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BUILDING A MARINE CADASTRAL INFORMATION SYSTEM FOR THE UNITED STATES – A CASE STUDY[1]

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Abstract

Depleted marine resources and increased threats by man-made pollutants are forcing many countries to increase law enforcement and begin offshore planning. Accurate, useable, and accessible digital boundaries, with defined territorial claims, are becoming essential for daily business in the ocean. The term cadastre has not often been used in the context of the marine environment, though many (and some may argue all) of the cadastral components such as adjudication, survey, and owner rights have a parallel condition in the ocean. This paper discusses some of the framework issues that must be considered in the development of marine cadastral data and the use of these data in a marine information system for the United States. The unique features of coastal and marine data, the policy framework that surrounds the development of these data, and the implications to state[2], national, and international policy are discussed. In addition, a specific case study, the Ocean Planning Information System is outlined as a "real world" application where these cadastral data have been applied toward integrated ocean planning and governance.

Introduction

The world's oceans cover approximately two-thirds of the earth's surface. Traditionally, ocean tenure has been held by the country with the largest naval fleet and the desire to control and/or use "its" coastal waters. The sense of nationalism to secure or extend domain has stimulated a series of claims, dividing the ocean, the living marine resources within, and sand and mineral resources in the seafloor (U.S. Department of State, 1969). Technological advances in mapping, such as the Global Positioning System (GPS), geographic information systems (GIS), and electronic charting display information systems (ECDIS) have enhanced and complicated the

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[1] **This paper is intended as a reference and should not be considered an official position of the United States Government.**
[2] **In this context, the term "state" refers to the individual coastal state that is a separate governing entity within the United States of America. The case study uses the individual states of North Carolina, South Carolina, Georgia, and Florida.**

development of ocean boundaries to delimit these claims. Today, mariners have the capability for precise positioning, causing the days of dead reckoning and paper navigation charts to become ancient history. Advances in mining technology have increased the commercial viability of offshore mineral extraction, which in turn has increased the pressure for accurate seafloor mapping. In the past, the majority of the mining was for oil, gas, and sulfur. Now offshore sand for beach renourishment projects has become a high demand resource. Depleted marine resources and increased threats by man-made pollutants are forcing many countries to increase law enforcement and begin comprehensive planning in the offshore environment. As a result, the need for accurate, useable, and accessible digital marine boundaries, defining territorial claims, is unprecedented for business in today's ocean.

Cadastre for the Marine Environment: The term cadastre has not often been used in the context of the marine environment. There are many similarities, but a few significant differences, between a marine and land cadastre. Many of the upland cadastral components such as adjudication, survey, and owner rights have a parallel condition in the ocean. These boundaries share a common element with their land-based counterparts in that in order to map a boundary, one must adequately interpret the language of the law and its spatial context. Other typical cadastral processes such as demarcation become problematic when applied to marine boundaries. Marine boundaries are delimited, not demarcated, and generally there is no physical evidence, only mathematical evidence left behind (Carrera, 1999). Physical evidence of upland boundaries, such as monuments, pins, hedgerows, or fences are not always practicable in the marine environment.

Because many maritime boundaries are described as lying a specific distance from the 'coast,' one of the most significant issues with respect to creating a marine cadastre is the mapping of the shoreline. The shoreline is a dynamic feature and the ability to establish its precise location, at any given point in time, may be technically possible, but the costs are generally large when applied to more expansive coastlines such as those in the U.S. Although the land-water interface may also affect waterfront property and the establishment of private property rights, this discussion will focus on its implications for offshore cadastral mapping.

Background

Tidal Datums: When mapping in areas affected by tidal fluctuation, the tidal datum, the base elevation defined by a certain tide phase, must be known, yet is often overlooked. Relevant tidal datums in the United States are mean higher high water (MHHW), mean high water (MHW), mean low water (MLW), mean lower low water (MLLW), or mean sea level (MSL) as depicted in Figure 1 (Shalowitz, 1964). Each land/water interface at the relative datum references a significantly different height. Knowing the location of these lines can be critical in determining the boundaries between international, national, state, and private rights. Tidal influences in this zone make mapping extremely complex and only accurate if this tidal fluctuation is taken into account. Tidal ranges between low and high water can vary from virtually zero change to over 50 feet in areas such as the Bay of Fundy, Canada. Tidal arrival times can also vary greatly from one location to another (e.g., front of an island vs. back of an island), thereby complicating shoreline mapping efforts. To achieve the maximum accuracy in tidal prediction, a series of continuous observations at one location for 18.6 years is required. Within this number of years, all significant astronomical modifications to the tides will have occurred. For practical reasons, the U.S. government maintains a tidal prediction control network of 140 permanent tide gauges and supplemental secondary temporary gauges, where needed. Tidal scientists use the control network data and other known ancillary information to predict tidal ranges and times. In addition to tidal influences, other elements complicate mapping in the coastal and ocean region. Hydrologic forces (e.g., weather, erosion) along the coastline cause many parts of this region to be extremely dynamic. Depending on the region, tidal influences exacerbated by extreme weather can make an accurate coastal survey quickly obsolete.

Historical Perspective: Understanding the nature of an offshore cadastre is not possible without a brief look back on how the process evolved. In this context, U.S. law (and also some international law) can be traced back to 6th century Roman civil law that stated that the sea and the shores of the sea were to be held as common areas. Following the Magna Carta, much of the Roman law was adopted by English common law, and certain submerged lands were held in "public trust by the king for the benefit of all English subjects." These basic principles have survived the American Revolution, and with slight modifications have become the basis of U.S. property law in the marine environment. (Reed, 2000; The Coastal State Organization, 1997). This body of law and its practice is often referred to as the Public Trust Doctrine, and these lands are often referred to as public trust lands. These may include: navigable lakes and rivers as well as the coastal belt between mean high and mean low water lines (i.e., the beach). In the U.S., the issue of states' rights further complicates the delineation of public trust lands. As a result, there are many different state interpretations of what constitutes public trust lands.

Who Has Jurisdiction – From The Land To The Open Water?

State Claims: Generally under U.S. law, upland private ownership extends to the MHW line. In some states, however, private rights will only extend to MHHW (e.g., Texas) or in some cases down to the MLW (e.g., Delaware) line. The selection of these seaward boundaries (tidal datums) has a relationship to when the individual states entered the Union (United States of America). Seaward of this line are the public trust lands that are managed by the state or federal government. In most cases, the individual coastal state has control of the sea bottom and marine resources from mean high water out to the state's seaward boundary (i.e., Submerged Land's Act boundary) at 3 nautical miles from the coast line (43 U.S.C. § 1312, unless reserved by the federal government, § 1313). As described in the United Nations Convention on the Law of the Sea (UNCLOS), the federal government has sovereign rights over all living and nonliving resources out to the extent of the continental shelf and exclusive economic zone (EEZ). Like many laws, there are exceptions to the rules. In some states and commonwealths (e.g., Texas, Puerto Rico, Gulf coast of Florida) the state has jurisdiction over the natural resources out to 3 marine leagues (9 nautical miles). Within this area, states have the authority to manage, administer, lease, develop, and use the natural resources of the ocean; and the federal government retains control over commerce, navigation, defence, fisheries[3], and international matters. There are also other special managed areas such as marine protected areas that can overlap both state and federal waters. See Figure 1.

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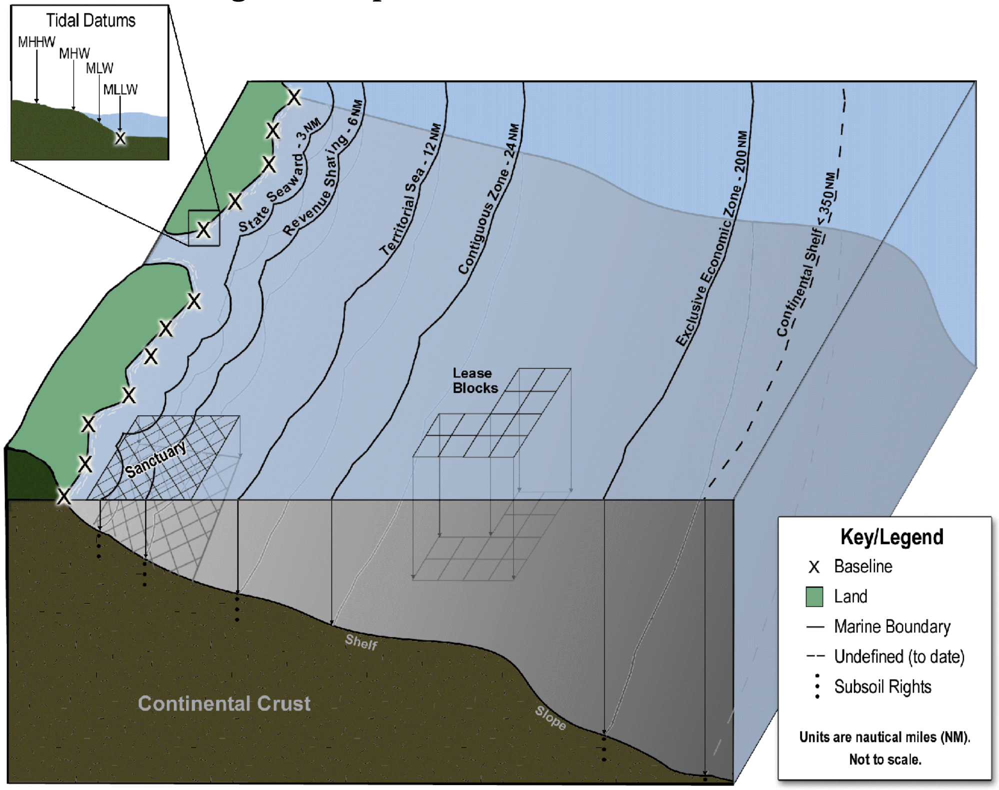
[3] The Magnuson Act gives the states primary responsibility over fisheries within the state seaward boundary, with a federal override if conservation needs are not being met.

Figure 1: Depiction of Marine Boundaries



<u>Boundary Explanations</u>

Tidal Datums – Mean Higher High Water (MHHW), Mean High Water (MHW), Mean Low Water (MLW), and Mean Lower Low Water (MLLW) are examples of tidal datums (i.e., vertical datums defined by a phase of the tide). Mean Sea Level (MSL) is the average height of the sea for all stages of the tide over a 19 year period (Shalowitz, 1964). In the U.S., the MLLW is the baseline from which several seaward boundaries are measured.

Baseline – The Xs represent the salient points of the baseline (MLLW) used in the calculation of the offshore boundaries. The straight portion, across the bay, is a closing line used to separate inland water bodies from the open sea and is also used in the calculation of the offshore boundaries.

Sanctuary – National Marine Sanctuaries, and other marine protected areas, often transcend federal and state jurisdictional boundaries, and may extend to the seafloor and subsoil resources.

State Seaward – Limit is generally situated 3 nautical miles from the baseline, although several U.S. states and commonwealth boundaries extend to 9 nautical miles. This limit may be fixed by a Supreme Court decree for Submerged Lands Act purposes. May be referred to as the Submerged Lands Act boundary, federal/state boundary, or the natural resources boundary.

Revenue Sharing – Zone extends 3 nautical miles beyond the state seaward limit. Also referred to as the Limit of the "8(g) Zone".

Territorial Sea – Extends 12 nautical miles from the baseline.

Contiguous Zone – In the U.S., this zone begins at the seaward limit of the territorial seal and extends seaward 24 nautical miles from the baseline (Presidential Executive Order on September 2, 1999).

Lease Blocks – Units that define subdivisions of the outer continental shelf within U.S. jurisdiction for the purpose of mineral leasing.

Exclusive Economic Zone – Extends from the seaward limit of the territorial sea to 200 nautical miles beyond the baseline from which the territorial sea is measured, or to a maritime boundary agreed upon by international treaty.

Continental Shelf – Limit not yet claimed by the U.S. Refer to Article 76 of the United Nations Convention on the Law of the Sea for delimitation criteria.

Moving offshore, another layer of shared rights is added with Section 8(g) of the Outer Continental Shelf Lands Act (43 U.S.C. § 1337(g)). This act states that 27 percent of all revenues from offshore lease production within 3 nautical miles beyond the state's seaward (i.e., Submerged Lands Act) boundary be given to the states. In many states, the accurate definition of this line has not been an issue, because the exploitation of offshore gas and oil has not been commercially viable. Nevertheless, in some cases, the financial consequences of the location of the boundary can be immense. As an example, in a case often referred to as Dinkum Sands, the federal government and the State of Alaska both claimed rights to offshore revenues (No. 84 Original, U.S. v. Alaska). This case resulted in 17 years of legal action for the Supreme Court to establish the right of the federal government to $1.6 billion dollars of oil and gas revenues. Similar Supreme court litigation has occurred with all 23 U.S. coastal states with the only exceptions being Washington, Oregon, and Hawaii. One can begin to see the complex nature of the multi-layered legal framework of state and federal tenure pertaining to the offshore environment and the importance of marine cadastre.

BiLateral Boundaries: Bilateral boundaries are boundaries between adjacent states extending from the shore to their seaward boundary or boundaries between adjacent nations (Shalowitz, 1962). Mirroring international maritime boundary negotiations, there have been considerable legal disputes in the U.S. concerning the determination of the lateral boundaries between the different U.S. entities. Disputes have historically escalated as boundary claims extend further offshore. This is because the extensive offshore claims create more opportunities for overlapping boundaries (Christie, 1994). Generally, internal U.S. marine boundary cases between states are settled by the U.S. Supreme Court and have been mostly driven by economic concerns. In many situations, boundaries have not been adjudicated and no precise boundary exists. An example of this is state lateral marine boundaries. Most land boundaries between adjacent states have long been resolved. In the case of marine lateral boundaries, the Texas/Louisiana, the South Carolina/Georgia, and the Maine/New Hampshire lateral boundaries have been judicially determined (Reed, 2000). Generally, the Supreme Court follows international practice in determining lateral boundaries and looks for equity through the use of equidistant median lines. The development of medial lines by application of the principle of equidistance is beyond the scope of this paper (see Shalowitz, 1962; International Hydrographic Organization. 1993). Resolved international lateral boundaries are few and follow a different path of resolution, often ending up in the International Court of Justice, and are well beyond the scope of this paper. When the U.S. extended its claim to the 200 nautical mile EEZ, this claim involved approximately three million square miles of ocean and created over 25 overlapping lateral boundaries (Christie, 1994). Generally, the U.S. and its neighbours have resolved boundaries peacefully and many bilateral treaties are in place to this effect, but there are still many unresolved boundaries. As is always the case when one tries to apply a mathematical solution to the intricate geographic nature of coastline configurations, the issues are never straightforward and make for interesting outcomes.

Federal Waters: Beyond a U.S. coastal state's seaward limit (3 or 9 nautical miles), international law and practice take effect, as specified by UNCLOS. To date, the U.S. has signed but not ratified the UNCLOS, but recognises the articles and generally abides by them. In 1988, U.S. President Reagan signed Presidential Proclamation 5928, which claimed a 12-nautical-mile territorial sea for the U.S. As established by the UNCLOS, the territorial sea is a belt of ocean that is measured seaward from the baseline of the coastal nation and subject to its sovereignty. This sovereignty also extends to the airspace above and to the seabed and subsoil. In addition to international law, individual coastal states may exert influence over federal activities within the U.S. territorial sea. Historically, a territorial sea was a 3-mile belt around a sovereign state, reflecting the state of technology of the times (distance that a cannon could be shot). A nation can exert exclusive jurisdiction of its territorial sea excepting the rights of innocent passage of foreign vessels.

In addition, under UNCLOS, a nation may claim a contiguous zone, which is an additional 12 nautical miles from the territorial sea. In 1999, U.S. President Clinton extended the U.S. contiguous zone from 12 to 24 nautical miles. This zone allows for an additional area where the sovereign state may enhance law enforcement and public health interests by exercising control over immigration, customs, pollution, and other illegal activities. Extending seaward past the contiguous zone, a nation may claim a fisheries zone for protecting living marine resources, as well as an EEZ that may extend to 200 nautical miles seaward from the shoreline. The EEZ is an area where a nation may extend protection to both living and nonliving resources above and below the seabed, and assert other associated rights as described under UNCLOS.

The next and relatively uncharted area of the sea that a nation may claim is the area of the continental shelf. Under the UNCLOS, Article 76, countries may claim sovereign rights over the continental shelf more than 200 nautical miles, but to do so must submit technical and scientific details of their claims. The data needed to support this claim are quite complex. The continental shelf boundary determination is one area where the geospatial analyses provided by a cadastral information system may be extremely helpful (Palmer and Pruett, 1999). The data necessary to support this extended offshore boundary may include sediment thickness, slope of the seabed, and the precise location of the 2,500 meter isobath. The actual combination of the parameters is beyond the scope of this paper, but one can see that the precise calculation of this boundary requires an extensive spatial analysis. The U.S. has not made a continental shelf claim to date. Very few countries have the resources or the financial incentive to apply the necessary technology to document this claim. One interesting note is that there is a time limit for making this particular claim. Data must be submitted to the Commission on the Limits of the Continental Shelf within ten years of the entry into force of the Law of the Sea Convention, November 16, 1994. This is a fairly short period of time for any country to research and document all the areas associated with an extensive continental shelf.

Technical Mapping Details

Baseline: Except for the state lateral boundaries, most of the aforementioned boundaries are drawn some distance from the baseline[4]. There are a number of internationally accepted low water tidal datums from which to determine the baseline, but in the U.S. the conservative MLLW line is used, as well as closing lines used to separate inland water bodies from the open sea. The baseline is derived from the normal baseline, which follows the sinuosities of the coast. In addition, bay closing lines are used to close off qualifying indentations along the coast, and river closing lines are used to close off the mouths of rivers. A number of rule-based spatial

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[4] Technically, this would be described as projecting the prescribed radius from the baseline.

determinations are used in establishing closing lines and help determine the status of islands and intermittently exposed features fringing the shore (International Hydrographic Organization, 1993). The determination of baselines has and will most likely remain a contentious process, as many nations (and many U.S. coastal states) attempt to claim the maximum allowable area. The term baseline can be a bit misleading because in actual practice it is not a line but a series of points representing the most seaward portions of the coast. Only the most seaward (salient) points affect the location of the offshore boundary. The rules of selecting baseline points and line segments are well beyond the scope of this article and the reader is referred to the UNCLOS documentation for clarification

The baseline itself has no real significance to the boundary delimitation issues under consideration here except that it is the basis for the calculation of most offshore boundaries (e.g., territorial sea, EEZ). The calculation for each of the offshore boundaries is mathematically complex. In the paper chart days, a compass was used to swing an arc from each salient point and create an envelope of arcs that could be joined to create the boundary. Today, computers are able to streamline the process and consider each baseline point and its influence on the solution. As the boundary increases in distance from the baseline, fewer baseline points are needed for the solution. Great care must be taken in developing this solution. A simple buffer on a projected (e.g., Mercator, etc.) map, which is a common operation to most GIS software, is not adequate in this instance and will produce errors. The correct solution must be three-dimensional projection over the earth's ellipsoidal surface (Ball, 1997).

Each point or line segment of a baseline can add enormous significance to the final projected boundary and the resulting regulated area. As an example, an island of the smallest significance can lead to a 3-mile boundary covering over 28 square miles, or an EEZ covering over 125,000 square miles of adjacent ocean and seabed (U.S. Department of State, 1969; Hodgson, 1974). The slight adjustment of a baseline point can result in a large change in the projected area. Another complicating factor is that the baseline, as defined by law, is ambulatory, and therefore most of the offshore boundaries derived from the baseline are ambulatory as well. The exception to this are boundaries fixed by Supreme Court decree for Submerged Lands Act purposes. The practical application of describing these ambulatory boundaries for use in a marine cadastral information system is problematic to say the least.

Potential Errors

The determination of baseline points can be time consuming and expensive. Until recently, baseline determinations and their resulting boundaries were generally portrayed only on paper nautical charts. As stated in the UNCLOS (Article 5), the normal baseline is "the low-water line along the coast as marked on large-scale charts[5] officially recognised by the coastal State [sovereign state]." As discussed earlier this was more than adequate in the pre-GPS, pre-GIS,

[5] In the U.S. the accepted chart is the one produced by the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA), and the tidal datum used is MLLW. The Supreme Court does not consider the line on the chart to be the actual baseline—which could have moved from accretion or erosion since the survey was completed or the chart printed. The Court will allow litigants to prove the actual location of the MLLW line, which will be used as the baseline (Reed 2000).

and pre-ECDIS days. The printed line delineating the outer limit of the territorial sea, on a current state (sovereign state)-approved U.S. 1:80,000 scale nautical chart, has a width of approximately .75 mm. This very small printed line equates to approximately 60 meters on the surface of the earth. This number rises, as the scale of the chart becomes smaller. The "exactness" of the boundary is increasingly becoming an issue as resource limitations force people to "push the envelope" on mineral extraction. There is some discussion within the Law of the Sea and the Commission on the Limits of the Continental Shelf (the Commission) technical documentation that supports the use of data other than charts. "A list of geographical coordinates of points, specifying the geodetic datum" is identified as acceptable documentation in the UNCLOS. Moreover, recognising the state of the technology, the Commission specifically outlines that digital data in any internationally recognised format is acceptable for submission of continental shelf claims (United Nations Commission on the Limits of the Continental Shelf, 1999). There is evidence that the International Court of Justice has accepted GIS in the development and documentation of boundary claims in the context of maritime boundaries (Carrera, 1999). It appears that modern mapping technologies are slowly becoming acknowledged in international marine cadastral applications as necessary tools in the description and enforcement of offshore claims.

The ability to accurately measure a feature must be weighed against the practicality of measuring that feature. In the case of the U.S., it is not feasible to constantly survey an estimated coastline of over 95,000 linear miles for which the majority is constantly changing. Countries with shorter coastlines may well be able to collect GPS coordinates for all baseline points, but currently in the U.S. a more practicable methodology has been constructed by using the official large-scale U.S. nautical chart and digitally selecting salient points from this source. In the case of controversy, additional supporting information can be used to supplement the chart. Such was the case of the recent U.S. and Mexican boundary negotiations as both countries jointly surveyed low water points to accurately determine the equitable maritime boundary (Smith, 1999). In other cases of negotiations between the federal and state governments, video data have been acquired to prove whether an offshore feature is above or below the relevant tidal datum (Thormahlen, 1999).

It is widely recognized that systematic and random errors of some magnitude exist in any mapping of spatial data. The production of offshore boundaries is susceptible to all of the same inaccuracies and possibly more than any land-based spatial data production. Any spatial data or map is an abstraction of reality and only accurate to some intrinsic level. The relationship between the errors within the boundary determination and the technology used to produce them (e.g., measurement software, scale and resolution of data, transformation algorithms, and a host of other parameters) is the subject of much research and is beyond the scope of this paper. One additional wrinkle that a cadastral information system faces is the interpretation of the legal framework, outlined in documents such as UNCLOS, judicial rulings, or the federal statutes and regulations. Many times these interpretations can be quite different between overseeing entities and cause extensive confusion for users of the regulations.

Other Offshore Boundaries: As if the previously described quagmire of jurisdictional rights for boundaries is not complicated enough, there are additional boundaries in the form of special management areas offshore. Examples of these areas include national marine sanctuaries, national parks, and outer continental shelf (OCS) lease blocks to regulate oil, gas, and mineral development. A host of other regulations impart special designations or oversee activities in parts of the U.S. oceans. The existing framework for managing offshore resources is a fragmented and complex system that is often poorly understood. A variety of laws, regulations, programs, and special jurisdictions have evolved over time to protect, develop, and manage ocean resources. Ocean policies and programs, however, have historically been developed and implemented as single-purpose regimes, with little thought to how they would interact with other resource management considerations (National Research Council, 1997). In the U.S. there is an overlapping and hierarchical management structure that increases the complexity.

Many of the ocean issues have a spatial component that can be examined using geospatial analysis in a specialised GIS (i.e., marine cadastral information system). To accomplish this spatial analysis requires defined geography of the boundary or regulation in a form suitable for use in a GIS. Most marine laws and regulations do not generally contain the necessary spatial components to accurately map their extents without some level of ambiguity.

Case Study

In a land-based development of a cadastral information system, the government entity must develop a methodology for georeferencing legal descriptions of property. In many cases, there are no known world coordinates listed on the plat or property description. Integrating thousands of property records is synonymous with putting together a massive jigsaw puzzle. Once completed, the ability to visualise property rights, regulations, laws, and management regimes can assist policy makers in understanding conflicts, revealing inconsistencies in national or state policy, educating or justifying boundary limits to the public, and providing a general organising structure to very complex data. To test this hypothesis in the marine environment, a prototype marine cadastral information system was developed for the southeastern U.S. This project is called the Ocean Planning Information System (OPIS) and is available on the Internet at <http://www.csc.noaa.gov/opis>. NOAA's Coastal Services Center, working with the four states of North Carolina, South Carolina, Georgia, and Florida and other federal partners, has been examining existing boundaries, their spatial accuracy and how these boundaries are used in offshore regulations (See Figure 2). This involved researching the international, federal, and state policy framework in the region and creating geo-regulations, or spatial "footprints" of the geographic area where individual policies apply.

Spatial data within OPIS have been developed utilising Environmental Systems Research Institute's (ESRI®) ARC/INFO® GIS. All regulatory, marine boundary, agency, and environmental data were then integrated using ESRI's ArcView® software. The OPIS Internet mapping application was created using ESRI's MapObjects™ Internet Map Server in conjunction with Visual Basic®, JavaScript, and Hypertext Markup Language (HTML). The entire OPIS Web site consists of over 350 HTML pages describing recent OPIS project activities, bathymetric collection efforts, beach nourishment issues, U.S. ocean policy, spatial data files, case studies, and project partners. Spatial data files supporting OPIS include: dredged material disposal sites, artificial reefs, sand resources, beach nourishment project by county, National Marine Sanctuaries, National Estuary Program sites, data buoys, shoreline, bathymetry, major waterways, outer continental shelf active lease sites, etc. The geospatial capabilities provided by GIS, in conjunction with the boundary or regulation and natural resource data, create a powerful tool for the ocean planning and governance community. Clearly, there is a need to understand the policy quagmire, and geography provides an excellent organising framework for doing just that.

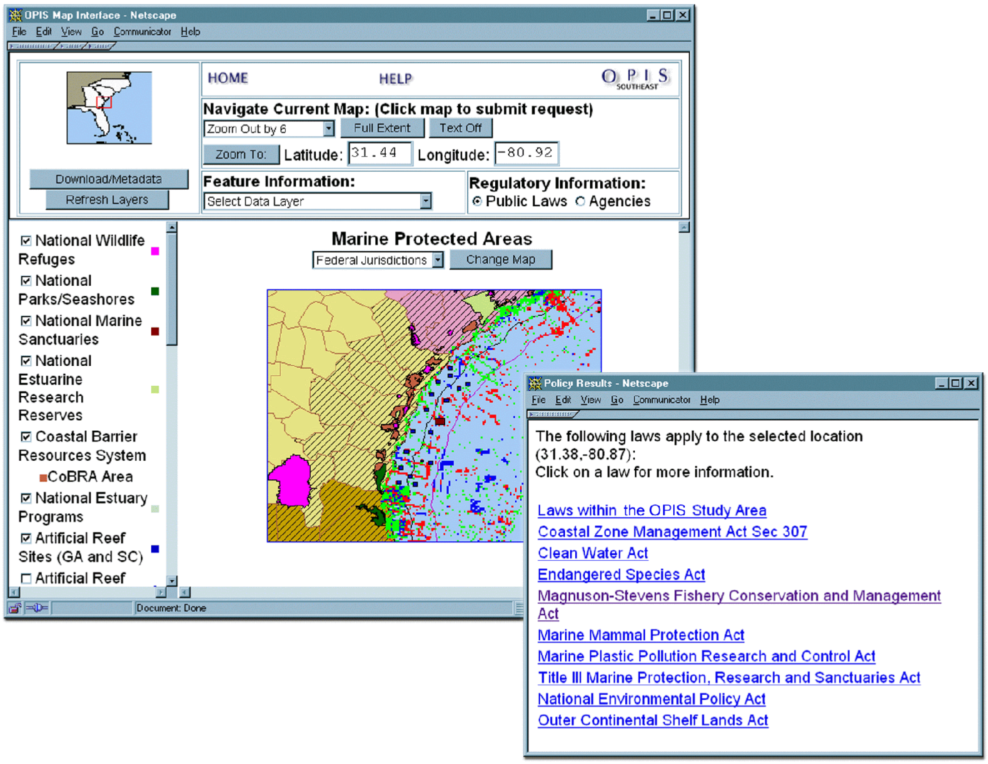

Figure 2 Case Study: Ocean Planning Information System (OPIS): Using the OPIS Internet mapping application (shown here), the user can navigate various maps of the southeastern U.S. coastal ocean, view the marine cadastre and other spatial data, and retrieve marine policy information.

The problem arises when a law or regulation is said to apply within a specific offshore area whose bounds purport to be described in the law. Policy makers and lawyers, not geographers, generally write these laws, and as a result, it is a challenge to accurately capture the geography intended by each individual law. To link the policy with the geography for this case study required a technical and geographic analysis of the regulatory structure that applies to the area. Very few U.S. regulations are written with modern mapping technology in mind. It is not uncommon to find incorrect, imprecise, or inaccurate boundary coordinates published in the *U.S. Code of Federal Regulation*s. Such instances may be the result of simple human error or misinterpretation of ambiguous legal language, or they may be the result of a lack of understanding of mapping principles and technologies. In other cases, there is a lack of understanding of mapping principles and the legal description may not adequately describe the geography, or it may be extremely complicated to develop a mapping solution. As discussed earlier, in a paper cadastral world, many of the inaccuracies associated with mapping a feature are masked by the scale and width of that feature portrayed on the paper map. In GIS, precise coordinates are needed. Many times fundamental cartographic concepts such as scale, resolution, datum, and projection are not considered. Because the digital representation and visualisation of the complex legal framework is necessary, it is essential that those who develop policy understand these important concepts. As a result, the data they develop can be easily integrated into technologies such as GIS, and ambiguities will thereby be minimized.

There are numerous examples of spatial ambiguities in laws and regulations that make mapping difficult. Even when regulations list geographic coordinates (x,y) that should be fairly straightforward, they often forget to list critical information such as the horizontal datum. Many times a boundary will reference a landmark, such as a headland or an ambulatory feature such as the "wash of the waves at high tide." Often times, a marine boundary description will designate a particular isobath (depth contour) and/or a vertical limit (air space above the ocean). In a digital world, where does one obtain this isobath? Should the line be captured from the nautical chart or should the original sounding data be used to calculate the line? If one does generate this contour or isobath from raw data, what algorithm and parameters should be used? The legal language is not easily interpreted for information system purposes and requires the user to be both cartographer and detective.

There are also cases of three-dimensional claims that are difficult to understand, impossible to enforce, and complex to map with the current GIS technology. One of these cases is the NOAA Channel Island National Marine Sanctuary (water) and the U.S. National Park Service (NPS) Channel Islands National Park (land and water). The NPS has exclusive jurisdiction over the islands and shared administration with NOAA and the State of California's Fish and Game Department from mean high tide out to 1 nautical mile. Within the 1 nautical mile area, NPS manages the surface waters, while NOAA and the state manage the area below the surface. The state and NOAA share jurisdiction of the entire marine environment from 1 nautical mile to 3 nautical miles (state's seaward boundary), and NOAA has total jurisdiction out to the National Marine Sanctuary Boundary at 6 nautical miles. Two problems arise, not only is the term in the legal description "mean high tide" not an actual tidal datum and ambulatory, but the inclusion of a vertical (surface waters) jurisdiction requires that the representative cadastral boundary be three-dimensional. This example is difficult to understand and complex to map, and even more complex to manage with regard to the resulting institutional responsibilities.

Other mapping problems and ambiguities can be highlighted as other legal descriptions are examined. In the case of the Hawaiian Islands Humpback Whale Sanctuary, the legal description uses terms such as "excludes the areas within three nautical miles of the upper reaches of wash of the waves." The Monterey Bay Sanctuary designation states, "excludes small areas of cities." It should be noted that NOAA, with the assistance of the MMS, is working to revise the NMS boundaries, attempting to clear up uncertainty, inconsistencies, and ambiguities that will allow them to be adequately portrayed in GIS and ECDIS.

Another example is the set of demarcation lines that have been established by the Convention on the International Regulations for Preventing Collisions at Sea, 1972 (commonly called COLREGS). COLREGS define boundaries across harbour mouths and inlets for navigation purposes. If a vessel is landward of the COLREGS line, it must adhere to the Inland Rules of Navigation established under the Inland Navigation Rules Act (33 U.S.C. § 2001 et seq.). Seaward of the COLREGS line, vessels are subject to rules of navigation established by the International Regulations for Preventing Collisions at Sea, as amended (33 U.S.C. § 1601 et seq.).

Historically, the COLREGS lines have been established by drawing a line across a harbour mouth on a paper nautical chart. In addition, geographic references that position these lines are published in the *U.S. Federal Register*. However, these references typically include no coordinates and, furthermore, often reference ambulatory or ephemeral geographic or man-made features. For example, the following language is used to describe a section of the COLREGS line running from Tybee Island to St. Simons Island, Georgia.

> "A line drawn from the southernmost extremity of Savannah Beach on Tybee Island 255° true across Tybee Inlet to the shore of Little Tybee Island south of the entrance to Buck Hammock Creek" (U.S. Department of Transportation, 1995)

From a digital mapping perspective, there are several problems inherent in this approach. For example, beaches are extremely dynamic natural features. Hence, the southernmost extremity of Savannah Beach may shift from storm to storm and year to year. As it does so, a heading of "255° true" may cease to connect the line with the intended location. Furthermore, the reference to the other end of this line segment, "the shore of Little Tybee Island south of the entrance to Buck Hammock Creek," is geographically vague, in addition to the fact that it references another ambulatory feature. Finally, no coordinate information is provided which would allow a mapping technician to create a precise and legally accurate map of the COLREGS line.

In the aforementioned case study, all of the digital data layers were created with the best information available in an attempt to reflect accurately the intent of the legal description. Every effort was made to document completely the source of all parts of the boundary in the associated metadata file. Where appropriate, hyperlinks were given to the legal textual description of the regulation. As new improved data become available, updates will be made to the digital files.

Conclusion

As evidenced by these examples, creating actual digital spatial map layers for use in marine cadastral information systems is often problematic. In many cases, the legal description of the boundaries may not adequately describe the geography, or it may be extremely complicated, requiring subjective interpretation. New legislation and regulations must take into consideration the state of mapping technology. Ideally, the policy regime will list the bounding coordinates and metadata (e.g., datum) with enough precision to create the spatial data layer adequately. Removing the ambiguities is a necessary component to reduce uncertainty for resource analyses done in GIS for planning and governance and in ECDIS for navigation applications. Moreover, the legitimising of digital spatial boundaries by governing agencies is critical for the advancement to legally accurate cadastral information systems.

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