River Habitat Mapping using Airborne Imaging Spectrometry (CASI-2)

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Abstract

A Compact Airborne Spectrographic Imager (CASI-2) is used to map the depth of the River Test, a chalk stream in southern England. Lyzenga's (1981) method is used to decouple variations in water depth from changes in bed material type. The results show that atmospheric correction improves the relationship between water depth and the logarithm of CASI reflectance, especially in visible wavelengths. The estimated accuracy of water depth was ± 20 cm, but validation was difficult due to the need to precisely co-locate the ground samples and the CASI data.

Keywords: *CASI, river habitat survey, water depth, atmospheric correction, ATCOR*

1. Introduction

The aim of this study is to use airborne imaging spectrometry to map the depth of the River Test, a river in south-central England which is economically important because of the fish populations it supports and is also of considerable ecological importance. The River Test flows for much of its upper course over chalk bedrock and as is typical of such rivers has stable flow, low sediment load (suspended and bedload), and high width-to-depth ratio. Water depth is extremely useful in determining the viability of salmonid populations as the fish require spawning grounds composed of well-aerated gravels at particular depth (Acornley and Sear, 1999). Water depth is also an important factor in the conservation and management of river habitats and is necessary to understand the geomorphology of the river, especially in relation to catchment response to climate and land use change.

Airborne imaging spectrometry offers much for the study of riverine habitats. Imaging spectrometers such as the Itres Instruments Compact Airborne Spectrographic Imager (CASI) provide excellent radiometric fidelity and many narrow spectral bands within the visible and near infra-red region. Airborne platforms are well-suited to river channel surveys as they can acquire long low-level flight lines aligned along the centre line of the river, with high spatial resolution and good geometric control.

2. Methodology

There is an exponential decrease in the intensity of light with depth due to dissolved organic matter, suspended sediment and algae present in the water. Absorption is wavelength-dependent, so for example, clear water absorbs more in the red than the blue region. Scattering of light also occurs, due to suspended particles in the water column which cause a change in the direction of electromagnetic radiation. The combination of these processes results in an approximately linear relationship between water depth and the logarithm of water surface reflectance, which is normally strongest in visible wavelengths. However, an earlier study by Acornley et al. (1995) showed that the clear water and shallow depth of the River Test means that this relationship also holds in near infra-red wavelengths, at least up to 820nm. In this region a field spectrometer was capable of measuring water depths of a few centimetres. Acornley et al. (1995) were unable to test this approach using data from an airborne imaging spectrometer due to the poor geometric quality of the CASI data available at the time. For this study the CASI data were geometrically corrected using instruments mounted on the aircraft which provided frequent updates on the position and attitude of the sensor and avoided the need to use ground control points.

The first question which arises when attempting to apply the results of the study by Acornley et al. (1995) to airborne CASI data is whether it is necessary to correct the data for the effect of the atmosphere. The CASI data were acquired at low level (1800m above mean ground level) so the atmospheric effect would have been minimal, however the water-leaving radiance, especially in the near infra-red, would also have been very small, so the possible effect of the atmosphere could not be ignored. Atmospheric correction was done using the program ATCOR-4 which uses a look-up table derived from the MODTRAN radiative transfer model. Horizontal visibility was estimated in the field and the water vapour content of the atmosphere was measured using a Microtops II sunphotometer.

Although the main interest of the study was mapping water depth, bed material type was also important as it could be expected to have had an influence upon the water-leaving radiance. Lyzenga (1981) described a remote sensing technique to map bed material types which takes account of differences in water depth and this was used to identify those sections of the river in which bed material types were constant. Lyzenga showed that the mathematical combination of reflectance in two bands could be used to create a depth invariant image. CASI Bands 24 and 16 with wavelength 700nm and 542nm respectively were used to calculate the depth invariant image.

The equation used was:

$$DI_{542,700} = \log_e(DN_{542}) - \left[\left(\frac{k_{542}}{k_{700}}\right) \times \log_e(DN_{700})\right]$$

Where,

$DI_{542,700}$ = Depth Invariant Index for bands 542nm and 700nm

DN_{542} = Atmospherically-corrected radiance in the542nm band

DN_{700} = Atmospherically-corrected radiance in the 700nm band

k_{542}/k_{700} = Ratio of attenuation by water in each of the bands.

A river channel mask was created by on-screen digitising. A suitable classification was then performed to classify the image into various bed type materials. If the section of the river is found to have one bed type material predominant then it can be assumed that the reflectance received at the sensor is only due to the depth of the river and not because of the river bed type material. A sample of known points with known depth was used to establish the relationship between depth and the log of reflectance. The equation thus obtained was used to create a map of water depth.

3. Data

The study area included a 10km reach of the River Test as well as the villages of Chilbolton and Wherwell, agricultural fields, mixed forest, and ecologically important wet grasslands in the valley floor. The data used for the study were acquired on 17th June 2006 by the Environment Agency as part of NCAVEO 2006 Field Campaign, using a CASI-2 with a nominal ground resolution of 1 metre. Field measurements of water depth and bed material type were used to validate the result.

4. Results

4.1 Effect of Atmosphere

The CASI image was atmospherically-corrected using ATCOR-4 and for 16 sample points the reflectance value was found out before and after applying the atmospheric correction. Normally, this relationship breaks down in the near infra-red as the water absorbs all the light, but the River Test is so shallow and its bed so bright, that the relationship is still valid at 822nm. A regression equation relating water depth to reflectance at 542 nm, 700 nm and 822 nm was created (Figure 1a and 1b). The high R^2 value shows the significance of atmospheric correction on the estimation of water depth from reflectance at 542nm. As expected, there is a linear relationship between water depth and the logarithm of reflectance after the effect of the atmosphere has been removed. Table 1 show that the improvement in fit is more significant in the visible and deep-red region than the near infra-red, as would be expected. Although the relationship with water depth is valid at all three wavelengths, it is more sensitive in the visible region, as shown by the slope term in the regression equation.

Figure 1a

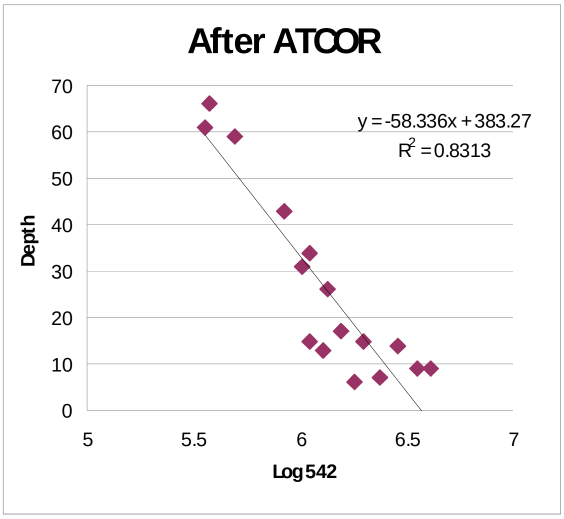

Figure 1b

Figures 1a and 1b: *Plots showing the relationship between water depth and log of reflectance values before and after atmospheric correction.*

	Before ATCOR	After ATCOR	Slope Term	Intercept
Depth vs. Log_e 822nm	0.72	0.7	-39.5	291.4
Depth vs. Log_e 700nm	0.76	0.8	-44.02	299.2
Depth vs. Log_e 542nm	0.6	0.83	-58.33	383.2

Table 1: *Regression coefficients (R^2) values in various bands before and after atmospheric correction. The slope and intercept term of the regression line after atmospheric correction is also given.*

4.2 River Bed Material

A depth invariant image was created using Lyzenga's method using CASI bands centred on 700 and 542 nm. A river channel mask was then applied to isolate the water pixels from the surrounding floodplain and the river channel pixels classified using an unsupervised technique (k-means). The classification was run several times, specifying a different maximum number of classes each time so as to investigate the stability of the class map produced (Figures 2a and 2b). This showed that large expanses of river channel had the same bed material type, which field validation showed to be gravel. These areas were than used for the second phase of the study in which water depth was estimated directly from the log of the atmospherically-corrected reflectance.

4.3 River Depth

A sample of 16 points with known depth was used to establish the relationship between depth and the log of reflectance at 542nm. This relationship was then applied to the rest of the river channel pixels. The result was validated using an independent set of field measurements of water depth located using dGPS. Average depth through the reach was 41cm (stdev. = 25cm) and the estimated accuracy was 20cm (rmse).The estimated depth at various reaches of the river is as shown in figure 2c.

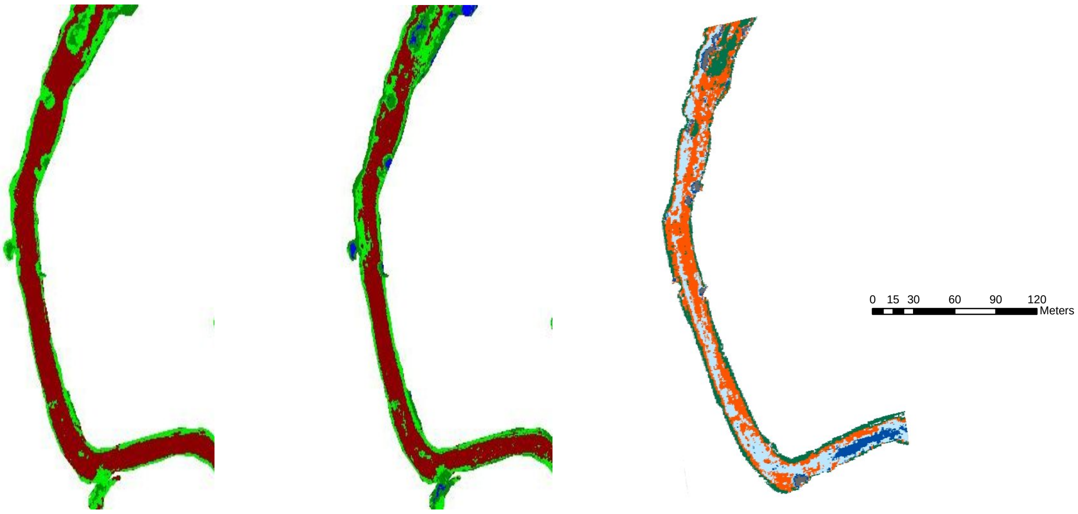

Figure 2a and 2b: *The classified Depth-Invariant image with five and six classes (left and centre sub-images respectively), showing that most of this reach of the river had the same bed material class (brown colour), except for the small areas of in-stream vegetation (green).*

Figure 2c (right-hand sub-image): *Image showing depth within this reach of the river, with dark blue representing the deepest portion of the river (55-72 cm), light blue representing depth 45-55 cm, and orange representing depth 29-45 cm.*

5. Limitations of the study

Some of the limitations of the study are

1. The small pixel size (1m) was necessary to capture the detail within the river, but this meant that very accurate co-registration of the ground data and the CASI data was necessary. Although the parametric method employed in this study was much better than relying on ground control points, the precision necessary to match the ground measurements with individual pixels was not always achieved, so not all the field measurements were useable.
2. The shadows of the riparian vegetation made delineation of the edge of the river prone to error.
3. Mixed pixels mean that the water depth values along the river edge are unreliable.

6. Conclusion

Airborne imaging spectrometry has considerable potential as a tool for estimating water depth in gravel-bed rivers with low sediment loads. Under these conditions even the near infra-red wavelengths contain useful information. However, very high spatial resolution presents problems as well as opportunities: the detail is necessary because of the small size of the features, but centimetric scale geometric correction is very challenging, even in a well-mapped country like the UK.

7. Acknowledgements

Assistance in the field was provided by Kevin Exley, Peter Walker, Andrew Harwood and a team from the GeoData Institute, University of Southampton. We are grateful to the Environment Agency for acquiring the data and Elisa Anderson for preliminary data processing. Financial support for the experiment was provided by NERC, defra, and the NCAVEO partner institutions. Data from the NCAVEO 2006 Field Campaign are provided courtesy of NCAVEO via the NERC Earth Observation Data Centre (NEODC).

8. References

ACORNLEY, R.M., CUTLER, M.E.J., MILTON, E.J. and SEAR, D.A., 1995**.** Detection and mapping of salmonid spawning habitat in chalk streams using airborne remote sensing. *Remote Sensing in Action. Proceedings of the 21st Annual Conference of the Remote Sensing Society*, Remote Sensing Society, 267-274.

ACORNLEY, R.M. and SEAR, D.A., 1999. Sediment transport and siltation of brown trout (*Salmo trutta*, L.) spawning gravels in chalk streams. *Hydrological Processes*, 13, 447-458.

LYZENGA, D. R., 1981. Remote sensing of bottom reflectance and water attenuation in shallow water using aircraft and Landsat data. *International Journal of Remote Sensing* 2, 71-82.