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Bioeconomic modelling: Integrating economic and environmental systems?

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Abstract: The term 'bioeconomic modelling' is typically used by economists to describe models that have both economic and biophysical components. Given that socio-economic analyses should be a basic part of integrated environmental assessment, it is useful to compare bioeconomic modelling and integrated environmental modelling. Traditionally, bioeconomic models are used to analyse human uses of ecosystems for production and consumption. As such, the analysis focuses on changes in a limited set of environmental indicators that matter (directly) to human beings. The normative nature of economics, and its anthropocentric focus on human welfare, risks overlooking ecosystem values that are not directly visible. Furthermore, the degree to which existing bioeconomic models incorporate ecological complexities and dynamics is typically quite limited. Although bioeconomics provides useful methods to integrate socioeconomic values into biophysical analyses, improved representation of the dynamic interrelationships between natural processes and socio-economic systems is needed to allow an integrated assessment of multiple values. This paper critically reviews the characteristics of bioeconomic models in forestry, fisheries, agricultural systems, and nonmarket valuation. I discuss how selected models represent environmental and socioeconomic systems. The overview will enable a more informed decision about whether and how bioeconomic models/modelling can contribute to the development of integrated environmental decision support tools.

***Keywords**:* Bioeconomic modelling; Economic assessment; Integration challenges

1 INTRODUCTION

Models that aim to provide environmental decision support need to allow an integrated assessment (IA) of values, be they economic, ecological or social [Rotmans and Asselt 2003]. Ideally, such decision support tools reflect the trade-offs between natural (biophysical and ecological) processes and socioeconomic systems, to help evaluate how management actions affect different policy objectives [van den Bergh et al. 2001].
In the economics literature, bioeconomic modelling is widely advocated as the paradigm to support integrated environmental management. The term 'bioeconomic' is broadly used to indicate that a model has both economic and biophysical components [Knowler 2002][1]. Bioeconomic models are extensions of traditional mono-disciplinary economic models, which typically aim to quantify human uses of ecosystems for production and consumption activities [Braat and van Lierop 1987]. The representation of environmental processes in these models tends to be fairly narrow. Successful integration of biophysical analyses and economics still constitutes a major challenge, both from the perspective of economic models incorporating biophysical data, and biophysical models integrating sound economic analyses.

[1] Technically, biophysical models that include simple economic calculations could be considered 'bioeconomic', but such models are not reviewed in this paper. The focus is on traditional bioeconomic modeling as it originates from the economics literature.

This paper reviews the integration characteristics of selected bioeconomic models in forestry, fisheries, agriculture, and ecosystem valuation. I discuss the modelling techniques employed, the extent of the biophysical analyses, and the socioeconomic values considered. A characterisation of bioeconomic models and their caveats will help the IA community determine whether these bioeconomic models could provide a useful paradigm to further use in environmental modelling research.

2 FOREST SYSTEMS

Bioeconomic models have traditionally been used to determine the optimal level of resource extraction to maximise economic profits [van der Ploeg et al. 1987]. Such models predominantly consider the yields of renewable resources like fish or timber (Table 1).

The bioeconomic modelling of forests has been dominated by the Faustmann-Pressler-Ohlin model [Perman et al. 1999]. At the core of this model is a forest value growth equation. The objective is to determine what optimal rotation *age* will maximises net present value (NPV) of timber production for a forest stand; given tree growth, timber prices, and planting costs.

A second strand of models use mathematical programming to maximise the (expected) NPV of forest biomass *volume*, rather than tree age [Touza et al. 2008]. Environmental conditions enter the model as exogenous variables in the timber growth equation or as environmental constraints (e.g. land availability).

In forestry models, biological production is typically a simple function of timber stock increasing at a certain growth rate [Vanclay 1994]. Additional elements can be introduced to account for multi-species forests, physiographic regions, or uncertainty [Rollin et al. 2005, Teeter et al. 2006][2]. The timber growth functions usually do not attempt to capture the ecosystem processes that affect tree growth (e.g. influence of light, temperature, or soil nutrient levels). Although physiological process models are available, such models are not typically used to predict timber yields for forest management [Vanclay 1994].

Forests may provide benefits beyond timber, such as biodiversity benefits or erosion prevention. Even if such nontimber benefits are included in forestry bioeconomic models, they are generally specified as simple functions of tree age or volume, rather than assessed using integrated biophysical models. For example, Touza et al. [2008] define a forestry optimisation problem where loss in forest ecosystem benefits (of unspecified type or value) are a linear function of timber harvest.

3 FISHERY SYSTEMS

As with forestry models, bioeconomic models of fisheries typically represent changes in fish populations by relatively simple biological growth functions. Fishery harvest is proportional to the levels of fish biomass and fishing efforts [Perman et al. 1999]. The economic objective is to determine what fishing efforts maximise profits. In early models, maximum profits were a simple function of maximum harvests. Now, environmental considerations are included by estimating maximum *sustainable* yields-at which steady-state levels of fish stocks and profits can be maintained.

Fisheries models have been used to determine the optimal levels of effort under different fisheries management regimes (i.e. varying fishing capacity, harvest levels, and/or season length). Their spatial scale depends on the fisheries under consideration. For example, Homans and Wilen [1997] consider the Halibut fishery

[2] Rollin et al. [2005] and Teeter et al. [2006] define stochastic elements to account for random exogenous price shocks. Note that the probability of environmental shocks is not accounted for.

in the North Pacific; and McLeod et al. [2007] focus on the Rock Lobster along the Western Australian coast [see Knowler 2002 for further examples].
In bioeconomic fisheries models, environmental conditions are normally incorporated as constant parameters in mechanistic population growth functions, limiting the ability of these models to account for environmental changes [Knowler 2002]. Exceptions include Kahn and Kemp [1985], who include varying environmental conditions, and determine how habitat loss impacts striped bass fisheries in Chesapeake Bay; Grigalunas et al. [2001], who assess the effects of disposing marine dredged sediments on fin fish and shellfish catch in and around the Providence River; and Knowler and Barbier [2001], who model eutrophication impacts on anchovy fisheries in the Black Sea. Environmental changes enter these models through impacts on the parameters for stock carrying capacity, intrinsic growth rates, or fish mortality.
Non-financial benefits from aquatic ecosystems (e.g. ecological services, biodiversity and recreation possibilities) are not typically included in bioeconomic fisheries models [Eggert 1998]. There is also a need to better account for the negative environmental externalities imposed by commercial fisheries (for example, costs imposed by bottom trawling that erodes seabeds and leads to increased water turbidity) [Eggert 1998].

Table 1. A comparison of bioeconomic model characteristics.

	Forestry	Fisheries	Agriculture	Nonmarket values
Type of resource assessed	Single- or multi-species forest strands	Single- or multi-species fisheries	Represen-tative farm systems	Variable
Modelling techniques	LP/DP*	Accounting, LP/DP	Accounting, Regression, LP/DP	Env.* valuation techniques
Spatial scales and dynamics	Per hectare timber production	Vary with habitat of study species	Paddock, whole-farm	Vary with resource under valuation
Temporal scales and dynamics	Steady state harvest models based on annual or seasonal changes in harvest activities			Typically 15–30 year impacts
Biophysical analysis	Mechanistic biological growth functions. Env. conditions exogenous. Limited accounting for externalities or multiple ecosystem benefits			Env. scenarios based on econometric considerations or expert opinion
Socio-economic analysis	Maximise NPV* of profits from forestry, fish harvesting, agricultural production			Maximise NPV* of allocating env. resources across users & nonusers

* LP / DP = linear / dynamic programming; Env = environmental; NPV = net present value

4 AGRICULTURAL SYSTEMS

Agro-economic models are mainly used to predict the impacts of changes in environmental resources (e.g. soil quality or water quantity) on agricultural production [Braat and van Lierop 1987: 51]. Bioeconomic modelling of agricultural systems can be characterised by three different approaches [Weersink et al. 2002]: (i) accounting, (ii) regression, and (iii) mathematical programming.

Accounting models are simple descriptive book-keeping systems of agricultural production system [Bouman et al. 1999, 1998]. Examples include simple gross margin analyses [e.g. Firth 2001], or technical coefficient generators such as LUCTOR and PASTOR, which quantify resource budgets and farm level activities in terms of inputs and outputs [Hengsdijk et al. 1999]. Although accounting models allow for an assessment of the impacts of land use on environmental indicators,

they have limited ability to represent the dynamics of environmental processes, and feedback loops between environmental changes and land use decisions.
Regression models use statistical estimates of site-, or region-specific agro-economic production functions based on observed relationships between prices, farm inputs, policies, and physical characteristics of the land. For example, Gonzalez-Alvarez et al. [2006] analyse how changes in the marginal costs of irrigation water affects agricultural water demand, using a standardised index of water demand for different crops. In a more elaborate approach, Antle et al. [2001; 2007] use results from the CENTURY biophysical simulation model [Parton et al. 1987] to estimate environmental parameter inputs into a regression analysis of carbon sequestration rates on farms.
A major drawback of regression models is their large data requirements: series of consistent observations are needed, which are often lacking for environmental variables [Weersink et al. 2002]. Janssen and van Ittersum [2007] further note that regression models are constructed from observed historical relationships and can therefore not easily predict alternative future scenarios. Finally, regression models do not include feedback effects between changes in agricultural production and environmental conditions.

Agro-economic mathematic programming models can optimise or simulate the ‘optimal’ demand for environmental inputs that would maximise farm profits, subject to input and/or output prices, available capital or labour, and prevailing environmental conditions [e.g. climate or land availability; Hazell and Norton 1986]. Optimisation models such as MIDAS [Kingwell and Pannell 1987, Morrison et al. 1986, Pannell 1996] have the advantage of allowing a detailed specification of farm management activities and restrictions simultaneously, including technologies, multiple crop rotations, livestock management, and different soil types [e.g. Monjardino et al. 2010, Moxey et al. 1995]. The analytical focus of agro-economic optimisation models is typically that of profit maximisation or cost minimisation, with environmental parameters exogenous to the model. Few examples account for environmental pollution impacts on and from agriculture [exceptions include Kopke et al. 2008, Oglethorpe and Sanderson 1999]. Extensions in bioeconomic farm modelling will need to allow integrated analyses of multiple values (environmental impacts and profits) affected by agricultural systems [e.g. by using multiple goal programming; see Zander and Kächele 1999].

There are some examples of models that integrate farm-economics with biophysical assessments (although not necessarily developed by economists). The Patuxent watershed model allows an assessment of the ecosystem impacts of agricultural production in Maryland [Voinov et al. 1999]. The Maipo River Basin model integrates hydrological processes with agronomic and economic system components into one (coarsely aggregated) framework [Cai et al. 2003]. Although the Patuxent and Maipo River Basin models have their weaknesses, they support IA by integrating environmental and economic system components at different spatial scales. They are still largely economically focussed, with the models’ objective functions remaining the maximisation of returns to agricultural production.

5 VALUING ENVIRONMENTAL SYSTEMS

Environmental systems produce benefits beyond those that are usually accounted for in the models described above. Bioeconomic models tend to focus on productive (marketable) environmental goods and services, but typically don’t incorporate intangible ecosystem goods and services—such as recreation opportunities or aesthetic amenity [Turner and Daily 2008]. Economic valuation techniques [e.g. travel cost methods, hedonic pricing, contingent valuation, choice experiments; Hanley and Barbier 2009] can be used to estimate these nonmarket values that environmental resources provide to human beings.[3] Bioeconomic

[3] Values are estimated in monetary terms. Although one might object to an expression of environmental values in terms of money, this provides a useful common indicator of value.

valuation models extend traditional economic cost-benefit analyses by including estimates of nonmarket environmental values in the analysis.
Bioeconomic valuation models have been developed for different environmental systems, such as wetlands, rivers, coastal zones, and agricultural lands. Their scale of analysis varies with the resource under valuation. For example, Whitten and Bennett [2005] describe a bioeconomic valuation model for wetlands management in the NSW Murrumbidgee floodplains, Australia. They use expert interviews to predict how wetland management would affect native bird and fish populations. The nonmarket values impacted by those environmental changes are subsequently estimated in a choice experiment valuation study. The authors acknowledge that improved ecological predictions require further biophysical modelling. Moore [2008] uses a bioeconomic model to estimate the NPV of invasive species management. Nonmarket values of threatened native forests were estimated in a contingent valuation (CV) study. These values provide inputs into a dynamic biological model. However, the scenarios developed for the CV survey are not based on careful ecosystem assessments, thus lacking scientific foundation. Kragt et al. [2011] develop a bioeconomic model to assess the NPV of catchment management changes in Tasmania. Although the authors use process-based biophysical models to represent catchment hydrology, ecological impacts (on riparian vegetation, threatened species, and seagrass) are predicted based on expert interviews. Again, ecological complexities are ill-captured in the valuation exercise.

There are few examples of integrated bioeconomic valuation studies. Massey et al. [2006] use a more sophisticated dynamic modelling approach for summer flounder fisheries in Maryland; incorporating water quality conditions, fish reproduction, migration, and abundance; and recreational and commercial harvest levels. Their approach provides a more thorough scientific bases for the subsequent (stated choice) valuation study than is usually the case in bioeconomic models.
Settle et al. [2002, 2006] use STELLA software to examine how invasive lake trout affect native cutthroat trout in Yellowstone Lake. Biological models are linked to valuation surveys that measure the welfare visitors derive from Yellowstone National Park. The results show that people preferred fixing the Park's roads over protecting native cutthroat trout populations, which highlights the potential differences between economic and ecological values.
Environmental valuation studies need to be integrated with biophysical models to develop reliable valuation scenarios. Generally, bioeconomic valuation models lack scientific foundation [Brookshire et al. 2007]. Increased collaboration with biophysical modellers will help increase the credibility of valuation studies.

6 DISCUSSION

Bioeconomic models aim to link and integrate biophysical and economic analyses. Four types of bioeconomic models were discussed in this paper (Table 1). Forestry and fishery harvest models, and models of agro-economic production aim to maximise resource production subject to specified constraints that can include environmental conditions. Bioeconomic valuation models assess the impacts of environmental changes on human welfare by incorporating market and nonmarket environmental values. Many authors have discussed the challenges of integrating biophysical and economic analyses [Bouman et al. 1999, Ewert et al. 2009, Kragt 2012, Nunes and van den Bergh 2001, Spangenberg and Settele 2010, Wam 2010 - Table 2]. For brevity, only two important bioeconomic modelling challenges are further discussed in this section.

Table 2. Example integrated bioeconomic modelling challenges (non-exhaustive).

Compatibility of data, e.g.:	• Aggregation across temporal and spatial scales • Economic assessment of marginal changes (flows) versus biophysical predictions of levels (stocks)
Model choices, e.g.:	• Simulation versus optimisation versus dynamic approaches
Epistemology, e.g.;	• Divergent 'languages' between disciplines
Representation of systems e.g.:	• Deterministic versus stochastic • General versus specific focus

6.1 Simplicity versus complexity

Bioeconomic models usually have a sound economic underpinning to investigate how changes in environmental resources impact upon socioeconomic systems. However, their representation of natural systems is typically very basic (e.g. by means of mechanistic time-dependent growth functions). Relatively simple biophysical models are used to predict changes in the environmental indicators deemed to matter directly to people. The complex underlying natural processes (e.g. hydrological or ecological) that drive environmental changes are usually not well represented.

It should be noted that such limited characterisation of natural processes is not necessarily problematic. Bioeconomic models focus on economic impacts. As long as changes in indicators are relatively well predicted, a representation of complex biophysical interactions may not be needed.. Some biophysical scientists may find it difficult to come to terms with the limited description of environmental systems in bioeconomic models. The paradigm held by biophysical scientists of 'irreducible complexity of ecosystem functioning' [Wam 2010] can present a barrier to interdisciplinary advancements in bioeconomic modelling.

6.2 Economic versus ecological values

One should be cognisant of the anthropocentric basis of bioeconomic modelling. An important difference between bioeconomic models and integrated environmental models, is their foundation in *normative* economics. Bioeconomic models are based on the economic paradigm that values are derived from *impacts on human welfare*. The objective function in bioeconomic models is to allocate environmental resources to those uses that yield the highest net benefit to human beings.

Benefits generated by ecosystems are estimated in monetary terms using nonmarket valuation techniques. Money is used as an approximate unit for comparing ecosystem values-which environmental modellers may not feel comfortable. A common argument is that environmental systems have intrinsic values that cannot be captured in dollar amounts [Nunes and van den Bergh 2001]. The economic objective of allocating resources efficiently based on human preferences, may not necessarily reflect the objectives of those pursuing improved ecological benefits [Spangenberg and Settele 2010]. However, in the author's experience, it is useful to communicate ecosystem values in monetary units, as decision makers are familiar with dollar values. For environmental economists, using such approximate monetary values is still better than ignoring ecosystem benefits in traditional cost-benefit analyses.

The general premise of bioeconomic analyses is that environmental resources contribute to social wellbeing. In this, economists consider the values of all stakeholders, be they landholders, scientists, or general public. A typical argument in the ecological modelling literature is that scientific experts are much better placed to judge the value of environmental systems, because they understand the relevance and complexity of ecosystem-functions relationships [Nunes and van den Bergh 2001]. The discussion about 'whose opinions and values matter' has not yet been resolved.

6.3 Conclusion

Assessing the impacts of environmental management changes requires analyses of human welfare effects. Bioeconomic modelling allows this assessment by evaluating the costs and benefits associated with environmental resource use. Bioeconomic models offer a useful addition to existing biophysical/ecological models by allowing thorough analyses of socio-economic values, and making testable predictions about environment-human interactions. It is now time to expand integrated modelling, and use the bioeconomic modelling experiences, to address a wider range of biophysical outcomes as well as economic costs and benefits. Future modelling efforts should aim to include market and nonmarket impacts of environmental changes in their framework. Enhanced representation of natural processes and dynamics would improve the ability of bioeconomic models for IA of various policy objectives. This necessitates a more integrated approach that acknowledges the multiple linkages and feedbacks between natural and socioeconomic systems.

REFERENCES

Antle, J, S Capalbo, K Paustian & M Ali, Estimating the economic potential for agricultural soil carbon sequestration in the central united states using an aggregate econometric-process simulation model, *Clim Chang*, 80(1), 145-171, 2007.

Antle, JM, SM Capalbo, S Mooney, ET Elliott & KH Paustian, Economic analysis of agricultural soil carbon sequestration: An integrated assessment approach, *J Agric Resour Econ*, 26(2), 344, 2001.

Bouman, BAM, HGP Jansen, RA Schipper, A Nieuwenhuyse, H Hengsdijk & J Bouma, A framework for integrated biophysical and economic land use analysis at different scales, *Agric Ecosyst Environ*, 75(1-2), 55-73, 1999.

Bouman, BAM, RA Schipper, A Nieuwenhuyse, H Hengsdijk & HGP Jansen, Quantifying economic and biophysical sustainability trade-offs in land use exploration at the regional level: A case study for the northern atlantic zone of costa rica., *Ecol Model*, 11495-109, 1998.

Braat, LC & WFJ van Lierop, *Integrated economic-ecological modeling*, Elsevier Science Pub. Co., Amsterdam ; New York 1987.

Brookshire, DS, LA Brand, J Thacher, MD Dixon, K Benedict, JC Stromberg, K Lansey, D Goodrich, M McIntosh, J Grandy, S Stewart, C Broadbent & G Izon, Integrated modeling and ecological valuation: Applications in the semi arid southwest, paper presented at Workshop "Valuation for Environmental Policy: Ecological Benefits", Washington DC, April 23-24, 2007, 2007.

Cai, X, DC McKinney & L Lasdon, An integrated hydrologic-agronomic-economic model for river basin management, *J Water Resour Plan Manage*, 129(1), 4-17, 2003.

Eggert, H, Bioeconomic analysis and management, *Environ Resour Econ*, 11(3), 399-411, 1998.

Ewert, F, MK van Ittersum, I Bezlepkina, O Therond, E Andersen, H Belhouchette, C Bockstaller, F Brouwer, T Heckelei, S Janssen, R Knapen, M Kuiper, K Louhichi, JA Olsson, N Turpin, J Wery, JE Wien & J Wolf, A methodology for enhanced flexibility of integrated assessment in agriculture, *Environ Sci Policy*, 12(5), 546-561, 2009.

Firth, C, The use of gross and net margins in the economic analysis of organic farms, paper presented at UK Organic Research 2002: Proceedings of the COR Conference, Aberystwyth, 26-28th March 2002, 26-28th March 2002, 2001.

Gonzalez-Alvarez, Y, AG Keeler & JD Mullen, Farm-level irrigation and the marginal cost of water use: Evidence from georgia, *J Environ Manag*, 80(4), 311-317, 2006.

Grigalunas, T, JJ Opaluch & M Luo, The economic costs to fisheries from marine sediment disposal: Case study of providence, ri, USA, *Ecol Econ*, 38(1), 47-58, 2001.

Hanley, N & EB Barbier, *Pricing nature. Cost-benefit analysis and environmental policy*, Edward Elgar, Cheltenham, UK, 2009.

Hazell, PBR & RD Norton, *Mathematical programming for economic analysis in agriculture*, Macmillan, 1986.

Hengsdijk, H, BAM Bouman, A Nieuwenhuyse & HGP Jansen, Quantification of land use systems using technical coefficient generators: A case study for the northern atlantic zone of costa rica, *Agric Syst*, 61(2), 109-121, 1999.

Homans, FR & JE Wilen, A model of regulated open access resource use, *J Environ Econ Manage*, 32(1), 1-21, 1997.
Janssen, S & MK van Ittersum, Assessing farm innovations and responses to policies: A review of bio-economic farm models, *Agric Syst*, 94(3), 622-636, 2007.
Kahn, JR & WM Kemp, Economic losses associated with the degradation of an ecosystem: The case of submerged aquatic vegetation in chesapeake bay, *J Environ Econ Manage*, 12(3), 246-263, 1985.
Kingwell, RS & DJ Pannell, *Midas, a bioeconomic model of a dryland farm system*, Pudoc, Wageningen, the Netherlands, 1987.
Knowler, D, A review of selected bioeconomic models with environmental influences in fisheries, *J Bioecon*, 4(2), 163-181, 2002.
Knowler, D & EB Barbier, An open-access model of fisheries and nutrient enrichment in the black sea, *Mar Resour Econ*, 16(3), 195-217, 2001.
Kopke, E, J Young & R Kingwell, The relative profitability and environmental impacts of different sheep systems in a mediterranean environment, *Agric Syst*, 96(1-3), 85-94, 2008.
Kragt, M, *Lessons from integrated bio-economic modelling in the georges catchment, tasmania*, In: Lefroy, T, A Curtis, AJ Jakeman & J McKee, CSIRO Publishing, Canberra, 2012.
Kragt, ME, LTH Newham, J Bennett & AJ Jakeman, An integrated approach to linking economic valuation and catchment modelling, *Environ Model Softw*, 26(1), 92-102, 2011.
Massey, DM, SC Newbold & B Gentner, Valuing water quality changes using a bioeconomic model of a coastal recreational fishery, *J Environ Econ Manage*, 52(1), 482-500, 2006.
McLeod, P, B Lindner & J Nicholls, Out of the pot and into the money: Managing the western rock lobster fishery by ite's or itq's?, paper presented at 51st Conference of the Australian Agricultural and Resource Economics Society, Queenstown, New Zealand, 13 – 16 February 2007, 2007.
Monjardino, M, D Revell & DJ Pannell, The potential contribution of forage shrubs to economic returns and environmental management in australian dryland agricultural systems, *Agric Syst*, 103(4), 187-197, 2010.
Moore, CC, Using empirical benefit estimates in a bioeconomic model of invasive species control, PhD thesis, North Carolina State University, Raleigh, NC, 2008.
Morrison, DA, R Kingwell, DJ Pannell & MA Ewing, A mathematical programming model of a crop-livestock farm system, *Agric Syst*, 20243-268, 1986.
Moxey, AP, B White & JR O'Callaghan, The economic component of nelup, *J Environ Plan Manage*, 38(1), 21-34, 1995.
Nunes, PALD & JCJM van den Bergh, Economic valuation of biodiversity: Sense or nonsense?, *Ecol Econ*, 39(2), 203-222, 2001.
Oglethorpe, DR & RA Sanderson, An ecological-economic model for agri-environmental policy analysis, *Ecol Econ*, 28(2), 245-266, 1999.
Pannell, DJ, Lessons from a decade of whole-farm modeling in western australia, *Rev Agric Econ*, 18(3), 373-383, 1996.
Parton, WJ, DS Schimel, CV Cole & DS Ojima, Analysis of factors controlling soil organic matter levels in great plains grasslands, *Soil Sci Soc Am J*, 51(465), 1173-1179, 1987.
Perman, R, Y Ma, J McGilvray & M Common, *Natural resource and environmental economics, 2nd edition*, Pearson Education Limited, Harlow, 1999.
Rollin, F, J Buongiorno, M Zhou & J Peyron, Management of mixed-species, uneven-aged forests in the french jura: From stochastic growth and price models to decision tables, *For Sci*, 51(1), 64-75, 2005.
Rotmans, J & M Asselt, *Integrated assessment modelling*
climate change: An integrated perspective, In: Martens, P, J Rotmans, D Jansen & K Vrieze, Springer Netherlands, 2003.
Settle, C, TD Crocker & JF Shogren, On the joint determination of biological and economic systems, *Ecol Econ*, 42(1–2), 301-311, 2002.
Settle, C & JF Shogren, Does integrating economic and biological systems matter for public policy? The case of yellowstone lake, *Top Econ Anal Policy*, 6(1), Article 9, 2006.
Spangenberg, JH & J Settele, Precisely incorrect? Monetising the value of ecosystem services, *Ecol Complex*, 7(3), 327-337, 2010.
Teeter, L, M Polyakov & X Zhou, Incorporating interstate trade in a multi-region timber inventory projection system, *For Prod J*, 56(1), 19-27, 2006.
Touza, J, M Termansen & C Perrings, A bioeconomic approach to the faustmann-hartman model: Ecological interactions in managed forest, *Nat Res Model*, 21(4), 551-581, 2008.
Turner, R & G Daily, The ecosystem services framework and natural capital conservation, *Environ Resour Econ*, 39(1), 25-35, 2008.
van den Bergh, JCJM, A Barendregt, AJ Gilbert, M van Herwijnen, P van Horssen, P Kandelaars & C Lorenz, Spatial economic–hydroecological modelling and evaluation of land use impacts in the vecht wetlands area, *Environ Model Assess*, 687-100, 2001.

van der Ploeg, SWF, LC Braat & WFJ van Lierop, Integration of resource economics and ecology, *Ecol Model*, 38(1-2), 171-190, 1987.

Vanclay, JK, *Modelling forest growth and yield. Applications to mixed tropical forests*, CAB International, Wallingford UK, 1994.

Voinov, A, R Costanza, L Wainger, R Boumans, F Villa, T Maxwell & H Voinov, Patuxent landscape model: Integrated ecological economic modeling of a watershed, *Environ Model Softw*, 14(5), 473-491, 1999.

Wam, HK, Economists, time to team up with the ecologists!, *Ecol Econ*, 69(4), 675-579, 2010.

Weersink, A, S Jeffrey & D Pannell, Farm-level modeling for bigger issues, *Rev Agric Econ*, 24(1), 123-140, 2002.

Whitten, SM & JW Bennett, *Managing wetlands for private and social good: Theory, policy and cases from australia*, Edward Elgar, Northampton, 2005.

Zander, P & H Kächele, Modelling multiple objectives of land use for sustainable development, *Agric Syst*, 59(3), 311-325, 1999.