

APPLYING GEOSPATIAL TECHNOLOGIES TO WEEDMAT MONITORING AND MAPPING: THE YTHAN ESTUARY, NE SCOTLAND

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ABSTRACT: This paper examines the potential for using archival colour vertical aerial photography to map the spatial location, distribution, extent and changes over time in weedmat coverage for the Ythan estuary, North East Scotland, UK. Archival colour aerial photography scanned into a computer, and processed using image processing techniques resulted in a series of mosaiced images for visual interpretation of the location and extent of weedmats for each year of photography selected. Input of the imagery into a Geographical Information System (GIS) enabled the derivation of maps showing change and quantitative estimates of the areal coverage of macro-algal weedmats for each year. It is concluded that macro-algal weedmats can easily be differentiated on colour aerial photography from background mud and sand deposits, but it is not possible to reliably separate individual macro-algal species from each other, or to distinguish weedmat densities without the availability of additional co-incident field data.

KEYWORDS: GIS, REMOTE SENSING, WEEDMAT, ARCHIVAL, AERIAL PHOTOGRAPHY

INTRODUCTION

This paper outlines a practical working methodology for the use of multi-temporal archival panchromatic and colour aerial photography and GIS for the extraction of multi-temporal spatial information (location and extent) of macro-algal weedmats in the Ythan Estuary, North East Scotland. The reasons for undertaking this work are threefold. Firstly, casual observations made over time at the estuary suggest that the extent of weedmats in the estuary has changed and generally increased over time. To establish whether this is the case or not requires multi-temporal observations of the location and extent of the weedmats in the estuary. Secondly, whilst ground survey techniques are obviously crucial in confirming observations, time available and the costs of undertaking the work are usually prohibitive, especially on a repeat basis. A cost-effective alternative is therefore required. Finally, establishing a standardised approach to weedmat monitoring and mapping is required in order to compare coverage for each year as well as to establish a baseline for future studies that may involve modelling.

BACKGROUND

Around the world, macro-algal weedmats¹ have increasingly become a topic of interest over time. Despite this, according to Edwards (1999) relatively little has been written about the remote sensing of macro-algal weedmats and/or the assessment of macro-algal biomass. However, studies by Budd et al. (1980, 1981, 1982, 1983, and 1985), Coulson and Budd (1979), and Collier et al. (1996a, b, c) and Baily et al. (2002) have used aerial photography to monitor and map algal weedmats. The latter utilized a combination of specially flown colour infrared (CIR) aerial photography, photogrammetric techniques and GIS software to map intertidal vegetation, specifically *Spartina*, *Ulva*, and *Enteromorpha* in Langstone, Portsmouth, and Chichester Harbours on the south coast of England. Aerial photo-interpretation of both single and stereo CIR photography at a scale of 1:10,000 was used to map the areas of vegetation from 1998, 1999 and 2000. Young et al. (2000) also made use of specially flown CIR stereo aerial photography at a scale of 1:7200 combined with Differential Global Positioning System (DGPS), ground-truth and ancillary data to map distributions of eelgrass and green macro-algae (*Ulva* and *Enteromorpha*) in the USA. They also used a 35mm hand-held camera with CIR film as a demonstration of an inexpensive way to map spatio-temporal distributions of green macro-algae in a coastal estuary. Green et al. (1998) demonstrated the practicality of using a 35mm camera, film, and filter combination on a large-scale model aircraft to monitor and map macro-algal weedmats using a digital image processing system. Natural Environment Research Council² used archival aerial photography and other airborne imagery (1991-1994), including Airborne Thematic Mapper (ATM³) imagery for the monitoring of algal weedmats for UK estuaries.

A significant feature of the Ythan Estuary in North East Scotland, and well-documented in the past by Raffaelli and Nicol (1988), Raffaelli and Plomer (1989), and Raffaelli and Way (1996), has been the presence of benthic macro-algae (*Enteromorpha*, *Ulva*, and *Chaetomorpha*) resulting in the formation of extensive 'green' mats over the intertidal flats of the estuary. Studies by Raffaelli et al. (1988, 1989, 1996), used a combination of aerial photographs dating from the 1940s to the late 1990s and field work, to (a) identify the location and distribution of the weedmats, (b) to establish the possible cause(s) of the weedmats (e.g. increasing amounts of nitrogenous fertiliser being applied to the Ythan catchment over time), and (c) to determine the impact upon invertebrates in the underlying estuarine sediments, shorebird populations and their behaviour (see for example: Lewis and Kelly, 2001; and Dunne, 2003).

The methods for repeat environmental data acquisition, monitoring and mapping are well documented in Raffaelli and Plomer (1989) and Raffaelli and Way (1996) and include: field surveys; photo-interpretation of specially flown vertical aerial photographs acquired from light aircraft flying at 1000-1500 feet; and projection of

¹ Macro-algae or macroscopic algae are more commonly referred to as seaweed and are large plant-like structures found in coastal and estuarine waters around the World

² NERC, 1997. Webpage (no longer available)

³ In the UK, the Airborne Thematic Mapper (ATM) is a scanning sensor for collecting multispectral data in the visible, near/short/ thermal infrared (<http://www.nerc.ac.uk/arsf/Pages/Instruments/ATM.htm>)

colour photographic slide transparencies for manual tracing and area assessment with the aid of mm graph paper and a planimeter.

Since the work by Raffaelli et al. (1988, 1989, 1996), geospatial technologies such as remote sensing, Geographical Information Systems (GIS), Global Positioning Systems (GPS), the Internet and mobile GIS have all developed very quickly for use on desktop and, more recently, portable computers. There is now considerable potential using this technology to repeat and check the results from previous studies; capacity to build up digital environmental databases comprising geo-rectified and mosaiced photography and vector map layers that can be used as a baseline for future monitoring and mapping exercises; and to derive quantitative information e.g. distance and area measurements more quickly. Some justification for an approach that uses geospatial technology is provided by Young et al. (2000: II-286) who state that *'the rapid development of benthic macroalgae on estuarine mudflats during the summer growing season makes difficult the accurate documentation of spatial and temporal distributions of such algae from ground surveys alone'*.

STUDY AREA

The Ythan Estuary (57°N, 2°W) lies approximately 20 km to the North of Aberdeen on the east coast of Scotland. It is a tidal estuary that extends about 8km inland to Ellon, and it drains a predominantly agricultural catchment. The estuary averages 300m wide, with an average depth at high water of 2.5m with a tidal range of less than a meter to 3m or more (Figure 1).

OBJECTIVES

The overall objective of this work was to devise a practical remote sensing- and GIS-based methodology to extract information (location and extent) about macro-algal weedmat coverage in the Ythan Estuary derived from multi-temporal archival aerial photography of varying scales acquired from different sources. More specifically to:

- Use archival aerial photography;
- See if it was possible to detect and map macro-algal weedmats from the aerial photography without the opportunity to undertake ground-truthing;
- Establish a practical procedure by which it was possible to derive recommendations to improve future opportunities for monitoring and mapping the weedmat coverage in future years;
- Identify any temporal trends in the location, distribution and areal extent of the macro-algal weedmats;

and

- Create an environmental database as the basis for both the development of a desktop GIS and an online GIS-based Internet public information system for the Ythan Estuary.

The practical work involved the following tasks:

- Acquisition of the aerial photographic data sets from different sources;

- ❑ Inspection and selection of the aerial photographs deemed to be most suitable for the work; scanning of the aerial photographic datasets;
- ❑ Geo-correction of the scanned aerial photography using a desktop scanner; Mosaicing of the geo-corrected aerial photography in a digital image processing system;
- ❑ Manual and on-screen photo-interpretation, classification and mapping of the multi-temporal aerial photography within GIS software.

All of the aerial photographs available were scanned using a desktop scanner at 150 dpi in order to minimise the filesizes of the raster images. The images were geo-corrected using between 4 and 16 GCPs per image, a polynomial transformation (orders 1 and 2), and resampling using the nearest neighbour algorithm. Where possible, the overall RMSE (Root Mean Square Error) was reduced to <1. Geo-referencing utilized digital Ordnance Survey (OS) Land-Line Plus 1:2,500-1;10,000 scale map tiles for the study area downloaded from the Edina Digimap service (<http://edina.ac.uk/digimap>). Each image was geo-referenced to the Transverse Mercator, Airy Spheroid, OSGB 1936 Projection/Spheroid/Datum.

In order to conserve computer disk storage space and to aid in the display monitor and memory requirements each mosaic was 'cropped' using a digitised boundary of the high water mark (HWM) of the Ythan Estuary catchment area derived from Ordnance Survey (OS) Landline data. The HWM boundary was digitised and used as a 'cookie cutter' to reduce the extent of the mosaics to the boundary of the estuary.

Using a combination of the pan and zoom tools, units of macro-algal weedmats, identified with the aid of a photo-interpretation key, were delineated by tracing the boundaries with the aid of the default on-screen interactive digitising tools. Minor edits to the digitised boundaries were then completed once all the units had been mapped. This was done so as to minimise the human errors associated with on-screen digitising. In order to maintain consistency in the interpretation and digitising of the weedmat units the work was carried out by a single individual.

INTERPRETATION

Frequently a minimum mappable unit (mmu) is defined as the basis for determining a 'cut-off' point or 'threshold' to help decide which units to digitise and which to ignore. This is defined in terms of spatial dimensions of the smallest possible unit e.g. weedmat unit that can be visually identified and its boundaries mapped. In this study it depended upon the scale of the photography used and ranged from approximately 3-5 metres. Careful consideration also has to be given to exactly where a boundary line is drawn around the feature of interest. The use of the zoom tool with onscreen digitising helps the interpreter to map small units, the decision to include being based upon whether it looks like weedmat and its size in relation to ease of digitising and knowledge of the appearance of weedmat on the ground.

To some extent the choice of which unit to map also depends upon:

- ❑ Original photographic scale;
- ❑ Quality of the aerial photography/mosaic;
- ❑ Degradation of the original photographic image e.g. steps undertaken in the creation of the digital image used for onscreen digitising and interpretation i.e. scanning, mosaicing and colour balancing;

- Quality of display monitor and screen display resolution used during onscreen digitising and interpretation process;
- Image sharpness and the contrast between the features of interest and the background or surrounding area or surface; sometimes difficult at the edges of photographs;
- Image magnification and zoom; some features are more easily identified when zoomed out (homogeneity and context) whilst others benefit from zooming in (detail);
- Eyesight of the interpreter;
- Knowledge and experience of the interpreter.

Additional help in the interpretation can be provided through experience, references to contextual information, and the examination of hardcopy aerial photographs that generally have a sharper image than their scanned digital equivalent.

Background information about the features and environment of interest can provide important assistance in the interpretation of aerial photography. In the case of weedmats, typically *Enteromorpha* forms vast mats that lie on the surface of estuarine mud- and sand-flats. These mats can either be very fine coverings (thin) or several cms deep (thick). Free-floating mats of *Enteromorpha* may also be deposited on other vegetation types. *Ulva* is frequently associated with *Enteromorpha*, and inhabits the middle to low intertidal zone (or eulittoral to sublittoral zone) and grows in sheltered environments but may also be found in brackish water, particularly estuary environments. *Ulva* may often be found attached to rocks in the middle to low intertidal zone but can also survive in water as deep as 10m in calm and protected harbours. They are also often found in abundance where there are enhanced nutrient supplies (sewage outfalls), metal contamination, where wave shearing forces are low and herbivory is reduced. Young et al. (1998: II-39) note that '*in late summer, substantial quantities of green macroalgae often break loose from the substrate and are deposited in other habitats of the intertidal area*'. Additional information is also provided from knowing about the type and distribution of sediment. It is known that some weedmat species are more closely associated with certain sediment types (Orr, 2002). Where the density of the weedmats is such as to allow underlying substrate to show through this may alter the visual appearance of the weedmats. For example, where there are mussel beds or seaweed then this may make the weedmat may appear visually darker. In this study help in this respect is provided by the acquisition of several sediment maps for the estuary that were digitised as separate GIS layers (Orr, 2003; and Chan, 2003) (Figure 2). Knowledge of the hydrography of the estuary is also useful, and some information on this was forthcoming from Stove (1978). Bearing this information in mind, the general location of weedmats in each mosaic also seemed to correspond to the known 'habitat conditions' i.e. sheltered environments such as are found in harbours, the middle to low intertidal zone, and calm shallow water.

Methods

One major constraint of this work was that operationally it had to be completed in approximately three weeks. This included selecting, scanning, geo-correcting, and mosaicing the aerial photography for four dates (1989, 1992, 1994, and 2000), photo-interpretation of each aerial photographic set, import into a GIS, identification, delineation and digitising of the weedmat unit boundaries, and completion of the GIS database including documentation (metadata) (Figure 3).

Interpretation Key

An approach that is frequently used to aid in the photo-interpretation process is a photo-interpretation key providing a visual guide for the interpreter. An Internet search for examples of keys relating to macro-algal weedmats did not, however, yield any useful examples. A practical alternative, therefore, was to devise a photo-interpretation key for the work being undertaken. This approach assumes that macro-algal weedmats are likely to be generally very similar in their appearance on all of the aerial mosaics and through time. For example, weedmats generally appear a distinct 'emerald green' on colour photographs in contrast to their bottom sediment surroundings (sand and mud: pale brown to grey brown). The interpretation key was constructed by locating examples of the different classes (dense and sparse weedmat)

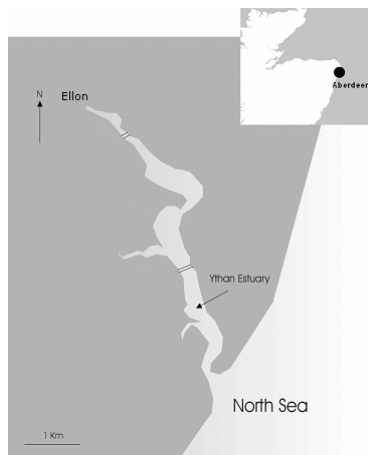


Figure 1. - Map of the Ythan Estuary Study Area

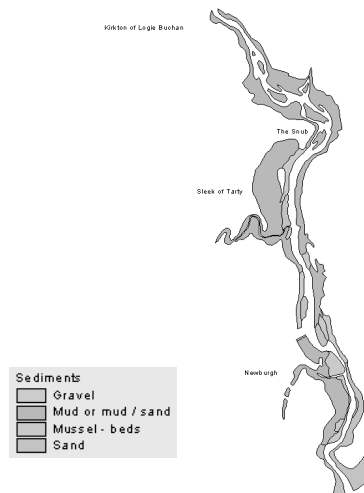


Figure 2. – A Sediment Map of the Ythan Estuary

to be interpreted, where additional information provides some certainty as to the correct identity and representativeness of the class.

Spectral Profiles

The use of spectral profiles for each different class to be mapped can also be very helpful when interpreting an image. In effect this provides a simple way by which it is possible to establish the visual colours of the different classes. Unfortunately, once again, an Internet search yielded no good examples of spectral data for macro-algal weedmats. As a practical alternative, therefore, the spectral profile tool in the digital image processing software was used to generate some basic profiles of the examples of weedmat units as an aid to classifying the images.

COMPARISONS AND PROBLEMS

One of the main objectives of this work was to identify any temporal trends in the location, distribution and areal extent of the macro-algal weedmats. This was based upon comparisons between measurements derived in this study and those of Raffaelli

et al. (1988, 1989, 1996). Using the display and overlay functionality of a GIS it was possible to undertake the following:

- ❑ Check the quantitative area measurements of Raffaelli et al. (1988, 1989, 1996);
- ❑ Overlay maps from both sources for the same year to compare both the interpretations and quantitative measurements.

Weedmat maps by Raffaelli and Way (1996) for the South Quay area at Newburgh, whilst very generalised, could be compared by digitising the original maps and inputting them into a GIS. It was possible to locate four ground control points in these maps allowing them to be geo-corrected, sufficient to facilitate overlay with our geo-corrected aerial photographs and mosaics as well as with maps for each date. This allows some basic comparisons to be made between different years and potentially forms a basis within a GIS to produce a 'change map' using different colours and shadings that can be viewed separately or as part of a simple animation.

PRACTICAL CONSTRAINTS

Some practical constraints included:

- ❑ The type, quality, scale and extent of coverage of the archival aerial photography: not all of the photography had been flown for the current purpose, and much of it was of relatively poor quality, variable scale, condition and there was incomplete coverage by the flight lines. Other photography was, by comparison, high quality, large scale colour aerial photography specially flown for the task;
- ❑ Although some of the photography had been flown around approximately the same time each year, some had not, and furthermore there were no overflights throughout the 'growing season';
- ❑ Scanning was undertaken using a low-cost desktop scanner: although physically possible to scan aerial photography using this low-cost hardware, it would have been more appropriate to source and use a photogrammetric scanner. However, such devices are often not available and are expensive to purchase. Therefore, there may be loss of information and distortions present in the scanned photography that will affect the interpretation;
- ❑ Geometric correction of some of the photographic frames was found to be difficult because of the lack of easily identifiable ground control points (GCPs) on both the aerial photographs and the reference maps. This is a common problem in estuarine (and other) areas. One solution is to undertake fieldwork using a portable GIS, GPS, and digital map base. If it is possible to commission the aerial photography, then it may also be possible to place ground control points on the ground visible in the imagery. Alternatively, aerial photography now often automatically includes GPS co-ordinates;
- ❑ Colour balancing results from Erdas Imagine were not uniform and were often relatively poor compared to those achieved using another software product, PanaVue (<http://www.panavue.com>). Differences between photographs within a single flight can occur due to sun-sensor-ground angles, sensor view angle, and small atmospheric changes. Between flight differences can also result from the use of different film batches, cameras and photographic processing. Although some results were not as good as had been hoped for in providing a 'colour balanced' mosaic, on the whole it did not create a serious problem when interpreting the mosaic on-screen;
- ❑ Although cutting the filesize of each mosaic aided in the digitising procedure speeding up the display of the image backdrop for digitising, in practice the full image mosaic provided more context for the weedmat interpretation and information extraction.

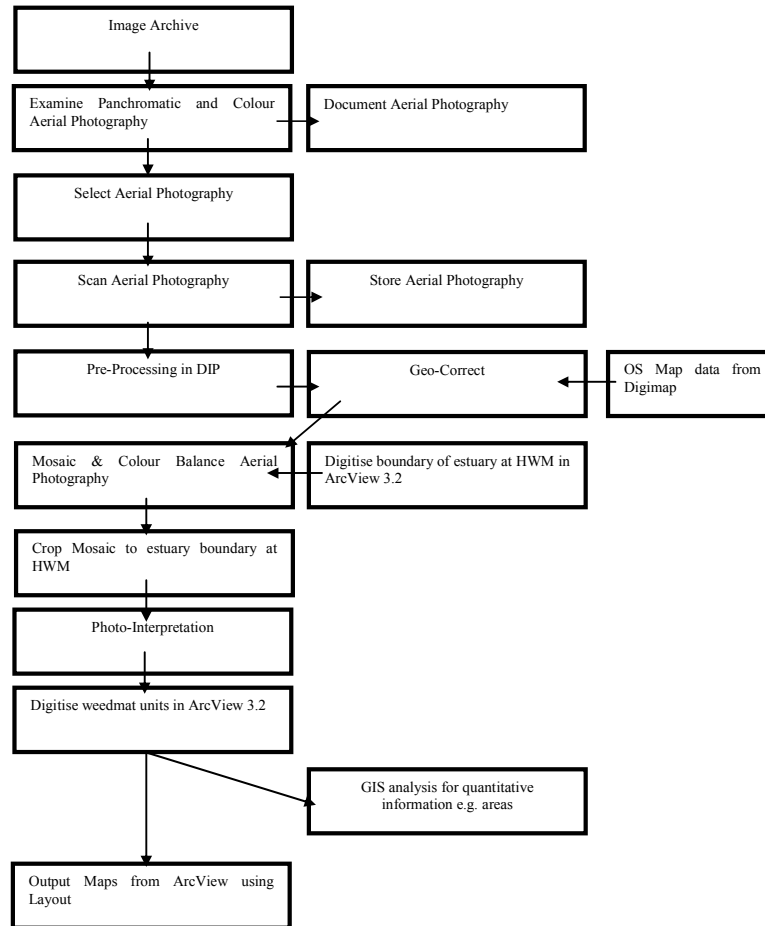


Figure 3. – The Methodology for Weedmat Mapping

DISCUSSION

Macro-algal weedmats are relatively easily identified on good quality colour aerial photography acquired at scales of 1:3000 - 1:5000, providing that the weedmat density is quite high (Figure 4). Identification is significantly aided by the distinct contrast with the background or substrate. However, identification is less straightforward on smaller resolution, archival and panchromatic photography. Comparison with larger scale photographs and ground-based 35mm photography confirms this. These findings concur with those of Raffaelli et al. (1988, 1989, 1996) regarding the visual recording of weedmats with a density greater than 1kg/m^2 , although it was not possible to confirm this observation through fieldwork in this study. Where weedmats are not so dense and the units are sparse or small, or the weedmats are submerged at the time of the overflight it is far less easy to identify the weedmats and particularly to ascertain their unit boundaries, extent and exact ground coverage.

Despite the potential problems outlined above it is possible to conclude the following: the spatial distribution and location of the weedmats in the Ythan Estuary is very similar for each year. This is to be expected given the likely causes of weedmats e.g. pollution, shelter, sediment substrate etc.; as might be expected there also appear to be differences in the areal weedmat coverage from year to year.

As found by Raffaelli et al. (1988, 1989, 1996) there is a trend over time. However, although such similarities and trends appear to exist it is difficult to quantitatively establish the degree to which the estimates are similar or accurate. Possible sources of differences and error are:

- The different interpretations (choice of the minimum mappable unit (mmu), identification and mapping of the weedmat units (boundary detail));
- The comparability of the method used to derive weedmats by each interpretation;
- The accuracy and origin of the image rectification used as the basis for mapping;
- The quality of the aerial photography used.

Thus, although quantitative estimates of weedmat area can be practically and easily obtained, it is relatively difficult to establish whether they are accurate estimates and how much error is associated with each of the different components of the methodology used in both the current and previous studies. In the current study, for example, there was no opportunity to gather ground-truth information for the dates of aerial photography used. In future studies there is a need to ensure that coincident ground-truthing can be undertaken to aid in the detailed interpretation of the aerial photography.

Aerial photo-interpretation of either paper prints or digital scanned images may not be easy. Young et al. (1998), for example, noted a problem in being able to distinguish macro-algal weedmats when they co-exist with other vegetation. Baily et al. (2002) noted problems due to variability in the CIR photography from year to year, atmospheric/weather conditions, processing, time, and film deterioration, all of which inhibit interpretation. The appearance of vegetation on a photograph may also vary as a function of the angle of light and the position of the photograph when it was taken. They also point to a quotation from Daels and Antrop (1978) who observe that interpretation should only be made from within a single stereopair and not across different years. Furthermore, an important point is the subjective nature of the interpretation due to differences in image quality and the skill and experience of the observer. Boundary definitions vary as change in density of cover can be gradual. Additionally, Daels and Antrop (1978) note that vegetation mapping requires photographs taken at the peak of the growing season, in good weather, at low spring tide. In reality, however, a perfect combination of these factors is not always possible.

The application of digital image processing techniques to the analysis of colour aerial photography is not particularly straightforward and the classification of the weedmats is not always successful or repeatable. Young et al. (1999: 1176) observe that *'the use of digital image processing techniques alone to classify was problematic ... because macroalgae, for example, share the spectral characteristics of other classes in the visual portion of the electromagnetic spectrum'*. A solution proposed by Young et al. is *'to use these techniques as a first step in the classification process, followed by a visual examination of the imagery, and to edit the results in a traditional approach to photo-interpretation'*. Alternative approaches might be to use contextual information in the classification process.

RECOMMENDATIONS

To extend the work undertaken here, it is suggested that further acquisition of aerial photography should take the following considerations into account:

- ❑ For comparisons with previous data and information derived from aerial photographs overflights should be acquired at approximately the same time and at the same scale as previously using the same camera setup, film type and processing;
- ❑ Some aerial overflights are also made for other times during the season to try to ascertain whether or not there is an optimum period for aerial photographic acquisition to assist in the identification and mapping process. The optimum periods for such overflights could be established by examining previous aerial photography and a range of other information sources such as graphs. A summary of these graphs suggests the following timetable for aerial overflights (Table 1);
- ❑ Colour Infrared (CIR), colour negative (Young et al., 1999) and/or multispectral aerial photography is considered for future studies, the former offering the opportunity to maximise the identification and separability of the macro-algal communities from the substrate. Other sources of remotely sensed imagery are considered as alternatives to traditional aerial photography offering better spatial and spectral resolution helping to assist in weedmat interpretation. These include CASI (**C**ompact **A**irborne **S**pectrographic **I**mager), ATM (**A**irborne **T**hematic **M**apper), LIDAR (**L**ight **D**etection and **R**anging), high-resolution satellite imagery and airborne digital photography;
- ❑ Collection of additional field or ground-based data and information coincident with the aerial photography (or other imagery) to assist in the photo-interpretation process.

FUTURE STUDIES

A number of additional studies are now underway as part of a long-term objective to develop an environmental database for the Ythan Estuary and to continue to examine the problem of weedmat monitoring and mapping in the Ythan Estuary. These studies are designed to overcome some of the limitations identified in the current study, and an established methodology for using geospatial technologies to derive such

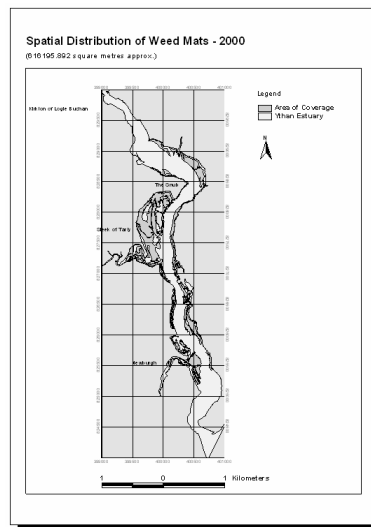


Figure 4. An example GIS map showing the spatial distribution of weedmats

information. These studies include mapping weedmat coverage from more recent aerial photography (Chan, 2003; Dunne, 2003), ground-truthing of the weedmats (Orr, 2002), and the use of mobile mapping technology to map additional geographical information (Chan, 2003); for example, sediment distribution. Future studies of the weedmats will also attempt to utilise a wider range of

Table 1. - Seasonal Succession of Bloom Macro-Algae (adapted from Raffaelli et al., 1998, p. 108)

Macro-Algae	From	To	Peak
<i>Enteromorpha spA</i>	May	November	May-June
<i>Enteromorpha spB</i>	May	November	July-September
<i>Chaetomorpha linum</i>	Mid-May	November	July/August
<i>Ulva lactuca</i>	Late May	Mid-October	September

remotely sensed imagery including imagery from airborne platforms such as CASI and Lidar, and satellites for which it will be possible to organise coincident ground-truthing. There are already plans to fly multispectral digital camera and video sensors mounted on a microlight over the Ythan⁴. In part this will help to provide a regular and flexible source of remotely sensed imagery that will replace the aerial photography flown to date using a traditional aerial camera mounted on a light aircraft.

In the longer term, the digital datasets generated in this study will provide a useful resource and form a baseline database for the Ythan Estuary. Already the weedmat datasets have been used as the basis for several studies of bird distribution⁵ (Dunne, 2003). The map datasets will also be utilized within an online mapserver to provide public access to environmental information about the Ythan Estuary and its surrounds.

SUMMARY AND CONCLUSIONS

The current study was primarily initiated to develop a practical methodology for the derivation of weedmat maps for the Ythan Estuary using existing archival remotely sensed imagery. This work also provided a basis upon which to compare and contrast the extensive work already undertaken by Raffaelli and Nicol (1988), Raffaelli and Plomer (1989), Raffaelli and Passoni (1992), and Raffaelli and Way (1996), by creating comparable maps based upon independent interpretations, and also enabling the digital capture of the datasets first created by these studies for integrated analysis and further comparison. Input of the datasets to a GIS also provided an opportunity to integrate the weedmat maps with other datasets to create a series of environmental datasets for future analyses and to assist in the interpretation and mapping exercise. The practical methodology developed will also be useful as a baseline for subsequent work in the Ythan that will utilise new sources of airborne and spaceborne remote sensing, the results of which can easily be visualised in ways that might be useful in the wider context of a public information system.

Whilst general comparisons between the different studies of the Ythan weedmat problem can be made, the results of any detailed comparisons must be interpreted very carefully because assessments of the coverage have been derived from photographs of varying scales, quality and date, and by different methods and interpreters. In order to monitor and map the macro-algal weedmat coverage

⁴ personal communication with G. Wright – Macaulay Institute, Aberdeen, Scotland, UK (2003)

⁵ personal communication with I. Patterson – University of Aberdeen, Scotland, UK (2003)

accurately in the future, and to determine if there is a genuine change over time, will require very careful planning and execution of any aerial overflights. Ideally this will necessitate special and frequent overflights. This is a matter for serious consideration in the development of future monitoring and mapping studies whereby it is possible to ensure appropriate aerial photography, scale and resolution for the task; and appropriate timing of the overflights at one or more points during the season. For example, aerial photographs need to be acquired throughout the season, as well as late on in the season when the macro-algal coverage is known to peak.

To this end, however, the current and past studies do provide a very useful basis upon which to develop a practical methodology for the future that can be used as a baseline for monitoring and mapping strategy for the Ythan Estuary.

In conclusion, the combination of digital data capture, conversion and input capabilities, digital image processing and GIS technology offers considerable potential to create a baseline GIS-based system as the basis for future multi-temporal monitoring and mapping of environmental change of macro-algal weedmats in the Ythan Estuary. The proposed methodology for mapping weedmats is greatly simplified, both timewise and practically, once the initial investment in the technology has been made, and in the long-term, is far more efficient in terms of the number of steps required to undertake the mapping. It also helps to make the method of working for further studies far more consistent, objective and standardised.

It is clear, however, that whilst it is possible to utilise archival imagery with the aid of computer technology for studies for which it was not intended, any future work must ensure that the type of remotely sensed imagery, its timing and acquisition are more closely matched to the requirements of the task. Based upon the current experience it is possible to develop an appropriate strategy that will overcome the limitations of using archival imagery thereby providing a solid foundation for more accurately estimating the spatial distribution, amount and trends in macro-algal weedmats in the future using remote sensing.

Although this study initially only set out to develop a practical methodology to extract information about macro-algal weedmats from archival aerial photography, further consideration suggests that any future studies should also take into account other sources of information to aid in the extraction of information. For example, another way to aid in the location and mapping of the weedmats in the context of their geographical location and setting would be to utilise a Digital Elevation Model (DEM). Draping aerial photography and map data over the DEM would help to provide another way of visualising the data. Although the topography of the Ythan Estuary and its surrounds is not dramatic, the use of vertical exaggeration, zoom and pan tools in a GIS provides an opportunity to examine the environment from a different perspective and to help in the interpretation. The availability of both LIDAR data and CASI imagery would also aid in the monitoring and mapping of weedmats in the future. Another more analytical type of approach would be to examine the impact of changing agricultural regimes on sediment load and deposition, and both water quality and temperature and its impact on weedmat growth, as a basis for developing a modelling approach to weedmat location and distribution. At the time of this study such information was not available and this would therefore be a topic for future investigation.

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