Collaborative spatial decision making in environmental restoration management: an experimental approach

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ABSTRACT

This paper presents the results of an experimental study about the use of collaborative spatial decision support tools to aid environmental restoration management and decision making. Similar, but non-geographic tools were developed and successfully applied in the 1990s for the computerised support of group decision making aimed at solving business problems. Yet, there are significant differences between business applications and spatial applications including environmental management. These differences motivated the study of habitat restoration reported in this paper. The results demonstrate that maps—the most common representation structures of spatial data in geographic information systems—play only a limited support role. Development of new ways to visualise spatial information and novel integrations of maps with analytical tools including multiple criteria decision models may help develop more effective collaborative spatial decision support systems.

Key words | collaborative decision making, environmental management, GIS, spatial decision support systems

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INTRODUCTION

A growing number of problems in environmental management, including the management of water resources, are being recognised as candidates for public–private collaborations. Examples include controversies such as landfill and hazardous waste facility siting (Popper 1981; Susskind & Cruikshank 1987; Schneider *et al.* 1998), polluted urban land use (so-called brownfield) redevelopment projects (Davis & Margolis 1997; Bartsch & Collaton 1997), and salmon habitat restoration plans (NOAA 1993; Brunell 1999). Most of those public–private problems are called 'wicked' and 'ill-structured' (Rittel & Webber 1973) because they contain intangibles not easily quantified and modelled, structures only partially known or burdened by uncertainties, and potential solutions mired by competing interests, values and perspectives (Susskind & Cruikshank 1987). The primary rationale for enhanced stakeholder participation in public–private environmental management is based on the democratic maxim that those affected by a decision should participate directly in the decision making process (Smith 1982; Parenteau 1988).

The above perspectives indicate a broad-based need for methodology addressing the needs of group decision making in general and collaborative spatial decision making (CSDM) more specifically. A *collaborative* interaction is one whereby the participants in a group agree to work on the same task (or subtask) simultaneously or at least with a shared understanding of a situation in a near-simultaneous manner (Roschelle & Teasley 1995). Working in a collaborative manner, participants create synergy, and each comes away with a synergistic sense of how to undertake decision making.

Methodologies and tools encompassing collaborative spatial decision making come from many sources. They include Geographic Information System (GIS) technology, work on GIS extensions aimed at improving its decision support capabilities (Densham 1991), work on group support systems (GSS) technology as well as theoretical and empirical studies of its use (Jessup & Valacich 1993), work on capturing the dynamics of argumentation (Conklin & Begeman 1989), and research on the human dimensions of groupware and computer networking (Oravec 1996).

During the 1980s GIS was touted as a decision support system (Cowen 1988) and later, both in research and in practical applications, it became an important component of spatial decision support systems (Densham 1991). GIS, however, was not considered to be a decision support tool for groups in the sense of group support systems developed for business applications. Yet, the mapping and data visualisation capabilities of GIS combined with spatial analytical tools and decision models have potentially much to offer in terms of decision support for groups. Because the development of commercial GSS software in the 1990s (e.g., Lotus Notes from IBM, Group System from GroupSystems Corp., and MeetingWorks from Enterprise Solutions) was preceded by the studies in the 1980s on group use of computer technology, one would presume that GIS systems offer similar potential for support of collaborative and participatory decision problem solving. During the 1990s, GIS (Godschalk *et al.* 1992; Faber *et al.* 1994, 1995, 1996), their offspring spatial decision support systems (SDSS) (Armstrong 1993; Carver 1991; Densham 1991; Eastman *et al.* 1995; Heywood *et al.* 1995; Jankowski 1995; Reitsma 1996; Jankowski *et al.* 1997; Malczewski 1999; Thill 1999), and spatial understanding (and decision) support systems (SUSS/SUDSS) (Couclelis & Monmonier 1995; Jankowski & Stasik 1997) were suggested as information technology aids to facilitate geographical problem understanding and decision making for groups, including groups embroiled in environmental conflict. Clearly, research concerning collaborative decision making for geographically oriented, public policy problems continue to gain momentum. Unfortunately, most of the CSDM research is about GIS development rather than about GIS use, without a strong theoretical link between the two. Little has been done until recently to study the use of GIS technology at a decision group level. Even though the case can be made for transferability of research results from business problem-oriented experiments to collaborative spatial decision making, unlike a business decision problem such as the selection of a product marketing plan, spatial decision problems are unique in making location and associated spatial relationships an explicit part of a spatial decision situation. This gap between the understanding of the implications of using decision support software in non-spatial versus spatial group decision processes motivated an empirical study of habitat restoration reported in this paper.

To set the context for the presentation of study results the next section describes an experimental decision scenario. This is followed in the third section by the description of GIS-based collaborative decision support software used in the experiment. The results of the experiment are discussed in the fourth section. The conclusion offers a discussion of prospects for future development of collaborative spatial decision support systems.

HABITAT RESTORATION DECISION PROBLEM

This section provides an overview of the case study of habitat site selection along the Duwamish Waterway in Seattle. The case study, which is a collaborative spatial decision problem, served as a realistic context for a human–computer–human interaction experiment involving the use of GIS-based group decision support software.

Habitat restoration in the Duwamish Waterway—the experiment background

The Elliott Bay/Duwamish Restoration Program, and in particular a panel of decision makers, was charged with implementing a 1991 consent decree that described the need for restoration of wildlife and fish habitat in the Duwamish Waterway of Seattle, Washington, USA (Jankowski *et al.* 1997). The consent decree settled a 1990 law suit filed by the US Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) on behalf of the United States of America against the City of Seattle and the Municipality of Metropolitan Seattle (Metro), now the King County Department of Metropolitan Services, for allowing contaminants to foul the habitat. Fault was not established, but the City and Metro agreed to do what they could by paying $24 million in damages. Of the $24 million, $2 million was allocated for contaminant source control, $12 million for sediment cleanup, $5 million for real estate acquisition, and $5 million for restoration/development. Because 98% of the original habitat is gone in the area, the challenge is perhaps more of a development process than a restore process. Overall, the $12 million is likely to be sufficient to cover only a few sites.

In this collaborative decision problem scenario the panel of decision makers has been tasked with selecting sites for habitat development/restoration in the Duwamish Waterway. Agreement exists on several basic values, e.g., environmental protection and restoration, cost-effectiveness, and public involvement that underlie the decision process among the different stakeholder groups. However, how various groups express that agreement provides deeper insights into the spectrum of values the panel should consider as it approaches its work.

The panel holds strong values for environmental protection and stewardship, most often expressed in terms of protecting and preserving existing resources and habitats and restoring the health and viability of marine animals injured by contamination. Generally, the panel prefers a long-term, holistic approach rather than a short-term approach to improving resources and managing them, also preferring a commitment to long-term maintenance and sustainability of projects implemented by the panel. Building a foundation of projects that will form the basis for future efforts is also important to the panel. Many panel members feel a responsibility to protect and enhance fisheries for Native Americans and believe it is important that source control be taken care of before habitat restoration and sediment remediation.

How the panel works together, how it spends the money available to it and how it communicates with the public are other strong values held by the panel. Some panel members feel strongly that the panel should function as a partnership, working co-operatively beyond individual interests to address the broader picture of

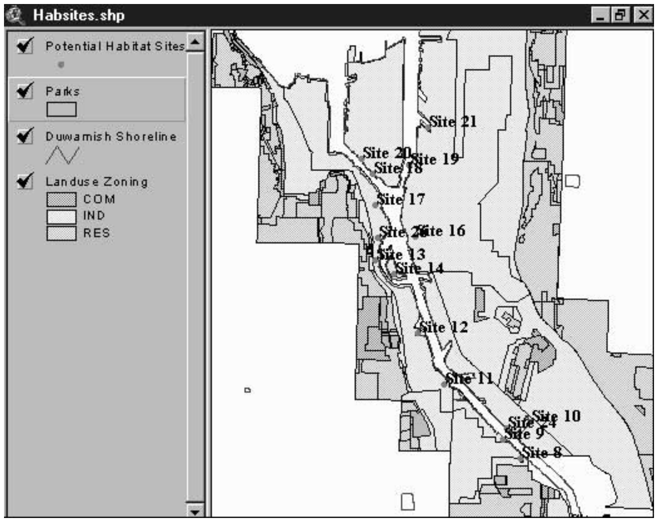

Figure 1 | Potential habitat redevelopment sites in the Duwamish Waterway. Land use zoning codes indicate: COM, commercial; IND, industrial; RES, residential.

environmental stewardship. Cost-effectiveness is a strong value, expressed primarily in the sense of getting the maximum return for the dollars spent, including the leveraging of funds from other sources to produce greater results. Some panel members see an important need to involve the public early in the process so the public knows what the panel is doing and can be encouraged to become stewards and so the panel can benefit the most from the public's points of view. The panel has agreed that it will listen to user groups who voice different values for decision making.

Case study design

A GIS data set consisting of 20 potential habitat sites in the Duwamish Waterway was considered in this decision problem study (see Figure 1 and Table 1). Each site is described using 11 attributes (see Table 2). The panel members used these attributes (criteria), and weighted them according to a stakeholder perspective.

The study used 109 participants formed into 22 groups of 5 participants per group (one group had only four members). The choice of 5-person groups stems from Vogel's (1993) review of several experiments in group support systems research that showed mixed results with

Table 1 | Habitat site descriptions (site numbers are not necessarily in sequence due to drop outs. Source: NOAA 1993).

SITE 3: This site is located at the head of navigation on the Duwamish Waterway. Portions of the site are currently being restored by federal agencies and the Port of Seattle under the Coastal America Partnership. It is possible that the rest of the site may be restored by the Port at a later date.

SITE 4: This parcel abuts the south end of the Seattle City Light substation, between the river and West Marginal Way South, and is in the vicinity of Turning Basin Number 3. This site may be benefited from adjacent Hamm Creek and offers an opportunity to daylight the lower portion of this stream.

SITE 5: This parcel abuts the north end of the City Light substation, between the river and West Marginal Way South. Hamm Creek, the focus of restoration efforts by a local volunteer group, increases the potential habitat benefits this site affords. City Light North is the largest potential habitat development site identified and offers an opportunity for a combination of freshwater and tidal wetland restoration as well as stream and riparian corridor improvements for the lower reach of Hamm Creek.

SITE 6: Habitat restoration activities in this side channel off the Duwamish River might include raising the elevation of dredged areas by placing material in the water.

SITE 7: A narrow parcel adjacent to this warehouse development may offer the possibility for shoreline improvements at the top of the bank.

SITE 8: Riprap (large rocks) and eroding shoreline at this small City of Seattle park could be replaced with an expanded beach area and the establishment of a fringing marsh.

SITE 9: A street right-of-way adjacent to the Duwamish River in the South Park neighborhood, this site would benefit from debris removal and shoreline plantings.

SITE 10: This side channel could offer opportunities for regrading adjacent upland as well as shoaling dredged subtidal areas. Habitat restoration here should not proceed until site contamination issues are addressed.

SITE 11: Repairs and expansion of the First Avenue South bridge may afford opportunities for habitat improvement in adjacent shoreline areas. Slopes could be regraded and vegetation established in areas underneath or along the bridge and its approaches.

SITE 12: A small cove' north of the Port of Seattle's T-115 properties might present opportunities for expansion and intertidal area improvements.

SITE 13: The Port of Seattle has set aside the shoreline area of T-107 and adjacent Kellogg Island for habitat purposes. At T-107, opportunities exist for debris removal, minor regrading, and the establishment of a fringing marsh.

SITE 14: The southern portion of Kellogg Island has been raised to an elevation of 30 feet and higher with dredged materials. Return of the island to its former intertidal elevation and re-establishment of original salt marsh conditions have long been considered by the Port and various resource agencies. Northern portions of the island have retained much habitat value and were not considered for enhancement during site evaluation.

SITE 16: Portions of this site have been restored by the Port of Seattle. Additional excavation and shoreline enhancement activities remain possible at T-108.

SITE 17: While creation of a tidal slough is planned for the northern portion of the Port of Seattle's T-105, additional enhancement and restoration could be pursued south of the Coastal America project work. Taken together, these projects have the potential to provide improved intertidal habitat along a relatively long portion of the Duwamish shoreline in the lower estuary.

SITE 18: An opportunity exists for relatively small-scale habitat work in association with landscaping planned under the new bridge.

SITE 19: Intertidal mounds' created in the waterway for mitigation and adjacent shoreline areas would benefit from habitat enhancement.

SITE 20: If fill material in an area currently used for parking adjacent to the West Waterway were excavated, the site could be regraded to an intertidal elevation.

SITE 21: Pier 27 contains a slip adjacent to the East Waterway, the majority of which is no longer used. Cut-and-fill activities here could significantly expand and improve intertidal habitat.

SITE 24: This site, formerly the pump station for the old Georgetown steam plant, is still in public ownership. Fill material and retaining walls could be removed to increase intertidal area, and interpretive materials could be developed in conjunction with the old structure.

SITE 26: Formerly the site of a large sawmill, this site is currently being considered for purchase by the Seattle Department of Parks and Recreation. Acquisition would include about 10 acres of submerged lands with important habitat value adjacent to Kellogg Island. Habitat restoration activities could be coordinated with development of a park at this site.

groups of 3 or 4, but beneficial results starting with a group size of 5. Each group member was asked to choose and adopt one of five stakeholder perspectives representing the make-up of the Duwamish restoration panel. The stakeholder perspectives included: a regulatory/resource agency representative, an elected official, a technical/academic expert, an environmental group representative, and a business/community leader.

Table 2 | Definitions of attribute data for the Duwamish Waterway habitat sites (Source: NOAA 1993).

Addresses Injury: Extent to which possible site restoration activities will address injury to fish and wildlife (in percent).
Contamination: *Distance to nearest contamination* (*in feet*) *relative to the proposed restoration site*.
Cost: Cost of engineering, construction, and maintenance (dollars).
Ecological suitability: Habitat suitability; extent to which the site can provide larger gains for the estuarine ecosystem as a whole (1 = least suitable, 5 = most suitable); if the location of the site in the system ensures that the habitat will be utilised, the site should receive a higher rating; habitat types and their location within the estuary should be determined based on principles of landscape ecology.
Existing habitat: Proximity to other existing habitat (in feet); potential for target resources to utilise other habitats with connection to the potential restoration site.
Existing land use: Existing land use (1 = least suitable, 5 = most suitable); nature and condition of surrounding (adjacent) land use; noise, bright lights, or otherwise disturbing human activities and land uses may reduce habitat value and utilisation of restoration site.
Ownership: Property ownership (1 = least suitable, 5 = most suitable); private property is rated lower on this scale because of difficulties associated with property acquisition.
Potential land use: Potential/future adjacent land use (1 = least suitable, 5 = most suitable); potential land use includes considerations of such attributes as shoreline designation, zoning, comprehensive or project-specific planning (such as the Port of Seattle container plan), etc. Noise, bright lights, or otherwise disturbing human activities and land uses may reduce habitat value and utilisation of restoration sites.
Public access: Public access; distance to nearby street for accessing and viewing the site (in feet).
Public facilities: Proximity to public facilities such as parks, public schools, marinas, fishing piers, etc. (in feet).
Site size: *Amount of potential restorable habitat area* (*in acres*).

In recruiting the experiment participants noj special competence was sought, only an interest in the environmental decision task to be undertaken. Of the 109 participants, 104 finished the study. The average age of the participants was 28 years. The average education attainment was close to completion of an undergraduate degree, although there were several graduate students and participants from off-campus with an interest in GIS and habitat restoration.

A realistic decision task was adopted to structure experiment treatments about site selection for habitat restoration (development) in the Duwamish Waterway of Seattle, Washington. The decision task was being performed by the National Oceanic and Atmospheric Administration (NOAA) Habitat Restoration Panel (NOAA 1993) due to a law suit settled against the City of Seattle and King County for inappropriate storm sewer drain management. For years storm sewer drains had been releasing unfiltered storm water containing highway gasoline and oil contaminants into Puget Sound (Elliott Bay), degrading the fish and wildlife habitat. A GIS database for the site selection problem was compiled from City of Seattle and King County sources. The site selection decision process was expected to involve conflict management during social interaction due to the different perspectives inherent in the views of participating members. Thus, site selection activities were particularly interesting from the standpoint of software tool use and its interplay with group interaction.

Each decision group met for five meeting sessions, one in each of five consecutive weeks (or as close as possible to that schedule), and worked on a different version of the habitat site-selection task. In each of the five sessions, groups were asked to work toward consensus on the selection of three preferred sites (or as many as the $12 million budget would allow) out of the total number of sites presented to them. The total number of sites varied from eight to twenty.

Group interaction was videotaped in each session. Data were collected by session using questionnaires and coding interaction of videotapes. Each participant filled out a background questionnaire (education, sex, age, etc.) and attended a two-hour CSDM software training session. At the end of each session, groups were asked to fill out a session questionnaire which provided a means for the participants to self-assess group use of the tools, group interaction, and the level of satisfaction with the overall group selection.

Interaction coding systems (Nyerges *et al.* 1998) were used to perform data capture from videotapes on which the research team recorded the use of CSDM software as a process of group interaction. An interaction coding system is a set of key words that reliably summarises the character of a process from a thematic perspective.

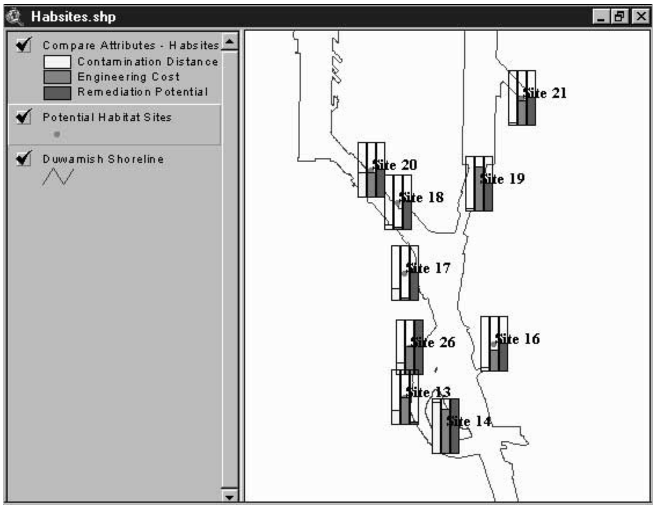

Figure 2 | Multiple histobar map allows the user to view the distribution of attribute values and can potentially help make judgements about the relative importance of criteria.

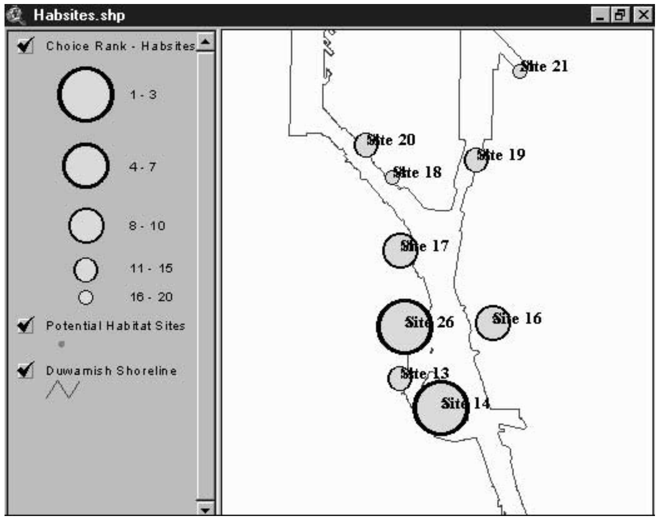

Figure 3 | Option ranks map uses rank-graduated circle size to display ranking results and option locations to help visualise spatial relationships.

GIS-BASED GROUP DECISION SUPPORT SOFTWARE USED IN THE EXPERIMENT

This section describes the software–GeoChoicePerspectives (2000)–used in the experiment. The software was used as a technological structure in human–computer–human interaction decision process.

Required software capabilities

The functional capabilities of the model for spatial decision support include the visualisation of decision options and their attributes with the variety of user selected maps, multiple criteria evaluation tools, voting, and consensus building tools.

- *Decision option visualisation tools*. The nature of the decision options can be reviewed by creating attribute comparison maps (Figure 2). These maps let the user observe and compare numeric information on various option attributes. Background information on decision options can be explored on thematic maps. Option ranks can be presented as a graduated circle map (with site ranking labelled in each circle (Figure 3)). Options represented on a map can be hotlinked with documents, photos, and video clips providing additional background information.
- *Multiple criteria evaluation tools*. Properties of evaluation criteria can be set by valuation, standardisation, threshold, and cut-off values (a criterion valuation function lets the software distinguish among benefit, cost, and range criteria). The criterion weights can be assigned using AHP-based pairwise comparison (Figure 4), ranking, and rating techniques. Ranking of decision options can be generated using one of three aggregation functions (decision rules): weighted summation, ordinal ranks, and ideal point (Jankowski *et al.* 1997). The user can explore the 'robustness' of the ranking to changes in criterion weights by performing sensitivity analysis (Figure 5).
- *Voting tools*. The participants can vote electronically on the choice of criteria, cut-off values, threshold values, standardisation method for valuation of criteria, criterion weighting method, criterion weights, aggregation function, and the order of ranked decision options (Figure 6). They can even vote on some more specific and personal aspect of

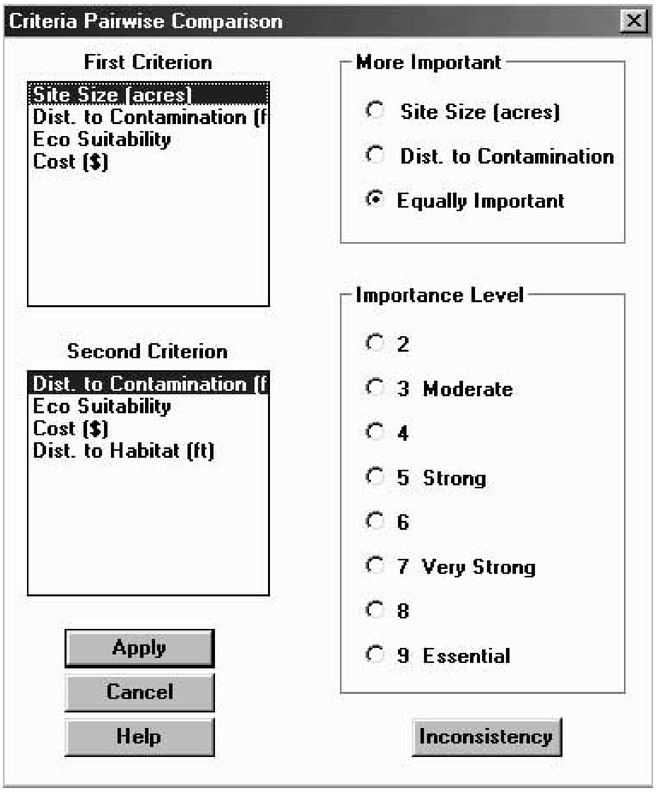

Figure 4 | Pairwise comparison criterion weighting function.

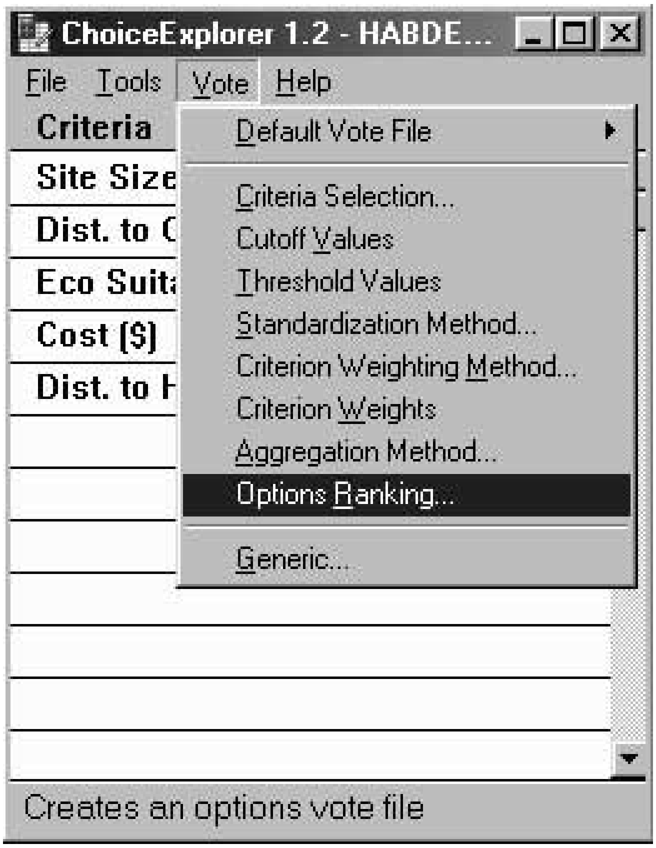

Figure 6 | Voting tools enable the participants to vote on every aspect of criteria selection and option ranking process.

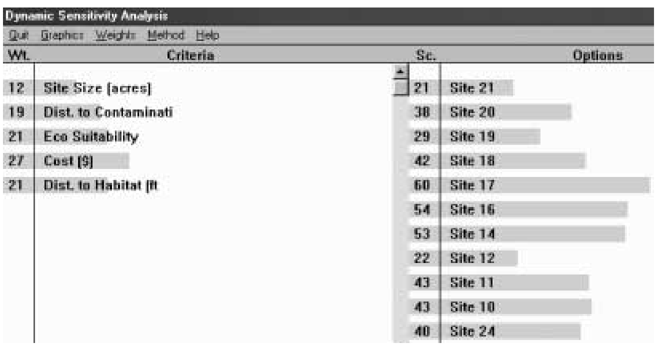

Figure 5 | Dynamic sensitivity analysis allows evaluating changes in the ranking in response to changes in criterion weights.

the decision problem by using the generic-voting feature.

- *Consensus building tools*. Consensus mapping can be used to communicate which options rank high and receive the most group support. The map (Figure 7) uses circle size to represent overall group preference including the group ranking, based on Borda score (Hwang & Lin 1987), and the variance of the ranking. Participant votes can be aggregated using non-ranked and ranked methods. A non-ranked method is the standard 'simple majority count' (in other words, all items that get a vote from a participant are deemed to receive an equal preference). This method, even though democratic, may lead to a mediocre decision option winning. A ranked vote method takes into consideration the order of significance of what is being voted upon (such as options). The voting position of a decision option is determined by adding the ranks for each option from every voter using the Borda social preference function (Hwang & Lin 1987). The ranked vote method prevents a contentious option

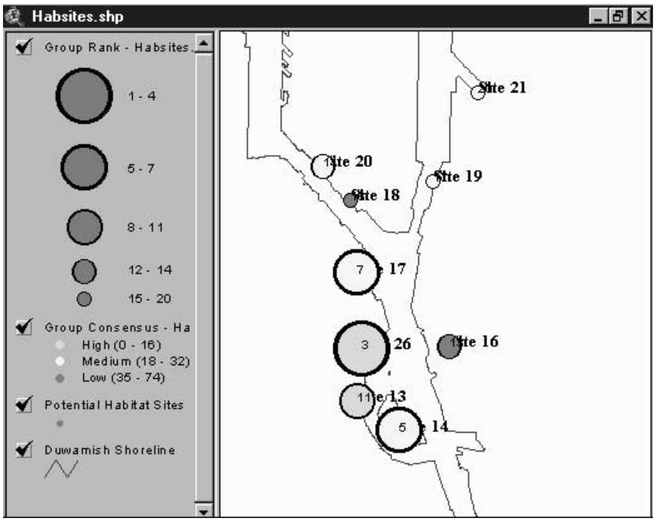

Figure 7 | Consensus map uses circle size and colour to display the group ranking vote results. The larger the circles the higher the rank scores. Green colouring indicates relatively higher consensus for those options, yellow indicates relatively medium, and red indicates relatively low consensus.

which ranks very high with some participants and very low with other from winning.

RESULTS

Experimental findings were analysed in regard to the group use of maps and decision models, dynamics of group decision process, and task complexity.

In regards to map use, background thematic maps were used predominantly to visualise the locations of decision alternatives and also to evaluate trade-offs among the decision alternatives. It was surprising to see that special purpose maps (option ranks map—Figure 3, and consensus map—Figure 7) designed to facilitate conversations about evaluation and prioritisation were not used as much as one would have thought—in less than 5% of the overall map uses. One can speculate that background maps showing site locations are easier to interpret than the special purpose maps that try to combine location and ranking. There is no evidence in this experiment to suggest that typical GIS maps were very effective in prioritising evaluation criteria or displaying the results of sensitivity analysis, and the position of the group on the final ranking of decision alternatives. Groups used maps predominantly to visualise the evaluation results and much less to structure/design the decision problem. The high frequency of using situation maps and orthophoto images, especially during the evaluation/selection of alternatives, shows the usefulness of reference maps (i.e., both a general situation map and a realistic orthophoto image) in presenting the results of decision alternative rankings. The question arises then: are typical GIS-generated maps simply not adequate for problem exploration, criteria identification, valuation, and prioritisation or are there new ways of engaging 'old' maps needed to provide better decision support? Based on the analysis of variance reported in Jankowski & Nyerges (2000), maps used in the experiment played only a limited support role in the decision stages of the experiment. How to improve the existing maps and which direction should be taken in the design of new types of maps and visualisation aids are open research questions. In regards to overall map use and facilitation, there was a noticeable difference between the mean of map uses in facilitated sessions that included both individual and public display and facilitated sessions with only a large public display computer screen. Maps were used more frequently to assist the decision process in sessions with only a public display. Testing to see if the influence of a facilitator can help with interpretation is one way to go. Testing a variety of simple to more complex displays is another approach.

Decision process-oriented findings were somewhat intriguing. It was surprising to find that the participants used multiple criteria evaluation tools without much difference in the frequency of use in both halves of the experiment in which they engaged in multiple criteria-based evaluation. The first half of every experimental session (sessions were repeated by groups) involved more exploration discussion during which the participants were trying to understand the problem and the decision task whereas the second half was more analytical and involved the decision problem solving. One can speculate that the first, more 'exploratory' half of the experiment would be marked by a more frequent use of maps than the second half. The much less frequent use of maps during the first half of the experimental sessions indicates a re-examination of the exploratory usefulness of maps is needed. Another finding indicated that different phases of the decision process had two different levels of conflict: analytical detail phase characterised by high conflict and exploratory-structuring phase characterised by low level of conflict. There was less conflict during problem exploration because interests and values were not at odds with each other. There was more conflict during criteria selection and alternative evaluation because interests showed up here. The higher level of conflict during the evaluation phase tells us that analytical decision aids aimed at conflict management are likely to help move through conflict, such conflict now being recognised as a necessary part of making progress in environmental disputes. Future designs of collaborative spatial decision support software should take this into consideration, and provide capabilities to manage conflict more directly.

When it came to evaluating task complexity, the findings are also unexpected. Task complexity, which varied from simple—requiring the evaluation of only eight sites using three evaluation criteria—to complex—requiring the evaluation of twenty sites with eleven criteria—was not associated with the level of inner-group conflict, a finding somewhat contrary to current literature. We expected simple tasks to exhibit low group conflict and complex tasks to be associated with higher conflict, which was not the case. Other factor differences such as a task with public-only display versus a task with public–private displays showed differences in conflict. However, whether the difference is due to the opportunity to voice opinion or due to conflict over what to display is not clear.

CONCLUSION

Many spatial decision problems of a participatory nature are likely to involve conflicting perspectives on facts and interests, as well as world views (Renn *et al.* 1995). Together these differences add to the complexity of trying to come to agreement. GIS-based group support software systems such as GeoChoicePerspectives (GCP) are not expected to 'generate' the consensus, but only help in the negotiation of shared understandings that lead to agreements. Many reports in the literature indicate that conflict is a necessity in complex, participatory decision making. Conflict is necessary to sort through the differences in facts, interests, and world views (Renn *et al.* 1995). Only after such conflict arises might there be a chance for integration of the differing aspects, promoting a shared understanding of differences, and perhaps subsequent agreement.

The description of the habitat restoration experiment described here focused on the use of maps and multiple criteria decision models as they related to the habitat decision task. The habitat decision task as described above consisted of only one major task—that of option evaluation—with a series of subtasks. The criteria were identified, and the basic set of options was provided. This masked the fact that multiple stakeholders were interviewed to gain an understanding of what was of concern. It also masked the fact that a select few decision participants generated the initial set of options for site selection, itself a group process. To highlight a different approach, Renn *et al.* (1995) described an energy policy process that looked the same, consisting of three steps, but was very different because a different 'culture-focused' group was used for each phase of a participatory decision process: (1) values and criteria elicitation was undertaken by stakeholder groups, (2) option generation was performed by a group of experts, and (3) options evaluation was performed by a randomly selected group of the general public. Each of those phases is likely to generate a different dynamics, and hence system requirement to help sort through the nature of disagreements. Providing technology to support each of the different phases, taking into consideration the different participant groups that might be involved, and documenting the results of each phase is a very important part of the transparency of the process. Developing information technology that takes into consideration easy access to analytic results, and highlighting the commonality and differences in perspectives, requires further integration of collaboration technologies and GIS technologies. Such integration is the likely development direction of collaborative spatial decision support systems that may aid public environmental disputes including water resource management.

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