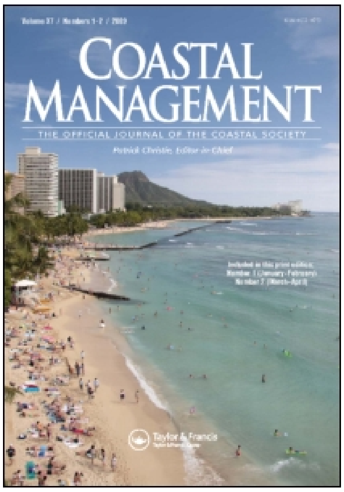

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MINOE: A Software Tool to Analyze Ocean Management Efforts in the Context of Ecosystems

Julia A. Ekstrom[ab]; Gloria T. Lau[a]; Daniel J. Spiteri[a]; Jack C. P. Cheng[ac]; Kincho H. Law[a]
[a] Engineering Informatics Group, Department of Civil and Environmental Engineering, Stanford University, Stanford, California, USA [b] Earth Science Division, Lawrence Berkeley National Laboratory, Berkeley, California, USA [c] Department of Civil and Environmental Engineering, Hong Kong University of Science and Technology, Hong Kong

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MINOE: A Software Tool to Analyze Ocean Management Efforts in the Context of Ecosystems

JULIA A. EKSTROM,[1,2] GLORIA T. LAU,[1]
DANIEL J. SPITERI,[1] JACK C. P. CHENG,[1,3]
AND KINCHO H. LAW[1]

[1]Engineering Informatics Group, Department of Civil and Environmental Engineering, Stanford University, Stanford, California, USA
[2]Lawrence Berkeley National Laboratory, Earth Science Division, Berkeley, California, USA
[3]Department of Civil and Environmental Engineering, Hong Kong University of Science and Technology, Hong Kong

Transitioning ocean governance into an integrated ecosystem-based approach requires improved knowledge of existing governance arrangements. This article presents a software tool, MINOE, to assist policymakers, scientists, and others involved in ecosystem-based management initiatives to navigate through management documents as they relate to a user-defined ecosystem. The tool uses a conceptually modeled ecosystem, defined by the user, and text analysis of a set of management-related documents to determine which ecosystem linkages are potentially acknowledged in the documents. For illustration, the set of documents included with MINOE currently (and used to demonstrate the software in this article) are laws and regulations from four geopolitical jurisdictions for the year 2006; however, users may also import other documents for a more tailored application. Features include an interactive matrix containing results about the set of management documents within the user's scope and scale of interest. In addition, MINOE includes metrics and visualization tools to synthesize information derived from the documents. The article presents the software tool, describes potential uses for the tool, and ends with a discussion of future work to expand the program.

Keywords ecosystem-based management, gaps, governance, institutional analysis, laws, policy analysis

Introduction

Transitioning ocean governance into an integrated ecosystem-based approach requires improved knowledge of ecosystems and existing governance arrangements (Rosenberg

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Address correspondence to Julia A. Ekstrom, University of California, Berkeley, Climate and Energy Policy Institute, Berkeley Law, 2850 Telegraph Avenue, Suite 435 #7220 Berkeley, CA 94705–7220, USA. E-mail: jaekstrom@gmail.com

& McLeod, 2005). There has been an increased effort to compile, model, and synthesize ecological and biophysical data (Dunn & Halpin, 2009; Halpern et al., 2008; Myers & Worm, 2003; Worm et al., 2006). However, relatively less attention has been paid to understanding ocean management systems and even less effort has been spent on developing tools that generate governance syntheses based on ecosystem type, site-specific stressors, and societal values (Sherman et al., 2005). A growing literature focused on governance and management in the context of large marine ecosystems (LME) recognizes the importance of monitoring governance factors, along with socioeconomic and biophysical factors of a given system, and has developed frameworks and methods to monitor and assess interconnections between social and biophysical systems (Hennessey & Sutinen, 2005; Juda, 1999; Juda & Hennessey, 2001; Knecht & Cicin-Sain, 1993; Olsen et al., 2006; Sherman, 1991; Sutinen et al., 2000; Wang, 2004). Together factors such as existing governance systems, ecosystem type, site-specific stressors, and societal values shape the way ecosystem-based management (EBM) is implemented in any given place or at any scale (Crowder & Norse, 2008; Ehler, 2008; Juda, 2003).

Understanding of biophysical systems has advanced considerably through the coordination of monitoring programs, for example, that provide data over time about oceanographic regimes, climate variability, nutrient and pollution outputs, fish population changes, and many others (see, e.g., literature on LME, such as Sherman and Alexander (1989) and Sherman et al. (1991)). This has allowed improved understanding of large- and small-scale changes over time and drivers and impacts in the biophysical systems (Ohman & Hobbie, 2008). Technological tools have played a central role in this monitoring and synthesis of biophysical data. Tools such as remote sensing, for instance, have provided scientists with access to global sea surface temperature data (Acker, 2007), estimates of projected freshwater from snowmelt (Dozier, 1989), and global land use changes. Similar to ecological monitoring, compilation and synthesis of baseline data about governance can provide a way to assess governance from a comprehensive perspective (Sutinen et al., 2000; Juda & Hennessey, 2001). Such data could provide insight to changes in the management of multiple sectors across scales and across time. More fundamentally, data indicating what agencies and what laws govern ocean- and coastal-related activities could assist lawmakers and agency personnel develop strategies from an informed perspective for improving coordination. Recognizing the need for producing governance baseline information, this article presents MINOE an open source desktop software application (available at http://minoe.stanford.edu) developed to assist stakeholders and others involved in ecosystem-based management initiatives access information about ocean and coastal governance.

As a caveat, we note up front that the software system we present is in its infancy. MINOE is a fully operational software, but only a single database is provided with this free software. This provided database includes laws and regulations from four geopolitical jurisdictions from the year 2006 (Ekstrom, 2009). In addition to or instead of the documents provided, users may import their own documents (such as laws, regulations, or other document types) into the software to perform an analysis on different sets of documents. Ongoing research efforts involve development of systematic and semi-automated algorithms to compile legal and other management-related documents from the Web so that we may ultimately help provide documents representing additional jurisdictions, other types of management documents, and document collections representing different points in time. Therefore, in describing how MINOE works throughout this article, we often refer to the laws and regulations or the management documents. Within the context of this article, the terms for these types of documents are used interchangeably, which is meant to indicate that the user can use the software to conduct analysis on any variety of documents; however, only the aforementioned set of laws and regulations are included with MINOE for this study.

This article is organized as follows: The next section presents the background development of the tool. The system design, features, and program functionality of MINOE are described in the third section. The fourth section discusses the uses of MINOE for regulatory analysis, management scenario assessment, and marine policy education. Finally, this article is summarized with a discussion on the future work on how MINOE fits into the larger picture of ocean observing systems and monitoring programs.

Background

The input of over one hundred ocean stakeholders helped form the framework and text analysis techniques upon which MINOE was built (Ekstrom, 2008). In search of determining what key aspects of governance could be useful for baseline data, over three years, agency and nongovernmental organization (NGO) personnel, academic scientists, and other ocean stakeholders were interviewed and consulted about problems caused from fragmented management (Ekstrom, 2008). The synthesis of this stakeholder feedback revealed a set of common patterns that make up institutional obstacles to transitioning into an ecosystem-based approach: gaps and overlaps. Both of these obstacles differ widely by the scale and topic of interest, ecosystem type, societal values, and site-specific stressors. This finding drove the development of a set of techniques that could provide useful information to those involved in implementing EBM. Gaps, the first common problem, comprise those elements and relationships in an ecosystem that are not explicitly accounted for in management. At the crux of understanding gap analysis is the notion of a "gap" as merely something that should exist, but does not (Ekstrom & Young, 2009). The following quotes (emphasis added) illuminate particular aspects of management that EBM proponents view as missing from existing practices, as a result of a sector-based approach:

> The goal of EBM is to maintain the health of the whole as well as the parts. It **acknowledges the connections among things**. (Pew Oceans Commission, 2003)
>
> EBM looks at **all the links among living and nonliving resources**, rather than considering single issues in isolation.. . . Instead of developing a management plan for one issue . . ., EBM **focuses on the multiple activities** occurring within specific areas that are defined by ecosystem, rather than political, boundaries. (USCOP, 2004)

The literature quoted here substantiates that decisions need to be made with acknowledgment of connections within any given ecosystem. The gaps analysis performed with MINOE provides an avenue to identify gaps in management using text-based analysis of legislation. The theoretical foundation and detailed discussion of this technique is available in Ekstrom and Young (2009). Users supply the ecosystem elements and linkages through a user-defined model providing flexibility by place-based standards, values, and ecological attributes (Figure 1a). MINOE then outputs laws and regulations based on the user's modeled system (Figure 1b).

A.

			ecological							social			
			species					habitat		human stressors			
			crab	seabird	eelgrass	salmon	spartina	ocean	estuary	dredge	pesticide	sewage	climate change
ecological	species ○	crab	---	0	1	0	1	1	1	1	1	0	1
		seabird	---	---	1	0	1	1	1	1	1	0	1
		eelgrass	---	---	---	1	1	1	1	1	1	1	1
		salmon	---	---	---	---	0	1	1	1	0	0	1
		spartina	---	---	---	---	---	0	1	0	1	0	1
	habitat □	ocean	---	---	---	---	---	---	1	0	0	0	1
		estuary	---	---	---	---	---	---	---	1	1	1	1
social	human stressors △	dredge	---	---	---	---	---	---	---	---	0	0	0
		pesticide	---	---	---	---	---	---	---	---	---	0	0
		sewage	---	---	---	---	---	---	---	---	---	---	0
		climate change	---	---	---	---	---	---	---	---	---	---	---

B.

			ecological							social			
			species					habitat		human stressors			
			crab	seabird	eelgrass	salmon	spartina	ocean	estuary	dredge	pesticide	sewage	climate change
ecological	species ○	crab	421	0	0	104	1	60	6	0	0	0	0
		seabird	---	5	0	1	0	0	0	0	0	0	0
		eelgrass	---	---	18	1	0	0	1	13	0	0	0
		salmon	---	---	---	1759	0	31	53	1	1	0	0
		spartina	---	---	---	---	58	0	6	5	7	1	0
	habitat □	ocean	---	---	---	---	---	347	35	9	0	4	0
		estuary	---	---	---	---	---	---	160	3	0	6	0
social	human stressors △	dredge	---	---	---	---	---	---	---	228	0	13	0
		pesticide	---	---	---	---	---	---	---	---	408	2	0
		sewage	---	---	---	---	---	---	---	---	---	757	0
		climate change	---	---	---	---	---	---	---	---	---	---	4

Figure 1. Mapping between a user's ecosystem model and law matrix (adapted from Ekstrom and Young, 2009). Figure 1a shows an example of a conceptual ecosystem model of what a user can input into MINOE to run an analysis. The ecosystem model's elements are represented as rows and headers and the direct linkages between elements are represented as cells containing existence (1) or absence (0) of a linkage. Figure 1b contains the text analysis results produced by MINOE for the laws and regulations of Washington state using the same ecosystem model structure as defined by the user in Figure 1a. Diagonal cells (in gray with white text) contain the total frequency that each term (representative of an ecosystem element) occurs in the documents. Non-diagonal cells contain the frequency in which terms representing two ecosystem elements co-occur close to one another. The cells that are linkages in ecosystem model (Figure 1a) are highlighted black if the terms do not occur close to one another in any document (indicating a "gap"). The cells are highlighted gray with black text if the terms do co-occur close to each other at least once in the document collection.

A second common problem arising from fragmented management has been the "overlaps" (Crowder et al., 2006; USCOP, 2004). These arise in different forms (jurisdictional and functional—see Ekstrom et al., 2009), but are essentially when more than one agency (or department) has management authority over a resource or area. In some cases overlaps can provide benefits to management, such as when they are used to coordinate among agencies to save money (through shared resources), reduce duplicative effort, or streamline decision-making. Overlaps can also create barriers to effective management in cases, for example, where the implementation of one law conflicts with the mandate or objectives of another (Young, 2002). Some scholars point out that overlaps are useful in that they create institutional diversity that support a check and balance system, which may maintain resilience of the governance system (Folke et al., 2005). No matter the type of overlap, knowing their existence and nature is essential for adapting or reforming institutional arrangements. Using text analysis of laws and regulations, techniques have been developed that assist in finding overlaps (Ekstrom & Lau, 2008; Ekstrom et al., 2009; Lau et al., 2006). These techniques can then be used to assist in identifying and better understanding the nature of overlaps.

MINOE: A Tool for Analyzing Ocean Management

MINOE is an open source desktop application developed to generate management information about any ecosystem of interest. The tool includes the gaps analysis described earlier but also provides some information about overlaps. The user-interface takes the user through a series of simple steps in the form of a wizard to set up the analysis and then generate the results. Results are provided through two modules: the matrix module, which is the same form as the user-defined ecosystem model; and the visualization module, which creates an interactive network diagram of the results data.

Analysis Set-Up (User Input)

The presented application allows users to navigate and retrieve existing management documents as they relate to an ecosystem. MINOE uses a conceptually modeled ecosystem, defined by the user, to set up the analysis of laws and regulations. The program then performs text analysis of laws and regulations (supplied through the program) to determine which ecosystem linkages are potentially acknowledged in the documents. Those ecosystem elements that do not co-occur within a given distance of one another in a law are potential "gaps." A user can then further examine the sufficiency, history, and efficacy of those laws that do contain acknowledgment of linked ecosystem elements. As an additional feature, users may also import text documents directly into the program for analysis from their personal computers. To function properly with MINOE's features, the user must include a metadata file documenting the title or description of each document and responsible agency or agencies. Other metadata such as document type (statute, regulation, management plan, etc.), year, and geographic location (California, Oregon, Washington, etc.) are incorporated in the indexing (for search filter and results display purposes) through this metadata file. For interested readers, the instructions on how to import documents are included in the user guide (see http://minoe.stanford.edu).

The primary features offered through the MINOE tool and described in this article include:

- Construction or import of an ecosystem model
- Selection of filtering criteria

- Synthesis of results
    - Numeric, quantitative analysis and display of document information (here shown only as laws and regulations) aligned with ecosystem model
    - Visualization to graphically depict data

The following describes the system as the user sets up an ecosystem model and ends in the visualization module.

Ecosystem Model. Matrices are common formats for developing and quantitatively portraying system relationships. This approach is especially common as characterization of ecosystem models where a matrix format is generated as typical output from scientific and stakeholder workshops about monitoring needs and assessment. One example of such a process that created ecosystem matrices was the Puget Sound Ambient Monitoring Program (Newton et al., 2000), which produced a set of matrices that define the monitoring needs of the region's estuary and associated human activities to maintain or strengthen the resilience of the social–ecological system. As another example, state and federal agency personnel, NGOs, and university scientists conducted a series of workshops to organize and prioritize impacts of wave energy parks off Oregon's coast (Boehlert et al., 2007). The reports summarizing findings of the workshops published a series of matrices to organize impacts of various stressors and other linkages that need to be considered for implementing and monitoring such wave parks. These matrices from the Oregon workshop, the Puget Sound Program, and others—individually or combined— are designed to inform and direct management (Newton et al., 2000; Thom et al., 2003). Modeled links noted in the cells (see Figure 1) can help organize what scientific relationships exist so that management personnel can account for such system relationships. These matrices can be used in MINOE to evaluate the laws, regulations, other management documents, and government agencies that deal with the issues defined in the ecosystem models.

Matrices represent a common way to organize the complexity of stressors, activities, and other elements and their associated linkages to inform scientific research and management (Newton et al., 2000). MINOE, therefore, uses the matrix format as the structure of input for the program's analysis. To enter the user's ecosystem model, MINOE takes the user through a series of steps in the form of a wizard. First the user lists the elements to make up the ecosystem. Each element is defined by a single term or phrase or a set of terms and phrases (Step 1, Figure 2). For example, when climate change is one of the ecosystem elements (Figure 1), the user may choose to input *climate change* and *global warming*. As another example if coho salmon is one of the ecosystem elements, the user may choose to input *coho* and also *Onchorhynchus kisutch*, *O. kisutch*, or *silver salmon*. If the user is interested in more laws and regulations dealing more generally with the fish, he or she might choose to include *salmon* and *salmonid*.

Once all the elements are entered, MINOE uses them to generate a spreadsheet containing a symmetrical matrix (Step 2, Figure 2). In each cell the user inserts a one or zero representing the existence (or non-existence) of a relationship between the corresponding elements. For elements unrelated in the ecosystem model, the user inserts a zero in the corresponding cell.

Alternatively, the user may import an existing ecosystem model from a spreadsheet program, such as Excel if it is saved as a comma delimited file (.csv). A user may input ecosystem models that incorporate species relationships in the form of foodweb ecosystem models, such as those generated by Ecopath with Ecosim (Christensen & Walters, 2004). Incorporation of human dimensions is also a critical part of ecosystem-based management

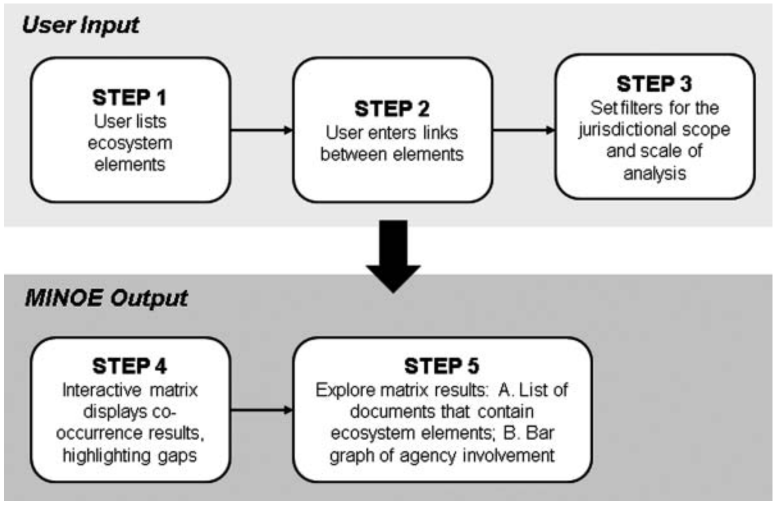

Figure 2. Workflow diagram of running an analysis in MINOE. Steps 1 and 2: the user constructs an ecosystem model matrix in MINOE; Step 3: the user defines the search criteria for analysis (year of documents), jurisdictions (location and scale), document type (regulations and statutes in example), or specific inclusion or exclusion of documents for analysis); Step 4: MINOE outputs an interactive matrix displaying text analysis results of documents searched based on the ecosystem model, similar to Figure 1b; and Step 5: the user may view list and text of the documents containing the ecosystem elements or a bar graph of the agencies responsible for those documents.

(Juda & Hennessey, 2001; Cortner et al., 1998; Grumbine, 1994); therefore, users may choose to input ecosystem models with elements and relationships representing not only ecological linkages, but also human activities, societal values, and economic industries. Models including human elements likely will be generated qualitatively based on economic activities, human impacts, and ecological elements and the relationships among one another (dependencies, positive and negative impacts).

Scope and Scale of Governance. Governance varies widely in scope and scale based on the context and nature of the question. The variance in scope and scale also plays a role when analyzing governance in the context of an ecosystem. One user may be more interested in federal U.S. statutes, while another user may need to investigate the regulations and authoring agencies for a specific state. Another user may need to access regulations from multiple states simultaneously. Therefore, MINOE allows users the flexibility of setting the scope and scale of analysis through a filtering criteria wizard (Step 3, Figure 2). Currently, a sample document collection included in MINOE contains statutes and regulations from four geopolitical jurisdictions (States of Washington, Oregon, and California, and Federal United States) for the year 2006. Using this collection, for example, a user may want to view results for both Federal law and California State law simultaneously for a single ecosystem. In this case, the user would select the year of interest and then the jurisdiction of interest, and add these documents as a single group. Then for the noted federal-state comparison, the user could select the same year and add documents from the comparison jurisdiction for the second group of documents to be included in the analysis. Alternatively, as proposed in Ekstrom and Young (2009) a user may want to look at a single jurisdiction over multiple years. To perform this analysis, a user may designate a particular year and then compare this base year's results to a later period for the same regional scope to examine change. To perform this analysis, the user would need to import additional sets of documents into MINOE representing different years. Such multi-year analyses could reveal an increased sensitivity and consideration of ecosystems, for example, as a result of amendments to legislation such as the Outer Continental Shelf Lands Act and the Fisheries Conservation and Management Act. In addition, it could be used to help track the emphasis on ecosystem stressors such as climate change.

Lastly, a user may select the specific documents to include for analysis. This may be useful for evaluating the regime related to a single sector, such as fisheries management. In the case of evaluating federal fisheries, a user could choose to include only the Magnuson Stevens Fishery Management and Conservation Act, Endangered Species Act, and Marine Mammal Protection Act along with the fishing-related regulations (fishery management plans). The documents indexed in MINOE are listed in the wizard under Search by Document in the middle of the screen.

Results

Once the filtering options are set (into relevant groupings), the system performs the analysis on the text of the documents selected using the ecosystem model. As described in what follows, results are presented in a matrix format that matches the user's ecosystem model elements. Users then can access the information displayed in cells, which corresponds to laws, regulations, and agencies.

Law Matrix. The results are initially generated in a matrix-based module (Step 4, Figure 2). The program organizes the laws and regulations within the search criteria as a matrix of the same dimensions as the target ecosystem. The diagonal cells of the matrix contain the frequency for the single corresponding term in the same compilation. Results are presented in the same format as shown in Figure 1, for instance, which shows the term *crab* occurs a total of 421 times in the Washington State laws and regulations analyzed while the term *seabird* occurs only 5 times in the same collection of documents. Each non-diagonal cell contains the co-occurrence frequency of each dyad of terms (e.g., *salmon* and *estuary* have 53 co-occurrences in the Washington State group of documents). Cells that contain ecosystem relationships in the model are highlighted, while those cells that were zero in the ecosystem model remain white. Each cell contains the number of times the corresponding terms (representing ecosystem elements) occurs within a given distance of one another in the selected compilation of laws and regulations.

If a cell represents a linkage in the ecosystem model (>0) and contains zero frequency, it is marked as a "gap." Gaps are highlighted as black (see Figure 1b). For example, a linkage exists in the ecosystem model between salmon and climate change (see Figure 1a); this same cell in the law matrix results for the State of Washington contains zero (Figure 1b), indicating that there are no laws or regulations for the State of Washington in this collection of documents that reference the terms *salmon* and *climate change* together. Therefore, despite the understanding of the large threats to salmon from climate change (Battin et al., 2007; Hare & Francis, 1995; Mantua et al., 1997), no regulation or law explicitly acknowledges this relationship, according to this collection of laws from 2006.

If a cell represents a linkage in the ecosystem model (>0) and corresponding elements co-occur in one or more laws, it is marked as a potential linkage in law. These linkages are highlighted in gray (color can be adjusted in module by user). An example of a modeled linkage acknowledged in law is the relationship between eelgrass and dredging. A link was noted as extant in the ecosystem model (see Figure 1b). This same cell in the law matrix for the State of Washington results indicates that there are 13 incidences in which the terms *dredging* and *eelgrass* co-occur together. Therefore, the link between eelgrass and dredging modeled in the ecosystem is likely accounted for in the laws or regulations of Washington State. The user then may opt to view what laws and regulations contain the co-occurrence of these terms and view the text of the documents.

Laws and Agency Involvement. The user may retrieve more specific information for each cell. Right clicking on the cell of interest, the user can opt to view (1) what laws and regulations contain these elements (Step 5, Figure 2) and (2) what agencies are responsible for these laws and regulations that contain the elements and relationships of interest (Figure 3). Selection of the first option brings up a list of laws and regulations, each of which the user can open and view the text of individual documents for the highlighted terms that represent the relevant ecosystem elements. The second option of responsible agencies creates a bar graph of agencies involved in the cell's corresponding elements (Figure 3). The x-axis contains the relevant agencies and the y-axis is the frequency of the elements' co-occurrence for each agency.

The diagram of relative agency involvement (Figure 3) is interactive so that the user may double click on each individual bar (representing an agency) to view the list of documents

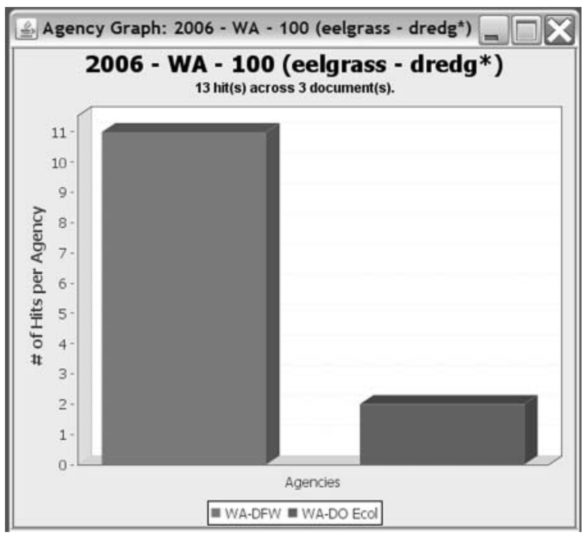

Figure 3. Bar graph showing the co-occurrence of terms in documents for each agency. From the interactive matrix (Step 4, Figure 2), the user can right click on any matrix cell and choose to view what agencies are associated with the cell's document count. The relevant agencies are represented as a bar graph charting the frequency of co-occurrences in documents that contain the ecosystem elements *eelgrass* and *dredg** within 100 words of one another. This metric indicates an approximation of the degree of agency involvement. From left to right, each bar represents an agency and the height of the bar serves as an estimate for each agency's relative degree of involvement in management of preventing, monitoring, or managing for the impact of dredging on eelgrass beds. (Agencies include WA-DO Ecol: Washington Department of Ecology, and WA-DFW: Washington Department of Fish and Wildlife.) Therefore, in the figure shown, the Washington Department of Fish and Wildlife has a higher relative involvement than Washington Department of Ecology in addressing the relationship between dredging and eelgrass (according strictly to the documents analyzed here).

that contain the selected ecosystem elements (*eelgrass* and *dredg** in Figure 3). For example, if a user wants to know what are the laws and regulations under the Washington Department of Fish and Wildlife that refer to the terms *eelgrass* and *dredging* together, the user clicks on the bar labeled DFW and opens the list of laws. Each document can then be opened in a document viewer to view the text of the document in which *eelgrass* and *dredging* are mentioned. The document viewer includes automatic highlighting of the search terms, a navigation bar indicating where the terms are located in the document, additional search functionality, and the option to save document text to an external clipboard.

The user now has access to the text of the regulation (Washington Administration Code) under the authority of the Washington State Department Fish and Wildlife that directly addresses the link between dredging and eelgrass. This quote: "Dredging shall avoid adverse impacts to eelgrass (Zostera spp)" (Washington Administrative Code Hydraulic Code Rules. 2006) indicates the knowledge of the agency that a relationship exists between dredging activity and eelgrass beds, and signifies the agency's intent to protect eelgrass from direct impacts of dredging. Whether this rule is followed, monitored, and enforced on the ground is a question requiring further investigation beyond analysis of laws and regulations.

Synthesis

MINOE includes features to help users synthesize the results of analyses through statistical analysis and through a visualization of the data. The following presents the basics and use of each feature.

Measuring the Fit of Laws to the Ecosystem. For users to assess overall relationship between the ecosystem model and the document matrix (in terms of its gaps and links), three metrics are provided to gauge overall similarity. First is the ratio of gaps to modeled links (Ekstrom & Young, 2009). Second is the calculation of similarity between the ecosystem model and the associated law matrix using Jaccard's Coefficient when the ecosystem model contains binary data to represent linkages. Third is the calculation of similarity between the ecosystem model and the associated law matrix using the Quadratic Assignment Procedure (QAP). This metric is used when the ecosystem model contains various strengths of links. These three similarity metrics allow comparison among ecosystem models for a single jurisdiction, helping to answer whether the governance for one place is more prepared to deal with one ecosystem (or scenario) compared to others.

The matrix comparison metrics also allow quantitative analysis of the laws related to the same ecosystem model over multiple years (once a user imports law collections that represent additional years). Such time series data could illuminate the feedbacks between management actions and the health of ecosystem services. In addition, regulatory time series data could be used in combination with other data (e.g., surveys of agency personnel) to evaluate disconnect between what is written in law and regulation and how various factors (e.g., leadership, budget allocations, politics) influence how management is implemented on the ground.

Visualization. To assist users synthesize and explore the data, MINOE provides a network diagram tool through its visualization module. The ecosystem model used earlier to demonstrate MINOE has only 11 elements (Figure 1), which is small compared to those a user may need to investigate. As the number of elements increases, the complexity of the model increases exponentially, making interpretation of results more challenging. The increased complexity makes the matrix view of the results especially difficult, even with various colors to code the linkages and gaps according to the model. The visualization module offers the option to not view those co-occurrences of terms that are not noted as links in the ecosystem model, therefore simplifying the data for the user. In addition, the relative frequency of individual ecosystem elements is demonstrated through relative sizing of the terms.

The user can activate this module through the matrix-based module or directly at the start of the program without inputting an ecosystem model. If the user activates this module through the matrix-based window, each modeled element is displayed in the visualization window. The size of each element is based on the frequency in which it occurs (for example, the element *ocean* will be displayed larger than the element *eelgrass* if *ocean* occurs more frequently than *eelgrass*). The tool draws solid lines between elements that are linked in the model and that co-occur within a given distance of one another in any document analyzed (Figure 4). The thickness of the solid lines adjusts based on the relative frequency of co-occurrences for the two linked elements. In Figure 4 a thick line connects *salmon* and *ocean* because there are 113 co-occurrences of these elements in the Washington state laws (see Figure 1), while a relatively thin line connects *estuar** and *spartina* because there are only six co-occurrences of the two ecosystem elements. MINOE draws dotted lines (default colors can be adjusted) between the elements that are linked in the ecosystem model but do not co-occur in any law, such as between *eelgrass* and *spartina*. The user can access

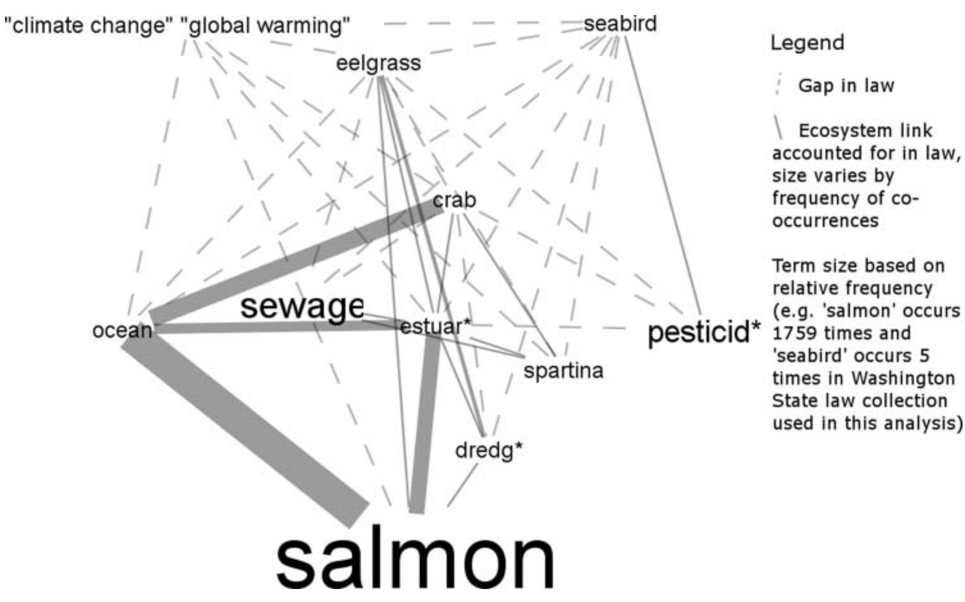

Figure 4. A network diagram displayed using the visualization module of MINOE. The network diagram shown here uses the same information presented in Figure 1. Dotted lines indicate gaps (those ecosystem modeled links that do not co-occur within law), and gray lines indicate those modeled links for which ecosystem elements do co-occur closely together in one or more law. Thickness of line varies with the frequency of elements' co-occurrence. Terms representing ecosystem elements are sized relative to the frequency of occurrence in the document collection. As such, the term *salmon* is the largest in size because this term occurs the more times (1,759 occurrences) than any of the other terms used to construct the ecosystem model.

the corresponding list and text of laws and the chart of agency involvement through this visualization module (Figure 3).

As with the results in the matrix module, the user can right click on any ecosystem element to view additional information. This includes a list of relevant laws and the bar graph of gauging involvement of agencies to managing a specific element or linkage.

MINOE can support analysis of management documents flexible to the needs of the user. It allows users to input their ecosystem model of choice and conduct the analysis on any scope and scale of documents. Lastly, MINOE provides features to help users analyze and synthesize the data generated. The following presents ideas for applications for which MINOE has been and could be used.

Applications

MINOE provides a myriad of benefits even in its basic form. Such benefits may assist domain experts as well as non-experts as a first step to further investigation:

- Offers a system to retrieve laws and regulations from four geopolitical jurisdictions for the year 2006 (or other documents, if the user imports them) using the framework of a user-defined ecosystem (or other system of interest)
- Provides objective estimation of agency involvement using a suite of laws and regulations from comprehensive suite of sectors representative of four geopolitical jurisdictions
- Provides information in a transparent manner, allowing easy access to the source text for determining context

There are several potential applications for the presented system including governmental and nongovernmental organization personnel, policy advocates, resource users, concerned citizens, and policy course instructors and students. As a tool for agencies, it could be used to assist improving collaboration, enhance strategic resource sharing, and increase strategic policymaking. The technique could also be useful for individual agencies in writing new regulations to determine whether there are resource-sharing opportunities with other agencies in order to fulfill mandates. The following presents three applications for which MINOE assist in: (A) regulatory analysis; (B) generation of information about legal frameworks; and (C) education.

Regulatory and Legislative Analysis

Most directly, MINOE can be used to assist regulatory and legislative analysis. For example, one of the main goals set by the California Aquatic Invasive Species Management Plan was for the State to conduct an analysis of existing management, identifying what laws and regulations the State already has that pertain to each specific pathway and invasive species (DFG, 2008). Additionally, one of the plan's primary tasks is to identify which agencies are and should be involved in management of invasive species. Given the complexity and long list of pathways through which non-native species are introduced into the state waters (DFG, 2008; OTA, 1993; Schmitz & Simberloff, 2001), this can be a time-consuming project. Tasked with documenting all California State legislation relevant to aquatic invasive species, a California State Research Fellow used the beta version of MINOE, in combination with more traditional law databases, to carry out this project. By comparing these data resources, a list of strengths and limitations of the MINOE beta versions arose. When compared to on-line law databases that were not specifically designed for ecosystem analysis, unique advantages of using MINOE include:

- Access to an approximation of agency responsibility (through bar graphs)
- Matrix-based search
  - Facilitates investigation of documents addressing linkages between elements
  - Provides system-perspective of regulation across state and federal and across multiple states for comparison
  - Identification of regulations containing overlapping concepts
  - Identification of potential gaps in legislation
- Ability to access multiple jurisdictions through a single application

The primary limitation identified by testers of the MINOE beta version included the need to have updated and user-defined collections of documents. The final release of the first version of MINOE will allow users to import their own collections and those regular updates provided through the MINOE project website (http://minoe.stanford.edu). Users can then import new legislation, but also other types of management documents such as international treaties and associated texts. MINOE in this way could provide a useful tool to assist a gaps analysis of international regulation and governance as conducted by the International Union for the Conservation of Nature (Gjerde et al., 2008).

Tool for Building Management Scenarios

MINOE can also serve as an extension to ecosystem modeling programs. The increasing interest and need for applying the ecosystem concept in management and decision-making have generated a growing number of scenario-building tools and research programs focused on valuing ecosystem services (NatureServe Accessed, 2009). These tools thus far focus on the natural science of ecosystems and are beginning to integrate these data with economic information. MINOE could be used in conjunction with these ecological and economic EBM tools to provide baseline law and regulation data in relation to the ecological and economic elements. For example, Ecopath with Ecosim (EwE), built by a team of scientists and software engineers at University of British Columbia, is a desktop application ecosystem modeling software used to assist in identifying optimal management strategies for fisheries management (Christensen & Walters, 2004; Pauly et al., 2000). EwE creates quantitative ecosystem models of direct and indirect linkages between species, habitats, and other ecosystem elements. Using a suite of management scenarios, the EwE can help scientists and managers identify what aspects of the economic supply chain will be affected by various ecosystem changes. MINOE could be used in conjunction with EwE to provide users with useful information about the existing legal framework in which the use and protection of ecosystem elements are being regulated, whether the ecosystem linkages are accounted for in any regulations, and what agency or suite of agencies potentially should or could be involved in the implementing the scenario.

Educational Application

Relative to the programs, courses, and collaborations of natural sciences in university settings for understanding the oceans, there are few courses and programs that specifically focus on ocean and coastal governance in the United States. MINOE can serve as a unique tool to support marine and coastal governance courses, for use by students and scholars at several educational levels and in several domains of research. Most readily, teachers of introductory courses in ocean governance or marine policy could assign students to investigate how a concept, such as “ecosystem,” is regarded in laws and regulations, under what responsible agencies, and how the use of the concept has changed over time (for example, what Presidents signed Executive Orders and in what years). Coursework and research questions for which MINOE can serve as a useful tool are many. As such, in a small way, use of MINOE can contribute to strengthening educational efforts of ocean and coastal governance.

Summary and Discussion

The first version of MINOE presented here is a fully operational software tool. However, this is the first of many steps we envision for the longer-term objective of interoperating baseline governance information with biophysical data. To continue testing and demonstrating the utility of MINOE, it is important that we continue to compile document collections representing management efforts from additional regions and different years. A next important step for this system is to integrate text analysis capacity with spatial coverage of the laws, regulations, and other documents imported by users. Development for this added spatial dimension likely will use spatial data layers of the United States federal and coastal state statutes generated by the NOAA Coastal Services Center’s Legislative Atlas (National Oceanic and Atmospheric Administration, 2007; Willis, 2006). In addition, collection of legislation for multiple points in time can assist evaluation of temporal changes in legislation from a cross-sector and system-wide perspective. Compiling data over time about management will eventually assist in use of ecological and biophysical data to link patterns of ecological change to management attributes. This will also provide a way to track management response to natural resource changes (for example, in abundance, distribution, and diversity). In the short term, research efforts need to be put toward the systemic compilation and cleaning (removal of markup) of laws, regulations, and other management documents so collections for any geographic region can be generated quickly and easily with few resources.

Ultimately, MINOE likely will be made available as a Web interface and include advanced on-line navigation techniques that could help a user navigate to associated court cases, management plans, and agency and nongovernmental organization websites. More advanced text mining of the document results could also prove useful, such as extracting terminological taxonomies and ontologies for improved concept definition. In addition, interoperating MINOE with a system such as RegNet (Lau et al., 2006) could help reveal similarities between results and retrieve other similar documents. For instance, once a user identifies a section of the law from Washington State that mentions the terms *eelgrass* and *dredging*, RegNet can be integrated to retrieve relevant sections of law from other collections based on textual and structural similarity. RegNet detects section similarity based on shared textual features as well as shared document structure, and therefore has the potential to reveal hidden similarities between sections of law that could be difficult to identify using a user-defined list of synonyms.

In this article, we have presented an open source tool designed to help organize baseline information about agency jurisdiction, laws, and regulations across geopolitical scales and over time. Although the tool is still in its early stages in terms of its potential and the datasets included, we present the functionality it does have now, how users can currently use it, as well as ideas for potential application with further development. As government—and the laws, regulations, policy documents, management plans, court cases, and others—become more complex, information management systems to retrieve basic information to inform government agency personnel, law-makers, and other stakeholders about what rules and rights already exist is critical to effective management. While the development of MINOE has focused on ocean and coastal law and regulation, this tool can be applied to any domain and on any type of document. It would be especially useful for other domains that experience especially complex cross-jurisdictional challenges, such as salmon, fresh water quality and quantity, and emergency disaster management. It could provide assistance for those evaluating complex governance systems needing improved coordination and integration across sectors, for which the list is endless.

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