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Review

Visualization for planning and management of oceans and coasts

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ABSTRACT

This paper reviews visualization tools available to environmental planners and managers working on ocean and coastal environments. The practice of visualization involves making and manipulating images that convey novel phenomena and ideas. First I describe visualization within the context of visual environmental communication, an emerging and rapidly evolving discipline. A review of the literature on visualization is provided and a typology of cartographic visualization and scene simulation is proposed. Ways to make visualizations relevant for work with the public and policy makers is discussed. While significant progress has been made in the area of visualization for climate change with much of it focusing on coastal impacts, little attention has been given to visualizing the marine environment within the framework of visualization studies. More technical work on integrating maps and scenes is needed for planning and management of ocean and coasts, including research on advanced GIS methods for decision-making and virtual reality.

1. Introduction

Rachel Carson, a founder of the modern environmental movement, wrote three books about oceans – all best sellers – before writing her most famous book: *Silent Spring*. Few may remember these ocean primers. The second of these books, *The Sea Around Us* (1952), was adapted to film following its publication. Beyond the business angle, is the idea that a book, using written words to inform about the sea world, was not enough. Director Irwin Allen (later coined the “Master of Disaster” for films like *The Poseidon Adventure* and *Towering Inferno*) turned Carson's book into an entertaining look at a world unknown to most of the viewing public. This adaptation went on to win the Academy Award for Best Documentary Feature in 1953.

Over half a century later, reams of information exist about oceans going far beyond what Carson likely dreamed possible. Much of today's data documents the ongoing degradation of oceans and coasts and the implications for the rest of our planet. This information is essential for planners and various other professionals increasingly involved in efforts of marine spatial planning (Collie et al., 2013; Eastern Research Group, 2010; Ehler and Douvere, 2009). How can professionals get the word out about the oceans' predicament so that this information can best be used for decision-making in a marine planning context? What tools are at their disposal? Visualization is clearly one of them. A case in point is the pivotal role visual simulation played in the approval of the array of 130 wind turbines for energy production off the coast of Cape Cod in 2010. Much of the debate concerning the impact of the offshore wind farm hinged on the accuracy of simulated seascapes (Phadke, 2010).

Marine and coastal environments engender special communication challenges. Visualization techniques such as maps, graphical displays and virtual reality, are particularly important as environments being impacted by development are farther from shore. In these locations which are often purposefully far from population clusters, environments are unfamiliar to the general public and policy makers. They are hard, if not impossible, for much of the public to access. Dramatic changes are taking place in oceans due to climate change that require both 3D (depth) and 4D (time) representation capabilities. While there has been some work on visualizing climate change both through simulation maps and scenes along coastlines (see Shaw et al., 2009), communicating about climate change effects in the deep sea lags far behind.

Environmental planners often obtain information about the physical world and use it to improve foresight. They also need to make it easier for stakeholders to examine their own medium-term and long-term futures, to envision what is virtually inaccessible or to envision what doesn't *yet* exist. This article reviews current progress on visualization techniques for planning and management

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of oceans and coasts from a general technical perspective. It discusses communication tools for two target audiences: the public and policy makers.

I draw on work in the area of visual environmental communication and visual representation. I begin by placing the topic of visualization for oceans and coasts into the wider trajectory of research on visual representations of the environment as a form of communication. Maps and visual scenes are discussed. Scenes in this context refer to a full range of imagery including photos, movies, video, imaginaries and more. These types of scenic images are well-known mechanism for planning and management, often used to facilitate public participation and as a basis for decision-making about terrestrial environments. This article serves as a review of current progress on researching these mechanisms with insights highlighting new directions and further research needs for seascape visualization.

2. Visual communication

The idea that "seeing *is* knowing" is well entrenched in Western society (Jenks, 1995). Therefore, research on how images are perceived and how visuals influence the viewer is important. To answer these question researchers have drawn on psychology, neuroscience, cognitive science and communications (Hasson et al., 2008) which has led to a significant body of knowledge sought by media professionals and just about anyone who has an agenda to promote. The practice of visualization involves making and manipulating images that convey novel phenomena and ideas and therefore both the informative and the ideological come into play. Tufte (1990) describes visualization as a medium for clarifying certain complex data and it has great advantages over the written word or the voice alone. The visual sense is by far the most dominant component of human sensory perception (Bruce et al., 1996).

Recent work on visualization promotes expanding the sense of the visual, incorporating political economy of all types of representation – television, film, photographs, across different fields, and including the broadest range of representations possible – from maps, to photos, to visual representation of data in graphs and tables (Hansen and Machin, 2013; Valiela, 2009). Environmental visualizations could be 2D, 3D or 4D maps, graphical representations of data or real, imagined and/or manipulated scenes such as photo images shown in a virtual reality setting.

Visualization has been studied in recent years within the context of environmental communication[1] (Hansen and Machin, 2013). Environmental communication is a relatively new discipline but one gaining in interest, especially as tools such as crowdsourcing and social media monopolize channels of everyday interactions and local activism takes on global challenges, such as changing behaviors to mitigate climate change (Sheppard, 2012). The discipline emerged as a field of research in its own right for two main reasons. First, researching all aspects of communication on environmental issues –including those doing the communicating, their positions, historical-political affiliations and means of communication –is necessary to fully understand the scope, scale and content of socio-environmental problems. The second reason is that in the face of the major environmental crises of our time, communication influences public opinion and it can promote sustainable behaviors (Katz-Kimchi, 2013). The discipline has developed such that it considers myriad modes of communication from discourse and rhetoric to conservation and environmental protection as themes in popular media (see Cox, 2013).

Images have a major role in popular media and therefore an emphasis of environmental communication deals with the visual. Within the framework of environmental communication, scholarly work analyzes how different modes of representation influence the viewer; such analyses have focused on a broad range of environmental advocacy media campaigns, such as those dealing with wildlife conservation (Milstein, 2008), climate change (Sheppard, 2012) and pollution protection (Schwarz, 2013). In regards to general environmental advocacy, researchers have found that television and other media increasingly use decontextualized global, symbolic and iconic images to reach a more universal audience, disconnected from a particular geographic/historical place and time or a particular social/cultural milieu (Hansen and Machin, 2008). But beyond the "aspatial" (non-spatial) nature of environmental representation in the popular media that largely ignores geographic location, landscape assessment research deals with connecting images to place and vice versa (Lange, 2011; Orland, 1992). For example, as local activism takes on global challenges, such as changing behaviors to mitigate climate change or for conservation planning, more research on visualization is place-based. In the case of sea-level rise, the focus has been on visualizing the land and sea interface where communities may be most impacted in order to mobilize viewers to take action or make decisions.

3. Visual representations of the environment

Hansen and Machin (2013) claim that the public vocabulary on the environment is to a large extent a visual one. Scholars such as Chias and Abad (2013) and Lange (2011) have brought the study of visualization into the realm of environmental planning. The role of planning has evolved over the years to frequently be a communication between planners and communities, where planners guide the communities to decisions (Cinderby, 2010; Kingston, 2007). However, these decisions by communities may be incorporated, or not, by decision-makers (Arnstein, 1969; Randolph, 2011). Opposite the public, or community members, are the decision-makers who usually determine policy. The planner may be somewhere in the middle, bridging the science-policy gap while infusing opinion, knowledge and preferences of the public into the decision making process.

Communication of knowledge between the scientific and management communities can be a difficult process complicated by the distinctive nature of the career goals of practitioners, scientists and decision-makers. Planning practitioners are often working to implement the goals of their clients, scientists are busy researching topics that are "hot", current and fundable, whereas decision-makers are at the mercy of elected officials and their appointees. In the latter case, goals are short-term – i.e., something needs to get done during the incumbent's term –and for academic scientists, time is needed to conduct experiments, write about them and ensure continued funding. Therefore, the use of visual representations by environmental planners for interfacing between science and policy has become important, especially when time-frames are short and data is complex (Gill et al., 2013). Visuals that often take the form of maps in a planning context (Smith and Brennan, 2012) can reduce or convey complexity of situations that call for timely decisions.

Visual researchers point out that we are increasingly surrounded by an immense proliferation of visual images such that the traditional division between maps and other image types has become blurred (Smith and Brennon, 2012; McKinnon, 2011).

[1] Article 2 of the National Communication Association's charter for the Environmental Communication Commission declares "The purpose of the Commission is to promote scholarship, research, dialogue, teaching, consulting, service and awareness in the area of environmental communication" (1998, para. 2).

However, for purposes of this review visualizations are categorized as two main types: maps and scenes. This article uses a very broad definition of "scene". The term refers to any type of image portrayed through a variety of media, including, film, photography, video — digital or analog. Advanced GIS technologies are making the combination of maps and scenes much easier. However, despite the ease with which one can migrate from a map to a scene while maintaining the geographic location of an image, the simultaneous presentation is still rather crude with a frame transition often involved. Once the viewer is immersed in a scene, for example, using Google Earth, his location on a map has become ambiguous (See Fig. 1). Therefore the distinction holds.

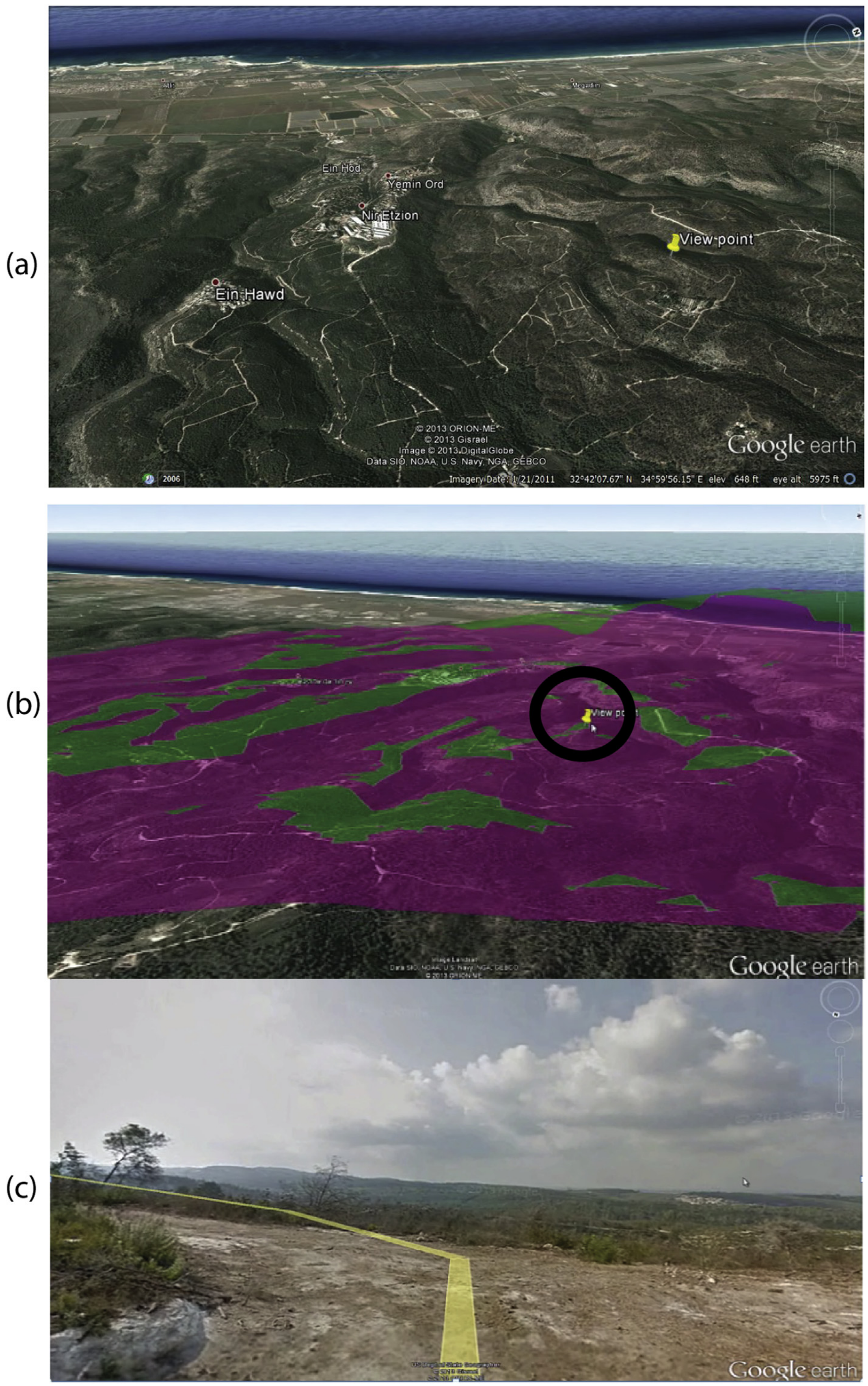


Fig. 1. Visualizing seaside views from land using Google Earth. In (b) seen and unseen area in the view shed are shaded green and pink respectively as calculated from the circled viewpoint based on a digital elevation model (DEM); (c) shows the view in one direction from the viewpoint. The yellow line indicates the route of camera travel. (For interpretation of the references to colour in this figure caption, the reader is referred to the web version of this article.)

3.1. Visualizing the environment using maps

Mapping has its roots in cartographic visualization. A 1966 article in *The Cartographer* proposed a new term, **graphicacy**, to complement the existing terms – literacy, articulacy, and numeracy – already used in the field (Hallisey, 2005). "Graphicacy" is the ability to communicate effectively and understand those relationships that cannot be expressed solely with text, spoken words, or mathematical notation through the use of visual aids, particularly maps (Balchin and Coleman, 1966). More significant than the term itself, is the concept behind it – that words or mathematics are insufficient to communicate about many phenomena. Over time, the notion of graphicacy has evolved into the concept of cartographic visualization (Hallisey, 2005).

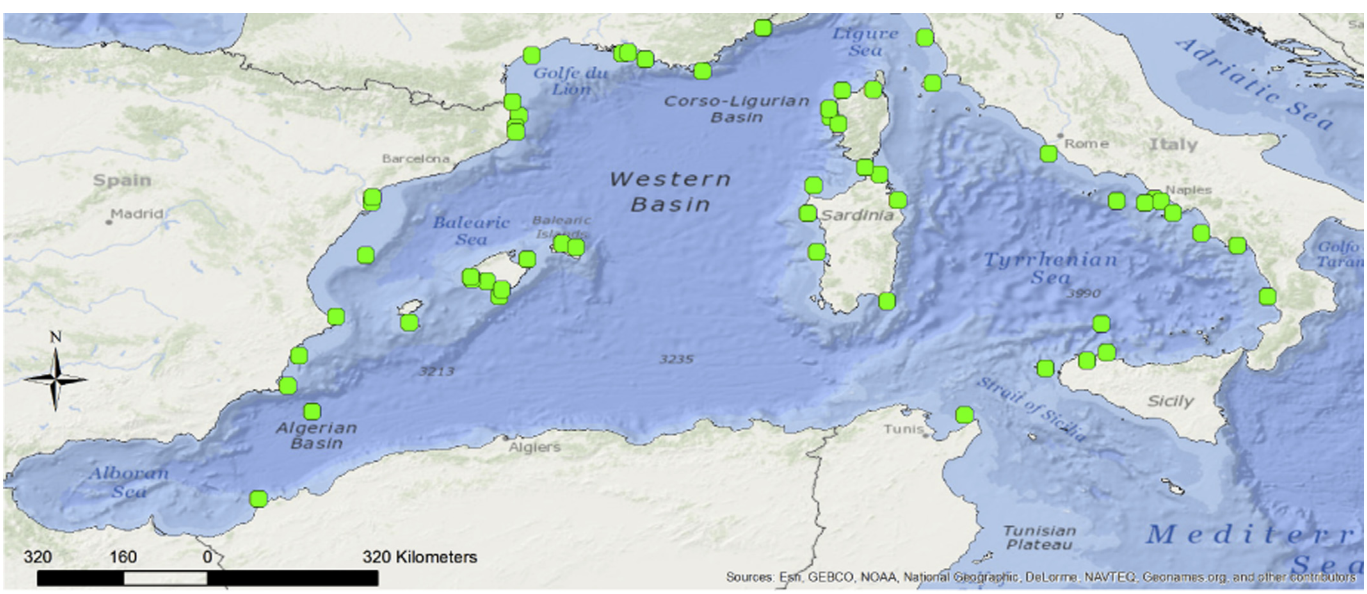
The map-communication model of cartography textbooks widely used from the mid-1950s through the 1980s emphasized improving map design. These revolved around better ways to depict hachures and to determine optimal sizes for symbols (termed 'symbology' in GIS; or more generally "semiotics") to effectively communicate with the map user. These concerns have much to do with viewer (user) perception and are not trivial by any means. However, today cartographic visualization is more concerned with 2D, 3D and 4D geospatial representation and accuracy, and it strives to accomplish much more than the straight forward graphic depiction of features.

Recognition of the power of visualization in conjunction with advances in GIS has led to advanced uses of cartographic visualization with features linked to dynamic data sets (see Fig. 2). Examples of these are cartographic techniques incorporated into decision support tools, frequently used with advanced GIS applications for marine conservation planning and marine spatial planning as discussed below. Mapping spatial information of all types, including images, is necessary for full understanding, especially in an environmental planning (e.g., Chias and Abad, 2013) and management (e.g., Orland, 1992) context; however, this coincides with the recognition that spatial analytical techniques alone are sometimes inadequate to convey the full meaning of proposed changes, especially for work in the marine environment (Smith and Brennan, 2012).

3.2. Land- and seascape scenes

Since the term "scene" refers to the use of an image as a simulation of the viewed environment, it is a type of model as is a map. However, an advantage to the use of scenes, especially manipulated scenes for planning is the ability to depict existing conditions and proposed improvements together in a way that approximates reality. As long ago as the 1700s, a hinged set of slides flipped up or down was used by architects to help clients visualize the effects of proposed changes. These techniques were subsequently augmented by photography as a tool for landscape analysis and communication (Zube et al., 1987). Much more than simple photography is used today. As an example, seascape images generated through advanced ocean data collection techniques, such as multi-beam echo sounders, can be used for much more than preparation of hydrographic charts for safe navigation (e.g., marine habitat assessment, fisheries management and subsea engineering) (Mayer, 2012).

In making the jump from 2D photographs to 3D landscape representations, digital landscape representations have developed



OBJECTID *	Shape *	MPA	Country	DATE_	INTL_DES	NATL_DES	CAT_IUCN	ECOREG	MA_AREA	TE_AREA	perc_ter	NT_LT_MU	MU	N_Tot_Area
7	Point	Archipelago di La Maddalena	Italy	1994	1	1	2	Western Mediterranean	150.46	51.54	.255149	MU	1	202
8	Point	Archipelago Toscano	Italy	1989	1	1	2	Western Mediterranean	615	177	.223485	MU	1	792
9	Point	Archipielago de Cabrera	Spain	1991	1	1	2	Western Mediterranean	86.8	13.2	.132000	MU	1	100
10	Point	Area Amantea	Italy	2004	0	1	Uns	Western Mediterranean	75	0	0	LT	0	75
13	Point	Asinara National Park	Italy	1997	0	1	2	Western Mediterranean	107.3	52.02	.326513	MU	1	159.32
14	Point	Bahia de Palma	Spain	1982	0	1	4	Western Mediterranean	23.94	0	0	MU	1	23.94
15	Point	Parco Sommerso Baia	Italy	2002	0	1	Uns	Western Mediterranean	17.7	9.5	.349265	MU	1	27.2
16	Point	Bouches de Bonifacio	France	1999	1	1	4	Western Mediterranean	792	2.6	.003272	MU	1	794.6
19	Point	Cabo de Palos Islas Hormigas	Spain	1995	1	1	5	Western Mediterranean	16.29	2.69	.141728	MU	1	18.98
20	Point	Cabo de San Antonio	Spain	1993	0	1	Uns	Western Mediterranean	9.67	0	0	LT	0	9.67
21	Point	Calangues	France	2011	0	1	Uns	Western Mediterranean	22	65	.747126	LT	0	87
22	Point	Cap Couronne	France	1996	0	1	Uns	Western Mediterranean	2.1	0	0	NT	0	2.2
23	Point	Cap d'Agde	France	2002	1	0	Uns	Western Mediterranean	23.29	0	0	MU	1	23.29
24	Point	Cap De Creus	Spain	1998	1	1	6	Western Mediterranean	30.56	107.67	.778919	MU	1	138.23
26	Point	Capo Caccia-Isola Piana	Italy	2002	1	1	4	Western Mediterranean	26.31	0	0	MU	1	26.31

Fig. 2. Cartographic visualization of the distribution the marine protected areas in the Mediterranean Sea.

from abstract and static representations to realistic visualizations capable of being explored through dynamic spatial movement, as immersive experiences in multiple spatial and temporal scales (Wagner, 2011; Beard et al., 2008; Lange, 2011). The use of such visual representations based on digital or virtual environments is established in planning as part of environmental impact assessment that invariably requires analysis of expected visual impacts (Chias and Abad, 2013; Phadke, 2010).

Spatial visualization research has addressed ways to combine maps and scenes together for spatial and spatio-temporal visualization. Such research ranges from high-resolution specific site or landscape-unit scale (e.g., Chias and Abad, 2013) to lower resolution ecosystem area-wide or regional scale (e.g., He et al., 2010), usually depending on the application and context. For example, to depict climate change (Sheppard, 2012), geo-visualizations provide temporal variation and combine 4D maps and scenes that can effectively show time series changes at a large scale. Geo-referenced images are not necessary shown simultaneously with maps, but rather, one type of visualization leads to another. For example snow cover is portrayed according to forecasted predictions of snowfall. The 3D analysis (using a DEM) of where snow will fall, leads to the creation of a 4D scene that can be viewed in a virtual reality theatre with a near-reality dramatic effect.

With perhaps the exception of spatial visualization for communicating about climate change, planning has focused on conveying scenes as images at the site scale, whereas fields such as environmental planning and management have more frequently addressed the topic of cartographic visualization at area-wide regional scale. This is particularly true for visualization of the marine environment (Smith and Brennan, 2012; Alain, 2011) where often low-resolution will suffice (e.g., He et al., 2010; Alexander et al., 2012). There is much to be gained by bringing research on the visualization in environmental planning and marine planning closer together and integrating both cartographic visualization and land and seascapes (Mayer, 2012). Such integration could also encourage visualizations that cross landscape units so that both terrestrial and marine environments are viewed together (See Fig. 3).

4. Visualization applied to oceans and coasts

Even though familiarity with the ocean and the changing nature of its resources has been so essential to the fate of human populations, it has often remained beyond serious scrutiny. In the past, sentiments often prevailed in face of facts (Airame et al., 2010). Henry David Thoreau noted in the 1850s during a visit to Cape Cod, "We do not associate the idea of antiquity with the ocean, nor wonder how it looked a thousand years ago, for it was equally wide and unfathomable always" (Bolster, 2012).

The lack of understanding, knowledge and data about the oceans is almost always described among the differences between terrestrial and marine environments. The terrestrial environment is much easier to access and more familiar to the general public than is the marine environment (Agardy, 2000; Hynes et al., 2014). Therefore levels of public knowledge and informed-ness about the oceans are of concern to those working on marine planning (Smith and Brennan, 2012; Potts et al., 2011). Knowledge is vital for developing an individual's perception of ocean and coasts and the resources they provide and it is a key component in the development of effective policies (Steel et al., 2005). Furthermore, while the planning and management of visualization could be fast and convenient, database development to feed models (see Fig. 5 below) can be complex, time-consuming, expensive and the integrative use of data is not easy (de Jonge, 2007).

A report on research recently conducted in Europe on the public perceptions of the seas – FP7 Project KnowSeas – describes coastal communities as being on the 'front line' in terms of impacts from the implementation of marine spatial planning and conservation measures. A survey conducted among 7000 individuals in seven European coastal countries concluded that while the public generally recognizes the importance of the marine environment, the overall effectiveness of scientific communication of marine environmental issues requires further investment (Potts et al., 2011). Other reports (European Commission & DG Mare, 2012; U.S. Commission on Ocean Policy, 2004; Pew Oceans Commission, 2003) have come to similar conclusions as mentioned below.

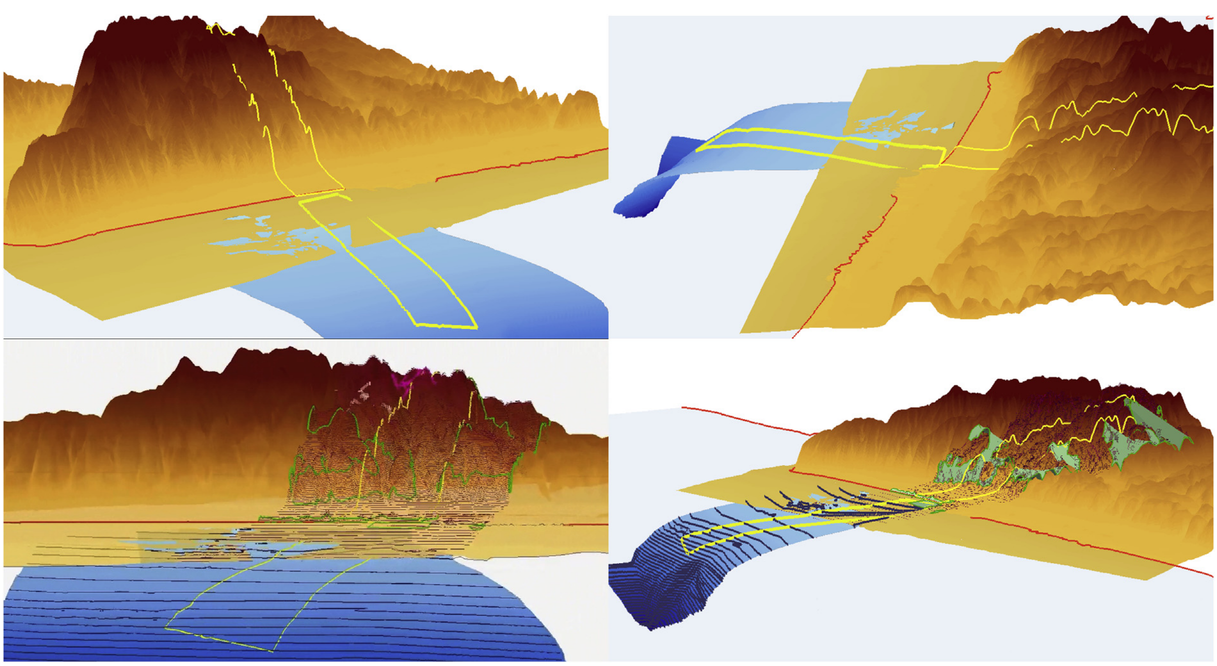


Fig. 3. ArcScene (ESRI)-generated 3D visualization options. The four images portray different perspectives and various layers of information including terrestrial-coastal topography (isolines) and marine bathymetry (isobaths). The areas of interest is indicated as a transect depicted by the yellow lines crossing terrestrial-coastal-marine land and seascapes.

The distinction between the cartographic visualization of ocean and coastal data and scenes created to promote environmental engagement for activism on environmental issues, e.g., climate change (Shaw et al., 2009) or pollution prevention (Peeples, 2013), is a crucial one. Environmental communication research has leaned towards the latter with all its socio-cultural epistemology, whereas the former category tends towards research on best practices for conveying data. Landscape assessment and preference research has made some inroads by bringing GIS-modelling to bear on visual representations of the environment (Lange and Bishop, 2001). But despite its importance, there is a lack of the use of underwater scenes for conveying information in a science-policy context.

In regards to cartographic visualization, data collected from marine observation projects and outcomes of marine modeling are often too abstract to intuitively represent marine characteristics to the general public. Data from several long standing sensor arrays such as weather stations, seismic monitoring networks, sea-level gauges and a host of satellite sensor programs are supplemented by data from numerous smaller scale networks that incorporate both fixed and mobile sensors. This growing volume of data is multi-dimensional and heterogeneous with complex spatial and temporal regimes and multiple variables. For example, the Gulf of Maine Ocean Observing System (GoMOOS) has one of the longest continuous data records of complex, high dimensional data. The GoMOOS array includes data buoys spatially distributed around the gulf that collect and report meteorological and oceanographic variables hourly from multiple depths (http://gyre.umeoce.maine.edu/ or www.gomoos.org). Surface and near surface measurements are added to subsurface measurements that include water column current profiles, temperature, salinity, ocean color, multi-wavelength light attenuation, light scattering, chlorophyll florescence, and dissolved oxygen. Marine planning efforts invariably use data provided by these types of remote sensing initiatives although for visual portrayal of these data there are often issues related to scale in addition to complexity (Smith and Brennan, 2012).

Researchers in the field of communication contend that processing of these data towards useful and accessible visual information should be one of the main interests of the global marine field (He et al., 2010). Oceanographic processes always occur in a 3D space with features such as boundary uncertainty, time-spatial unity and dynamic tendencies that complicate visual applications (Agardy, 2000). As a case in point, as of the writing of this article, SeaSketch (formerly MarineMap), a GIS platform for interactive and collaborative ocean planning, does not yet provide users with 3D visualization capabilities.

Significant advances made in detection and observation technologies add knowledge, but they also add drama. These models and representations based on models can and should be used to raise awareness of marine and coastal issues of concern. As a case in point, the 2006 documentary movie about climate change *An Inconvenient Truth*, featuring former US Vice President Al Gore showed the effects of water covering much of Manhattan and the state of Florida as a result of sea level rise caused by future climate change. Whether or not this reflects fact or predictions of worse case scenarios that may never come to pass, the drama created by the scenes depicted based on climate-change models is palpable. There is much to be learned by planners from researchers working on visualization of climate change, much of which involves infusing maps and simulated scenes of coastal change effects (Sheppard, 2012).

As for deep ocean applications, advanced spatial visualization techniques have not effectively dealt with the importance of the third (depth) dimension, although there are some recent advances in this area (see Mayer, 2012). In many instances 4D (time) is dealt with before 3D, such as evidenced in the example of simulated flooding in the Al Gore movie. Even 3D maps and depictions are often viewed two-dimensionally. Prohibitively expensive stereoscopic glasses are required in a virtual-reality theatre setting with special software to view 3D maps and scenes in true 3D. However, new screens are under development which will make the use of special glasses obsolete.

Although landscape preference assessments have rarely been applied to the complex marine environment, they have been applied to coasts, usually beaches (Ergin et al., 2006; Phillips et al., 2010). These studies have been quite good at developing indicators for scenic evaluation which may be particularly helpful for planning approaches such as ecosystem-based management and decision-making incorporating ecosystem service assessment. Despite the lack of progress on environmental representation of seascapes, a marine spatial planning stakeholder analysis survey conducted in US states and regions found visualization to be a highly desired component of the planning process with the term "visualization" appearing frequently throughout the report (Eastern Research Group Inc, 2010).

The concern for visual representation for marine planning purposes is quite new. A critical view of mapping techniques for purposes of marine spatial planning is presented by Smith and Brennan (2012) who raise issues about the inherent reliability of the maps being created by the marine planning process in Scotland. The authors point out that the marine maps used not only represent reality but *produce* it. They draw attention to the fact that GIS, depended on for informing the management of marine areas, is susceptible to creativity and selectivity. However, this research fails to point out unique characteristics of marine spatial mapping or imaging. The authors' findings apply to terrestrial mapping just as much as they apply to marine and coastal situations.

Perhaps a more interesting example is that researching an ongoing collaboration that articulates fishermen's way of knowing the marine environment (Alexander et al., 2012). This is a good example of how traditional ecological knowledge can be incorporated during a spatial planning process through the use of advanced tools of visual communication, in this case touch tablets. Such collaboration approximates visual research conducted that infuses the use of virtual reality to understand environmental—cultural interaction (see Wagner, 2011).

The generic process for developing visualizations (See Fig. 4) includes data collection, the use of models, the purveying of the results of models as images (combining hardware and software mechanisms), and finally user-interaction with the system. However, it should be clear that this is an iterative process meaning that user interactions will both influence, and be influenced by, methods of visualization.

5. Ocean and coastal visualization for diverse audiences

Both visual images (scenes) and cartographic visualization of marine environments are areas needing more research; more work needs to be done on infusing the two types of media. Research on integrating these two types of media could bring about much better visualization for environmental planning which needs good solid information, well conveyed and accessible to both the public and decisions makers, especially for hard to access fragile and imperiled environments, such as most of the globe's oceans and coastal areas.

In addition to dilemmas about *what* techniques to use for visualizing geographic data with maps combined with imagery of place, planners are often faced with the questions about *what* to present. Despite what appears above lamenting the shortcoming in visualization of all four dimensions of ocean data, there is much available (Airame et al., 2010). Planners themselves must contend with a type of information explosion. The remainder of this review

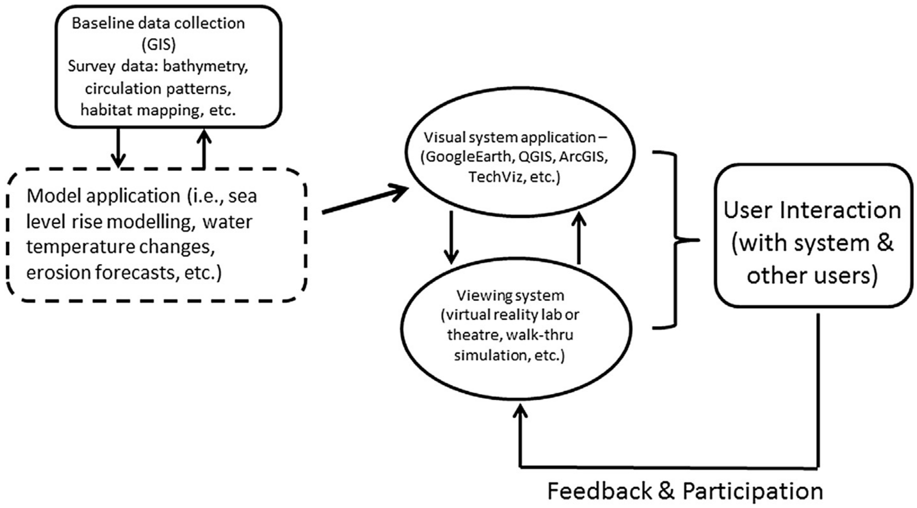


Fig. 4. A work flow to achieve the goal of visualization for coastal and ocean planning and management.

addresses points raised in the literature regarding different audiences, usually consisting of either the stakeholders (the public) or policy makers. The distinction is followed by a brief description of advanced visualization techniques applied for marine and coastal planning.

5.1. Visualization for communicating with the public

A decade ago, the Pew Oceans Commission published a report entitled *America's Living Oceans: Charting a Course for Sea Change*. The report called for "a new era of ocean literacy that links people to the marine environment" (Pew Oceans Commission, 2003). The Commission, charged with proposing new approaches and actions to counter deteriorating conditions in US ocean waters, concluded that there is a "need to provide the public with understandable information about the structure and functioning of coastal and marine ecosystems, how ecosystems affect daily lives, and how we affect ecosystems." Similarly, the Report of the US Commission on Ocean Policy detailing the deteriorating condition of the US coastal waters states: "To successfully address complex ocean- and coastal-related issues, balance the use and conservation of marine resources, and realize future benefits of the ocean, an interested, engaged public is essential" (U.S. Commission on Ocean Policy, 2004).

More recently the European Community's Blue Growth project report "Scenarios and Drivers for Sustainable Growth from the Oceans, Seas and Coasts" (European Commission & DG Mare, 2012)[2] consistently includes public engagement as an integral part of all possible scenarios analyzed. The language used in this report emphasizes the importance of the concepts "public opinion", "public acceptance" and "public conviction". Real progress in achieving public acceptance and conviction cannot be obtained without understanding (and influencing) public opinion and this cannot be done without good channels of communication (Airame et al., 2010).

Nearly all members of the general public are either directly or indirectly involved in activities and behaviors that place ocean and coastal areas at risk. Therefore it is important to assess the scope and depth of policy-relevant knowledge among the public and to learn where people tend to acquire their information about oceans and coasts.

Seminal research on the topic of public knowledge about ocean policy issues was conducted by Steel et al. (2005). This research on "ocean literacy" investigated levels of public knowledge and informed-ness concerning oceans. Using data gathered from a national random sample of over 1200 citizens, two hypotheses—trans-situational and situation-specific—were examined as explanations of public knowledge levels concerning ocean policy issues. The trans-situational hypothesis evaluates socioeconomic status (SES) as an explanation for levels of knowledge. The situation-specific hypothesis evaluates personal experiences and contexts that might overcome SES characteristics. Interestingly, the authors reported that newspapers and the internet are likely to improve citizen knowledge on ocean issues, while dependence on television and radio as the main channels of communication were found to be less effective (Steel et al., 2005). This likely has connections to visual communication theories and requires more investigation.

Other more general studies based on surveys of public perceptions have found that the difference between the public and scientific perception of the main threats to the marine environment suggest that better communication is needed between the relevant authorities conducting planning efforts and the general public (e.g., Hynes et al., 2014). Other than conventional sources of information (i.e. newspapers, radio, television), the public learns about ocean and coasts from personal experience, such as first-hand visitation or museum displays and movies. Such communications may be less agenda-driven than scientist–scientist communication or scientist-to-policy maker communication (Potts et al., 2011) and could also make significant contributions.

The coastal area is one that is well known for its propensity toward conflicts between user groups and a frequently contentious user base (Portman et al., 2012). Getting conflicting user groups to come together can be impractical or impossible. Often the basic task of identifying the relevant stakeholders and convincing them to take part in a public process can be complex (St. Martin and Hall-Arber, 2008; Portman, 2007). Engaging hard-to-reach sectors of the public in planning initiatives can be challenging due to various types of barriers ranging from physical (such as difficulty in attending public hearings) to technical (e.g., difficulty understanding what is being said due to language issues or using the internet and computers as is often the case with elderly or very young populations).

[2] This report builds on earlier policy initiatives to recognize the contribution of marine and coastal resources in realizing the Europe 2020 strategy towards sustainable growth.

There are many tools that planners can use to facilitate public involvement in marine and coastal planning and management. Researched-based guidance exists to involve the public in scoping for impacts of marine development (see Portman, 2009), in the planning of marine protected areas (Airame et al., 2010) and for using participatory GIS (known as PPGIS or PGIS) to solicit socio-economic data (see St. Martin and Hall-Arber, 2008). These activities may revolve around data generation, data presentation or actual decision-making, and will benefit greatly from the use of advanced visualization techniques as described below.

5.2. Visualization for communicating with policymakers

As mentioned, communication of knowledge between the scientific and management communities can be a difficult process (Hynes et al., 2014; Airame et al., 2010). Common tools used by planners are those that construct the future and include projections and forecasts derived from baseline (usually scientific) data. A projection is not a prediction but rather the result of entering hypothetical assumptions into a mechanistic quantitative procedure. A forecast represents a best guess about the future, achieved by adding judgment about the most likely future behaviors and other assumptions. Part of the judgment required includes decision-making about the quality of input data, the type of analytical model needed to provide the most realistic results, and the type of planning being conducted (i.e., rational comprehensive, incremental, adaptive etc. (see Portman et al., 2013)).

Standard methods for constructing projections used for rational planning, such as the cohort-component method of population projection or trip generation models in transportation are accounting systems that rely on hypothetical assumptions (Myers and Kitsuse, 2000). Accuracy of baseline data is an essential issue to get projections right. Spatial information databases are needed with improved visualization capabilities, both for charts and in 3D to help the planner make decisions on data accuracy. For example, accurate transitions must be made by combining surface imagery from airborne or satellite mapping with precise underwater mapping from sonars and bathymetry charts (Alain, 2011; Mayer, 2012).

By contrast, advocacy planners may be involved in drawing attention to the need for policy change through the use of a focusing event as an agenda-setting mechanism. Agenda setting is the collection of activities engaged in to direct the attention of public officials toward a particular problem and it can benefit greatly from visualization. An interesting case in point is the use of a method called Rapid Assessment Visual Expedition (RAVE). In the summer of 2010, the International League of Conservation Photographers (iLCP) and the Chesapeake Bay Foundation (CBF) combined forces and used a RAVE to draw attention to the environmental issues surrounding the Chesapeake Bay watershed (see Schwarz, 2013). In a short period of time, advocates for the bay enlisted the services of expert photographers to generate images that were used as communication tools. The event in itself brought policy-makers to acknowledge the importance of the controversial Chesapeake Bay Clean Water and Ecosystem Restoration Act.

The general public has been gaining in importance also as producers of visualization materials, through providers such as Google Earth (Lange, 2011) or through citizen science initiatives. An interesting case of citizen science for which information collected by the public and later used by policy makers for marine planning of tidal energy infrastructure took place around the Mull in Kintyre (see Alexander et al., 2012). The planner's role may be that of gate keeper, weeding through visualized material (cartographic or photographic) to provide to policy-makers. Both community members and policy makers should be considered when preparing user cases as described in the next section and as illustrated in Fig. 5.

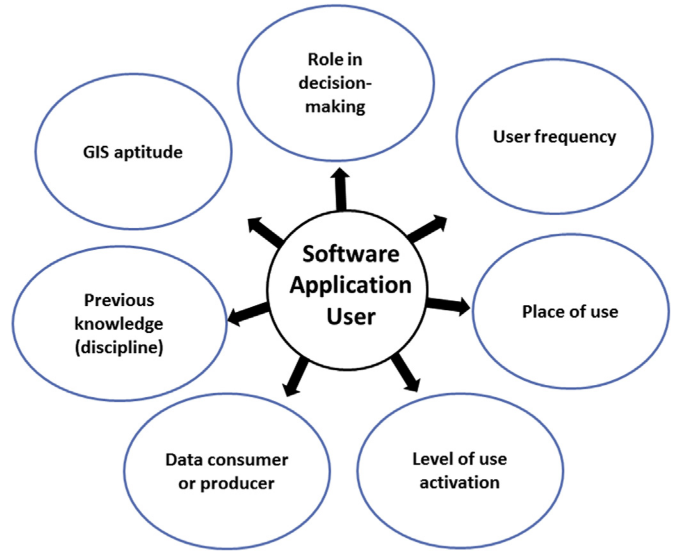


Fig. 5. User cases address all these factors and can lead to successful PGIS which can in turn, lead to better information and data, (e.g. through citizen science) and greater participation in decision making.

6. Advanced visualization tools

Visual methods should make the information available and interpretable to a variety of audiences and should be suitable to the planning and management tasks at hand. Advanced visualization techniques gaining ground in recent years for coastal and ocean planning include web-based GIS platforms (e.g., interactive decision support tools) and immersion and reality theatre (e.g., IMAX 360° screens and high-resolution sound systems). These systems are at the cutting edge of efforts to link between environmental conditions, proposed development through marine planning and coastal zone management initiatives.

6.1. Advanced GIS

Web-based systems, or what is considered software as a service (SaaS)[3] are being tailored to planning initiatives. They can allow anyone with a web-browser to actively participate in marine and coastal planning efforts. These applications use GIS and they are becoming more participatory, intuitive and user-friendly all the time.

Some of these services are quite basic; they simply allow "layers" of information to be uploaded and displayed. By turning layers "on" or "off" these systems are used to inform users about what exists where. On-line images show the geographic location of marine and coastal infrastructure, use areas, environmental conditions, and proposed locational boundaries. Other applications are more complex; they apply algorithms that consider preferences, weights or chosen measures of efficiency, expressed as costs. By processing information taken from GIS layers, a recommended option or group of options is arrived at.

An example of the first type of application, used for collaborative planning design is SeaSketch. It allows users to (1) initiate a project

[3] Sometimes referred to as "on-demand software", SaaS is a software delivery mode in which software associated data are centrally hosted on the cloud (internet).

by defining a study region, (2) upload map layers from existing web services, (3) define “sketch classes” such as prospective marine protected areas, transportation zones or renewable energy sites, (4) create sketches and receive automated feedback on those designs, such as the potential economic impacts of a marine protected area, and (5) share sketches and discuss them with other users in a map-based chat forum.

Other examples of more complex decision support tools that can be used for planning are MARXAN with ZONES and ZONATION. These have been frequently applied to marine and coastal environments, mostly with the goal of balancing conservation with development (Leathwick et al., 2008; Stewart et al., 2007). Zonation offers the use of a number of algorithms based on what is considered a step-wise heuristic. Its meta-algorithm starts from the full landscape and iteratively removes those areas (cells in a grid) whose loss causes the smallest marginal loss in the overall conservation value. MARXAN uses stochastic optimisation routines (i.e., spatially explicit simulated annealing) to generate spatial reserve systems that achieve particular biodiversity representation goals with reasonable optimality.

In choosing the type of application to use, whether to use existing software or develop an application depends on the resources available and the ultimate goals of a planning process or management approach. If public participation is very important, then it would be wise to carefully weigh options starting with an exercise that identifies all possible users and their needs. This can be done by carefully researching current existing options, as these are continuously evolving, and devising a set of “user cases” (Jacobson, 2004). User cases are frequently employed for graphic user interface design of software applications. User cases answer questions such as illustrated in Fig. 5 for each potential user or user group.

6.2. Reality-theatre

Visualization techniques have been used in planning first through the use of physical models, and later through drawing and painting. Initially perspective drawings were used. These evolved into before and after replications based in real-world views. Analog photomontage and then digital photomontage became the next generation (Lange and Bishop 2001). Now virtual environments have the potential to become cutting-edge tools for simulating land and seascapes. This can involve using theatre-like laboratories and technologies. An advantage of visualization techniques, such as virtual reality that includes 3D and interactive viewing, is that environments that don't yet exist or are inaccessible, can be reached virtually. That is particularly true for the marine environment where physically being present in a submarine location is often either too expensive or impractical for other reasons.

Whereas audiences will often forget information they see in graphs, what they come closer to really experiencing through visualization techniques may be ‘unforgettable”. Multi-media (e.g., sound and physical changes that affect viewing experience) scene simulation that includes virtual reality and immersion theatre can be connected to spatial and temporal display of maps and even data set presentation.

In a book on visual research methods, Wagner (2011) contends that in their potential to link cultural ideas, socio-economics and material things through visual representation and touch-based interaction, virtual reality environments have engendered changes in how we understand the world. Examples are the common experience of “visiting” websites, writing on virtual “walls”, or “talking” within someone through on-line chat, so commonplace that they have changed our definition of reality. Similarly, virtual and augmented reality technologies are increasingly being used for research, education and soliciting feedback from the public in the planning context.

A pertinent example of the use of virtual reality for educating the public about marine environments is the Deep Sea Extreme Environment Pilot (DEEP). Educators at the Scripps Institute of Oceanography developed this interactive freely downloadable game to inspire and inform about sea exploration through the operation of remote operated vehicle (ROV) on a virtual sea floor (see http://siogames.ucsd.edu/deep.html). Although the target audience for its creation was middle school pupils, it will reach the public-at-large through its use in museums, science centers and aquariums. *Science* magazine awarded the game honorable mention in its 2013 Science and Engineering Visualization Contest for the game's high quality realistic visual attributes (reported in February 7, 2014 edition of *Science*).

7. Conclusions

This review has covered some of the methods and tools available to environmental planners and managers working on oceans and coasts. It focuses on crossing the science-policy divide. After all, integrating science and policy is one of the main challenges to both efforts of integrated coastal zone management and marine spatial planning. Some would say that planners have a moral obligation to communicate both to the public and to policy-makers choices regarding the marine and coastal environment that they affect and that they are affected by. Visualization in this context can be about influencing minds and sometimes changing behaviors, as is most environmental planning and management. In order to be effective, change behaviors or inform decision making, planners must influence perceptions based on what they know about the environment and others have yet to learn.

At the same time though, planners need to solicit response from the public, who often know much more than the planners themselves about a given situation or environment. To do so requires more than just transferring information through visualization to the viewers. It demands maintaining the use of best practices, the latest technologies appropriate to the context in terms of available resources and viewer capacities, as well as the maintenance of certain standards. There is much available research to draw on of course, and much of it from work done on terrestrial environments. The submerged environment has particular challenges and therefore more research is needed, however, by drawing on other fields such as landscape architecture and planning, cartography, conservation planning, and even systems analysis (e.g., user cases) the emerging field of visualization for oceans and coasts can best be served.

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