Northern Australia Environmental Resources Hub

National Environmental Science Programme

Integrated models, frameworks and decision support tools to guide management and planning in Northern Australia

Stand-alone summary

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Cover images
Front cover: Irrigated agriculture in northern Australia (photo Michael Douglas).
Back cover: Part of the decision tree created from this project.

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Aim of review

There is a lot of interest in developing northern Australia while also caring for the unique Australian landscape (Commonwealth of Australia 2015). However, trying to decide how to develop and protect at the same time can be a challenge. There are many modelling tools available to inform these decisions, including integrated models, frameworks, and decision support tools, but there are so many different kinds that it is difficult to determine which might be best suited to inform different decisions. To support planning and development decisions across northern Australia, this project aimed to create resources to help end-users (practitioners) to assess:

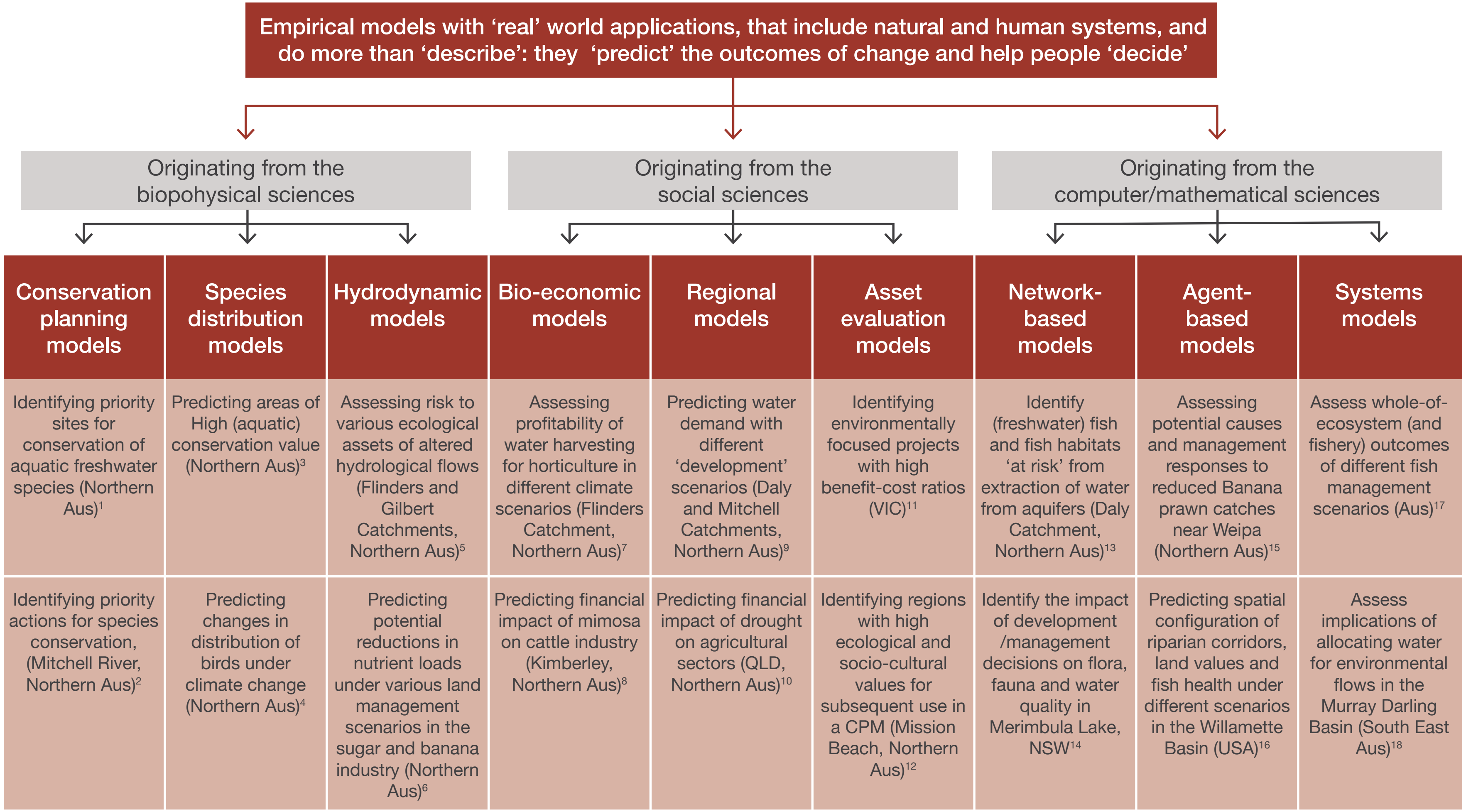
- the availability and suitability of particular modelling tools; and
- the feasibility of using, developing, and maintaining different types of modelling tools.

Tools reviewed

First, to scope our work, we conducted a very broad-scale literatre review on the numerous different models and modelling approaches, determining which types of tools should be included in our analysis and clarifying what we mean by the phrase *integrated decision support tool* (IDST). For the purposes of this project, an IDST must:

1. integrate data from both the natural and the human realms;
2. do more than simply describe, visualise, collate or disseminate information; it must generate its own sets of predictions and/or decisions; and
3. have been used in applied settings and populated with regionally relevant data (i.e. the IDST must be more than a conceptual diagram or a method such as a particular type of statistical analysis).

Using insights from the literature to assess the availability and suitability of various tools, we identified three broad categories of IDSTs: those originating from within (1) the biophysical sciences, (2) the social and economic sciences, and (3) the mathematical/computing sciences. Each broad category of IDST was further divided into three sub-categories (Figure 1).



Empirical models with ‘real’ world applications, that include natural and human systems, and do more than ‘describe’: they ‘predict’ the outcomes of change and help people ‘decide’

Originating from the biopohysical sciences			Originating from the social sciences			Originating from the computer/mathematical sciences		
Conservation planning models	**Species distribution models**	**Hydrodynamic models**	**Bio-economic models**	**Regional models**	**Asset evaluation models**	**Network-based models**	**Agent-based models**	**Systems models**
Identifying priority sites for conservation of aquatic freshwater species (Northern Aus)[1]	Predicting areas of High (aquatic) conservation value (Northern Aus)[3]	Assessing risk to various ecological assets of altered hydrological flows (Flinders and Gilbert Catchments, Northern Aus)[5]	Assessing profitability of water harvesting for horticulture in different climate scenarios (Flinders Catchment, Northern Aus)[7]	Predicting water demand with different ‘development’ scenarios (Daly and Mitchell Catchments, Northern Aus)[9]	Identifying environmentally focused projects with high benefit-cost ratios (VIC)[11]	Identify (freshwater) fish and fish habitats ‘at risk’ from extraction of water from aquifers (Daly Catchment, Northern Aus)[13]	Assessing potential causes and management responses to reduced Banana prawn catches near Weipa (Northern Aus)[15]	Assess whole-of-ecosystem (and fishery) outcomes of different fish management scenarios (Aus)[17]
Identifying priority actions for species conservation, (Mitchell River, Northern Aus)[2]	Predicting changes in distribution of birds under climate change (Northern Aus)[4]	Predicting potential reductions in nutrient loads under various land management scenarios in the sugar and banana industry (Northern Aus)[6]	Predicting financial impact of mimosa on cattle industry (Kimberley, Northern Aus)[8]	Predicting financial impact of drought on agricultural sectors (QLD, Northern Aus)[10]	Identifying regions with high ecological and socio-cultural values for subsequent use in a CPM (Mission Beach, Northern Aus)[12]	Identify the impact of development /management decisions on flora, fauna and water quality in Merimbula Lake, NSW[14]	Predicting spatial configuration of riparian corridors, land values and fish health under different scenarios in the Willamette Basin (USA)[16]	Assess implications of allocating water for environmental flows in the Murray Darling Basin (South East Aus)[18]

Figure 1. Broad categories and sub-categories of IDSTs considered in this review, showing regionally relevant applications of those models.

1. Hermoso et al., 2012; 2. Cattarino et al., 2015; 3. Kennard et al., 2010; 4. VanDerWal et al., 2013; 5 DSITIA, 2014; 6. Armour et al., 2009; 7. Petheram et al., 2016; 8. Cook et al., 2015; 9. Stoeckl et al., 2013; 10. Horridge et al., 2005; 11. Pannell et al., 2012; 12. Pert et al., 2013; 13. Chan et al., 2012; 14. Ticehurst et al., 2008; 15. Dambacher et al., 2015; 16. Bolte et al., 2006; 17. Fulton et al., (2011); 18. Mainuddin et al., 2007.

Resources created

1. Overview of the key characteristics and technical specifications of each type of IDST

The nine sub-categories of IDSTs were differentiated according to a range of factors such as the focus of the model (e.g. on aquatic species, hydrological systems, economics, or interactions between systems), the spatial and temporal scale of data used within the models, and the techniques used to analyse data within the models. For each sub-category of IDST, we summarised core characteristics in a table of technical specifications. These nine separate tables describe the main purpose of each generic sub-category of IDST, the key outputs, the realms considered, the dominant realm(s), whether or not there were interactions between and within realms, the length of time required to run the model, overall costs of developing, IT requirements, the type of problem-solving technique used and the type of data required (including the temporal and spatial nature of data used for input and generated for output). Table 1 on the next page collates information from each of the tables, into a single high-level overview.

2. Short literature review of sub-categories of IDSTs with critical references for those who wish to learn more

There is a vast amount of literature on each sub-category of IDST; for some, there were more than 1000 examples of applications worldwide. Rather than attempting to generate a comprehensive review of each, we provided a short review, using insights from the literature to critically evaluate and assess their strengths and limitations. Each short review provides several references and importantly, references to journal articles or other publications that provide detailed reviews. Those interested in learning more about a particular sub-category of IDST are thus provided guidance on where to go to learn more.

3. Case studies

For each sub-category of IDST, we also prepared a comprehensive collection of applied case studies, describing in layman's terms what they set out to do, what they tried, what they got, what they learnt, and what they may need to do next. Whenever possible, we selected examples from northern Australia. When we were unable to find applications in this region, we sought examples that had been applied elsewhere in the world but in contexts similar to that of northern Australia (i.e. with relatively intact ecosystems, significant Indigenous populations and development that is largely focused around industries that are reliant upon natural resources).

4. Overview of the decision-making context in which each type of IDST is likely to be most useful

Insights from the reviews, case studies and information relating to the detailed technical specifications were used to provide a short layman's summary (targeting users, rather than creators of IDST) of the decision-making context in which each type of IDST is most likely to be useful.

Further details on technical specifications and case-studies can be found from the main report, available online at http://www.nespnorthern.edu.au/projects/nesp/review-of-models-frameworks-and-decision-support-tools-for-northern-australia

Table 1. Key characteristics of different types of IDSTs.

Characteristic	Species distribution models (SDM)	Conservation planning models (CPM)	Hydrological models	Bioeconomic models	Regional models	Asset/ Project Evaluation models	Network based models	Agent-based models (ABM)	Systems (SM) models
Purpose of model (decide/ predict/ optimise)	Predict species distribution	Decide best conservation policy	Predict impacts of 'change' on water resources	Optimise economic situation	Predict growth trajectories and impacts	Identify areas/ projects of highest 'value'	Decide or predict	Decide, predict, or optimise.	Decide, predict
Dominant 'realm'	Aquatic and/or Terrestrial	Aquatic and/or Terrestrial	Natural for modelling. Human for objective	Economic	Economic	Human	No dominant realm unless modelled	No dominant realm unless modelled	No dominant realm unless modelled
Aquatic or Terrestrial species or processes	Can be predictor or predicted	Can be an objective; few processes	Can be outcome; no processes	Can be, but if present often as a constraint	Rarely, if ever included, but could be	Value of state; no processes	Can be 'node'; simple processes	Can be an 'agent'	Can be an entire sub-component
Hydrological processes	Only if correlated with species; no processes	Rarely – if so, as a constraint; no processes	Always	Limited; if present often as a constraint (no process)	Limited; as an input & output (not a process)	Value of state; no processes	Can be 'node'; simple Bayesian processes	Can be boundary condition; no processes.	Can be an entire sub-component
Other biophysical variables or processes	Only if correlated with species; no processes	Rarely – if so, as a constraint; no processes	Often as influencing water dynamics	Limited; if present often as a constraint	Sometimes as an 'output' e.g. pollution	Value of state; no processes	Can be 'node'; simple Bayesian processes	Can be an 'agent'	Can be an entire sub-component
Economic agents or processes	Only if correlated with species; no processes	Almost always – typically as a constraint; no processes	Can be outcome; no processes	Always	Always	Core objective but; no processes	Can be 'node'; simple Bayesian processes	Can be an 'agent'	Can be an entire sub-component
Social agents, issues or processes	Only if correlated with species; no processes	Rarely	Can be outcome; no processes	Welfare effects on humans sometimes incorporated	Social indicators included in some models	Some attempt to value state; no processes	Can be 'node'; simple Bayesian processes	Can be an 'agent'	Can be an entire sub-component
Spatial resolution	Limited only by available data	Limited only by available data	Limited only by available data	Limited only by available data	Typically large	Challenged if values cross boundaries	Limited only by available data	Limited only by available data	Limited only by available data
Interaction between scales[1]?	Potentially	No	Yes	Yes	Not normally	Yes	No	Yes, emergent features across scales	Yes, depending on choice of sub-components

Characteristic	Species distribution models (SDM)	Conservation planning models (CPM)	Hydrological models	Bioeconomic models	Regional models	Asset/ Project Evaluation models	Network based models	Agent-based models (ABM)	Systems (SM) models
Temporal resolution[2]	Normally nontemporal	Normally nontemporal	Dynamic (often daily time-step)	Lumped, dynamic, or continuous	Nontemporal or lumped	Normally nontemporal or lumped	Normally lumped	Lumped, dynamic, or continuous	Lumped, dynamic, or continuous
Dynamic Feedbacks?	None	None	In most models	In some models	In some models	Very rarely	In some models	In most models	In most models
Convergence (point, cycle, chaotic)	Point estimate of probability	Best point estimate found	Typically point estimate of response to scenario	Typically point convergence.	Depends on model (typically multiple chaotic equilibria)	Point estimate	Typically converges to point solution	Typically chaotic patterns	Typically chaotic patterns
Computational complexity of problem and problem solving approach[3]	Computationally tractable. Statistical techniques used to predict	NP hard problem. Heuristics used to decide best policy	Computationally hard problems. Numerical heuristics used to predict water dynamics	Simplified optimisation with biophysical constraints. Brute force deterministic techniques to find best policy	Simultaneous equations, potential nonlinear equations. Iterative approaches to identify equilibria	Complexity hidden in the background (methods for determining values); once determined, not complex to compare values	Complex problems (assumed learnable). Stochastic methods to parameterise; networks used to predict/ decide	NP hard problems. Agents allowed parallel (brute force deterministic) computations to predict patterns	Tradeoff between breadth and depth of computation[4]
Sensitivity analysis undertaken?	Sometimes	Not usually	Not usually	Sometimes	Not usually	Sometimes	Usually for BBNs, difficult for ANNS	Sometimes	Sometimes
Scenario analysis included?	Sometimes	Sometimes	Almost always	Almost always	Almost always	Sometimes	Sometimes	Sometimes	Sometimes
Addresses uncertainty[5]?	If addressed, via scenario analysis or ensemble modelling	If addressed, via scenario analysis	If addressed, via scenario analysis	Addressed via scenario analysis	Addressed via scenario analysis	If addressed, via scenario analysis	Addressed in model design	Not usually	Not usually

[1] E.g. changes at the micro scale, impacting meso or maro scale.

[2] After Kelly et al. (2013), differentiated as: nontemporal, lumped – big steps, dynamic – small steps, continuous – steps converge to zero.

[3] Heuristic vs brute force approach / Deterministic vs stochastic methods / Decision problematic vs Optimisation problematic.

[4] e.g. simple high level models which may lose important micro level feedback vs. low level exacting computations that lose macroscopic insights.

[5] Unknown information – including information about data, model input and parameters.

5. Insights from model users and model builders

To further assess the feasibility of using, developing, and maintaining different types of IDSTs, we developed questionnaires and interviewed relevant northern stakeholders (i.e. creators and potential users of IDSTs). Using a snowball sampling technique where interviewees referred additional stakeholders to take part, we interviewed 40 current and potential IDST users (30 of whom had used an IDST) and from 17 model builders. Amongst other things, these interviews highlighted that decision-makers use a variety of different methods to collate information, with IDSTs being rated as generally more useful than public meetings and internet surveys, but often less useful than private consultations, negotiation and consensus-seeking approaches. Modelling tools that displayed outputs visually were considered to be the most useful, particularly for influencing policy.

Our interviews with model builders highlighted the considerable time (often several years) and resources (several millions of dollars) required to build the larger (coupled) systems models (Table 2). It was also noted that a number of off-the-shelf models exist that could be tailored for a specific region, landscape or industry within less time and with much less resources.

Table 2. Overview of the resources required to develop IDSTs.

Name of tool	Development cost	Development time
Collaborative Habitat Investment Atlas (CHIA)	> $600k (≈ 4 x 150k)**	4 years
Biodiversity Forecasting Tool	> $225k (≈ 1.5 x $150k)**	1.5 years
Atlantis	~$4 million	~1 year
Bayesian Belief Network	~$300 000	~4 years
Priority Threat Management Tool	$100 000 to $300 000	2 years
C Plan	> 300k (2 x $150k)**	~2 years
Marxan	> 450k (3 x $150k)**	3 years
Weed Management Scenario Model	$40 000	2 years
Pest Priority Matrix	A wage salary by council ≈ $150k**	1 year
LUTO	~$5 million	3 years - still ongoing
Australian Hydrological Geospatial Fabric (GEOFABRIC)	$300 000 for software, $40 million for data	1 year
Fitzroy Basin Water Quality Improvement Plan	$160 000	1 year & 4 months
Australian water balance model (AWBM)	> $3.75 m (25 x $150k)**	25 years
Method to use GIS and SD model	$50 000	2 years

** our ‘best case’ estimates from development time.

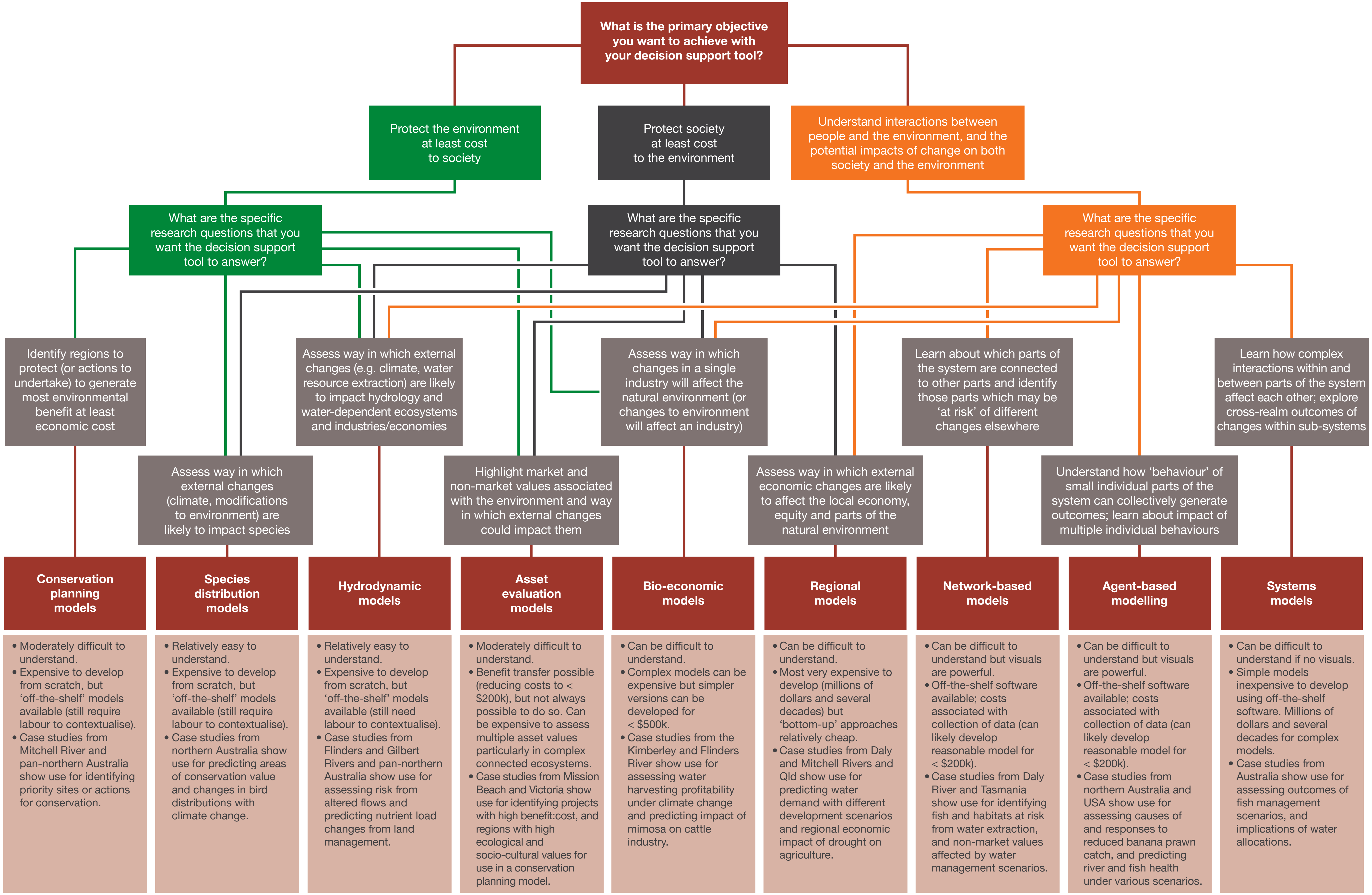
Key learnings and guidance on how to select an IDST that is best 'fit for purpose'

Overall, our project highlighted that a useful way to think about which type of model to use is to first consider one's primary objective and then use that objective as a first-round 'filter'. For example, the primary goal of many of the early IDSTs developed by biophysical scientists was to protect key species at minimum 'cost'. So practitioners who have a primary goal or a legislative requirement to protect aspects of the natural realm (e.g. conservation of a species) may find these models to be the most useful. Similarly, the primary goal of many of the early IDSTs developed by social and economic scientists was to promote social and economic objectives (e.g. maximising social welfare, or promoting GDP growth) at least cost to the environment. Consequently, practitioners whose primary job/objective is social or economic may find these IDSTs to be most useful.

That said, our detailed discussion of IDSTs, highlights that each sub-category of IDST is most suited to different decision-making contexts. It is important that the primary objective itself should drive the choice of model, rather than choosing a model just because it originated in the same field in which the researcher or practitioner operates. For example, hydrological models and bioeconomic models often involve deep integration, thus helping to foster understanding about the way in which different parts of the human system interact with the natural system—it is not only the systems models which can do this. Similarly, although hydrological models focus primarily on the biophysical (hydrological) system, their objective is often largely anthropogenic—namely to determine how much water it is 'safe' to extract for use in an economic system. So, primary objectives that are linked to the environment (such as wanting to conserve a species) are not necessarily best met with models from the biophysical sciences. Likewise, objectives that are primarily linked to society are not necessarily best achieved by models from the social and economic sciences.

To guide decision-makers through the complex labyrinth of model choices, we thus developed a stylised flowchart of the types of questions addressed by each of our nine sub-categories of models (Figure 2). This flowchart shows how those questions link to the primary objectives of decision-makers, while also synthesising stakeholder perceptions and experiences regarding the ease of understanding of model outputs, and the likely resources (human, financial and time) required for model development or application.

We stress that once a decision is made to proceed with data modelling or the use of a model, a second round of decisions on the actual model to use should be undertaken. Most evident from our review of each sub-category of IDST is that there are likely to be numerous variants and applications of each, and decision-makers will need to decide which, if any, is most suited to their needs. Our report provides additional assistance to those decision-makers by providing references to more comprehensive reviews of each type of IDST, to researchers/modellers who have developed these models, and also provides examples of applications relevant to northern Australia.



What is the primary objective you want to achieve with your decision support tool?

Protect the environment at least cost to society

Protect society at least cost to the environment

Understand interactions between people and the environment, and the potential impacts of change on both society and the environment

What are the specific research questions that you want the decision support tool to answer?

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Identify regions to protect (or actions to undertake) to generate most environmental benefit at least economic cost

Assess way in which external changes (e.g. climate, water resource extraction) are likely to impact hydrology and water-dependent ecosystems and industries/economies

Assess way in which changes in a single industry will affect the natural environment (or changes to environment will affect an industry)

Learn about which parts of the system are connected to other parts and identify those parts which may be 'at risk' of different changes elsewhere

Learn how complex interactions within and between parts of the system affect each other; explore cross-realm outcomes of changes within sub-systems

Assess way in which external changes (climate, modifications to environment) are likely to impact species

Highlight market and non-market values associated with the environment and way in which external changes could impact them

Assess way in which external economic changes are likely to affect the local economy, equity and parts of the natural environment

Understand how 'behaviour' of small individual parts of the system can collectively generate outcomes; learn about impact of multiple individual behaviours

Conservation planning models

- Moderately difficult to understand.
- Expensive to develop from scratch, but 'off-the-shelf' models available (still require labour to contextualise).
- Case studies from Mitchell River and pan-northern Australia show use for identifying priority sites or actions for conservation.

Species distribution models

- Relatively easy to understand.
- Expensive to develop from scratch, but 'off-the-shelf' models available (still require labour to contextualise).
- Case studies from northern Australia show use for predicting areas of conservation value and changes in bird distributions with climate change.

Hydrodynamic models

- Relatively easy to understand.
- Expensive to develop from scratch, but 'off-the-shelf' models available (still need labour to contextualise).
- Case studies from Flinders and Gilbert Rivers and pan-northern Australia show use for assessing risk from altered flows and predicting nutrient load changes from land management.

Asset evaluation models

- Moderately difficult to understand.
- Benefit transfer possible (reducing costs to < $200k), but not always possible to do so. Can be expensive to assess multiple asset values particularly in complex connected ecosystems.
- Case studies from Mission Beach and Victoria show use for identifying projects with high benefit:cost, and regions with high ecological and socio-cultural values for use in a conservation planning model.

Bio-economic models

- Can be difficult to understand.
- Complex models can be expensive but simpler versions can be developed for < $500k.
- Case studies from the Kimberley and Flinders River show use for assessing water harvesting profitability under climate change and predicting impact of mimosa on cattle industry.

Regional models

- Can be difficult to understand.
- Most very expensive to develop (millions of dollars and several decades) but 'bottom-up' approaches relatively cheap.
- Case studies from Daly and Mitchell Rivers and Qld show use for predicting water demand with different development scenarios and regional economic impact of drought on agriculture.

Network-based models

- Can be difficult to understand but visuals are powerful.
- Off-the-shelf software available; costs associated with collection of data (can likely develop reasonable model for < $200k).
- Case studies from Daly River and Tasmania show use for identifying fish and habitats at risk from water extraction, and non-market values affected by water management scenarios.

Agent-based modelling

- Can be difficult to understand but visuals are powerful.
- Off-the-shelf software available; costs associated with collection of data (can likely develop reasonable model for < $200k).
- Case studies from northern Australia and USA show use for assessing causes of and responses to reduced banana prawn catch, and predicting river and fish health under various scenarios.

Systems models

- Can be difficult to understand if no visuals.
- Simple models inexpensive to develop using off-the-shelf software. Millions of dollars and several decades for complex models.
- Case studies from Australia show use for assessing outcomes of fish management scenarios, and implications of water allocations.

Figure 2. Selecting an IDST according to primary objective (of decision-maker) and typical problem being considered.

Finally, we re-iterate a point made earlier: decision support tools help make the decision-making process transparent, documented, reproducible, robust, and also contribute a coherent framework to explore the options available (Sullivan 2002). But they are not, and should not, be a *substitute* for thinking about complex problems in other ways. They are, instead, *complementary*. There is evidence to suggest that better computers do not, by themselves, lead to better decisions (Cortés et al. 2000; Ascough et al. 2008) – the same is likely also true of IDSTs.

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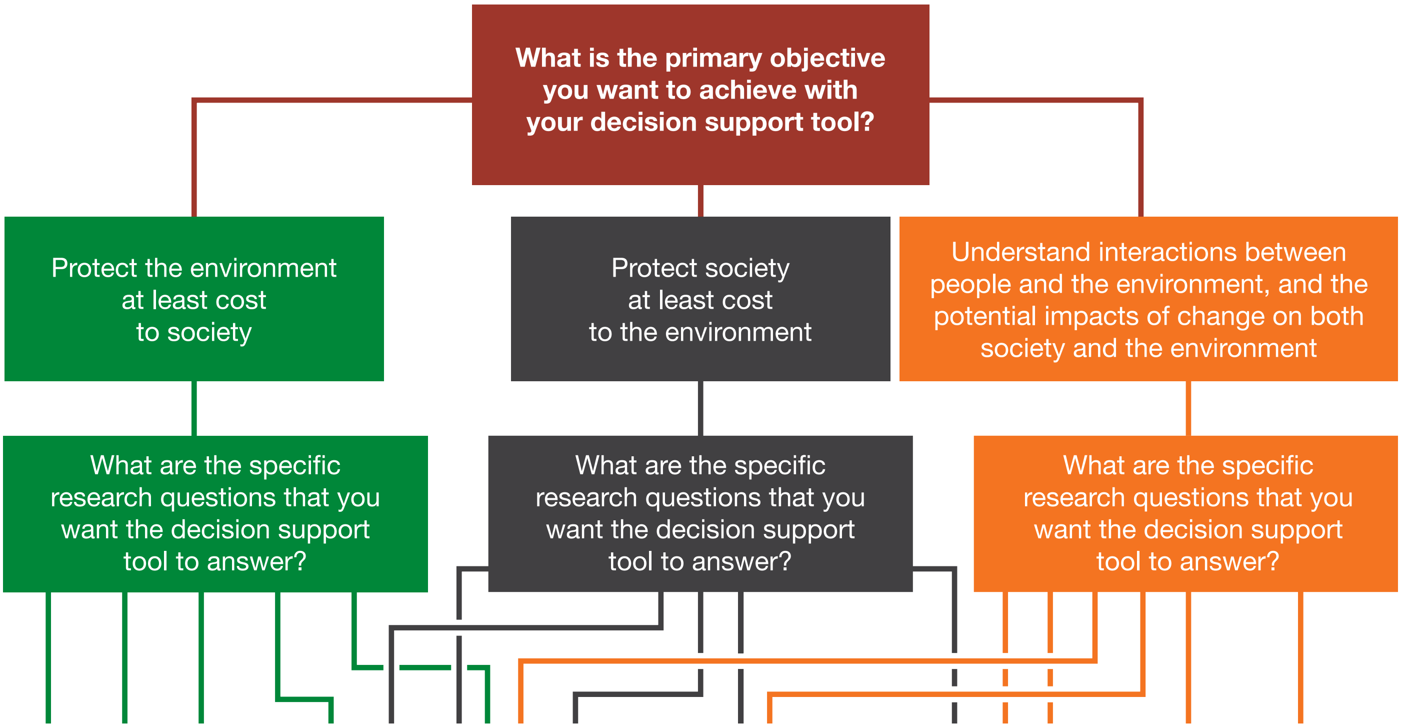

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