Vital Signs Trade-Offs Workshop: Review of selected research at ORNL

Oxford, United Kingdom
5-7 February, 2014

Keith L Kline klinekl@ornl.gov

Environmental Science Division
Climate Change Science Institute
Oak Ridge National Laboratory
Oak Ridge, Tennessee
http://www.ornl.gov/sci/ees/cbes/

With special acknowledgement to Virginia Dale and Esther Parish for content. Thanks to Conservation International and the Gates Foundation (sponsors) and to DOE for ongoing research support.

U.S. DEPARTMENT OF ENERGY

Climate Change Science Institute
AT OAK RIDGE NATIONAL LABORATORY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Different tools for different purposes (see Fact sheet)

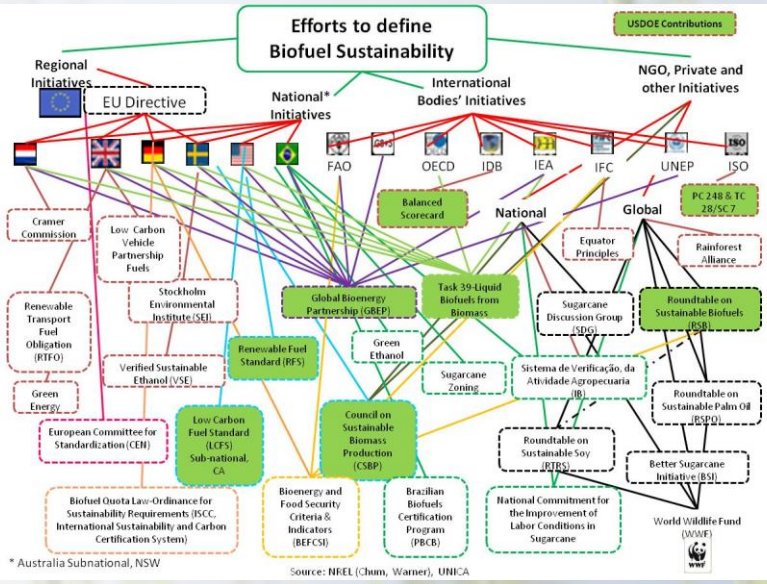
- BLOSM (Biomass Location for Optimal Sustainability Model) – watershed/regional scale (Parish et al. 2012)
- POLYSYS (Policy Analysis System) – agriculture and forestry, partial equilibrium model; county-national scale
- GTAP (Global Trade Analysis Project) general equilibrium model; global economy scale
- Causal Analysis applied to land-cover change – multiple scales
- EPIC (Environment Policy Integrated Climate) biophysical model with environmental elements, multiple scales
- SWAT (Soil and Water Assessment Tool) – watershed scale
- Indexed Decomposition Analysis: statistical approach to examine relationships among factors within a system
- DELTA (Dynamic Ecological- Land Tenure Analysis) – state, regional scale
- RSim (Regional simulator) resource use and constraints in a five-country region
- BioLUC, a dynamic land change model based on the STELLA platform, global

Sustainable design approaches

- Stakeholder engagement to define problem, goals and priorities, assess options, and validate proposed solutions
  - Define sustainability objectives, specifying spatial and temporal scales
  - Consider constraints and opportunities
  - Apply tools to obtain range of solutions
  - Analyze trade-offs and complementarities
  - Extract general rules
  - Monitor to guide further improvements over time
- Use of indicators to measure change

Multiple initiatives are exploring indicators for sustainability – e.g. for bioenergy…

- ISO (International Organization for Standardization)
- GBEP (Global Bioenergy Partnership)
- CSBP (Council on Sustainable Biomass Production)
- RSB (Roundtable on Sustainable Biofuels)
- Many more



BUT

- Some indicators focus on management practices although knowledge is limited about which practices are "sustainable"
- Implementation is limited by indicators being too
  - ✓ Numerous
  - ✓ Broad
  - ✓ Costly
  - ✓ Difficult to measure

ORNL Approach to Assessing Bioenergy Sustainability in Support of Department of Energy

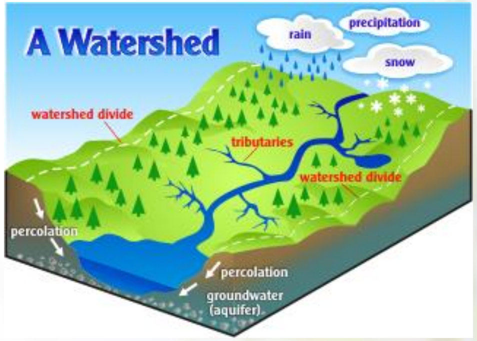
Select Indicators

Establish baselines and targets

Evaluate indicator values

Identify trends and tradeoffs

Develop and test best practices



Sustainability Indicators

A measurement that provides information about the effects of human activities on the environment, society or economy.

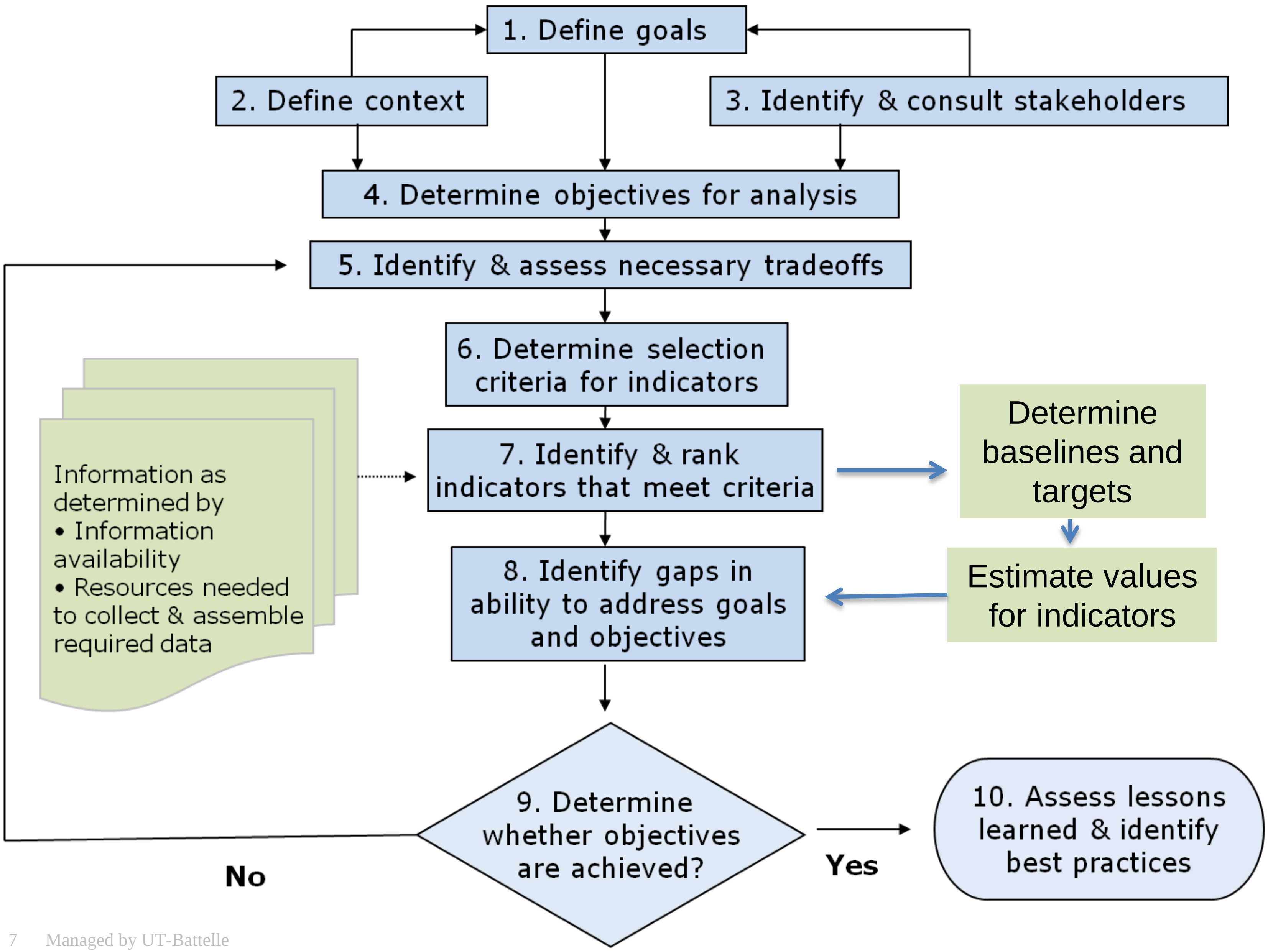
Indicators should be

- Useful
  - Policymakers
  - Producers
- Technically effective
  - Sensitive to stresses on system
  - Anticipatory: signify impending change
  - Have known variability in response
- Practical
  - Easily measured
  - Consider context of measure
  - Broadly applicable
  - Predict changes that can be averted by management actions

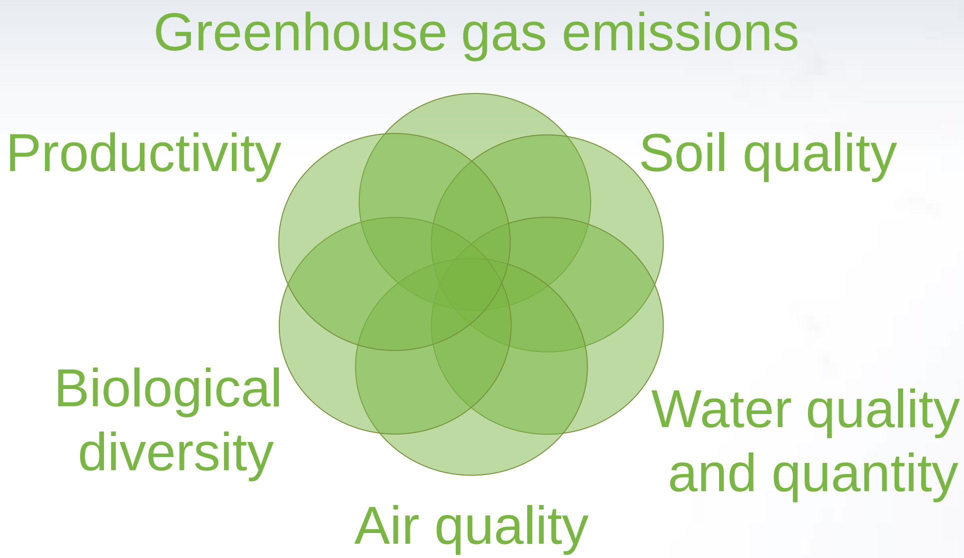
Dale and Beyeler. 2001. Challenges in the development and use of ecological indicators. *Ecological Indicators* 1: 3-10.

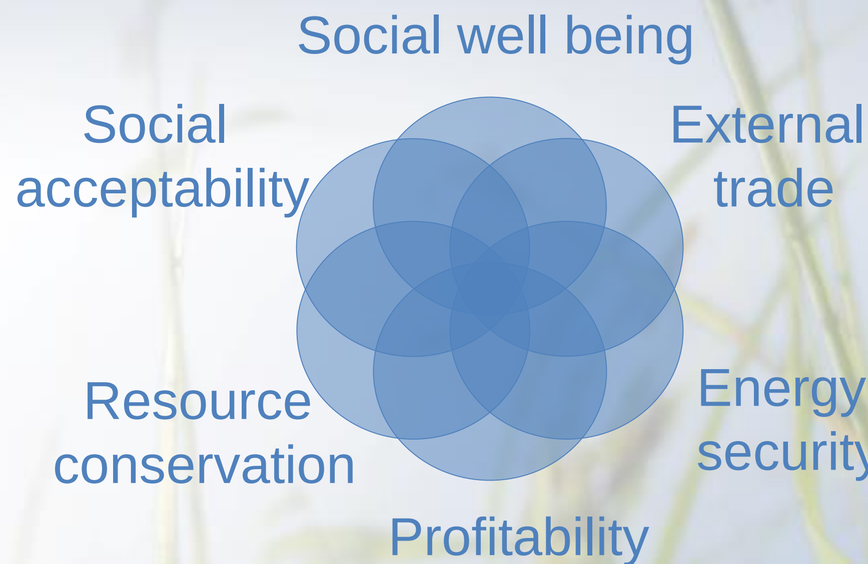
Oak Ridge National Laboratory

Framework for Using Indicators to Assess Issues



Categories for indicators of environmental and socioeconomic sustainability





McBride et al. (2011)
Ecological Indicators
11:1277-1289

Dale et al. (2013)
Ecological Indicators
26:87-102.

Recognize that measures and interpretations are <u>context</u> specific

Efroymson et al. (2013) ***Environmental Management*** **51:291-306.**

Categories of environmental sustainability indicators

Environment	Indicator	Units
Soil quality	1. Total organic carbon (TOC)	Mg/ha
	2. Total nitrogen (N)	Mg/ha
	3. Extractable phosphorus (P)	Mg/ha
	4. Bulk density	g/cm^3
Water quality and quantity	5. Nitrate concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	6. Total phosphorus (P) concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	7. Suspended sediment concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	8. Herbicide concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	9. storm flow	L/s
	10. Minimum base flow	L/s
	11. Consumptive water use (incorporates base flow)	feedstock production: m^3/ha/day; biorefinery: m^3/day

Environment	Indicator	Units
Greenhouse gases	12. CO_2 equivalent emissions (CO_2 and N_2O)	kgC_{eq}/GJ
Biodiversity	13. Presence of taxa of special concern	Presence
	14. Habitat area of taxa of special concern	ha
Air quality	15. Tropospheric ozone	ppb
	16. Carbon monoxide	ppm
	17. Total particulate matter less than 2.5μm diameter ($PM_{2.5}$)	$\mu g/m^3$
	18. Total particulate matter less than 10μm diameter (PM_{10})	$\mu g/m^3$
Productivity	19. Aboveground net primary productivity (ANPP) / Yield	gC/m^2/year

McBride et al. (2011) *Ecological Indicators* 11:1277-1289

Categories of socioeconomic sustainability indicators

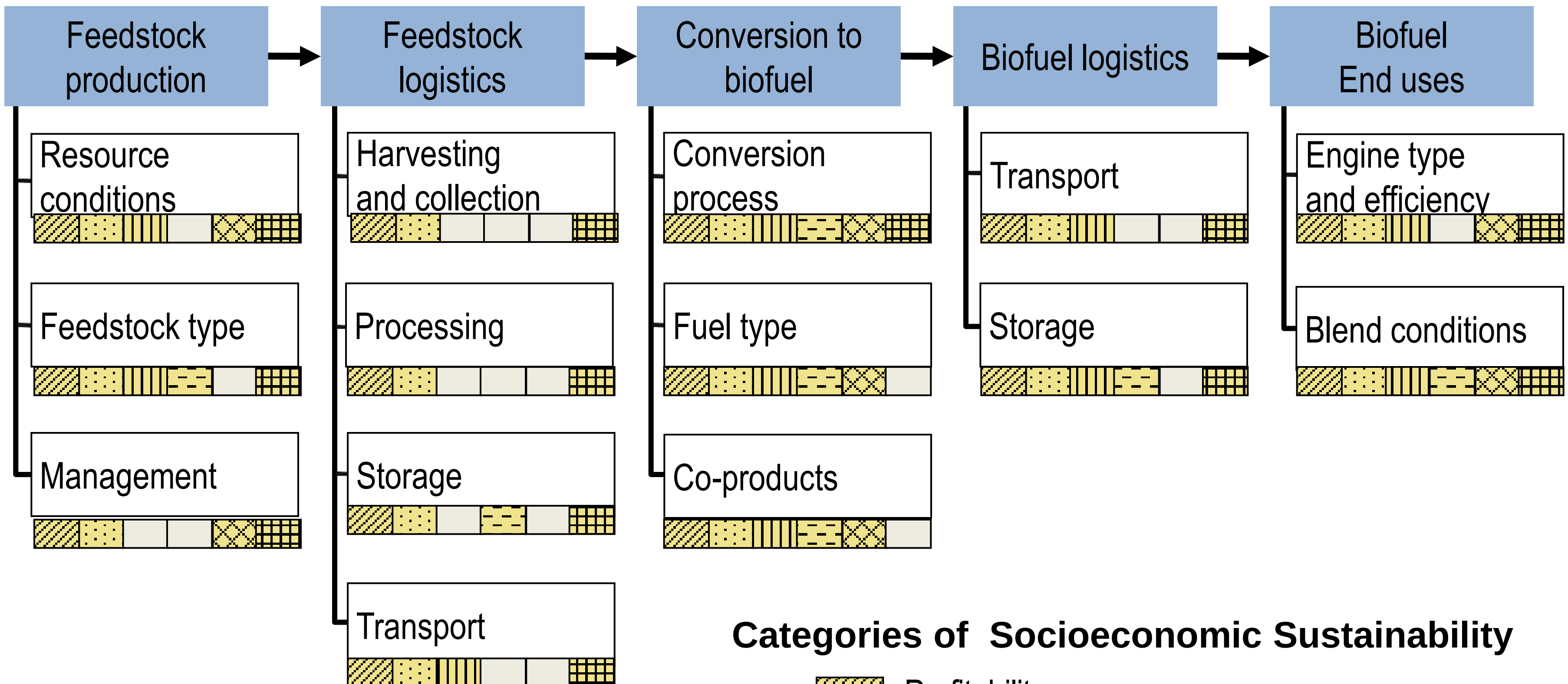
Ten minimum practical measures

Category	Indicator	Units
Social well-being	Employment	Number of full time equivalent (FTE) jobs
	Household income	Dollars per day
	Work days lost due to injury	Average number of work days lost per worker per year
	Food security	Percent change in food price volatility
Energy security	Energy security premium	Dollars /gallon biofuel
	Fuel price volatility	Standard deviation of monthly percentage price changes over one year
External trade	Terms of trade	Ratio (price of exports/price of imports)
	Trade volume	Dollars (net exports or balance of payments)
Profitability	Return on investment (ROI)	Percent (net investment/ initial investment)
	Net present value (NPV)[2]	Dollars (present value of benefits minus present value of costs)

Category	Indicator	Units
Resource conservation	Depletion of non-renewable energy resources	MT (amount of petroleum extracted per year)
	Fossil Energy Return on Investment (fossil EROI)	MJ (ratio of amount of fossil energy inputs to amount of useful energy outputt
Social acceptability	Public opinion	Percent favorable opinion
	Transparency	Percent of indicators for which timely and relevant performance data are reported
	Effective stakeholder participation	Number of documented responses to stakeholder concerns and suggestions reported on an annual basis
	Risk of catastrophe	Annual probability of catastrophic event

Dale et al. (2013) ***Ecological Indicators*** **26:87-102.**

Looking at the biofuel supply chain in terms of socioeconomic sustainability indicators



Categories of Socioeconomic Sustainability

- Profitability
- Social well being
- External trade
- Energy security
- Resource conservation
- Social acceptability
- Categories without major effects

Dale et al. (2013) ***Ecological Indicators*** **26: 87-102.**

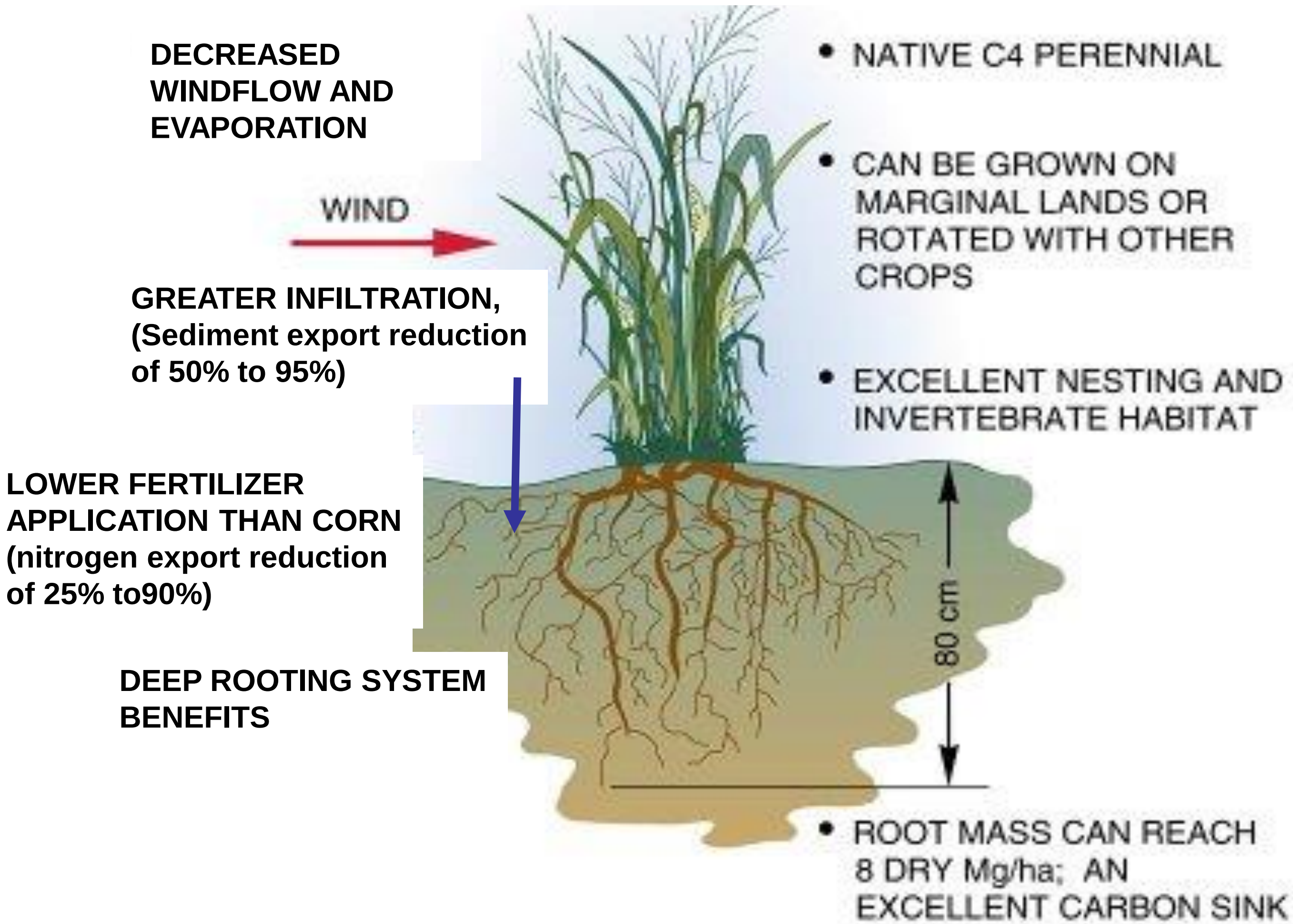
Adapting Suite to Particular Contexts

- **Indicator set is a starting point for sake of efficiency and standardization**
  - Particular systems may require addition of other indicators
  - Budget may require subtraction of some indicators
  - Some indicators more important for different supply chain steps
- **Protocols must be context-specific**

Interpreting Suite as a Whole

- Indicators constitute an integrated suite
- Multivariate statistical methods should be applied to measured values.
- Provide insights for tradeoffs in decision-making.

BLOSM Case Study: Switchgrass (native perennial crop) Different crops will be appropriate for different conditions



Dale et al. (2011) *Ecological Applications* 21(4):1039-1054.

Assessing multiple effects of bioenergy choices

An optimization model identifies “sustainability conditions when using switchgrass in east Tennessee

Spatial optimization model

- Identifies where to locate plantings of bioenergy crops given feedstock demand from Vonore refinery
- Considering
  - Farm profit
  - Water quality constraints

Parish et al., *Biofuels, Bioprod. Bioref*. 6,58–72 (2012)

Soil and Water Assessment Tool (SWAT model)

Input data

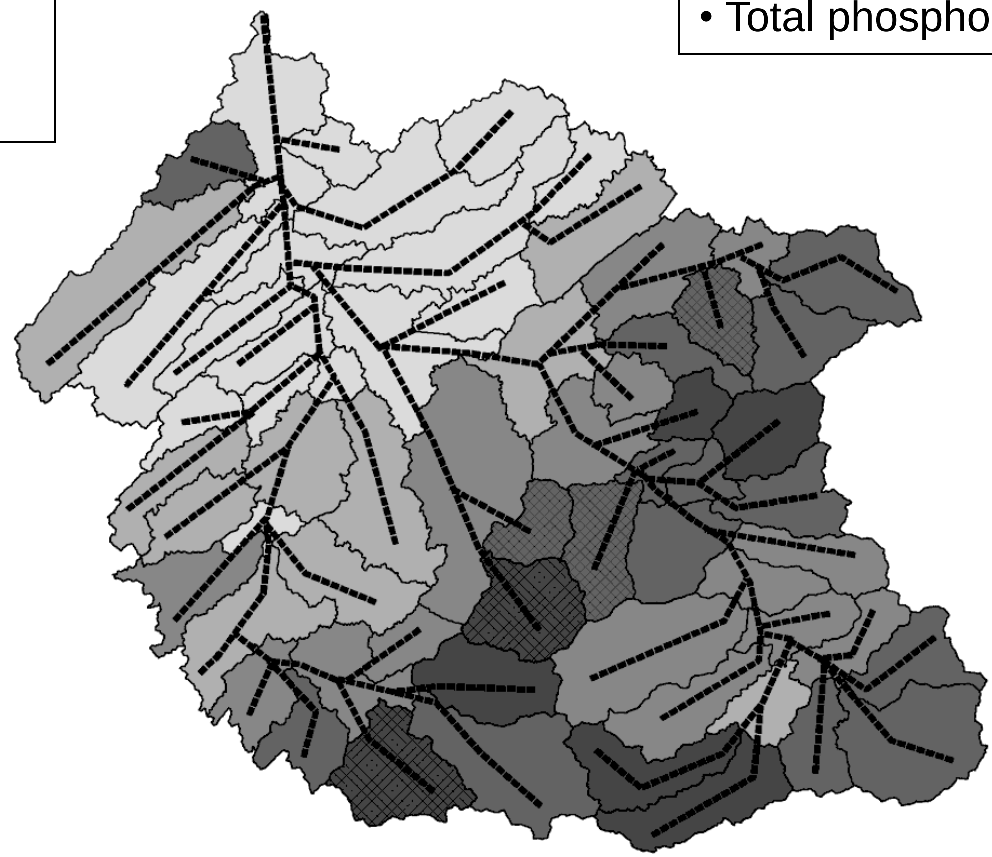
- Existing land cover
- Soil type
- Elevation/slope
- Hydrology
- Prevailing climate
- Parameters for modeling perennial switchgrass growth
- Management (e.g., fertilizer use)
- Network of sub-basins

Soil and Water Assessment Tool (SWAT)

Results from paired subbasin runs on ORNL's supercomputer for conversion of HRUs* to switchgrass:

- Total sediment
- Total nitrogen
- Total phosphorous

SWAT defines a hydrologic response unit (HRU) as a unique combination of land cover, soil and slope class within a subbasin.



Hydrologic/economic optimization model interface

Input data
- Existing land cover
- Soil type
- Elevation/slope
- Hydrology
- Prevailing climate
- Parameters for modeling perennial switchgrass growth
- Management (e.g., fertilizer use)
- Network of sub-basins

Soil and Water Assessment Tool (SWAT)

Results from paired subbasin runs on ORNL's supercomputer for conversion of HRUs* to switchgrass:
- Total sediment
- Total nitrogen
- Total phosphorous

Policy Analysis System (POLYSYS)

County values for crop
- Price

Switchgrass field trials (Jager et al. 2010)
- Yield

Objective functions can consider
- ✓ Farm profit
- ✓ Water quality impacts at sub-basin level
  - Total nitrogen concentration
  - Total phosphorus concentration
  - Total sediment concentration

Assumptions
- ✓ Convert only agricultural or pasture land
- ✓ Meet switchgrass production target

Biomass Location for Optimal Sustainability Model (BLOSM)

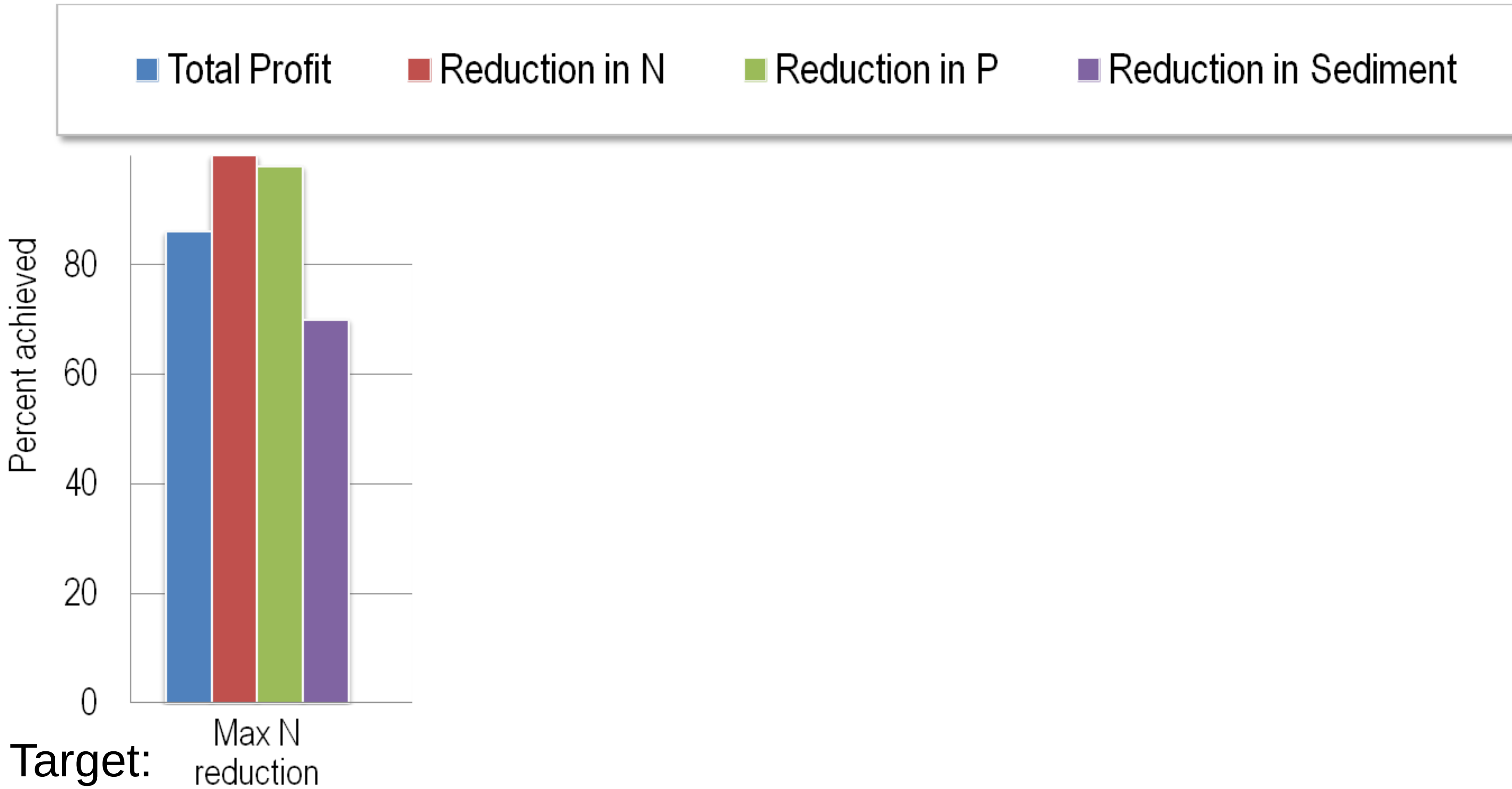
Parallel runs of 63 catchments on an ORNL supercomputer examined effects of converting individual HRUs to switchgrass

Optimal locations for planting bioenergy crops

* Note that SWAT defines a hydrologic response unit (HRU) to be a unique combination of a land cover, soil and slope class within a subbasin.

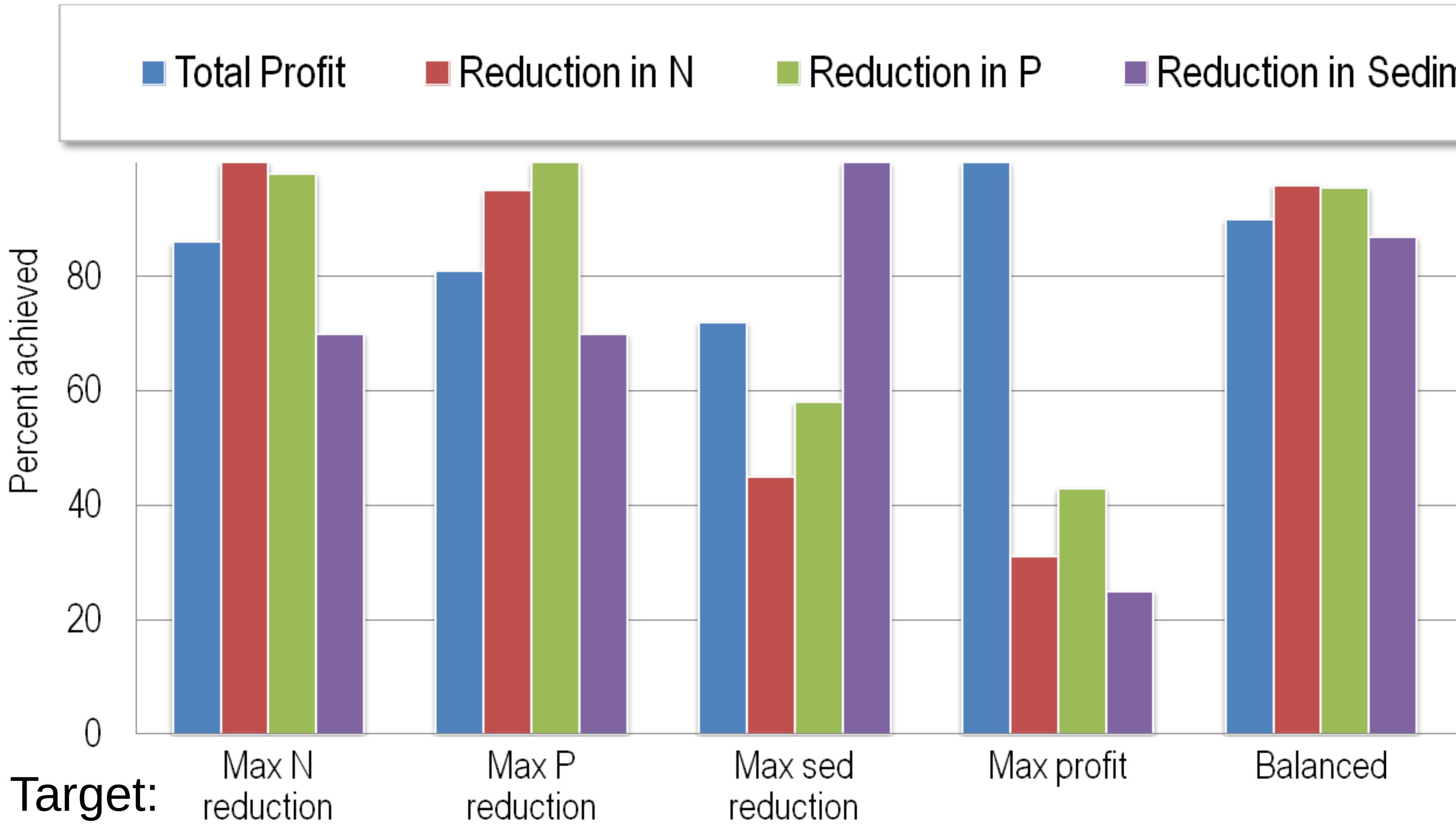
See: Parish et al. 2012. Biofuels, Bioprod. Bioref. 6(1):58-72.

Balancing objectives: Design of cellulosic bioenergy crop plantings may both improve water quality and increase profits while achieving a feedstock-production goal



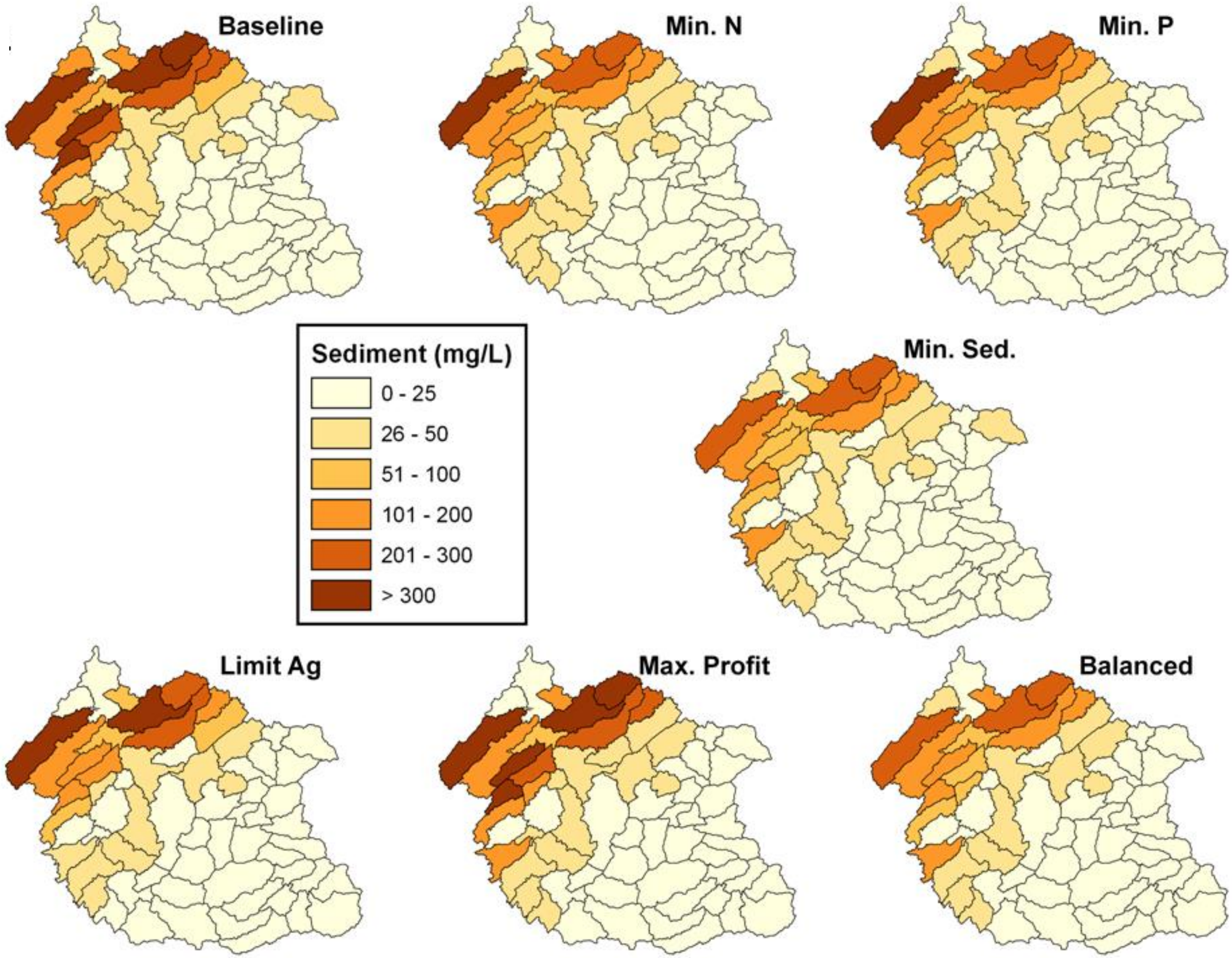
Target:

Balancing objectives: Design of cellulosic bioenergy crop plantings may both improve water quality and increase profits while achieving a feedstock-production goal



Modeled acreage for switchgrass in this watershed:
1.3% of the total area (3,546 ha of 272,750 ha)

Projected sediment concentrations under 6 BLOSM scenarios



But measuring water quality is costly and difficult

Consider indirect measures:

Land-use change

↓

Changes in water quality

↓

Changes in habitat

↓

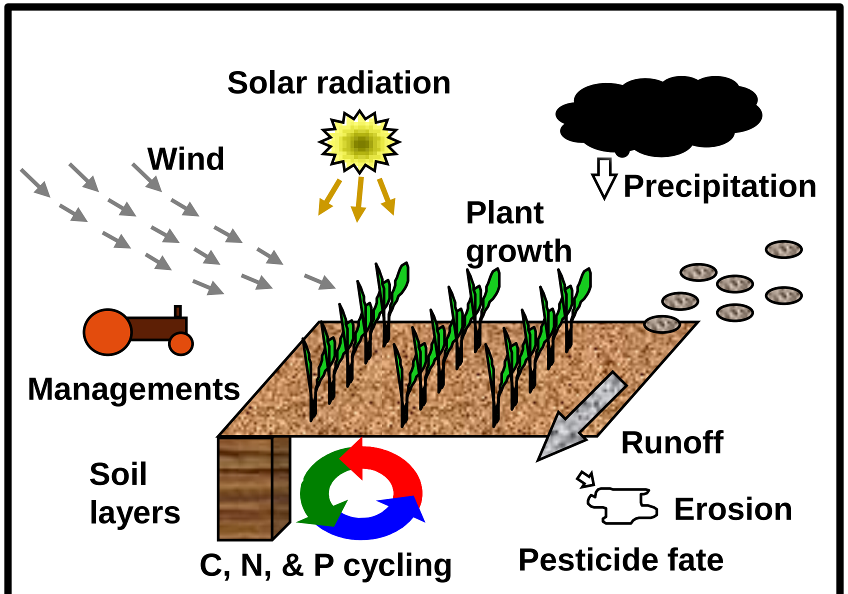
Changes in macroinvertebrate species

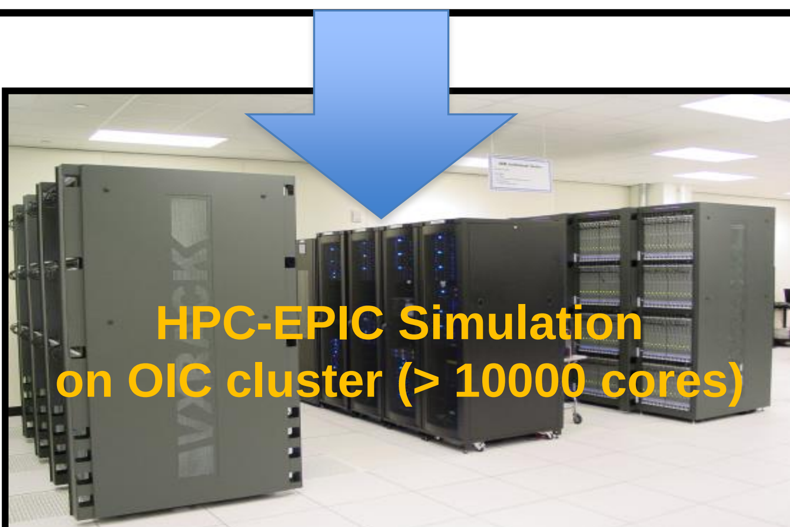
EPT richness = number of distinct taxa in the insect orders:

- Ephemeroptera (mayflies)
- Plecoptera (stoneflies)
- Trichoptera (caddisflies)

Managed by UT-Battelle
for the U.S. Department of Energy

Environment Policy Integrated Climate (EPIC) Model (or mpi_EPIC; Kang et al. in prep.)





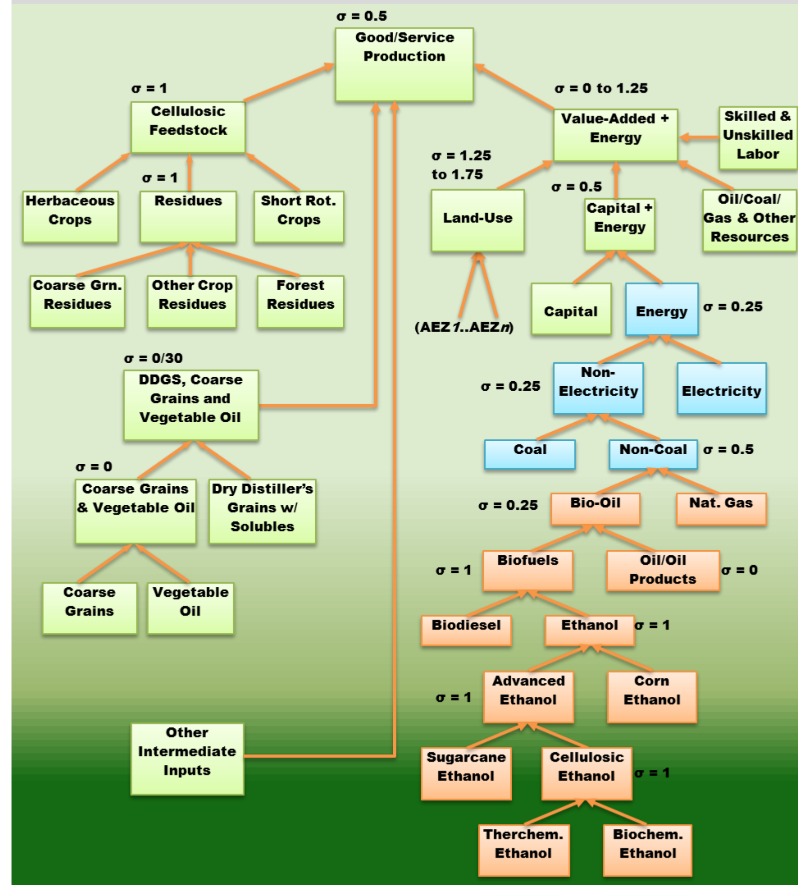
- Developed by USDA in 1980s
- EPIC continually improved over 30 years
- Model for BMPs used by USDA-NRCS
- Calibrated for 94 food & bioenergy crops, tested in over 60 countries / regions
- Key processes simulated
  - ✓ Plant growth and yield
  - ✓ Management: tillage, fertilizers, irrigation, pesticides
  - ✓ Water balance; irrigation, drainage
  - ✓ Carbon cycling, including eroded carbon
  - ✓ Nitrogen cycling
  - ✓ Erosion by wind and water
  - ✓ Nonpoint source (NPS) pollutant fate
  - ✓ GHG emission

Overview of the GTAP-DEPS model framework

(Debo Oladosu)

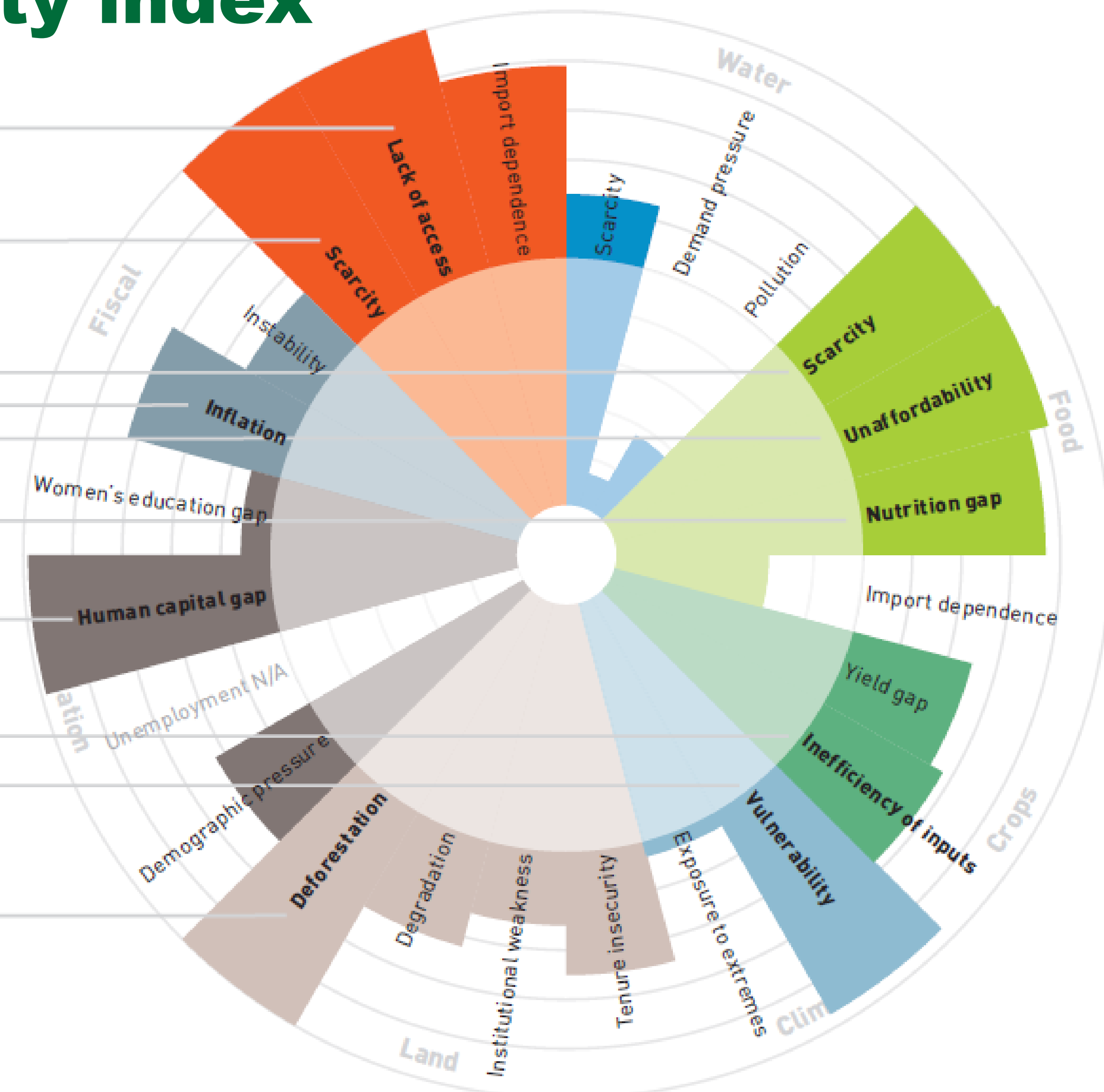
- GTAP-DEPS* is a version of the GTAP general equilibrium framework
- Model dimensions:
    - 33 Sectors; 18 Regions; 2001-2030
- Major enhancements
    - Land supply/demand sub-models with 3 sources of yield change
    - Oil, gas and coal supply curves
    - Explicit dynamics: 2001-2030
    - US Biomass supply curves based on Billion Ton Update (POLYSYS)
- Modeling of biofuel policy reflects its implementation as a mandate – without new taxes or subsidies

Production structure in GTAP-DEPS



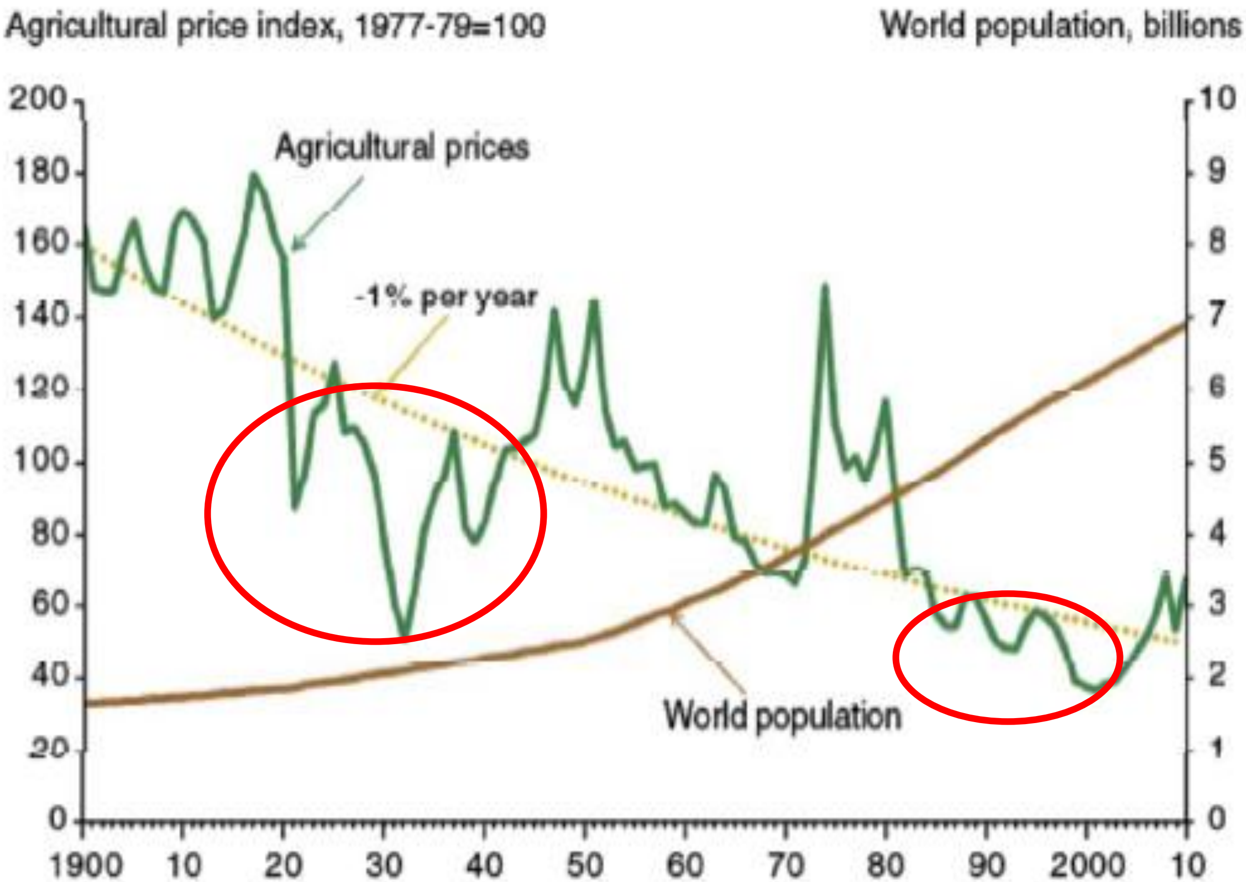
*GTAP-DEPS:GTAP for Dynamic Energy Policy Simulations (see Oladosu, 2012; Oladosu et al, 2012). The standard GTAP (Global Trade Analysis Program) model is described in Hertel et al., 1997)

Earth security index



Tanzania

Real agricultural prices have fallen since 1900, even as world population growth accelerated



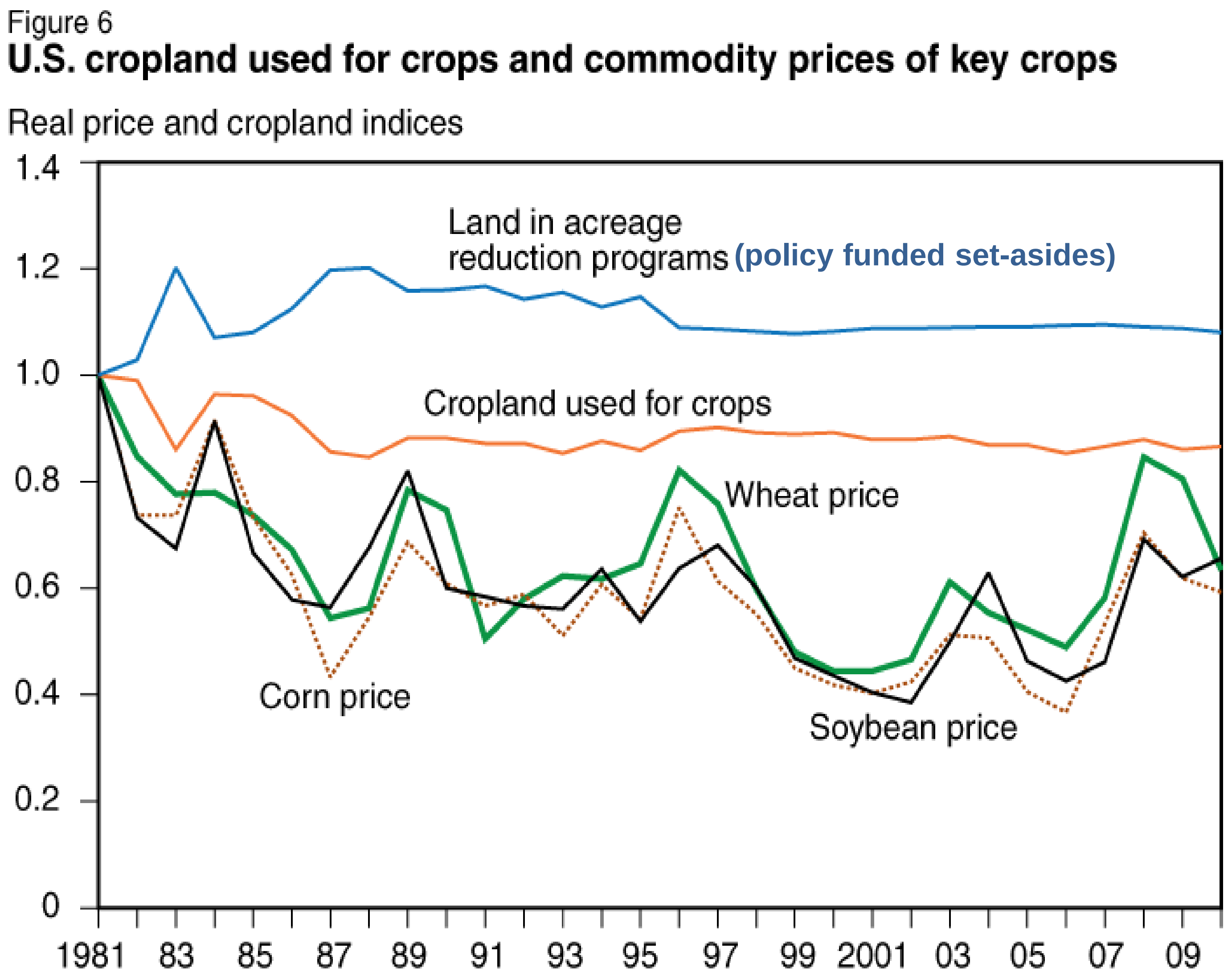
Source: USDA, Economic Research Service using Fuglie, Wang, and Ball (2012). Depicted in the chart is the Grilli-Yang agricultural price index adjusted for inflation by the U.S. Gross Domestic Product implicit price index. The Grilli-Yang price index is a composite of 18 crop and livestock prices, each weighted by its share of global agricultural trade (Pfaffenzeller et al., 2007). World population estimates are from the United Nations.

Consider historic data and trends

What drives destructive land transitions?

Crop prices?

Check assumptions about price/LUC



Source: USDA ERS 2011. http://www.ers.usda.gov/publications/eib89/

Contrary to some modeling assumptions, in the US, expectations of commodity prices and risk affect choices of ***what*** to grow on previously defined agricultural landscapes, not ***how much*** **total area** is dedicated to agriculture

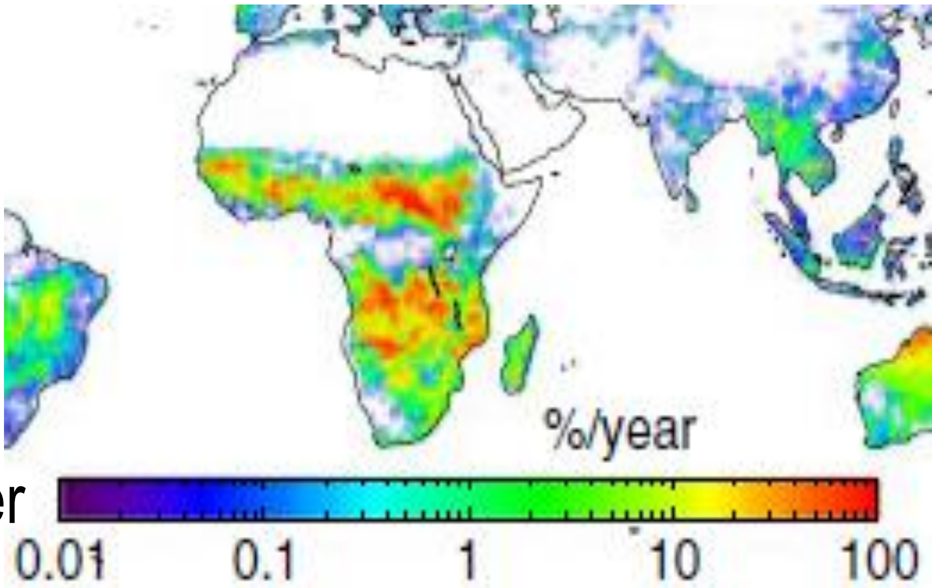
"I sense a great disturbance in the force"

- Volcanic eruption
- Earthquake
- Tsunami
- Invasive species/ pests/ disease
- Drought/flood/ice storm
- Hurricane, "derecho" blowdowns
- Wildfires…

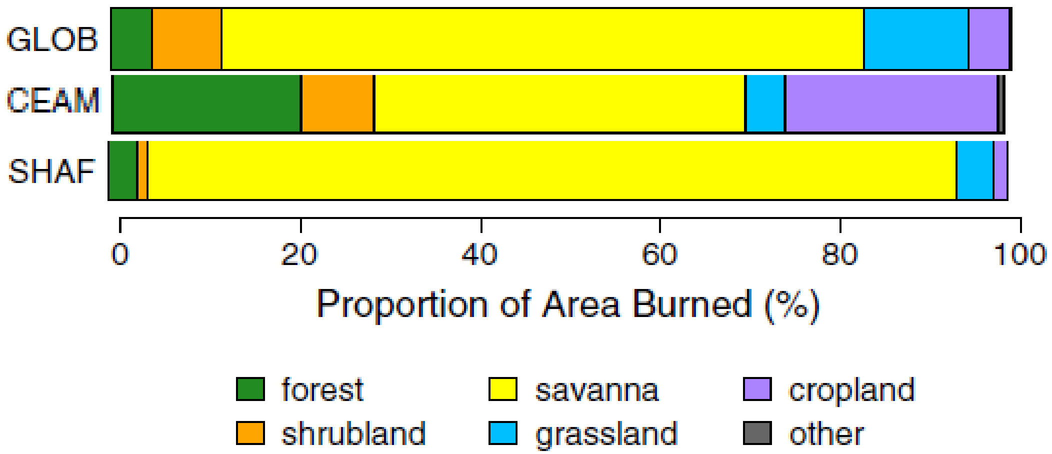
Disturbances – absent from most models – have significant influence on some sustainability indicators

Fire and global burned areas

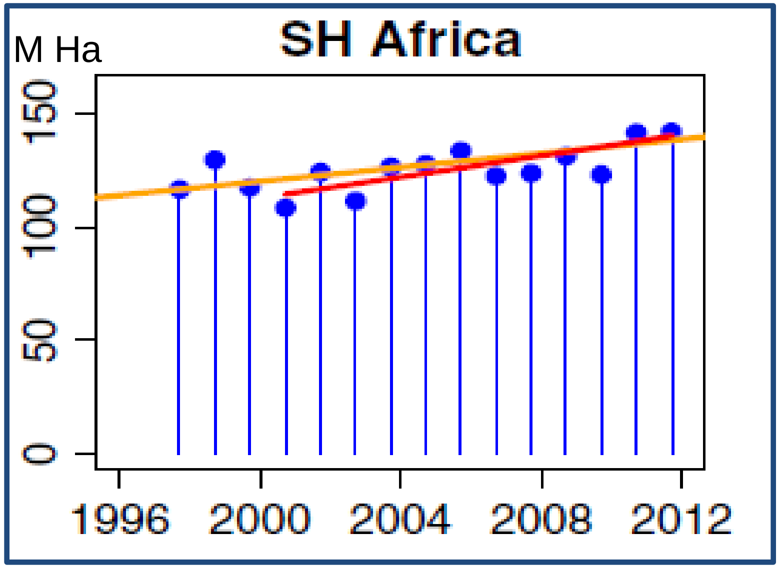
- Estimates of annual burned area
  - 350 Mha (Giglio et al. 2013 using GFED4; avg. for 1997-2011)
  - Including small fires adds 35% = Total est. 450 Mha (Randerson 2013)
- Most in Africa savannah
- Some areas burn multiple times per year



% of grid cell that burns annually



GLOB = Global; CEAM = Central America;
SHAF = Southern Hemisphere Africa

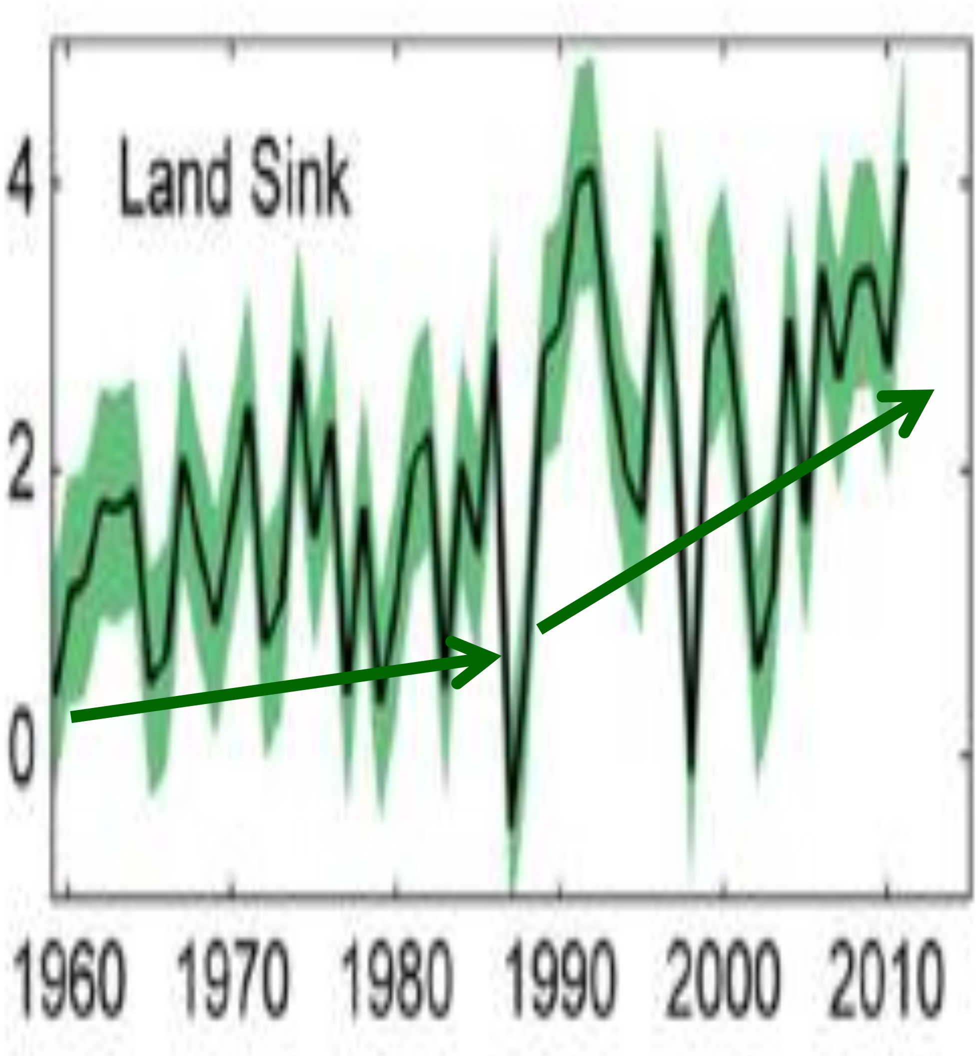


 Managed by UT-Battelle
for the U.S. Department of Energy

Fires in Africa in Sept 2013 (NASA Earth Observations)

http://earthobservatory.nasa.gov/GlobalMaps/view.php?d1=MOD14A1_M_FIRE

- 74% of NW and Central Mozambique (savannah, shrub) and over 40% of total national territory burn each year (Taquidir 1996 – based on satellite analysis).
- Recent research suggests the satellite analysis understates fire area due to exclusion of small agricultural fires (Randerson 2012)



Opportunity:

Improve NET land SINK via management.

Investment in management requires incentives.

Integrated development for energy and food security, perhaps?

Source: Global Carbon Project 2013

Global scale modeling using EPIC: simulations require data for validation and calibration of environmental effects (e.g., Δ SOC)

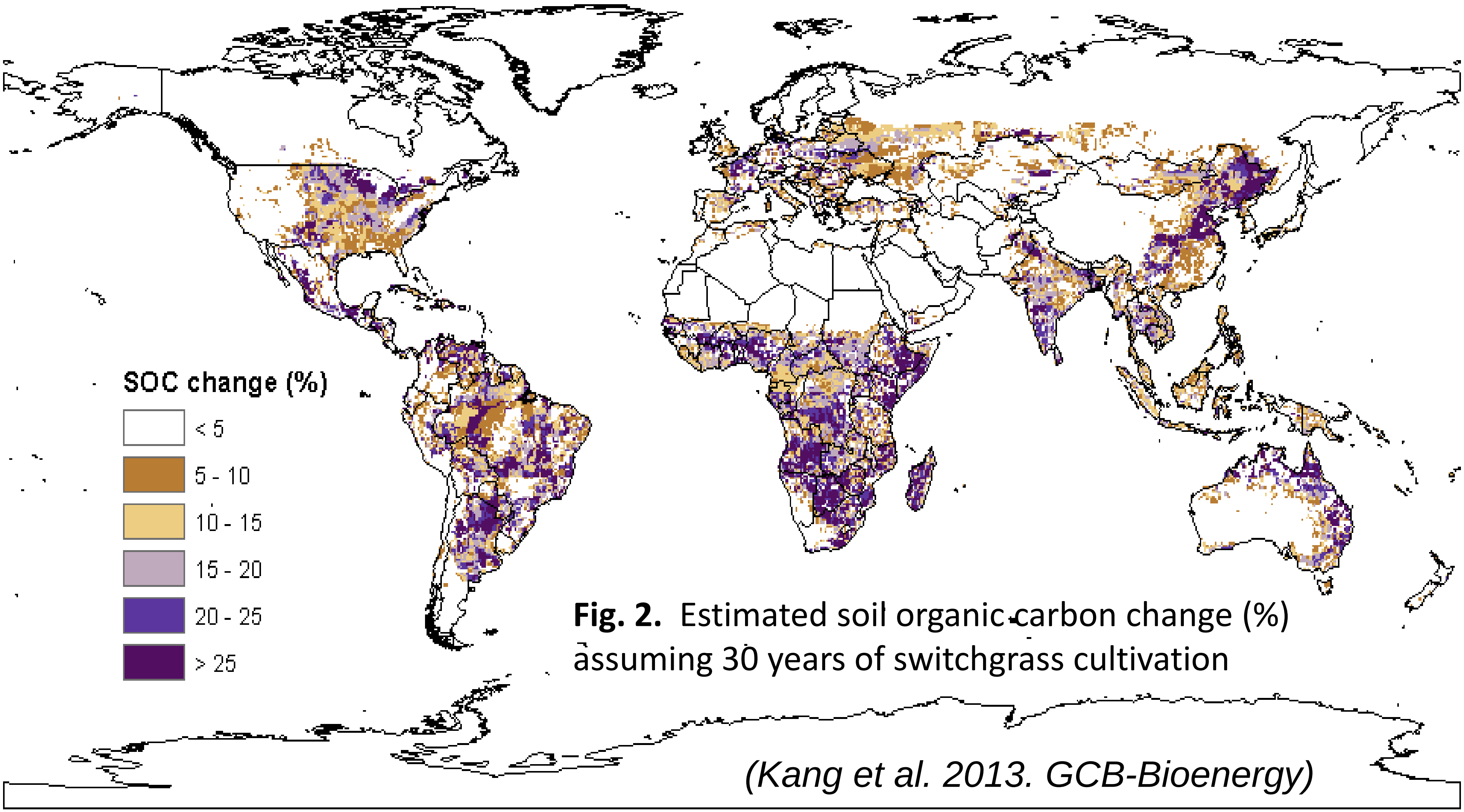


Fig. 2. Estimated soil organic carbon change (%) assuming 30 years of switchgrass cultivation

(Kang et al. 2013. GCB-Bioenergy)

Thank you!

CBES
Center for BioEnergy Sustainability

http://www.ornl.gov/sci/ees/cbes/

References

- Dale VH, SC Beyeler 2001. Challenges in the development and use of ecological indicators. Ecological Indicators 1: 3-10.
- Dale VH, R Lowrance, P Mulholland, P Robertson. 2010. Bioenergy sustainability at the regional-scale. Ecology and Society 15(4): 23. [online] URL: http://www.ecologyandsociety.org/vol15/iss4/art23/
- Dale VH, KL Kline, LL Wright, RD Perlack, M Downing, RL Graham. 2011. Interactions among bioenergy feedstock choices, landscape dynamics and land use. *Ecological Applications* 21(4):1039-1054.
- Dale, VH, RA Efroymson, KL Kline, MH Langholtz, PN Leiby, GA Oladosu, MR Davis, ME Downing, LM Eaton, MR Hilliard. In review. Indicators to support assessment of socioeconomic sustainability of bioenergy systems. Ecological Indicators.
- Efroymson, R. A., V. H. Dale, K. L. Kline, A. C. McBride, J. M. Bielicki, R. L. Smith, E. S. Parish, P. E. Schweizer, D. M. Shaw. 2012. Environmental indicators of biofuel sustainability: What about context? Environmental Management DOI 10.1007/s00267-012-9907-5
- Giglio L., J. T. Randerson, G. R. van derWerf, P. S. Kasibhatla, G. J. Collatz, D. C. Morton, and R. S. DeFries. Assessing variability and long-term trends in burned area by merging multiple satellite fire products. Biogeosciences, 7, 1171–1186, 2010.
- McBride A, VH Dale, L Baskaran, M Downing, L Eaton, RA Efroymson, C Garten, KL Kline, H Jager, P Mulholland, E Parish, P Schweizer, and J Storey. 2011. Indicators to support environmental sustainability of bioenergy systems. *Ecological Indicators* 11(5) 1277-1289.
- Parish ES, M Hilliard, LM Baskaran, VH Dale, NA Griffiths, PJ Mulholland, A Sorokine, NA Thomas, ME Downing, R Middleton. 2012. Multimetric spatial optimization of switchgrass plantings across a watershed. *Biofuels, Bioprod. Bioref*. 6(1):58-72.

Acknowledgements

<u>Collaborators include</u>
LM Baskaran, M Davis, B Davison, ME Downing, LM Eaton, RA Efroymson, C Farley, NA Griffiths, M Hilliard, H Jager, S Kang, PN Leiby, M Langholtz, LR Lynd, G Marland, A McBride, S Surendran Nair, GA Oladosu, ES Parish, RD Perlack,, T Wilbanks, SB Wright, LL Wright…

DOE OBP staff –
Z Haq, K Johnson, A Lindauer, P Grabowski, A Goss-Eng.

Other labs and organizations –
H Chum, D Inman (NREL), M Wang (ANL), MTU-PIRE project, others

CBES
Center for BioEnergy Sustainability

Climate Change Science Institute
AT OAK RIDGE NATIONAL LABORATORY

Research supported by the U.S. Department of Energy (DOE) under the Office of the Biomass Program and performed at Oak Ridge National Laboratory (ORNL). Oak Ridge National Laboratory is managed by the UT-Battelle, LLC, for DOE under contract DE-AC05-00OR22725.

The views in this presentation are those of the author who is responsible for any errors or omissions.