6. Remote sensing and GIS integration

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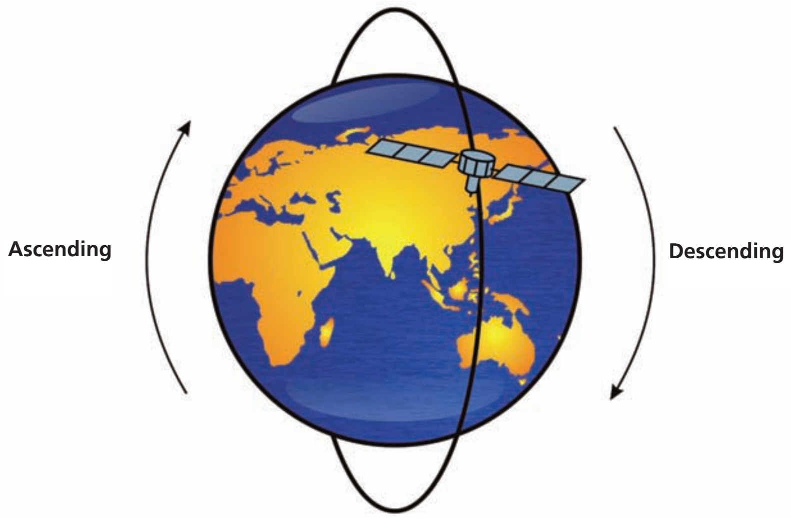
Aquaculture, and especially fisheries, is practised over a large proportion of the Earth's surface and, therefore, data gathering can represent a significant challenge to GIS work. However, satellite remote sensing is increasingly able to provide for these data demands, especially because it provides a unique capability for regular, repeated observations of the entire globe or specific regions at different spatial scales. This chapter introduces the basics of remote sensing and provides practical guidance for planning and implementing the use of this technology, including data sourcing, selection and acquisition, image processing, and the integration of imagery with GIS. The chapter concludes with four case studies showing applications of remote sensing under a range of pertinent scenarios.

Remote sensing functions on the principle that specialized satellite-based sensors can detect electromagnetic radiation (EMR) that is variably emitted or reflected from features on the earth's surface. Recorded EMR values can then be converted into a signal that can be transmitted to ground receiving stations and ultimately displayed as either numerical data or as an image on a computer. EMR energy takes the form of waves, which themselves are classified by their wavelength or frequency such as X-rays, visible light, infrared or microwaves. The source of energy for EMR can be either from the sun or from a radar system that transmits its own electromagnetic energy pulses. Different objects or features on the surface absorb, emit and reflect EMR having different wavelengths in a predictable and repeatable way, i.e. they are said to have recognizable spectral signatures. This allows for the classification of objects or features that are recorded by the sensor, though in many cases it may be necessary to verify (or ground truth) specific features to be certain of the correct identification of the data, e.g. the spectral signature of vegetation or water may vary with the altitude of the sun or with the stage in a plant's growth. There are many types of remote sensing sensors and the technical paper gives details of those relating to fisheries or aquaculture work.

The majority of remotely sensed data are obtained from sensors mounted on satellites. There are two main types of satellite systems:

(i) **Polar orbiting satellites.** These satellites typically orbit the earth at 12 to 16 times per day at heights varying from about 250 to 1 600 km. Their orbits cross each pole and, because the earth is spinning on its axis, each revolution of the satellite passes over a different strip of the Earth's surface (Figure 6). The width of this strip from which data are collected is called the "swath"and this may vary greatly, e.g. typically from 10 to 1 000 km. Individual orbiting

FIGURE 6
Polar satellite orbits



satellites may be operational for several decades and thus vast data sets will accumulate, which are useful for examining spatial changes over seasons or from year to year.

(ii) **Geostationary satellites.** These satellites operate from an orbit of 35 900 km, at which height they are sited permanently over the equator and over the same Earth location. These satellites therefore have a high observational frequency. However, their height means that the data resolution is low, and they are thus used mainly for telecommunications or meteorological purposes.

As well as satellite systems, there are airborne sensors that are mounted in a range of manned or unmanned aircraft (or in balloons). These are not able to provide long-time series of data, but they are able to capture much more specific and detailed imagery.

The data gathered through remote sensing can be characterized in a number of important ways:

- Information content. The varied EMR emissions detected, and their subsequent processing, allow data to be gathered on an increasingly wide range of parameters.
- Spatial extent. This refers to the size of area covered by any imagery.
- Spatial resolution. This is the size of the individual picture elements (pixels) that make up an image, and it typically varies from extremely low resolution (»20 km^2) to high resolution (»1 m^2).
- Revisit frequency. This defines the frequency that observations can be made of the same area.
- Time series. The time period for which consistent observations are available.

- Timeliness. The speed that a product is made available to a user.
- Levels of processing. This describes the amount of processing that the data supplier has conducted before the product is made available to the user.

Different types of remote sensing data are suitable for specific fisheries and aquaculture applications, and for most applications the main types of data are categorized into optical or radar-based imagery. The technical paper provides background on the technical differences between these categories, and detail is provided on the main satellite systems that are being used for data gathering in each imagery category. Here, it suffices to provide examples of the parameters about which information can be gathered using one or other remote sensing method. Optical imagery can provide valuable information on land cover and land use information for inland fisheries applications, ocean condition data such as chlorophyll-*a* and suspended sediment concentrations, bathymetry, sea surface temperature, and data to support coastal zone fisheries and aquaculture management. Through the use of light detection and ranging (LIDAR) detailed topographic information can be derived. Radar-based imagery provides information on sea surface height, surface currents, waves and winds, the flooded status of vegetation or the surface roughness of a waterbody, i.e. these are all parameters where surface height characteristics are variable. The recent Soil Moisture and Ocean Salinity (SMOS) satellite is additionally able to gather radar-based data on marine salinity values.

What are the general areas associated with fisheries or aquaculture that remote sensing information is supporting and where is this work being pursued? These applications areas are described as follows:

(i) **In support of aquaculture development.** Most remote sensing applications in this area are being conducted by the United States of America, though much work is also carried out in a number of rapidly developing Asian countries, but with few examples from European countries. The main issues addressed by remote sensing are strategic planning for development, the suitability of sites, and for zoning purposes. For example, GIS and remote sensing are essential tools to help define locations and quantify expanses of areas suitable for offshore mariculture development. A number of specific examples are provided to show how remotely sensed data can benefit aquaculture development.

(ii) **To support aquaculture practice and management.** Remote sensing applications under this heading are aimed at: (a) the inventory and monitoring of aquaculture and the environment; and (b) examining the environmental impacts of aquaculture. The first of these applications areas is important as a means of evaluating where and to what extent a range of aquaculture developments is taking place, with this work often being in response to the needs for spatial planning. The second applications area is extremely important because it is essential that any environmental impacts from aquaculture are absolutely minimized, and, conversely, it could be disastrous if factors in the environment impact upon aquaculture practices. Examples of relevant remote sensing applications are given.

(iii) For various aspects of marine fisheries monitoring and management. As in aquaculture development, there are an overwhelming number of publications illustrating applications of remote sensing to marine fisheries monitoring or management undertaken by the United States of America or by developing Asian countries; there are relatively few European examples. However, compared with its use in aquaculture and marine fisheries, remote sensing has been relatively little used for inland fisheries. Remote sensing data has been particularly useful in locating optimum fishing locations by sensing those areas where fish aggregations occur, usually in relation to marine productivity or along temperature fronts between warm and cooler waters. Vessel monitoring systems using global positioning systems data also rely on remote sensing techniques. Data from remote sensing are particularly useful in a wide range of fisheries research and modelling, where information on factors such as water temperatures, chlorophyll-*a*, ocean currents and bathymetry may be important inputs to the work.

Of critical importance to the use of remotely sensed techniques are considerations relating to the implementation of remote sensing methods, i.e. so that the data secured can be reliably used within a GIS. Whether or not to implement remote sensing capability is normally dependent on the results of a scoping study. This study helps define the viability of the proposed activity and it addresses important questions, such as:

- What are the overall goals and objectives of the programme?
- What is the physical area of interest?
- What spatial scale and/or spatial resolution is desired?
- What is the frequency of data required, how quickly does the data need to be delivered, and for what time period?
- Can existing data address the information needs?
- Can information provided by remote sensing meet project needs?
- Do remote sensing data need to be integrated with other data and models?
- What is the available budget to buy imagery and complete image processing for the duration of the programme?
- What expertise and tools are available to process and integrate the remote sensing data?

The ability to carry out a scoping study will require a certain level of expertise in remote sensing methods, though the study may be carried out by an external consultant. An essential element of the scoping study concerns remotely sensed data and/or imagery requirements and acquisition. The technical paper provides, by data themes and different satellite systems, detailed information on the range of data available and all the principal sources (suppliers) for this data. There is also a section on data costs, noting that costs per image may be highly variable (usually according to image resolution), that overall remotely sensed imagery is decreasing in cost, and indeed that there is much useful imagery that can be freely obtained from the Internet.

Because imagery can be purchased having varied levels of pre-processing, it means that it is quite likely to need some processing or editing before the data can be directly used in a GIS. This can usually be done by specialized software, most of which is highly compatible with GIS or is, indeed, fully integrated into proprietary GIS. Image processing includes a hierarchy of processes:

(i) geometric or radiometric correction;
(ii) training and validation data;
(iii) image analysis, processing or classification;
(iv) accuracy assessment; and
(v) change detection.

Each of these processes is explained, though the user is likely to need additional information from the data providers, image processing guides, local experts, or from numerous sources on the Internet.

Wider technical support and training in the use of remote sensing is provided under a number of suitable headings:

(i) **Web resources and organizations.** A wide variety of these resources provide valuable information about remote sensing applications in fisheries and aquaculture and also links to useful imagery.
(ii) **Book resources.** Although these tend to be more general introductory books, i.e. because few texts concentrate specifically on remote sensing applications to fisheries or to aquaculture, many of them have sections devoted to ocean or marine applications of remote sensing.
(iii) **Technical training materials.** These are remote sensing tutorial and/or exercise manuals, with some of them including marine themes, and all of them accessible via the Internet.
(iv) **Software and tools.** Two categories of software are listed: (a) remote sensing software that is freely available, much of which may be specific to certain tasks; and (ii) the main proprietary remote sensing software; this varies greatly in its degree of sophistication and, therefore, usually in its price.

The chapter concludes with four case studies. The first study is concerned with the inventory and monitoring of aquaculture and the environment in the Republic of the Philippines (Travaglia *et al.*, 2004). This study was carried out by four experts (with some additional field verification assistance) over a six-month period. The objective was to test, under operational conditions, a radar-based remote sensing methodology for the inventory and monitoring of shrimp farms. The use of radar allowed for the discrimination of ponds and dykes from the surrounding water surfaces and rice paddies, and the fish ponds and dykes detected were quantitatively assessed for the Lingayen Gulf area of the Republic of the Philippines. Data were obtained from two ERS-2 SAR images having a spatial resolution of 25 m, plus a RADARSAR-1 Fine Mode SAR image having a 9 m resolution. The case study details the methodology used including the necessary image processing. The results allowed the area having fish ponds to be very accurately calculated, and, when compared with the area established for 1977 (by manual means), the image showed that a 60 percent increase in fish pond area had occurred. The detection of sea cages was more difficult because of rough water conditions when the imagery was obtained and, because of their small size, there was some uncertainty in identifying fish traps and pens. However, advances in imaging radar since this study was made mean that remote sensing methods are now highly reliable for the inventory of most aquaculture facilities.

The second case study concentrated on the use of remote sensing to monitor and model harmful marine algal blooms in the southern part of the Republic of Chile. This collaborative study was carried out over one year by several small groups of private sector consultants, and it was designed to show how the use of remote sensing methods might assist the salmon farming industry in an area where algal blooms are a frequent problem. This could essentially be achieved by developing a prototype "harmful algal bloom" early warning system. The main imagery used was sea surface and chlorophyll-*a* data obtained from MERIS and MODIS remote sensing systems, with these data being combined with other local oceanographic, meteorological and coastline data. Because daily imagery could be obtained, models could be developed to show the existence and daily distributional patterns of potentially harmful blooms. The case study explains how the GIS-based work progressed, and the authors describe the range of outputs achieved including an estimation of their accuracy. The models developed could also significantly contribute to further aquaculture site selection choices, and they are likely to result in considerable financial savings for the aquaculture industry through an ability to take mitigation measures when required.

The third case study illustrates the use of remote sensing imagery to map seagrass beds in the Zakynthos Marine National Park in the Hellenic Republic, which is based on the work of Pasqualini *et al.* (2005). The importance of the seagrass *Posidonia oceanica* in the Mediterranean cannot be overstated, i.e. because of its role in many coastal processes, contributing to sediment deposition and stabilization, to attenuating currents and wave energy and in supplying a highly productive biological ecosystem. For conservation purposes, it is essential to map the distribution of this seagrass. There are challenges to using aerial or satellite remote sensing imagery for this mapping, mainly because of the fragmented nature of the beds and to the depths at which they might be growing. Various methods have been tried and in this study the authors' objectives were to use SPOT-5 multispectral imagery at three different resolutions to see which produced the most accurate results. The methods used are described in some detail, including the extensive ground truthing (physical verification of seagrass beds) necessary in a study area of some 70 km^2. The results show that even using the coarsest resolution (10 m) quite accurate maps can be drawn (73 percent accuracy), though when the finest resolution was deployed (2.5 m) there was more detailed discrimination of the patchiness of the seagrass beds, with the maps being 96 percent accurate. Since the study was concluded, the WorldView-2 sensing system has been launched, which provides a sub two-metre resolution for this type of work.

The final case study looks at the use of remote sensing and satellite communication systems to establish where fish and squid feeding aggregations occur in Pacific waters off the Japanese coast, and therefore to supply predictions of potential fishing zones in near-real-time to fishing vessels via Internet and satellite connections. The study was a long- term project carried out by university-based researchers, private companies and a regional development agency (Saitoh *et al.*, 2009), with the longer-term aim of managing the fisheries sustainably. A complete system (TOREDAS) has now been developed, comprising four components: (i) data acquisition system; (ii) database; (iii) analysis module; and (iv) Internet and on-board GIS. The case study provides details on the exact development methods used, including the remote sensing data required and their satellite sources. All image processing and subsequent GIS work was accomplished by the development team, and there was strong cooperation from various fishing fleets in terms of supplying marine and catch data and for vessel monitoring system link-ups allowing for the collection of real-time information on likely optimal fishing locations. Illustrative examples of the GIS output are provided that clearly demonstrate the correspondence between fishing vessel locations and chlorophyll-*a* and sea surface temperatures. Although the TOREDAS system could potentially allow for larger marine catches, it is considered that the educational aspects of the system will allow for the appreciation of the needs for sustainable fishing, and other benefits to fishers will accrue in terms of reduced fuel requirements and in time saving when searching for fishing grounds.

The chapter concludes with a brief analysis of the significant advances that are currently under way in the field of remote sensing, especially with regard to the variety of parameters for which data can be gathered, the increasingly higher resolution of the data that can be obtained, significant cost reductions in data, and the timeliness of data. These advances, combined with the increasing ease in integrating remote sensing data into GIS projects and the actual proliferation of data per se, mean that the prospects for the continuing use of remotely sensed data become ever more encouraging.