Managing Eco-System Services Decisions

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Introduction

“Eco-system services” is a recent term that describes the benefits humankind gains from its interaction with natural resources. As such, it requires making complex decisions at the intersection of ecology, society and the economy. In this paper we are specifically interested in the process of making eco-system services decisions in a manner that; considers the interaction of all types of information, honors all stakeholder viewpoints and measures the impacts on all three parts of the intersection. These decisions are often spatial, multi-objective, and based on uncertain data and estimates.

Eco-system services decisions are generally focused on: *provisioning*, such as the production of food, energy and water; *regulating*, such as the control of climate and disease; *supporting*, such as nutrient cycles and crop pollination; or *cultural*, such as spiritual and recreational benefits. Eco-system service decisions in these areas are complex and plagued by uncertainty. The choices made during the decision-making process have potentially far reaching and crucial impacts across the many diverse stakeholders. In this paper we outline the characteristics of a system to support eco-system services decisions and present an example of a system developed for supporting a representative, provisioning problem.

The example system was developed to support the siting of wave energy generation devices off the Oregon coast. These machines convert wave energy into electricity. The needed decisions are about where to best locate devices with known impact on the eco-systems, tourism, fishing and other considerations while providing the highest return on investment in terms of electricity generation, jobs developed, and other socio-economic measures. Before detailing this system, sixteen characteristics of an ideal eco-system services decision are itemized. The example system will be compared to these sixteen to see how well it fulfills them.

An Ideal Decision Support System for Eco-System Services

The goal here is to describe the characteristics of an ideal system needed to support making robust eco-system services decisions. Traditionally, the concept of decision support means to supply data and models to help the decision-makers during their deliberation[1]. While this information is crucial, it is only one part of the decision making process that we address here. What we describe are the needs for a decision making environment where all the data and models can be fused with stakeholder estimates, opinions and values (i.e. what is important) in a dashboard for managing the process needed to choose a course of action. There are four broad categories of characteristics for an ideal system: the stakeholders, the information, the information uncertainty, and the geo-spatial nature of the information and decision guidance. Within these four there are sixteen specific characteristics.

Stakeholders

More than most any other type of decision, eco-system services rely on and affect many different classes of stakeholders including regulatory agencies, proposal proponents, decision makers, residents, NGOs, etc.

The decision-makers want to find a "best" course of action that, at the same time, develops buy-in from all constituencies. With buy-in the resulting choice stands a stronger chance of implementation and a reduction in second guessing. The process used in making the decision can have a great effect on building stakeholder buy-in. While all participants know that their favorite outcomes may not be the ones chosen, generally people can accept decisions if they feel their voices have been heard and the process is transparent.

Voices can best be heard if the process helps separate what the stakeholders know (e.g. information) from what they think is important (values). For example, a fisherman may know that a patch of ocean is good for fishing (information), and they place high value on conserving good fishing areas. Another stakeholder may have no knowledge about fishing areas and rank the importance of conserving such areas lower than other considerations. The goal, during the decision-making process is to use the best information (further developed in the following items) while honoring each stakeholder's values.

In summary, to support the myriad of stakeholders, an ideal eco-system services decision process must:

1. Support the range of stakeholders
2. Separate information from values

Information

Information used in making eco-system services decisions ranges from scientific data to stakeholder estimates and opinions. There are often large repositories of data that can be brought to bear on these problems (see footnote 1), but often this information is not in the form that can easily used by decision-makers. For example, while the depth of the ocean along the coast and the geologic nature of the bottom may be in the data

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[1] EPA database US EPA. (2009) "Ecosystem Services Decision Support: A Living Database of Existing Tools, Approaches, and Techniques for Supporting Decisions Related to Ecosystem Services – Science Brief." Publication No. EPA/600/R-09/102.

store, these need to be combined with other data to ascertain the suitability of a patch of ocean for locating a wave energy generator.

To be usable by decision-makers, information must be in terms of factors that help measure the similarity and differences between options. We use the term “measures” for these factors and divide them into two categories, Scientific Measures and Stakeholder Measures.

Scientific Measures are based on data. To make use of the data, analytical models are built that combine the data into more usable measures. These models may be relatively simple or more likely complex and massively parallel with each interdependent with other models of the eco-systems, technology and infrastructures.

Measures not directly supported by analytical models are referred to as stakeholder measures. Often good models do not exist and the best that can happen is that stakeholders make numerical estimates based on a combination of personal experience and the data that are available. Further, often a decision is dependent on qualitative measures that have no basis in data at all. In these cases, stakeholder opinions may drive the decision. This is especially true for many societal measures and forecasts where the models are no better than an educated guess. In this paper we use the term “estimate” to mean an approximation for a quantitative measure (e.g. the depth off Cape Perpetua is about 100 meters) and “opinion” for a qualitative Yes/No or Good/Bad assessment.

Managing this information in such a way that decision-makers can understand it and make the best use of it is one of the key challenges of the process. While all the information is uncertain to one degree or another (see the next item), it can also be conflicting. For example, the scientific data might say that an area is a poor candidate for fishing while the fishermen say they catch fish there all the time. Or one analytical model gives one prediction of sea level in ten years, while another gives a different result.

In summary, an ideal eco-system services decision process must:

3. Support scientific data and models
4. Support stakeholder estimates and opinions
5. Manage the information in a manner that supports the decision making process
6. Support conflicting information

Uncertainty

The information used to make eco-system services decisions, regardless of its form, is uncertain. This is an under-statement as it is the uncertainty that not only drives the decision, but is one of the prime factors that make such decisions so hard. In most eco-system services decisions there are four sources of uncertainty

Data Uncertainty: This includes errors or uncertainty in the datasets, such as the error rate in bathymetry or geologic mapping. There are many sources for the uncertainty in scientific data and will increase use of resources for data collection might reduce the uncertainty no amount of data collecting will make all of the uncertainty go away. For example: in considering a decision that includes concern for whales (i.e. cetaceans), the depth and bottom characteristics of the ocean are only sparsely mapped and they change with the season, tides and weather patterns.

Model Uncertainty: Analytical models built to reduce eco-system and economic data into measures that are more useful to the decision-makers are themselves, uncertain. Model uncertainty has two sources, the suitability of the model (how well the model matches the application) and fidelity of the model (the ability of the model to match reality). Some models are used to understand the past and present, but most decisions require projections into the uncertain future. While accurate forecasts can be made in some limited areas, for most eco-system, financial, and technical situations, models used for forecasting are dominated by their uncertainty.

For example, while the depth of water at a location is important to cetaceans, so are many other factors such as availability of kelp and the bottom characteristics. A model can be built based on these factors that indicates how likely any patch of ocean is to support cetaceans. While this model may be suitable, it may lack fidelity, and so this uncertainty compounds the measurement uncertainty.

Estimate and opinion uncertainty: If scientific information and models were complete and without uncertainty, then analytical optimization methods could be used to find the best course of action. In reality, many decisions are based on stakeholder estimates for uncertain or incomplete data and on their opinions about the unmeasurables. Where traditional decision support systems supply stakeholders' information that they interpret and bring to bear on their problem, they fill in the missing and incomplete information based on their uncertain and incomplete knowledge and experiences.

Data/model/estimate inconsistency: While not truly an "uncertainty", often information is conflicting. The science may say one thing and stakeholders another, stakeholders may disagree amongst themselves and there may even be conflicting science data or models. Separating information from values helps reduce conflicts, but they still occur and there is no "right" answer. Inconsistency needs to be made transparent and the best information formed from the fusion of the inconsistent information.

In summary, while some uncertainty can be reduced by collecting more data and building better analytical models, much of it cannot. Thus, a system that is designed to support eco-system services decisions, and does not support uncertainty, is poorly matched to the need. In order to manage uncertainty, an ideal eco-system services decision process must:

7. Capture and manage data uncertainty
8. Be responsive to model uncertainty
9. Capture and manage estimate and opinion uncertainty
10. Make evident and afford control of information inconsistency

Geo-spatial

Many eco-system service decisions are geo-spatial. In searching for the best location to site a new technology, for example, there may be thousands of optional locations to consider. The goal in considering these is to filter them and find the best options to consider in more detail. Thus, the decision making process is a two phase effort, filtering and then discriminating amongst the front-runners. The measures used in each of these will be different, as will the need for managing the information; thus an ideal eco-system services decision process must:

11. Allow rapid geo-spatial filtering of options
12. Support relative comparison of options across discriminating measures.

Decision guidance

The ultimate goal is to offer help to the decision-makers as they manage the information and stakeholders in their effort to make a decision, build buy-in and take action. To adequately manage these complex problems and to build buy-in, the process must be transparent. Any cloudiness will show up later with the issues being revisited and the results being questioned.

No eco-system services problem will have one clear “best” option. All options will have strengths and weaknesses that need to be traded-off against each other to find the most-satisfactory course of action. Decision-makers must be given help in making these trade-offs as they are complex and uncertain. Part of managing trade-offs[2] is to aid decision-managers as they identify areas that need attention as part of a rational decision-making structure.

Thus an ideal eco-system services decision process must:

13. Make the decision process transparent
14. Support trade-off evaluations
15. Guide decision makers about what to do next to reach closure.
16. Provide a rational structure for decision vetting and justification

In the next section we compare a recently developed system to the sixteen ideal system characteristics.

An example: BASS

The marine renewables industry is advancing at an unprecedented pace. Technology progress and clarity about the leasing and licensing process have fostered proposals around the nation in both state and federal waters. As these proposals are evaluated, too often decision makers lack the tools and information needed to properly account for ecosystem services and the tradeoffs associated with alternative human uses of the ocean. Siting issues in the context of coastal and marine spatial planning (CMSP)

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[2] Trade Studies with Uncertain Information, David Ullman and Brian Spiegel, Sixteenth Annual International Symposium of the International Council On Systems Engineering (INCOSE), 8 - 14 July 2006

require decision-support systems that address stakeholder-inclusive, spatial multi-objective decision-making in uncertain conditions.

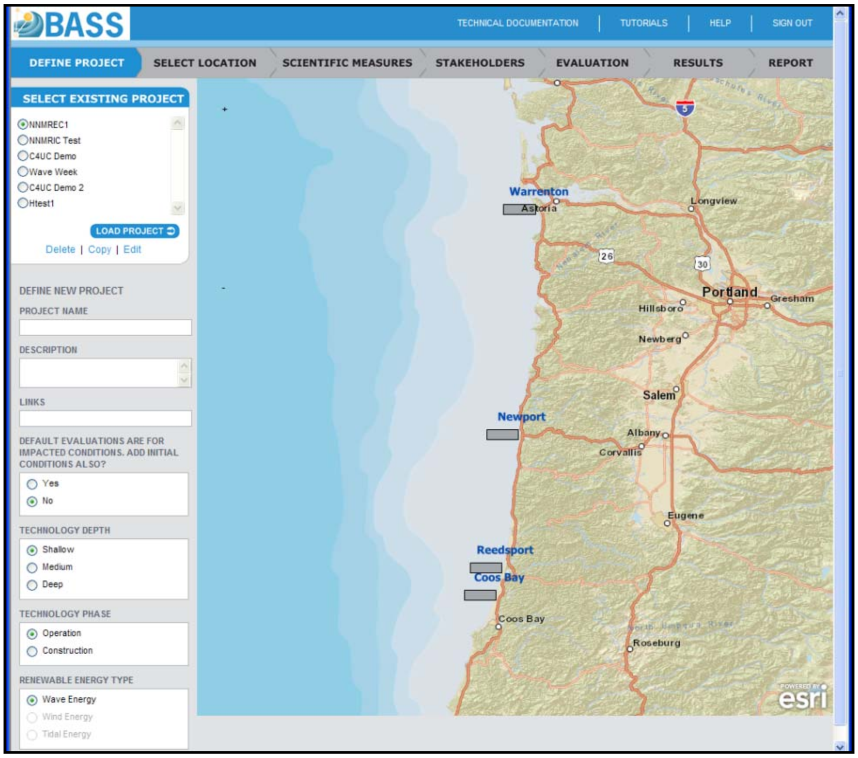
Responding to this need the ***Bayesian Assessment for Spatial Siting*** **(BASS)** tool[3] was developed in 2011-2013 by a consortium of Oregon State University, Dr. David Ullman and Parametrix. BASS is a multi-criteria decision analysis system that functions with uncertain information and stakeholder input to evaluate ocean renewable energy project proposals. Its development was funded by a National Oceanographic Partnership Program guided by the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE).

BASS was developed to support a wide variety of scenarios. Examples include:

- A planning entity seeking to identify areas suitable for developing a technology
- A project developer vetting site alternatives.
- An agency lead evaluating alternatives.
- An agency evaluating a permit application

The example used here is for an agency lead evaluating alternatives.

BASS is a web-based system that can be easily accessed by decision managers and stakeholders. Its primary screen looks as shown in Figure 1. This is dominated by an interactive map showing the geo-spatial nature of the system. Across the top is a set of tabs (here in the decision-manager's view) that lead to the functionality which will be used to compare with the ideal characteristics. Only enough detail is presented here to compare BASS to the ideal. information on the use of BASS can be found in the Users Manual[4].



● NNMREC1
○ NNMRIC Test
○ C4UC Demo
○ Wave Week
○ C4UC Demo 2
○ Htest1

PROJECT NAME

DESCRIPTION

LINKS

DEFAULT EVALUATIONS ARE FOR IMPACTED CONDITIONS. ADD INITIAL CONDITIONS ALSO?
○ Yes
● No

TECHNOLOGY DEPTH
● Shallow
○ Medium
○ Deep

TECHNOLOGY PHASE
● Operation
○ Construction

RENEWABLE ENERGY TYPE
● Wave Energy
○ Wind Energy
○ Tidal Energy

Figure 1 BASS main screen example

BASS makes use of two types of Bayesian analysis to manage uncertain information. The first of these, Bayes nets are an established tool for modeling uncertain systems. They

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[3] Funded by the Bureau of Ocean Energy Management (BOEM), the Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE), and the National Oceanic and Atmospheric Administration (NOAA), 2011-2013.

[4] See www.davidullman.com/BASSUsersManual

greatly simplify complex problems by only combining elements that are probabilistically related by some sort of causal dependency. Bayes nets are also infinitely adaptable. Beginning with limited knowledge about a problem, they can be extended when new knowledge is acquired and changed as information improves, thus they are “live” systems rather than deterministic models. Bayes nets are heavily used in modeling ecosystems.

A second Bayesian system is used to fuse the model results with the potentially inconsistent stakeholder estimates, opinions and values. This system has been developed over the last ten years by David Ullman and was marketed as a standalone decision support tool called *Accord*[5]. *Accord* is now exclusively used as an engine in products such as BASS.

Fgure 2 shows a screen shot of the tabs that control BASS. While the arrow shape of the tabs imply a left to right progression, after the project is defined there is no order as BASS is object oriented and anything can be changed at any time. The tabs are shown below expanded to show all functions. Numbers have been added to aid with the comparison.

Figure 2: Tab Structure in BASS

Defining a project, the first tab, includes identifying areas of ocean as options. There are four such areas (grey boxes) defined in Figure 1. These areas are the alternatives that are being considered with the objective of choosing one of them for installation of a wave energy farm.

1. Support the range of stakeholders
BASS allows the decision manager to define any number of stakeholders by specific individual name, group name, or any other title. It also allows the decision-managers to define “proxies”, where the manager stands in for a stakeholder. The decision-manager can invite stakeholders to participate in the decision process via email requesting estimates and values which they can input over the web. These results are automatically fused with those of others and viewable by the decision-manager.

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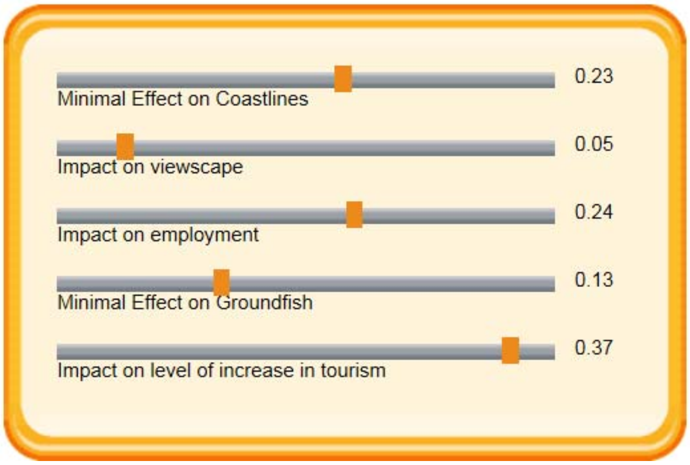
[5] See http://www.robustdecisions.com/decision-making-software/

2. Separate information from values

BASS divides the information used to evaluate alternatives into Scientific Measures (3rd tab) and Stakeholder Measures (2nd tab under Stakeholders). Scientific measures are those objectives for which there are data and a model. Managers can choose which models to include in a specific project. In BASS there are currently over twenty costal and marine spatial planning models to choose from. In this example, only “Minimal Effect on Groundfish”, and Minimal Effect on Coastlines” have been included.

Stakeholder measures have no formal model and can be qualitative or quantitative. For this example three stakeholder measures were defined: “Impact on Viewscape”, Impact on Employment” and “Impact on Level of Increase in Tourism”. The first two are qualitative, good/bad. Tourism impact is quantitative with the desire to have the wave energy systems actually draw 100 additional tourists a month to the area. Separate from the measures (i.e. information) are the stakeholder values.

Each stakeholder, manager or proxy is presented with a concatenated list of all the scientific and stakeholder measures, Figure 2. They are then each asked to either rank order or distribute 100% of the value amongst them to indicate how important each is to the selection of a site. Here tourism is valued the highest and impact on the Viewscape the lowest.



Minimal Effect on Coastlines 0.23

Impact on viewscape 0.05

Impact on employment 0.24

Minimal Effect on Groundfish 0.13

Impact on level of increase in tourism 0.37

Figure 3: Example of Values Capture

3. Support scientific data and models

BASS interacts with extensive databases of scientific data. It uses these data in Bayes Net models that produce measures that support the decision-making process. More models can be added as needed. Bayes Nets are used as they produce probability distributions based on the uncertainty in the data. For example, if whales like a certain depth of water, certain bottom conditions and to have kelp nearby, the Bayes Net model will combine data on these three data sets for each patch of ocean considered to give a probability that conditions are favorable for whales. Additionally, the model will give the certainty (i.e. the standard deviation) of the probability. This analysis could have also been accomplished using methods other than Bayes Nets, such as Monte Carlo analysis. Regardless, BASS operates on probability distributions

While the models themselves are run external to BASS, the results are used by BASS (as described below) and can be displayed in BASS. A separate display is used to view raw data.

4. Support stakeholder estimates and opinions

Estimates and opinions can be collected through email invitations or directly input into BASS. Estimates are in terms of high, most likely and low values (resulting in an assumed distribution). For example, for the Stakeholder Measure “Impact on Level of Tourism” one stakeholder input estimates of low = 10, most likely = 30 and high = 50 tourists per month.

Other stakeholders entered other estimates. BASS uses a Bayesian algorithm to fuse these into an overall probability distribution.

Opinions are captured in terms of Yes/No or Good/Bad and degree of certainty. For example, one stakeholder input her opinion on “Impact on Viewscape” as probably good, but fairly uncertain. BASS captures both the goodness (i.e. the yesness) and certainty either using sliders or a proprietary, interactive Belief Map[6].

5. Manage the information in a manner that supports the decision making process

BASS has a unique compute engine that can fuse all the uncertain model results, estimates, opinions and values to give the overall satisfaction for each alternative site. Further, this can be modified to include or exclude the different measures or stakeholder values so the decision-makers can see the effect of these factors.

Further, all scientific model results, estimates and opinions are available to the decision-makers to review.

See items 12-16 for more on BASS decision-manager tools.

6. Support conflicting information

When there is more than one estimate or opinion, BASS fuses these into a single value using a Bayesian updating algorithm. This does not average the information but takes certainty into account in forming a best estimate or opinion and also computes a level of consensus.

7. Capture and manage data uncertainty

BASS pre-processes the data using Bayes Nets models whose input is the data distribution. As described in item 3, other analysis methods could be used in place of the Bayes Nets, but these methods must be responsive to the data uncertainty.

8. Be responsive to model uncertainty

There is no explicit capability in BASS to manage model uncertainty either in the Bayes Nets models or in the Accord methods. However, stakeholders take into account their belief in model fidelity when making estimates or voicing opinions, both of which are managed in the system.

9. Capture and manage estimate and opinion uncertainty

Estimates, opinions and values are all managed with *Accord.* Unlike Bayes nets, *Accord* is not a modeling system, but a complementary Bayesian-based uncertain information fusion system that extends multi-criteria decision analysis with uncertainty and that embodies a structured decision making process. *Accord* uses a graphically rich user interface that helps decision makers select the best course of action given the available information. It is used in near-real time to manage trade-offs between alternatives, help management reach a decision while building buy-in from stakeholders, and identify the areas of needed additional research or information

10. Make evident and afford control of information inconsistency

Using input and data analysis methods from *Accord*, inconsistent model and stakeholders’ evaluation results can be fused. Additionally, the input information and the fused results can be seen and reviewed by the decision-managers.

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[6] *Making Robust Decisions*, David G. Ullman, Trafford Publishing, 2006, p197-221

11. Allow rapid geo-spatial filtering of options

Using a small set of Scientific Measures, a large set of alternatives can be rapidly filtered with BASS. Usually there are a few measures that can be used to weed out options that are not viable. Then, the remaining alternatives can be evaluated in more detail by including more scientific measures and stakeholder measures.

12. Support relative comparison of options across discriminating measures

BASS's results page shows, for each alternative location, the satisfaction as computed by *Accord.* This display makes the relative comparison of the alternatives easy for the decision-makers to understand. In the example in Figure 4, Area 43 is 68.61% satisfactory when evaluated against the five measures defined earlier. On the Results page of BASS, the satisfaction can be recalculated in real time to show the satisfaction for any one measure or from any stakeholders' viewpoint (i.e. using their values).

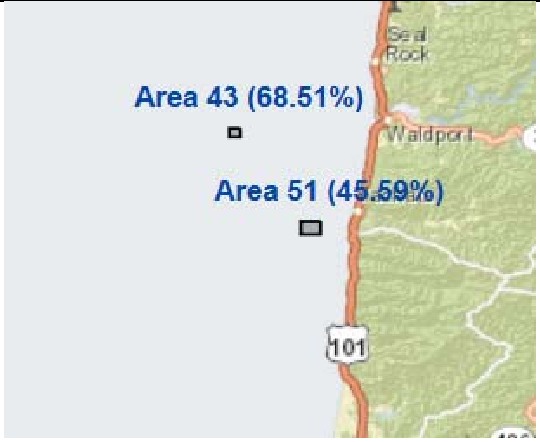

Figure 4: Two alternative sites compared

13. Make the decision process transparent

The BASS tab structure shown in Figure 2 makes the major steps needed very clear. Again, BASS is object based and so these steps need not be done in any particular order and can be revisited as needed, after the problem is defined. Thus, it easy to see and change what information was used in calculating the satisfaction. The only aspect that is not transparent in BASS is how the satisfactions are calculated. There are papers[7] describing the algorithms but the details are complex to the point that they cannot be made totally obvious. However, the system behaves in expected ways giving decision-makers confidence that the analysis is doing rational things.

14. Support Trade-off evaluations

A key part of any decision is being able to understand the trade-offs. Being able to toggle on and off different measures and viewpoints on the Results page gives the decision-makers the ability to trade off success relative to one measure for failure relative to another measure.

15. Guide decision makers about what to do next to reach closure

Choosing the best course of action is not the only result of the decision-making process. Before the decision-managers get to the point of selecting one option, there are many iterations of the process to refine, clarify and collect more information. It is important to understand the cost/benefit of doing this additional work and BASS tries to help with its "What next" tab. The analysis that underlies this tab examines the uncertainty in the models, estimates and opinions, along with the values; and computes where to best do additional work to improve the information and get a more robust result.

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[7] Ibid, Appendix A

16. Provide a rational structure for decision vetting and justification
BASS provides a clear structure for explaining and exploring how a decision was reached. Although not made explicit in BASS, the Accord engine has the ability to record and play back each step in the process along with justification, if entered,.

BASS clearly meets most of the ideals for an ideal eco-system services decision support system. What is especially strong is that the system, as developed, can be applied to any eco-systems services decision problem. BASS is a new system and still relatively untested. Initial use and prior history with Accord, Bayes Nets and other parts of the system imply that we have developed a useful tool. As more is learned with it, the ideal characteristics and BASS itself will be updated.