered to people as food require fishing boats (built capital), fisher-folk (human capital), and fishing communities (social capital) to produce.
2. Regulating services – services that regulate different aspects of the integrated system. These are services that combine with the other three

[1] R. Costanza et al., *The value of the world's ecosystem services and natural capital*, "Nature" 1997 No. 387, p. 253-260; *The Millennium Ecosystem Assessment, Ecosystem and Human Well-being: Synthesis*, Island Press,Washington 2005.
[2] J. Boyd, S. Banzhaf, *What are Ecosystem Services?,* "Ecological Economics" 2007 No. 63, p. 616--626; E. F. Granek et al., *Ecosystem services as a common language for coastal ecosystem-based management,* "Conservation Biology" 2010 No. 24, p. 207-216.
[3] R. Costanza, H. E. Daly, *Natural capital and sustainable development,* "Conservation Biology" 1992 No. 6, p. 37-46.
[4] R. Costanza et al., *An Introduction to Ecological Economics,* St. Lucie Press, Boca Raton 1997.
[5] *The Millennium,* op. cit.

capitals to produce flood control, storm protection, water regulation, human disease regulation, water purification, air quality maintenance, pollination, pest control, and climate control. For example, storm protection by coastal wetlands requires built infrastructure, people, and communities to be protected. These services are generally not marketed but have clear value to society.

3. Cultural services – ecosystem services that combine with built, human, and social capital to produce recreation, aesthetic, scientific, cultural identity, sense of place, or other "cultural" benefits. For example, to produce a recreational benefit requires a beautiful natural asset (a lake), in combination with built infrastructure (a road, trail, dock, etc.), human capital (people able to appreciate the lake experience), and social capital (family, friends and institutions that make the lake accessible and safe). Even "existence" and other "non-use" values" require people (human capital) and their cultures (social and built capital) to appreciate.
4. Supporting "services" – services that maintain basic ecosystem processes and functions such as soil formation, primary productivity, biogeochemistry, and provisioning of habitat. These services affect human well-being indirectly by maintaining processes necessary for provisioning, regulating, and cultural services. They also refer to the ecosystem services that have not yet, or may never be intentionally combined with built, human, and social capital to produce human benefits but that support or underlie these benefits and may sometimes be used as proxies for benefits when the benefits cannot be easily measured directly. For example, net primary production (NPP) is an ecosystem function that supports carbon sequestration and removal from the atmosphere, which combines with built, human, and social capital to provide the benefit of climate regulation. Some would argue that these "supporting" services should rightly be defined as ecosystem "functions", since they may not yet have interacted with the other three forms of capital to create benefits. We agree with this in principle, but recognize that supporting services/functions may sometimes be used as proxies for services in the other categories.

This categorization suggests a very broad definition of services, limited only by the requirement of a contribution to human well-being. Even without any subsequent valuation, explicitly listing the services derived from an ecosystem can help ensure appropriate recognition of the full range of potential impacts of a given policy option. This can help make the analysis of ecological systems more transparent and can help inform decision makers of the relative merits of different options before them.

Valuation

Many ecosystem services are public goods. This means they are non-excludable and multiple users can simultaneously benefit from using them. This creates circumstances where individual choices are not the most appropriate approach to valuation. Instead, some form of community or group choice process is needed. Furthermore, ecosystem services (being public goods) are generally not traded in markets. We therefore need to develop other methods to assess their value.

There are a number of methods that can be used to estimate or measure benefits from ecosystems. Valuation can be expressed in multiple ways, including monetary units, physical units, or indices. Economists have developed a number of valuation methods that typically use metrics expressed in monetary units[6] while ecologists and others have developed measures or indices expressed in a variety of non-monetary units such as biophysical trade-offs[7].

There are two main methods for estimating monetary values: revealed and stated preferences. Both of these typically involve the use of sophisticated statistical methods to tease out the values[8]. Revealed preference methods involve analyzing individuals' choices in real-world settings and inferring value from those observed choices. Examples of such methods include production-oriented valuation that focuses on changes in direct use values from products actually extracted from the environment (e.g. fish). This method may also be applicable to indirect use values, such as the erosion control benefits forests provide to agricultural production. Other revealed preference methods include hedonic pricing, which infers ecosystem service values from closely linked housing markets. For example, urban forest ecosystems and wetlands may improve water quality and that may be (partially) captured in property values[9]. The travel cost valuation method is used to value recreation ecosystem services and estimates values based on the resources, money and time visitors spend to visit recreation sites.

Stated preference methods rely on individuals' responses to hypothetical scenarios involving ecosystem services and include contingent valuation and structured choice experiments. Contingent valuation utilizes a highly structured survey methodology that acquaints survey respondents with ecosystem improvements (e.g. better stream quality) and the ecosystem services they will generate (e.g. increased salmon stocks). Respondents are then asked to value ecosystem improvements usually using a referendum method[10].

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[6] A. M. Freeman, *The Measurement of Environmental and Resource Values: Theories and Methods*, 2nd Edition, RFF Press, Washington DC 2003.

[7] R. Costanza, *Value theory and energy,* in: *Encyclopedia of Energy* Vol. 6, ed. C. Cleveland, Elsevier, Amsterdam 2004, p. 337-346.

[8] T. Haab, K. McConnell, *Valuing Environmental and Natural Resources: The Econometrics of Non-Market Valuation,* Edward Elgar Publishing Ltd: Cheltenham, UK 2002.

[9] D. J. Phaneuf, V. K. Smith, R. B. Palmquist, J. C. Pope, *Integrating property value and local recreation models to value ecosystem services in urban watersheds,* „Land Economics" 2008 No. 84, p.361-381.

[10] A. Boardman, D. Greenberg, A. Vining, D. Weimer, *Cost-Benefit Analysis: Concepts and Practice*, 4th Edition, Prentice Hall, Inc: Upper Saddle River, New York 2006.

Choice experiments are sometimes called conjoint analysis. This method presents respondents with combinations of ecosystem services and monetary costs and asks for the most preferred combinations. Based on these choices, ecosystem service values are inferred.

A key challenge in any valuation is imperfect information. Individuals might, for example, place no value on an ecosystem service if they do not know the role that the service is playing in their well-being[11]. Here is an analogy. If a tree falls in the forest and there is no one around to hear it, does it still make a sound? Assume in this case that the "sound" is the ecosystem service. The answer to this old question obviously depends on how one defines "sound". If "sound" is defined as the perception of sound waves by people, then the answer is no. If "sound" is defined as the pattern of physical energy in the air, then the answer is yes. In this second case, choices in both revealed and stated preference models would not reflect the true benefit of the ecosystem service. Another key challenge is accurately measuring the functioning of the system to correctly quantify the amount of a given service derived from that system[12].

But recognizing the importance of information does not obviate the limitations of human perception-centered valuation. As the tree analogy demonstrates, perceived value can be a quite limiting valuation criterion, because natural capital can provide positive contributions to human well-being that are either never (or only vaguely) perceived or may only manifest themselves at a future time. A broader notion of value allows a more comprehensive view of value and benefits, including, for example, valuation relative to alternative goals/ends, like fairness and sustainability, within the broader goal of human well-being[13]. Whether these values are perceived or not and how well or accurately they can be measured are separate (and important) questions.

Case Studies

Early valuation syntheses

Scientists and economists have discussed the general concepts behind natural capital, ecosystem services, and their value for decades, with some early work as far back as the 1920's. However, the first explicit mention of the term "eco-

[11] B. Norton, R. Costanza, R. Bishop, *The evolution of preferences: why "sovereign" preferences may not lead to sustainable policies and what to do about it,* "Ecological Economics" 1998 No. 24, p. 193-211.

[12] E. B. Barbier et al., *Coastal ecosystem-based management with non-linear ecological functions and values,* "Science" 2008 No. 319, p. 321-323; E. W. Koch et al., No*n-linearity in ecosystem services: temporal and spatial variability in coastal protection,* "Frontiers in Ecology and the Environment" 2009 No. 7, p. 29-37.

[13] R. Costanza, *Social goals and the valuation of ecosystem services,* "Ecosystems" 2000 No. 3, p. 4-10.

system services" was in Ehrlich and Mooney in 1983[14]. More than 6,000 papers have been published on the topic of ecosystem services since then. The first mention of the term "natural capital" was in Costanza and Daly[15].

One of the first studies to estimate the value of ecosystem services globally was published in *Nature* entitled 'The value of the world's ecosystem services and natural capital'[16]. This paper estimated the value of 17 ecosystem services for 16 biomes to be in the range of USD 16-54 trillion per year, with an average of USD 33 trillion per year, a figure larger than annual GDP at the time. Some have argued that global society would not be able to pay more than their annual income for these services, so a value larger than global GDP does not make sense. However, not all benefits are picked up in GDP and many ecosystem services are non-marketed, so GDP does not represent a limit on real benefits[17].

In this study, estimates of global ecosystem services were derived from a synthesis of previous studies that utilized a wide variety of techniques like those mentioned above to value specific ecosystem services in specific biomes. This technique, called "benefit transfer," uses studies that have been done at other locations or in different contexts, but can be applied with some modification. See Costanza (1998) for a collection of commentaries and critiques of the methodology. Such a methodology, although useful as an initial estimate, is just a first cut and much progress has been made since then[18].

Major World Reports on Ecosystem Services

More recently the concept of ecosystem services gained attention with a broader academic audience and the public when the Millennium Ecosystem Assessment (MEA) was published[19]. The MEA was a 4-year, 1,300 scientist study commissioned by the United Nations in 2005. The report analyzed the state of the world's ecosystems and provided recommendations for policymakers. It determined that human actions have depleted the world's natural capital to the point that the ability of a majority of the globe's ecosystems to sustain future generations can no longer be taken for granted.

[14] P. R. Ehrlich, H. Mooney, *Extinction, substitution, and ecosystem services,* "BioScience" 1983 No. 33, p. 248-254.

[15] R. Costanza, H. E. Daly, *Natural capital and sustainable development,* "Conservation Biology" 1992 No. 6, p. 37-46.

[16] R. Costanza et al., *The value of the world's ecosystem services and natural capital*, "Nature" 1997 No. 387, p. 253-260.

[17] R. Costanza et al., *The value of the world's ecosystem services: putting the issues in perspective,* "Ecological Economics" 1998 No. 25, p. 67-72.

[18] R. Boumans et al., *Modeling the Dynamics of the Integrated Earth System and the Value of Global Ecosystem Services Using the GUMBO Model*, "Ecological Economics" 2002 No. 41, p. 529-560; U.S. Environmental Protection Agency Science Advisory Board, *Valuing the Protection of Ecological Systems and Services: A Report of the EPA Science Advisory Board,* EPA-SAB-09-012. Washington, DC: EPA. http://yosemite.epa.gov/sab/sabproduct.nsf/WebBOARD/ValProtEcolSys&Serv?OpenDocument, 2009 [Date of entry: 20-07-2012].

[19] *The Millennium*, op. cit.

In 2008, a second international study was published on The Economics of Ecosystems and Biodiversity (TEEB)[20], hosted by United Nations Environment Programme (UNEP). TEEB's primary purpose was to draw attention to the global economic benefits of biodiversity, to highlight the growing costs of biodiversity loss and ecosystem degradation, and to draw together expertise from the fields of science, economics, and policy to enable practical actions moving forward. The TEEB report was picked up extensively by the mass media, bringing ecosystem services to a broad audience.

The Ecosystem Services Partnership and ongoing work

With such high profile reports being published, ecosystem services have entered not only the public media[21], but also into business. Dow Chemical recently established a USD 10 million collaboration with The Nature Conservatory to tally up the ecosystem costs and benefits of every business decision[22]. Such collaboration will provide a significant addition to ecosystem services valuation knowledge and techniques. However, there is significant research that is still required. Our scientific institutions can help lead this process through transdisciplinary graduate education, such as the Ecosystem Services for Urbanizing Regions program funded by the National Science Foundation's Integrative Graduate Research and Education Traineeship program[23].

Hundreds of projects and groups are currently working toward better understanding, modeling, valuation, and management of ecosystem services and natural capital. It would be impossible to list all of them here, but the new Ecosystem Services Partnership[24] is a global network that does just that and helps to coordinate the activities and build consensus.

The following lays out the research agenda as agreed to by a group of 30 participants at a meeting in Salzau, Germany, in June 2010, at the launch of the ESP.

Integrated Measurement, Modeling, Valuation and Decision Science in Support of Ecosystem Services

The scientific community needs to continue to develop better methods to measure, monitor, map, model, and value ecosystem services at multiple scales. Ideally, these efforts should take place using interdisciplinary teams and strategies and in close collaboration with ecosystem stakeholders. Moreover, this in-

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[20] P. Sukhdev, P. Kumar, *The economics of ecosystems & biodiversity*, http://www.teebweb.org/, 2008 [Date of entry: 20-05-2012].

[21] J. D. Schwartz, *Should We Put A Dollar Value On Nature?*, "Time Magazine", Time Inc., http://www.time.com/time/business/article/0,8599,1970173,00.html, 2010 [Date of entry: 20-05-2012].

[22] B. Walsh, *Paying for Nature,* "Time Magazine", Time Inc., http://www.time.com/time/magazine/article/0,9171,2048324,00.html, 2011 [Date of entry: 20-05-2012].

[23] *Ecosystem Services for Urbanizing Regions,* http://www.pdx.edu/esur-igert, Portland State University 2011 [Date of entry: 20-05-2012].

[24] *Ecosystem Services Partnership*, http://www.es-partnership.org/ [Date of entry: 20-05-2012].

formation must be provided to decision makers in an appropriate, transparent, and viable way, to clearly identify differences in outcomes among policy choices. At the same time, we cannot wait for high levels of certainty and precision to act when confronting significant irreversible and catastrophic consequences. We must synergistically continue to improve the measurements with evolving institutions and approaches that can effectively utilize these measurements.

1. *Trade-offs*
   Ecological conflicts arise from two sources: (1) scarcity and restrictions in the amount of ES that can be provided and (2) the distribution of the costs and benefits of the provisioning of the ES. ES science makes trade-offs explicit and, thus, facilitates management and planning discourse. It enables stakeholders to make sound value judgments. ES science thus generates relevant social-ecological knowledge for stakeholders and policy decision makers and sets of planning options that can help resolve sociopolitical conflicts.
2. *Accounting and Assessment*
   Accounting attempts to look at the flow of materials with relative objectivity, while assessment evaluates a system or process with a goal in mind and is more normative. Both are integrating frameworks with distinctive roles. Both ecosystem service accounting and assessment need to be developed and pursued using a broader socio-ecological lens. Within the broader lens we also need to balance expert and local knowledge across scales.
3. *Modeling*
   We need modeling to synthesize and quantify our understanding of ES and to understand dynamic, non-linear, spatially explicit trade-offs as part of the larger socio-ecological systems. Stakeholders should be active collaborators in this model development process to assure relevancy. These models can incorporate and aid accounting and assessment exercises and link directly with the policy process at multiple time and space scales. In particular, modeling can quantify potential shifts in ES under different environmental and socioeconomic scenarios.
4. *Bundling*
   Most ES are produced as joint products (or bundles) from intact ecosystems. The relative rates of production of each service vary from system-to-system, site-to-site, and time-to-time. We must consider the full range of services and the characteristics of their bundling in order to prevent creating dysfunctional incentives and to maximize the net benefits to society[25]. For example, focusing only on the carbon sequestration service

[25] E. Nelson et al., *Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales*, "Frontiers in Ecology and the Environment" 2009 No. 7, p. 4-11; S. Polasky, E. Nelson, D. Pennington, K. Johnson, *The impact of land-use change on ecosystem services, biodiversity and returns to landowners: a case study in the State of Minnesota,* "Environmental and Resource Economics" 2011 No. 48, p. 219-242.

of ecosystems may in some instances reduce the overall value of the full range of ES.

5. *Scaling*
   ES are relevant over a broad range of scales in space, time, governance and complexity, including the legacy of past behavior. We need measurement, models, accounts, assessments and policy discussions that address these multiple scales, as well as interactions, feedbacks, and hierarchies among them.

Adaptive Management and New Institutions for Ecosystem Services

Given that pervasive uncertainty always exists in ecosystem service measurement, monitoring, modeling, valuation, and management, we should continuously gather and integrate appropriate information regarding ES, with the goal of learning and adaptive improvement. To do this we should constantly evaluate the impacts of existing systems and design new systems with stakeholder participation as experiments from which we can more effectively quantify performance and learn ways to manage such complex systems.

1. *Property Rights*
   Given the public goods nature of most ecosystem services, we need institutions that can effectively deal with this characteristic using a sophisticated suite of property rights regimes. We need institutions that employ an appropriate combination of private, state and common property rights systems to establish clear property rights over ecosystems without privatizing them. Systems of payment for ecosystem services (PES) and common asset trusts can be effective elements in these institutions.
2. *Scale-matching*
   The spatial and temporal scale of the institutions to manage ecosystem services must be matched with the scales of the services themselves. Mutually reinforcing institutions at local, regional and global scales over short, medium and long time scales will be required. Institutions should be designed to ensure the flow of information across scales, to take ownership regimes, cultures, and actors into account, and to fully internalize costs and benefits.
3. *Distribution Issues*
   Systems should be designed to ensure inclusion of the poor, since they are generally more dependent on common property assets like ecosystem services. Free-riding, especially by wealthier segments of society, should be deterred and beneficiaries should pay for the services they receive from bio-diverse and productive ecosystems.
4. *Information Dissemination*
   One key limiting factor in sustaining natural capital is lack of knowledge of how ecosystems function and how they support human well-being. This can be overcome with targeted educational campaigns that are tai-

lored to disseminate success and failures to both the general public and elected officials and through true collaboration among public, private and government entities.

5. *Participation*
   Relevant stakeholders (local, regional, national, and global) should be engaged in the formulation and implementation of management decisions. Full stakeholder awareness and participation, not only improves ES analyses, but contributes to credible, accepted rules that identify and assign the corresponding responsibilities appropriately, and that can be effectively enforced.
6. *Science/Policy Interface*
   ES concepts can be an effective link between science and policy by making the trade-offs more transparent[26]. An ES framework can therefore be a beneficial *addition* to policy-making institutions and frameworks and to integrating science and policy.

Conclusions

Natural capital and ecosystem services are key concepts that are changing the way we view, value, and manage the natural environment. They are changing the framing of the issue away from "jobs vs. the environment" to a more balanced assessment of all the assets that contribute to human well-being. Significant transdisciplinary research has been done in recent years on ecosystem services, but there is still much more to do and this will be an active and vibrant research area for the coming years, because better understanding of ecosystem services is critical for creating a sustainable and desirable future. Placing credible values on the full suite of ecosystem services is key to improving their sustainable management.

[26] E. F. Granek et al., *Ecosystem services as a common language for coastal ecosystem-based management,* "Conservation Biology" 2010 No. 24, p. 207-216.