ENVIORNMENTAL FARMING ACT SCIENCE ADVISORY PANEL

Evaluation Framework Working Group

February 23, 2012

Marin County Cooperative Extension Office

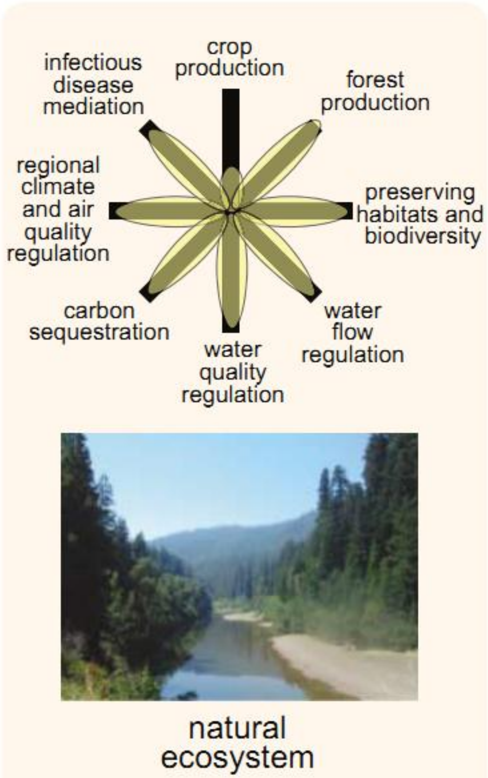
Novato, CA

Amrith Gunasekara, PhD

Science Advisor to the Secretary

Evaluation Framework - Background

- Goal is to evaluate and put for an evaluation framework



Quantitative Measures:

- Recreation

# of visitors to a national park

(Larsen et al., 2008)

- Biodiversity data

Number of species

(Larsen et al., 2008)

- Carbon Storage

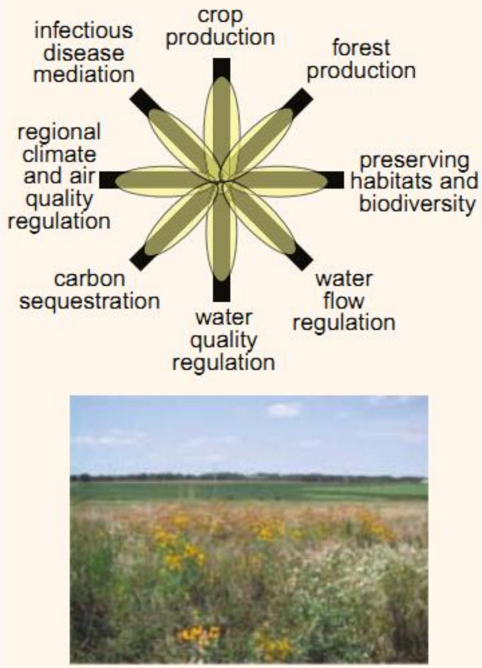
CO_2 emissions

(Chan et al., 2006)

(Foley et al., 2005)

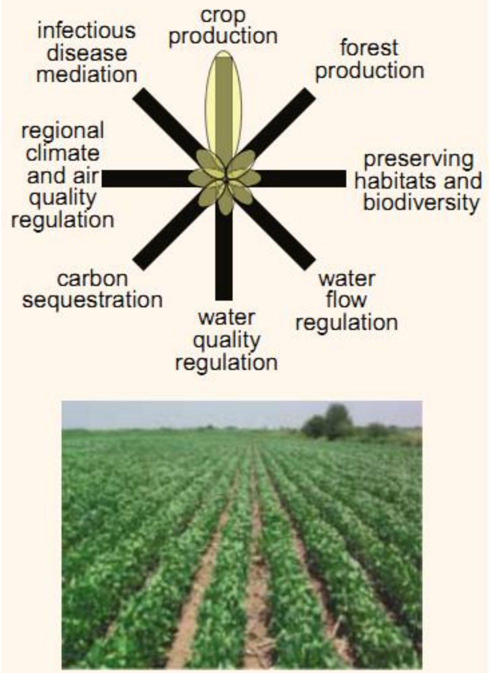
Evaluation Framework - Background

Agriculture with Ecosystem Services



cropland with restored ecosystem services

Agriculture



intensive cropland

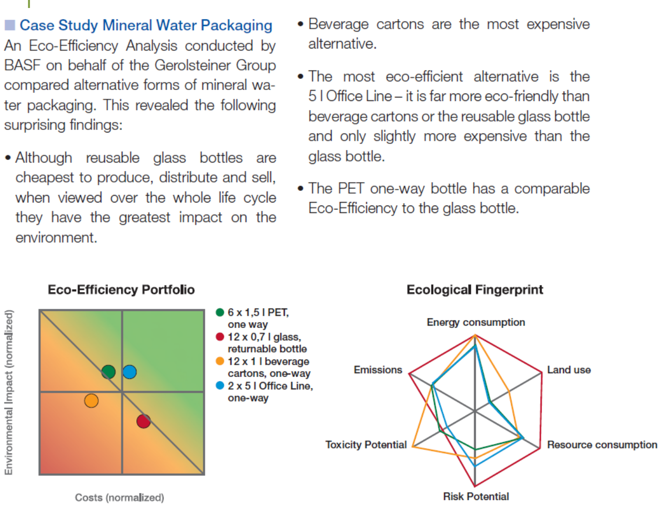
(Foley et al., 2005)

Questions

- Can we use numbers?
- What sort of assessment scales?
- Use of the scientific method to uphold final evaluation framework?
- Are there statistical methods that can quantify qualitative inferences?
- We don't want to reinvent the wheel but can we come up with something to support future incentives?
- Do we want to recognize existing programs?

Sustainability Assessment Programs

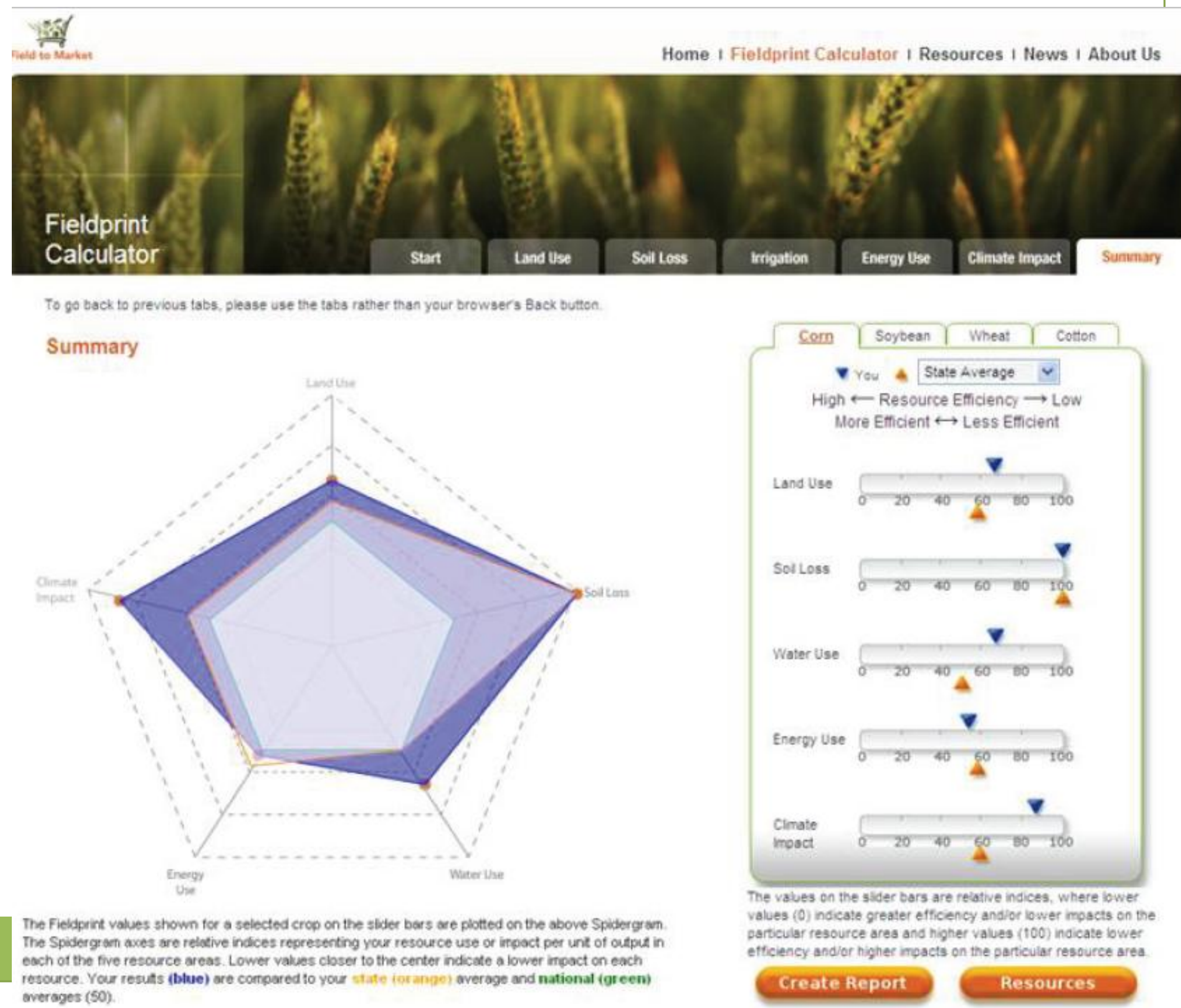
- Stewardship Index
- Field to Market
- BASF



Case Study Mineral Water Packaging

An Eco-Efficiency Analysis conducted by BASF on behalf of the Gerolsteiner Group compared alternative forms of mineral water packaging. This revealed the following surprising findings:

- Although reusable glass bottles are cheapest to produce, distribute and sell, when viewed over the whole life cycle they have the greatest impact on the environment.
- Beverage cartons are the most expensive alternative.
- The most eco-efficient alternative is the 5 l Office Line – it is far more eco-friendly than beverage cartons or the reusable glass bottle and only slightly more expensive than the glass bottle.
- The PET one-way bottle has a comparable Eco-Efficiency to the glass bottle.



Other Scales of Evaluation

- EDF

Environmental Benefits/Risk: N	Environmental Benefits/Risk: P	Environmental Benefits/Risk: Sediments	Good Neighbor & Community Relations	**Assessment Results**	Economic Opportunity/Cost	Regulatory Red Flag	Human Protection/Risk	Improved Financial Stability	Eco-Label Opportunity	Nutrient Trading Potential	Carbon Trading Potential	Reduced Insurance Rate Opportunity	Improved Financing Opportunity	State, Fed Assistance Opportunity
1	1	0	0	2	0	0	0	0	M	0	0	0	0	0
-1	-1	0	-1	-3	0	0	0	L	L	0	0	L	L	M

LEGEND

2	Significant positive impact
1	Positive impact
0	Neutral/no net impact
-1	Negative impact
-2	Significant negative impact
$	Low upfront cost - Immediate/near-term savings/payback
$	Upfront cost ($ varies) - **High** potential savings/payback
$	Upfront cost ($ varies) - **Low** potential savings/payback
$	Potential source of continued losses
	Positive impact / Opportunity
0	Neutral impact
	Negative impact / Risk
H	Significant positive impact on creating opportunities
M	Medium positive impact on creating opportunities
0	Neutral/no net impact on creating opportunities
L	Negative impact on creating opportunities
VL	Significant negative impact on creating opportunities

CLEAN STREAM DAIRIES

WATER QUALITY SELF-ASSESSMENT

EDF ENVIRONMENTAL DEFENSE FUND
Finding the ways that work

SureHarvest SUSTAINABILITY SOLUTIONS

Need questions template for projects? For information gathering

Other Scales of Evaluation

- MEA

Table 8.5. Indirect Drivers of Food Provision (compiled by authors from assessment of literature and evidence)

		Past 50 Years		Current Trends		
Drivers		Change	Relevance of Driver	Change	Relevance of Driver	Remarks/Examples
Demand factors						
Population growth and structure	In	+/++	med	–/+	low/med	Europe static/shrinking; North America still growing
	Dg	+++	high	+/+++	med/v. high	East Asia slow; SSA, WANA, SA highest growth rates
Urbanization	In	++	med	–/+	low	70–80% urbanized
	Dg	+++	med	++/+++	med/high	40% urbanized, 3%/yr growth, 80% of global urban total
Income growth	In	++	med/high	++	med/high	slow to medium long-term growth
	Dg	+/+++	high	–/+++	high	some negative, esp. SSA; strong growth: East Asia
Food prices	In	––	med	–/o	low/med	well-integrated markets, productivity growth
	Dg	–	high	–/+	med/high	weaker markets, lower productivity growth
Food marketing: branding and advertising	In	++	med	+++	med	major diet changes are through switching brands/product
	Dg	+	low	+/++	med	less in poor rural areas, but increasing, e.g., radio, tv
Diet and health information	In	++	med	++/+++	med/high	increased information on the healthfulness or otherwise
	Dg	o/+	low	+/++	med	related to specific food types or food processing
Consumer concerns with production context	In	x	low	xx	low/med	concerns with environmental, food safety, child labor,
	Dg	o/x	low	o/x	low	equity, GMOs, animal welfare, etc. issues
Dietary (and lifestyle) preferences	In	o/x	low/med	o/x	low/med	largely consequence of marketing, diet, and health info
	Dg	x/xxx	med/high	xx	med/high	largely consequence of urbanization and income growth
Consumer demands for minimum produce grades, standards, labels	In	++	med/high	+++	high/v. high	most producers conform; contract farming on the rise
	Dg	o/+	low	o/+++	med/v. high	major challenge to poor smallholders

Key:
In – industrial-country grouping; Dg – developing-country grouping
Increases: + low; ++ medium; +++ high; decreases: – low, – – medium, – – – high; – –/+ indicates a range from – – to +
Change (no sign): x low, xx medium, xxx high, o no change.

Other Scales and Frameworks

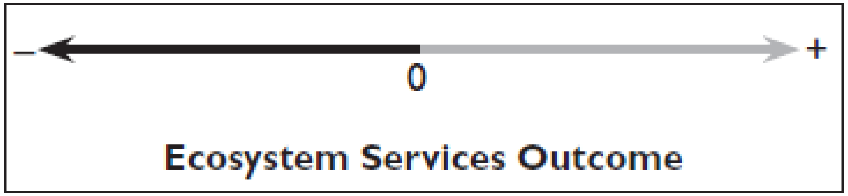
Stacking Ecosystem Services Payments: Risks and Solutions

by David Cooley and Lydia Olander

David Cooley is an Associate for Project Development at the Duke Carbon Offsets Initiative at Duke University. He has also worked as a researcher at the Nicholas Institute for Environmental Policy Solutions at Duke University. Lydia Olander is the Director of the Ecosystem Services Program at the Nicholas Institute for Environmental Policy Solutions at Duke University. She leads the National Ecosystem Services Partnership.

III. A Conceptual Framework for Assessing the Ecosystem Services Outcomes of Stacking

Figure 1. Ecosystem Services Outcome Axis



Other Scales and Frameworks

Figure 1. Ecosystem Services Outcome Axis

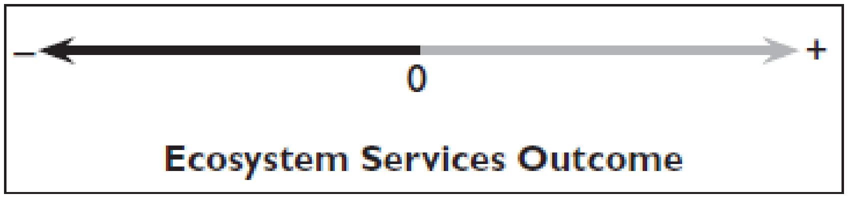
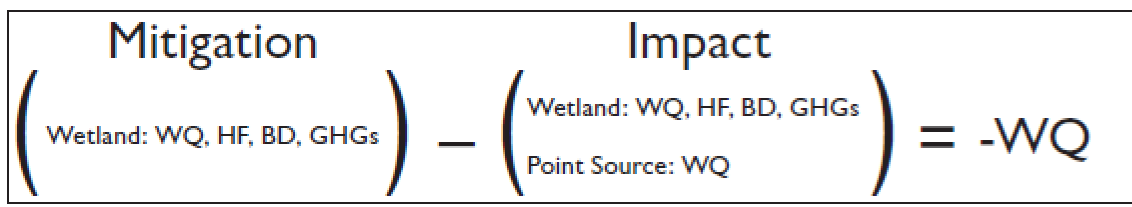


Figure 2. An Example of a Negative Ecosystem Services Outcome Due to Double Counting



Note: Impacts on the wetland will have effects on several ecosystem services, including water quality (WQ), hydrologic functioning (HF), biodiversity (BD), and GHGs. Because the mitigation site sells its WQ benefits twice—to offset both the affected wetland and the point source impacts—a net loss of water quality occurs.

Insectaries - Vineyards

Pollination services (Swinton et al., 2007)

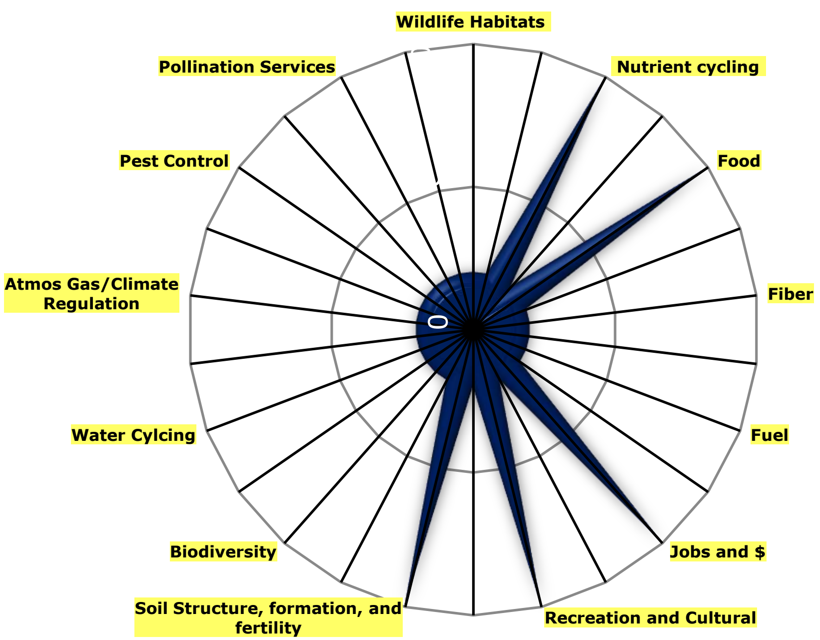
Contribute to fruit, nut, and vegetable production

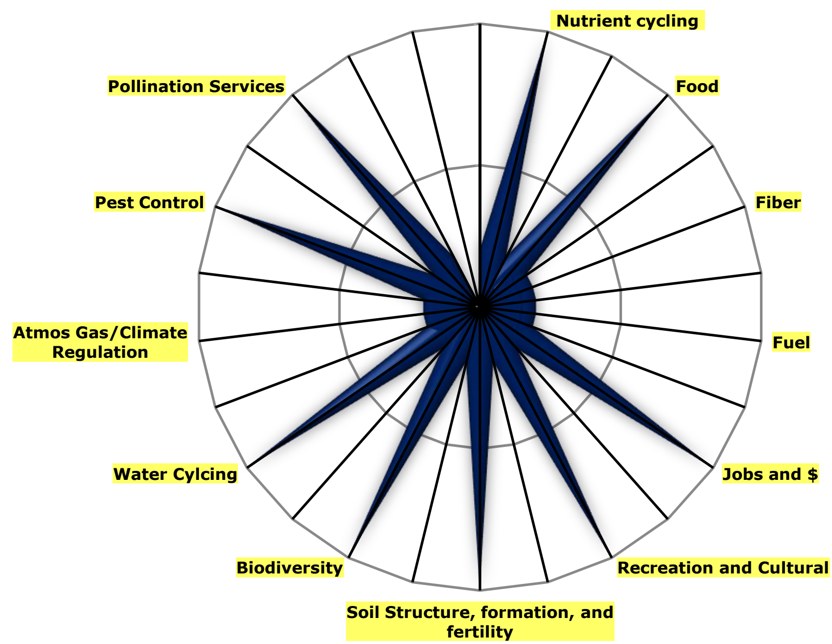
http://www.almondboard.com/Consumer/AboutAlmonds/Pages/default.aspx
http://www.sustainablewinegrowing.org/certifiedparticipant/5/Fetzer_Vineyards_Bonterra_Vineyards.html
http://www.benziger.com/

Insectaries - Vineyards

Before

After





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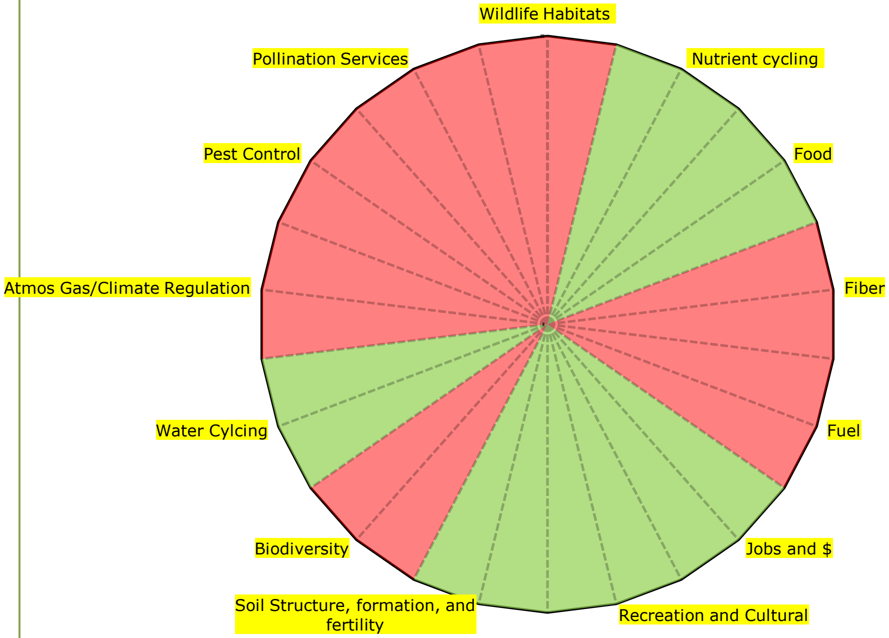
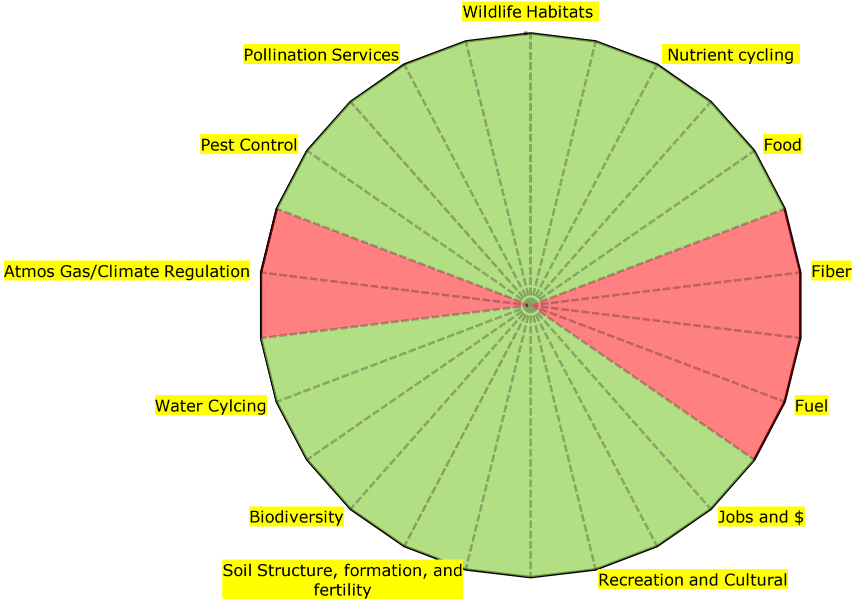
Insectaries - Vineyards

Before

After





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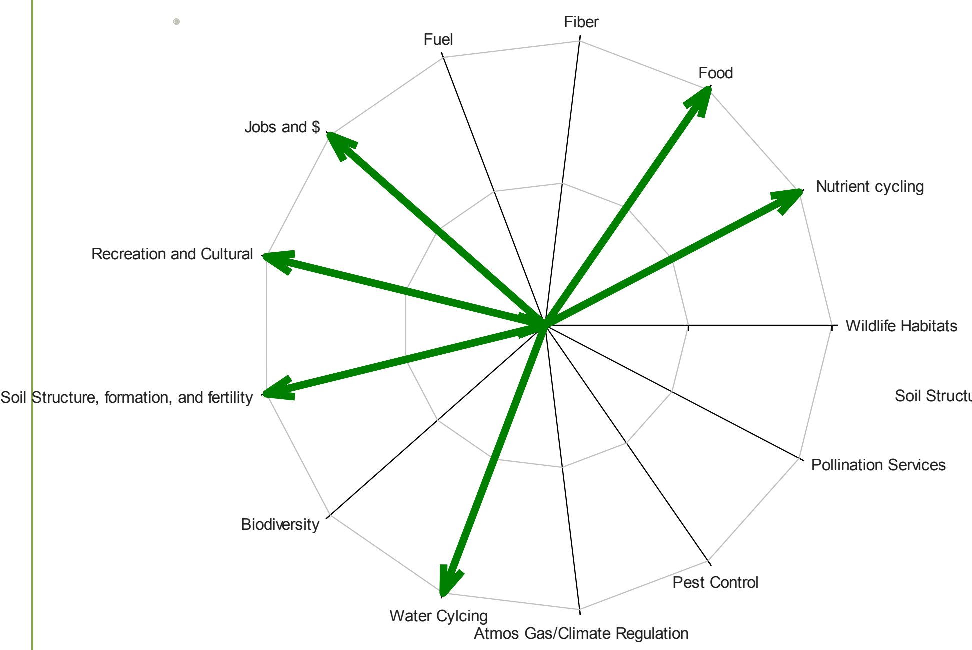
Insectaries - Vineyards

Before



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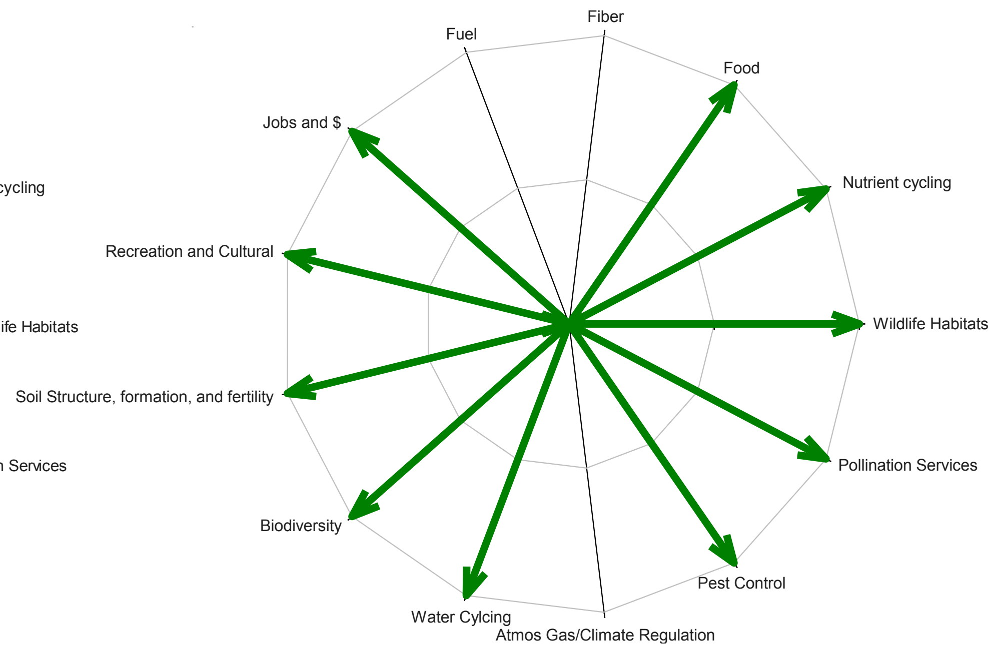

Grazing – Public Lands

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Bay Area's April showers may not bring May flowers

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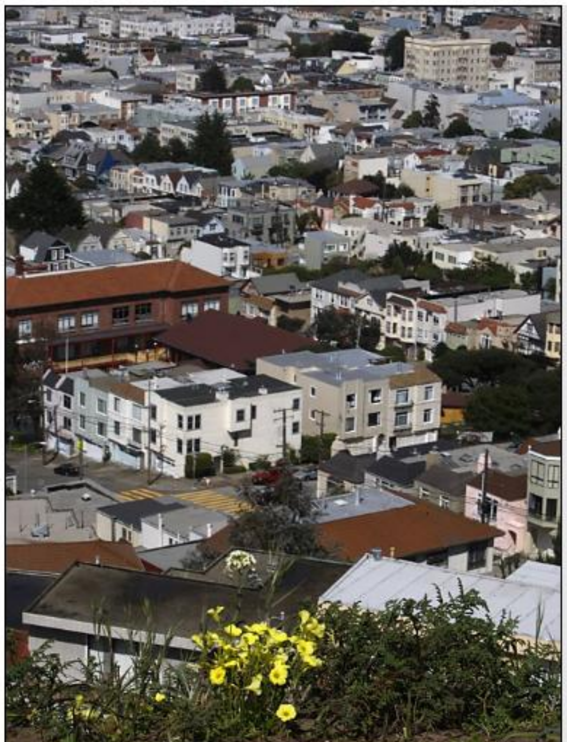

Botanists say that recent rains and warm weather have helped produce such a bounty of nonnative, invasive and aggressive grasses that wildflowers, like these at Grand View Park in San Francisco, may be crowded out.

Photo: Anna Vignet / The Chronicle

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"Botanists say, downpours that soaked the Bay Area in March have produced such a bumper crop of nonnative grass that the wildflowers could well be crowded out."

"A bumper crop of green grass sounds good until you consider that grasslands in the Bay Area are mostly invasive species that are very aggressive and competitive, especially for water and sunlight. The grasses take over the hills and open space and leave the wildflowers in the dirt, so to speak."

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Bay Area's April showers may not bring May flowers

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A woman passes some California poppies at Grand View Park in S.F.

Photo: Anna Vignet / The Chronicle

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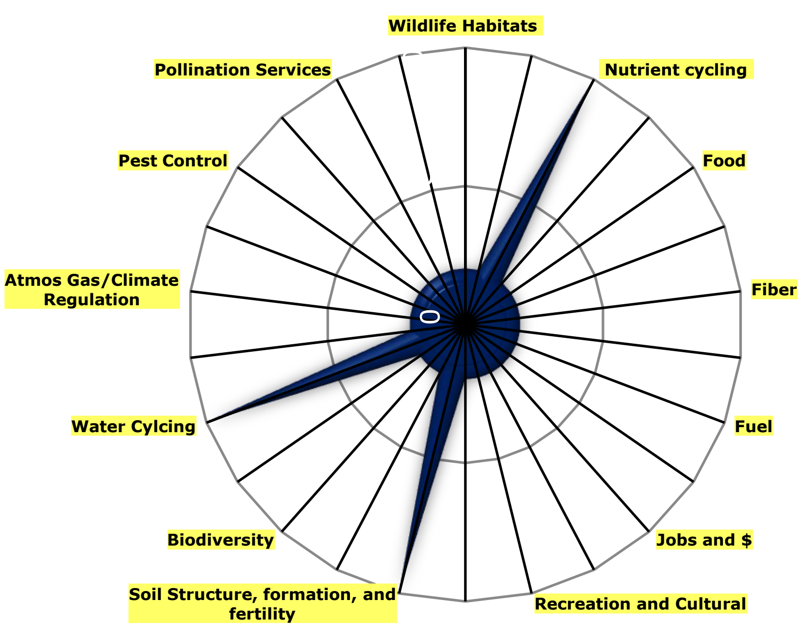
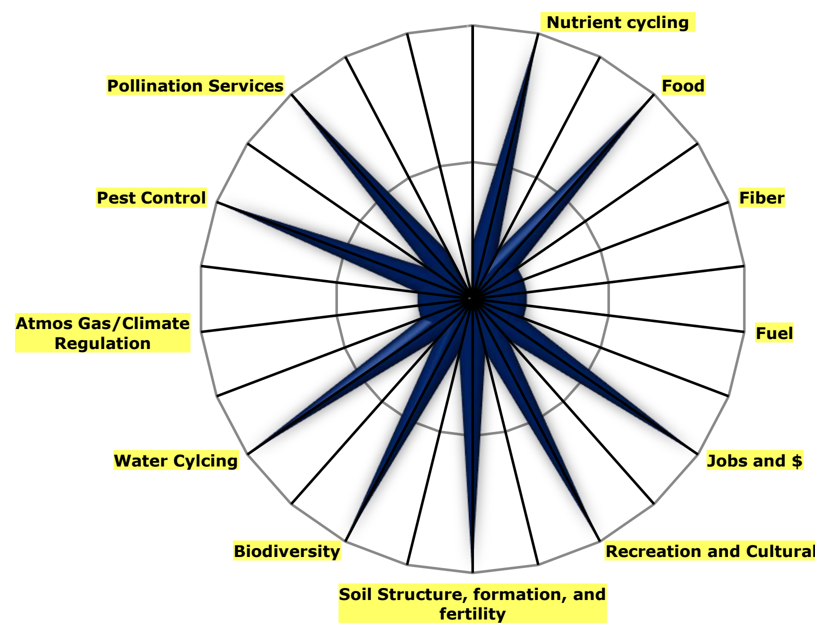
"Development in the cities and suburbs and bad rangeland management in the remaining open country are culprits." He believes that a certain amount of grazing by cattle and other animals helps keep down the grass and lets the wildflowers bloom.

In the past, "open space on Mount Diablo was used by cattle ranchers as grazing land. But the state park system expanded the park, closed the area to grazing and now, the wildflowers on the mountain are nothing like what they were."

Grazing – Public Lands

Without Grazing (Present) | **With Grazing**



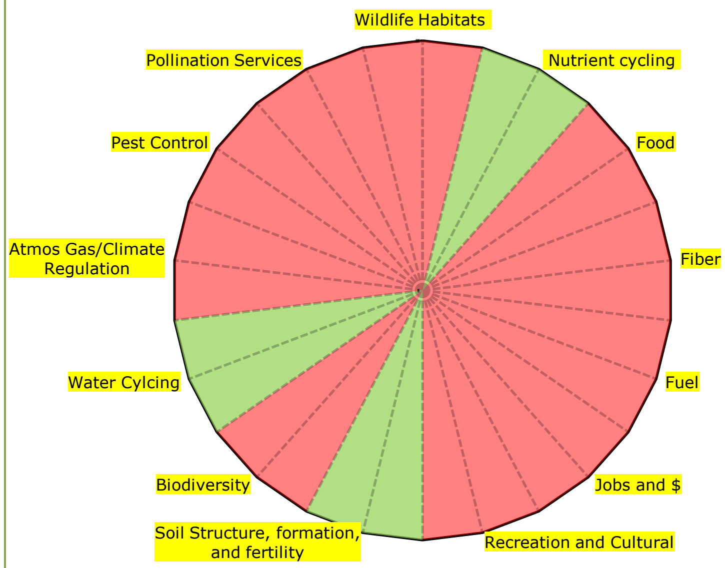


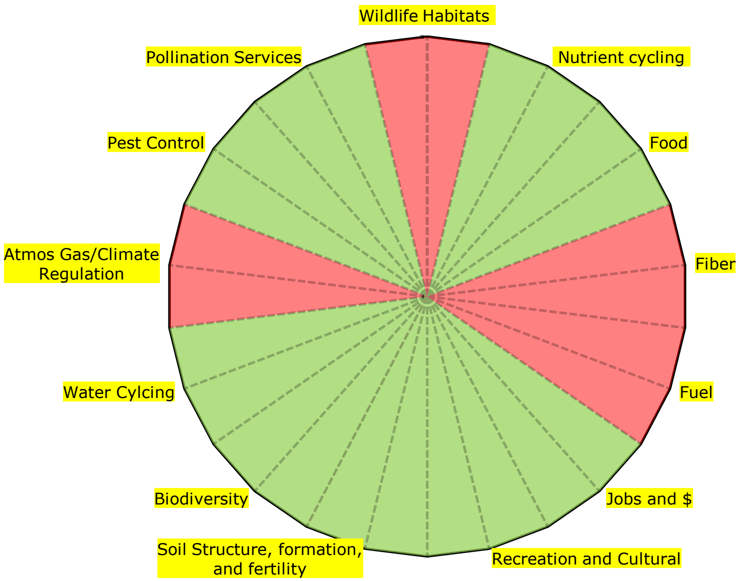
http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2011/04/04/MNTQ1IOIQ1.DTL

Grazing – Public Lands

Without Grazing (Present)

With Grazing





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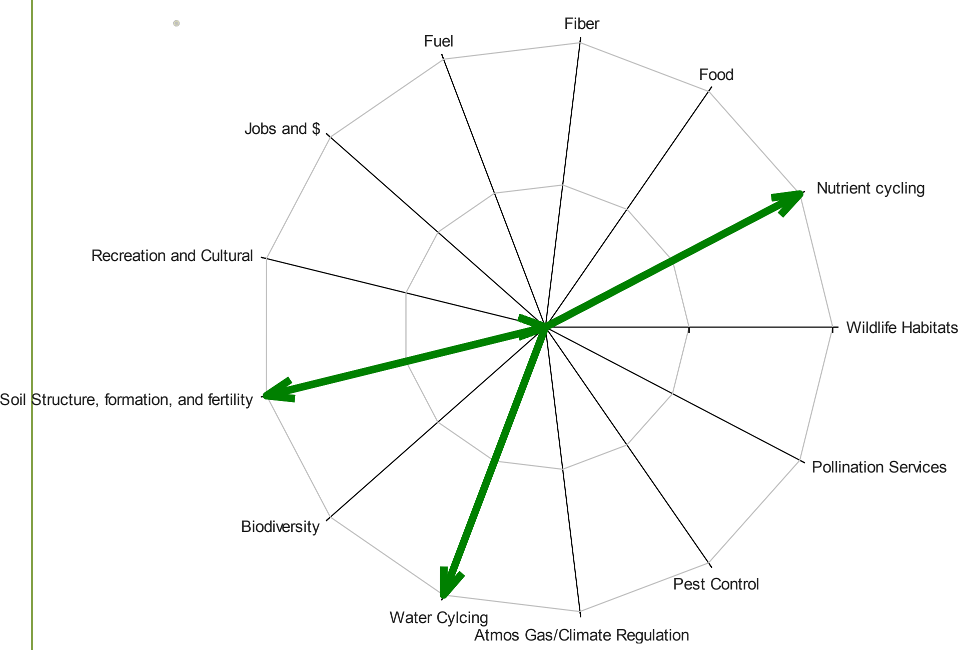
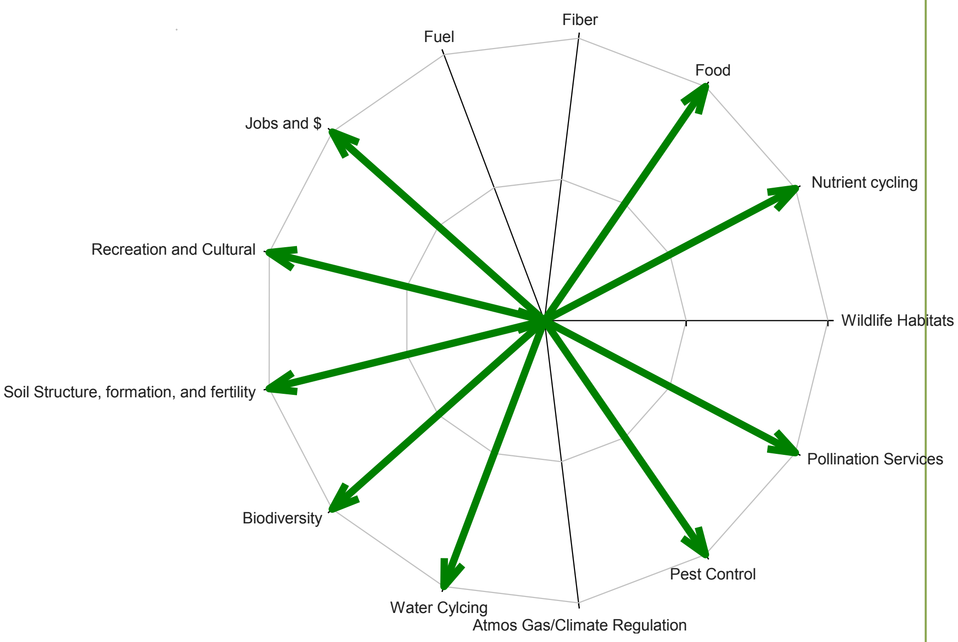
Grazing – Public Lands

Without Grazing (Present)

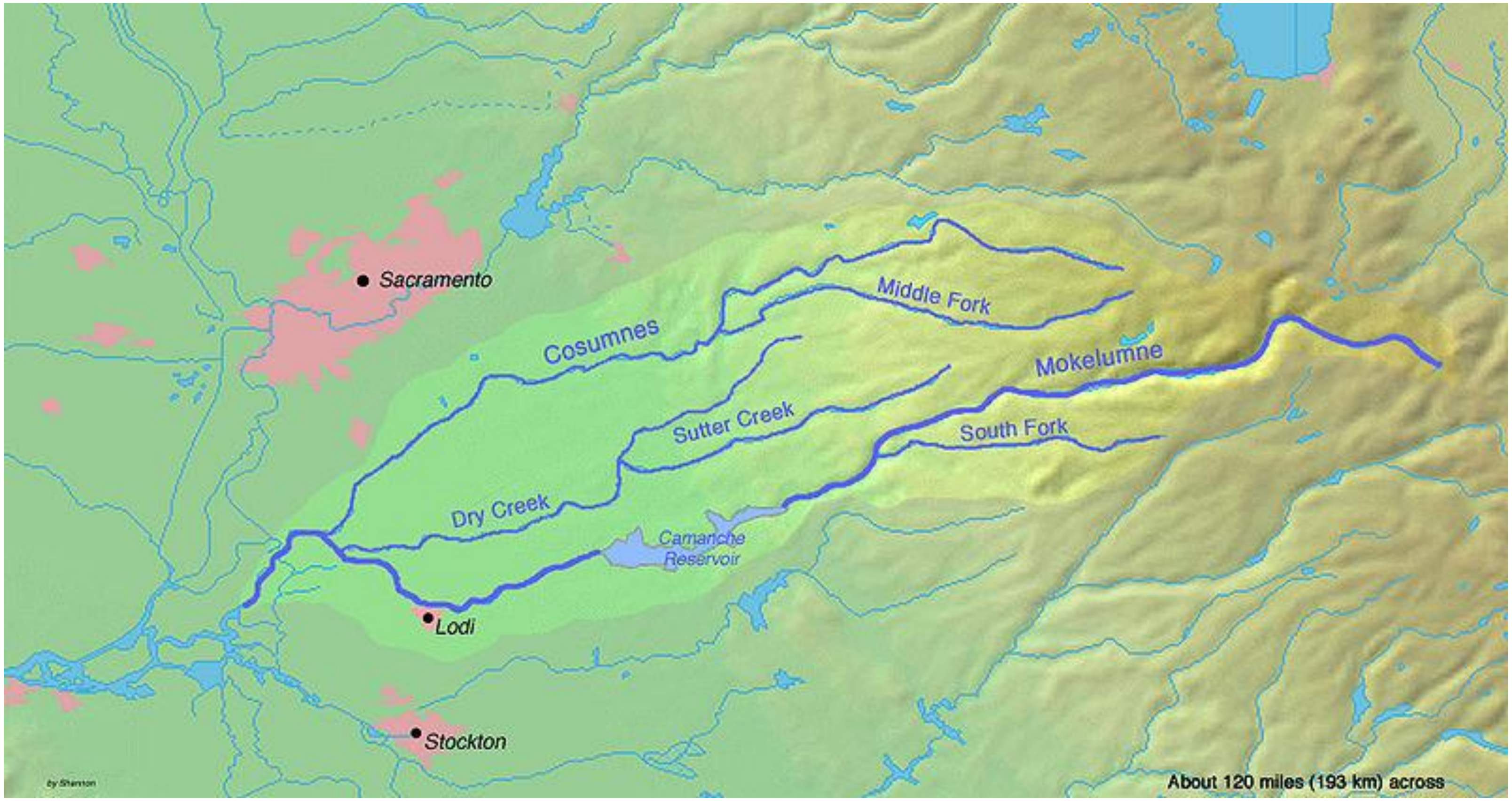


With Grazing

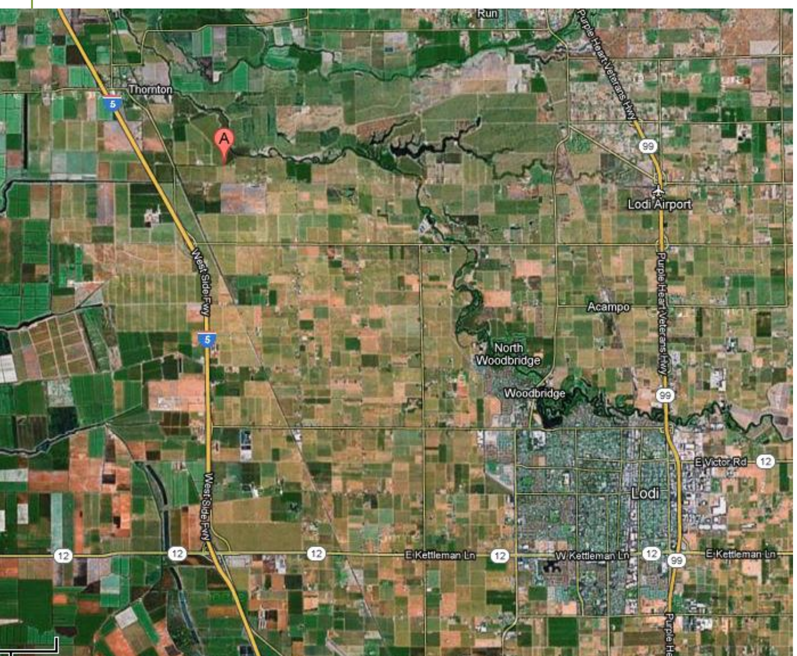


Sigmaplot

Mokelumne Watershed



Mokelumne Watershed



➢East Bay Municipal Utility District sources 90% of its water from the Mokelumne River

➢Serves 1.2 million people.

➢Started in late 2010, the Mokelumne Watershed Project seeks to address some of the threats from fire and development to the water supply and aquatic habitat. Program launch is anticipated in 2012.

➢Participants: Land managers, particularly of forested land, are the targeted service providers for this project.

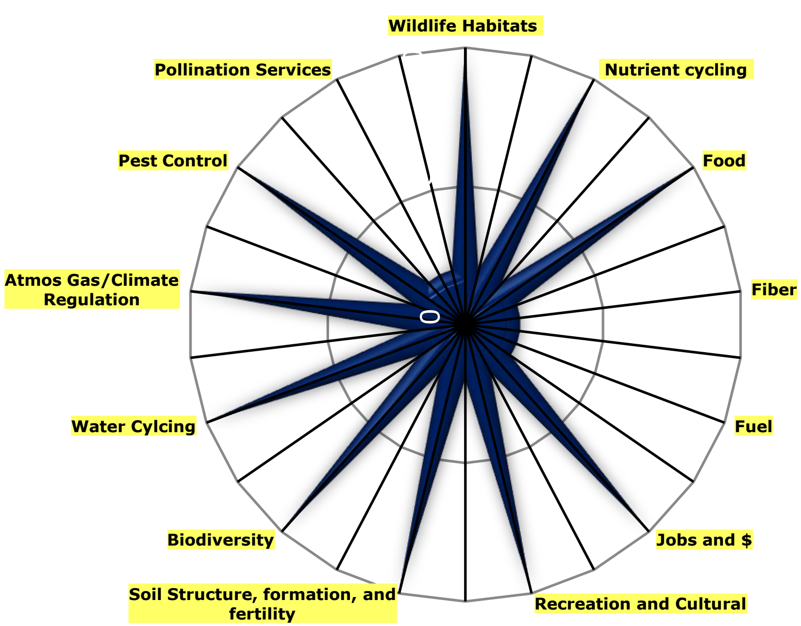
➢Other Stakeholders: Environmental Defense Fund, Sustainable Conservation, and the Sierra Nevada Conservancy manage the preparation of the project.

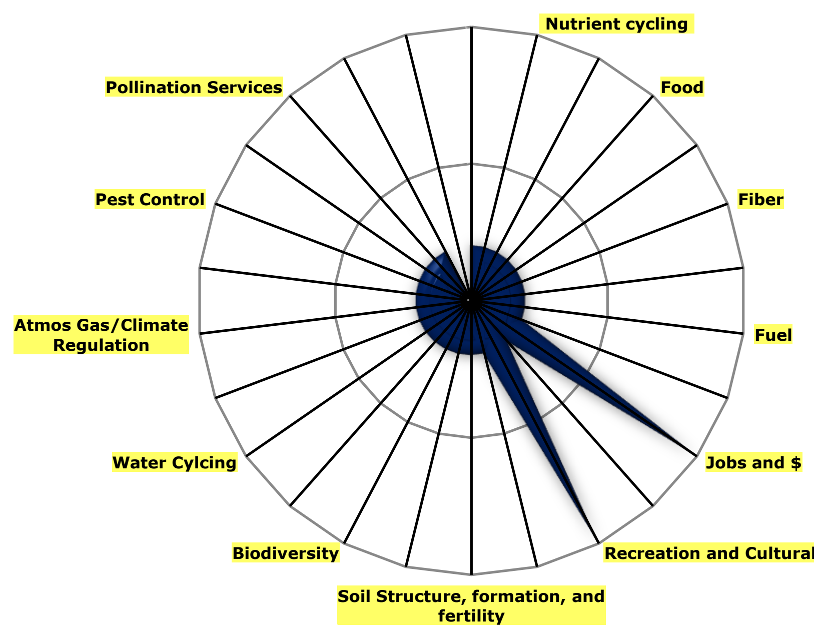
➢**Ultimately, the hope is to engage ratepayers in funding management upstream, and to compensate landowners based on performance.**

Mokelumne Watershed

Mokelumne Project

Without Project in event of fire or major land use change

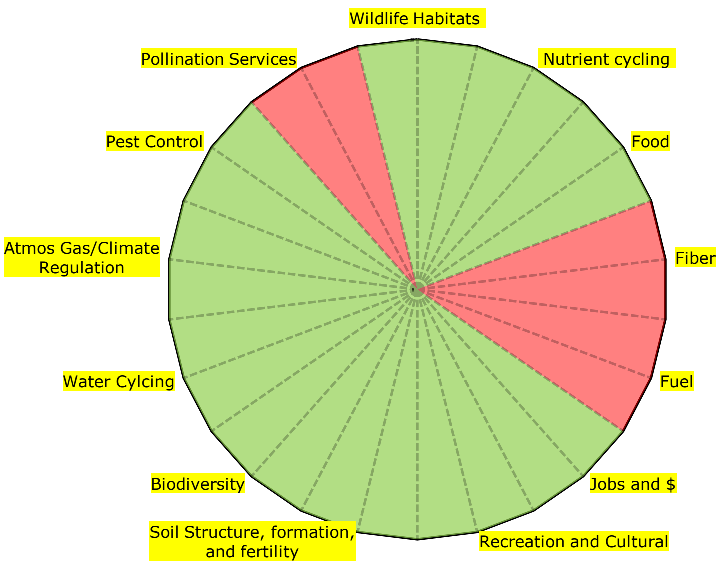




http://www.conservationregistry.org/projects/17170#fulldescr

Mokelumne Watershed

Mokelumne Project



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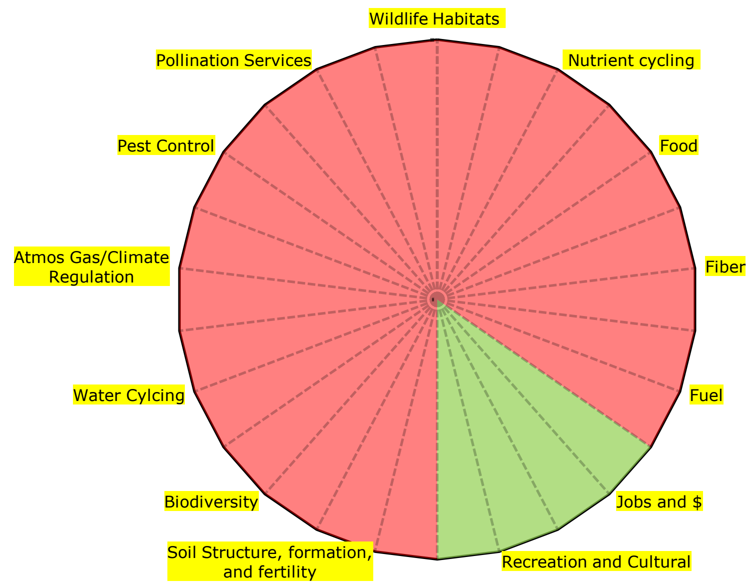

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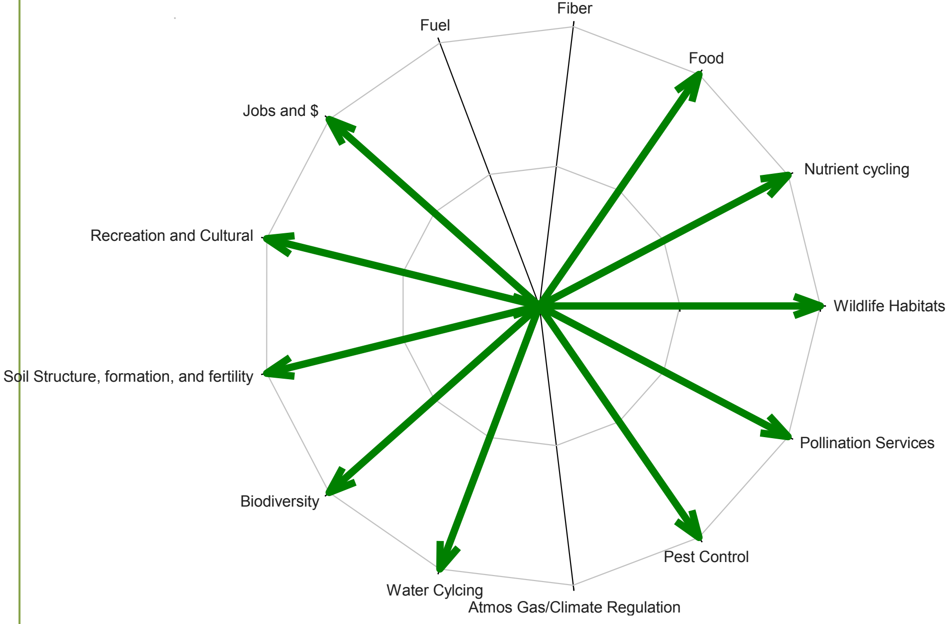
Mokelumne Watershed

Mokelumne Project



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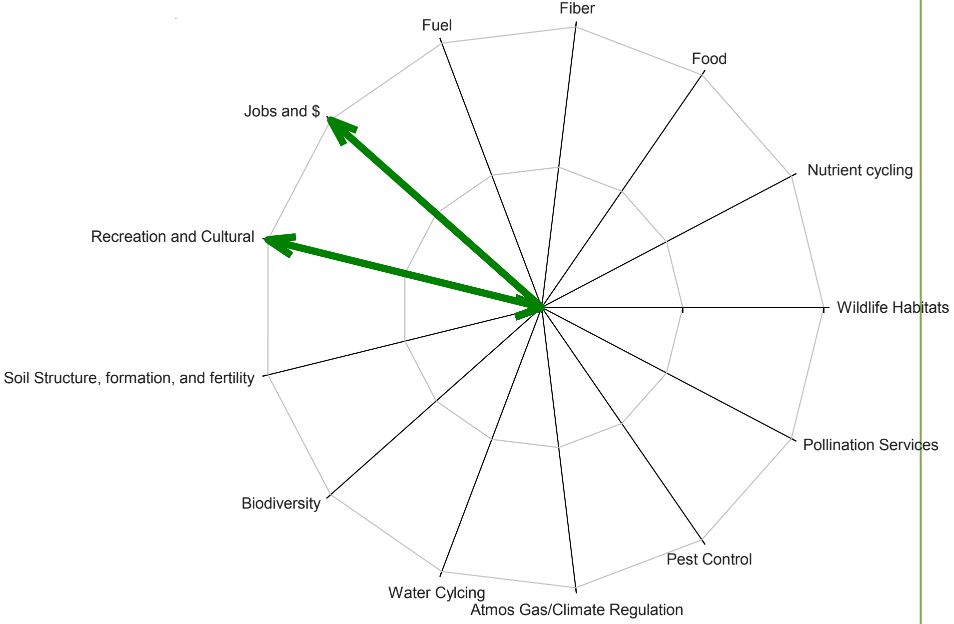

Sigmaplot

Do we want to go further?

Ecology Letters, (2006) **9**: 1146–1156 doi: 10.1111/j.1461-0248.2006.00963.x

REVIEW AND SYNTHESIS

Quantifying the evidence for biodiversity effects on ecosystem functioning and services

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Abstract

Concern is growing about the consequences of biodiversity loss for ecosystem functioning, for the provision of ecosystem services, and for human well being. Experimental evidence for a relationship between biodiversity and ecosystem process rates is compelling, but the issue remains contentious. Here, we present the first rigorous quantitative assessment of this relationship through meta-analysis of experimental work spanning 50 years to June 2004. We analysed 446 measures of biodiversity effects (252 in grasslands), 319 of which involved primary producer manipulations or measurements. Our analyses show that: biodiversity effects are weaker if biodiversity manipulations are less well controlled; effects of biodiversity change on processes are weaker at the ecosystem compared with the community level and are negative at the population level; productivity-related effects decline with increasing number of trophic links between those elements manipulated and those measured; biodiversity effects on stability measures ('insurance' effects) are not stronger than biodiversity effects on performance measures. For those ecosystem services which could be assessed here, there is clear evidence that biodiversity has positive effects on most. Whilst such patterns should be further confirmed, a precautionary approach to biodiversity management would seem prudent in the meantime.

Keywords

Biodiversity–ecosystem functioning, diversity manipulations, ecosystem property, ecosystem services, ecosystem type, experimental design, meta-analysis, stability, trophic level.

Ecology Letters (2006) 9: 1146–1156

Statistics

Table 2 Results from one-way analyses of variance (ANOVA)s in the sequence of decreasing *F*-values and multiway ANOVA using this sequence for fitting the corresponding fixed terms (see Methods for details)

H no.	Variable	d.f.	Sum of squares	Mean squares	*F*	*P*-value	% Explained variance
One-way ANOVA							
12	Organization level EP	2	2031.7	1015.9	40.27	<0.001	15.4
5	Type direct manipulations*	2	1802.5	901.2	35.00	<0.001	13.6
7	Maximum species number	2	1319.0	659.3	24.57	<0.001	10.0
2	Experimental system	2	1071.0	535.3	19.54	<0.001	8.1
3	Ecosystem type	7	2255.8	322.3	12.89	<0.001	17.1
11	Ecosystem property	28	3241.7	115.8	4.83	<0.001	24.5
16	Study site	74	6168.6	83.4	4.39	<0.001	46.7
1	Type diversity measure	3	377.2	125.7	4.33	0.005	2.9
15	Nature of EP	1	86.5	86.5	2.92	n.s.	0.7
8	Trophic-level manipulated	5	305.1	61.0	2.08	n.s.	2.3
9	Trophic-level measured	6	295.2	49.2	1.67	n.s.	2.2
10	Number of links	1	37.4	37.4	1.28	n.s.	0.3
14	Cycle type EP	4	143.9	36.0	1.21	n.s.	1.1
13	Biotic vs. abiotic EP	1	27.3	27.3	0.93	n.s.	0.2
6	Type indirect gradient*	2	14.1	7.1	0.24	n.s.	0.1
4	Direct vs. indirect	1	2.2	2.2	0.07	n.s.	0.0
ANOVA for selected model							
12	Organization level EP	2	2031.9	1016.0	83.69	<0.001	15.38
5	Type direct manipulations†	2	1295.5	647.4	18.19	<0.001‡	9.81
7	Maximum species number	2	349.3	174.7	4.91	<0.05‡	2.64
2	Experimental system	2	485.0	242.5	6.81	<0.01‡	3.67
3	Ecosystem type	7	660.3	94.3	2.65	<0.05‡	5.00
11	Ecosystem property	28	1196.6	42.7	3.52	<0.001	9.06
16	Study site	65	2501.7	38.5	1.08	n.s.‡	18.94
	Reference (within study site)	26	925.5	35.6	2.93	<0.001	7.01
	Residual	337	3762.4	12.0			28.49
	Total	444	13208.1	29.8			100.00

H no., hypothesis number (see Table 1); n.s., not significant ($P > 0.05$).
*These two terms include the last term (direct vs. indirect) as a category 'none'.
†This term includes the term 'direct vs. indirect' as a category 'none'.
‡*F*-test using reference ID as error term.

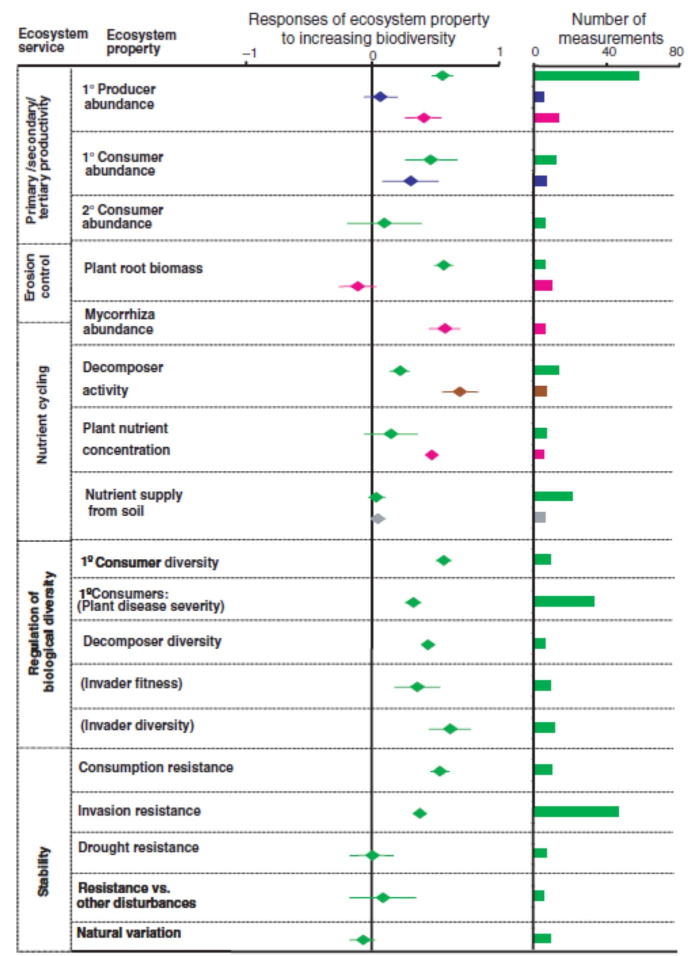

Figure 3 Magnitude and direction of biodiversity effects (shown are mean values and SE of normalized effect sizes Z_r, weighted by the reciprocal of the variance of the individual Z_r-values) and number of measurements available for ecosystem properties organized into ecosystem services. Coloured bars show differential effects of trophic level manipulated: green, primary producers; blue, primary consumers; pink, mycorrhiza; brown, decomposer; grey, multitrophic (multiple levels simultaneously manipulated). Ecosystem properties shown in parentheses were considered of negative value for human well being, and thus opposite of effect sizes are shown.

Balvanera et al. 2006. Ecological Letter. 9: 1146.

Do we want to go further?

- ❑ Stewardship Index – detailed farm level analysis
- ❑ Field to Market - detailed farm level analysis

- Can we use numbers? YES
- What sort of assessment scales? Numerical and YES/NO
- Use of the scientific method to uphold final evaluation framework? YES…need to ask questions for data gathering
- Are there statistical methods that can quantify qualitative inferences? YES
- We don't want to reinvent the wheel but can we come up with something to support future incentives? YES…use YES/NO
- Benefit is that it is easy to comprehend
- Do we want to recognize existing programs?

Questions

References

- Foley J.A. et al. 2005. Global consequences of land use. Nature. 309: 570-574.

- Balvanera et al. 2006. Quantifying the evidence for biodiversity effects on ecosystem functioning and services. Ecological Letter. 9: 1146.

- http://www.conservationregistry.org/projects/17170#fulldescr

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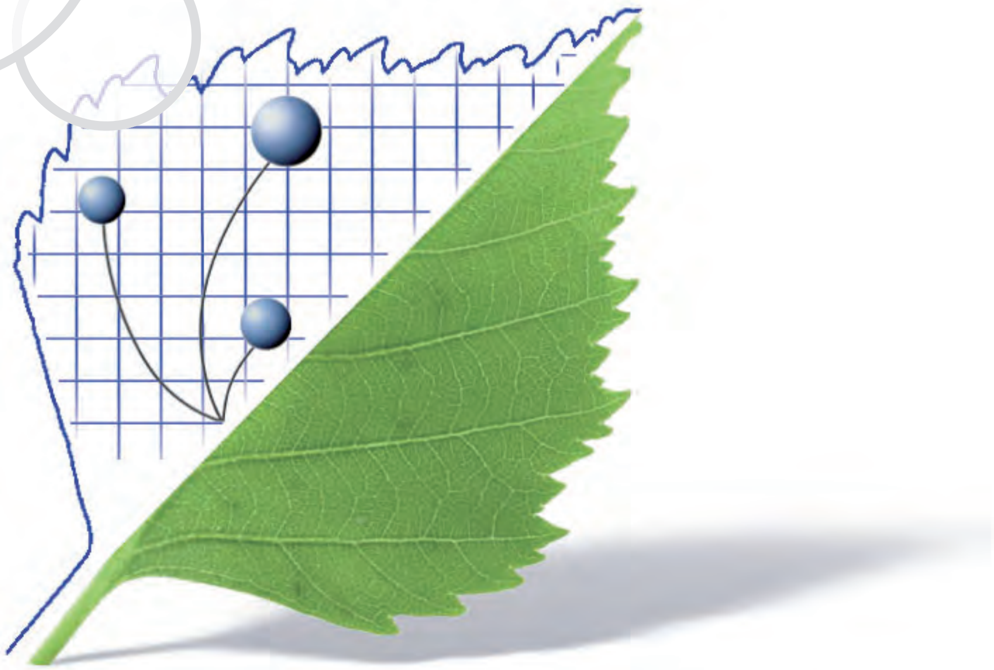
Quantifying Sustainability



EFFICIENCY IN ECOLOGY, ECONOMY AND SOCIETY

BASF

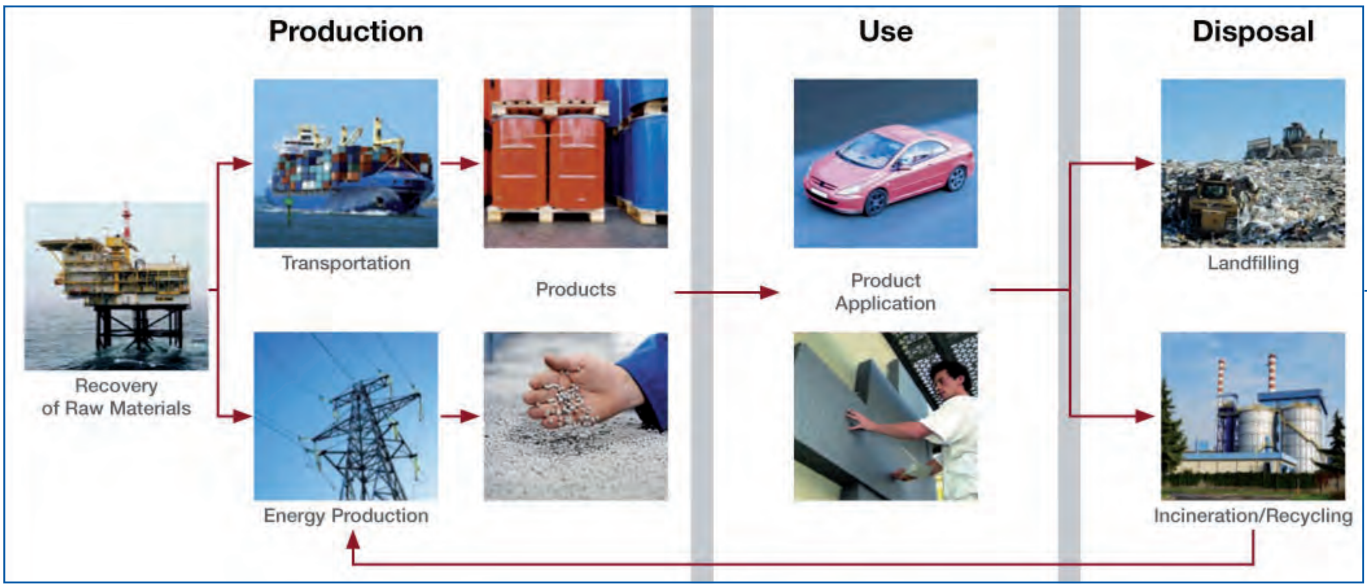
The Chemical Company

How to Measure Sustainability?

Glass or plastic? Diesel or biodiesel? Chemical process or fermentation? What makes ecological sense and what is economically efficient?

The findings are sometimes surprising. The **Eco-Efficiency Analysis** developed by BASF is a tool for assessing products and processes on a comprehensive and comparative basis.

BASF's Eco-Efficiency Analysis is based on ISO 14040 and 14044 for ecological evaluations. BASF's method for Eco-Efficiency Analysis is certified by the German Association for Technical Inspection (TÜV) and by the NSF.

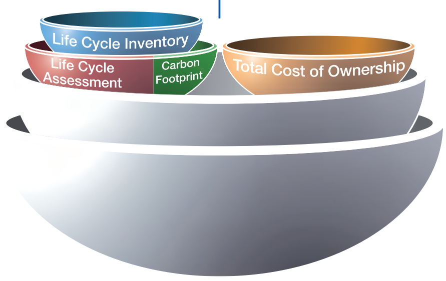


Holistic calculation along the whole life cycle.

Life Cycle Inventory, Life Cycle Assessment, Carbon Footprint, Environmental Product Declaration, Total Cost of Ownership

A **Life Cycle Inventory** is an inventory of all relevant emissions, material and energy flows (inputs and outputs) along the life cycle of a product.

A **Life Cycle Assessment** encompasses the effects on the environment on the basis of the life cycle inventory. This is used to calculate the effects on the environment along the complete life cycle (production, use and disposal). The standards series ISO 14040 and 14044 gives general rules for conducting Life Cycle Assessments. Life Cycle Inventories and Life Cycle Assessments form the basis of every Eco-Efficiency Analysis.



A **CO_2-balance** or **Carbon Footprint** is part of the Life Cycle Assessment of a product and is an assessment of the product's global warming potential. Carbon Footprints can be compiled not only for products or processes but also for complete companies. Based on Life Cycle Assessments of numerous products and processes the BASF CO_2-balance was the first company-wide CO_2-balance published.

The results of a Life Cycle Assessment of a product can be outlined in an **Environmental Product Declaration (EPD).** The main purpose of an environmental declaration is to provide easily accessible quality-assured data on the environmental impact of a product or process. This public document is an environmental declaration (type III) according to ISO 14025.

The **Total Cost of Ownership (TCO)** is a cost calculation that not only includes costs of purchase but also all aspects of subsequent use of the products under consideration (for example: energy costs, maintenance, environmental protection cost). Thus the cost drivers can be determined.

Eco-Efficiency Analysis

*Literature:

WBCSD Congresses in Antwerp, November 1993, March 1995 and Washington, November 1995, WBCSD publications 1996.

A. Kicherer, S. Schaltegger, H. Tschochohei, B. Ferreira Pozo, Int J LCA 12 (7) 537 (2007)

P. Saling et al, Int J LCA 7 (4) 203 (2002)

R. Landsiedel, P. Saling, Int J LCA 7 (5) 261 (2002)

BASF, along with Roland Berger Strategy Consultants and other partners, developed the **Eco Efficiency Analysis***, to assess the sustainability of products and processes. Over 450 analyses have been carried out: internally for BASF business units but also for external partners and customers.
The analysis is a comparative method that assesses alternatives using a Life Cycle Assessment approach with the whole life cycle of a product or process in a holistic manner. This includes the environmental impact of the raw materials extraction, the use of the product by customers or end consumers as well as options for recycling and disposal. In addition to the categories energy and resource consumption, wastes, air and water emissions, the method incorporates the human toxicity/eco-toxicity potential and risk potential. Furthermore, water use and land use associated with the life cycle of a product are assessed as well.

Application of Eco-Efficiency Analysis

Eco-Efficiency-Analysis has become a standard tool within the BASF Group, used in the following areas:

STRATEGY
Assisting strategic decision-making (location of a new production site, investment)

RESEARCH AND DEVELOPMENT
Facilitating the identification of product and process improvements

MARKETING
Enhancing product differentiation and improving customer retention

PUBLIC RELATIONS
Supporting dialogue with opinion makers, NGOs and politicians

Eco-Efficiency Label

BASF has developed a label to mark eco-efficient products. The requirements for using this label are:

- A completed Eco-Efficiency Analysis according to BASF's methodology
- Presentation of a third party evaluation (so-called Peer Review)
- Publication of the results on the internet

All products with an Eco-Efficiency Label can be found under: ***www.oeea.de***.

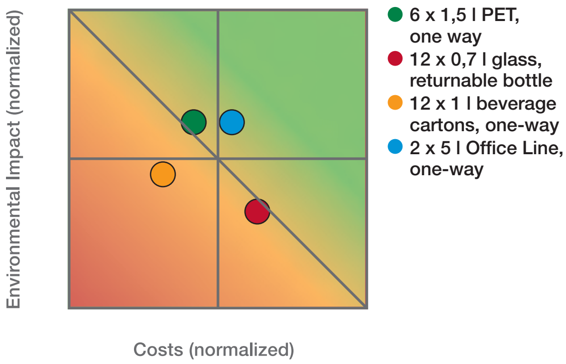
Example

Case Study Mineral Water Packaging

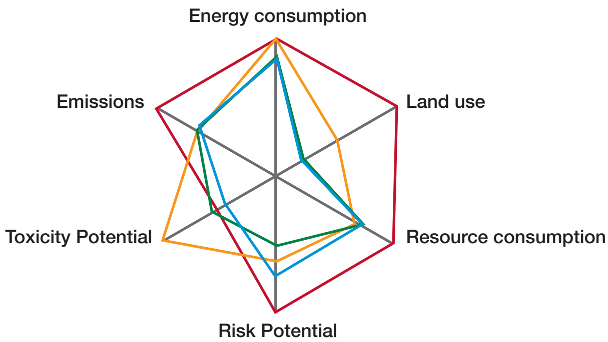
An Eco-Efficiency Analysis conducted by BASF on behalf of the Gerolsteiner Group compared alternative forms of mineral water packaging. This revealed the following surprising findings:

- Although reusable glass bottles are cheapest to produce, distribute and sell, when viewed over the whole life cycle they have the greatest impact on the environment.
- Beverage cartons are the most expensive alternative.
- The most eco-efficient alternative is the 5 l Office Line – it is far more eco-friendly than beverage cartons or the reusable glass bottle and only slightly more expensive than the glass bottle.
- The PET one-way bottle has a comparable Eco-Efficiency to the glass bottle.

Eco-Efficiency Portfolio



Ecological Fingerprint



Eco-Efficiency Internet-Manager

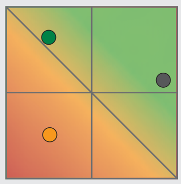
The Eco-Efficiency Internet-Manager is a useful tool when products or production process inputs are varied regularly (to meet the requirements of different customers, for example). Prerequisite is a completed Eco-Efficiency Analysis. A new Eco-Efficiency Portfolio is calculated as often as required simply by entering new parameters. Thus one Eco- Efficiency Analysis can cover a whole family of related products. It can answer different questions based on the existing models by scenario analyses.

Eco-Efficiency Internet-Manager

Simulation Mineral Water Packaging

1) Choice of Alternatives

PET one-way bottle	x
PET returnable bottle	x
Glass bottle	
Beverage cartons	x
Office Line	



Quantity mineral water 1.000 liter

2) Input PET one-way bottle

			material
Bottle content	1	liter	
Bottle weight	20	g	PET
Cap weight	5	g	PP
Label weight	1	g	paper

Example

SEEBALANCE®

■ **SEEBALANCE®** refers to the **S**ocio**E**co-**E**fficiency-Analysis developed by BASF**. It is an innovative tool which not only provides an assessment of the environmental impact and costs of products and processes, but also of the societal impact. The aim is to unify and quantify the performance of all three pillars of sustainability with one integrated tool for product or process assessment. The societal impact is represented by several evaluation categories. Assessed are a set of indicators considering the whole life cycle.

This method was developed in collaboration with the Öko-Institut Freiburg and the Universities of Jena and Karlsruhe as part of a project of the German ministry of research and education.

**Literature:

D. Kölsch, P. Saling, A. Kicherer, A. Grosse-Sommer, I. Schmidt (2007): How to Measure Social Impacts? What is the SEEBALANCE® about? – Socio-Eco-Efficiency Analysis: The Method. In: International Journal of Sustainable Development Vol. II, No. 1, 2008.

www.basf.com/group/corporate/de/sustainability/eco-efficiency-analysis/seebalance

SEEBALANCE® Methodology

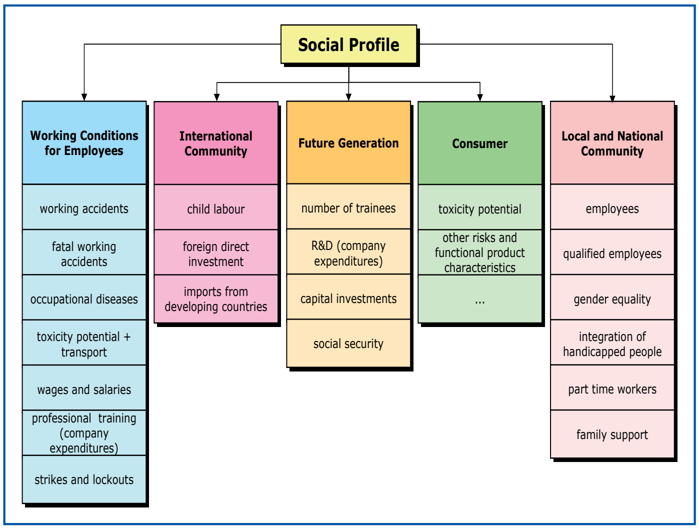
The societal impacts of the SEEBALANCE® are grouped into five stakeholder categories:

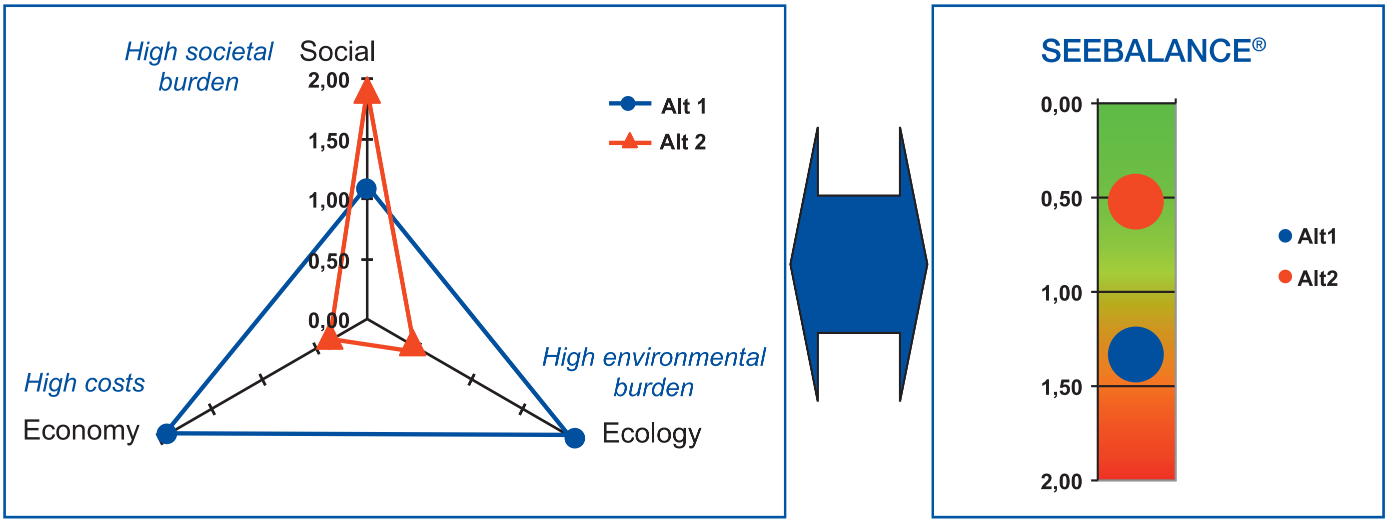
- **employees**,
- **international community**,
- **future generations**,
- **consumers**,
- **local & national community**.

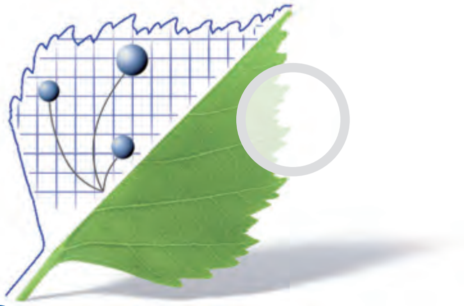
For each of these stakeholder categories measurable indicators are considered. Indicators for these categories include among others the number of employees, occupational diseases occurring during production but also risks involved product use by the end consumer. The societal indicators, analogous to the environmental ones, are summarized in a social impact score.

Inclusion of the additional (societal) axis results in the triangle graph that also can be summarized in a single overall result. It can be shown clearly which alternative is the most sustainable solution for a defined application. All three dimensions of sustainability are considered in this analytical approach.

The aim of the visualization is to summarize the complex numbers into a form that is easily understood by decision makers and stakeholders in the areas of marketing, R&D, strategy and politics. Results can be used to find weaknesses, show market opportunities, support strategic decision-making as well as effective communication. Scenarios can show the different effects of the input factors on the results. This flexible tool supports the improvement of product solutions in a very effective manner.







Overview

Our assessment methods and tools are: Eco-Efficiency Analysis, Eco-Efficiency Internet-Manager, Labels, SEEBALANCE®, Life Cycle Inventory, Life Cycle Assessment, Total Cost of Ownership, Environmental Product Declaration, Carbon Footprint, Sustainability Evaluation and Sustainability Consulting.

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Stacking Ecosystem Services Payments: Risks and Solutions

by David Cooley and Lydia Olander

David Cooley is an Associate for Project Development at the Duke Carbon Offsets Initiative at Duke University. He has also worked as a researcher at the Nicholas Institute for Environmental Policy Solutions at Duke University. Lydia Olander is the Director of the Ecosystem Services Program at the Nicholas Institute for Environmental Policy Solutions at Duke University. She leads the National Ecosystem Services Partnership.

Summary

Healthy ecosystems provide many services to society, including water filtration, biodiversity habitat protection, and carbon sequestration. A number of incentive programs and markets have arisen to pay landowners for these services, raising questions about how landowners can receive multiple payments for the ecosystem services they provide from the same parcel, a practice known as stacking. Stacking can provide multiple revenue streams for landowners and encourage them to manage their lands for multiple ecosystem services. However, if not well-managed, it may also lead to a net loss of services.

Healthy ecosystems provide many services to society, including water filtration, biodiversity habitat protection, and carbon sequestration.[1] Payments and markets for ecosystem goods and services are on the rise around the globe.[2] They hold the potential to promote sustainable resource use and to provide a stream of revenue to landowners that encourages conservation and improves land management decisions. In theory, payments for ecosystem service provision can make standing trees more valuable than cut trees and farms more valuable than suburban sprawl.[3]

A variety of environmental laws, government programs, and voluntary commitments have led to a wide variety of payments and markets for ecosystem goods and services.[4] As these payments and markets have begun to demonstrate success,[5] landowners and land managers have taken note—and begun to ask whether they can receive multiple ecosystem service payments for services generated on a single land parcel, a practice known as *stacking*. Stacking can be thought of as selling different products from a single activity, like selling both the wool and the meat from a sheep. However, ecosystem services often differ from simple com-

Authors' Note: The authors contributed equally to the development and writing of this Article. The authors would like to recognize significant contributions from the Duke University Ecosystem Services Working Group, in particular the faculty members who guided our work and who were essential in developing the ideas we put forth: Brian Murray, Alex Pfaff, Jeff Vincent, Jim Salzman, and Martin Doyle. We would also like to thank Rich Woodward, J.B. Ruhl, Al Todd, Bill Hohenstein, and Derik Broekhoff for their helpful reviews of this Article. We also thank Karen Bennett for her work on an earlier version.

1. For a description of various ecosystem services, see Gretchen Daily, Nature's Services: Societal Dependence on Natural Ecosystems (1997). *See also* Kai M. Chan et al., *Conservation Planning for Ecosystem Services*, 4 PLoS Biology 2138 (2006), and Elena M. Bennett et al., *Understanding Relationships Among Multiple Ecosystem Services*, 12 Ecology Letters 1394 (2009).
2. Ecosystem goods and services are ecological processes, products, and qualities that directly or indirectly improve human welfare, for example, by cleaning air and water, protecting biological diversity, and regulating nutrients and hydrologic flows. In this Article, the authors differentiate ecosystem services markets and programs from environmental markets, defining ecosystem services programs to be those programs that pay for goods and services provided by landscapes and ecosystems, rather than those generated by facilities or point sources.
3. In addition to payments for ecosystem services, information about the value of the services can affect policy and business decisions to protect or enhance them.
4. See *infra* Section I, for a more thorough description of specific ecosystem service markets and payment programs.
5. *See, e.g.*, Tara O'Shea & Lydia Olander, *Finding Successful Ecosystem Service Projects and Programs in the United States*, Nicholas Institute (2011), and D. Evan Mercer et al., *Taking Stock: Payments for Forest Ecosystem Services in the United States*, Forest Trends' Ecosystem Marketplace and U.S. Forest Service (2011). The latter shows that payments to landowners for ecosystem services from forests in the United States equaled almost $1.9 billion in 2007.

modities, in that the value of the ecosystem products (services) is tied to a regulatory requirement to offset damages or measures to prove environmental performance. Hence, where required, landowners must ensure that all environmental damages are sufficiently mitigated or performance metrics met if they are to be paid.

Stacking payments could have a number of positive outcomes. First, it could be a means to support management of multiple services by using a range of programs that each focus on the protection of single resources (for example, water quality or biodiversity). Paying for protection of multiple resources could push landowners to manage for all the ecosystem services their lands provide.[6]

Second, stacking could spur participation in ecosystem services programs, potentially increasing ecosystem service provision. A single market or payment program may not pay landowners enough to make projects cost-effective.[7] But multiple programs providing multiple payment streams could cover landowners' opportunity costs.

Third, stacking could encourage landowners to develop higher quality projects, such as restoring a wetland for water quality benefits, instead of simply planting a vegetative buffer. Higher quality projects might not be cost-effective with a single payment stream. Again, multiple payment streams may be the solution.

Stacking is not without its critics, however. Ecosystem services payments that come from the sale of offsets or mitigation credits allow environmental impacts. Thus, offset and mitigation projects must ensure that the ecosystem services they provide are sufficient to fully mitigate all the impacts they allow. Stacking multiple credits can complicate this accounting.

Another concern, particularly for those involved with carbon or greenhouse gas (GHG) offsets markets, is that stacking could result in payments to landowners that are beyond those needed to initiate the given ecosystem services project.[8] Most GHG or carbon offset programs include an "additionality" criterion that requires any payment or credit received to be associated with an increment of additional services that would not have been supplied without the payment. This is required so that the program generates new GHG emissions reductions to offset emissions by other entities.

Even for programs that do not involve offsets, giving a second payment to a landowner who requires only one payment to proceed with a conservation action can be problematic. If programs have scarce resources, they may seek assurance that they will get the greatest environmental benefit from the resources they spend. These programmatic requirements for additionality and cost-effectiveness could limit the potential for landowners to be paid for all the services they provide, but not all programs and sources of finance will be thus constrained.

Ecosystem services markets face several other challenges, including measurement of service provision, spatial redistribution of services,[9] and trade offs in which an increase in one service decreases provision of another service.[10] These challenges arise even in single-service transactions, and stacking itself does not necessarily have a positive or negative effect on them. This Article focuses on issues directly affected by or caused by stacking.

A somewhat sparse but helpful literature is developing on the topic of stacking. The World Resources Institute has a fact sheet on the additionality concerns of credit stacking.[11] Jessica Fox laid out some of the basic concepts in an earlier article,[12] and she and others conducted a survey of ecosystem service practitioners on the state of credit stacking in the United States.[13] J.B. Ruhl wrote an overview of some of the legal and policy issues with stacking.[14] Richard Woodward published a paper on the economics of stacking multiple ecosystem payments.[15] In addition, the firm Kieser and Associates issued a concept paper on selling mul-

6. Many articles in the scientific literature demonstrate that managing for one ecosystem service does not necessarily result in increased provision of other services. *See, e.g.*, Bennett et al., *supra* note 1, and Benis Egoh et al., *Mapping Ecosystem Services for Planning and Management*, 127 Agric., Ecosystems & Env't 135 (2008). *See also* Daniel F. Morris, *Ecosystem Service Stacking: Can Money Grow on Trees?*, Resources for the Future, Weathervane blog, http://www.rff.org/wv/archive/2009/08/03/ecosystem-service-stacking-can-money-grow-on-trees.aspx, and Defenders of Wildlife, *Bundling and Stacking Ecosystem Service Credits*, http://www.defenders.org/programs_and_policy/biodiversity_partners/ecosystem_marketplace/mfn/bundling_and_stacking.php.
7. Nicholas Bianco, *Stacking Payments for Ecosystem Services*, World Resources Institute Fact Sheet 2 (2009), *available at* http://pdf.wri.org/factsheets/factsheet_stacking_payments_for_ecosystem_services.pdf.
8. This phenomenon is sometimes described as financial additionality in carbon offset protocols.
9. *See, e.g.*, J.B. Ruhl & James Salzman, *The Effects of Wetland Mitigation Banking on People*, 28 Nat'l Wetlands Newsl. 1, 8-13 (Mar./Apr. 2006) (demonstrating that wetland mitigation banks redistribute ecosystem services from urban to rural areas).
10. *See, e.g.,* Robert B. Jackson et al., *Trading Water for Carbon With Biological Carbon Sequestration*, 310 Sci. 1944, 1944 (2005) (finding that planting trees for carbon sequestration can reduce available water quantity, decreasing stream flow in some cases).
11. Bianco, *supra* note 7.
12. Jessica Fox, *Getting Two for One: Opportunities and Challenges in Credit Stacking, in* Conservation and Biodiversity Banking: A Guide to Setting up and Running Biodiversity Credit Trading Systems (Routledge 2007).
13. Jessica Fox et al., *Stacking Opportunities and Risks in Environmental Credit Markets*, 41 ELR 10121 (Feb. 2011).
14. J.B. Ruhl, *Stacking and Bundling and Bears, Oh My!*, 32 Nat'l Wetlands Newsl. 24-25 (Jan./Feb. 2010).
15. Richard Woodward, *Double Dipping in Environmental Markets*, 61 J. Envt'l Econ. & Mgmt. 153-69 (2011).

tiple ecosystem services.[16] Suzie Greenhalgh also wrote a paper on the related topic of bundling.[17]

However, these contributions have not lessened confusion about how policies and regulations should address stacking. While policymakers, researchers, and practitioners debate what constitutes stacking and whether it should be encouraged or discouraged, project developers and landowners are left to wonder about the validity of current projects and the potential to participate in future ecosystem programs.

I. U.S. Policies Governing Stacking of Ecosystem Services Markets and Payment Programs

Stacking of ecosystem service markets and payments has only become an issue because landowners are beginning to have opportunities to receive multiple payments for the ecosystem services they provide. Ecosystem service markets and payment programs can be roughly divided into two categories: (1) offsets and mitigation credits, which allow other entities to impact the environment; and (2) conservation payments and incentives, which are designed to promote conservation or improved ecosystem management. In each case, the entity making the payment can be the government, a private entity, or a nonprofit organization.

A. *Offsets and Mitigation Credits*

In the United States, different agencies oversee different pollutant loads or management actions on the same ecosystems. In addition, different laws, such as the Clean Water Act (CWA)[18] and the Endangered Species Act (ESA),[19] protect specific aspects of environmental quality. Regulated entities have the option to comply with these laws by offsetting or mitigating their environmental impacts through payments for ecosystem services. The laws have driven development of different markets with different types of credit for ecosystem services. Some of the credits represent individual ecosystem services, such as water quality protection, whereas others—so-called bundled credits—represent all the services provided by a particular ecosystem. Some credits are designed to offset impacts from a point source, such as a facility smokestack or effluent pipe; others (bundled credits) are designed to mitigate ecosystem services impacts, such as damage to a stream. No matter the type of offsets or mitigation credit, landowners are paid to generate ecosystem services that are used to compensate for environmental damages that happen elsewhere.

Although federal agencies have issued guidance documents[20] concerning ecosystem services markets, they have promulgated few regulations that could clarify the potential for stacking.

Water quality credits are an optional tool for compliance with the CWA. The CWA regulates point source polluters, such as wastewater treatment plants or industrial facilities, through national pollutant discharge elimination system (NPDES) permits,[21] but many watersheds face significant water quality problems from nonpoint sources, such as agriculture, which are not regulated as point sources.[22] In watersheds where stringent regulation of point sources has been insufficient to achieve necessary water quality improvements, regulators would continue permitting point sources only under the condition that they pay for pollutant reductions from nonpoint sources. This type of water quality trading involves an entity with a regulatory compliance obligation and a landowner who does not have a compliance obligation but who voluntarily participates in the trade. For example, a facility with an NPDES permit could meet compliance in part by paying a farmer who does not have a compliance obligation to plant a forested riparian buffer to capture nitrogen flowing off her crop fields before it enters the waterway. In this way, nitrogen pollution from the facility is offset by the decrease in pollution by the farmer, and the overall amount of pollution in the waterway remains unchanged. Oregon's Tualatin Basin has an NPDES permit that includes nonpoint trading using vegetated buffers to shade streams and reduce water temperature. Most other water quality trading programs that allow nonpoint trading have been established to comply with more stringent state regulations for a variety of pollutants, including nitrogen and phosphorus.[23] However, many of these programs have had few trades, and several are funded through grants rather than by point sources, and thus are voluntary on both sides.[24] If nonpoint sources were covered by nutrient regulations, trading would be between two entities with regulatory compliance obligations. However, no water quality trading systems in the United States appear to have taken this approach.

Wetland and stream credits are used to achieve compliance with §404 of the CWA,[25] under which developers may impact a wetland or stream only if their impacts are offset through the restoration, creation, or enhancement of a

16. Kieser & Associates, Ecosystem Multiple Markets: A White Paper (2004), *available at* http://www.envtn.org/uploads/EMM_WHITE_PAPERApril04.pdf.
17. Suzie Greenhalgh, *Bundled Ecosystem Service Markets—Are They the Future?*, prepared for presentation at the American Agricultural Economics Association Annual Meeting, Orlando, Fla., July 27-29, 2008, *available at* http://ageconsearch.umn.edu/bitstream/6166/2/467628.pdf.
18. 33 U.S.C. §§1251-1387, ELR Stat. FWPCA §§101-607.
19. 16 U.S.C. §§1531-1544, ELR Stat. ESA §§2-18.
20. Unlike regulations, guidance documents do not carry the force of law.
21. National Pollution Discharge Elimination System. *See* 33 U.S.C. §1342 (2009).
22. 33 U.S.C. §502(14) (2009).
23. *See* U.S. Environmental Protection Agency (EPA), Water Quality Trading, List of All Trading Programs, *available at* http://water.epa.gov/type/watersheds/trading/upload/tradingprograminfo.xls.
24. For a discussion of legal and institutional barriers to implementing trades between point and nonpoint sources that make trading programs less market-like in practice than many researchers and policymakers suggest, see Kurt Stephenson & Leonard Shabman, *Rhetoric and Reality of Water Quality Trading and the Potential for Market-Like Reform*, 47 J. Am. Water Resources Ass'n 15-28 (2011).
25. 33 U.S.C. §1344 (2009).

wetland or stream elsewhere. Wetland and stream credits are a type of bundled credit, which is designed to offset a range of critical functions and services lost to the impacted wetland.[26] This mitigation program is one of the few ecosystem service programs governed by regulations, rather than guidance documents. According to those regulations, a mitigation project "should be located where it is most likely to successfully replace lost functions and services."[27] In practice, regulators typically identify a subset of ecosystem functions and services to assess for compliance. For example, the North Carolina Wetland Assessment Method (NC WAM) assesses three wetland functions: hydrology; water quality; and habitat.[28]

Endangered species habitat credits are used to achieve compliance with §10 of the ESA,[29] which allows landowners to impact endangered species habitat if they obtain a permit from the U.S. Fish and Wildlife Service (FWS) or the National Marine Fisheries Service (NMFS). The FWS has implemented this policy by allowing the establishment of conservation banks, which restore, create, or otherwise protect endangered species habitat.[30] Landowners who seek to impact endangered species habitat may purchase credits from conservation banks to offset their impacts. Like wetland credits, species or habitat credits are a type of bundled credit, because the credited habitat is expected to have all of the critical elements to support populations of the endangered species. Strictly speaking, conservation banking might not be considered an ecosystem services market, because the banks are intended to benefit endangered species and not necessarily to benefit humans.[31] However, these banks can be included in stacks of other, more human-oriented environmental markets and tend to provide a number of ecosystem services as co-benefits, and thus are relevant to this discussion.

Carbon offsets are ecosystem payments for actions that sequester or avoid emissions of carbon dioxide or other GHGs, which are not currently required by federal law.[32] However, two smaller regulatory programs in the United States (one state and one regional) place a cap on GHG emissions from some sources, and allow these capped entities to purchase carbon offsets from uncapped sources as an option for meeting compliance. Under A.B. 32,[33] California has developed a cap-and-trade program that allows a range of land management-based offsets, including forest management and avoided forest conversion,[34] and it is considering some activities involving improved agricultural management. Ten states in the Northeast and Mid-Atlantic have joined to form the Regional Greenhouse Gas Initiative (RGGI), which limits carbon emissions from the power sector and allows land management-based offsets, including afforestation and agricultural manure management.[35] In practice, however, offsets have not been an active part of the RGGI program, due in part to the low cost of obtaining allowances from other point sources.

Carbon offsets are also available in voluntary markets.[36] These markets support a wide range of activities that increase sequestration or avoid GHG emissions, such as tree planting, changes in livestock manure management, or changes in fertilizer use.[37] Voluntary markets for other ecosystem services have recently emerged. The American Forest Foundation and World Resources Institute have developed a crediting system for gopher tortoise habitat, which is not yet regulated under the ESA.[38] The Willamette Partnership in Oregon is developing credits for restoration of prairie habitat, which currently lacks a policy driver.[39] The Business and Biodiversity Offset Program is developing pilot projects, including one in the United States,[40] in which businesses offset their biodiversity impacts. The Bonneville Environmental Foundation has created a voluntary market for water restoration credits, providing incentives for water rights holders to leave water in water-scarce ecosystems.[41]

26. 33 C.F.R. §332.3(b)(1) (2010).
27. *Id.*
28. N.C. Dept. of Trans., Corps of Engineers, N.C. Dept. of Env't and Nat. Res., U.S. EPA, U.S. Fish and Wildlife Service, North Carolina Wetland Assessment Method User Manual (2010), *available at* http://portal.ncdenr.org/web/wq/swp/ws/pdu/ncwam [hereinafter NC WAM].
29. 16 U.S.C. §1539 (2009).
30. FWS, Guidance for the Establishment, Use, and Operation of Conservation Banks (2003) [hereinafter Guidance for Conservation Banks].
31. *See supra* note 3.
32. Several bills have been introduced in the U.S. Congress to address climate change, including the American Clean Energy and Security Act (H.R. 2454, 2009), the Clean Energy Jobs and American Power Act (S. 1733, 2009), and the American Power Act (discussion draft, 2010, *available at* http://kerry.senate.gov/imo/media/doc/APAbill3.pdf). Each of these bills would have placed a limit on GHG emissions, while allowing regulated entities to purchase offsets from land use and other activities.
33. Cal. Health & Safety Code §§38500 et seq. (2010).
34. California Environmental Protection Agency, Air Resources Board, Proposed Regulation to Implement the California Cap-and-Trade Program Part V: Staff Report and Compliance Offset Protocol: U.S. Forest Projects (2010), *available at* http://www.arb.ca.gov/regact/2010/capandtrade10/cappt5.pdf.
35. Regional Greenhouse Gas Initiative Model Rule 91 (2008).
36. Kate Hamilton et al., *Building Bridges: State of the Voluntary Carbon Markets 2010*, Ecosystem Marketplace (2010).
37. Details on the various offset types found in the voluntary markets can be found on the registry websites: Climate Action Reserve (CAR), http://www.climateactionreserve.org; Voluntary Carbon Standard (VCS), http://www.v-c-s.org; American Carbon Registry (ACR), http://www.americancarbonregistry.org. CAR offers voluntary credits in addition to compliance-grade credits for use in the California cap-and-trade program.
38. Willamette Partnership, Measuring Up: Synchronizing Biodiversity Measurement Systems for Markets and Other Incentive Programs 17 (2011), *available at* http://willamettepartnership.org/measuring-up/Measuring Up w appendices final.pdf.
39. Willamette Partnership, Upland Prairie Habitat, *available at* http://willamettepartnership.org/ecosystem-credit-accounting/prairie/copy_of_upland-prairie-habitat.
40. Business and Biodiversity Offset Program, http://bbop.forest-trends.org/.
41. Bonneville Environmental Foundation, http://www.b-e-f.org/business/products/wrcs/.

Table 1. Number of Ecosystem Markets and Projects in the United States

Ecosystem service market	Number of projects
Water quality trading	14 trading programs[a]
Wetland and stream mitigation banks	797 banks[b]
Endangered species/conservation banks	116 banks[c]
Carbon offsets	73 projects[d]

a. U.S. EPA, *State and Individual Trading Programs*, http://water.epa.gov/type/watersheds/trading/tradingmap.cfm. At least five of these "trading programs" appear to be one-time trades or deals. How many projects have been developed within the other programs is unknown.

b. Becca Madsen et al., State of Biodiversity Markets Report: Offset and Compensation Programs Worldwide 11 (2010), *available at* http://www.ecosystemmarketplace.com/documents/acrobat/sbdmr.pdf.

c. *Id*. at 18. This number includes 19 sold-out banks and 20 pending banks.

d. CAR, https://thereserve1.apx.com/myModule/rpt/myrpt.asp?r=111; The Climate Trust, http://climatetrust.org/sequestration.html; ACR, http://www.americancarbonregistry.org/carbon-registry/projects. The vast majority of these projects are from the CAR, and most of those (65) are listed, but not fully registered.

B. Conservation Payments and Incentives

The federal government and various state governments have developed numerous programs to incentivize conservation practices, including several programs authorized by the Farm Bill.[42] These conservation incentive programs include both land retirement programs, such as the Conservation Reserve Program (CRP),[43] through which land is taken out of agricultural production, and working lands programs, such as the Environmental Quality Incentives Program (EQIP),[44] which offers incentives for improved management practices on working farms and forests. The lands enrolled in these incentive programs provide a variety of ecosystem services, and may be eligible to participate in other ecosystem markets or payment programs.[45]

Some government incentives come not in the form of direct payments, but as loan guarantees, tax incentives, and other public financing options. A common tax incentive to promote conservation is the *conservation easement*. Under a conservation easement, a landowner retains ownership of his or her land but cedes certain rights to develop the land. In general, conservation easements are flexible instruments, and the details of allowed management can change from contract to contract. For example, most conservation easements preclude commercial or residential development, but some may allow agricultural use or periodic timber harvest.[46] Easements often do not explicitly outline who owns the ecosystem services generated by the eased land—the landowner or the easement holder. Easements are often held by land trusts or other conservation organizations that manage the lands for a landowner. Whether a landowner who has sold a conservation easement retains rights to sell ecosystem services remains unclear. Although conservation easements are a ceding of development rights, they are not necessarily a ceding of the right to sell ecosystem services. This issue will not be resolved for existing contracts until a court decision interprets the arrangement or statutory guidance is created. Nevertheless, new conservation easements can be written so as to clarify which party retains ownership of the ecosystem services generated by a project.[47]

Voluntary payments for biodiversity also exist. For example, the Nature Services Exchange, a project of the University of Rhode Island and EcoAsset Markets Inc., allowed people who valued grass-nesting bird species, such as the bobolink, to pay farmers to delay their hay harvests until after the nesting season.[48] In addition, Walmart has joined with the National Fish and Wildlife Foundation to create the Acres for America program, through which Walmart pledges to protect one acre of important habitat or open space for every acre occupied by Walmart's U.S. facilities.[49]

C. Stacking Policies

Existing policy contains little guidance on stacking of ecosystem service payments in U.S. programs. In the absence of such guidance, some suggest that stacking be viewed through the lens of property rights. Under traditional common law, owning real property comes with a series of rights, colloquially referred to as the "bundle of sticks." These rights include the right to exclude others from the land, to use the property as the owner wishes, and to give that property away whenever and to whomever the owner wishes. Owners also can harvest the natural resources of their land, as long as one use does not harm another. He or she can sell rights to mine on the land and can give another the right to grow crops on it or build windmills to harvest energy on it. Under this traditional property definition, a landowner's ability to stack ecosystem service credits would be unlimited, as long as the generation of one service does not harm other services. The rights to sell carbon sequestration, wetland acres, or water quality credits would be distinct, fundamental property rights of land ownership. Without any other policy, traditional property rights would be the underlying default legal position on stacking; stack-

42. The Food, Conservation, and Energy Act of 2008, Pub. L. No. 110-234 (2008).
43. 7 C.F.R. §§1410.1 et seq. (2010).
44. *Id.* §§1466.1 et seq. (2010).
45. *See infra* note 66 and accompanying text.
46. Land Trust Alliance, *Conservation Easements*, http://www.landtrustalliance.org/conservation/landowners/conservation-easements.
47. For a discussion of potential language to be inserted into conservation easements intended for carbon offsets projects, see James L. Olmstead, *Carbon Dieting: Latent Ancillary Rights to Carbon Offsets in Conservation Easements*, 29 J. Land, Resources & Envt'l L. 121-41 (2009).
48. Nature Services Exchange, http://www.natureservicesexchange.com/.
49. As of 2010, Walmart had committed $35 million, conserving 625,000 acres, http://walmartstores.com/Sustainability/5127.aspx (last visited Jan. 10, 2012). Other examples of voluntary biodiversity offsets include the Business and Biodiversity Offsets Program, which has a pilot project in which the city of Bainbridge Island, Washington, is protecting important habitat on the island to offset impacts from residential development, *available at* http://bbop.forest-trends.org/guidelines/low_bainbridge-case-study.pdf.

ing, whether beneficial or problematic, would be implicitly allowed in all cases. However, ecosystem services credits are not necessarily like other property rights. Although a landowner may have the right to sell them, some credits only have value because demand for them is driven by government regulations, which could contain various restrictions on rights.

Federal guidance on water quality trading programs is largely silent on the issue of stacking.[50] Regulations for wetland and stream mitigation banking[51] and guidelines for conservation banking[52] address the question of stacking with other ecosystem services payments largely indirectly. Wetland and stream banking regulations state that "where appropriate, compensatory mitigation projects . . . may be designed to holistically address requirements under multiple programs and authorities for the same activity."[53] This language appears to leave the door open to the possibility of stacking. In particular, the regulations state that "[c]ompensatory mitigation projects may also be used to provide compensatory mitigation under the Endangered Species Act."[54] However, both wetland and stream banking regulations[55] and guidelines for conservation banking[56] clearly disallow stacking mitigation credits on top of restoration projects that have already received funding from a federal payment program.

In terms of the carbon market, guidance and protocols from the voluntary carbon market, rules for the RGGI and the California program under the Climate Action Reserve (CAR), and the proposed federal program under the American Clean Energy and Security Act (ACES)[57] are all also silent on this issue. Only the proposed federal American Power Act (APA)[58] states that projects are not necessarily excluded from providing carbon offsets if they receive payments for providing other ecosystem services, including government conservation payments. However, it also instructs the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Agriculture (USDA) to develop procedures and guidelines for determining eligibility for such projects.[59] The carbon markets typically include rules for additionality to ensure that credited activities would not have occurred in the absence of the project, which may preclude stacking. For example, the CAR does not allow projects to generate credits if the land was covered by a conservation easement for more than one year before the start of the project.[60]

By contrast, regulations concerning almost all of the Farm Bill conservation incentive programs, including the CRP and the EQIP, expressly allow the sale of environmental credits from enrolled lands.[61] Each program has slightly different language, but in general, the regulations state:

> USDA recognizes that environmental benefits will be achieved and environmental credits may be gained [by landowners] by implementing conservation practices and activities funded through these payment programs. USDA asserts no direct or indirect interest in these credits. However, USDA retains the authority to ensure that the requirements of their program are met.

II. What Is Being Stacked and Different Forms of Stacking

A wide range of credits and payment types can be stacked, and they can be stacked in multiple ways. An understanding of these possibilities allows assessment of the interaction of the various programs and markets.

A. *Types of Stacked Credits*

As discussed above, ecosystem service markets and payment programs can be roughly divided into two categories: (1) offsets and mitigation credits; and (2) conservation payments and incentives (hereinafter PES, for payments for ecosystem services). Offsets and mitigation credits are distinct from one another, in that offsets are typically meant to offset emissions of a single pollutant, such as carbon dioxide emissions or discharge of nitrogen to a waterway, whereas mitigation typically refers to credits to offset impacts to whole ecosystems, such as wetland or endangered species habitat.

These types of credits and payments can be stacked in three ways:

- *PES with PES*, which would not directly allow any environmental impacts elsewhere and thus would have no negative effect on ecosystem services due to stacking;
- *PES with offsets or mitigation credits*; and
- *offsets or mitigation credits with other offsets or mitigation credits.*

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50. U.S. EPA, 2003 Water Quality Trading Policy, http://water.epa.gov/type/watersheds/trading/tradingpolicy.cfm (last visited Jan. 10, 2012).
51. 33 C.F.R. §§332.1 et seq. (2010).
52. Guidance for Conservation Banks, *supra* note 30.
53. 33 C.F.R. §332.3(j)(1)(ii) (2010).
54. *Id.* §332.3(j)(3) (2010).
55. *Id.* §332.3(j)(2) (2010).
56. Guidance for Conservation Banks, *supra* note 30, at 6. Conservation banks only partly funded by federal money can generate credits proportional to the nonfederal funds used to establish the bank. For example, a bank funded 50% by federal funds would only receive one-half of the credits that it would otherwise receive.
57. H.R. 2454 (2009).
58. *Available at* http://kerry.senate.gov/imo/media/doc/APAbill3.pdf.
59. American Power Act §735(f) (2010).
60. Climate Action Reserve, Forest Carbon Protocol Version 3.2, 12 (2010).
61. These programs include the CRP, 7 C.F.R. §1410.63(c)(6); the Grassland Reserve Program, 7 C.F.R. §1415.10(h); the EQIP, 7 C.F.R. §1466.36; the Wetlands Reserve Program, 7 C.F.R. §1467.20(b)(1); the Conservation Stewardship Program, 7 C.F.R. §1470.37; the Farm and Ranch Lands Protection Program, 7 C.F.R. §1491.21(g); and the Wildlife Habitat Incentives Program, 7 C.F.R. §363.21.

Offsets and mitigation credits can be further subdivided based on whether the credit seller or buyer is covered by government regulation:

- *Regulated-regulated* trades occur when a regulated entity sells emissions allowances that it does not need to another regulated entity. These trades could occur in a cap-and-trade system.
- *Regulated-voluntary* trades occur when a regulated entity offsets its emissions by paying for reductions by an unregulated (or voluntary) entity.
- *Voluntary-voluntary* trades occur when an unregulated entity voluntarily purchases offsets from another unregulated entity. Such trades occur in the voluntary carbon market.

The carbon market currently has several *voluntary-voluntary* projects. Efforts to regulate GHGs at the state or federal level could lead to *regulated-voluntary* projects if forests and other nonpoint sources are excluded from the cap or to *regulated-regulated* projects if they are included.

The water quality market has a few examples of *regulated-voluntary* trades, in which landowners voluntarily supply nutrient or temperature reductions to point sources, but much of the activity in this market has been *voluntary-voluntary* trades, because it has been funded by grants, rather than driven by regulation. *Regulated-regulated* water quality projects appear not to exist, because nonpoint sources typically do not have regulatory compliance obligations.

Wetland, stream, and species banking are generally *regulated-voluntary* trades, in which a landowner voluntarily supplies wetland, stream, or species credits to those that need them. Some efforts to credit *voluntary-voluntary* species credits are underway.

B. *Different Forms of Stacking*

1. Stacking

Stacking occurs when a landowner receives more than one payment from an ecosystem service market or payment program on a single property parcel. Stacking can take three forms:

Horizontal stacking occurs when a project performs more than one distinct management practice on non-spatially overlapping areas and the project participant receives a single payment for each practice. For example, a landowner plants trees and receives nutrient credits for the forested buffer along a stream and carbon credits for the trees in the upland part of the property. Because the credits are sold for spatially distinct parts of the same property, this practice may not be considered true stacking and can also be called credit grouping.

Vertical stacking occurs when a project participant receives multiple payments for a single management activity on spatially overlapping areas (that is, on the same acre). For example, a landowner plants a forested riparian buffer to receive both water quality credits and carbon credits. This type of stacking is comparable to the general definition of stacking used by Fox and her colleagues: "Establishing more than one credit type on spatially overlapping areas, *i.e.*, in the same acre,"[62] but that definition focuses only on stacking of credits from markets.

Temporal stacking is similar to vertical stacking, in that the project involves only one management activity, but payments are disbursed over time. For example, a landowner restores habitat to receive endangered species credits. Later, when a carbon market develops, the landowner receives carbon offset credits.

In any type of stacking, payments can include credits from ecosystem service markets, public financing, or other incentives. Of the three types of stacking described here, horizontal stacking is the least controversial, because each management activity is credited only once. Hence, this Article focuses primarily on issues associated with vertical and temporal stacking.

2. Bundling

Bundling occurs when a project participant receives a single payment for providing multiple ecosystem services. Generally, no attempt is made to add up the individual values of the ecosystem service to determine the payment levels. Wetland mitigation banking is an example of a bundled ecosystem service credit: a single payment is made for provision of multiple ecosystem services, including water quality improvements, biodiversity habitat, and hydrologic functioning, but the price of the credit is not necessarily based on the value of the individual services. Conservation easements are another example of a bundled credit in which the purchaser protects all of the ecosystem services on the parcel with a single payment. Bundled credits in the United States have been developed to mitigate or offset full ecosystem impacts, like loss of a wetland or endangered species habitat. They are measured in units that encompass the services—acres of wetland, for example—but they do not necessarily measure all the services directly.

These different types of credits (PES versus offsets or mitigation credits, regulated versus voluntary, single-service credits versus bundles) can be stacked in many different ways (see Table 2 and Appendix). In the section below, we explore the risks inherent in various combinations of stacking for ecosystem services outcome.

62. Fox et al., *supra* note 13.

III. A Conceptual Framework for Assessing the Ecosystem Services Outcomes of Stacking

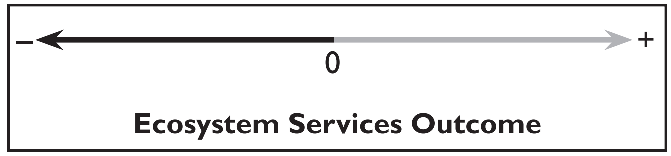
Given the general lack of law and policy to address stacking and growing concern and confusion about the subject, this Article presents a simple conceptual framework to assess the ecosystem service outcomes of this practice. The framework is constructed to assess the primary objective of ecosystem service markets and payment programs: replacement or enhancement of ecosystem goods and services. The goal is to find common ground in distinguishing the types of stacking that offer few or no problems in achieving this objective from those that are more problematic. The hope is that the framework will help policymakers and program managers design more effective policies.

In vertical and temporal stacking, where offset and mitigation programs are part of the stack, negative ecosystem services outcomes are possible, because credit purchasers are allowed to impact the environment.

Stacked projects must fully account for and mitigate the environmental impacts allowed by the sale of credits. Figure 1 presents an axis of net ecosystem services outcomes. Where a stacked project falls along this axis is determined by the following equation:

A stacked project in which the (negative) impacts allowed are greater than the services provided will produce a net negative outcome, and it will fall in the area toward the left of the axis. A stacked project that provides services sufficient to offset all impacts would fall in the middle at the zero point, and a stacked project that provides more than enough services to offset impacts would be positive, falling in the area to the right side of the axis.[63] In theory, most ecosystem services markets aim to replace ecosystem services lost to environmental impacts, which would place them at the zero point; however, with conservative crediting and trading ratios, transactions could lead to a net gain of ecosystem services, pushing a project—and a stack of which it is a part—to the right side of the axis.

Figure 1. Ecosystem Services Outcome Axis



Stacking ecosystems service credits can complicate the task of accounting, making it more difficult to ensure that all damages have been fully mitigated, especially because ecosystem services are not always fully separable. The framework presented here could be used as an accounting framework for bilateral trades in which environmental impacts and mitigation activities are connected, allowing regulators or project developers to track which impact each credit was intended to mitigate or offset. For example, if a project developer restores a coastal wetland and sells the resulting wetland mitigation credits directly to a party impacting a wetland, the project developer could potentially determine whether his or her wetland project provided "extra" ecosystem services,[64] such as GHG sequestration beyond that necessary to offset GHG emissions from the impacted wetland. These extra services could potentially be credited. Most bundled credits, such as wetland credits, are used in bilateral trades, so it could be possible to use the direct accounting presented here, given sufficient metrics and data. However, this accounting is not easy to implement, even for single-credit transactions, given ecological complexity, interconnected functions, and scientific uncertainty about the ecosystem service provision resulting from different management or restoration activities.[65]

In a market-based system, however, credits are supposed to be fungible, and when they are traded, ownership is independent of the project that generated them. Credits trading in units, such as tons of GHG equivalents or pounds of nitrogen, can exchange freely. Thus, directly linking impacts at one site to mitigation at another would not be possible. However, this accounting framework can still help policymakers understand when and why the ecosystem services outcomes of stacking can be negative.

A. *Where Stacking Might Be a Problem*

Two circumstances could lead to a negative ecosystem services outcome as a result of stacking. One is double counting, whereby one ecosystem service is sold twice to offset two separate impacts. The other, identified by the carbon markets, is lack of additionality, whereby projects would have occurred without the credit payment (landowners

63. An important implicit assumption of evaluating different ecosystem services on one axis is that they can be measured in the same units. If all the stacked services offset all the allowed impacts, this assumption does not pose much of a problem. However, some projects could result, for example, in a net positive gain for one service, such as carbon sequestration, and a net loss for another service, such as endangered species habitat. Using the equation above, the net gain in carbon sequestration could potentially be used to compensate for the habitat loss. Perhaps the most straightforward way to address this situation is to require that each service in a stacked transaction completely offset each impact it allows. However, policymakers could choose to take a more nuanced approach by establishing weights for each service on the basis of stakeholder preferences, which could be used to evaluate trade offs among services in a stacked transaction. Therefore, a net gain in carbon sequestration could potentially compensate for habitat loss, if the preference for carbon sequestration is weighted heavily enough.

64. In this example, the wetland project is assumed to follow the intent of the regulations to replace all services, and thus the GHG impacts would be included. Hence, "extra" implies GHG benefits beyond those needed to replace lost services.

65. *See, e.g.*, Charles Abdalla et al., *Water Quality Credit Trading and Agriculture: Recognizing the Challenges and Policy Issues Ahead*, 22 Choices 117, 120 (2007); Shelley Burgin, *"Mitigation Banks" for Wetland Conservation: A Major Success or an Unmitigated Disaster?*, 18 Wetlands Ecology & Mgmt. 49 (2010).

would utilize the payment from the other stacked credits), and thus do not generate additional benefits to offset the impacts (which are point source emissions, in the case of carbon markets).

1. Double Counting

Double counting occurs when stacked credits include redundant services. This situation is most likely to occur when bundles of services overlap with another single-service credit or another bundle. One example is wetland mitigation credits and water quality credits. The wetland bundle would include the water quality services provided by the wetland. If a wetland mitigation project sells the bundled wetland credits to one buyer for a wetland impact and the single water quality credits to a different point source buyer for the water quality impact (Figure 2), only one supply of water quality services would cover two impacts on water quality, resulting in a net negative ecosystem service outcome using the framework presented here.

Figure 2. An Example of a Negative Ecosystem Services Outcome Due to Double Counting

Mitigation		Impact	
(Wetland: WQ, HF, BD, GHGs)	–	(Wetland: WQ, HF, BD, GHGs Point Source: WQ)	= -WQ

Note: Impacts on the wetland will have effects on several ecosystem services, including water quality (WQ), hydrologic functioning (HF), biodiversity (BD), and GHGs. Because the mitigation site sells its WQ benefits twice—to offset both the affected wetland and the point source impacts—a net loss of water quality occurs.

At least one real-world example of this type of stacking problem exists. In 2000, a company[66] developed a project in eastern North Carolina to sell wetland and stream credits to the N.C. Department of Transportation to offset impacts to wetlands and streams from road building projects. In 2009, this company sold water quality credits from the same project—without performing any additional management activities—to the N.C. Department of Environment and Natural Resources to offset nitrogen impacts to the Neuse River Basin.[67] At the time, the state had no regulations governing this type of credit stacking. According to local experts, if all other existing, already-sold mitigation sites were allowed to stack nitrogen credits, the market could be flooded with 1.1 million pounds of nitrogen credits, exceeding all credits generated since the program began in 2001.[68] The state has not allowed additional trades of this sort and has since developed a proposed rule that would completely disallow stacking of nutrient offset credits or buffer credits from projects that provide wetland credits.[69]

To address the risks of double counting, programs and policies could consider additional environmental review when credits are stacked, limiting projects to horizontal stacking (like the Willamette approach),[70] or perhaps even restricting stacking of bundles with other credits. Regulations and guidance must be clear about what credits are and are not included in bundles. Given that bundled credits tend to be part of bilateral trades, policymakers may be able to assess ecosystem services outcomes on a project-by-project basis to determine if extra services can be sold.

2. Additionality

For programs and markets focused on carbon or GHGs, additionality has been a key criterion for project eligibility. The purpose is to ensure that carbon offsets are generated only from activities that would not have occurred in the absence of a payment.[71] For carbon credits to be considered real and to compensate for point source emissions, they must go beyond business as usual (or an established baseline)—beyond what would have happened anyway. For GHG programs—in both regulatory and voluntary markets—additionality is the primary concern related to stacking.[72] Additionality has not been a fundamental tenant of other ecosystem service programs, but it may be an important consideration.

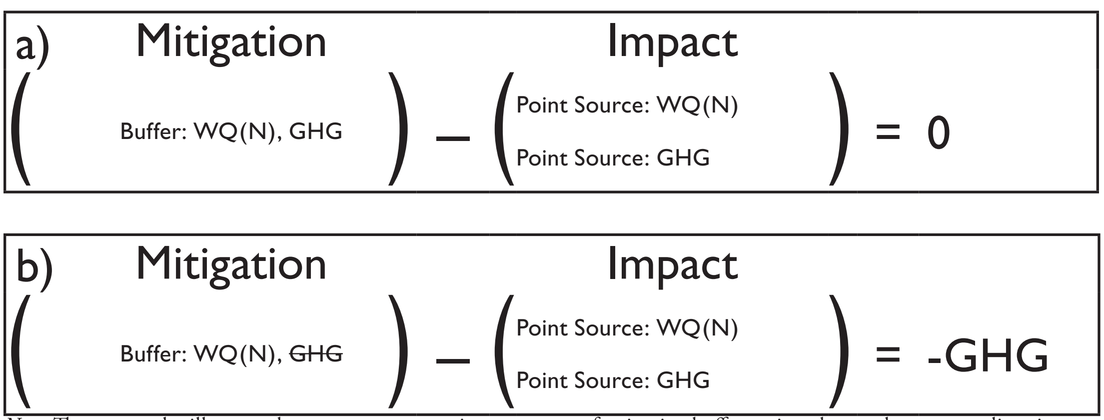
Additionality is often tied to two related objectives: one for individual projects and credits; and the other for programs as a whole. The first objective is to ensure that *offsets* are a real and additional enhancement in ecosystem services to compensate for the allowed environmental impact; this environmental objective has economic consequences because paying for nonadditional projects is inefficient. The second objective is to increase the cost-effectiveness of *programs*. If programs pay only for activities that are additional (that would not have occurred otherwise), they save money; this economic objective has environmental consequences because the saved money can be used to finance even more environmental benefits. The conceptual framework proposed in this Article is based on environmental

66. Environmental Bank and Exchange (EBX).
67. Dan Kane, *EBX Is Paid Twice for Wetlands Work*, News & Observer (Dec. 8, 2009).
68. Martin Doyle & Todd BenDor, *Stream Restoration: Who Really Benefits?*, News & Observer (Dec. 16, 2009).
69. 15A N.C.A.C. 02B.0295, *available at* http://portal.ncdenr.org/c/document_library/get_file?p_l_id=1169848&folderId=1727035&name=DLFE-26311.pdf.
70. *See infra* notes 96 and 97 and accompanying text.
71. *See, e.g.*, Mark Trexler et al., *A Statistically-Driven Approach to Offset-Based GHG Additionality Determinations: What Can We Learn?*, 6 Sustainable Dev. L. & Pol'y 30, 31 (2006).
72. *See* Bianco, *supra* note 7.

outcomes, and thus these outcomes are the primary objective of additionality in this assessment of stacking. The economic objectives and consequences for programs are discussed below.

For an example of how additionality affects the net ecosystem services outcome, consider a project that creates a stream buffer that will reduce nitrogen loading for a water quality benefit and sequester carbon. In the context of the environmental axis and without consideration of the additionality criterion, the accounting framework in this report shows that all impacts are offset with a net ecosystem services outcome of zero (Figure 3a). However, if the water quality program provides sufficient payment for the project to move forward on its own, the project did not need a carbon payment. The carbon payment would not generate *additional* carbon storage to offset the *additional* GHGs emitted, so GHGs would be released into the atmosphere that would not be offset, resulting in a net negative ecosystem services outcome (Figure 3b). If the project generated additional carbon storage that would not have been generated by the activity associated with the water quality credit—for example, tree planting that was not required for the landowner to receive the water quality payment—horizontal stacking is occurring. As noted above, such stacking does not pose additionality concerns.

Figure 3. Two Examples of Ecosystem Services Outcomes: One (a) That Does Not Take Additionality Into Consideration and One (b) That Does.



Note: These examples illustrate the net ecosystem services outcomes of a riparian buffer project that stacks water quality nitrogen (WQ(N)) and GHG credits and in which one payment is sufficient to pay for the project.

Resolving the additionality issue requires knowledge of what would have happened in the absence of the program or market and therefore is theoretically impossible. However, it can be somewhat addressed in practice. Determining when a specified activity is not occurring under current economic conditions and is therefore unambiguously additional is easy. It is also possible to identify activities that are being implemented and will need to be assessed for additionality using a variety of imperfect tools and tests.

Many tests can be used to help programs distinguish likely nonadditional projects.[73] One test is a timing test. If an already-implemented project applies for carbon credits, it probably did not need the extra funding, so it would not be considered eligible. If such a project was created with funding from one type of credit, it would not be eligible for carbon credits too (a case of temporal stacking). Another relevant test is a financial additionality test, which requires determining whether a project needs a payment to be financially viable. If a project is eligible for two ecosystem service markets or payments, and one payment is sufficient to pay the full costs of the project, it would fail this additionality test. If, however, neither payment alone provided sufficient funding, additionality would not be an issue, and stacking would be allowed.

Programs may use a timing test to exclude projects outright if they are already established and receiving a payment or credit stream. But given that costs and payments can change over time, it may make sense to use timing as a preliminary screen, but not as a final test to exclude projects. Programs differ in how they apply financial additionality; some use a project-specific test of financial barriers, whereas others use standardized tests of common practice to infer financial additionality. Project-specific tests have been viewed as subjective and complicated and slow to verify; standardized tests are considered more objective, transparent, and simple to apply, but limiting to participation.[74] Under a project-specific approach, a project would have to show that payments for other environmental services were not sufficient to initiate and maintain the project by themselves. Under a standardized approach, a program would develop criteria based on trends in existing markets or programs. Ideally, the program would have data on relative adoption rates for each relevant practice, in different regions, and for different systems over time to parse out a "propensity score" to use as a threshold or to set a crediting value. Often, data are insufficient. In these cases, estimates of average costs for a particular project type (practice) must be used in lieu of expected credit value to assess whether multiple payments are needed. When performance standards are generated without sufficient data, nonadditional projects are more likely to be allowed, and good additional projects to be left out. If a program declares one payment

73. *See generally* Trexler et al., *supra* note 71.

74. Derik Broekhoff, *Expanding Global Emissions Trading: Prospects for Standardized Carbon Offset Crediting*, International Emissions Trading Ass'n (2007).

sufficient to cover costs, projects must give up rights to sell the other credit types if they want to participate, basically creating a bundle out of the co-benefits from the project.

Everyone recognizes the imperfections of offsets markets and additionality, and many continue to work toward improved approaches. Changing circumstances alter business as usual over time, which shifts whether projects need multiple payments, and thus what is really additional. This reality is particularly problematic for investors who want to know whether they can stack additional payments to meet projected project costs. Given the complexities of addressing additionality in program implementation, programs may choose to explore different policy approaches, including trading ratios and discounting or systemwide adjustments, but these approaches introduce different complexities and create different winners and losers in the system.[75]

If the criterion of additionality is not applied, and many landowners are paid for projects that do not achieve additional benefits, more projects will be necessary to meet any set target or objective. In this case, one alternative policy option is a trading ratio, whereby, for example, two or more tons of carbon or pounds of nitrogen reduced are required for every one ton or pound of carbon or nitrogen credit awarded; this ratio will lower the value for each reduction, spreading the burden of nonadditionality across all projects and sellers. Many ecosystem service markets already use conservative trading ratios and discounting to reduce risk from scientific or measurement uncertainty. If stacking is allowed, trading ratios would also have to account for the impacts of stacking on achieving the program target or objective. If stacking increased the nonadditional projects, the trading ratio would need to increase, further decreasing the value of credits. If regulations are sufficiently stringent to keep values high (two or more times the opportunity and real costs), trading ratios and discounts might work.[76]

B. Where Stacking Is Not a Problem

Horizontal stacking of incentive payments or market credits in any combination involves non-spatially overlapping parts of a single property. Because each part of the property is credited only once, this type of stacking is uncontroversial. Some may not even consider it stacking.

Vertical stacking of incentive payments with other incentive payments will create no problems in terms of ecosystem services outcome. Because none of the payments allow environmental impacts elsewhere, they cannot lead to negative ecosystem services outcomes. However, they could entail economic consequences.

Vertical stacking of market credits can also lead to a net zero, or positive, ecosystem service outcome, if the project fully accounted for all impacts and is additional. For example, consider a landowner who plants a forested riparian buffer that generates both water quality and carbon credits, neither of which is sufficient on its own to pay for the buffer. If the carbon credits are sold to offset GHG emissions from a point source (and the transaction does not lead to negative water quality impacts), and the water quality credits are sold to a separate point source (and this transaction does not lead to increased GHG emissions), the project accounts for all of its impacts and has no negative environmental outcome (Figure 3a).

If there were complete regulatory coverage of ecosystem impacts across sectors, additionality would no longer be a necessary requirement. Business-as-usual activities can receive credit under a regulatory cap as part of political dealmaking with the assumption that the cap will be ratcheted down over time, eliminating the free riders. This phenomenon was called "hot air" in the development of the Kyoto Protocol.[77]

C. Summary: Where Stacking Does and Does Not Work

Vertically or temporally stacked offset and mitigation credits—for programs designed to replace losses to ecosystem services—can sometimes, but not always, be problematic. Incentive payments and horizontally stacked credits are usually not problematic. Table 2 lists all the combinations of major types of ecosystem services credits now available and under consideration in the United States. It also indicates potentially problematic combinations.

Two general findings emerge. First, stacking bundled mitigation credits with other offsets can result in double counting (also called double dipping). Second, all transactions involving offsets and mitigation credits may face additionality concerns, except those involving *regulated-to-regulated* trades. Only activities not subject to a cap (unregulated/voluntary activities) need to demonstrate additionality.

D. Incomplete Coverage

Incomplete coverage of impacts is another issue that is not necessarily unique to stacking, but it can interact with stacking. Incomplete coverage of impacts occurs when programs and policies to cover various co-occurring ecosystem services impacts do not exist or are voluntary. When co-occurring impacts are not accounted for, they are not mitigated or offset. This situation can arise when regulatory programs cover only some types of nonpoint impacts. The United States has made great strides in covering environmental impacts from point sources (GHG emissions are

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75. Brian C. Murray & W. Aaron Jenkins, *Designing Cap and Trade to Account for "Imperfect" Offsets*, Duke Environmental Economics Working Paper EE 10-03, Duke Univ., at 10 (2010).

76. Trading ratios are often conservative to account for scientific or measurement uncertainty. Lydia Olander, *Designing Offsets Policy for the U.S.*, Nicholas Institute Report 08-01, p. 40 (2008). These ratios have been suggested as a means to address additionality. *See* Karen Bennett, *Additionality: The Next Step for Ecosystem Service Markets*, 20 Duke Envtl. L. & Pol'y F. 432 (2010).

77. *See, e.g.*, Christoph Böhringer et al., *Hot Air for Sale: A Quantitative Assessment of Russia's Near-Term Climate Policy Options*, 38 Envt'l & Resource Econ. 545 (2007).

Table 2. Combinations of Ecosystem Service Credits and Their Potential Types of Stacking Risks

Credit/Payment #1	Credit/Payment #2	Double Counting	Additionality
PES	PES		
PES	Offsets/mitigation (bundled)		Maybe
PES	Offsets/mitigation (single service)		Maybe
Offsets/mitigation (bundled)	Offsets/mitigation (bundled)	Likely	Maybe
Offsets/mitigation (bundled)	Offsets/mitigation (single service)	Maybe	Maybe
Offsets/mitigation (single service)	Offsets/mitigation (single service)		Maybe

a notable exception), but in most cases, nonpoint sources remain unregulated.

Coverage of some nonpoint impacts—for example, water quality impacts from deforestation—but not others—for example, the GHG impacts from deforestation—can lead to a negative ecosystem services outcome. If the water quality impact from forest loss is offset with the purchase of water quality credits from a tree-planting buffer project, the coincident GHG benefits from the tree planting will help offset the GHG impacts from the deforestation. However, if the tree-planting buffer project is allowed to stack offsets, and it sells its GHG benefits to some other party, the GHG impacts from the deforestation will remain unmitigated. If stacking is not allowed, some uncovered impacts may be mitigated by the co-benefits provided by other projects. However, this strategy penalizes projects for a flaw in the system. The alternative would be to extend regulations to cover the relevant impacts.

Incomplete coverage is unlikely to be a problem when stacking offsets to point source impacts, most of which are captured by one regulation or another. This is the type of credit most commonly traded. However, stacking of nonpoint source credits may raise a transitional problem if the regulatory programs for nonpoint sources develop at different times or in an uncoordinated fashion.

IV. Economic Considerations for Stacking

Stacking can change the costs and revenues of projects and programs. Moreover, it may not be an efficient approach to spurring conservation of at-risk land.

A. Can Stacking Lead to "Overpayment" of Projects?

For offsets programs, consideration of financial additionality seems to suggest a problem of paying too much, but it is really a problem of payments that produce no additional environmental benefit—an environmental rather than a cost concern, even though it has economic consequences. But in the context of incentive programs (payment for ecosystem services), for which funding may be limited, stacking may primarily raise concern about paying more than is needed. For an incentive program, seeking to conserve lands or incentivize improved management with limited resources, each dollar spent paying a project participant more than what he or she needs to recoup costs stops inducing the behavioral change entailed by the project, and is a dollar that cannot be spent to fund another ecosystem services project. However, from a project perspective, there is no problem with projects receiving more payment than is necessary—that is, earning a profit—as long as the environmental objective is met. Any "overpayment" of a project simply represents a "rent" or transfer of funds from one entity to another, which is not necessarily economically inefficient.

Farm Bill conservation programs allow stacking, but they are not currently designed to adjust their payments to account for copayment by a market credit.[78] Thus private market funding cannot be used to reduce program costs or spread the federal resources to additional land. If Farm Bill conservation programs included a reverse auction or bid-down mechanism to allow the level of payment to change, participants might be willing to accept a lower payment from these programs if they also are receiving payments from another ecosystem services program.

B. How Does Stacking Affect the Value of Credits?

Stacking can change the value of ecosystem credits by increasing their overall supply and reducing their prices. A landowner who previously could only sell one of his or her ecosystem services can now sell multiple services from the same project, and at a lower price than that he or she would accept if only one service could be sold. Thus, by allowing landowners to tap into multiple payment streams, stacking can decrease the price they receive from each stream.[79] For example, if most landowners who plant a forested riparian buffer receive both water quality payments and carbon offsets, the supply of each credit type will increase, and the price for each will decrease. The above-noted example of stacking from North Carolina illustrates this dynamic;

78. According to the USDA Farm Service Agency's CRP (http://www.fsa.usda.gov/FSA/newsReleases?area=newsroom&subject=landing&topic=pfs&newstype=prfactsheet&type=detail&item=pf_20100726_consv_en_ebi_39.html), applicants can submit bids for payment below the maximum per-acre payment rate, which may increase their chances of having their application accepted. It has been suggested that other conservation programs, such as the Grasslands Reserve Program and the Wetlands Reserve Program, could benefit from a more direct bidding process, such as a reverse auction. Felix Spinelli, *Pros and Cons of a Reverse Auction to Evaluate Conservation Easements*, prepared for presentation at the Agricultural & Applied Economics Association's 2011 AAEA & NAREA Joint Annual Meeting, Pittsburgh, Pa., July 24-26, 2011.

79. *See* Woodward, *supra* note 15 and accompanying text.

if all existing wetland restoration projects were allowed to sell water quality credits, the supply of these credits would increase dramatically, and their price would crash.[80]

Ecosystem services programs can be designed to be more or less responsive to shifts in credit prices. Mitigation or conservation banks or offset programs that use administratively set credit fees (for example, in-lieu fee systems) will likely not adjust pricing or will adjust it slowly. Competitive bidding could make credit prices respond more quickly to market conditions as would more open-market programs. Similarly, stacking could reduce the overall costs of incentive programs that have flexible payment systems.[81]

These considerations have implications for additionality. If stacking brings down prices, adding a new ecosystem service market to the system can change what is deemed additional; projects that initially could cover their costs by selling one credit may need to sell two types of credit if prices drop. Therefore, some projects, which were originally considered nonadditional because their costs were covered by one credit stream, may later be additional. As credit prices adjust to stacking, more projects will need to stack payments to meet costs, and thus fewer projects will be nonadditional.

Project developers and landowners need ecosystem services payments that meet or exceed opportunity costs so they can, at a minimum, break even. Although stacking may seem a great idea to help landowners profit from the services they provide, they should realize that it can bring down credit prices. As a result, they may have to engage in more credit markets over time.[82]

C. Can Stacking Be Used to Conserve Land at Risk of Conversion?

Some landowners or conservation-minded organizations, like land trusts, may look to stacking of ecosystem services credits as a means to allow landowners to generate enough revenue to prevent conversion of land to other uses. Many ecosystem services programs target shifts in land management (for example, adding buffers, changing forest stocking) and thus are likely to provide funding sufficient only to meet the opportunity costs of such shifts. Stacking credits in an attempt to meet the opportunity costs of avoided conversion is an imperfect approach. Areas at risk of conversion tend to have high land prices; therefore, the opportunity costs of conversion may be too high to be met by stacking credits focused on management changes. A better approach would be to design programs targeting avoided conversion. For example, avoided forest conversion projects can be developed for carbon credits through the CAR[83] and international projects to reduce emissions from deforestation are possible through the Verified Carbon Standard and American Carbon Registry. The carbon value of forest lands with high above-ground carbon stocks is enough to avert conversion of these lands when funds are provided upfront. These particular programs will only help conserve lands with high carbon stocks, which are not necessarily lands with other conservation priorities (such as hydrological, spiritual, or biodiversity services). Including other conservation priorities in avoided conversion programs would require a policy that would target conservation of land for these other values or for the bundled value. Conservation of bundled values also tends to be addressed through some payment for ecosystem services programs and tools like conservation easements and tradable development rights, rather than through ecosystem services markets. However, some wetland and stream mitigation programs include provisions to allow avoided loss to mitigate impacts.[84] In 2005, 20% of wetland and stream mitigation was in the form of "preservation."[85]

V. Policy Implications of Stacking

Many different agencies and laws regulate, manage, and incentivize the conservation and enhancement of ecosystem services, which has resulted in the development of numerous payments and credit types. Stacking these payments can sometimes lead to negative outcomes. However, policymakers have several options for avoiding such problems.

A. Double Counting

Double counting occurs when one of the credit types being stacked is designed to mitigate impact to a full ecosystem, requiring a bundle of services. Any other credit type stacked with such a bundle will likely overlap with one of the services that is included in the bundle. If so, the result is two separate impacts and only one offsetting activity, leading to a net loss of ecosystem services.

Given that ecosystem services programs are run by different agencies at different levels of governance, regulators may need to clarify program guidance for bundled mitigation programs to ensure that only generation of extra services (services beyond those expected to be damaged) can be stacked. Otherwise, the bundled programs may need to disallow stacking altogether. In most states, current regulations and guidance for bundled mitigation do not require regulators to ascertain whether a project is stacking credits.

80. *See* Doyle & BenDor, *supra* note 68.
81. Perhaps recognizing these potential benefits, the Natural Resources Conservation Service and the Farm Services Agency currently allow stacking of ecosystem services credits on top of most of their payment programs. *See supra* note 61.
82. *See* Woodward, *supra* note 15 and accompanying text.
83. The CAR currently has registered nine avoided conversion projects, none of which has yet earned offset credit. *See* http://www.climateactionreserve.org/how/projects/ (last visited Jan. 10, 2012).
84. *See, e.g.*, U.S. Army Corps of Engineers, Wilmington District Regulatory Program, "Mitigation Banks," http://www.saw.usace.army.mil/wetlands/mitigation/mitbanks.html (last visited Jan. 10, 2012) (showing that mitigation banks can preserve, rather than restore, wetlands to generate credits, but preserve wetlands face a higher trading ratio (5:1) compared to restored wetlands (1:1)).
85. Becca Madsen et al., *State of Biodiversity Markets Report*, Ecosystem Marketplace (2010).

Federal regulations for compensatory mitigation instruct developers "to successfully replace lost functions and services,"[86] suggesting that services are intended to be fully covered. This regulation appears to argue against stacking credits in such cases. Other regulations and guidance apparently leave the door open for stacking.[87] Neither the law nor the guidance addresses stacking with offset credits directly, and no legal cases have questioned the intent of the law on whether stacking would be allowed to provide clarifying precedent. State and regional guidance documents used for program implementation are more specific, but they can increase confusion by directly specifying some services within the bundle, while not specifying others, implying that unspecified services might not be included in the bundle. For example, guidance for the NC WAM specifies that the services being replaced include hydrologic services, water quality, and biodiversity, but it does not mention GHGs.[88] With growing interest in coastal wetland restoration as a potential GHG mitigation approach for offsets markets, stacking for coastal restoration may become a real issue for coastal wetlands.[89]

Two accounting approaches under development attempt to address concerns with double counting. The environmental engineering firm Parametrix has developed an approach called EcoMetrix that divides each potentially creditable ecosystem service into component ecosystem functions to ensure that each underlying function is credited only once.[90] The Willamette Partnership has an approach for the sale of multiple credits being tested in several of its pilot projects.[91] Under its approach, projects eligible to sell multiple credits would link the credits it sells. For example, if a landowner sells one-half of his or her wetland credits, his or her available habitat and water quality credits would be reduced by one-half.[92] This approach could be considered a form of horizontal stacking, in that the project area cannot sell more than 100% of any of its credit types.

B. *Policy for Additionality*

The inclusion of additionality as a criterion for carbon or GHG offset markets is designed to ensure that payment was required for a project to move forward. If credit types are stacked but only one payment was needed, it can be argued that the second set of credits is nonadditional. Thus, the impacts they allow would result in a net negative ecosystem services outcome.

The cleanest way to avoid problems with additionality in the carbon market is to include all impacts (sources) under the regulatory cap. However, when this strategy is not politically feasible, programs use tests or rules of thumb to help avoid nonadditional projects when stacking. No policy solution for additionality is perfect, but researchers continue to collect data and explore new ways to design programs to reduce the impacts of nonadditional credits. If the additionality criterion is not a desirable policy choice, programs can move toward conservative discounting or trading ratios, but these measures will have different distributional effects on funding flows.[93]

C. *Incomplete Coverage*

Incomplete coverage of impacts results when services are not covered by a regulatory program; because the services are not accounted for when they are impacted, they may not be replaced. Given the fairly strong regulatory network covering point sources in the United States, incomplete coverage is less of a problem for point source impacts than nonpoint sources, which are currently mostly unregulated. Most of the trading occurring in the United States now involves nonpoint source-point source trading; however, discussion of regulation for nonpoint impacts leaves the door open for nonpoint-nonpoint trading. One example is the state of Maryland's proposed policy of no net loss of forest resources.[94] Attempts to extend coverage of environmental policies to nonpoint impacts should consider that extending coverage for only some impacts could lead to a net loss of ecosystem services if credit stacking is allowed. This problem would be solved with a more integrated approach to environmental management of nonpoint impacts in the United States.

D. *Federal Incentive Programs*

If federal payment programs like those funded through the Farm Bill (for example, the CRP and the Wetland Reserve Program) wish to leverage funding from regulatory and voluntary market programs, they will need to change their rules. The federal programs would need to specify how ecosystem service benefits should be parsed (or unbundled), so that projects could use market funds for certain benefits, while obtaining separate incentive funds for other benefits not covered by existing markets. The federal programs would also need to allow farmers to reduce their bids for incentive payment funding on the basis of their level of market funding. This shift in policy would favor projects that could receive some complementary market funds over

86. 33 C.F.R. §332.3(b) (2010).
87. *Id.* §332.3(j)(1)(ii) (2010).
88. NC WAM, *supra* note 28.
89. *See* Philip Williams & Associates, Ltd., *Greenhouse Gas Mitigation Typology Issues Paper: Tidal Wetland Restoration* (2009), *available at* http://www.climateactionreserve.org/how/protocols/future-protocol-development/#tidalwetland.
90. This approach divides each ecosystem service into component ecosystem functions and then divides each ecosystem function into component ecosystem attributes, e.g., soil and vegetation, which are measured on the landscape. Some ecosystem services will have ecosystem functions in common with other services. In these cases, whenever one service is credited, all its component functions are made ineligible for additional crediting, such that if another service has that same function, the allowable amount to be credited is decreased. Parametrix, *EcoMetrix Tool*, *available at* http://www.parametrix.com/cap/nat/_ecosystems_ecometrix.html.
91. Willamette Partnership, http://willamettepartnership.org/ecosystem-credit-accounting/pilot-projects (last visited Jan. 10, 2012).
92. Devin Judge-Lord, Willamette Partnership, Personal Communication, June 3, 2011.
93. *See* Murray & Jenkins, *supra* note 75.
94. Md. Code Ann., Nat. Res. art. 5-104.

those that could not—a program design consideration. An assessment of the ways in which the shift in project types will affect environmental outcomes is needed to ensure that the desired objectives are achieved.

VI. Conclusions

Stacking could provide a way to integrate the various laws, policies, and voluntary programs that have emerged in the United States. It could help landowners to manage for the multiple ecosystem services their lands provide and avoid the risks of focusing on a single service. Those optimistic about the growth of ecosystem services programs and markets suggest that stacking could also be a way for landowners to gain sufficient revenues from their land, so that ecosystem services production would become a profitable alternative to more traditional types of land management.

Although stacking of various credit types can, in theory, lead to systematic losses of ecosystem services, this risk can be avoided. In addition, many ecosystem services programs use bilateral trades, wherein credits are sold and then retired to meet voluntary targets or mandatory requirements. In this case, it may be possible to directly account for ecosystem services outcomes and to ensure that stacking of credits results in no net loss of ecosystem services. Bundled projects could ensure that they are generating the stacked service in excess of that lost at the original impact site. And where nonpoint impacts are the target, impacts to other ecosystem services can be tracked to ensure that they are replaced by the mitigation project. This type of accounting to ensure that all impacts are addressed is difficult and expensive. Metrics for measuring various ecosystem services are in various stages of development and are often fairly rough.[95] They are a focus of the ecosystem services community and an active area of research. Because ecosystem services credits and payments are governed and regulated by a variety of agencies, accurately accounting for the services provided and impacts allowed by stacked projects will require significant coordination across agencies and across levels of government. One option could be to create a database of all ecosystem services projects, which would allow regulators to identify the projects participating in multiple markets or programs.

Although current policy is largely silent with regard to stacking, the potential risks are known and can be addressed by clarifying policies for double counting, by carefully considering nonpoint source impacts in stacked trades until coverage of nonpoint sources is more complete, and by applying additionality tests where required. Where bilateral trades are the norm, acceptable metrics are needed to track ecosystem services impacts and offsets in order to avoid net environmental loss. Stacking can provide many benefits to the environment and to landowners, but good policy will be required to prevent possible negative outcomes.

95. *See generally* James Boyd & Spencer Banzhaf, *What Are Ecosystem Services? The Need for Standardized Environmental Accounting Units*, 63 Ecological Econ. 616 (2007), and Christian Layke, *Measuring Nature's Benefits: A Preliminary Roadmap for Improving Ecosystem Service Indicators*, World Resources Institute Working Paper (2009), *available at* http://pdf.wri.org/measuring_natures_benefits.pdf.

Appendix

Table A1. All Possible Combinations of the Major Ecosystem Services Credits Available Now or Under Consideration in the United States*

Credit #1			Credit #2			Double Counting	Additionality	
Credit type	***Service***	***Reg or Vol***	***Credit type***	***Service***	***Reg or Vol***		***Credit #1***	***Credit #2***
PES	n/a	n/a	PES	n/a	n/a			
PES	n/a	n/a	Offsets/mitigation	W/S	Reg-vol			Maybe
PES	n/a	n/a	Offsets/mitigation	WQ	Reg-reg			Maybe
PES	n/a	n/a	Offsets/mitigation	WQ	Reg-vol			Maybe
PES	n/a	n/a	Offsets/mitigation	WQ	Vol-vol			Maybe
PES	n/a	n/a	Offsets/mitigation	Carbon	Reg-reg			Maybe
PES	n/a	n/a	Offsets/mitigation	Carbon	Reg-vol			Maybe
PES	n/a	n/a	Offsets/mitigation	Carbon	Vol-vol			Maybe
PES	n/a	n/a	Offsets/mitigation	Species	Reg-vol			Maybe
PES	n/a	n/a	Offsets/mitigation	Species	Vol-vol			Maybe
Offsets/mitigation	W/S	Reg-vol	Offsets/mitigation	WQ	Reg-reg	Likely	Maybe	
Offsets/mitigation	W/S	Reg-vol	Offsets/mitigation	WQ	Reg-vol	Likely	Maybe	Maybe
Offsets/mitigation	W/S	Reg-vol	Offsets/mitigation	WQ	Vol-vol	Likely	Maybe	Maybe
Offsets/mitigation	W/S	Reg-vol	Offsets/mitigation	Carbon	Reg-reg	Maybe	Maybe	
Offsets/mitigation	W/S	Reg-vol	Offsets/mitigation	Carbon	Reg-vol	Maybe	Maybe	Maybe
Offsets/mitigation	W/S	Reg-vol	Offsets/mitigation	Carbon	Vol-vol	Maybe	Maybe	Maybe
Offsets/mitigation	W/S	Reg-vol	Offsets/mitigation	Species	Reg-vol	Likely	Maybe	Maybe
Offsets/mitigation	W/S	Reg-vol	Offsets/mitigation	Species	Vol-vol	Likely	Maybe	Maybe
Offsets/mitigation	Species	Reg-vol	Offsets/mitigation	WQ	Reg-reg	Maybe		Maybe
Offsets/mitigation	Species	Reg-vol	Offsets/mitigation	WQ	Reg-vol	Maybe	Maybe	Maybe
Offsets/mitigation	Species	Reg-vol	Offsets/mitigation	WQ	Vol-vol	Maybe	Maybe	Maybe
Offsets/mitigation	Species	Reg-vol	Offsets/mitigation	Carbon	Reg-reg	Maybe	Maybe	
Offsets/mitigation	Species	Reg-vol	Offsets/mitigation	Carbon	Reg-vol	Maybe	Maybe	Maybe
Offsets/mitigation	Species	Reg-vol	Offsets/mitigation	Carbon	Vol-vol	Maybe	Maybe	Maybe
Offsets/mitigation	Species	Vol-vol	Offsets/mitigation	WQ	Reg-reg	Maybe	Maybe	
Offsets/mitigation	Species	Vol-vol	Offsets/mitigation	WQ	Reg-vol	Maybe	Maybe	Maybe
Offsets/mitigation	Species	Vol-vol	Offsets/mitigation	WQ	Vol-vol	Maybe	Maybe	Maybe
Offsets/mitigation	Species	Vol-vol	Offsets/mitigation	Carbon	Reg-reg	Maybe	Maybe	
Offsets/mitigation	Species	Vol-vol	Offsets/mitigation	Carbon	Reg-vol	Maybe	Maybe	Maybe
Offsets/mitigation	Species	Vol-vol	Offsets/mitigation	Carbon	Vol-vol	Maybe	Maybe	Maybe
Offsets/mitigation	WQ	Reg-reg	Offsets/mitigation	Carbon	Reg-reg			
Offsets/mitigation	WQ	Reg-reg	Offsets/mitigation	Carbon	Reg-vol			Maybe
Offsets/mitigation	WQ	Reg-reg	Offsets/mitigation	Carbon	Vol-vol			Maybe
Offsets/mitigation	WQ	Reg-vol	Offsets/mitigation	Carbon	Reg-reg		Maybe	
Offsets/mitigation	WQ	Reg-vol	Offsets/mitigation	Carbon	Reg-vol		Maybe	Maybe
Offsets/mitigation	WQ	Reg-vol	Offsets/mitigation	Carbon	Vol-vol		Maybe	Maybe
Offsets/mitigation	WQ	Vol-vol	Offsets/mitigation	Carbon	Reg-reg		Maybe	
Offsets/mitigation	WQ	Vol-vol	Offsets/mitigation	Carbon	Reg-vol		Maybe	Maybe
Offsets/mitigation	WQ	Vol-vol	Offsets/mitigation	Carbon	Vol-vol		Maybe	Maybe

*Combinations not listed are unlikely to occur (or are impossible to implement) in the United States.

Notes: PES = payments for ecosystem services or PES; *W/S* stands for wetland or stream mitigation credits; *WQ* stands for water quality credits, which can include nitrogen, phosphorus, temperature, or other pollutants. "Reg" and "vol" indicates whether the trade is *regulated-regulated*, *regulated-voluntary,* or *voluntary-voluntary.*

Additionality can be viewed in terms of each credit in the stack; PES and *reg-reg* credits do not face requirements to show additionality. For this reason, additionality has been divided into two columns.

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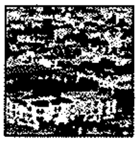
Bay Area's April showers may not bring May flowers

Carl Nolte, Chronicle Staff Writer
Monday, April 4, 2011



This year's unusually wet spring could have unintended consequences: April showers may not bring the flowers that bloom in May.

The reason, botanists say, is that the downpours that soaked the Bay Area in March have produced such a bumper crop of nonnative grass that the wildflowers could well be crowded out.

"After a lot of rain, the grass really grows a lot and can screen out the wildflowers," said David Amme, a biologist with the East Bay Regional Parks District.

Last week's warm weather has given the grass a huge boost, he said.

"When things start to warm up," he said, "you can sit there and watch it grow."

A bumper crop of green grass sounds good until you consider that grasslands in the Bay Area are mostly invasive species that are very aggressive and competitive, especially for water and sunlight. The grasses take over the hills and open space and leave the wildflowers in the dirt, so to speak.

Will it be a good year for wildflowers? "I don't think so," Amme said. "I could be wrong. ... We'll see."

Amme, who is an authority on native grasses in California, said the growth of invasive grass is a process that has been going on a very long time.

It began with the first European settlement in the 18th century, accelerated after the 19th century Gold Rush and exploded in recent times. The invasive species, particularly tall oat grass and brush, have taken over more and more.

"It's like a murder mystery, a whodunit," he said.

Development in the cities and suburbs and bad rangeland management in the remaining open country are culprits, he said.

He believes that a certain amount of grazing by cattle and other animals helps keep down the grass and lets the wildflowers bloom.

"When I was a kid in high school back in the '60s, Mount Diablo was covered in wildflowers in the spring," he said.

Back then, the open space on Mount Diablo was used by cattle ranchers as grazing land. But the state park system expanded the park, closed the area to grazing and now, Amme said, the wildflowers on the mountain are nothing like what they were.

The same thing happened in San Francisco and on the Peninsula, he said, but in those cases, the culprit was population growth and development. Amme cited writings by Alice Eastwood, a botanist with the California Academy of Sciences, who described San Francisco wildflowers around Lake Merced in beds "so thick it was impossible to avoid stepping on.

"The yellow violet, viola pedunculata, was especially common, known to children as Johnny-jump-up. Today, new roads, golf links, vegetable fields and human habitation have driven them away."

That was written more than a century ago.

Today, isolated areas of native plants and wildflowers survive - some in the East Bay, like Point Molate near Richmond, or on the ridgetops of the Berkeley Hills. But there are also areas in the heart of cities, like Twin Peaks, Bayview Hill and the Presidio in San Francisco.

Another spot is San Bruno Mountain, just over the county line in San Mateo County. San Bruno Mountain is the largest urban open space in the country.

"There are still a lot of pretty flowers out there," said Holly Forbes, curator at the UC Berkeley botanical garden. She went to the top of Twin Peaks the other day and saw poppies, cream cups, sun cups and others: orange, red and blue.

But she also noticed that along Interstate 280, near the Crystal Springs reservoirs, there are forests of Scotch broom, a particularly invasive brush that crowds out everything else.

She said the remaining open space has to be tended. "You have to manage it," she said.

"It will still be a good year" for wildflowers, said Laura Baker of the Native Plant Society. "In areas where there is good stewardship, there is a happier story to tell."

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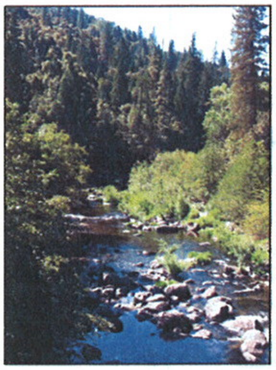
http://sfgate.com/cgi-bin/article.cgi?f=/c/a/2011/04/04/MNTQ1IOIQ1.DTL

This article appeared on page **A - 1** of the San Francisco Chronicle

Mokelumne Watershed Environmental Benefits Program



David Edelson, TNC

The Mokelumne Environmental Benefits Program is an innovative, collaborative and voluntary effort to protect and restore nature's benefits, support local economies, and sustain rural communities, from the headwaters of the Mokelumne River in California's Sierra Nevada mountains to its confluence with the Sacramento-San Joaquin River Delta. Our premise is simple: by measuring and tracking economic investments and environmental outcomes, we can substantially increase both the amount and effectiveness of watershed restoration activities. By creating a framework where environmental benefits are tracked and traded, the Program incentivizes environmental stewardship.

"For the Lodi region, productive agriculture depends on a healthy Mokelumne River; by protecting the watershed and its wildlife we are investing in a thriving economy and community."

–Chris Storm, Vino Farms

Our vision

We envision a future in which public and private sectors are brought together to develop and participate in investment opportunities that reward sustainable resource management and watershed restoration in the Mokelumne River watershed. Under this vision, landowners and land managers will be compensated for undertaking sustainable management practices and restoration activities. By providing incentives, the Mokelumne Program will foster healthier forests and streams and improved water quality and flows, resulting in jobs, cost savings, and other societal benefits.

The Mokelumne

The Mokelumne supplies drinking water to more than 1.3 million California residents, produces an average of 1000 GWh of hydropower which gives electricity to about 215,000 homes, and supports an extensive agricultural economy of more than 800,000 acres of important crops such as winegrapes and orchards. At the same time, the watershed provides critical habitat for many sensitive fish and wildlife species, including fall-run chinook salmon, steelhead trout, red-legged frog, northern goshawk and American marten. The Mokelumne also offers outstanding recreational opportunities such as hiking, camping, biking, rafting, and fishing. But like many watersheds in the state, the Mokelumne faces threats from high-intensity fire, land use patterns and practices, and climate change impacts.

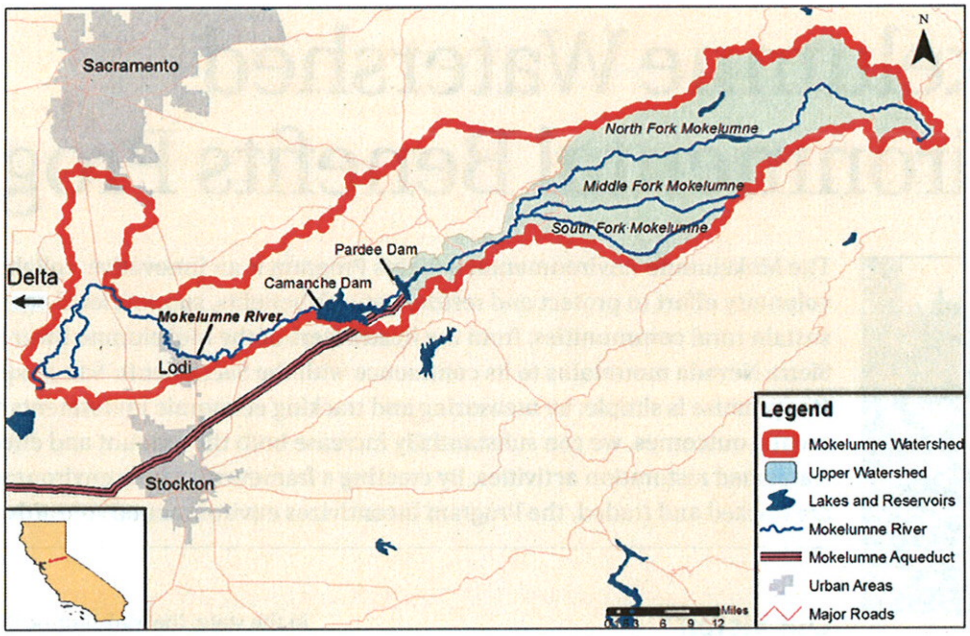
Mathew Grimm, EDF

Illustrated above, the Mokelumne River reaches the end of its journey as it joins the Sacramento-San Joaquin River Delta. Agriculture, including vineyards, is the primary land use of the lower watershed.

Friends of the River

The Mokelumne is a fishing hotspot of the region. Above, Mikey Wier, Fly Fishing Ambassador for Patagonia, Inc., displays a Mokelumne River Rainbow Trout.

Mokelumne Watershed



We envision a future in which public and private sectors are brought together in a program that rewards sustainable resource management.

Our objectives

- Create new opportunities for landowners and land managers to restore, protect and enhance the watershed and support the local economy.
- Provide a performance-based environmental accounting system to track environmental improvements.
- Establish a broad-based collaborative program to ensure results are adapted to local conditions and supported by local communities.
- Educate stakeholders and decision-makers about the wide-array of environmental benefits provided by the Mokelumne watershed.
- Devise a verifiable investment vehicle for public and private investors seeking to improve environmental values.
- Consider the application of this approach to other California watersheds.

The program

By rigorously quantifying and monitoring environmental benefits, the Program will encourage cost-effective investments in forest, meadow, and streamside restoration, thereby providing private and public landowners and land managers with incentives to implement sustainable land management practices.

Collaborative process

Sustainable Conservation, Environmental Defense Fund, Sierra Nevada Conservancy, and The Nature Conservancy have convened a working group of local and regional stakeholders to develop and implement the Program. The working group includes broad representation from watershed groups, the U.S. Forest Service, local governments, East Bay Municipal Utility District, Foothill Conservancy and other environmental interests, private landowners, and the San Joaquin County Resource Conservation District.

This material is based upon work supported by the Natural Resources Conservation Service, U.S. Department of Agriculture, under number 69-3A75-11-194.

Sustainable Conservation

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Mokelumne Watershed Environmental Benefits Program

The Mokelumne Watershed Environmental Benefits Program is an innovative, collaborative and voluntary effort to protect and restore nature's benefits, support local economies, and sustain rural communities. These ecosystem services, such as clean and abundant water, flow from the headwaters of the Mokelumne River in California's Sierra Nevada mountains, through the Central Valley and down to its confluence with the Sacramento-San Joaquin River Delta. The Program's premise is simple: by measuring and tracking economic investments and environmental outcomes, we can substantially increase both the amount and effectiveness of watershed restoration activities. By creating a framework where environmental benefits are tracked and traded, the Program incentivizes environmental stewardship.

Our vision

We envision a future in which public and private sectors are brought together to develop and participate in investment opportunities that reward sustainable resource management and restoration throughout the Mokelumne River watershed. Under this vision, landowners and land managers will be compensated for undertaking sustainable management practices and restoration activities. By providing incentives, the Program will foster healthier forests and streams and improved water quality and flows, resulting in jobs, cost savings, and other societal benefits.

Our objectives

- Create new opportunities for landowners and land managers to restore, protect and enhance the watershed and support the local economy.
- Provide a performance-based environmental accounting system to track environmental improvements.
- Establish a broad-based collaborative program to ensure results are adapted to local conditions and supported by local communities.
- Educate stakeholders and decision-makers about the wide-array of environmental benefits provided by the Mokelumne watershed.
- Devise a verifiable investment vehicle for public and private investors seeking to improve environmental values.
- Consider the application of this approach to other California watersheds.

The program

In September, 2011, the Program was awarded both a National and a State Conservation Innovation Grant through the USDA Natural Resource Conservation Service. Funding will be primarily be used to assess the condition of the watershed, identify restoration opportunities, develop and test tools to measure environmental outcomes and create an accounting framework to track environmental progress. By rigorously quantifying and monitoring environmental benefits, the Program will encourage cost-effective investments in forest, meadow, and streamside restoration, thereby providing private and public landowners and land managers with incentives to implement sustainable land management practices.

Collaborative process

Sustainable Conservation, Environmental Defense Fund, Sierra Nevada Conservancy, and The Nature Conservancy have convened a working group of local and regional stakeholders to develop and implement the Program. The working group includes broad representation from watershed groups, the U.S. Forest Service, local governments, East Bay Municipal Utility District, Foothill Conservancy and other environmental interests, private landowners, and the San Joaquin County Resource Conservation District.

FAQ's

1. *Why the Mokelumne Watershed?*

The Mokelumne River provides 90% of East Bay Municipal Utility District's water supply, which serves 1.3 million California residents. In addition, it produces an average of 1000 GWh of hydropower which gives electricity to about 215,000 homes, and supports an extensive agricultural economy of more than 700,000 acres of important crops such as winegrapes and orchards. At the same time, the watershed provides critical habitat for many sensitive fish and wildlife species, including fall-run chinook salmon, steelhead trout, red-legged frog, northern goshawk and American marten. The Mokelumne also offers outstanding recreational opportunities such as hiking, camping, biking, rafting, and fishing. The diverse ecosystems and land uses across the Mokelumne Watershed are representative of many California watersheds, providing a framework that could be used across the state.

Additionally, the Mokelumne Watershed has well-established, inclusive stakeholder groups which provide an opportunity to create strong long-standing partnerships to develop an environmental benefits program that will evaluate and implement a number of environmental opportunities using a landscape approach.

2. *What Upper Watershed Opportunities may be addressed by the Program?*

The upper Mokelumne watershed faces challenges common in the Sierra region – high risk of catastrophic wildfire, development pressures, and a lack of economic vitality and diversity. These challenges create a strong need for:

1. Forest fuels reduction and fire hazard mitigation on public and private lands.
2. Improvement of water quality from historical water pollution from hydraulic mining and timber harvesting.
3. Improvement of habitat connectivity (riparian forests, meadows, etc) that has been fragmented through development and regional transit patterns to support local wildlife populations.

3. *What Lower Watershed Opportunities may be addressed by the Program?*

Below Camanche Dam in the lower watershed, the pressing issues center around the health and sustainability of the Mokelumne River. Similar to other parts of the Central Valley, this area is home to highly viable agriculture lands that face potential loss of acreage due to flood risk, creating the need for levee and streambank erosion control and prevention of channel incisement. Likewise, the Mokelumne River is home to Central Valley spring-run Chinook salmon and the Central Valley steelhead trout. As a result, there are great opportunities for restoration including:

1. Improvement of instream flows and decreased water temperatures to support historical upstream migration of anadromous fish -chinook salmon and steelhead trout- to the Mokelumne River.
2. Expansion of riparian vegetation to connect fragmented terrestrial habitat and riparian forests as well as effectively reducing surface and subsurface flows of agricultural runoff, stabilizing banks, moderating water temperatures and contributing biomass to the aquatic ecosystems.
3. Floodplain restoration to reconnect the river with its floodplain, improve habitat connectivity and biodiversity of habitats while preventing current channel incisement and land and crop losses.

The Mokelumne's Story

The Mokelumne River watershed covers 1,700 sq mi of five counties in eastern California, winding its way over 80 miles from the peaks of the Sierra Nevada to its mouth at the San Joaquin River. The headwaters of the Mokelumne River originate in the Sierra Nevada Mountains at approximately 3100 meters in elevation. The river flows down the western slope of the Sierras and continues its journey west flowing through a broad alluvial floodplain. Its waters join the Cosumnes River to the north and finally enter the San Joaquin-Sacramento Delta. Two major dams were constructed along the river: Pardee Dam, built in 1929 in the Sierra foothills, and Camanche Dam constructed further downstream in 1963. The watershed is divided into two subwatersheds at the Pardee dam: the 352,000 acre Upper Mokelumne watershed reaches above the dam and the Lower Mokelumne watershed extending below the dam with approximately 700,000 acres.

Over the course of the past century, fire suppression, grazing, and climate change, among other factors, have altered the forest structure to what is found today in the Sierra Nevada. Low-density forests with clusters of large trees and low surface fuel loads have been replaced by high fuel loads and several-fold increases in stem density. These changes have increased the risk of forest fire in the Sierra Nevada including the upper Mokelumne watershed

Historical photographs from the Land Use Photo-Archive and aerial images from 1927 show extensive gallery forests that once covered the Mokelumne floodplain along with a diverse mosaic of oxbow lakes, backwater areas and secondary channels. With the construction of dams in the Mokelumne, river regulation changed flooding frequency. Once flooding was not longer a threat, forest was replaced or fragmented by agriculture.

From the period of 1910 to 2001, it is estimated that forests in the lower Mokelumne watershed were reduced by 73% with the majority of land converted to agriculture. In the lower Mokelumne River (LMR) riparian vegetation is found along most of both banks of the river from Camanche Dam to New Hope (Thornton). However, riparian vegetation is found as a thin corridor with evidence of little regeneration and fragmentation is an issue.

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REVIEW AND SYNTHESIS

Quantifying the evidence for biodiversity effects on ecosystem functioning and services

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Abstract

Concern is growing about the consequences of biodiversity loss for ecosystem functioning, for the provision of ecosystem services, and for human well being. Experimental evidence for a relationship between biodiversity and ecosystem process rates is compelling, but the issue remains contentious. Here, we present the first rigorous quantitative assessment of this relationship through meta-analysis of experimental work spanning 50 years to June 2004. We analysed 446 measures of biodiversity effects (252 in grasslands), 319 of which involved primary producer manipulations or measurements. Our analyses show that: biodiversity effects are weaker if biodiversity manipulations are less well controlled; effects of biodiversity change on processes are weaker at the ecosystem compared with the community level and are negative at the population level; productivity-related effects decline with increasing number of trophic links between those elements manipulated and those measured; biodiversity effects on stability measures ('insurance' effects) are not stronger than biodiversity effects on performance measures. For those ecosystem services which could be assessed here, there is clear evidence that biodiversity has positive effects on most. Whilst such patterns should be further confirmed, a precautionary approach to biodiversity management would seem prudent in the meantime.

Keywords

Biodiversity–ecosystem functioning, diversity manipulations, ecosystem property, ecosystem services, ecosystem type, experimental design, meta-analysis, stability, trophic level.

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INTRODUCTION

Human needs have been, and continue to be, satisfied at the expense of altered land use, climate, biogeochemical cycles and species distributions (MA 2005). As a result, biodiversity is declining a thousand times faster now than at rates found in the fossil record (MA 2005), raising concerns about consequences of such loss for ecosystem functioning, the provision of ecosystem services and human well being (Schläpfer & Schmid 1999; Chapin *et al.* 2000; Loreau *et al.* 2001; Kinzig *et al.* 2002; Díaz *et al.* 2005; Hooper *et al.* 2005; MA 2005; Srivastava & Vellend 2005). Such concerns have moved beyond the science community to the global stakeholder and policy community with the publication of the Millennium Assessment (Díaz *et al.* 2005; MA 2005). That analysis acknowledges that biodiversity probably plays a significant role in directly providing goods and services as well as regulating and modulating ecosystem properties (this term is used here to include 'processes' and 'functioning') that underpin the delivery of ecosystem services.

Considerable research has gone into teasing out the linkages between biodiversity, functioning and services (Naeem & Wright 2003), and experimental approaches now account for 40% of the publications in this area (Fig. 1). Most experiments have manipulated diversity or have assembled different diversities as a treatment variable and documented the response of ecosystem properties and processes, including modifying effects of environmental factors on such relationships (Naeem *et al.* 1994; Tilman 1996; McGrady-Steed *et al.* 1997; Hector *et al.* 1999). The experimental designs used, results obtained and interpretations made, have not been consistent and the field has been contentious and lively

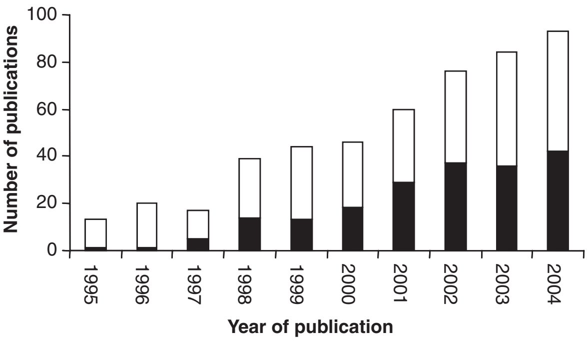

Figure 1 The number of biodiversity–ecosystem functioning articles published during the last decade is steadily growing (ISI Web of Science). Experimental work (filled section) has contributed around 40% of the total number of articles (total bar) since the beginning of this century.

(Grime 1997; Wardle *et al.* 1997; Huston *et al.* 2000; Lepš 2004). Attempts have been made to provide common frameworks, identify areas of consensus or future challenges, as well as potential management and policy implications (Schläpfer & Schmid 1999; Loreau *et al.* 2001; Kinzig *et al.* 2002; Schmid *et al.* 2002; Díaz *et al.* 2005; Hooper *et al.* 2005), but these syntheses have taken the form of largely subjective assessments through qualitative literature reviews. Such reviews provided an important foundation (in particular Schmid *et al.* 2002) for us to construct a more complete database using strict selection criteria (Schläpfer & Schmid 1999) for the formal meta-analysis presented here. Specifically, we pose the following questions: (i) what are the most commonly addressed relationships between biodiversity and ecosystem properties? (ii) How do the experimental designs used and the ecosystem properties measured affect the outcomes and interpretation of biodiversity–ecosystem functioning relationships? (iii) What can be learnt about biodiversity–ecosystem service relationships that could be useful for decision makers?

METHODS

Data collection

One hundred and three publications were included in our database, representing 446 ecosystem property measurements from 1954 to June 2004 (see Appendix S1 and Table S1). These publications were identified from the ISI Web of Science and Biological Abstracts database using criteria previously using the following search terms (Schläpfer & Schmid 1999): *biodiversity or species richness* and *stability or ecosystem function or productivity or yield or food web*. Where appropriate, we contacted authors of publications to obtain additional information and additional publications. Information about specifics of experimental designs, the ecosystem properties measured and the significance and size of reported effects were entered into our database. We did not include duplicate records, for example, the same experiment and same measurement reported in a different publication or measured in a different year (repeated measures). If, however, the repeated measures were used to derive a new variable such as temporal variation in the ecosystem property, these data were included. We did not include studies that compared monocultures with mixtures of a single higher diversity level or single-species removal experiments. We used all records that reported effect sizes, allowing us to calculate correlation coefficients for the relationship between biodiversity and ecosystem property, but we excluded studies from our database, which reported only significance.

Data analyses

Biodiversity effects were measured as simple or multiple correlation coefficients, r. Using r instead of r^2 (the coefficient of determination) had the advantage that we could assign negative and positive signs to effects. Maintaining negative and positive effects and using a Z-transformation (see below) allowed us to test the overall distribution for normality and to obtain normally distributed error terms after fitting explanatory terms.

Simple correlation coefficients (365 records) were only available where biodiversity was treated as an independent continuous variable or where a linear or log-linear contrast was made for the factor biodiversity. When biodiversity was analysed as a factor with more than one level (or as a polynomial), we calculated multiple correlation coefficients from the entries in the analysis of variance tables (81 records). We used adjusted r^2 values to derive correlation coefficients because these correct for the degrees of freedom used to fit a model (Sokal & Rohlf 1995). When the relationship between the levels of the biodiversity factor and the response variable was generally negative, we gave the multiple correlation coefficient a minus sign. In addition to the sign, we also noted the shape of the relationship (see below). To simultaneously analyse simple and multiple correlation coefficients we normalized them using Fisher's z-algorithm (Rosenberg *et al.* 2000)

$$Z_r = 0.5 \times \ln\left(\frac{1+r}{1-r}\right) \quad (1)$$

and analysed these Z_r-values as a new dependent variable. We did all analysis with all 446 correlation coefficients and with the subset of the 365 simple coefficients. Because the results were the same, we only present those from the full analysis.

The common, normalized effects measure allowed us to analyse all data together with a single general-linear modelling framework, despite the overwhelming heterogeneity of studies. Based on major controversies as well as areas of consensus identified in previous qualitative synthesis (Schläpfer & Schmid 1999; Loreau *et al.* 2001; Kinzig *et al.* 2002; Schmid *et al.* 2002; Díaz *et al.* 2005; Hooper *et al.* 2005), a set of hypothesis were constructed about possible effects of the specifics of experimental designs and the ecosystem properties measured on the biodiversity effects observed (Table 1). The studies were classified into groups using a separate explanatory factor for each of the hypotheses (Table 1). The significance and explanatory power of these factors and of interactions was then assessed in mixed-model analyses of variance (ANOVA). Study site and reference were random terms in the model.

We compared a small number of alternative models for the fixed terms using adjusted r^2 values (which gave the same model ranking as Akaike and Bayesian information criteria). The selected final model contained only main effects but no interactions of fixed terms. Due to correlations between fixed terms, we assessed their explanatory power in two ways if they were entered: (i) first into the model or (ii) in a sequence of decreasing order of their F-values when entered first. The random effects were added after the fixed effects in the sequence study site/reference, imposing a nesting of these terms. In one case, a single publication reported results from two study sites and in another case, a single publication reported results from two separate experiments. In these two cases, we gave each publication two reference IDs to ensure full nesting. To avoid weak pseudo-replication due to measurements of multiple ecosystem properties in single experiments, terms referring to specifics of experimental design and study site could be tested against the reference ID instead of the residual mean square as error term. We used this very strict test but list the mean squares in the ANOVA table so that readers can calculate the more liberal F-test as well. The reciprocal of the variance in the individual Z_r values, based on the individual study sizes, was used as a weighting factor in the ANOVA (Crawley 1993). This ensured that studies with small sample sizes were not over-rated in comparison with studies with large sample sizes. Throughout the paper, we report result in terms of these weighted average normalized effect sizes Z_r and their standard errors.

Ecosystem properties that could unequivocally be related to ecosystem services (MA 2003; Díaz *et al.* 2005), and thus that could be assigned a positive (or negative) value for human well being, were further analysed based on mean values and standard errors of effect sizes. Some judgment is involved in the assignment of positive or negative value, because a particular ecosystem property may not be seen as the same benefit by all stakeholders of biodiversity

Table 1 Hypotheses tested in the meta-analysis and corresponding explanatory terms in ANOVA

Explanatory term	Null hypothesis
Type of diversity measure	H_1, biodiversity effects are independent of type of diversity measure used to estimate relationship (e.g. species vs. functional diversity)
Type of experimental system	H_2, biodiversity effects are independent of type of experimental system (e.g. bottle, field)
Ecosystem type	H_3, biodiversity effects are independent of ecosystem type (e.g. grassland, forest)
Main cause of diversity changes	H_4, biodiversity effects are independent of main cause of diversity changes (direct vs. indirect manipulation of diversity)
Design for direct species diversity manipulations	H_5, biodiversity effects are the same whether total density is held constant (substitutive designs) or not (additive or designs without control of total density)
Type of indirect species diversity gradients	H_6, biodiversity effects are independent of the type of indirect species diversity gradients [natural variation vs. gradient (e.g. nitrogen addition)]
Maximum species number	H_7, biodiversity effects are independent of maximum species number in most diverse treatment
Trophic-level manipulated	H_8, biodiversity effects are independent of trophic level manipulated
Trophic level measured	H_9, biodiversity effects are independent of trophic level measured
Number of trophic links between them	H_{10}, biodiversity effects are independent of number of trophic links between level manipulated and level measured
Ecosystem property	H_{11}, biodiversity effects are independent of the ecosystem property measured
Organization level of ecosystem property	H_{12}, biodiversity effects are independent of the level of organization at which the ecosystem property was measured (population- vs. community- vs. ecosystem-level)
Biotic vs. abiotic ecosystem properties	H_{13}, biodiversity effects are independent of whether ecosystem property is biotic or abiotic
Dominant cycle to which ecosystem property belongs	H_{14}, biodiversity effects are independent of whether ecosystem property is associated to water, nutrient, energy or biotic dynamics
Nature of ecosystem property	H_{15}, biodiversity effects are independent of whether ecosystem property is a stock or a rate
Study site	H_{16}, biodiversity effects are independent of location of study site

Listed are the null hypotheses we tried to reject.

(Srivastava & Vellend 2005). Only those ecosystem properties for which at least five effect size measurements were available were included in the analysis.

Groupings for specifics of experimental design and ecosystem properties (number of records in parentheses)

Type of diversity measure
These included species richness (393), functional group richness (23), evenness (11) and diversity indices (19). Although we aimed to include diversity effects in the broadest sense of the word, the majority of studies examined species richness effects only. Some studies reported effects of functional group richness, but only a few of these were intentionally designed from the start to examine effects of varying functional diversity.

Type of experimental system
System types were bottle (microcosm studies) or pot (111), greenhouse, including climate chambers (62) and field (273). Pot and greenhouse systems differ from field systems in that the latter experience natural climate and light regimes. Field systems included studies that directly and indirectly manipulated species diversity.

Main cause of diversity change
Direct manipulations (398) of diversity were distinguished from indirect ones (48). Indirect manipulations were found only in field studies and were further categorized as follows.

Type of indirect species diversity gradients
Indirect manipulations of diversity were divided into natural variation (39) and gradient (9). In the first category, naturally varying diversity levels were constructed. In the second category, a natural (succession) or experimental gradient in environmental conditions (nutrient application or multiple factors) generated the differences in diversity levels.

Design of direct species diversity manipulation experiments
Direct manipulations of diversity were subdivided into those which were set up so that total density remained constant, i.e. substitutive experiments (357), and others, mostly additive experiments (41).

Maximum species number
Three levels of maximum diversity were recognized: low (≤10 species, $n = 211$), intermediate (11–20 species, $n = 104$) and high (>20 species, $n = 131$).

Ecosystem type
These encompassed forest (43), grassland (258), marine (32), freshwater (68), bacterial microcosm (seven), soil community (15), crop/successional (10) and ruderal/salt marsh (13).

Trophic level manipulated and trophic level measured
Studies that manipulated diversity and/or measured diversity effects at different trophic levels were categorized into: primary producer (319 manipulated and 241 measured), primary consumer (30 and 91), secondary consumer (four and 13), detritivores (15 and 38), mycorrhiza (47 and 15), multitrophic (31 and five) and ecosystem level (0 and 43). 'Multitrophic' refers to studies where diversity was manipulated on more than one trophic level or where the ecosystem property involves more than one trophic level (e.g. total macrofaunal biomass). Ecosystem level refers to properties measured in the entire ecosystem within the abiotic compartment (e.g. nutrient loss from the system).

Number of trophic links
We counted the number of trophic links between the trophic level manipulated and the level at which the property was measured (Fig. 2).

Effect form
The shapes of the biodiversity–ecosystem property relationships were classified into negative (40), negative linear (92), negative log-linear (41), idiosyncratic (113), positive (70), positive linear (56), positive log-linear (34). This classification was performed independently of significance or size of biodiversity effects simply by inspecting results presented in the text and figures of the publications analysed. This variable is similar to the effect size itself and could be used as an alternative dependent variable in log-linear analysis of deviance. We include this variable in the supplementary online material but except for a single case (see below) the only reported dependent variable in the present paper is effect size *per se*.

Ecosystem properties measured
We included any physical characteristics of the ecosystems, including process rates of energy and nutrient flow. To simplify comparisons, we grouped similar ecosystem properties (EP), which resulted in 28 groups; an additional group was used to collect those measures that could not be assigned. We distinguished between properties of the ecosystem and those of an invader (defined as any species added after the establishment of a community) and we also distinguished between effects on means of properties measured and those that relate to their variances.

Organizational level of the ecosystem property measured
We distinguished between population-level properties, recorded for individual target species, such as density, cover

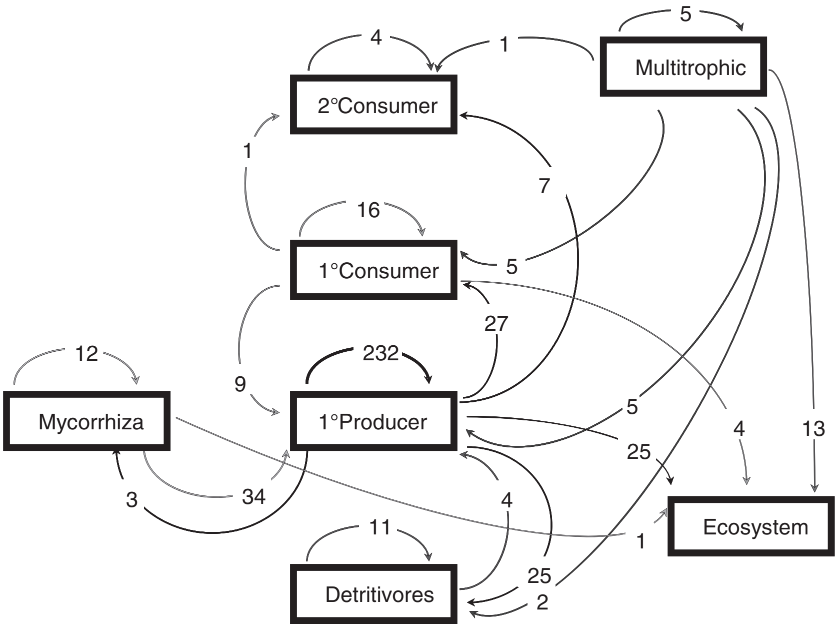

Figure 2 Number of measurements in published biodiversity–ecosystem functioning experiments for different trophic levels manipulated (base of arrow) and trophic levels measured (end of arrow). A dominance of measurements and manipulations of primary producers was observed.

or biomass, and their temporal variance; community-level properties, recorded for multispecies assemblages, such as density, biomass, consumption, diversity and their temporal variance; and ecosystem-level properties, recorded for abiotic components, such as nutrient, water or CO_2 and their temporal variance.

Dominant dynamic of ecosystem property

Properties were assigned to the ecosystem cycle in which they predominate: water, nutrient, energy or biotic dynamics.

Nature of ecosystem property

Stock vs. rate measurements of ecosystem properties were distinguished.

Ecosystem service

Ecosystem services are the benefits people obtain from ecosystems. Our classification followed that of the Millennium Ecosystem Assessment (MA 2003; Díaz *et al.* 2005). A list of ecosystem properties considered to underpin each ecosystem service, as well as the directionality of expected benefits to human well being, is provided below in the *Results* section.

Groupings according to place of study and identity of experiment (number of groups in parentheses)

Location of study site (60)

Site location of an experiment ranged from a precise place to a broad region, depending on the extent of the study.

Study site (75)

Generally equivalent to location, this term was used to distinguish different studies within a single location. Study site reflects a set of environmental conditions particular to that experiment.

Reference ID (105)

This corresponded to individual publications, except where a single publication reported results from more than one study, in which case this publication received two reference IDs. This ID is used to distinguish between groups of potentially non-independent measurements in order to avoid pseudo-replication.

RESULTS

The overall mean of the standardized effect sizes Z_r (weighted by the reciprocal of the variance of the individual Z_r-values) was significantly positive ($\bar{X} = 0.101 \pm 0.028$, $t = 3.57$, d.f. $= 445$, $P < 0.001$), indicating that negative responses of ecosystem properties to biodiversity manipulations are less frequent or less strong than positive ones. Nevertheless, the reported effect sizes varied greatly, ranging from −2.71 to 2.39. In the following sections, we explore the sources of this variation.

Effects of specifics of experimental design and study site

Some specifics of the experimental design which we originally expected to have an influence on effect sizes in fact could not be included in the final analysis model, suggesting that they need not be a concern when designing future biodiversity experiments. For instance, there was only a weak influence of the type of diversity measure on measured effect sizes (Table 2). Of particular note is that effect sizes were only slightly larger when functional-group rather than species richness was manipulated (adjusted mean values ± SE of Z_r-values: 0.191 ± 0.103 vs. 0.116 ± 0.030).

In contrast, the type of experimental system employed (bottle vs. greenhouse vs. field) strongly modified biodiversity effects (Table 2). More positive effects were found where environmental variables could be controlled best, such as in greenhouses and climate chambers (0.467 ± 0.084) compared with bottle/pot experiments (0.100 ± 0.051) or field experiments (0.007 ± 0.033).

Effect sizes also varied markedly between different types of ecosystem (Table 2). For the four ecosystem types which were represented most frequently in the data set, average effect sizes were close to zero (grassland 0.039 ± 0.038, freshwater −0.010 ± 0.065, marine −0.006 ± 0.109, forest −0.116 ± 0.076), whereas average effect sizes were larger and positive for the ecosystem types with fewer records (ruderal/salt marsh, 1.058 ± 0.154; bacterial, 0.317 ± 0.095; crop/successional, 0.245 ± 0.052; soil, 0.094 ± 0.086). This could imply that the research community's perception of the magnitude and direction of biodiversity effects may be biased by the focus to date on relatively few ecosystem types that included measures of negative impacts on properties. There was considerable variation among study sites, but this was not significant in the multiway ANOVA using the strict F-test with reference ID as error term (Table 2). In other words, effect sizes varied as much between references within study sites as between study sites.

Although average effect sizes were practically identical for studies that manipulated biodiversity directly or indirectly

Table 2 Results from one-way analyses of variance (ANOVA)s in the sequence of decreasing F-values and multiway ANOVA using this sequence for fitting the corresponding fixed terms (see Methods for details)

H no.	Variable	d.f.	Sum of squares	Mean squares	*F*	*P*-value	% Explained variance
One-way ANOVA							
12	Organization level EP	2	2031.7	1015.9	40.27	<0.001	15.4
5	Type direct manipulations*	2	1802.5	901.2	35.00	<0.001	13.6
7	Maximum species number	2	1319.0	659.3	24.57	<0.001	10.0
2	Experimental system	2	1071.0	535.3	19.54	<0.001	8.1
3	Ecosystem type	7	2255.8	322.3	12.89	<0.001	17.1
11	Ecosystem property	28	3241.7	115.8	4.83	<0.001	24.5
16	Study site	74	6168.6	83.4	4.39	<0.001	46.7
1	Type diversity measure	3	377.2	125.7	4.33	0.005	2.9
15	Nature of EP	1	86.5	86.5	2.92	n.s.	0.7
8	Trophic-level manipulated	5	305.1	61.0	2.08	n.s.	2.3
9	Trophic-level measured	6	295.2	49.2	1.67	n.s.	2.2
10	Number of links	1	37.4	37.4	1.28	n.s.	0.3
14	Cycle type EP	4	143.9	36.0	1.21	n.s.	1.1
13	Biotic vs. abiotic EP	1	27.3	27.3	0.93	n.s.	0.2
6	Type indirect gradient*	2	14.1	7.1	0.24	n.s.	0.1
4	Direct vs. indirect	1	2.2	2.2	0.07	n.s.	0.0
ANOVA for selected model							
12	Organization level EP	2	2031.9	1016.0	83.69	<0.001	15.38
5	Type direct manipulations†	2	1295.5	647.4	18.19	<0.001‡	9.81
7	Maximum species number	2	349.3	174.7	4.91	<0.05‡	2.64
2	Experimental system	2	485.0	242.5	6.81	<0.01‡	3.67
3	Ecosystem type	7	660.3	94.3	2.65	<0.05‡	5.00
11	Ecosystem property	28	1196.6	42.7	3.52	<0.001	9.06
16	Study site	65	2501.7	38.5	1.08	n.s.‡	18.94
	Reference (within study site)	26	925.5	35.6	2.93	<0.001	7.01
	Residual	337	3762.4	12.0			28.49
	Total	444	13208.1	29.8			100.00

H no., hypothesis number (see Table 1); n.s., not significant ($P > 0.05$).
*These two terms include the last term (direct vs. indirect) as a category 'none'.
†This term includes the term 'direct vs. indirect' as a category 'none'.
‡F-test using reference ID as error term.

(hypothesis 4), and between versions of indirect manipulations (hypothesis 6), average effect sizes were smaller if direct manipulations maintained total density constant (substitutive designs, 0.031 ± 0.030) than if they did not (0.868 ± 0.102) (Table 2). This confirms something which has long been known to agricultural scientists and plant ecologists using substitutive designs (Harper 1977), the importance of not confounding increasing species richness and total density in experiments.

Average effect sizes were positive if the maximum species richness was larger than 20 species (0.344 ± 0.052) and close to zero for the other two categories (two to 10 species: −0.049 ± 0.030; 11–20 species: −0.034 ± 0.081) (Table 2). Yet only 33 of 105 experiments (reference IDs) employed more than 20 species at the highest diversity level. With respect to effect form there was an indication that the odds ratio between linear and log-linear-negative or -positive relationships was greatest in experiments where maximum species richness was lowest ($P < 0.05$), but even where maximum species richness was high, this ratio was > 1.

There were no overall effects of trophic level manipulated, trophic level measured or number of trophic links between manipulated and response trophic levels (Table 2). Nevertheless, productivity-related effect sizes did significantly decline with increasing number of trophic links ($F_{1,140} = 5.74$, $P < 0.05$).

Effects of ecosystem properties measured

Biodiversity effects differed significantly among the 29 different groups of ecosystem properties (Table 2). A large fraction of the variance in effect sizes was explained by comparing population-, community- and ecosystem-level measures of ecosystem properties (Organization level EP in Table 2). Biodiversity negatively affected population-level measures (−0.332 ± 0.053), but positively affected community-level measures (0.270 ± 0.036). Ecosystem-level measures showed an intermediate response (0.066 ± 0.046). In contrast, no differences were found between biotic and abiotic ecosystem properties, stocks and rates, nor between those more related to carbon, nutrient, water or biotic cycles (terms 'biotic vs. abiotic EP', 'nature of EP' and 'cycle type EP', respectively, in Table 2).

Biodiversity–ecosystem service relationships

Biodiversity effects were explored in more detail by plotting mean values and SE for groups of ecosystem properties in Fig. 3 and relating these groups to ecosystem services.

Productivity is a fundamental supporting ecosystem service that underpins the provision of services such as food or wood (MA 2003; Díaz *et al.* 2005). Generally, increasing biodiversity at one trophic level increased productivity at the same trophic level (Fig. 3). Plant diversity also appeared to enhance belowground plant and microbial biomass (Fig. 3), indicating positive biodiversity effects on the regulating ecosystem service of erosion control, as large root and mycorrhizal networks are expected to reduce soil erosion.

Positive biodiversity effects (Fig. 3) were found for most ecosystem properties associated with nutrient cycling services. Plant diversity had positive effects on decomposer activity and diversity, and both plant and mycorrhizal diversity increased nutrients stored in the plant compartment of the ecosystem. It is unclear whether plant or detritivore diversity has a general effect on soil nutrient supply.

Increasing the diversity of primary producers contributed to a higher diversity of primary consumers, which we consider here as a supporting service (Fig. 3). Our results also suggest positive effects of biodiversity on the closely related regulating service of pest control; higher plant diversity contributed to lowering plant damage (Fig. 3). The effects of plant diversity on the performance and diversity of predatory insects or other animals that control pests require further investigation. In the case of the regulation of invasive species, a service of economic significance and an area of considerable debate (Levine & D'Antonio 1999; Fargione *et al.* 2003), we found reduced invader abundance, survival, fertility and diversity when plant diversity was higher (Fig. 3).

Temporal stability is directly linked to reliability of service delivery (Díaz *et al.* 2005). Our analysis indicates that more diverse systems have greater temporal stability, as well as greater resistance to external forces such as nutrient perturbations and invading species (Fig. 3). However, this was not the case for other stressors such as warming, drought or a high variance in other environmental conditions. In contrast to the suggestion of qualitative reviews (e.g. Srivastava & Vellend 2005), portfolio and insurance effects of biodiversity (Tilman 1996; Naeem & Li 1997; Yachi & Loreau 1999), i.e. effects on variances or disturbance responses of ecosystem properties, are not more common than performance effects of biodiversity, i.e. effects on means of ecosystem properties ($F_{1,444} = 0.09$, $P = 0.75$).

DISCUSSION

The database assembled here clearly contains an over-representation of some ecosystem types and ecosystem properties, especially grasslands and primary production measures. It is not surprising that experimental grassland plots are often used as model systems in biodiversity studies, because grassland is a widespread system, experiments can be relatively easily set up at constant total density (as opposed to microcosms with strong population dynamics),

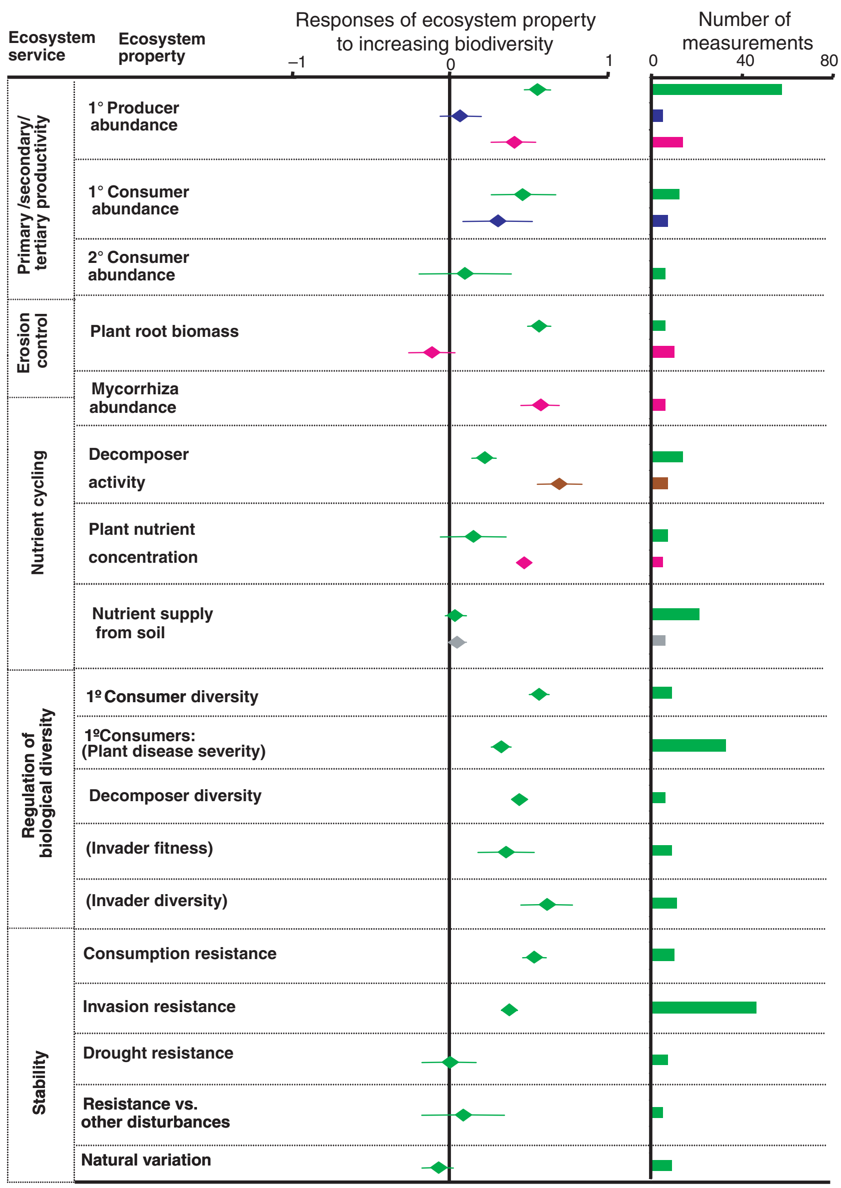

Figure 3 Magnitude and direction of biodiversity effects (shown are mean values and SE of normalized effect sizes Z_r, weighted by the reciprocal of the variance of the individual Z_r-values) and number of measurements available for ecosystem properties organized into ecosystem services. Coloured bars show differential effects of trophic level manipulated: green, primary producers; blue, primary consumers; pink, mycorrhiza; brown, decomposer; grey, multitrophic (multiple levels simultaneously manipulated). Ecosystem properties shown in parentheses were considered of negative value for human well being, and thus opposite of effect sizes are shown.

yet they do not require very large areas (as opposed to forests). In addition, primary productivity plays a major role in delivering a wide range of ecosystem services. Nevertheless, future biodiversity experiments should embrace a broader range of systems, properties and trophic levels if the generality of these relationships is to be established. In particular, a recent experiment that came to light after our analysis was carried out (Bell *et al.* 2005), suggests that bacterial systems hold great promise for future research of biodiversity effects on ecosystem functioning.

Notwithstanding this heterogeneity in the database, our analyses indicate an overall significant positive effect of biodiversity on ecosystem processes. We do not believe that this represents a publication bias towards positive effects, because finding a significantly negative effect would be just as interesting and just as likely to be reported. Nevertheless, there was significant variation between studies in the magnitude and direction of biodiversity effects, attributable mainly to specifics of experimental design and the ecosystem properties measured, as also argued in qualitative reviews (Hooper *et al.* 2005).

Specifics of experimental design and ecosystem properties

A large number of negative effects were associated with population-level measures, whilst positive effects were associated with community-level measures. This result provides perhaps the strongest empirical evidence to date for the prediction that individual populations are expected to fluctuate more with increasing biodiversity, but the community stability and productivity should be enhanced (May 1981; Tilman 1996).

In contrast to the outcomes of qualitative reviews (Hooper *et al.* 2005), we could not find a simple dependence of biodiversity effects on the trophic levels manipulated or measured. However, we did find productivity-related biodiversity effects that declined with increasing number of trophic links between those trophic levels which were manipulated and those at which the property was measured. This intuitively compelling result has never been reported before. It is clear that experiments need to be extended beyond the single trophic level approach to better understand such variations in biodiversity effects across an ecosystem (Petchey *et al.* 2002; Raffaelli *et al.* 2002).

Variation in biodiversity effects among study sites and references suggest that local environmental or specific unrecognized experimental factors may either increase or decrease biodiversity effects. Previous work (Hector *et al.* 1999) had already indicated important influences of location on biodiversity effects. The additional variation among references within study sites, which actually made the variation between sites non-significant, is reported here for the first time.

Sufficient information is not available to permit analysis of biodiversity-modifying factors, such as nutrient levels or elevated CO_2 (Hooper *et al.* 2005), but it is clear that biodiversity effects are significantly weaker in less-controlled experimental systems. Indeed, it is much more difficult to maintain diversity treatments on open field plots than in closed bottles; environmental heterogeneity, unpredictable biotic and abiotic environmental fluctuations and sampling variances are greater in the former. Thus, while our results would suggest that further research under controlled conditions is needed to improve our understanding of biodiversity effects on ecosystem functioning, extrapolation of those results to the larger landscape scale is likely to be hindered by the greater environmental heterogeneity and its effects on ecosystem functioning (Loreau *et al.* 2001; Hooper *et al.* 2005). In this respect, field experiments are likely to be more meaningful for extrapolation to the landscape scales at which humans impact on biodiversity and hence service delivery. On the other hand, in a recently constructed grassland experiment in Jena, Germany, Rosher *et al.* (2005) found a similar plant diversity–productivity relationship in small plots of 12.25 m^2 and in plots more than 30 times larger (400 m^2).

The effect on our understanding of the relationship between biodiversity and ecosystem functioning of differences in the way biodiversity is manipulated, how experiments are set up, and how response variables are measured in such experiments has been much debated (Schmid *et al.* 2002; Lepš 2004). Different experimental designs and setups are acknowledged to have their own advantages and shortcomings; but the present analysis has allowed a formal assessment of the degree to which these really are important. Surprisingly, we found no significant differences between those experiments where diversity was manipulated directly and those involving indirect manipulations by altering environmental conditions. However, there was clear evidence in favour of substitutive designs with control for constant total density of individuals at the start of an experiment. If total density is allowed to vary, in most cases in parallel with species richness, larger effects are seen, but one cannot unequivocally attribute them to biodiversity or density. In other words, such experiments are confounded.

Using a large number of species at the highest diversity levels of an experiment increases the chances of detecting biodiversity effects, although this must be weighed up against the increased work involved in setting up such an experiment. Nevertheless, there is a clear need to include higher levels of species richness in experiments. Unfortunately, interesting new simulation and empirical studies which used non-random extinction scenarios (Raffaelli 2004; Solan *et al.* 2004; Zavaleta & Hulvey 2004; Bunker *et al.* 2005; Schläpfer *et al.* 2005; Srivastava & Vellend 2005) could not be included in our analysis because they were published after our analyses were complete.

An important question when designing a biodiversity–ecosystem functioning experiment is what expression of diversity to manipulate: richness, evenness or functional groups? The literature is somewhat divided on this issue (Díaz & Cabido 2001; Loreau *et al.* 2001; Hooper *et al.* 2005; Petchey & Gaston 2006; Wright *et al.* 2006), but the predominant view is that functional groups may be more important than species richness, consistent with our own findings.

Biodiversity–ecosystem service relationships

Where ecosystem properties could be related to ecosystem services (Srivastava & Vellend 2005), clear positive effects of biodiversity were found, for both regulating and supporting services. Nevertheless, our ability to make these linkages at spatial (landscape) scales relevant to the human enterprise is limited at present (Kremen 2005). There is an urgent need to extend experimental, observational and theoretical work on biodiversity effects for an array of ecosystem functions that can be linked to ecosystem services, such as water quantity and quality, pollination, regulation of pests and human diseases, carbon storage and climate regulation, waste management and cultural services, and to evaluate biodiversity–ecosystem service relationships at the larger spatial scales relevant to management (Kremen *et al.* 2004; Balvanera *et al.* 2005).

The role of biodiversity in buffering environmental variation and thus providing consistent service delivery has received extensive theoretical treatment (Tilman 1996; Yachi & Loreau 1999; Hooper *et al.* 2005). In general, a positive effect of biodiversity is expected on the stability of ecosystem properties (Tilman 1996; Naeem & Li 1997; Yachi & Loreau 1999; Hooper *et al.* 2005), and qualitative reviews have suggested that such effects on the variance in processes (stability) may be stronger than the effects on means (stocks and fluxes; Srivastava & Vellend 2005). The quantitative results from our meta-analysis do not support this view, rather indicating that biodiversity effects on disturbance buffering are dependent on the nature of the disturbance. Thus, while biodiversity effects on buffering of nutrient perturbations and invading species were positive, biodiversity effects on buffering influences of warming, drought or high environmental variance were neutral or slightly negative.

CONCLUSIONS

Whilst there are many qualitative reviews and position statements about the effects of biodiversity on ecosystem properties and services, our analysis provides the first extensive quantitative meta-analysis of this relationship. This analysis suggests that simple generalizations among ecosystem types, ecosystem properties or trophic level manipulated or measured will be difficult to sustain. Considerations of the way in which biodiversity is defined and manipulated, and disentangling the many separate effects and the interactions between them, as well as those with environmental heterogeneity, will be a major challenge for the next generation of experiments. We offer our database (*Supplementary material*) as a building block for continued synthesis attempts. The advantages of a formal meta-analysis are illustrated by the following novel contributions we have been able to bring to the synthesis: (i) biodiversity effects are weaker if biodiversity manipulations are less well controlled (e.g. field vs. greenhouse or climate chamber); (ii) biodiversity effects are weaker if the highest diversity levels in an experiment are lower (e.g. ≤ 10 vs. > 10 species); (iii) biodiversity experiments should avoid confounding diversity and total density (they should use a substitutive design); (iv) biodiversity effects are weaker at the ecosystem than the community level and negative at the population level; (v) productivity-related biodiversity effects decline with increasing number of trophic links between level manipulated and level measured; (vi) biodiversity effects on stability measures are not obviously stronger than biodiversity effects on performance measures.

There are clear messages for policy makers from these analyses. First, for those ecosystem services that could be assessed in the present study, there is clear evidence that biodiversity has positive effects on the provision of those services and that further biodiversity loss can only be expected to compromise service delivery. Secondly, whilst further research is needed to confirm such linkages, in particular to extend the work to a broader range of systems and properties, society in the meantime should proceed in a precautionary manner in its use and management of biodiversity.

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SUPPLEMENTARY MATERIAL

The following supplementary material is available for this article:

Appendix S1 Literature used for the meta-analysis.
Table S1 Database used in the meta-analysis.

This material is available as part of the online article from: http://www.blackwell-synergy.com/doi/full/10.1111/j.1461-0248.2006.00963.x

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