Journal of Coastal Conservation 8: 7-16, 2002

Using GIS for siting artificial reefs – Data issues, problems and solutions: 'Real World' to 'Real World'

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Abstract. As GIS becomes an increasingly more 'user-friendly' tool, and more people recognize the benefits of the technology in their work environment, inevitably greater use will be made of it for a wide range of applications. The ease with which a GIS can now be used often overshadows the complexity underlying this technology and the potential difficulties that can (and do) arise when this is not fully understood. In practice, there are two routes open to the application of GIS technology for environmental studies. The first is to commission new data for the research. The second is to make use of existing data sets. Data are at the heart of any GIS application. A detailed knowledge about the data sources, the method of collection, capture, scale and sampling strategy, especially if the data are to be used in any analysis, modelling or simulation studies, is fundamental to any application. Unfortunately, information about data (metadata) is seldom available, especially for archival or legacy data sets. Furthermore, although it is now relatively easy to acquire digital data, to input, store, manipulate and display this data, and to output the results of any GIS analysis in the practical sense, little consideration is given to the problems associated with data quality and how this will ultimately affect present and future analyses and use of the output for planning and decision-making. The need to raise awareness about data quality for applications is set in the context of the development of an environmental database for the Moray Firth, Northeast Scotland, and more specifically the use of selected data sets from the database to aid in the proposed siting of an artificial reef. Using this example, this contribution explores the problems associated with the use of both existing analog and digital data sets as the basis for environmental applications, the problems of data acquisition, data quality, data standards, error and how these can affect the operational use of the data in GIS analyses. The solution to such problems appears to lie with improved error assessment and reporting. The outcome of this contribution is an attempt to offer guidance and solutions to researchers and applications specialists undertaking similar studies, by suggesting to what extent studies, such as the artificial reef siting, can safely make use of existing data sets without risking the problems associated with judgements based on inadequate information, and generated or inherent error.

Keywords: Exclusion mapping; Metadata; Moray Firth; Scotland; Special Decision Support System.

Introduction

Until quite recently most applications of Geographical Information Systems (GIS) have focused on land-based studies rather than marine and coastal environments. A monograph by Bartlett (1994) covers some of the wide range of applications undertaken to date, whilst other papers (e.g. Fairfield 1987; Davis & Davis 1988; Riddell 1992; Deakin & Diment 1994; Green 1994a, b, c; 1995) illustrate some of the specific ways in which GIS has been used to date. With increasing interest now being shown in our marine and coastal environments, more GIS-based applications, particularly those developing Spatial Decision Support Systems (SDSS) (see, for example, Raal & Davids 1995; Canessa & Keller 1997) are being developed. Demand from end-users has subsequently placed greater pressure on commercial software developers to provide more user-friendly front-ends to GIS systems, e.g. ArcView for ArcInfo, with the aim of assisting, e.g. coastal zone managers, to use this technology in their work environment. Interest in the benefits of communications and networking technology e.g. the Internet and the World Wide Web, has recently been examined by a number of studies (e.g. Green 1996, 1997).

As GIS becomes a more 'user-friendly' tool, and more people, not necessarily GIS specialists, recognize the benefits of the technology in their work environment, greater use will undoubtedly be made of GIS. Whilst this is good in itself, the ease with which a GIS can now be used tends to overshadow the complexity of the technology and the potential difficulties that can (and do) arise when the technology is not fully understood. It is, for example, relatively easy to acquire digital data, to input, store, manipulate and display this data, and the results of any analysis in a practical sense. The problem is that there is seldom any mention of data quality associated with GIS analyses.

In practice there are two routes open to the application of GIS technology in environmental studies. The first is to collect entirely new data for the research. The second is to make use of existing available data sets,

both analog and digital. In an ideal world 'starting from scratch' is probably the best approach to any research, except where historical trends are an important component of a study. Acquiring and subsequently using the 'right data' for the 'right job' is then almost a certainty. The appropriate scale, spatial sampling, and boundaries are then collected for the specific application in mind. More often than not, however, there are many data sets already available in both analogue and digital format which could potentially be used for other applications; but as an aid to a study, rather than for quantitative analysis. Unfortunately whilst some data sets may be of use for an environmental application, many may not in fact be appropriate, and may have limited use in practice.

A GIS is relatively simple to develop in theory and the data are easy to acquire, whether archival or new, for a wide variety of applications. But, in practice, there are many fundamental considerations to be taken into account when undertaking a GIS project which relate directly to the data available for use in the study. Knowledge of the source of the data, the method of data collection, capture, scale and sampling strategy are all important if the data are to be used in any analyses, modelling or simulation studies. Without such information, it is very difficult to make use of the data sets, not in terms of their practical usage, but in a legitimate way. Unfortunately information about data is not always recorded at the time of collection or forthcoming when multiple data sets from multiple organizations are involved. Furthermore, there are currently few requirements to collect spatial data to any standard, and no requirement to document (metadata) the data, although bodies such as the AGI (Asociation for Geological Information) in the UK for example have produced documents advocating the need to consider standards and data quality (Anon. 1996). This means that without having such information to hand when using 'second and third-hand' data, it becomes very difficult to justify and to defend the use of individual and combined data sets for an application, particularly where an analysis is planned. In a practical sense the data can be used. However, there is considerable potential for the generation of error. Without knowledge of the individual and cumulative error contributed at each stage in an analysis it becomes very difficult for end-users to make decisions based on the outcome of an analysis. In some cases the error inherent in a data set or generated through analysis may not be significant, and may even be quite small. In other cases the output may contain sufficient error that could affect the usefulness of the results, and even decisions made.

This paper seeks to address some of the problems associated with these data issues and problems, and to offer some practical solutions and guidance for the practitioner. It is set in the context of the development of an environmental database for the Moray Firth, North East Scotland, and more specifically the use of selected data sets from the database for the proposed siting of an artificial reef. Using this example, this contribution explores the problems associated with the use of both existing analog and digital data sets as the basis for an environmental application, the problems of data acquisition, quality, standards, and error, and how these can affect the operational use of the data in GIS analyses. There is also the question of how one makes use of historical or archival data to study temporal changes (e.g. sediment movement over time) where old data sets have to be used out of necessity. The solution to such problems would appear to lie with improved error assessment and reporting. The outcome of this contribution is an attempt to offer guidance and solutions to researchers and applications specialists undertaking similar studies. It suggests to what extent studies, such as the artificial reef example, can safely make use of existing data sets without risking the problems associated with judgements based on inadequate information, and generated or inherent error.

Artificial reef siting

To date it would appear that there is relatively little literature on the siting of artificial reefs utilizing GIS technology (see for example, Nakamuna 1985; Bohnsack & Sutherland 1985; Matthews 1986; Grove et al. 1991; Bruno et al. 1996; Herrington et al. 1997; App. 1).

Traditional approach

In 1995, AURIS Environmental (Heaps 1995) undertook a detailed feasibility study of the siting of artificial reefs in the Moray Firth, Scotland, UK. This investigation employed many different data sources and consulted with numerous expert groups. The local fishermen's association was particularly influential and was eventually responsible for helping to short-list the potential sites for the proposed reef. Paper-based maps were used in the analysis but were only small-scale and contained generalized information. The entire selection process employed and described in the AURIS report was essentially empirical and is based on the criteria summarized in Table 1.

A technique referred to as 'Exclusion Mapping', a type of sieve mapping, was employed to eliminate areas with the most obvious constraints, thus helping to narrow down the most suitable location zones. Although this procedure is not described in detail in the AURIS Report, the use of conventional maps is normally difficult to undertake and is error-prone.

Table 1. The selection process.

- Outwith the main trawling areas
- Outwith the main shipping lanes
- With boats and facilities able to exploit a small reef
- Minimal impact on the other local users
- Minimal impact on the environment
- Firm, sandy substrate and
- Accessible to local facilities

More specifically:

- Within a reasonable distance from the shore for sport angling activities (less than 16 km)
- With a fairly level topography (for stability and future expansion)
- With optimal hydrography
- At an optimal distance from areas of biological activity
- A steady current through a reef to prevent stagnation and to supply the reef fauna with food
- 30 - 40 m adequate depth (Matthews 1986)
- Firm sand (in particular firm and hard packed)
- Should not be placed on an already highly productive habitat
- On the fish path (i.e. for fish congregation) and intercept of the currents; siting planned to intercept the current most effectively with the longitudinal axis orientated to intersect the currents at right angles (Grove et al. 1985)
- Situated close to the intended user-group placed in less than 50 m depth (to facilitate diving surveys and ensure the reef is within the photic zone)
- Greater than 20 m clearance, i.e. ample clearance to navigation
- The reef should be less than half the length of the storm waves

Whilst this 'traditional' manual approach has been well-tested for many similar tasks and has been deemed reliable in the past, the fact that it is not computer-based means that it also really only provides a one-off solution. Since all the focus is on one task, further analyses of the data sets collected are unlikely to be considered, largely because they are so time consuming.

A GIS approach to the problem of locating the optimum site for an artificial reef offers a number of distinct advantages over the traditional approach adopted by AURIS outlined earlier. The most significant of these is the creation of a 'general' environmental database, the data sets of which can potentially be used for numerous other applications, the artificial reef being just one of the many possibilities. The primary advantage is that the source data, held digitally within a GIS is more flexible and accessible and can also be analysed directly using the system's functionality.

Moray Firth Project

The Moray Firth Project undertaken by Ray et al. (1996a-c) followed on from the Moray Firth Review carried out by Scottish Natural Heritage (SNH) (Harding-Hill 1993). The investigations carried out in this 'Pilot Study' aimed to develop the use of GIS for environmental management, with particular reference to the necessary background research, acquisition of data and the conversion of data into a widely used GIS format (ArcInfo). The purposes of this study were: to ascertain what data sets existed for the study area; to catalogue and document these data sets; to create a digital environmental database; to select those data sets from the total set that were deemed to match criteria for siting an artificial reef; and to use those selected as the basis for optimizing the siting of an artificial reef using a GIS. Methodologies were also proposed for the continued development of this pilot by developing ideas for a particular siting application; that is, a demonstration system highlighting the potential advantages of utilizing GIS technology in these and other areas of coastal zone and environmental management applications.

The first part of the study examined the project life-cycle of developing a Pilot GIS. This included the initial background research, a scoping study, the use of questionnaires, followed by an examination of the problems associated with the acquisition of numerous disparate data sets from many different sources. These data sets were prepared and converted into a common format before being co-registered for compatibility in the spatial database for analysis.

The final part of the study proposed a model, using a GIS approach, for the siting of decommissioned oil and gas structures, for use as steel artificial reefs in the Moray Firth (Figs. 1-4).

The potential use of GIS as a general environmental management tool for applications both in the Moray Firth and other areas was then reviewed.

Data sets

The main problems found to be associated with the environmental data sets gathered was firstly, their initial acquisition and secondly, problems with some of the data sets. Some of these identified problem areas are summarized in Table 2.

Table 2. Potential problem areas with data sets.

- Copyright
- Standards
- Cost
- Ownership
- Documentation (metadata)
- Multiple users
- Currency
- Format
- Size
- Scale
- Source
- Original use/project
- Method of data capture
- Updating
- Geographical extent
- Interpolation
- Georeferencing
- Analysis
- Confidentiality

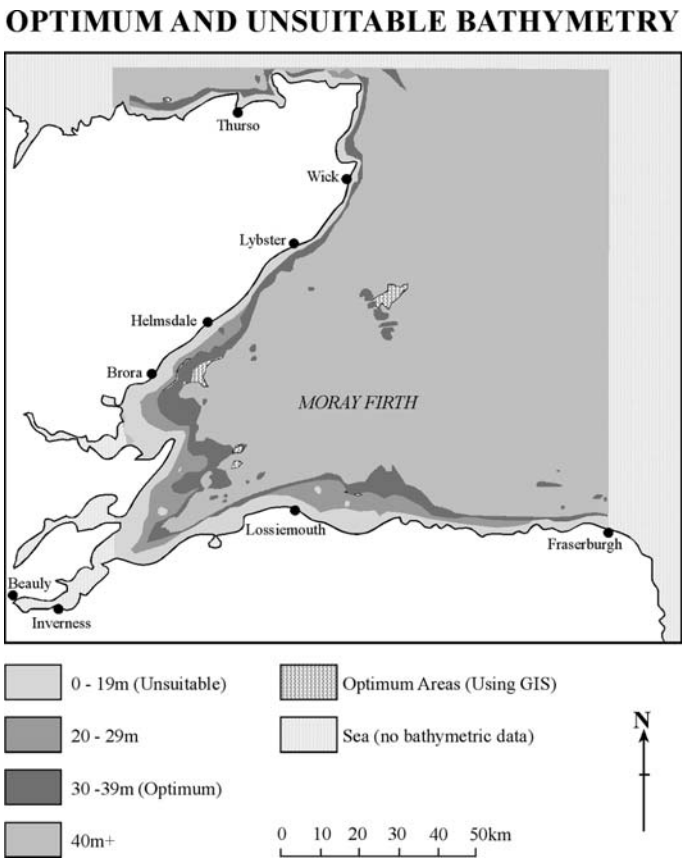

Fig. 1. Location of optimal and unsuitable bathymetry (map drawn in ArcInfo by S.T. Ray).

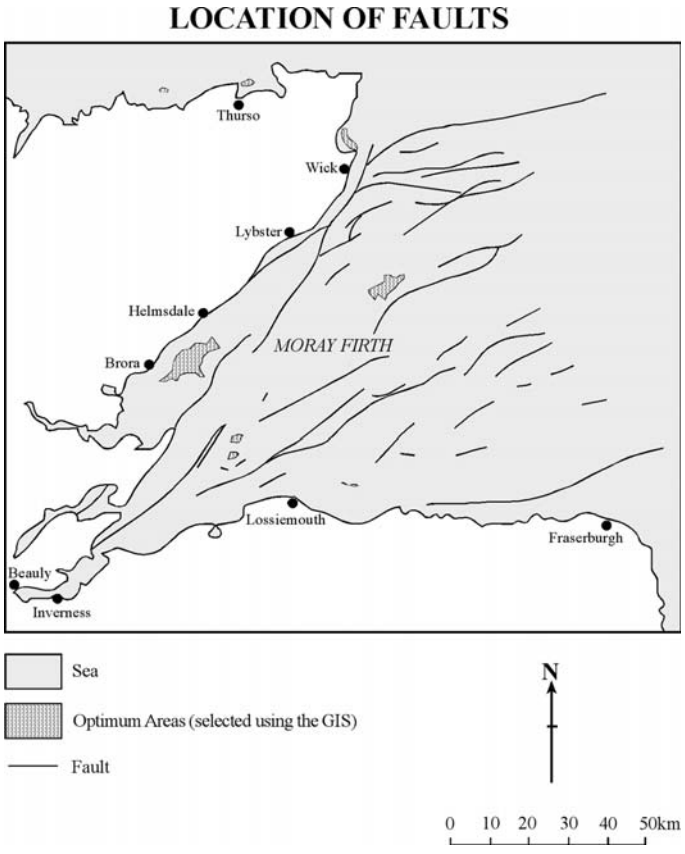

Fig. 2. Location of faults (map drawn in ArcInfo by S.T. Ray).

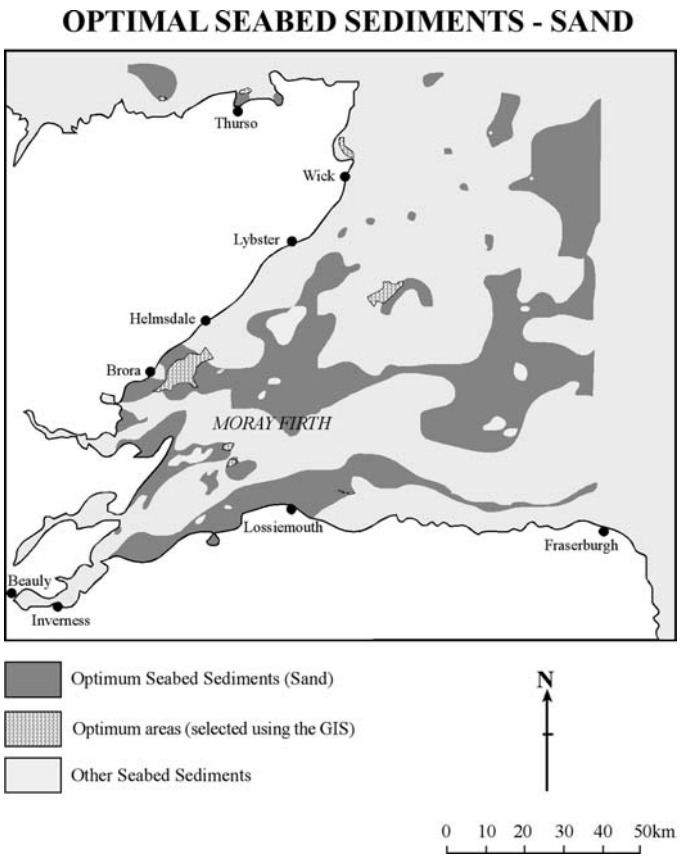

Fig. 3. Location of optimal sea bed sediments – Sand (map drawn in ArcInfo by S.T. Ray).

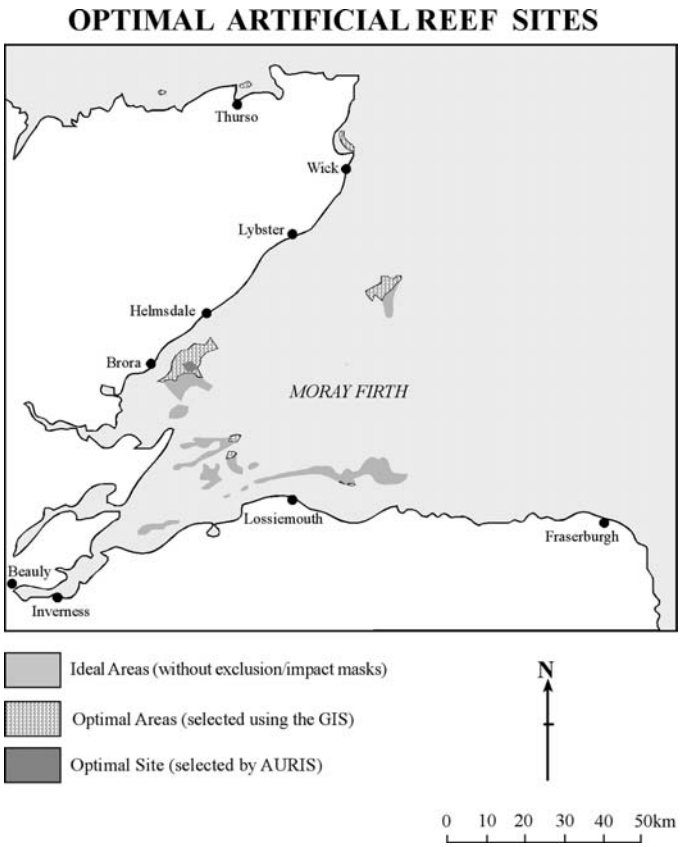

Fig. 4. Location of optimal artificial reef sites (map drawn in ArcInfo by S.T. Ray).

Data acquisition

There are basically two routes open to any new GIS project application, i.e. to make use of existing available data sets, or to start from scratch. In most cases the latter is not an economically justifiable approach because of the time and costs associated with data collection and capture e.g. digitizing, scanning and labour. In addition, it is seldom practical, may duplicate the work of others, and can be an extremely time-consuming exercise. The former, however, requires that you know what data sets are available; whether they can be used; what costs are involved; and above all whether they are of the right spatial scale for the intended application. Depending upon the goals of the project, it may be that many of the data sets available are indeed unsuitable, bearing in mind that it is unlikely that they were originally collected for the intended purpose, in this case artificial reef siting.

Availability

Although much of the data available can be obtained free-of-charge for a research project, such as the one carried out here, there were still many data sets which were not easily accessible, despite the non-commercial nature of the project. Some data could only be released for specific lengths of time and for others, deletion of the files was required at the end of the project. Finally, certain data were spatially referenced to a lower resolution than was required or ideal.

Confidentiality

Despite the considerable potential value of some data sets to the project, which included the names and addresses of individuals, access is controlled by confidentiality regulations and still others, with defence implications, for example, are also restricted.

Copyright

Copyright varies, with some of the official organizations who are potential suppliers of data, being more restrictive than others. Where project funds are limited then the cost of buying data and then paying royalties may be too great to justify their use, even though they might be considered vital to the application.

Licence

Licence agreements may have to be signed for essential data, e.g. geological and related bathymetric data in this project. The conditions attached, although strict, were reasonable in this case and applied to a term of three yr, the data being restricted to the Moray Firth Project.

Costs

Only one licence had to be paid for in this project but due to convenience (in suitable digital form) and the importance to the project, finance in this case was provided for its acquisition. Some important data sets (e.g. for meteorological data and topographic data) would have been quite costly but these were not regarded as essential for the current stage of this GIS pilot application.

GIS competition

GIS is increasingly becoming part of the work environment of many organizations. Some have a directive to set up a system whilst others are still involved in digitizing data with a view to using it 'in-house'. For this and other reasons they are reluctant to pass it on for use within other projects. Of the organizations contacted for this project at least five were creating data sets with a view to setting up GIS for coastal and marine purposes.

Data sets

Standards

Very few of the data sets provided by organizations had any sort of standard attached to them. This had some important repercussions on the possibilities open to the reporting of potential errors and on significance in the decision-making process. The more data sets that are collected to a common standard the higher will be the likely quality especially for use in analyses.

Multiple users

The final GIS database, once in working order, may have to enable multiple users, all using the same data. Most GIS can enable this at the present time. However, this brings related problems of data security, overloading the system, IT support, as well as complications with the licence agreements.

Size

The size of the data files is always important in any GIS project. However, it is more important in a small organization with limited disc storage space. The requirement for more frequent backups and data management

therefore becomes necessary. Large raster data sets, e.g. satellite imagery, take up a great deal of disk space, and require powerful computer systems to both display and analyse the data sets.

Original use / Project aims

In most cases, data sets that are already available usually form the basis for many new projects and applications. One argument used to justify this is that they have multiple potential uses, are already available, do not require additional expenditure, and avoid unnecessary duplication of effort. However, many environmental data sets are in fact acquired for a specific purpose (small projects and are not part of a larger data acquisition strategy), and not the one that individuals find a new use for. Whilst some applications can make use of these, others may find that they are incompatible with other data sets, are of the wrong scale, and so on. Due care and attention must therefore be exercised in the use of archival data and those not acquired specifically for a new project.

Method of data capture

Knowing something about the method of data capture is very important, particularly for a pilot application. Data capture might have been undertaken by trained professionals carrying out surveys to specific requirements, or by amateurs with no real sense of accuracy for fieldwork. The quality of the data may therefore be suspect. This problem can also apply to the data loading, with reference to digitizing, scanning, and data import using software packages other than those used originally. These methods of data capture will all lead to many errors which then accumulate throughout the import process. In addition, the provision of a record of the entire process (e.g. a log file) is very important in tracing and identifying a weak link, or a potential source of large errors in the final results. Boats, for instance, with satellite tracking devices, although getting better, are possibly less accurate than a surveyed portion of the coastal strip. Awareness of this and consideration in the GIS use and analysis must all be taken into account.

Updating

Knowledge about the currency of the data and the frequency of updates is also vital, especially if different data sets acquired on different dates are being used. Provision of this information in the metadata is vital, and knowing when a data set was collected, how, and when it was updated is often information that is not available.

Geo-referencing

Data sets are often provided as either grid coordinates or latitude and longitude. Therefore a first step is to convert all the data sets to a single common coordinate system. If they are all supplied in the same coordinate system, this will enable more efficient data loading and once again there is less room for error to creep in.

Multiple sources

Data in any environmental application may ultimately come from many different supply sources. As a direct result the data set will contain many variations e.g. some topics or themes will be very well covered with very detailed data sets for many years and locations, whilst other topics will have been recorded for a restricted number of sites and with insufficient temporal resolution. This means that many data coverages will not be directly comparable thereby limiting their potential for procedures such as GIS overlay mapping analysis. Many data sets may indeed contain more or less the same data on overlapping regions, therefore being a duplication of both cost and effort and limiting the potential for sharing of the data sets between organizations.

Format

Another critical factor is the format in which the data sets are provided. Due to the likely different nature of data from different sources, for which there is no requirement for adherence to a standard, there will be many formats. ArcInfo export files tend to be preferred but more typically data comes in the form of formatted ASCII (either geographical: latitude/longitude, or National Grid), paper lists/tables (which have to be inputted by hand), DXF, DBase, and paper maps (requiring digitizing). Many data sets are obtained in a format which can only feasibly be converted into one or other of points, arcs or polygons (points, lines, areas). A variety of data conversion procedures therefore have to be adopted with extensive use often being made of software such as Microsoft Excel followed by the use of ArcInfo routines.

Feature type / Interpolation

Many coastal data sets are collected at point sources directly on the coast and can not therefore be interpolated or extrapolated into the marine zone if needs be. Equally there are too few primarily marine data sets and this can prove very restrictive for any spatial analysis. Few data sets appear to be acquired in a digital format that can lead to complex and time-consuming data

conversion procedures. Due to survey collection methods of original data some material can have very low precision, both in the survey and for the sample locations. There is also very little information about the actual sources of the data, collection techniques, quality, and known errors. Some potentially useful data sets are of restricted value due to their one-off survey characteristics and the limited spatial locations and time-periods for which they were available.

Quality

The quality of available data varies considerably. In part, if it is archival data, this is not surprising as methods of data collection and the equipment used have improved considerably over time. Some data may have been surveyed by trained professionals whilst others had been collected by amateur volunteers. Some data sets may themselves have been previously compiled from multiple and unspecified sources in different formats and thus are devoid of standards and are potentially more error-prone. When metadata are sought from data source contacts some are surprisingly vague about the provenance of many of the data sets even in their own databases.

Desirable characteristics of the data for the pilot GIS are summarized in Table 3.

Table 3. Desirable characteristics of the data sets required for a pilot GIS.

- Covering both environmental and socio-economic data
- Reasonably large spatial scale of origination
- High density of data values, good coverage and geographical distribution
- Up-to-date information
- Some historical data sets to provide for temporal trends
- Pre-defined data format
- Low/no cost implications
- Full availability and access to the data with few restrictions
- Information to be provided on data collection techniques
- Full data description (metadata)
- Quality of the data including an estimate of the errors involved
- Digital (preferably ArcInfo) format

Discussion

There are, based upon a simple example of collecting together existing data sets in an environmental database for an application, many factors that need to be considered when planning to use archival and other data of uncertain origin. Knowledge of the data sets available, including their source, format, and quality, can provide a far firmer basis upon which to proceed with a project. Where funds are short, it is inevitable that one option that will be considered is the use of the existing data. This may in fact be possible providing that the applications specialist is clearly aware of the limitations and constraints that exist in the use of spatial and temporal data. It is important to take all these factors into account when undertaking a similar project because it ultimately affects what analyses are carried out, the conclusions drawn, and their potential use for planning and decision-making.

Conclusions: solutions and recommendations

As discussed at the outset of this contribution, researchers usually have two choices open to them when using GIS for an environmental application. In an ideal world, and given sufficient funding and manpower resources, a study such as the one outlined above would start from scratch to ensure that the right data sets were available for the right job. Unfortunately, it is not an ideal world, and more often than not existing data sets are often utilized (and sometimes blindly) because of the cost and time involved in starting afresh. This is perfectly acceptable providing the uses that the data are put to are limited to e.g. visualization or very simple analyses. The researcher must be aware of the pitfalls, and the end-user aware of the quality of the data sets used to derive output. Clearly where information is available about the component data sets then it is possible to utilize them more fully knowing that they were collected at a certain scale, and using a known sampling strategy. At the end of such an analysis it is then possible to provide a measure of support or level of confidence for the end-user e.g. in the form of an error report that is meaningful to the end-user. Any decisions then made using the analysis can utilize the report e.g. placement of the artificial reef is accurate to within ±100 m as a measure of certainty. Where data sets are unaccompanied by detailed information then the researcher should proceed with care, using only the data sets that can legitimately be used, and where analysis is undertaken that some doubt be expressed about the results derived from the analysis. Where component data sets are accompanied by relatively little information, the message is that the researcher should exercise a measure of, if not considerable caution concerning the quality of the results of the analysis.

Table 4 is intended as a set of guidelines for individuals wishing to pursue similar environmental projects to the artificial reef siting example, providing some solutions and recommendations. In effect it aims to be a practical reference for researchers, indicating the stages

Table 4. Options, solutions and recommendations.

• Avoid use of the data sets completely (not practical)
• Limit use of the data sets e.g. solely for visualization/illustrative purposes with no quantitative analysis
• Provide error estimates for single and composite data sets as an indication of their usability
• Create new data sets from scratch

that might be considered when planning or undertaking a project.

Growing interest in the use of Geographical Information Systems (GIS) has led to more and more applications being undertaken. All too frequently, however, the applications of such technology by non-GIS specialists ignore the recognized problems associated with geographical data sets.

This contribution has set out to examine a typical environmental project based around the use of existing data sets with the intention of highlighting some of the possible areas in which there are potential pitfalls for the unwary. It is clear that there are many, particularly for the applications specialist who relies, out of necessity, on archival data sets.

The conclusions of this contribution are that providing the researcher is made aware of and recognizes the potential pitfalls and attempts to take account of them in the study, limiting the study to legitimate uses of the data, as outlined, then the existing geographical data sets can be useful. However, if no account is taken of the limitations of the data, then it becomes very difficult to have any confidence in the outcome of any data analysis that makes use of these data sets.

The fact that there are few guidelines provided for those collecting data, and few if any incentives at present to collect data in a standardized form means that many data sets, which are potentially very valuable and useful will continue to have limited use outside of the project for which they were originally gathered and intended. This means that there will be many digital data sets available which can indeed legitimately become part of an environmental database, effectively little more than a data catalogue, but they will not be of much other use unless well documented, and potentially of little real use in an analytical sense.

In the UK the National Geospatial Database Framework (NGDF; Watts 1997) has been proposed as one way of securing the collection and archiving of standardized geospatial data sets for more widespread and long-term use. Although little has been said to date about marine and coastal data sets (the Ordnance Survey and the UK Hydrographic Office did collaborate on the development of an experimental coastal zone map series and are collaborating in a new project with the British Geological Survey (BGS) on a new digital initiative, it is clear that much stands to be gained by formalizing the collection and documentation of spatial data sets (both archival and new) which will ultimately facilitate more correct, widespread and long term usage. The most important issue though is to draw attention to a requirement to provide detailed documentation on data sets that are available either free or at cost so that awareness of the need to acquire and use quality data is brought to the attention of the GIS practitioner.

References

Anon. (Scottish Natural Heritage) 1994. *Focus on Firths*. Leaflet, Edinburgh.

Anon. (AGI Data Quality Working Group) 1996. *Guidelines for geographic information content and quality: For those who use, hold, or need to acquire geographic information*. AGI Publication No. 1/96.

Bartlett, D. 1994. GIS and the coastal zone: Past, present and future. I&E Committee Publication. *AGI Publication 3/94*.

Bohnsack, J.A. & Sutherland, D.L. 1985. Artificial reef research: A review with recommendations for future priorities. *Bull. Mar. Sci*. 37: 11-39.

Bruno, M.S., Herrington, T.O., Rankin, K.L. & Ketteridge, K.E. 1996. *Monitoring study of the Beachsaver Reef at Avalon, New Jersey*. Tech. Rep. SIT-DL-9-96-2739, Stevens Institute of Technology, Avalon, NJ.

Canessa, R. & Keller, C.P. 1997. User assessment of coastal spatial decision support systems. In: *Proceedings Coast-GIS'97*.

Davis, B.E. & Davis, P.E. 1988. Marine GIS: Concepts and considerations. GIS/LIS 1988. In: *Proc. ACSM/ASPRS*, pp. 159-168. San Antonio, TX.

Deakin, R. & Diment, R.P. 1994. Strategic planning and decision support: The Use of GIS in the Coastal Environment. In: *Proc. AGI'94,* pp. 13.3.1-13.3.5. Birmingham, UK.

Fairfield, F.M. 1987. Marine planning with geographic information systems. In: *Proc. Coastal Zone'87*, pp. 1023-1030.

Green, D.R. 1994a. GIS and marine information systems: Some recent developments in the United Kingdom. In: *Proceedings Hydro'94 of the Ninth Biennial International Symposium of the Hydrographic Society*, pp. 6.1-6.27. Special Publication No. 33, Aberdeen, UK.

Green, D.R. 1994b. GIS and marine information systems: An overview of some recent developments in the United Kingdom. In: *Proceedings of the Sixth Biennial National Ocean Service International Hydrographic Conference*, pp.

Green, D.R. 1994c. Using GIS to construct and update and estuary information system. *Proceedings of the Conference on Management Techniques in the Coastal Zone*, pp.. Centre for Coastal Zone Management, University of Portsmouth, UK.

Green, D.R. 1995. User-access to information: A priority for estuary information systems. In: *Proceedings of COAST-GIS'95: International Symposium on GIS and Computer Mapping for Coastal Zone Management*, pp. University College, Cork, IR.

Green, D.R., Rix, D. & Corbin, C. 1997. *The AGI sourcebook for GIS 1997*.

Green, D.R. & Massie, G. 1997. FEF Pilot Information System. In: *Proceedings CoastGIS'97 - The next millennium*, pp..

Green, D.R., Ray, S., Wood, M. & Wright, R. 1996. *Development of a GIS of the Moray Firth and its application to environmental management*. Final Report, Aberdeen University.

Grove, R.S., Sonu, C.J. & Nakamuna, M. 1991. Design and engineering of manufactured habitats for fisheries enhancement. In: Seaman, W. & Spragne, L.M. (eds.) *Artificial habitats for marine and freshwater fisheries,* pp. 109-152. Academic Press, London, UK.

Harding-Hill, R. 1995. *The Moray Firth review*. Scottish Natural Heritage, Inverness, UK.

Heaps, L. 1995. *Feasibility study for the construction of a high profile artificial reef in the Moray Firth*. Final Report, AURIS Environmental, Aberdeen, UK.

Herrington, T., Bruno, M.S. & Ketteridge. K.E. 1997. Monitoring study of the Beachsaver Reef at Cape May Point, New Jersey. *Technical Report* SIT-DL-96-9-2751. Stevens Institute of Technology, Avalon, NJ.

Matthews, H. 1986. *Artificial reef sites: Selection and evaluation*. pp. 50-54.

Nakamuna, M. 1985. Evolution of artificial reef concepts in Japan. *Bull. Mar. Sci*. 37: 271-278.

Raal, P.A., Burns, M.E.R. & Davids, H. 1995. Beyond GIS: Decision support for coastal development, a South African example. In Furness, R.A. (ed.) *CoastGIS'95: Proceedings of the International Symposium on GIS and Computer Mapping for Coastal Zone Management*, pp. 273-282. International Geographical Union Commission on Coastal Systems, Sydney, AU.

Ray, S., Green, D., Wood, M. & Wright, R. 1996a. Putting nature in its place. *Mapping Awareness* 10-9: 20-23.

Ray, S., Green, D.R., Wood, M. & Wright, R. 1996b. Getting the data for the job: Planning for a coastal marine GIS. *Proceedings of the GIS Conference at Brno. GIS Frontiers in Business and Science, Part 2*, pp. 1-8. Brno, CZ.

Ray, S., Green, D.R., Wood, M. & Wright, R. 1996c. *Establishing an environmental GIS for siting an artificial reef*. Paper presented at a One-Day Seminar of the Association for Geographic Information Marine and Coastal Zone Management GIS Special Interest Group, University of Manchester, UK.

Riddell, K.J. 1992. Geographical Information and GIS: Keys to coastal zone management. *GIS Europe* 1-15: 22-25.

Watts, P.A.G. 1997. Plans for the coastal zone. In: *Proceedings* of CoastGIS'97, pp.

App. 1. Additional reading on artificial reefs.

http://water.dnr.state.sc.us/marine/pub/seascience/artreef.html
http://www.ncfisheries.net/reefs/
http://bigshipwrecks.com/
http://www.fosusa.org/environ/reef1.htm
http://www.pir.sa.gov.au/pages/fisheries/rec_fishing/rec100.htm:sectID=266&tempID=10
http://www.asrltd.co.nz/reefs.html