Environmental Modelling & Software 55 (2014) 120–131

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Scenario modelling to support industry strategic planning and decision making

Romy Greiner[a,*], Javier Puig[b], Cindy Huchery[c], Neil Collier[a], Stephen T. Garnett[a]

[a] Research Institute for the Environment and Livelihoods, Charles Darwin University, Darwin, NT 0909, Australia
[b] Department of Lands, Planning and the Environment, Northern Territory Government, Darwin, NT 0801, Australia
[c] ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD 4810, Australia

ARTICLE INFO

Article history:
Received 8 January 2014
Accepted 9 January 2014
Available online 8 February 2014

Keywords:
Dynamic simulation model
Scenario planning
Participatory action research
Mediated modelling
Validation
Pastoral industry
Australia

ABSTRACT

The Pastoral Properties Futures Simulator (PPFS) is a dynamic systems model, developed within a participatory action research partnership with the pastoral industry of Australia's Northern Territory. The model was purpose-built to support the industry's strategic planning capacity in the face of environmental, market and institutional uncertainty. The mediated modelling process sought to maximise social learning of industry stakeholders. Simulations were conducted using scenarios representing combinations of climatic, market, institutional and technological assumptions. Stochastic parameters included rainfall and product prices. Economic and environmental performance of model farms, including greenhouse gas emissions, were estimated. A critical evaluation of the tool finds the PPFS fit for purpose. However, limitations include lack of output validation, small number of scenarios and simplistic treatment of environmental impact dimensions. With further development, the PPFS can provide a platform (a) to assist with industry planning across the whole of Northern Australia and beyond, and (b) for policy analysis and development in the context of the Australian pastoral industry.

1. Introduction

Participatory scenario planning has become an important tool to help governments, industries and communities to prepare and plan for the future, manage risks and harness opportunities. Models are commonly used to assist the planning process and can help reduce collective biases while promoting ownership and action (Andersson et al., 2008; Bryant and Lempert, 2010; Kwakkel and Pruyt, 2012; Jones et al., 2010a; Salter et al., 2009; Volkery et al., 2008). Models can help explore complex systems in a structured manner, stimulate imagination, visualise likely direction and magnitude of change, and reveal crucial trade-offs associated with choices.

The use of dynamic systems modelling as a tool for strategic decision making has been embraced by the tourism industry and for regional planning (Griffon et al., 2010; Jamal et al. 2004; Jones et al. 2010a,b; O'Connor et al., 2005; Schianetz and Kavanagh, 2008; Valencia-Sandoval et al., 2010; Walker et al. 1998). In an agricultural context, there have been many production models, bio-economic models at the farm scale (for a review see: Janssen and van Ittersum, 2007) and risk management models at the farm scale (Stewart and Fortune, 1995; Zeigler et al., 2000). However, there appear to have been relatively few industry-level applications (e.g. Sharma et al., 2006; Berger, 2006) despite early recognition of the potential (Anderson, 1974). In particular, there is an apparent paucity of applications of systems models designed to support strategic planning and participatory scenario planning in agriculture.

In 2009, the Northern Territory Cattlemen's Association (NTCA), the peak body for the pastoral sector in Australia's Northern Territory (NT), initiated the 'Futures Project', which aimed to identify risks and opportunities for the industry over coming decades in order to develop an industry strategy to ensure industry prosperity into the future. The NTCA embarked on a participatory action research partnership with Charles Darwin University to develop a modelling tool which could support the Futures Project. It was envisaged that the model would integrate best available information about the industry, its production systems and natural resource base, input and product markets and the institutional (policy) context. It would explore a number of scenarios into the medium-term future against the backdrop of climate change and

* Corresponding author.
E-mail address: romy.greiner@cdu.edu.au (R. Greiner).

1364-8152 © 2014 The Authors. Published by Elsevier Ltd. Open access under CC BY-NC-ND license.
http://dx.doi.org/10.1016/j.envsoft.2014.01.011

market uncertainty to explore what might be in store for the NT pastoral industry. This paper showcases the result of the joint endeavour, the Pastoral Properties Futures Simulator (PPFS). The purpose of the model as platform and structure for industry stakeholders to communicate, negotiate and integrate their perspectives defines it as a tool for 'participatory integrated assessment' (De Kraker et al., 2011).

The paper contributes to the literature by exemplifying and reviewing a model-assisted participatory scenario planning process, which assisted industry strategic planning and decision making in the face of complexity and uncertainty. While modelling results have been published previously (Puig et al., 2011), this paper focuses on the conceptual foundation and model architecture before illustrating the model capabilities and applications as a planning tool and critically reviewing its merit. In doing so, the paper responds to the standards of reporting recommended by Jakeman et al. (2006), including (1) clear statement of the objectives and clients of the modelling exercise; (2) documentation of the nature (identity, provenance, quantity and quality) of the data used to drive, identify and test the model; (3) strong rationale for the choice of model families and features, (4) justification of the methods and criteria employed in calibration; (5) thorough analysis and testing of model performance as resources allow and the application demands; and (6) a resultant statement of model utility, assumptions, accuracy, limitations, and the need and potential for improvement.

The paper describes the context in Section 2 and provides a detailed description of methodology with focus on the model heuristic in Section 3. Section 4 provides an appraisal of the model and illustrates key outcomes of the model-assisted industry strategic planning process. The concluding comments in Section 5 include ideas for further model development and application.

2. Context

Agriculture in the NT is dominated by the pastoral industry, which produces grass-fed cattle on typically vast pastoral properties, which cover up to 24,000 square kilometres of land. There are 216 pastoral stations in the NT, of which more than 90 per cent are members of the NTCA. The combined herd is approximately two million cattle (NTCA, 2009). Cattle sales contributed AUD 344 million to the NT economy in the year 2008–09 (DRDPIFR, 2009a) and the industry employed more than 1800 people (NTCA, 2009). Tenure is mostly pastoral leasehold[1] land (NTG, 2011) with some freehold. Among the many risks and challenges the industry faces (Ash and Stafford Smith, 2003) are:

- Market risk: The industry is vulnerable to the economic circumstances of both international and interstate markets (DRDPIFR, 2009a; Martin et al., 2007). It has a very high exposure to live cattle export to south-east Asian countries. During 2009, Indonesia purchased approximately 90% of live exported cattle but cut import quotas for live cattle in 2010 and imposed narrow import specifications as part of its drive towards self-sufficiency in beef production. As there are no abattoirs in the NT, all other cattle go to interstate markets. Transport costs are high due to long distances and fuel prices.
- Climate risk: Climate change is anticipated to result in an increase in temperatures in northern Australia and more intense cyclonic activity (CSIRO and BOM, 2007; Hughes, 2003). Direction of change in rainfall remains unclear for the north of Australia, while for central Australia it is considered likely that rainfall will decline (CSIRO and BOM, 2007). Climate change is a known uncertainty, with changes likely to affect pastoral production systems in different directions and various ways, including through changes in forage production and palatability, cattle reproduction and productivity, fire risk, plant composition and ecosystem functioning (DPIFM, 2008; Howden et al., 2008; Cobon et al., 2009; McKeon et al., 2009).
- Institutional risk: Much of the land in the NT is pastoral leasehold land and subject to land use and development restrictions. The industry is likely to be affected in various ways by climate-change related government policy, e.g. the introduction of the Carbon Pollution Reduction Scheme in July 2012. Institutional risk also compounds market risk as evidenced in June 2011, when the Australian Government temporarily suspended the trade of live cattle to Indonesia on the basis of animal ethics concerns.
- Other challenges: Environmental sustainability, land management and animal welfare are issues attracting the concern of agencies and consumers (Ash and Stafford Smith, 2003; DRDPIFR, 2009b; Garnett et al., 2010; Kutt et al., 2009; Petherick, 2005; Phillips et al., 2009).

Industry leaders know they need to address the risks and put strategies in place that enable the industry to prosper in the future. The NTCA implemented the *Futures Project* with the intention to (i) scope the views of members and other pastoral industry stakeholders about risks and opportunities for the industry, (ii) facilitate understanding of members and stakeholders about the complexity of factors that will shape the future of the industry and (iii) develop an agreed strategy for the industry to prosper in future (Puig et al., 2009).

3. Methods

Models tend to pursue a general purpose, including prediction, forecasting, management and decision-making under uncertainty, social learning and/or developing system understanding (Kelly et al., 2013). The primary purpose of the PPFS was to be a social learning tool, a tool which would help facilitate discussion and discourse among NT pastoral industry members and stakeholders and, it was hoped, might lead to improved decision-making under uncertainty (Puig et al., 2009). To truly support strategic planning, the PPFS would not be a 'black box', but would be transparent. It would be developed for the pastoral industry in association with pastoral industry experts and stakeholders. It would have to be able to capture key facets of the industry, explain relationships among multiple factors affecting the pastoral industry, illustrate potential industry trends and likely impacts of external shocks. Industry stakeholders—pastoralists and industry representatives in strategic positions alike—would be able to play and explore and visualise what the future may hold. In the process, it would challenge assumptions, remove prejudice, stimulate debate and improve communication (Antunes et al., 2006; Kassa et al., 2009; Sandker et al., 2007; Wollenberg et al., 2000). The assumption was that the PPFS could support a facilitated discussion process among groups of industry members and stakeholders and help deliver a consensus position. This, in turn, would critically inform the formulation of industry strategies which would improve the resilience and sustainability of the pastoral industry (Antunes et al., 2006; Costanza and Ruth, 1998). This purpose was reflected in both the design process and model architecture and achieved within the 9-month project time frame.

3.1. Stakeholder input into model design

The design process of the PPFS broadly followed the generic framework for effective decision support through integrated modelling and scenario analysis proposed by Liu et al. (2008, p.854) and the chronology is detailed in Puig et al. (2011). The following summarises the key considerations.

The PPFS was developed in collaboration with the pastoral industry for the pastoral industry to help facilitate industry strategic planning. Modelling with stakeholders has been shown to enhance ownership of and trust in models (Voinov and Bousquet, 2010; Lagabrielle et al., 2010). The social process of modelling is a learning process, which enables participants to better grasp the scale and operation of complex systems (Krueger et al., 2012) and helps modellers to build, parameterise

[1] There are two principal types of land tenure in Australia, freehold and leasehold (Crown land). Freehold landholders have indefeasibility of title and are not subject to land use constraints under state and territory pastoral land acts.

and drive models in data scarce situations (Brown Gaddis et al., 2010). A mediated modelling approach was adopted (Voinov and Bousquet, 2010).

The participatory action approach (McTaggart, 1991; Reason and Bradbury, 2001) ensured conversations with and input by the pastoral industry into all stages of model development, thereby generating social capital and maximising ownership and relevance of the PPFS for the industry strategic planning process. Industry expertise was important for the problem conceptualisation and for input into model parameterisation where gaps existed in published data and systems understanding. A professionally facilitated brainstorming process with industry stakeholders produced a suite of potential industry futures, which were captured as a set of distinct scenarios. The scenarios guided model analysis (Puig et al., 2009) and stakeholders were also involved in specifying the model's user interface. An iterative process of data acquisition, model-building and stakeholder consultation and model review was adopted (Robinson, 2004).

Scenario planning provided a secondary framework within this participatory action research approach. Scenario planning is about the integration of diverse information, including qualitative and quantitative, in a systemic way to lead to better decision making in the face of uncontrollable and irreducible uncertainty (Peterson et al., 2003; Amer et al., 2013). Scenarios took the form of 'probabilistic modified trend models' (Bradfield et al., 2005) with each scenario representing a narrative of a plausible set of emerging circumstances and actions the industry might choose to take in the future. Five contrasting scenarios narratives were developed. They were: (1) *Business as Usual*, (2) *Food First*, (3) *Integrated Future*, (4) *Quality First* and (5) *Worst Case*. Table 1 provides a summary description of the scenarios. The project brief was that the model needed to be able to mimic the scenario narratives and deliver glimpses of potential industry futures based on scenario assumptions. Thus, the scenarios provided critical guidance for model design and implementation.

3.2. Industry portrait

The cattle farms across the NT are geographically grouped into four regions, broadly defined by bio-ecological conditions, which are reflected in nuances in farm business structures and grazing systems. These regions have different sub-regional industry representatives (NTCA, 2009). Four model farms were developed to capture what were considered typical enterprise characteristics and cattle production systems in these regions (Puig et al., 2011). Initial production parameter values were obtained from Oxley et al. (2006) and missing values were provided by industry experts.

3.3. Programming language

The PPFS was implemented in Stella® software (ISEE Ssystems Inc., 2009). Stella was an appropriate choice from the suite of dynamic systems software options available because it offered an intuitive icon-based graphical user interface and had a track record of applications in ecological-economic systems analysis (e.g. Costanza and Voinov, 2001; Voinov et al., 2004; Argent, 2004) and mediated modelling (Voinov and Gaddis, 2008; Voinov and Bousquet, 2010). Stella features an object oriented program language that uses mathematical relationships, statistical functions and logical operations to create a model that represents the system. Being a dynamic modelling framework, it is able to incorporate feedback loops (i.e. cyclic operations) and project complex system dynamics through time. Stella® has proved proven powerful in a participatory action research context because of its interactive front-end (Constanza and Ruth, 1998; Kassa et al., 2009; Sandker et al., 2009) and ability to visualize conceptual links and model results as long-term trends (Villa et al., 2009). Both capabilities enhance peoples' analytical thinking of complex interactions within dynamic ecological and economic systems (Costanza et al., 1998; Costanza and Gottlieb, 1998; Costanza and Ruth, 1998; Costanza and Voinov, 2001; Collier et al., 2011a). Stella® uses a graphical user interface that is easy to use by lay persons because it incorporates intuitive controls to manipulate model parameters and run simulation of different scenarios.

3.4. Model design, architecture and parameterisation

The parameterization of the model was based on scientific information and statistical data where possible, including farm survey data from the Australian Bureau of Agricultural and Resource Economics (ABARE, 2009) and the Northern Territory pastoral survey (Oxley et al., 2006). Data were gleaned from the scientific literature, grey literature, historical records and expert knowledge. In the areas of cattle production systems and economics, and carbon dynamics in particular, expert knowledge provided the foundation for much of the model specification and parameter development as very little data was formally known or documented. Any parameter assumptions were verified in consultation with industry experts. Detailed listings of model parameters and assumptions are shown in Puig et al. (2009, 2011).

The PPFS conceived each farm as a system of interconnected system components, each of which captured an aspect of the business and described its dynamics. Components were implemented as modules and broadly described land use (including pastoral production, crop/horticulture production, conservation and carbon farming), cattle and crop production, environmental dimensions, energy use and employment (Fig. 1). Insights into the constituent elements of each module are given in the following sub-sections. Modules were linked through shared parameters and functional relationships between variables.

Table 1
Summary description of scenario narratives (adapted from Puig et al., 2009).

Scenario title	Scenario description
Business as usual (BAU)	The NT pastoral industry continues to be a strong provider for Australian meat with reliance on live export. Productivity has improved thanks to advances in technology, management and nutrition that counter the effects of climatic change. Environmental and conservation issues have increased in importance and there is strong scrutiny and regulation in these matters. Properties amalgamation is permitted across the NT to achieve economies of scale. Renewable energy is replacing diesel and other oil fuels since considerable increase in oil prices.
Food First (FF)	Increased global population and the impacts of climate change has resulted in a corresponding increase in demand for NT agricultural products, an expansion of horticulture and agriculture, a decrease in cattle numbers, but an increase in the intensity of production. Offsets of greenhouse gas emissions by fire and grazing management are applied to reduce emission on farm. Environmental, conservation and a range of social issues are forced off the agenda as the world focused on food production.
Integrated Future (IF)	Land Tenure reform facilitates diversification of land use; broadening the sources of on farm income. There is a decreased number of stock and marginal land has been destocked. New productive approaches are implemented based on strong local branding and marketing of branded product, management and marketing of environmental services, re-investment in the land and the incorporation of Indigenous knowledge in land management. There have also been continuing investments in infrastructure and education with important and positive consequences for rural NT communities and the skilled workforce.
Quality First (QF)	Individual and community aspirations have changed; there has been a major shift in focus due to economic shocks, oil shortages and significant climate change. The rate of depletion of resources has slowed, and awareness of the need for sustainability is high. There is important value adding with new diversified production and a new focus on quality and regional branding. Communities have moved to a direction of high employment and engagement with the regional economy and government. Indigenous knowledge is valued and applied and the environment is healthy and sustainable.
Worst Case (WC)	There is a major impact on productivity due to climate change and continue rising of oil fuel and input prices. The industry is seriously affected by the spread of weeds and the outbreaks of diseases. The pastoral sector finds limited opportunities for growth due to government regulations, consumer pressure and massive immigration. The production of the industry is marginal and survives on land unsuitable for horticulture or conservation. Many pastoralists have left the industry and those that remain have adapted to a totally different economy and environment.

3.4.1. Cattle herd

At the core of every farm was its cattle herd. The 'cattle herd' module was based on pastoral industry data (Oxley et al., 2006). It simulated the dynamics of a cattle herd using an age-structured population model similar to Collier et al. (2011b), in which cattle changed classes as they aged. Cattle could be retained for breeding or sold either for live export or on the domestic market. According to expert advice, sales strategies were model farm-specific and also depended on age and gender of the cattle. For example, cows and steers were sold to the domestic market from the

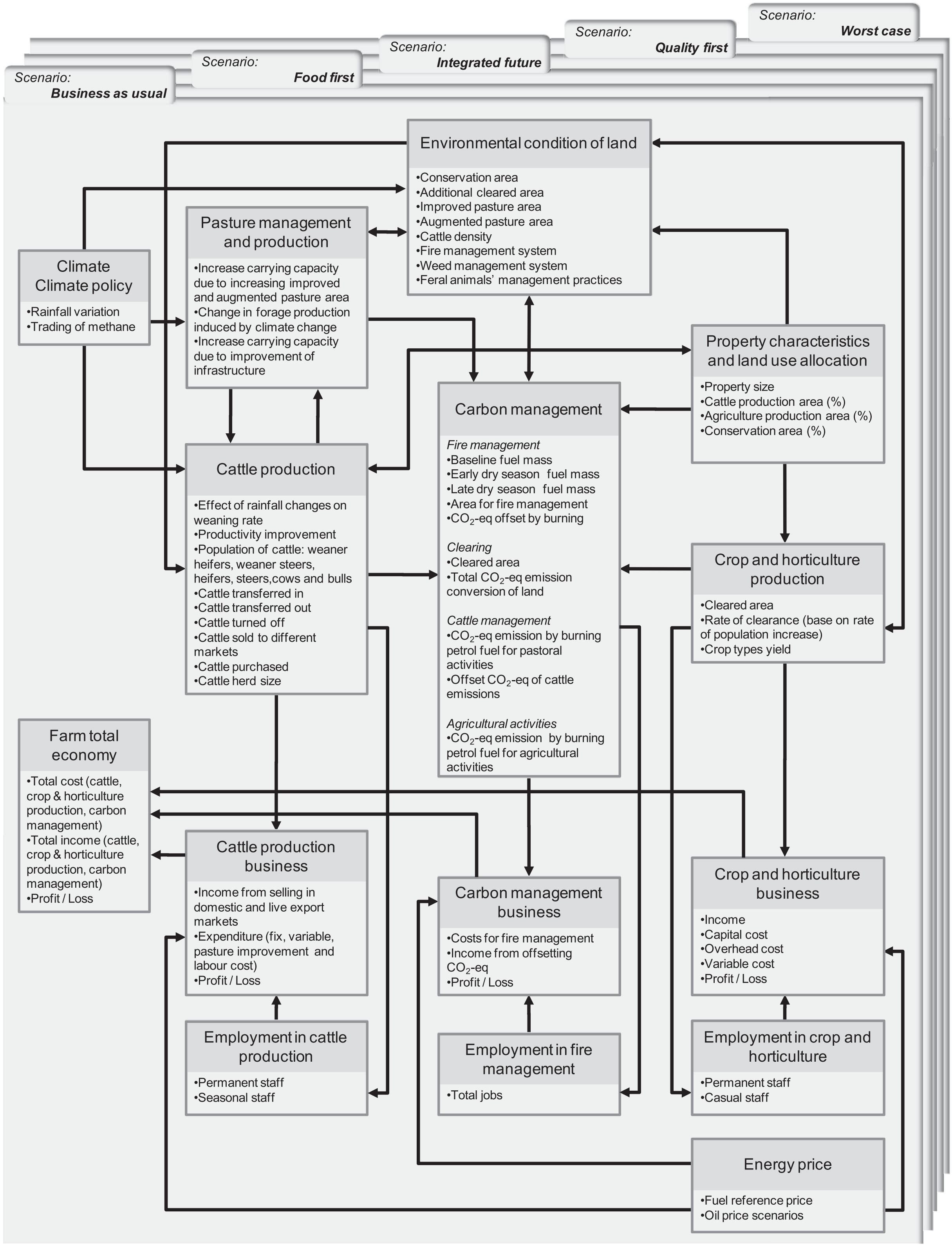

Fig. 1. Schematic overview of the PPFS architecture and major connections between modules.

Barkly and *Alice Springs* farms and to the live export market (at a younger age) from the *Top End* and *Katherine* farms. Bulls were only purchased or sold on the domestic market. Bulls were purchased when the ratio of bulls to cows fell below 1:20. A male-to-female ratio of 1:1 was assumed at calving. The base weaning rate was region-specific and ranged from 59.7% for *Alice Springs* to 70.3% for *Katherine* (based on ABARE, 2009; Oxley et al., 2006). The mortality of calves could be reduced (and weaning rate increased) through intensification of the production system (infrastructure investment and adoption of rotational grazing) but was also dependent on scenario conditions e.g. likelihood of survival was positively related to forage production and therefore, indirectly, rainfall during year of birth. Calf mortality was reduced by between 2% and 5% per 100 mm above-average rainfall, and *vice versa* (region-specific coefficients). An increase in herd size generated more cattle sales and *ceteris paribus* more income for the model farms in the 'cattle enterprise' module. However, more cattle also required more feed, labour and farm inputs, so herd size was linked to the 'employment', 'pasture management and production' and 'cattle enterprise' modules. The environmental dimensions of a larger herd were captured twofold, through grazing land condition indicators in the 'environmental condition of land' module and greenhouse gas (GHG) emissions in the 'carbon management' module.

3.4.2. *Pasture management and production*

This module estimated forage production and therefore potential carrying capacity of the property, annually, based on area of grazing land, areas of native and improved pasture, area of forage production on farm, type(s) of grazing land management practices and infrastructure (fencing, water points) development subject to a maximum carrying capacity constraint and cattle herd dynamics. The key external variable was rainfall. Forage productivity was 100 per cent if annual rainfall was 90–110% of mean with higher rainfall enhancing production and lower rainfall causing a production decrease, as per McKeon et al. (2009, 1990) and expert opinion. In this case, below-average rainfall of 70–90% of mean caused a 10% reduction in forage production, while rainfall below 70% of mean reduced forage production by 30%. Above-average rainfall of between 110–120% of mean generated 10% more forage production than an average year and rainfall above 120% of mean generated a 20% production increase through the PPFS user interface. For example, the user could decouple land productivity and size of herd by e.g. forcing increases or continued high stocking rates in low-rainfall years to explore the likely consequences of overgrazing.

3.4.3. *Cattle enterprise*

Profit or loss of the cattle enterprise was estimated by subtracting costs from income. Estimates were presented as net present values normalised to the year 2008. Income was principally generated by the sale of cattle. Beef producers are price takers and to mimic the high degree of price variability experienced by producers, price received per head of cattle sold in any given year was randomly generated from normally distributed beef price functions based on historical cattle sales data from July 1994 to June 2008 (ABARE, 2009). Switch and slider controllers on the PPFS interface enabled users to force certain prices or price ranges and explore e.g. the ramifications of a price collapse or a consistently high beef price.

Costs included fixed and variable costs of cattle production. Key variable cost items were labour and energy costs (for on-farm operations and cattle transport) while key fixed cost were associated with investments in infrastructure and pasture improvements (Miller and Stockwell, 1991). The interface let model users change the price of non-renewable energy or install renewable energy technologies which reduced on-farm energy use. Resulting investment costs and energy costs savings flowed into the 'farm business' module.

3.4.4. *Land use*

Farm land was exclusively used for pastoral purposes at the beginning of the planning period, which reflected the virtual absence of land use diversification under the current tenure system in the Northern Territory (NTG, 2011). However, the PPFS could model land use change subject to land capability and estimated rain-fed and irrigated water availability if a 'tenure reform' switch was activated to relax land use restrictions. Scenario-specific parameters mimicked different types and scales of land-use change (Table 2). Land use changes came into effect in year 10 of the 30-year simulation (2010). Once enacted, land use change triggered the commencement of 'crop and horticulture production'. A transition period was associated with land-use change, invoking investment costs, loss of pastoral production and year-by-year increase of production from the new land uses until full production was reached after five years. Land use composition had implications for estimated farm GHG emissions in the 'carbon management' module, and for environmental indices calculated in the 'environmental condition of land' module.

Table 2
Land-use assumptions in scenarios, by region: Percentage of land (%) grazing:crop & horticulture:conservation.

Scenario	Model farms			
	Top end	Katherine	Barkly	Alice Springs
Business as usual	100:0:0	100:0:0	100:0:0	100:0:0
Food first	85:15:0	85:15:0	90:10:0	90:10:0
Integrated future	57:15:28	52:15:33	75:10:15	60:10:30
Quality first	30:0:70	50:0:50	60:0:40	40:0:60
Worst case	100:0:0	100:0:0	100:0:0	100:0:0

3.4.5. *Crops and horticulture production*

Each model farm was assumed to have the potential to grow a specified number of agricultural and horticultural crops, with potential being principally limited by the maximum spatial extent of crop defined for each model farm. A series of constraints governed land-use change, namely presence of tenure-related land-use restrictions, annual rainfall, irrigation water availability and availability of labour—which were linked to the 'crop and horticultural enterprise' and 'employment' modules. Crop specific values were derived from Ngo and Owens (2004).

Agricultural development required clearing of the native vegetation, which consisted of a mixture of trees and grasslands, thus causing an increase in estimated farm GHG emissions in the 'carbon management' module. Increased emissions also resulted from use of fossil-fuel dependent mechanical equipment on agricultural land. A reduction in the number of cattle as a consequence of agricultural development partially off-set these GHG emissions. A principal assumption was made that in the longer term, the rate of agricultural development would be broadly linked to the rate of population growth in the NT. The reference population growth rate was 1.67% (Northern Territory Treasury, 2009).

3.4.6. *Crops and horticulture enterprise*

The profit or loss resulting from agricultural/horticultural development and activities was calculated similarly to profit/loss from grazing. Costs included capital costs associated with initial development, and variable costs and fixed costs associated with the installation of new infrastructure. Results of the 'crop and horticulture enterprise' module were directly linked to the 'farm business' module.

3.4.7. *Carbon management*

The 'carbon management' module estimated the carbon balance of model farms in terms of net emissions of GHGs. Emissions generated by cattle, use of fossil fuel and land clearing could be offset by sequestering carbon through changing land use to conservation and controlled burning regimes. Land clearing caused a loss of at least 61% of carbon contained in the cleared vegetation to the atmosphere (Law and Garnett, 2009). Conversion of pastoral land to agriculture resulted in a 30% loss of soil carbon (Post and Kwon, 2000). Greenhouse gases, carbon dioxide, methane and nitrous oxide were modelled as carbon dioxide equivalent (CO_2-e).

Participation in the emerging 'carbon economy' in Australia through controlled burning may provide an income diversification opportunity for pastoral properties in some circumstances (e.g. Greiner et al., 2009). Standard fire management in the scenarios mimicked the prevalence of intense late dry-season fires (patchiness effect 90%: Russell-Smith et al., 2009; burn efficiency 90%: Williams et al., 2004). In comparison, controlled burning led to fires being 'cooler' (patchiness effect 70%: Russell-Smith et al., 2009; burn efficiency 72%: Williams et al., 2004) and only one quarter of land being burnt (all regions except *Alice Springs*: 14%, equal to the average proportion of regional area burnt each year in the Tanami Desert, burn efficiency 100%: Allan and Southgate, 2002). The module simulated vegetation cover and consequently biofuel load based region-specific composition of grass, fine fuels, coarse litter, heavy litter and shrubs in the *Top End* and *Katherine*, grass in the *Barkly* and Spinifex grassland in the *Alice Springs* region (Burrows et al., 2006). Estimated load was also rainfall dependent.

NT cattle farms were net emitters of GHGs. Cattle were assumed to produce the equivalent of 1380 kg CO_2 per head and year through enteric fermentation 60 kg methane for animal live weight 425 kg (NTG, 2008) multiplied by methane's global warming potential factor 23 (IPCC, 2001). Enterprise-based CO_2-e emissions were estimated for fossil fuel used for grazing (per head of cattle) and agricultural production (per hectare), using an emission factor of 2.7 CO_2-e kg/l for diesel combustion as a base for the calculations (IPCC, 1997). All scenarios with the exception of the *Worst Case* assumed that fossil fuel consumption of properties would decline by 20% over 10 years due to adoption of renewable energy generation on farms (e.g. photovoltaic solar to power stations, solar water pumps).

3.4.8. *Carbon enterprise*

The 'carbon enterprise' module estimated the profit/loss associated with a model farms' CO_2-e balance if a cost for greenhouse gas emissions was imposed, as was conceivable under a carbon pricing or trading scheme. Farm total emissions included emissions from fire management, land clearing, cattle and vehicles. Emission reduction options included reducing cattle number (this off-set was activated in the PPFS interface by a switch controller) and controlled burning. Price for CO_2-e was assumed to rise at an annual rate of 4% with a starting price AUD 23 (Garnaut Climate Change Review, 2008).[2] Cost of fire management was assumed to be AUD 7.20 per square kilometre (Drucker et al., 2008). The monetary estimates of the 'carbon management' module flowed into the 'farm business' module.

3.4.9. *Energy price*

The 'energy price' module modelled changes in fuel price and amount of fuel used by model farms for pastoral and agricultural production. Three fuel price levels

[2] The Carbon Pollution Reduction Scheme, which come into effect in Australia on 1 July 2012, imposed a tax of AUD 23/ton carbon emitted for major polluters.

were parameterised: low, standard and high based on oil price projections (EIO, 2008). Changes in the cost of fossil fuels affected components of other modules including cost for fertilizers and herbicides, seeds, transport and cartage freight, fodder and oil fuel and oil used in managing production. The fuel reference price at start of simulation was set at AUD 1.26 as at the date 1 September 2009 for the port of Darwin, Australia (AIP, 2011). Model users could choose the fuel price level to be used in a simulation.

3.4.10. Farm business

The 'farm business' module estimated annual farm profit/loss across farm enterprises, aggregating income and costs from enterprise modules. All estimates were expressed as year 2008 net present values.

3.4.11. Employment module

The employment module had three components: 'employment in fire management' and 'employment in crop and horticulture production' and 'employment in cattle production'. Undertaking crop and horticulture production required the hiring of staff with staffing requirements based on crop type and area of production (DRDPIFR, 2008). Estimates of staff for the cattle enterprise were derived from farm survey data (Oxley et al., 2006). Staff requirements for controlled burning were calculated by applying a rate of one full-time employee for each 7500 t CO_2-e emitted with the practices (Heckbert et al., 2008).

3.4.12. Environmental index module

Pastoralism relates to the natural environment in a number of ways as cattle inevitably have impacts on soils, water, biodiversity and air (e.g. Steinfield et al., 2006; Landsberg et al., 1997). To be sustainable in the long term, the industry has to safeguard its natural resources and minimise negative impacts. One way of measuring environmental performance at the business, industry, regional or national scale is by devising and estimating an environmental index. Composite environmental indices (CEIs) aggregate environmental performance estimates across multiple dimensions and can be based on range of methods (Zhou et al., 2006). Problems associated with CEIs relate to loss of information (Zhou et al., 2006) and uncertainties associated with the selection of representative underlying variables and their weighting, both of which are application specific and typically based on expert opinion (Giannetti et al., 2009).

In the context of the PPFS, this module needed to concentrate on the fundamental manners in which pastoralism in northern Australia interacted with the environment, namely through extent of modifications made to the natural vegetation, cattle impact, carbon management and feral animal control. A CEI was constructed, the architecture of which resulted from discussion with scientists and other experts involved in the project. The CEI was composed of a number of subindexes, which were closely related to environmental performance, namely: percentage farm area under conservation, percentage farm area cleared, percentage of improved pasture area, percentage of augmented pasture area, stocking rate (number of cattle per km^2), presence of a controlled burning system, presence of a weed management system, and presence of feral animals management practices. Each subindex assumed an integer value of either 0 = 'poor', 1 = 'reasonable' or 2 = 'good'. Table 3 shows the criteria for assignment of subindex scores. Aggregation of subindices was by unweighted addition and subsequent standardisation to a value $0 \leq x \leq 100$ provided the CEI value for the model farm, with a value of 100 representing a situation of perfect safeguarding of the natural environment.

Table 3
Criteria applied for calculating the environmental condition index.

Indices	Region	Score		
		0	1	2
Conservation area (%)		≤5	>5 and <10	≥10
Additional cleared area (%)		≥5	<5 and >1	≤1
Improved pasture area (%)		≥3	<3 and >1	≤1
Augmented pasture area (%)		≥8	<8 and >3	≤3
Cattle (No./km^2)	Top End	≥15	<5 and >5	≤5
	Katherine	≥15	<15 and >5	≤5
	Barkly	≥5	<5 and >3	≤3
	Alice Springs	≥5	<5 and >1	≤1
Fire management		WC		BU, FF, IF, QF
Weed management		BU, FF, WC		IF, QF
Feral animals management		BU, FF, WC		IF, QF

3.4.13. Climate change module

Climate change is likely to affect farms operating in the NT (Foran, 2007) but manifest itself differently at different latitudes NT (CSIRO and BOM, 2007). In the north of the NT, mean air temperature is expected to rise by 1 °C over 30 years, in the south by 1.2 °C. In the north, very little change in mean annual rainfall is expected while in the south it is expected to decline by up to 5%. However, there is large uncertainty associated with these estimates. Because of the critical importance of rainfall to pastoral properties, a slider was implemented on the PPFS interface which let users adjust mean rainfall over the simulation period within a range of −20% to +20% of past average for all pastoral regions. Annual rainfall over the simulation period was stochastic, with annual numbers drawn from a Poisson function of historical records of average annual rainfall per region observed by the Bureau of Meteorology during the last fifty years (BOM, 2010). By moving the slider, a user could shift the function upwards or downwards. Annual rainfall determined forage production in the 'pasture management and production' module and calf mortality in the 'cattle herd' module. It did not affect agricultural and horticultural production, as this was deemed to be supported by available irrigation whenever needed.

3.5. Model user interface

The PPFS was purpose-built and specifically designed for use by members and stakeholders of the NT pastoral industry. Consequently, it was paramount to provide users with an intuitive and simple model interface, which fulfilled a number of functions. It would enable users to (1) access the scenario narratives, (2) explore the architecture and heuristic of the model structure, (3) run model simulations on the basis of parameter inputs of their choice and (4) see, compare and review the results of model simulations. Fig. 2 illustrates aspects of the user interface.

3.6. Model validation

In systems modelling, the ultimate objective of the validation process is to establish the structural validity of the model with respect to the modelling purpose so as to confirm its relevance. Validation refers to model structure, inputs and outputs. Matters of model structure and inputs have been addressed above, following the criteria spelled out by Jakeman et al. (2006). Typically, dynamic simulation models are output validated by comparing model results with past trends for selected variables (Gueneralp and Barlas, 2003; Bennett et al., 2013). However, in the context of abstract and multi-disciplinary models such as the PPFS output validation is difficult and rarely achieved (Doole and Pannell, 2013) and the question is reduced to whether the model is credible or adequate for intended use (Aumann, 2011).

The performance of the PPFS was repeatedly tested and verified firstly during the calibration process as functional relationships and constraints were adjusted until the experts were satisfied with the model's performance across all model dimensions. Secondly, as part of the pastoral industry strategic planning process and in the presence of scientists and other industry experts, a large number of model simulations were conducted to explore the scenarios and sensitivity–test parameters. As in many model applications (e.g. Brugnach et al., 2007; Tidwell and van den Brink, 2008; Voinov and Bousquet, 2010) verification and validation of the PPFS were purely expert and stakeholder-based. In these applications, the PPFS was shown to perform accurately and reliably relative to the mental models of industry experts and stakeholders. It was therefore deemed credible and fit for purpose (Aumann, 2011).

The PPFS results were not subjected to a formal output validation, which constitutes a major limitation in terms of its scientific credibility though not its acceptability by the pastoral industry. However, whole-of-system output validation in the context of complex agricultural models can be problematic and may be less important than model transparency and use to gain greater understanding of the underlying system (Johnson, 2011).

4. Illustration of model outcomes and assessment

4.1. Model capability

The PPFS is an agricultural systems simulation model, which was developed during the course of a 9-month consultancy project for and with the NT pastoral industry. Its primary purpose was to help facilitate and foster industry discourse and strategic planning capability in the light of increasing challenges to the sustainability of the industry from various sources of risk, including economic, environmental and institutional. Model structure and inputs were validated according to best practice but output validation was restricted to a qualitative assessment by industry experts and stakeholders who were part of the design, calibration and planning process. With this in mind, the PPFS is a prototype model which

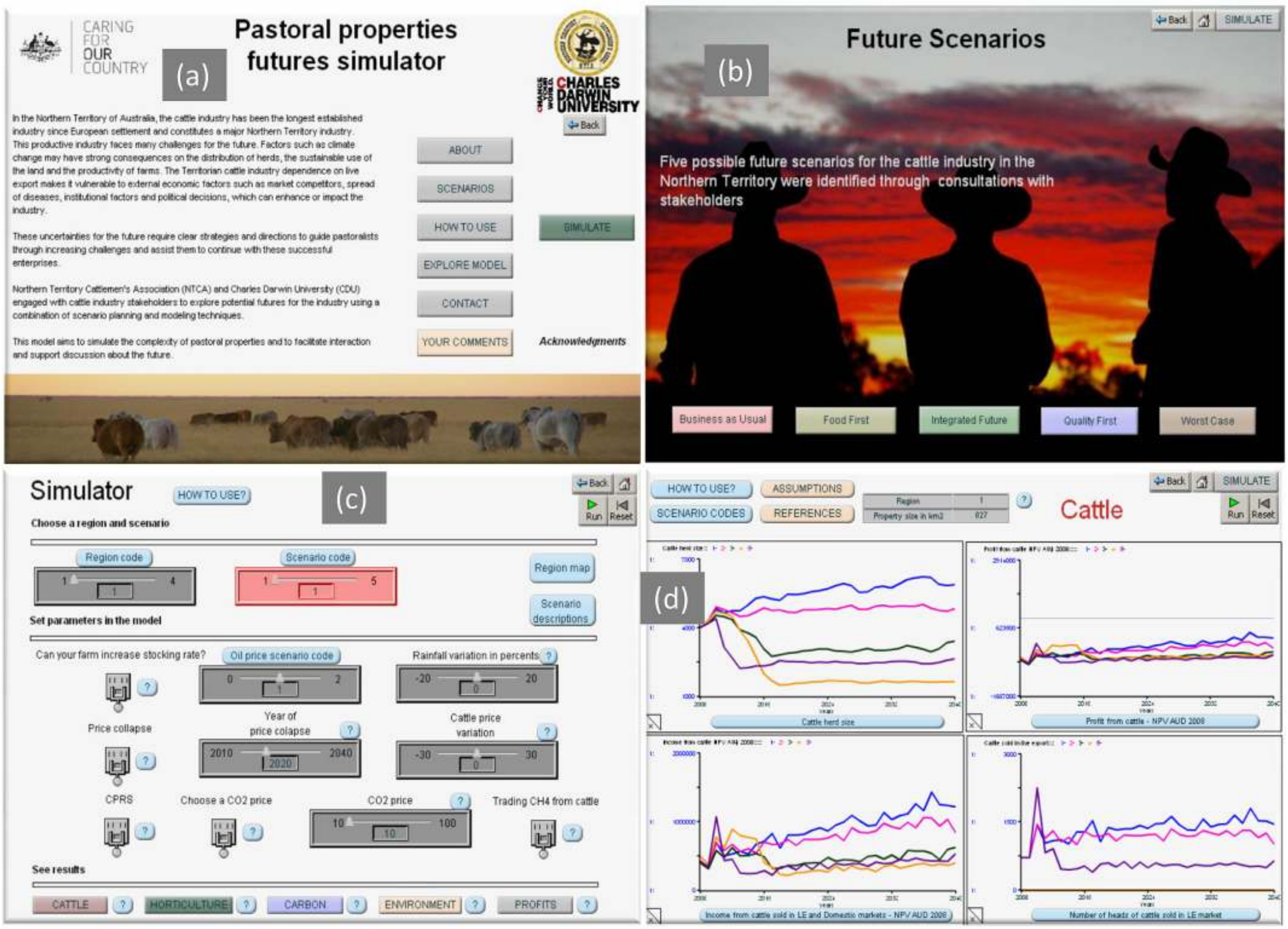

Fig. 2. Illustration of various aspects of the PPFS user interface: (a) home page with general information about the project and links to other forms; (b) page giving links to the description of the 5 scenarios; (c) simulator page where user can play with the value of different variables and choose a scenario; (d) example of a sector results page with graphs where each line represent a different scenario.

shows great promise and deserves more investment for improved reliability and continued contribution to the NT pastoral industry.

As numerical results of scenario modelling with the PPFS have been published elsewhere (Puig et al., 2011), the following discussion illustrates the model's capacity as a tool to facilitate social learning and industry discourse within the context of the limitations mentioned above. Results and illustrations have been selected to respond to the specific challenges mentioned in the context section of the paper and discussion content from pastoral industry workshops and scenario planning sessions is offered.

In a generic sense, model runs illustrated how sensitive farm profitability was to product and input price parameters and to rainfall assumptions. Land use diversification in *Integrated Future* and *Quality First* meant that farms were less impacted by market and climate fluctuations compared to other scenarios.

Among the four scenario narratives, none was economically superior for all four model farms, meaning the same suite of circumstances impacted the pastoral regions in the NT differently. Intensification of land use—based on improvements in infrastructure and management practice together with development of agriculture—such as described in *Business as usual* and *Food First*, was most profitable for northern regions, where pastoral land productivity and agricultural potential were already higher, compared to the more arid Alice Springs region.

Agricultural development on pastoral leasehold land in the NT land remains constrained by land tenure: pastoral leasehold land must be used exclusively for pastoral purposes, thus restricting enterprise diversification on pastoral properties. Very few properties have freehold title and are thus unconstrained. However, even once the tenure constraint was removed in some scenarios, the rate of agricultural expansion could not exceed the population growth rate. However, it emerged that the estimated rate of agricultural and horticultural development was endogenously limited due to capital costs and labour constraints: The NT has a low unemployment rate in the Australia context, high labour force participation and above-average incomes (ABS, 2012a,b), and enticing agricultural development is not a simple case of reforming tenure law. Overcoming labour shortages to support agricultural development is likely to require systematic policy approaches, which span economic and social domains. Participants in the planning workshops thought that the model results helped the pastoral industry formulate a case for lobbying for tenure reform but they also suggested that a strategy needed to be developed to find ways for the large Indigenous population of the NT, which experiences much

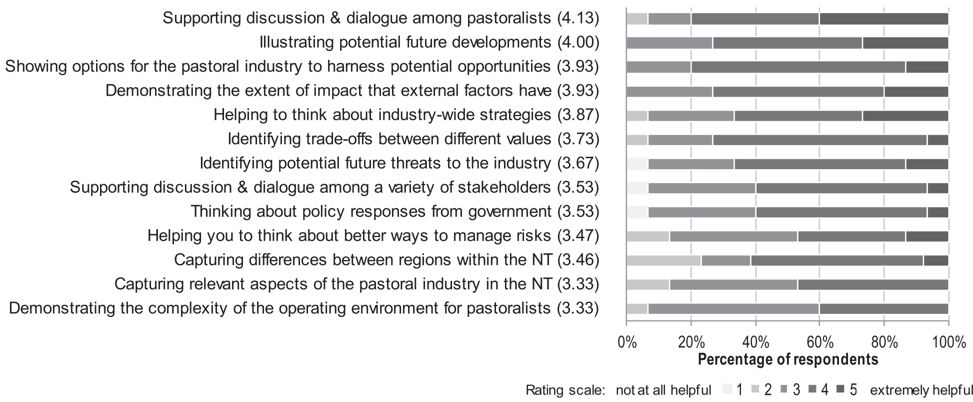

Fig. 3. Evaluation of the PPFS by industry stakeholders participating in the strategic planning workshops ($n = 15$).

lower workforce participation and much higher unemployment compared to the non-Indigenous population (ABS, 2004), to participate in and benefit from agriculture.

Trade-offs between economic and environmental farm performance were evident in the intensification scenarios *Business as Usual* and *Food First*. Both resulted in a decline in the farm CEI, caused by clearing native vegetation for agriculture and improving pastures for grazing, which reduced biodiversity and increased emission of GHGs. Trade-offs between production income and carbon income/cost were evident when a carbon price and carbon trading were introduced in the *Integrated Future* scenario. While GHG emissions imposed costs, northern farms (*Top End*, *Katherine* and *Barkly*) responded by reducing cattle numbers and adopting controlled burning practices, thus reducing farm GHG emissions and, in some cases, earning substantial income from carbon offsets. From an industry planning perspective, it was seen as important to clarify the rules around carbon sequestration and costs of GHG emissions so as to enable farms to exploit their propitious niche in

Table 4
Assessment of the PPFS according to the best practice criteria (Jakeman et al., 2006).

Step no	Step description	Score	Justification of score
1	Define model purpose	High	Purpose was clearly defined as a support tool for industry discourse, discussion and strategic planning. Thus there was a focus on social learning and improved qualitative understanding of the system, but also a quantitative component in terms of model ability to illustrate direction and magnitude of changes given certain assumptions.
2	Specify model context	High	The model context was highly specific. The brief was to develop a model to support a scenario-based industry strategic planning process of the pastoral industry in the NT, facilitated by its peak industry organisation. Duration of the planning process: 9 months. Stakeholders: Pastoral industry members and stakeholders. Model users: NTCA, pastoralists, stakeholders. Spatial scale: NT. Temporal scale: medium-term future. Resolution: Pastoral regions presented by model farms. Flexibility: mandatory.
3	Conceptualise system, data specification, prior knowledge	High	Conceptualisation was undertaken in consultation with NTCA and selected stakeholders and experts. Model complexity high because of need to generate insights into complex relationships (production-economic-environmental-emerging markets and policy). Available data sources identified. It was determined a 30-year simulation period would give clear indications of directions and magnitudes of change under different sets of assumptions.
4	Select model family and features	High	To enhance the exploratory nature of the model, a simulation approach was chosen over a normative/optimisation approach. Software (Stella©) provided a tested environment. Modular structure was determined as per (3). Parameterisation and functional specifications as per (3). Uncertainty was accounted through inclusion of stochastic parameters (e.g. rainfall, prices).
5, 6	Determine how model structure and parameter values are to be found and identify model structure and parameter values	High	The pastoral industry was conceived as an interconnected array of system components, represented by modules. The components were mostly clearly delineated but interconnections were also logical and clear. Where no formal data was available, industry and expert knowledge were used and/or parameters specified based on assumptions. Model calibration was undertaken through a series of meetings with industry members, experts and scientists.
7	Choose estimation/performance criteria and algorithm	Low	No formal parameter estimation algorithms were employed. Model calibration was entirely based on repeated simulation runs in the presence of industry members, experts and scientists with ultimate choice of parameter values determined by whether model behaviour matched mental models of participants.
8	Conduct verification including diagnostic testing	Low	Structural and data verification were undertaken where possible. Function of modules was tested. Qualitative performance assessment was undertaken (7) so that model was fit for purpose (adequate). Output validation was not conducted for several reasons: (1) client required industry acceptance not formal validation, (2) model-building was highly time-constrained and (3) lack of comparable output data.
9	Quantify uncertainty	Medium	Uncertainty in the model was dealt with allowing users to 'play with' and explore a wide range of parameter values and combinations through the user interface. Multiple runs of the same parameter settings could be undertaken and probability density curves developed. Alternative model structures and functional specifications were not tested.
10	Conduct model evaluation and testing	High	The model was fit for purpose. It performed very well against its key objective, i.e. support the strategic planning process. Industry meetings were supported by live model applications and the types and details of strategic directions was directly influenced by the model. Model results have been published in scientific literature.

the emergence of environmental services markets (Greiner, 2010). As of 2013, the reality of carbon farming is being commercially tested on two NT cattle farms, Henbury Station in the Alice Springs region and Fishers Creek Station in the Katherine regions.

Good farm financial performance and high CEI were achieved in the *Integrated Future* and *Quality First* scenarios, which assumed that a product price advantage could be established for beef produced in ecologically benign production systems. Higher product price could over-compensate reduced herd size and payments for environmental services produced additional financial benefits for farms. Planning workshop participants expressed a preference for these potential futures over those based on production intensification. Realizing these futures will require cattle market differentiation and price premiums for eco-beef, and the development of non-production based income streams, such as through payments for ecosystem services (e.g. Foran, 2007; Greiner et al., 2009; Fitzhardinge, 2012).

As a result of the participatory action research process, the NT pastoral industry agreed on a strategy to ensure industry prosperity and resilience into the future. The strategy had four major elements namely (1) diversifying trade relations, (2) adding value to cattle products, (3) improving environmental performance and (4) improving social relations.

There was an agreed urgent need for the diversification of trade avenues for NT cattle to reduce dependence on the live export market, in particular live export to Indonesia. At the time when this research was conducted, Indonesia bought 90% the NT's live exported cattle (NTG, 2010). Market diversification would shore up product prices and help the industry respond to the pressures and dynamics of the global market (Ash and Stafford Smith, 2003; Robertson, 2003). Trade diversification was not possible without product diversification, which in turn provided the opportunity for adding value to cattle products: the recommendation was to diversify pathways of cattle to market and products obtained from cattle. Instead of live cattle export and interstate transfer for slaughter, local slaughter and processing capacity would open the opportunity to produce and market quality certified boxed beef at a price premium. This would give recognition to the quality grass-fed cattle in the NT (Ash and Stafford Smith, 2003) and facilitate pastoral properties diversifying into conservation land uses and entering emerging environmental services markets (Greiner et al., 2009; Hunt, 2003). An abattoir is now under construction outside Darwin. It is being built by a large corporate cattle producer.

The cattle industry needed to become more proactively engaged in environmental management while also improving relationships with other interest groups and industries, in particular Indigenous peoples, conservation groups and tourism, who might have competing interests in the land. The industry needed to respond constructively to environmental concerns and emerging ecosystem services markets and support the integration of conservation and production on-farm. On one hand, climate change and climate-related government policy were a threat to the established ways of doing things on pastoral properties but, on the other hand, they facilitated opportunities for land use and income diversification.

4.2. Evaluation of the PPFS

Nineteen pastoralists participated in the three final planning workshops. They were asked to assess the PPFS on a number of criteria. The 5-point rating scale ranged from 1 = not at all helpful to 5 = extremely helpful. Sixteen pastoralists provided feed-back. Criteria and mean values are shown in Fig. 3. The industry feed-back indicates that the PPFS was indeed rated highly against its core business, i.e. to facilitate discussion by enabling industry members to systematically explore the future.

Based on the material presented above and in Puig et al. (2009, 2011), the PPFS is now also assessed against the 'ten iterative steps in development and evaluation of environmental models' proposed by Jakeman et al. (2006) (Table 4).

5. Conclusions

Model-assisted scenario-based planning can be a powerful tool for industries and communities to explore complexity and uncertainty, and develop strategies for active engagement with an uncertain world. The NT pastoral industry adopted this approach and commissioned the development of a quantitative systems model to facilitate social learning, industry discussion and strategy development at a critical point in time for the industry. The PPFS was built in a mediated modelling process to support industry strategic planning and delivered on its brief. It succeeded in conceptualising the NT pastoral industry as a complex economic-ecological system and combing key features of the industry, emerging opportunities and uncertainty about the future into a unifying, user-friendly modelling framework. The application of the PPFS helped the industry to agree on a preferred future and develop a clear set of strategies for pursuing this future in a climate and market-challenged world. Embedding model development within a participatory action research process was critical to this success.

The PPFS was tailored to a specific purpose, built within a challenging time frame with limited resources and constrained by the data and information available. Being a tool for participatory integrated assessment, model evaluation and validation methods were focused on the model purpose rather than selecting commonly used quantitative measures (Bennett et al., 2013). Its credibility underpins its capability to serve the industry and stakeholders well into the future. To meet future needs, the following improvements in particular are suggested, namely (1) more detailed treatment of grazing land management practices using emerging understanding and data (O'Reagain and Scanlan, 2011; O'Reagain and Scanlan, 2013; Scanlan et al., 2013, Walsh and Cowley, 2011), (2) greater differentiation between different types of cattle and beef product markets, (3) income opportunities from ecosystem services other than carbon, (4) closing the loop between rainfall, irrigation water availability and crop yields, (5) a more sophisticated way of dealing with environmental dimensions and feedback relationships, such as relating to land, water and biodiversity, and (6) modelling a larger range of market-based policy instruments. Formal output validation of the model after Bennett et al. (2013) will also be necessary to achieve not just industry but also scientific credibility, particularly if (a) the geographical scale of model applications is to be expanded or (b) the scope of application is to include policy analysis. Ex-post evaluation of events, such as the temporary ban of cattle live export to Indonesia in 2011 could be used for formal output validation of the PPFS, which would also give the PPFS more credence as a lobbying tool in conversations between the pastoral industry and government.

Acknowledgements

This project was funded by the Australian Government Caring for Our Country program. We are grateful to members and staff of Northern Territory Cattlemen's Association, in particular Luke Bowen, for guidance and support offered, and to all workshop participants for their engagement. We acknowledge all expert contributions into the building of the model and formulation of strategies. We appreciate the valuable contribution of Ian Perkins on the coordination and facilitation of the project. We thank Mark Austin for helpful comments on an earlier draft of this paper. Last but not least we thank three anonymous referees and the journal editor for their valuable comments.

References

ABARE, 2009. Farm Survey Data for the Beef, Slaughter Lambs and Sheep Industries. Australian Bureau of Agricultural and Resource Economics, Canberra. Available at: www.abareconomics.com/ame/mla/mla.asp (accessed 13.01.11.).

ABS, 2004. Australian Social Trends, 2004. Catalogue Number 4102.0. Australian Bureau of Statistics, Canberra.

ABS, 2012b. State and Territory Statistical Indicators, 2012. Catalogue Number 1367.0. Australian Bureau of Statistics, Canberra.

ABS, 2012a. Average Weekly Earnings, Australia, February 2012. Catalogue Number 6302.0. Australian Bureau of Statistics, Canberra.

AIP, 2011. Terminal Gates Prices. Australian Institute of Petroleum, Sydney. Available at: www.aip.com.au/pricing/tgp/index.htm (accessed 13.01.11.).

Allan, G.E., Southgate, R., 2002. Fire regimes in the spinifex landscape of Australia. In: Bradstock, R.A., Williams, J.E., Gill, M.A. (Eds.), Flammable Australia. The Fire Regimes and Biodiversity of a Continent. Cambridge University Press, Cambridge, pp. 145–176.

Amer, M., Daim, T.U., Jetter, A., 2013. A review of scenario planning. Futures 46 (0), 23–40.

Anderson, J.R., 1974. Simulation: methodology and application in agricultural economics. Rev. Mark. Agric. Econ. 42, 3–55.

Andersson, L., Olsson, J.A., Arheimer, B., Jonsson, A., 2008. Use of participatory scenario modelling as platforms in stakeholder dialogues. Water SA 34 (4), 439–447.

Antunes, P., Santos, R., Videira, N., 2006. Participatory decision making for sustainable development the use of mediated modeling techniques. Land Use Policy 23 (1), 44–52.

Argent, R.M., 2004. An overview of model integration for environmental applications—components, frameworks and semantics. Environ. Modell. Softw. 19 (3), 219–234.

Ash, A., Stafford Smith, M., 2003. Pastoralism in tropical rangelands: seizing the opportunity to change. Rangel. J. 25, 113–127.

Aumann, C.A., 2011. Constructing model credibility in the context of policy appraisal. Environ. Modell. Softw. 26 (3), 258–265.

Bennett, N.D., Croke, B.F.W., Guariso, G., Guillaume, J.H.A., Hamilton, S.H., Jakeman, A.J., Marsili-Libelli, S., Newham, L.T.H., Norton, J.P., Perrin, C., Pierce, S.A., Robson, B., Seppelt, R., Voinov, A.A., Fath, B.D., Andreassian, V., 2013. Characterising performance of environmental models. Environ. Modell. Softw. 40, 1–20.

Berger, P.A., 2006. Generating agricultural landscapes for alternative futures analysis: a multiple attribute decision making model. Trans. GIS 10, 103–120.

BOM (Bureau of Meteorology), 2010. Climate Data Online. Available at: www.bom.gov.au/climate/data/index.shtml (accessed 13.01.10.).

Bradfield, R., Wright, G., Burt, G., Cairns, G., Van Der Heijden, K., 2005. The origins and evolution of scenario techniques in long range business planning. Futures 37 (8), 795–812.

Brown Gaddis, E.J., Falk, H.H., Ginger, C., Voinov, A., 2010. Effectiveness of a participatory modeling effort to identify and advance community water resource goals in St. Albans, Vermont. Environ. Modell. Softw. 25 (11), 1428–1438.

Brugnach, M., Tagg, A., Keil, F., de Lange, W.J., 2007. Uncertainty matters: computer models at the science-policy interface. Water Resour. Manag. 21, 1075–1090.

Bryant, B.P., Lempert, R.J., 2010. Thinking inside the box: a participatory, computer-assisted approach to scenario discovery. Technol. Forecast. Soc. Change 77 (1), 34–49.

Burrows, N.D., Ward, B., Robinson, A.D., Behn, G., 2006. Fuel dynamics and fire behaviour in spinifex grasslands of the western desert. In: Bushfire Conference, Life in a Fire-prone Environment: Translating Science into Practice. Brisbane, 6–9 June 2006. Available at: www.griffith.edu.au/conference/bushfire2006/pdf/fuel-dynamics-and-fire-behaviour.pdf (accessed 13.01.11.).

Cobon, D.H., Stone, G.S., Carter, J.O., Scanlan, J.C., Toombs, N.R., Zhang, X., Willcocks, J., McKeon, G.M., 2009. The climate change risk management matrix for the grazing industry of northern Australia. Rangel. J. 31, 31–49.

Collier, N., Austin, B.J., Bradshaw, C.J.A., McMahon, C.R., 2011b. Turning pests into profits: introduced buffalo provide multiple benefits to indigenous people of northern Australia. Hum. Ecol. 39, 155–164.

Collier, N., Sandker, M., Garnett, S.T., Campbell, B.M., Sayer, J., Boedhihartono, A.K., 2011a. Science for action: the use of scoping models in conservation and development. Environ. Sci. Policy 14, 628–638.

Costanza, R., Ruth, M., 1998. Using dynamic modeling to scope environmental problems and build consensus. Environ. Manag. 22 (2), 183–195.

Costanza, R., Duplisea, D., Kautsky, U., 1998. Ecological modelling on modelling ecological and economic systems with STELLA. Ecol. Modell. 110 (1), 1–4.

Costanza, R., Gottlieb, S., 1998. Modelling ecological and economic systems with STELLA: part II. Ecol. Modell. 112 (2), 81–84.

Costanza, R., Voinov, A., 2001. Modeling ecological and economic systems with STELLA: part III. Ecol. Modell. 143 (1), 1–7.

CSIRO and BOM (Australian Commonwealth Scientific and Research Organization - Bureau of Meteorology), 2007. Climate Change in Australia: Technical Report 2007. CSIRO Publishing, Melbourne, Australia. Available at: climatechangeinaustralia.com.au/ (accessed 13.01.11.).

De Kraker, J., Kroeze, C., Kirschner, P., 2011. Computer models as social learning tools in participatory integrated assessment. Int. J. Agric. Sustain. 9 (2), 297–309.

Doole, G.J., Pannell, D.J., 2013. A process for the development and application of simulation models in applied economics. Aust. J. Agric. Resour. Econ. 57 (1), 79–103.

DPIFM (Department of Primary Industry, Fisheries and Mines, Northern Territory Government), 2008. Factsheet 1: NT Pastoral Industry and Climate Change Overview. Available at: www.nt.gov.au/d/Content/File/p/Climate_Change/CCFS01.pdf (accessed 13.01.11.).

DRDPIFR (Department of Regional Development, Primary Industry, Fisheries and Resources, Northern Territory Government), 2008. NT Plant Industries Profile 2007. Information Sheet IS60. Available at: www.nt.gov.au/d/Primary_Industry/Content/File/horticulture/IS60_NT_Plant_Industries_Profile.pdf (accessed 13.01.11).

DRDPIFR (Department of Regional Development, Primary Industry, Fisheries and Resources, Northern Territory Government), 2009a. Annual Report 2008–2009. Available at: www.nt.gov.au/d/Content/File/p/AR/AR_2009.pdf (accessed 13.01.11.).

DRDPIFR (Department of Regional Development, Primary Industry, Fisheries and Resources, Northern Territory Government), 2009b. Growing Our Primary Industries. Available at: www.nt.gov.au/d/Content/File/p/pi/growingourPI_21_10.pdf (accessed 13.01.11.).

Drucker, A.G., Garnett, S.T., Luckert, M.K., Crowley, G.M., Gobius, N., 2008. Manager-based valuations of alternative fire management regimes on Cape York Peninsula, Australia. Int. J. Wildland Fire 17 (5), 660–673.

EIO (Energy Information Organization), 2008. Annual Energy Outlook 2008. Available at: www.eia.doe.gov/oiaf/archive/aeo08/index.html (accessed 13.01.11.).

Fitzhardinge, G., 2012. Australia's rangelands: a future vision. Rangel. J. 34 (1), 33–45.

Foran, B., 2007. Sifting the future from the past: a personal assessment of trends impacting the Australian rangelands. Rangel. J. 29 (1), 3–11.

Garnaut Climate Change Review, 2008. Targets and Trajectories: Supplementary Draft Report. Available at: www.garnautreview.org.au/CA25734E0016A131/WebObj/GarnautReviewTargetsandtrajectories/$File/Garnaut%20Review%20Targets%20and%20trajectories.pdf (accessed 13.01.11).

Garnett, S.T., Woinarski, J.C.Z., Crowley, G.M., Kutt, A.S., 2010. Biodiversity conservation in Australian tropical rangelands. In: Toit, J. du, Kock, R., Deutsch, J. (Eds.), Wild Rangelands: Conserving Wildlife While Maintaining Livestock in Semi-arid Ecosystems. Blackwell Scientific, London, pp. 191–234.

Giannetti, B.F., Bonilla, S.H., Silva, C.C., Almeida, C.M.V.B., 2009. The reliability of experts' opinions in constructing a composite environmental index: the case of ESI 2005. J. Environ. Manag. 90 (8), 2448–2459.

Greiner, R., 2010. The potential for a conservation economy in the tropical savannas based on 'payments for environmental services'. In: Gerritson, R. (Ed.), North Australian Political Economy. Charles Darwin University, Darwin, pp. 163–179.

Greiner, R., Gordon, I., Cocklin, C., 2009. Ecosystem services from tropical savannas: economic opportunities through payments for environmental services. Rangel. J. 31 (1), 51–59.

Griffon, S., Auclair, D., Nespoulous, A., 2010. Visualising Changes in Agricultural Landscapes. In: Environmental and Agricultural Modelling. Springer, pp. 133–157.

Gueneralp, B., Barlas, Y., 2003. Dynamic modelling of a shallow freshwater lake for ecological and economic sustainability. Ecol. Modell. 167 (1–2), 115–138.

Heckbert, S., Davies, J., Cook, G., McIvor, J., Bastin, G., Liedloff, A., 2008. Land Management for Emissions Offsets on Indigenous Lands. CSIRO Sustainable Ecosystems, Townsville, Qld. Available at: www.csiro.au/files/files/pnpo.pdf (accessed 13.01.11.).

Howden, S.M., Crimp, S.J., Stokes, C.J., 2008. Climate change and Australian livestock systems: impacts, research and policy issues. Aust. J. Exp. Agric. 48, 780–788.

Hughes, L., 2003. Climate change and Australia: trends, projections and impacts. Aust. Ecol. 28 (4), 423–443.

Hunt, L.P., 2003. Opportunities for the future in Australia's grazed rangelands. Rangel. J. 25 (2), 183–195.

IPCC (International Panel on Climate Change), 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories Workbook, vol. 2. Cambridge University Press, Cambridge, UK.

IPCC (International Panel on Climate Change), 2001. Climate Change 2001: the Scientific Basis. In: Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K., Johnson, C.A. (Eds.), Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

ISEE Systems, Inc, 2009. STELLA Systems Thinking for Education and Research. Available at: www.iseesystems.com/softwares/Education/StellaSoftware.aspx (accessed 13.01.11.).

Jakeman, A.J., Letcher, R.A., Norton, J.P., 2006. Ten iterative steps in development and evaluation of environmental models. Environ. Modell. Softw. 21 (5), 602–614.

Jamal, T., Borges, M., Figueiredo, R., 2004. Systems-based modeling for participatory tourism planning and destination management. Tour. Anal. 9 (1), 77–89.

Janssen, S., van Ittersum, M.K., 2007. Assessing farm innovations and responses to policies: a review of bio-economic farm models. Agric. Syst. 94 (3), 622–636.

Johnson, I.R., 2011. Testing and evaluating large-scale agricultural simulation models. Perth, WA. In: Chan, F., Marinova, D., Anderssen, R.S. (Eds.), MODSIM2011, 19th International Congress on Modelling and Simulation -Modelling

and Simulation Society of Australia and New Zealand; Perth, WA; Australia; 12–16 December 2011, pp. 84–96.
Jones, T., Glasson, J., Wood, D., 2010a. Regional planning and resilient futures: destination modeling and tourism development-'The case of the Ningaloo Coastal region in Western Australia'. In: CAUTHE 2010: Tourism and Hospitality: Challenge the Limits, p. 720.
Jones, T., Wood, D., Hughes, M., Pham, T., Pamdubi, D., Spurr, R., Dwyer, L., Deery, M., Fredline, L., 2010b. Tourism Destination Modeling: Building a Sustainable Planning Tool for Australian Tourism Destinations. Sustainable Tourism CRC, Gold Coast, Australia. Available at: www.crctourism.com.au/BookShop/BookDetail.aspx?d=720 (accessed 13.01.11.).
Kassa, H., Campbell, B., Sandewall, M., Kebede, M., Tesfaye, Y., Dessie, G., Seifu, A., Tadesse, M., Garedew, E., Sandewall, K., 2009. Building future scenarios and uncovering persisting challenges of participatory forest management in Chilimo forest, central Ethiopia. J. Environ. Manag. 90 (2), 1004–1013.
Kelly, R.A., Jakeman, A.J., Barreteau, O., Borsuk, M.E., ElSawah, S., Hamilton, S.H., Henriksen, H.J., Kuikka, S., Maier, H.R., Rizzoli, A.E., van Delden, H., Voinov, A.A., 2013. Selecting among five common modelling approaches for integrated environmental assessment and management. Environ. Modell. Softw. 47 (0), 159–181.
Krueger, T., Page, T., Hubacek, K., Smith, L., Hiscock, K., 2012. The role of expert opinion in environmental modelling. Environ. Modell. Softw. 36 (0), 4–18.
Kutt, A., Felderhof, L., VanDerWal, J., Stone, P., Perkins, G., 2009. Chapter 04: terrestrial ecosystems of northern Australia. In: Northern Australia Land and Water Science Review 2009. Commonwealth Scientific and Industrial Research Organisation, Victoria. Available at: www.nalwt.gov.au/files/Chapter_04-Terrestrial_ecosystems.pdf (accessed 13.01.11.).
Kwakkel, J.H., Pruyt, E., 2012. Exploratory modeling and analysis, an approach for model-based foresight under deep uncertainty. Technol. Forecast. Soc. Change. http://dx.doi.org/10.1016/j.techfore.2012.10.005.
Lagabrielle, E., Botta, A., Daré, W., David, D., Aubert, S., Fabricius, C., 2010. Modelling with stakeholders to integrate biodiversity into land-use planning – lessons learned in Réunion Island (Western Indian Ocean). Environ. Modell. Softw. 25 (11), 1413–1427.
Landsberg, J., James, C., Morton, S., Hobbs, T., Stol, J., Drew, A., Tongway, H., 1997. The Effects of Artificial Sources of Water on Rangeland Biodiversity: Final Report to the Biodiversity Convention and Strategy Section of the Biodiversity Group, Environment Australia. Environment Australia and CSIRO, Canberra.
Law, R., Garnett, S.T., 2009. Understanding Carbon in the Northern Territory. An Analysis of Future Land Use Scenarios Using the National Carbon Accounting Tool. Report to the Tropical Savanna Management Cooperative Research Centre. School for Environmental Research, Charles Darwin University. Available at: www.nt.gov.au/nreta/water/drmac/pdf/ncat_final.pdf (accessed 13.01.11.).
Liu, Y., Gupta, H., Springer, E., Wagener, T., 2008. Linking science with environmental decision making: experiences from an integrated modeling approach to supporting sustainable water resources management. Environ. Modell. Softw. 23 (7), 846–858.
Martin, P., Van Mellor, T., Hooper, S., 2007. Australian Beef 07.1. Live Cattle Export Trade. Importance to Northern and Southern Australian Beef Industries. Australian Bureau of Agricultural and Resource Economics: ACT. Available at: www.abare.gov.au/publications_html/livestock/livestock_07/beef07.pdf (accessed 13.01.11.).
McKeon, G.M., Stone, G.S., Syktus, J.I., Carter, J.O., Flood, N.R., Ahrens, D.G., Bruget, D.N., Chilcott, C.R., Cobon, D.H., Cowley, R.A., Crimp, S.J., Fraser, G.W., Howden, S.M., Johnston, P.W., Ryan, J.G., Stokes, C.J., Day, K.A., 2009. Climate change impacts on northern Australian rangeland livestock carrying capacity: a review of issues. Rangel. J. 31 (1), 1–29.
McKeon, G., Day, K., Howden, S., Mott, J., Orr, D., Scattini, W., Weston, E., 1990. Northern Australian savannas: management for pastoral production. J. Biogeogr. 17, 355–372.
McTaggart, R., 1991. Principles for participatory action research. Adult Educ. Q. 41, 168–187.
Miller, C.P., Stockwell, T.G.H., 1991. Sustaining productive pasture in the tropics. 4. Augmenting native pasture with legumes. Trop. Grassl. 25, 98–103.
Ngo, H., Owens, G., 2004. Gross Margins for Horticultural Crops in the NT – General Guidelines. Agnote No H94. Northern Territory Government, Darwin.
Northern Territory Treasury, 2009. Northern Territory Population Projections, 2009. Available at: www.nt.gov.au/ntt/economics/nt_population.shtml (accessed 13.01.11.).
NTCA (Northern Territory Cattlemen's Association), 2009. Year in Review 2008/9. Available at: www.ntca.org.au/_assets/NTCA_08_09_Part1.pdf (accessed 13.01.11.).
NTG (Northern Territory Government), 2008. Factsheet 3: Reducing Greenhouse Gas Emissions from the NT Pastoral Industry. Department of Primary Industry, Fisheries and Mines. Available at: www.nt.gov.au/d/Content/File/p/Climate_Change/CCFS03.pdf (accessed 13.01.11.).
NTG (Northern Territory Government), 2010. Territory Quarterly. International Edition. Available at: www.theterritory.com.au/resources/img/pdf/publications/territory_quarterly/TQ-int-english.pdf (accessed 13.01.11.).
NTG (Northern Territory Government), 2011. Pastoral Land Act. Available at: www.austlii.edu.au/au/legis/nt/consol_act/pla142/ (accessed 15.08.13.).
O'Connor, M.H., MacFarlane, M., Fisher, J., MacRae, D., Lefroy, T., 2005. The Avon river Basin in 2050: scenario planning in the western Australian. Aust. J. Agric. Res. 56 (6), 563–580.
O'Reagain, P., Scanlan, J., 2013. Sustainable management for rangelands in a variable climate: evidence and insights from northern Australia. Animal 7, 68–78.
O'Reagain, P., Bushell, J., Holmes, B., 2011. Managing for rainfall variability: long-term profitability of different grazing strategies in a northern Australian tropical savanna. Animal Prod. Sci. 51 (3), 210–224.
Oxley, T., Leigo, S., Hausler, P., Bubb, A., MacDonald, N., 2006. Pastoral Industry Survey 2004: NT Wide. Department of Primary Industry, Fisheries and Mines, Northern Territory Government, Darwin. Available at: www.nt.gov.au/d/Primary_Industry/Content/File/PastoralSurvey_ntwide.pdf (accessed 13.01.11.).
Peterson, G.D., Cumming, G.S., Carpenter, S.R., 2003. Scenario planning: a tool for conservation in an uncertain world. Conserv. Biol. 17, 358–366.
Petherick, J.C., 2005. Animal welfare issues associated with extensive livestock production: the northern Australian beef cattle industry. Appl. Animal Behav. Sci. 92 (3), 211–234.
Phillips, C.J.C., Wojciechowska, J., Meng, J., Cross, N., 2009. Animal Int. J. Animal Biosci. 3, 1152–1166.
Post, W.M., Kwon, K.C., 2000. Soil carbon sequestration and land-use change: processes and potential. Glob. Change Biol. 6 (3), 317–327.
Puig, C.J., Huchery, C., Greiner, R., Collier, N., Garnett, S., Perkins, I., 2009. Pastoral Properties Futures Simulator. NTCA Future Project: Scoping Future Scenarios and Building Innovative Partnerships for Northern Territory Pastoral Lands. Report to the Northern Territory Cattlemen's Association. School for Environmental Research. Charles Darwin University, Darwin.
Puig, C.J., Greiner, R., Huchery, C., Perkins, I., Bowen, L., Collier, N., Garnett, S.T., 2011. Beyond cattle: potential futures of the pastoral industry in the Northern Territory. Rangel. J. 33, 181–194.
Reason, P., Bradbury, H., 2001. Handbook of Action Research: Participative Inquiry and Practice. Sage Publications Ltd.
Robertson, G.A., 2003. Global influences on rangelands of Australia. Rangel. J. 25 (2), 128–139.
Robinson, S., 2004. Simulation: the Practice of Model Development and Use. John Wiley & Sons Ltd, Chichester (UK).
Russell-Smith, J., Murphy, B.P., Meyer, C.P., Cook, G.D., Maier, S., Edwards, A.C., Schatz, J., Brocklehurst, P., 2009. Improving estimates of savanna burning emissions for greenhouse accounting in northern Australia: limitations, challenges, applications. Int. J. Wildland Fire 18 (1), 1–18.
Salter, J.D., Campbell, C., Journeay, M., Sheppard, S.R., 2009. The digital workshop: exploring the use of interactive and immersive visualisation tools in participatory planning. J. Environ. Manag. 90 (6), 2090–2101.
Sandker, M., Campbell, B.M., Nzooh, Z., Sunderland, T., Amougou, V., Defo, L., Sayer, J., 2009. Exploring the effectiveness of integrated conservation and development interventions in a central African forest landscape. Biodivers. Conserv. 18 (11), 2875–2892.
Sandker, M., Suwarno, A., Campbell, B.M., 2007. Will forests remain in the face of oil palm expansion? Simulating change in Malinau, Indonesia. Ecol. Soc. 12 (2), 37. Available at: www.ecologyandsociety.org/vol12/iss2/art37/.
Scanlan, J.C., MacLeod, N.D., O'Reagain, P.J., 2013. Scaling results up from a plot and paddock scale to a property – a case study from a long-term grazing experiment in northern Australia. Rangel. J. 35 (2), 193–200.
Schianetz, K., Kavanagh, L., 2008. Sustainability indicators for tourism destinations: a complex adaptive systems approach using systemic indicator systems. J. Sustain. Tour. 16, 601–628.
Sharma, T., Carmichael, J., Klinkenberg, B., 2006. Integrated modeling for exploring sustainable agriculture futures. Futures 38, 93–113.
Steinfield, H., Gerber, P., Wassenaar, T., Castel, V., De Haan, C., 2006. Livestock's Long Shadow: Environmental Issues and Options. Food and Agriculture Organisation, Rome.
Stewart, R.W., Fortune, J., 1995. Application of systems thinking to the identification, avoidance and prevention of risk. Int. J. Proj. Manag. 13, 279–286.
Tidwell, V.C., van den Brink, C., 2008. Cooperative modelling: linking science, communication and ground water planning. Ground Water 46, 174–182.
Valencia-Sandoval, C., Flanders, D.N., Kozak, R.A., 2010. Participatory landscape planning and sustainable community development: methodological observations from a case study in rural Mexico. Landsc. Urban Plan. 94 (1), 63–70.
Villa, F., Athanasiadis, I.N., Rizzoli, A.E., 2009. Modelling with knowledge: a review of emerging semantic approaches to environmental modelling. Environ. Modell. Softw. 24 (5), 577–587.
Voinov, A., Bousquet, F., 2010. Modelling with stakeholders. Environ. Modell. Softw. 25 (11), 1268–1281.
Voinov, A., Fitz, C., Boumans, R., Costanza, R., 2004. Modular ecosystem modeling. Environ. Modell. Softw. 19 (3), 285–304.
Voinov, A., Gaddis, E.J.B., 2008. Lessons for successful participatory watershed modeling: a perspective from modeling practitioners. Ecol. Modell. 216 (2), 197–207.
Volkery, A., Ribeiro, T., Henrichs, T., Hoogeveen, Y., 2008. Your vision or my model? Lessons from participatory land use scenario development on a European scale. Syst. Pract. Action Res. 21 (6), 459–477.
Walker, P.A., Greiner, R., McDonald, D., Lyne, V., 1998. The tourism futures simulator: a systems thinking approach. Environ. Modell. Softw. 14, 59–67.
Walsh, D., Cowley, R.A., 2011. Looking back in time: can safe pasture utilisation rates be determined using commercial paddock data in the Northern Territory? Rangel. J. 33 (2), 131–142.
Williams, R.J., Hutley, L.B., Cook, G.D., Russell-Smith, J., Edwards, A., Chen, X., 2004. Assessing the carbon sequestration potential of mesic savannas in the Northern Territory, Australia: approaches, uncertainties and potential impacts of fire. Funct. Plant Biol. 31, 415–422.

Wollenberg, E., Edmunds, D., Buck, L., 2000. Anticipating Change: Scenarios as a Tool for Adaptive Forest Management: A Guide. Center for International Forestry Research, Bogor, Indonesia. Available at: http://www.cifor.cgiar.org/nc/online-library/browse/view-publication/publication/744.html (accessed 13.01.11.).

Zeigler, B.P., Praehofer, H., Kim, T.G., 2000. Theory of Modeling and Simulation. Academic Press.

Zhou, P., Ang, B.W., Poh, K.L., 2006. Comparing aggregating methods for constructing the composite environmental index: an objective measure. Ecol. Econ. 59 (3), 305–311.