2. GIS hardware and software for fisheries and aquaculture

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2.1 INTRODUCTION

This section is concerned with the technological infrastructure needed to support the GIS operations. The approach taken here is to assume that the GIS is being assembled from scratch, although in reality it might be necessary to integrate a GIS into an existing information technology (IT) structure so that some or all of the hardware and software requirements may already be procured. This chapter will cover four main areas related to hardware: (i) hardware for data collection and inputs, (ii) processing and storage hardware, (iii) GIS output devices and (iv) GIS architecture. The chapter also looks at the range of GIS-related software that might be procured. As with most facets of IT, advances occur very rapidly with respect to both hardware and software needs, so information described here is likely to date quickly. This rapid technological advance is undoubtedly beneficial in the fisheries and aquaculture sectors because it provides the opportunity to expeditiously tackle a far wider range of problems than could previously be addressed. Megrey and Moksness (2009; p.2) importantly note that improved technology will “produce significant gains in work productivity, increase our basic understanding of natural systems, help fisheries professionals detect patterns and develop working hypotheses, provide tools to rationally manage scarce natural resources, increase our ability to organize, retrieve and document data and data resources, and in general encourage clear thinking and more thoughtful analysis of fisheries problems”. However, because there will be many circumstances, particularly in developing countries, when users are obliged to use more dated equipment, some hardware that might be considered as “nearly obsolete” will be described. Because there are almost an infinite variety of hardware items that could be of use, it is only possible to cover main items. A perusal of computing hardware trade magazines or Web sites will provide useful additional information on basic items.

With regards to the software, those proposing to adopt GIS packages have fundamental, though different, types of choices to make. Is it better to use existing proprietary software or to go down the possibly riskier route of adopting free software? What software will best suit the requirements? And to what extent are there specific fisheries or aquaculture GIS, and will they tackle the tasks required? Many readers will be unfamiliar with free or open source GIS software, so the content of Box 2.1 captures the spirit of this option, showing that the user might need to enter a world that can be rather specialized, but the gains from doing this can be substantial in terms of cost reductions, endless software possibilities, and in working in a milieu containing a powerful group of people willing to share experiences. Though this world of jargon and acronyms might scare the user, this need not be the case, and the section on software attempts to convey some of the wide range of possibilities.

One software option that will not be considered in detail here is that of doing all (or most) GIS mapping via the use of Web-based software applications. The reasons for this are: (i) this is currently a relatively complex route to achieving mapping and analysis aims; (ii) the user is at the mercy of having to use what is available online (which may not be the most appropriate programs and there may be relatively few GIS-based functions); and (iii) the bandwidth for Internet delivery may not be sufficient to receive and process data over the Internet. However, with current advances in this field of software delivery, then it is likely that this option will be worth exploring during the next few years, and indeed Box 2.2 provides a recent comment from the Design Research Laboratory at the North Carolina State University in the United States of America on why the use of Web-based GIS might be useful. For those wishing to explore this software option further, the following Web sites may be consulted:

- eSpatial: www.espatial.com;
- GeoMicro: www.geomicro.com/gis;
- Cadcorp: www.cadcorp.com/products_geographical_information_systems/web_based_gis.htm;
- Free Geography Tools: http://freegeographytools.com/2010/giscloud-an-online-geographic-information-system-application.

BOX 2.1

A quote giving the flavour of open source software

"At a GIS-related conference a couple of years ago, I presented a 3D visualization system for fisheries data, and the response from the group was impressive. Not because what I did was so great, but that it could be done with "free" software. There is a real growth in fisheries GIS worldwide, especially in the third world, supporting coastal fisheries management and aquaculture, and budgets for Arc and Oracle spatial are limited.

The most impressive thing I have found with Open Source GIS in the last couple of years is the interoperability. I can download shapefiles, e00 data or many other formats. Use avcimport, ogr2ogr, shapelib, shp2pgsql to extract & reformat, or load into PostGIS. I can query/browse with psql, pgaccess or graphically with QGIS/JUMP, I can analyse with GRASS or R and prepare high quality publication maps with GMT. Then toss mapserver at it to Web-enable the stuff. Add some GPS capture software."

Source: Wood (2004) (http://osdir.com/ml/gis.postgis/2004-06/msg00112.html – accessed 10 December 2012).

2.2 HARDWARE FOR DATA COLLECTION, INPUTS AND OUTPUTS

In Chapter 3 attention will be given to the capture of primary data (defined in Chapter 3), and in doing so, a range of input capture devices will be described. This equipment, therefore, needs little further discussion here. However, not all data are captured in the field as primary data, and some data are collected and processed by equipment that bridges several categories of hardware. This section briefly considers hardware for initial data inputs and analyses, plus hardware that allows for office-based data inputs.

2.2.1 Hardware for inputting data

This section examines: (i) computing for data collection and analyses; (ii) scanners; and (iii) digitizers. As well as describing the hardware itself, there is also a brief description of functionality.

Computing for data collection and analyses. This category of hardware is essentially an extension of the personal digital assistants (PDAs) (see Section 3.5.1). However, it is looked at here because the equipment can be considered as multifunctional with emphasis probably being given to its ability not only to capture data but also to its GIS-based computing functionality. Here, the discussion focuses on ruggedized handheld tablet computers. This category of equipment also overlaps with the more traditional laptop or palmtop computers. For many data collection purposes in the marine, fisheries or aquaculture sectors, it will be important to have a robust device commensurate with frequent adverse physical conditions, and it is of extra value to carry out data collection in conjunction with access to full computing powers including, perhaps, access to a larger screen, to GIS software and to the Internet (allowing for two-way data transfers). This computing equipment would not generally include mobile telephone functions, though some computers have digital photography and route-finding capabilities. It would also allow for a range of GIS functions to be pursued in real time. Figure 2.1 illustrates one of many brands of ruggedized handheld or tablet computers that come in a wide range of prices and functionality.[33] Ruggedized equipment is particularly useful if data need to be collected while in "hostile" environments, for example, at sea on board survey vessels. Data captured might frequently be downloaded to a desktop computer for further processing and use.

BOX 2.2
Why use Web-based GIS?

Web-based GIS is becoming more and more prevalent as time passes. The World Wide Web is a useful tool for gathering and manipulating data and information. Most information that is available in the world is now available over the Internet. Now much the same is true concerning GIS information.

Where formerly an individual would have had to buy an expensive software package to use and manipulate the data needed for GIS, the same is not so today. With the advent of Java-based programming, software applications for Web-based GIS work are now available. Some of these programs require the user to buy some software, and others require plug-ins to be added to Web browsers, but some require no special software additions at all. These use only the capabilities of existing Web browsers.

Because of these advances, many people who were not easily able to obtain information can now have it at their fingertips. People who have an interest in gathering information can find it accessible like never before. For the first time, the public can examine the same information as the policy-makers for hands-on examination of GIS material. Talk about citizen involvement!

Another useful facet of using Web-based GIS is that the people giving the information are completely in charge of the amount of information made available to the public. If there are privacy issues surrounding certain information, then it need not be made accessible to others. It is that simple. People cannot use or abuse information that they do not have. With Web-based information distribution, there is no need to worry about information "falling into the wrong hands".

With Internet connections becoming faster and faster, the amount of information that can be transferred over the Internet is staggering. Soon people will be able to examine GIS data while in a foreign country in order to make a purchasing decision on property that they have never seen. Analysis of data by a widely scattered group can also be accomplished in a faster, more efficient manner when the information is available almost everywhere in the world.

Source: Adapted from Design Research Laboratory at North Carolina State University at www.ces.ncsu.edu/depts/design/research/WECO/policyGIS/why.html (accessed 10 December 2012).

[33] See www.esri.com/software/arcgis/arcpad/key-features.html for a cheaper model.

FIGURE 2.1
A typical ruggedized tablet computer

Source: Maine Technical Source (2009).

FIGURE 2.2
Large format scanner

Source: Softcover International Limited (2011).

Scanners. Scanning also converts analogue[34] mapped or graphical data into digital formats, though here by the use of various scanning devices. Unlike digitizers, which capture user-selected data, scanners capture all the information from mapped or other sheets,[35] and the data are captured in a regular grid of pixels (see Section 5.8.2). Scanning works on the basis of two main principles. There is either a scanning photosensitive head that moves backwards and/or forwards over a static object that is being scanned, or the scanning head is static and the object moves in front of it. There are a range of different types of scanners varying from large format (Figure 2.2) to small flatbed scanners, and the type best used will depend on the size of any paper mapping to be scanned and on the cost that can be afforded. The detail to which scanned data is captured varies from about 400 to 2500 dpi (dots per inch). The amount of detail needed will largely be a function of the use to which any scanned images are put, and consideration must be given to the very large storage requirements for high-resolution images plus the burden on computing power.

Scanning can be used for several purposes in GIS. Scanned images can form an excellent backdrop to, for instance, road maps. Scanned images are also used as a digital filing system for maps. But perhaps the most common use for scanning is that it provides the on-screen images for heads-up digitizing (see digitizing below) or for automated vectorization.[36] It is worth noting that several authors (Longley *et al.*, 2005a; Lo and Yeung, 2002; Heywood, Cornelius and Carver, 2006) comment on the large number of processes that must be gone through from the initial scanning process to the resulting output being readily used for GIS purposes. Because a large format scanner is unlikely to be used much by most fisheries or aquaculture GIS offices, then a cheaper option would be to seek other means of obtaining scanned output, perhaps through the use of a commercial scanning office.

[34] See Section 3.5.1 for an explanation of analogue.

[35] This is advantageous because all data are quickly and usually accurately captured, but disadvantageous because GIS files need to be free from the "clutter" of wording, creases in the map, coffee stains, etc., and scanned files are unintelligent as they cannot differentiate between different information on a map.

[36] Vectorization means that, if clear and uncluttered mapped images are available, it is possible for a light sensitive device to follow required lines on a map capturing their location as (x,y) coordinates.

Digitizers. This form of hardware is used to convert graphical data, i.e. usually lines, points or polygons on maps, into digital data for GIS use. Digitizers are rapidly being phased out as a useful piece of equipment because more and more mapped data are being initially captured in a digital format by other means, e.g. by data loggers, PDAs or by digital scanning, or because on-screen digitizing is performed. However, it is important to discuss it here because there are circumstances when digitizers could still be utilized.

Figure 2.3 illustrates a typical digitizing table. Digitizers come in different sizes, from very large "tables" (~1.5 m wide) to small digitizing tablets (~30 cm wide). Embedded in their surface area is a fine grid of wires that will allow for interaction between the digitizing table and the cursor. A paper map is fastened to the surface and is registered so that exact geo-coordinates will be captured.[37] The cursor (or puck), containing a fine cross-hair set into a magnifying glass, is tracked along any line that needs to be digitally captured. While tracking is taking place, the operator either continually clicks on the cursor and every clicked point is captured as a georeferenced point, or the cursor is set to operate in "stream mode", whereby a point is automatically registered at a set time or distance interval, typically every 0.5 seconds or every 0.5 mm. The cursor or puck usually has a number of keys that allow for additional information to be collected, such as thematic codes, line thicknesses, colours or other identifiers. Georeferenced points are typically captured to 0.02 mm resolution. The digitizer is linked to a computer containing digitizing software and to a screen so that the user can see which lines have already been captured. It is usual to capture data on individual themes, e.g. rivers, county boundaries, forested areas, and to hold each theme (or map layer) as a separate file.

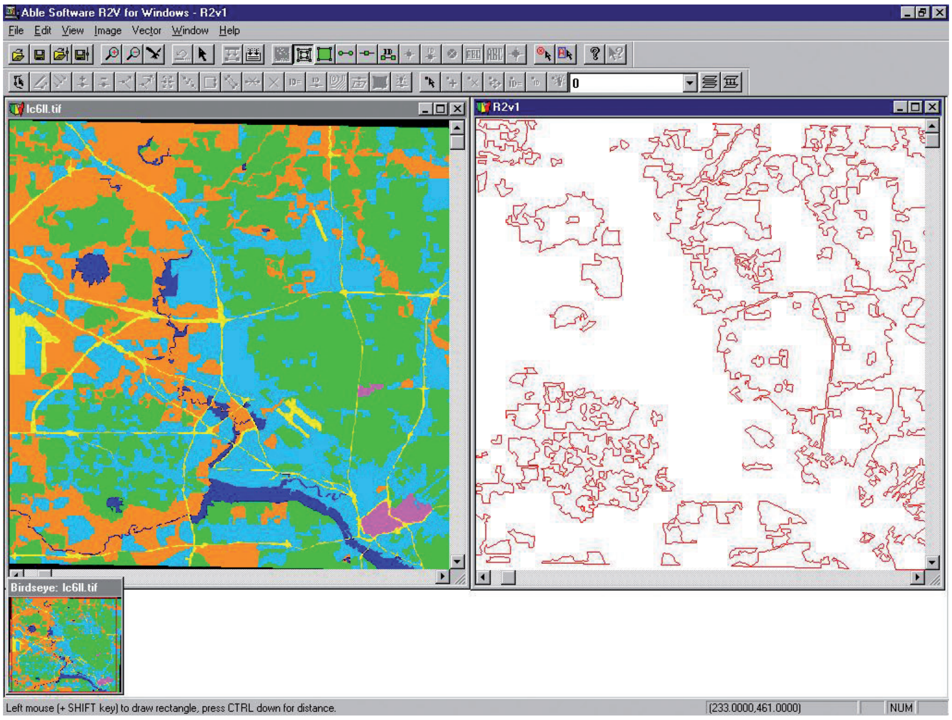
FIGURE 2.3
A large, adjustable digitizing table

Source: The Logic Group (2012).

Today, it is far more likely that on-screen digitizing (also commonly referred to as heads-up digitizing) will be done. Instead of the map being fastened to a table or tablet, the map will be shown as an on-screen image that has been scanned in. The digitizing operation is then carried out in much the same way as described above, but using the normal mouse and cursor and working with digitizing menus that may come as part of the GIS software. As shown in Figure 2.4, dual or split screens can be used so that both the original map and the already digitized lines can be viewed. Here, the green (woodland) areas have been digitized from the original map on the left. Digitizing is recognized as being skilled, but very time consuming and thus a labour-intensive task. For this reason, much high-volume digitizing work has been completed by specialist companies based in the People's Republic of China or the Republic of India where costs may be less than 25 percent of those in more developed economies.

[37] Registering usually requires capture of the location of three or more control points, usually situated at the corners of the map to bedigitized. Any GIS software used then "registers" exactly where the map is georeferenced relative to anywhere on the planet.

FIGURE 2.4
Screen image of raster to vector conversion software functioning as a split-screen display for digitizing



Source: Able Software Corp (2011).

2.2.2 Processing and storage hardware

The major hardware item examined under this heading is the computer itself. Section 1.3.2 outlined the tremendous advances that have occurred in computer technology over the past half century, and these have been enabled by developments in the wide range of parallel technologies that together contribute to the broad IT area. Technological advances have been accompanied by huge relative cost reductions such that computing is now available to a very broad spectrum of the public, government and business. This section simply gives advice on the attributes or specifications that computers being used for GIS work might aspire to and points out some of the peripheral devices or add-ons that might be useful.

Until comparatively recently, computers came in four categories denoting their respective computational power, i.e. mainframe, minicomputers, workstations and desktop computers. About 20 years ago, minicomputers were phased out, mainly because workstations increased their capacity so as to take over the role of minicomputers. In the last decade, workstations and desktops have virtually merged, but there has been a rapid emergence of laptop computers as a new category. Mainframe computers remain as a very wide range of powerful machines, with the most powerful of these being referred to as supercomputers. Box 2.3 briefly describes the current terminology for the most popular range of computer devices, and the prominence of mobile computing can readily be seen. As almost all GIS work can now be performed on desktop or laptop computers, the discussion can focus on these products and, indeed, because laptop capabilities now nearly equal those for most desktop computers, these two categories can be treated as equals.

In an area such as computing, where technological advances are rapid and constant, it is difficult to advise definitively on computer specifications. However, given that work in the fisheries and aquaculture fields tends to be very data intensive and rather

BOX 2.3

The present hierarchy and terminology of general computers

Large:	Super – Minisuper – Mainframe – Server – Supermini
Micro:	Personal – Workstation – Home – Desktop
Mobile:	Laptop – Portable – Tablet – Palmtop – Organizer – Pocket – Notebook – Personal digital assistant – Programmable calculator – Smartphone

Computer typology will vary between countries and within different business sectors. There is also a range of much more specialist computing devices.

complex, as is the case for GIS software, then these more sophisticated needs should be met by the use of "top-end" computing power. Financial restrictions may make this difficult for many users, so a careful check needs to be made on what GIS functionality can be obtained for any given expenditure on computers. Box 2.4 gives guidance as to the desirable specifications for any computer being used as a stand-alone machine for fisheries-related GIS work. If the computer is to be part of a network that is linked to a server (see below), then there may not be the need for such high storage capacity. However, if a stand-alone computer is to be used for highly data intensive projects, e.g. perhaps using many remotely sensed images or large amounts of sonar-derived acoustic data, storage should be increased to 1 terabyte. For those wishing to do GIS work using Apple Macintosh computers, the options are more limited than for conventional PCs.[38]

BOX 2.4

Suggested computer specifications for undertaking fisheries and aquaculture GIS work

The following are the present suggested minimum computer specifications that might apply for GIS-based work (for guidance only):

Operating system:	Linux, Unix, OS X, Windows XP or Windows Vista
Processor speed:	Intel dual-core 2.5 Ghz
Random access memory:	4 GB
Storage (disk memory):	500 GB
Video/graphics card:	256 MB DVI card
Wired network card:	10/100/1000 MBPS Ethernet card
Wireless network card:	802.11 B/G compatible
Disk drive:	CD-RW/DVD combo drive

Users of Macintosh computers may need to check these requirements. The specifications are for "high-end" machines and apply to 2012. There are other operating systems available and various suppliers make all of these items.

As well as the basic capacity of the computer, there are other considerations to be taken into account. Any computer used should have serial or USB ports,[39] a mouse, keyboard and at least one monitor. Flat screen monitors using liquid crystal display (LCD) technology are now the norm and, as pointed out above, more than one monitor can be useful[40], but not essential, for many GIS tasks. As maps are best

[38] GIS/Apple Macintosh options are summarized at: www.cartographica.com/article.php?story=20060228220202157 and www.gis2gps.com/tools/macpage.htm.

[39] USB ports have now largely replaced serial (and parallel) ports. This means that a range of devices such as mice, keyboards, memory sticks, scanners, digital cameras and external hard drives can all use identical plug-in facilities.

[40] Having more than one screen can significantly increase the work productivity rate: see Kim Komando Show: www.komando.com/columns/index.aspx?id=1488.

visualized at a larger size than is textual material, a minimum screen size of 22 inches (55 cm) is recommended, and the dpi of screens should also be of high definition (perhaps up to 2560 × 1600) and have a fast refresh rate in the range of 85 Hz.

It is also vital to consider digital storage media. Although any computer may have its own large storage capacity, it is essential to have back-up provision provided by some sort of external device or medium. There are four main ways of achieving this:

- **File server.** This is a separate computer with high data storage capacity, which is linked to other computers forming part of a local area network (LAN) (see Section 2.2.4). It means that there is no need for all files and data to be stored on each computer in the organization, allowing each desktop computer in the LAN to have lower specifications.
- **External hard drives.** These are similar to an ordinary internal hard drive, except that they are mounted on a disk enclosure and are simply plugged into a USB port. There is now a huge range of external drive options in terms of size and price with even small drives having up to a 1 terabyte capacity (for examples, see LaCie Srl: www.lacie.com/it/products/range.htm?id=10036). However, they are often less rugged and may be more bulky and expensive than memory sticks (see below).
- **Optical disk drive.** Examples of these are CD–ROMs or DVDs. One or the other of these disks is usually integrated into modern computers though they may be external and plug into a USB port. They can both read and record and are mostly used for distributing digital information or data. During the 1990s, CD–ROMs replaced floppy disks and magnetic tapes, but these have mostly given way to memory sticks and DVDs.[41]
- **Memory sticks.** Also called pen-, flash- or thumb-drives, these sticks, which plug into a computer's USB port, can store large amounts of data (typically 4–64 GB). They have advantages over CD–ROMs in terms of their memory capacity, their ruggedness, their reliability, their speed and compactness, and their ability to erase and thus rewrite. They are now frequently used for data back-up purposes.

There are two other important hardware items associated with computing that are discussed here: (i) uninterruptable power supply; and (ii) wireless routers and modems

- **Uninterruptable power supply (UPS).** This is a free-standing piece of equipment that provides emergency power when the main supplies are interrupted through complete failure or through voltage changes. UPS differs from an emergency power supply in that it provides instant power continuity, usually for periods of up to 30 minutes. UPS vary in size according to the amount of power that they need to protect. They are extremely important for computing because they can prevent severe data losses, especially in areas prone to frequent power cuts, and they can be programmed to automatically save any data.
- **Wireless routers and modems.** As most data will nowadays be delivered via the Internet, serious consideration must be given to making data delivery as efficient as possible. Traditionally, a wired connection has been made between the computer and the Internet source, and this has used telephone lines, a modem[42] and other DSL (digital subscriber line) technology. However, use of phone lines and DSL modems meant that data delivery speeds were very slow. In the 1990s, many urban areas were connected to cable networks allowing cable TV and broadband[43] Internet access via a cable modem, and data delivery speeds to computers

[41] Because of their higher storage capacity and the fact that they can play video films, DVDs have replaced most CD–ROMs from the business computing marketplace, though the latter remain important for audio purposes.

[42] Modem is short for "modulator-demodulator". Basically a modem converts an audio signal into a digital format and vice versa.

[43] The term "broadband" has gradually evolved to now describe Internet connections that range from 5 to 2 000 times faster than earlier DSL technologies. The concept of broadband incorporates both connection capacity (bandwith) and speed. Higher transmission speeds have been achieved mainly by the use of fibre optic cables.

FIGURE 2.5
A typical wireless router

Source: SlipperyBrick (2009).

were greatly increased.[44] Today, the technology for Internet download is more frequently based on wireless connections. Through the use of the wireless wide area network (WWAN), information is transmitted from an Internet source to the computer. For the transmission to function, the computer must be within receiving distance of a wireless router – in a so-called "hot spot" area which may have a radius of 30 metres.[45] Figure 2.5 illustrates a wireless (WiFi) router, whose purpose is to facilitate both incoming and outgoing communications through determining the next network point to which a data packet should be directed. It is likely that the future for Internet transmission will mostly rely on wireless technology and, indeed, most computers are now sold with the necessary wireless network (Ethernet) card to allow for this. For further information on wireless technology, see Discovery Communications, LLC: http://computer.howstuffworks.com/wireless-network1.htm.

2.2.3 GIS output devices

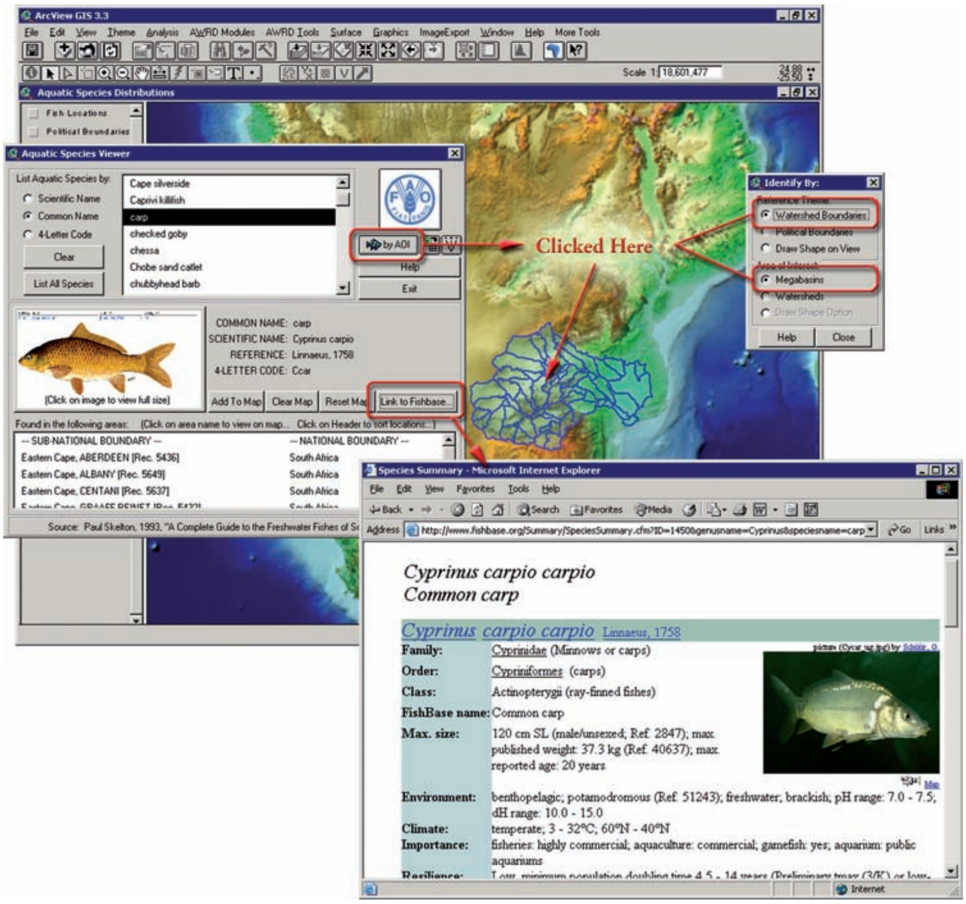
Although GIS output may be in various forms (textual, mapping, graphs, tables, spatial multimedia, etc.) and it can be sent to disks, to the screen, to the Internet or for hard copy output, under this heading two broad categories of GIS output can be distinguished. These are hardware for temporary, ephemeral output devices (soft copy) and hardware for permanent output devices (hard copy).

- **Ephemeral output devices.** This type of output includes graphics, maps or text that is temporarily displayed on the computer monitor – so the computer screen becomes the hardware output device for ephemeral images. These screen images can be used immediately by the GIS operative in any number of ways before being cleared from the screen (output) by either being deleted or saved as a file. Figure 2.6 illustrates screen output using Environmental Systems Research Institute (ESRI) ArcView GIS software. Items are usually filed via the use of hard drives, optical disks or memory sticks (see Section 2.2.2). Filed images may typically be stored as GIF, JPEG, PDF or TIFF images, or using the "Print Screen" on the computer keyboard, the images can be directly "pasted" into any document or slide, or into Microsoft Paint or Paint Shop Pro for further editing. Any material filed can be subsequently distributed (output) by, for instance, creating slide or multimedia shows, or by transmission to the World Wide Web. Material forming part of a slide or multimedia show is usually displayed via the use of a data projector. This is a device that projects computer output onto a white or silver fabric screen that is wall, ceiling or tripod mounted. Data projectors

[44] The bandwidth of the connection may be an important constraint to Internet use in many countries and users are advised to check on this before relying on the Internet, especially for down-loading large data sets.

[45] So-called WiMAX (Worldwide Interoperability for Microwave Access) technology is now emerging. This is designed to provide faster wireless access (3 Mbit/s) over far greater distances, i.e. perhaps 50 km.

FIGURE 2.6
Computer-generated temporary (ephemeral) screen output



Source: Jenness, *et al*. (2007).

typically accept resolutions of 800 × 600, 1024 × 768 or 1280 ×1024 and may also support standard video from a VCR, DVD or cable box. Data projectors are primarily associated with the ubiquitous Microsoft PowerPoint presentations.

Increasingly large amounts of data and information are being made available as output to the Internet. This is normally accomplished via the use of a Web-space provider or Internet service providers (ISP). These are companies that, after registering with them, will allocate the supplier space on one of their file servers. This service is frequently available free of charge. Using software called a file transfer protocol (FTP), any operative or organization creating desirable digital output can send copies of files from its own computer to the ISP, which will distribute the files via the Web on its behalf. All files given to the ISP will need to be properly organized in a logical system of files and directories, and any hyperlinks will need to have been established. GIS cartographic output over the Internet may be in the form of maps in reports, in atlases, or in virtually any source where maps can be of benefit to the supplier. Data for GIS can also be delivered in a similar manner. The following Web address provides additional useful information: www.ntchosting.com/encyclopedia.html.

- **Permanent output devices**. These comprise a wide range of plotters and printers. It is sometimes difficult to differentiate between these categories, but generally, plotters will draw lines, polygons, etc., usually on a paper or film medium, whereas printers will use one of several other means of reproducing graphical output, e.g. inkjet or laser printing. Table 2.1 summarizes the main hard copy output devices, listing them in increasing order of average cost. The output speed of printers is usually measured in “pages per minute” (ppm) for A4 size sheets. Printing of GIS generated maps can frequently be at lower speeds because of the density of information on a mapped page. Compared with the output to the screen, obtaining permanent hard copy output is slow and expensive. The range of colours obtained is usually less than on the screen, especially from plotters where the maximum may be only six. To obtain a large size output can be very expensive in terms of capital outlay for the printer or plotter and for supplies of consumables such as paper, film and inks. All output devices must be installed[46] so that they can communicate with the computer, and not all brands of equipment are compatible. Pen plotters have essentially become obsolete because inkjet technology is now of exceptionally high quality and output is rapidly obtained using an almost infinite array of colours. In fact, for most GIS-based work, users would utilize inkjet or laser printers, and both of these come in a large range of models, sizes, quality, etc.

TABLE 2.1
Summary of main hard copy output devices

Device	Colour	Speed	Resolution	Other comments
Inkjet printer	Mainly colour	A4 size = mono 5–30 ppm Colour 4–20 ppm A0 size = Colour 1–2 ppm	600–200 dpi	The most used hard copy output device. Advantages in terms of speed and cost. Millions of colours potentially available. Low-cost desktop versions may have low resolution and quality.
Pen plotter	4 to 6 colours	Ball point pen = 100 cm/sec Ink pen = 5 cm/sec	Drum: 0.025 mm Flat: 0.0075 mm	Can be large drum or flatbed. Flatbeds vary from A4 to A0 size. Quality output using ink is better than ballpoint. They cannot produce a solid region of colour.
Laser	Mono	A4 size = 100–200 ppm	600–1200 dpi	A4 size output is very inexpensive, though hardware is more expensive than for inkjet printers.
Colour laser	Colour	A4 size = 50–100 ppm	500–1000 dpi	The capital cost of these printers makes it difficult to compete with colour inkjets for small volume work.
Thermal wax	Colour	Less than 1 ppm	300 dpi	Produces high-quality colour prints, but is slow and expensive.
Electrostatic	Colour	A0 size = 1 ppm	200–400 dpi	Despite low costs for output, the high cost of these printers makes them difficult to justify for GIS work.

2.2.4 GIS architecture

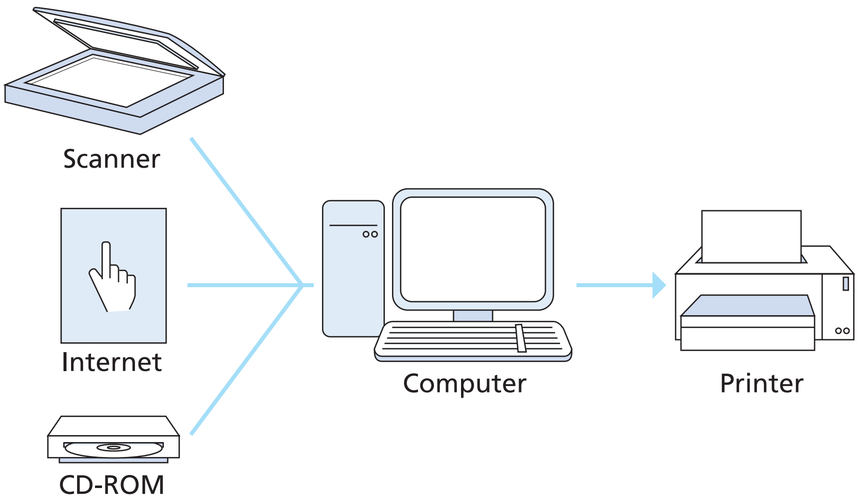
Here, the concern is with bringing the hardware devices together in order that the whole GIS can function in an optimum manner – it can be envisaged as hardware configuration. It is important to state that there is an almost infinite variety of ways in which hardware devices can be configured for GIS purposes, and the architecture that is finally adopted will be a function of the computing hardware that is inherited, the capital outlay available, the purposes of the GIS, the size of the organization doing the GIS work and a knowledge of what is available plus any personal preferences. Whatever system is adopted, there will be a possibility to readily make changes, additions and upgrades. Each of the systems described will be conceived in terms of networks, and the discussion on these will proceed from the simple to the more complex. Further details on the general aspects of computer networks may be found at: Micro2000: www.micro2000uk.co.uk/network_info.htm; or Techi Warehouse: www.techiwarehouse.com/cms/engine.php?page_id=d9e99072.

[46] This means that an installation process is performed whereby information about the device being installed is given to the host computer.

Personal area network

Although it is perfectly possible to undertake fisheries GIS work as an individual who is only deploying a computer and probably a printer, this so-called “stand-alone” configuration will not be discussed here, as nowadays any valuable fisheries GIS work would almost certainly be linked to a broader public, almost certainly via the Internet. So the simplest architecture considered is the personal area network (PAN). Figure 2.7 illustrates the main components of a PAN configuration.

FIGURE 2.7
Main components and linkages in a personal area network computer architecture

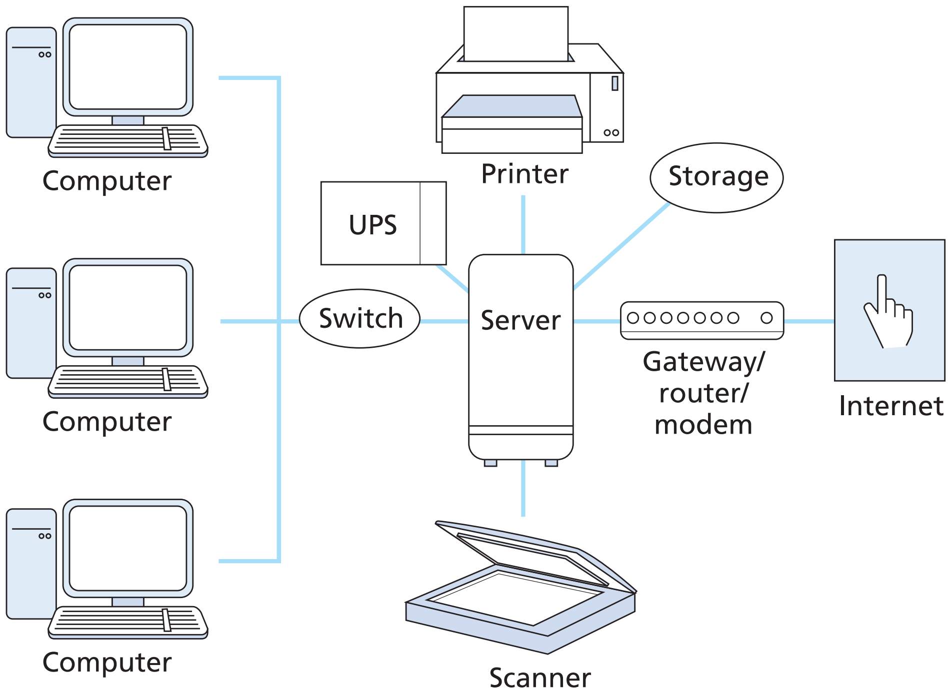


Here, a single desktop or laptop computer is linked to a normal array of peripheral computing devices. As it would be virtually impossible to undertake valuable fisheries or aquaculture GIS work without having access to the Internet, this link is shown. Internet access is important for both inputs to the GIS work (data and information) and for outputs from the GIS work. To achieve Internet access, it is vital that some sort of “gateway device” is installed, and this can be physically integrated to both a router and modem (see Section 2.2.2). A “gateway device” is any appliance that allows different parts of either the local area network (see below) or a wide area network (see below) to be functionally connected. Connections from the computer to the gateway and then to the Internet may be through a wired connection, but are now increasingly being achieved through wireless means. Both printer and scanner are likely to be A4 size, with the former being inkjet or laser. Additional hardware such as a laptop, memory sticks, any optical storage media and a modem might also form part of this basic configuration.

Local area networks

A local area network (LAN) would be a far more typical computer configuration for fisheries or aquaculture GIS. This derives from the fact that most of this work would be carried out in office or research laboratory situations, where several people may be working together on projects and where some of the equipment and most of the data would be shared. Figure 2.8 gives some idea of a LAN configuration, though there could be almost infinite variations in terms of actual devices and hardware capacity to this basic model.

FIGURE 2.8
Main components and linkages in a LAN computer architecture



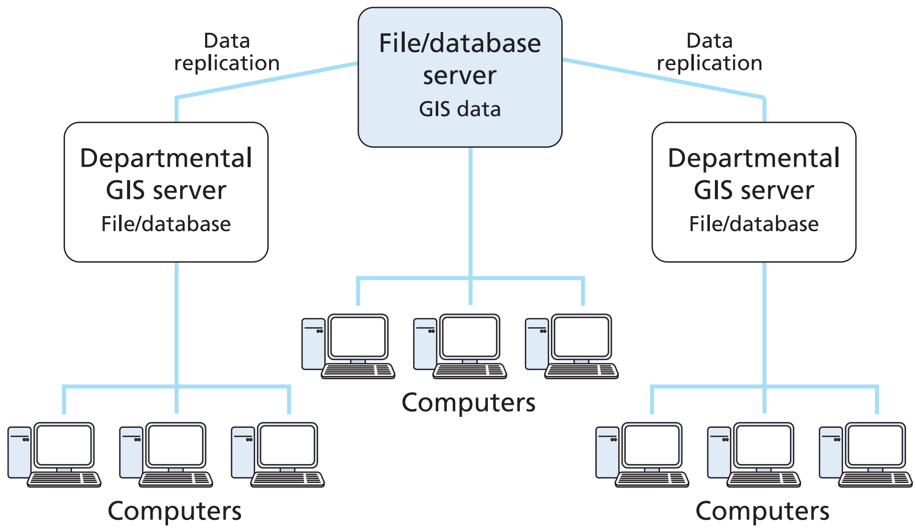
In the LAN configuration, there are likely to be a number of desktop computers according to the number of staff doing GIS (or other) work, with additional computers (including laptops) being easily accommodated. Because of the additional workload (relative to a PAN situation), a server will likely be deployed. Servers can store data files that are likely to be used by at least several of the employees, or they can do processing, etc. They can also facilitate the sharing of the various devices, meaning that it is not necessary for all of the computers to be capable of doing all functions or storing all data. The switch connects segments of the network. Printers and scanners can also be linked to the server, so there is no need for each person to have their own. A UPS is important in terms of data and file security in times of power failure. As in the PAN network, there is access to the Internet via a combination gateway/router/modem. It can be seen that a LAN network has considerable cost savings over a PAN, in terms of equipment saving, software licences and workload management, and the GIS sector of the LAN can be integrated to other sectors of a business or institution. Additional information on LANs is given at Farlex, Inc. (http://encyclopedia2.thefreedictionary.com/Local-area+networks).

Wide area networks

A wide area network (WAN) is basically an extension to a LAN, but instead of acting locally (usually within one office or institution), the WAN may be an area, regional, national or international network of linked computers[47]. Strictly speaking, as it also consists of a massive series of linked computers, the Internet itself is an example of a WAN. However, in terms of a fisheries or aquaculture GIS, the WAN may comprise the related work going on in dispersed institutions, e.g. within perhaps a larger university or fisheries research institutes or government fisheries departments.

An example configuration is shown in Figure 2.9. WANs function mainly as a convenient way of gaining remote site access for e-mailing, file transfer, etc., and access to the WAN by any PAN or LAN is gained via the router, which typically relies on wireless connections. Additional information on WANs can also be obtained from: Farlex, Inc. (http://encyclopedia2.thefreedictionary.com/Wide-area+networks).

FIGURE 2.9
A wide area network (or a distributed computing environment)



2.3 GIS SOFTWARE FOR FISHERIES AND AQUACULTURE

Before any discussion of specific GIS software for fisheries or aquaculture purposes can take place, it is necessary to place limits on what can be discussed. This is because the range of software that could be employed is very wide indeed and therefore the discussion is restricted only to software that might be of direct use. It does not cover software such as operating systems, word processing, databases, spreadsheets, image processing, graphical packages, digitizing software or remote sensing, any of which might be used in combination with GIS. There are a number of options that may be pursued in obtaining appropriate software:[48]

- to purchase a general proprietary package;
- to purchase a ready developed software system from a third-party user;
- to develop in-house software;
- to employ consultants to write new software;
- to obtain free and/or open source software;

[47] A WAN is sometimes referred to as a "distributed computing environment".

[48] Given that GIS can cover a wide range of applications, a single software does not often provide all the features and functions needed to carry out all the GIS tasks needed by a user, so it is common practice to use more than one software. GIS software selection is entirely dependent on the user's needs and capacity (i.e. hardware and trained personnel) to achieve the desired objectives.

- additionally, it is possible to acquire "extension tools", which are customized packages that can be added to a GIS in order to undertake particular GIS-based tasks.[49]

For the present purposes of this technical paper, it is assumed that the means of developing in-house software is not available and that, in terms of mainly cost and known GIS needs, it would not be appropriate to employ a consultant to develop what might have to be a very comprehensive software package. The software considered can best be examined under three headings:

- general proprietary GIS packages;
- specialist marine fisheries software;[50]
- free and open source GIS software.

2.3.1 General proprietary GIS packages

Here, proprietary software is defined as that which is supplied and owned by a private company, in the sense that it owns licensing arrangements and places restrictions on how the software can be used. Although proprietary GIS software packages first became available nearly 50 years ago and the number of such packages rose rapidly until the 1990s, today rationalization and concentration has occurred to the extent that only a few major companies dominate the field offering important general-purpose GIS packages. That is not to say that there are not a much larger number of GIS software products that are available and which have been developed by many proprietary software companies for more specific purposes. Moreover, many GIS users have adapted general proprietary GIS for fisheries and aquaculture-related spatial analytical[51] purposes.

All the main proprietary GIS packages consist of a collection of subprograms that together give the GIS software its wide range of functionality. The components of a GIS package should allow for at least the following minimum range of functions:

- for the input, editing, manipulation and export of geographic data in industry standard formats (e.g. jpeg, tiff, gif, etc.);
- usually for digitization and for textual entry and display;
- for geographic query, analyses, modelling, visualization and graphics display;
- for database management (DBM);
- for graphical user interface (GUI) allowing easy access to tools.

Many proprietary GIS also have separate software "modules" that can be added to the core GIS to enlarge the range of program functionality. There is frequently an additional charge made for these modules.

The price of proprietary GIS software packages varies greatly, according to: (i) the functional range of the complete package: (ii) the buyer;[52] and (iii) the number of seat licences bought. Some GIS suppliers market various suites of programs that function as "add-on" modules to the main program, and which sometimes add significantly to the overall cost. Some proprietary GIS programs can be purchased cheaply if the user is willing to buy an older version and, indeed, older versions can sometimes be obtained free. Generally speaking, software that is designed to operate using the raster model (see Chapter 7) will be cheaper than software that supplies both raster and vector functionality.

As all main proprietary GIS software products vary significantly in terms of their range of functions, it is difficult to make objective comparisons between products. In

[49] Two examples of customized extension tools can be found in: (i) Recommendation Domains for Pond Aquaculture (www.fao.org/fishery/gisfish/id/4815); and (ii) African Water Resource Database (www.fao.org/fishery/gisfish/id/2822).

[50] To the author's knowledge, there is no proprietary software specifically for aquaculture-related GIS work. The closest example is a specialized GIS software called MarGIS (www.marcon.ie/website/html/margisdemo.htm).

[51] "Spatial analytical" purposes may also be described as "geospatial" purposes.

[52] Buyers influence the price of software because discounts may be given, for instance, to educational users.

fact, GIS product purchase would seldom be based on its functionality or ease of use, but more on "what others use" and familiarity with well-branded software. Therefore, when purchasing software, it is extremely important to consider not only what the GIS is capable of doing relative to its price, but also factors such as the ease of finding GIS operatives trained in the use of specific software, plus the support given to software,[53] the quality of the visual output, and any compatibility (or interoperability) issues. Most proprietary GIS software providers have now developed products based on so-called "open standards" – this is to ensure a high level of interoperability across platforms, databases, development languages, and applications.[54] Table 2.2 provides a brief overview of some of the main proprietary GIS software, with "comments" being derived from user groups and discussion forums. Although these products will have been developed for normal terrestrial geographic analyses, they have all been utilized somewhere for aquaculture or a range of fisheries GIS purposes. A complete and updated list of commercial (proprietary) software can be found at www.spatialanalysisonline.com/SoftwareCommercial.pdf.

2.3.2 Specialist marine fisheries software

Some readers may wonder why those engaged in spatial decisions relative to fisheries or aquaculture do not simply acquire suitable software that has been developed for that purpose. The answer to this is quite straightforward. From an inland fisheries or aquaculture perspective, there is little point in developing specialized GIS. This is because these activities are more or less terrestrially based and so conventional GIS software capabilities can be deployed for almost all prospective analyses. For marine aquaculture, the situation is somewhat different and their spatial considerations would be more aligned to those of marine fisheries. However, for marine fisheries, specialist GIS software has been very slow to emerge, and this has largely been a function of the following:

- The necessity of capturing, handling and managing data, and performing spatial analyses, that are largely in three or four dimensions and that are concerned with mapping mainly moving variables. Few conventional GISs handle the vertical dimension, and maps of moving variables may have very low statistical significance.
- Fisheries tend to be a fragmented activity, in the sense that it has traditionally functioned as numerous small enclaves of activity, and as such has not warranted the development of a complex management tool.
- The functionality of any GIS developed for fisheries purposes would need to be very wide indeed, i.e. because there are so many facets and dimensions to the activity, and there would be few markets for such a large (and probably expensive) multifunctional software package.
- Terrestrial spatial analyses can function in an environment containing numerous physical or anthropogenic boundaries and other mappable structures, i.e. features that can form points and lines on maps. In the open sea, this is far more nebulous.

These restrictions have meant that it is difficult to identify specific market sectors for fisheries GIS, so few groups have seen an opportunity to benefit financially from developing specialist fisheries GIS software. There have been developments in marine, oceanographic and/or coastal GIS software applications and these have been documented in Valavanis (2002) and Wright *et al.* (2007).[55]

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[53] Importantly, this support could include not only official back-up support from the software provider, but also support from other in house or easily accessible colleagues or acquaintances.

[54] For more information on open standards and interoperability, see ESRI (www.esri.com/library/whitepapers/pdfs/spatial-data-standards pdf) or Open Geospatial Consortium (www.opengeospatial.org/standards).

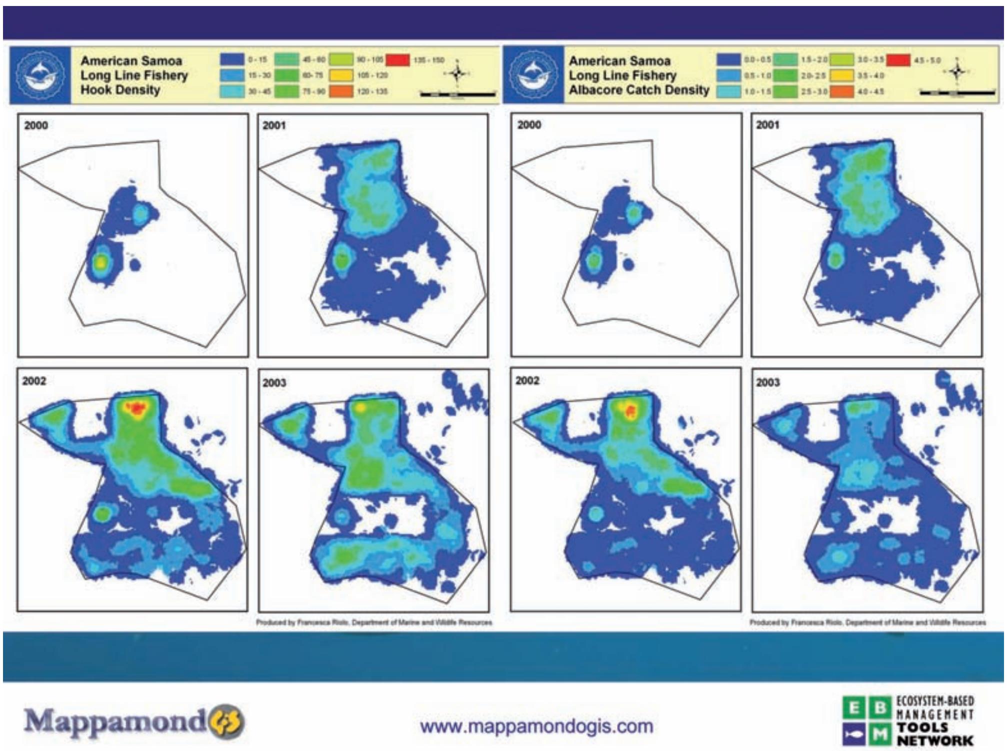
[55] Many marine and coastal software applications are listed at Capn' Dawn J. Wright and OrSt: (http://dawn-drupal.science.oregonstate.edu/soft).

TABLE 2.2
Overview of five main proprietary GIS software

GIS company (Web address)	Main products	Product strengths	Comments
ESRI (Environmental Systems Research Institute) (www.esri.com)	ArcView ArcInfo ArcGIS Engine ArcGIS Server ArcExplorer ArcPad plus others	• Online and instructor-led training • Extensive almost worldwide support, including user forums. • Wide range of specialized products. • Large market share means extensive familiarity with most products. • Basic software has a wide range of tools. • Wide range of additional services and data provided.	World's largest GIS by market share. Quite complex to learn. Easily copes with raster and vector. Demonstration products available online. ESRI publishing produces many GIS-related books. Runs on Windows and Unix platforms. ESRI sponsors a very popular annual GIS conference.
Clark Laboratories Clark University (www.clarklabs.org)	IDRISI Taiga Land Change Modeler Earth Trends Modeler	• Very inexpensive package – only US$95 for a student licence. • Provides nearly 300 modules for the analysis and display of digital spatial information. • Capable of very sophisticated GIS work. • Incorporates remote sensing image processing. • Made for the Windows platform. • Comprehensive tutorial material and technical assistance makes learning easy.	Developed within a university research environment. An integrated GIS and image processing software. Started in 1987, IDRISI is often used in teaching and research. The decision support modules are unique in that they specifically address multi-objective, multi-criteria resource allocation decision problems, as well as problems of assessing and incorporating uncertainty in the decision-making process.
Pitney Bowes MapInfo Corporation (www.mapinfo.com)	MapInfo Professional V.10	• One of the easiest GISs to use • Extensive training provision. • Made for the Windows platform. • Designed for easy visualization.	Since 1986, a commercial general-purpose product aimed mainly at the business market. This product integrates well with other Pitney Bowes business packages. Users still looking for an active discussion group.
Intergraph Corporation (www.intergraph.com)	GeoMedia Professional (one of many GeoMedia spatial products)	• Extensive training and technical support provision. • Many special purpose modules integrate to the basic product. • Wide range of functionality. • Claims to have the most comprehensive GIS on the market today.	This longstanding product integrates well with other applications. The company has been trying to broaden its horizons towards research uses. It provides a range of spatial management services, mostly to government departments. Difficult to gather neutral information on their GIS products.
CDA International Ltd (www.manifold.net)	Manifold Release 9	• Low-priced system gives good price to feature ratio. • Runs on all recent versions of Windows. • Impressive array of vector- and raster-based functionality. • Claims to have the most powerful database capabilities of any GIS. • Easy-to-use system. • Thriving online user group at www.georeference.org.	A new product compared with most commercial GIS. Prices for the basic Manifold software are in the US$250–US$350 range – more expensive versions are available containing more tools. Output from the GIS is basic compared with other GISs. Good range of technical support and accessories. Difficult user interface.

Despite the challenges outlined above, there has been progress in developing fisheries GIS software. Until the 1990s, almost all marine fisheries GIS work was performed on proprietary GIS software and examples of this work can be found in Nishida, Kailola and Hollingworth (2001). During the 1990s, GIS specialist applications were emerging that developed systems allowing for a limited range of marine and/or fishery GIS functionality, or niche software was being adapted to marine problems, e.g. to give 3D portrayals of fish shoals or bathymetry. There is now increasing work being promoted on applying small software applications to undertake specific GIS tasks, with much ofthis work being based on free and open source software (see Section 2.3.3) (Gill *et al.*, 2001; Wood, 2004; Wood and Dunn, 2004; Bordalo-Machado, Sousa and Matos, 2007). Some efforts have been made to integrate GIS functionality with fisheries electronic logbooks in order to map fish catches (Kemp and Meaden, 2002; Mikol, 2004), and Kiyofuji *et al.* (2007) report a modular fisheries GIS to support effective low-cost fishing around Japan. However, notwithstanding the many specialized software applications, few of these have been multifunctional in the sense that they could be called a comprehensive fisheries GIS. A recent multifunctional proprietary application that has emerged, one that integrates to ESRI's ArcGIS 9.x, is Fishery Analyst produced by Mappamondo GIS (see Mappamondo GIS: www.mappamondogis.it/products.htm). To quote the distributor "The main functions are quantitative estimation and visualization of catch and effort and their variation in space and time, analysis of fishing vessel utilization, data quality control, and deriving information on the location of important economic and threatened species. The application provides a

FIGURE 2.10
Output from Mappamondo GIS showing the development of albacore tuna catches around American Samoa from 2000 to 2003



Source: Riolo (2008).

Note: Maps produced by Mappamondo GIS using Fishery Analyst (www.mappamondogis.it/fisheryanalyst.htm). Data derived from the monitoring program run by the Pacific Islands Fisheries Science Center in Hawaii and the Department of Marine and Wildlife Resources in American Samoa.

user-friendly analysis interface allowing for easy and diverse output production. The interface allows the user to choose the analysis to perform (effort, catch density, catch per unit of effort etc.) and to select data on criteria such as year, vessel name and/or size, and fish species caught." An example of output from Mappamondo GIS is shown in Figure 2.10. Very recently, Mappamondo has launched a Web-based version of its fisheries GIS software called "Fishery Analyst Online" allowing the user to perform online many of the functional analyses mentioned above (see also Mappamondo GIS: www.mappamondogis.it/products.htm).

The only dedicated multifunctional fisheries GIS software package to have emerged is Marine Explorer produced by the Environmental Simulation Laboratory in Saitama, Japan (Environmental Simulation Laboratory Inc., 2007). This menu-driven software has been developed over the past 15 years as a joint public/private sector project. Marine Explorer can be used to input, store, manipulate and display a full range of fisheries or oceanographic data in both vertical and horizontal dimensions, with output being in mapping, chart or other graphical forms. The system has an integrated simple spreadsheet format for data entry and storage, though it can be linked to external databases and to remotely sensed data sources such as satellite or acoustic systems. Besides simple analyses, it can perform complex tasks such as fishing ground forecasting (to predict promising fishing grounds in real time), geostatistical analyses and abundance estimations. Table 2.3 outlines the main functions and illustrates software applications that can be integrated to Marine Explorer. It is now being used by more than 200 governments and research and university fishing agencies in 12 countries.[56]

2.3.3 Free and open source GIS software

Most groups already working in fisheries or aquaculture GIS will have chosen a core proprietary GIS and will presumably have become familiar with it. Given the length of time taken to gain this familiarity, in most cases it will be worth continuing with the chosen GIS and, indeed, the use of existing GIS software will generate an immediate return in terms of expediting analysis and modelling outputs. However, dependence on known software can deprive users of the flexibility to adopt an open-minded approach to resolving spatial problems. Thus, there are an increasing number of ad hoc GIS applications and spatial information systems designed to collate, manage and visualize spatial information related to a range of terrestrial and marine circumstances. Because of the need to have more flexibility, they are mainly based on open source software and, indeed, they can often be categorized as "freeware". They are discussed here both because of the greater flexibility that these programs may offer to the user and because of the significant cost savings than can accrue.[57]

It is important to describe the difference between "free" and "open source" software (FOSS). Free software (freeware) first emerged in the 1980s from the Free Software Foundation (FSF) established in the United States of America by Richard Stallman. The FSF took an opinion that software source code should be free and freely distributed as a matter of principle and not price, and they were sceptical of the power that could accrue through commercial control of software. The user is free to run, copy, distribute, study, change and improve the software - having access to the source code and to any software manuals is an essential free right to accomplish these freedoms. In the late 1990s, Eric Raymond founded the Open Source Initiative whose more pragmatic focus was on the commercial adoption of FOSS and the software development process used, i.e. rather than the ideology of

[56] See Marine Explorer Support on the www.esl.co.jp for more details.

[57] For example, the Norwegian Mapping Agency has recently switched to using the free GNU/Linux operating system for their online map servers at a saving of 2 million Norwegian kroners (US$327,000).

TABLE 2.3
Functional capabilities of Marine Explorer

Major functional areas	Examples of functions	Software applications Program environment
Spatial information database	**General GIS functions** • Spatial data entry, update, sort, search, filtering, etc. • Quality control **Special functions for fisheries and aquatic data** • Worldwide bathymetry database • Fine-scale local bathymetry database • Sonar and echosounder (mass data) processing • Satellite data processing, e.g. SST, ocean colour, sea surface height, etc.	• MS/Excel • MS/Access • Other databases • Satellite data • Processing programs (20 types) GeoTiff (acoustic data processing)
Visualizations and mapping (2D and 3D)	**General GIS functions** • Visualization by symbols (50 types) • Overlay (128 layers) • Polygon (for non-grid type data) • Composite satellite images **Special functions for fisheries and aquatic data** • Contours (horizontal and vertical) • Buffering (EEZ, MPA, moratorium area) • Presentation of bathymetry • Trajectory of conventional, archival and pop-up tags • Tracking of the movement of vessels (GPS) • Pinger tracking of animal movements • Management (detection of IUU vessels, effort control, and monitoring fisheries by VMS) • Satellite (SST, chlorophyll-a, sea surface height and currents) • Current data (ADCP) • Echosounder (fish distributions from echograms) • Sonar (composition of mosaic images to depict bathymetry)	• MS/Dot NET • Framework • Surfer • GeoTiff (acoustic data)
Spatial/ numerical analyses	**General GIS functions** • Computations of area and distances **Special functions for fisheries and aquatic data** • Gridding (catch, CPUE, SST, etc.) • Contour (density) estimations by kriging techniques (SST data from CTD) • Computation of average and anomaly distribution • Habitat Suitability Index (HSI) • Pinpoint forecasting of fishing and oceanographic conditions by match-up analyses using grid data including satellite information • Geostatistics (spatial GLM) • State-space model (Bayesian processing) • Spatial stock assessment (production models, VPA and integrated models) • Analyses of currents and tides	• Surfer • Spherical trigonometry for the globe (to compute accurate area and distances)

Note: ADCP = acoustic doppler current profiler; CPUE = catch per unit effort; CTD = conductivity, temperature and depth; EEZ = exclusive economic zone; GLM = generalized linear model; GPS = global positioning system; IUU = illegal, unreported and unregulated; MPA = marine protected area; SST = sea surface temperature; VMS = vessel monitoring system; VPA = virtual population assessment.
Source: Adapted from ESL (2008).

the FSF. Some freeware and open source software may need to be purchased and this is fine as long as the user retains the right to copy and change the software as required.[58] The emergence of FOSS can be viewed as part of a wider movement towards making freely available a much larger range of computing software and data that form "the foundation of a learning society where we share our knowledge in a way that others can build upon" (FSF, 2008).[59] So, both types of software, as well as providing access to free or very inexpensive GIS capability, come with a source code that can be modified and then passed on to others, or it may have simplified licensing arrangements and the user is not tied into the sometimes restrictive demands of the proprietary GIS software suppliers. The discussion that follows does not generally discriminate between freeware and open source GIS software.

The growth of FOSS has also spawned the creation of recognized subdivisions within the world of FOSS GIS, including strong support mechanisms. Thus, as well as the groups who are developing the software itself, there are groups interested in "libraries" (catalogues of projects and/or programs that are classified as FOSS), plus groups interested in Web-serving requirements for the online delivery of data and software. Ramsey (2007) also notes that groups within the FOSS GIS community can be subdivided according to the programming languages that they are working in, and with respect to the types of organizations that are promoting FOSS, e.g. government agencies, universities and/or research establishments, commercial companies and individual enthusiasts. Since 2006, the Open Source Geospatial Foundation (OSGeo) has been in operation and its mission is "To support the development of open source geospatial software, and promote its widespread use",[60] and Sveen (2008) claims that the FOSS GIS community is now centred around this OS Geospatial Foundation, which serves as a host for several projects. Additionally, there are now moves by the International Cartographic Association to achieve professional and technical operating standards for the development of free and open source geospatial software.[61] Although organizations are trying to pursue the rights for more users to have access to freeware,[62] on the other hand, many scientific institutions are trying to facilitate the exchange of information among the community of researchers and managers, and they may see the need to retain existing "conformist" proprietary GIS software. The balance between opting for conformity and choosing to migrate to cheaper experimental or developing GIS may be difficult to achieve. However, Steiniger and Bocher (2009) outline the enormous rate of expansion in the use of FOSS since 2006, with a 6 percent rise in two years in the number of FOSS GIS projects listed on the www.freeGIS.org Web site, and with some companies experiencing a 45 percent increase in free GIS downloads over the last three years. Taken together with the emerging support groupings,[63] plus the fact that 750 participants attended the FOSS4G (FOSS for Geospatial Conference) in 2007 in Victoria, Canada, and 869 attended the 2010 conference in Barcelona, Kingdom of Spain, this all points to the healthy nature of FOSS GIS developments. Table 2.4 summarizes the major advantages and disadvantages of FOSS compared with proprietary GIS.

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[58] There are a number of free GIS software products that cannot be classified as FOSS because of their licensing conditions - Google Maps and Google Earth are examples.

[59] For initiatives that focus especially on the free availability of geodata, see FreeGIS: www.freegis.org.

[60] For further details, see OSGeo: www.osgeo.org/content/foundation/about.html.

[61] See details at: http://ica-opensource.scg.ulaval.ca/index.php?page=home.

[62] See, for instance, www.fsf.org.

[63] Support is also available for most applications on mailing lists, discussion forums, wikis, search engines, etc.

TABLE 2.4
Major differences between proprietary and free and open source software

	Proprietary software	Free and open source software
Advantages	• Products are under warranty • All components should work together • Software is usually well documented • Pool of trained workers in some GIS brands	• No licence fees • No limit on the number of installations • No update enforcement • Support of open standards • Support usually available from several providers • Customization at API level • A wide range of unique functionalities • Access to source codes
Disadvantages	• Software price and maintenance fees • High training costs • Maintenance tied to specific licensed companies • Customized development can be difficult due to available resources from vendors • Support only as long as software company exists	• Installation and integration know-how necessary • Training costs • Software developments likely to be more tenuous

Source: Adapted from Weiss (2006).

The range of GIS software under the FOSS heading is vast, varying from complete GIS packages to small applications that just perform a selected task. Table 2.5 gives brief details on some of the main GIS FOSS packages,[64] and the project developer's Web sites should be consulted for further details. If users of FOSS are thinking of adopting such software for future use in order to maintain the long-term viability of the software, it

BOX 2.5
Questions to ask of any open source software projects

Evaluations of projects using open source software (OSS) should ask:
- Is the project well documented? Does the availability of the software provide direct access to both the source code and documentation about the internals of the code? Is there tutorial-level documentation for all three user categories (user, administrator, programmer) to enable people to work with the software quickly?
- Is the development team transparent? Is it clear who the core development team is? Is the development team mailing list public? Is the current development version of the code available online? Is membership in the team attainable via a merit-based process?
- Is the software modular? Is there a clear method to add functionality to the project that does not involve reworking the internals? Is this method documented clearly with examples? Is there a library of already contributed enhancements maintained by the wider user/developer community?
- How wide is the development community? Are multiple organizations represented in the core development team? Are core team members financially supported in their work by sponsoring organizations? Is the development community national or international? How large is the user mailing list? How large is the developer mailing list?
- How wide is the user community? What organizations have deployed the software? What experiences have they had?

The more of these questions that are answered in the positive, the healthier the OSS project is.

Source: Modified from Ramsey (2007).

[64] For a more detailed description of the evaluation criteria, please see www.spatialserver.net/osgis.

TABLE 2.5
A selection of major free and open source desktop GIS projects

Project/software (year founded)	Evaluation criteria					
	Application focus	User level**	Supported operating systems	Development platform	Development by	Software licence***
GRASS (1982) (http://grass.osgeo.org)	Analysis and scientific visualization, cartography, modelling and simulation	Good novice to expert	MS-Win, Linux, MacOSX	C, Shell, Tcl/Tk, Python	Research institutes, universities, companies, volunteers worldwide	GPL
QGIS (2002) (www.qgis.org)	Viewing, editing, GRASS-graphical user interface	Novice to research	MS-Win, Linux, MacOSX	C++, Qt4, Python	Universities, companies volunteers worldwide	GPL
uDig (2004/05) (http://udig.refractions.net)	Viewing, editing, analysis	Novice to research	MS-Win, Linux, MacOSX	JAVA (Eclipse RCP)	Companies, organizations, volunteers	Core Eclipse RCP is EPL
gvSIG (2003) (www.gvsig.org/web)	Viewing, editing, analysis	Novice to research	MS-Win, Linux, MacOSX	JAVA	Companies, universities, government	GPL
Kosmo (2005) (www.saig.es)	Viewing, editing, analysis	Novice to expert	MS-Win, Linux	JAVA	Companies (project driven, utilities, etc.), government	GPL
SAGA (2001/02) (www.saga-gis.org)	Analysis, modelling, scientific visualization	Novice to research	MS-Win, Linux	C++ (MS Visual C++)	Universities	LGPL (API), GPL
ILWIS (1985) (www.itc.nl/ilwis)	(Raster) analysis	Novice to research	MS-Win	MS Visual C	Universities, companies	GPL
MapWindow (1998) (www.mapwindow.org)	Providing core GIS and GUI functions, developing decision support systems	Novice to research	MS-Win	MS Visual Studio .NET (C++, C#, VB.NET)	Universities, companies, volunteers worldwide	Mozilla Public Licence Version 1.1
JUMP/OpenJUMP (2002/3)* (www.openjump.org)	Viewing, editing, analysis	Novice to research	MS-Win, Linux, (MacOSX)	JAVA	Volunteers worldwide	GPL

* There are various versions of JUMP that are now being developed by private companies.
** User levels: novice (viewing), experienced (editing, simple analysis), expert (analysis), research (scripting, programming).
*** Licences: often software use different libraries resulting in a mix of different licences; therefore, only the software-core licences are listed.

Note: GPL = general public licence.
EPL = Eclipse public licence
LGPL = library general public licence
RCP = rich client platform

Source: Modified from Steiniger and Bocher (2009).

is important to verify the background to the software developers, and in particular to ask the questions shown in Box 2.5. Valavanis (2002) suggests that the main criteria to look for when choosing any GIS software are the learning curve, ease of use, hardware platforms, networking capabilities, the amount and formats of data that they can process and their connection abilities with other external packages, e.g. statistical and visualization software. Moreover, when considering the use of FOSS, it is essential to see the exact range of functionality that is contained within the softwarepackage or application. For instance, of the software listed in Table 2.5, the only fully-fledged GIS packages would be GRASS and ILWIS, i.e. they could be compared with the proprietary packages covered in Table 2.2. Other applications in Table 2.5 have a more limited range of functionality. Beyond those listed, there are hundreds of smaller GIS applications and even smaller "plug-ins" that collectively perform a huge range of spatial analysis tasks. It is likely that most people involved in marine and fisheries GIS are using powerful GIS packages (proprietary or FOSS) as their main data servers and a series of peripheral applications and plug-ins (usually FOSS) for specific tasks (Valavanis, 2002). Sherman (2008) agrees that those who opt for the FOSS software route are essentially assembling a toolkit of loosely coupled FOSS applications rather than hoping to depend on one major software package to do all of the work.

Readers wishing to obtain up-to-date books covering all practical aspects of FOSS for GIS may refer to Kropla (2005) or Sherman (2008). For those who may wish to try out FOSS GIS without making a physical investment, this can be done using a live DVD or pen drive link. Thus, "OSGeo-Live 4.5 is a self-contained bootable DVD, USB pen drive or Virtual Machine based on Xubuntu, that allows users to try a wide variety of open source geospatial software without installing anything." (from http://live.osgeo.org/en/index.html). Readers wanting a good practical paper covering some of the numerous software issues confronting their use in a fisheries environment, may refer to Pierce, Wang and Valavanis (2002). The following Web sites provide additional information and more detailed listings of GIS freeware and open source software.

- FreeGIS Project: http://freegis.org;
- Open Source GIS: www.opensourcegis.org;
- Spatial Server.net: www.spatialserver.net/osgis;
- Government Open Source Software Resource Center: www.gossrc.org/geographical;
- GeoCommunity: http://software.geocomm.com;
- Spatial Analysis Online: www.spatialanalysisonline.com/SoftwareFree.pdf.