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Summary:	This document indicates the procedure to acquire high-resolution satellite imagery suitable to inshore habitat mapping and provide information on the variety of data available, the feasibility of getting low-tide imagery from these data and the efficiency of the data delivery chains. It also explores post-processing of the imagery to produce documents ready for use by habitat interpreters.
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Recommended operating guidelines for high-resolution satellite imagery

1. General principles of operation

Satellites provide a means for looking at very large expanses of land within a very short time period. Satellite sensors create pictures of the Earth from space using electromagnetic radiation covering a range of frequencies, from radio waves to gamma rays. Electromagnetic radiation from the sun or emitted from the satellite itself hits objects on the Earth and a portion of that radiation is reflected back to the satellite. Sensors on the satellite measure the wavelength and intensity of the reflected radiation. Different objects do not reflect radiation in the same way: clear water, for example, will reflect light differently than turbid water.

Satellite imaging is attractive because it can cover relatively large areas (spanning up to several thousand square kilometres) at relatively low cost. It is seldom possible, however, to acquire satellite imagery under the appropriate conditions for effective benthic mapping (such as low-tide or calm sea state). Satellite imaging has proven useful above all in tropical, clear water environments for coral habitat mapping.

Satellite multispectral instruments can create multiple images of a scene or object using light from different parts of the spectrum. The imagery has been used very successfully to map vegetation of all types for many years, including tidal vegetation such as seaweed and saltmarshes. It is not as effective on sedimentary areas, where subtle colour nuances are not fully reflected by the few spectral bands currently found on satellite sensors. If the proper wavelengths are selected (especially blue and green sections of the visible spectrum), under optimal conditions the nearshore shallow seafloor can be mapped using satellite multispectral imagery (Meinesz *et al.* 1991). This technique is especially useful for mapping shallow shelf areas where deposition, erosion and growth of coral reefs can change the bottom topography over a period of a few years (Sabins 1997). Water penetration increases with decreasing wavelengths (from IR to blue), so the blue-green wavelengths are likely to penetrate deepest in clear water.

Satellite data can be purchased from cloud-free archives, although this has proved impractical for obtaining spring low-tide situations (only a few days per year), or be specifically programmed for low-tide windows, provided the system allows this. On the Atlantic coast of North West Europe the spring low tide occurs in conjunction with the orbiting satellites' overpass (between 10 and 12 am UT). Therefore, potential low-tide acquisitions can be identified by crossing the tide tables and the satellite ephemeris and requesting acquisitions at these times.

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The main systems operating today and their overall capabilities are briefly described below.

2. Variety of systems available

2.1 Landsat Enhanced Thematic Mapper Plus (ETM+)

The Enhanced Thematic Mapper Plus (ETM+) is a multispectral scanning radiometer that is carried on board the Landsat 7 satellite. The sensor has provided nearly continuous acquisitions since July 1999, with a 16-day repeat cycle. The ETM+ instrument provides image data from eight spectral bands (Table 1). The spatial resolution is 30 m for the visible and near-infrared (bands 1-5 and 7). Resolution for the panchromatic (band 8) is 15 m and the thermal infrared (band 6) is 60 m. The approximate scene size is 172x183 km, which makes Landsat advantageous in terms of price per pixel. However, since satellite programming is not possible with Landsat, the only recourse is to archive data, which makes obtaining a low-tide image nothing short of a miracle. This is why Landsat has been little used in temperate areas, where low tide is a key condition for tidal-zone mapping, but more widely used in tropical clear water coastal zones where tidal ranges are smaller.

Table 1. Landsat ETM+ spectral band characteristics (from http://landsat.gsfc.nasa.gov website).

Sensor	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7	Band 8
ETM+	0.450 - 0.515 (µm)	0.525 - 0.605 (µm)	0.630 - 0.690 (µm)	0.775 - 0.900 (µm)	1.550 - 1.750 (µm)	10.40 - 12.50 (µm)	2.090 - 2.350 (µm)	0.520 - 0.900 (µm)
Ground resolution	30 m	30 m	30 m	30 m	30 m	60 m	30 m	15 m

2.2 Satellite d'Observation de la Terre (SPOT)

The SPOT programme was created by the French Centre National d'Etudes Spatiales (CNES) and has developed into an international programme with ground-receiving stations and data distribution outlets in more than 30 countries.

The current features of Spot 5 (Table 2) are:

- 10 m full-colour resolution;
- 2.5 and 5 m ‘pseudo’ colour resolution;
- 60 x 60 km² image size;
- 2-3 day repeat cycle (at 45° latitude);
- Very efficient programming service allowing low-tide shots;

- Regular delivery time of one week.

able 2. SPOT instrument specifications (from http://spot5.cnes.fr website).

Satellite	**Spot 1,2,3**	**Spot 4**	**Spot 5**
High-resolution instrument (mapping)			
	2 HRV	2 HRVIR	2 HRG
Spectral bands	1 panchromatic (10 m) 3 multispectral (20 m)	1 panchromatic (10 m) 3 multispectral (20 m) 1 short-wave infrared (20 m)	1 panchromatic (2.5 or 5 m) 3 multispectral (10 m) 1 short-wave infrared (20 m)
Swath	2 x 60 km	2 x 60 km	2 x 60 km
Revisit interval	2-3 days	2-3 days	2-3 days
HRS instrument (stereoscopy)			
Spectral bands			1 panchromatic (10 m)
Swath			120 km; aft telescope-20°, forward telescope+20°
Revisit interval			26 days

The Spot system is bound to give way in 2008 to the Pléiades constellation, with the following improvements:

- Resolution: 2.8 m multispectral, 0.7 m panchromatic;
- Revisit: once per day;
- Coverage: an area of 110*110 km^2 can be covered in one overpass;
- A blue spectral band is added (enhancing underwater mapping capability);
- Reactivity for programming < one day, data delivery < one week.

2.3 Ikonos and QuickBird

Ikonos (1999) and QuickBird (2001) are the first commercially available high-resolution satellites in the world. The usefulness of Ikonos imagery is being tested by the National Oceanic and Atmospheric Administration (NOAA) in the United States to accurately map coral reefs in the Pacific, in spite of the fact that it can only penetrate to a maximum depth of 30 m under ideal conditions. Their high-resolution and short revisit rate (approximately 3 days – Table 3) make the images very valuable for shoreline mapping and coastal change detection at very local level. The effective programming capabilities needed to attain such a revisit rate, however, have yet to be assessed.

It should be mentioned that data from these new high-resolution satellites are not yet widely available owing to security and licensing issues, and they are still very expensive. They were used effectively in the assessment of the 2004 tsunami in South East Asia.

Table 3. Ikonos and QuickBird specifications (from http://www.geosys.fr, http://www.spotimage.fr and http://www.digitalglobe.com websites).

	Resolution (m)	Image size (km)	Revisit interval (day)
Ikonos (1999)			
P	1	11 x 11	11 + programming
MS	4	11 x 11	11 + programming
QuickBird (2001)			
P	0.61	16.5 x 16.5	1 to 3.5 days *
MS	2.44	16.5 x 16.5	1 to 3.5 days *
P = Panchromatic; MS = Multispectral – 4 bands (Blue, Green, Red and Near Infra-Red) *The revisit rate for QuickBird is 1 to 3.5 days depending on the latitude at 70 cm resolution and maximum off-nadir angle			

3. Review of existing standards and protocols

3.1 Data acquisition

Satellite data acquisition has mostly been dealt with above. Its ability to meet users' requirements largely depends on each sensor type and ground segment operationality or perhaps better: response capabilities. It is quite difficult to obtain figures for the ratio of actual acquisition versus shooting effort in terms of programmed acquisition, since figures are rarely publicised by satellite operators. It is sufficient to say that in some instances in Western Europe, several months were required to get a low-tide, cloud-free image. Moreover, moving up the English Channel and further into the North Sea, the typical spring low-tide window progressively moves into phase opposition with the satellite overpass time. Therefore, spring low-tide periods are impossible to target in the Eastern Channel, which means that recourse to digital airborne imagery is needed.

When choosing between several sensors meeting acquisition time requirement, an optimum trade-off between coverage and resolution (two parameters that vary conversely) has to be sought. In the past, the rather limited spatial resolution (see Figure 1) and the orbital cycle features of the current satellite systems did not allow them to provide imagery often enough or with sufficient detail to be useful in most coastal zones. This is now changing, with satellite constellations of very high resolution, side-looking sensors with much higher agility (e.g. Pléiades) which will be able to cover a much longer coastal stretch in a single overpass. In summary, high detail and adequate coverage can now be simultaneously achieved.

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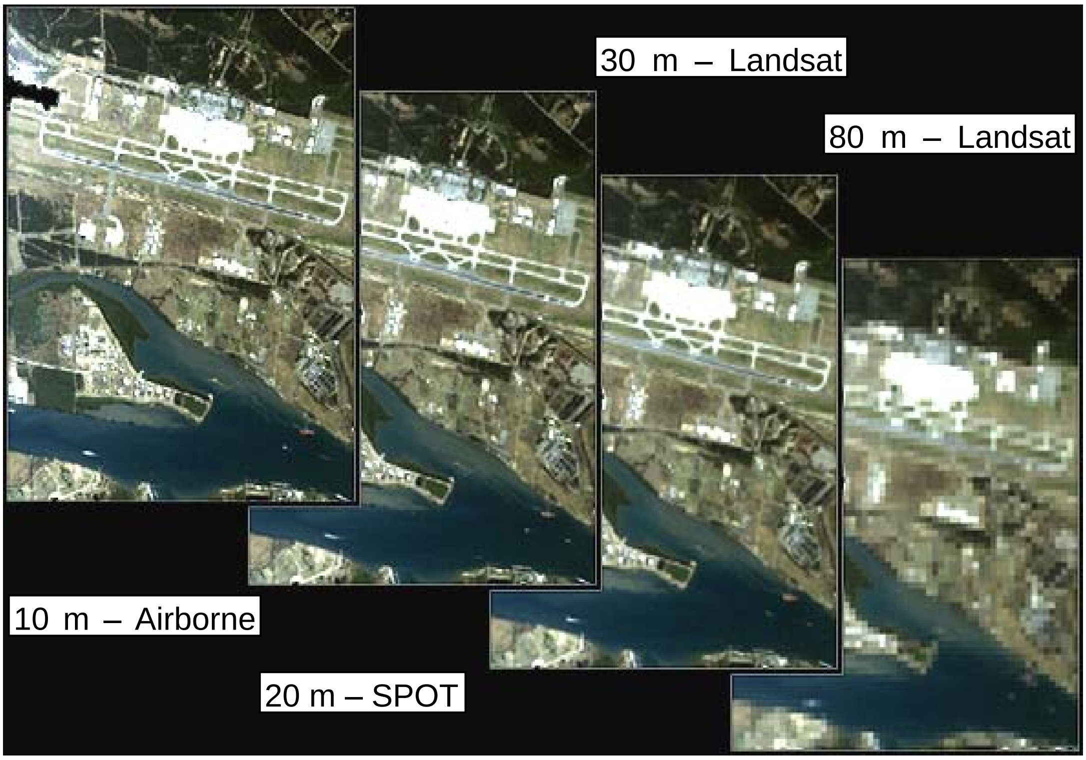

Figure 1. A comparison from various platforms (from http://www.airtargets.com.au website).

3.2 Data post-processing

In remote sensing, data processing means the operations necessary to bring the imagery into a state where it can be dispatched to interpreters. These operations are covered in "Progress in Phycological Research, Seaweed and Remote Sensing" (Guillaumont *et al.* 1997), as well in the *Remote Sensing Handbook for Tropical Coastal Management* (Mumby *et al.* 2000). Fundamentally, two post-processing steps are required.

Geometric corrections are needed to georeference the imagery; i.e. to plot the data into a mapping system, thereby ensuring registration with other data. These corrections are made necessary by the fact that both satellite and airborne platforms at first deliver raw imagery. The viewing geometry and platform altitude are both precisely known (with satellite and aircraft alike), making it possible to resample the imagery to a given mapping reference. Any piece of satellite data can be assigned a position with accuracy to within a few decametres (in a 'blind' way; i.e. using orbital and viewing positional data). If a reference is made available (e.g. a topographic map or another image), then resampling is only limited by the budget error associated with GCP (ground control point) matching and pixel size, which, in the case of the forthcoming Pléiades, will be brought down to a few metres. It is noteworthy, however, that the relative accuracy of satellite imagery (i.e. its internal coherence) is excellent thanks to the stability of the space platform.

Radiometric corrections are required for any remote sensing data, whether satellite or airborne, in order to retrieve a highly defined quantity – the normalized measurement of backscatter called ‘reflectance’. In summary, the intrinsic feature of a ground target when imaged by an electromagnetic system is its ground reflectance. This quantity, being unique to a given target, can be compared and monitored over time. Most systems, however, fall short in measuring reflectance in two aspects: a) they are far from the target and only record ‘at-sensor radiance’, so reaching ground reflectance will then require some additional effort; and b) the radiance itself is affected by atmospheric noise; i.e. the influence of the air column between the ground and the sensor. While some users are satisfied with the relative value (the radiance) allowing one-off classifications, others need to retrieve reflectance, as a safer way to deal with multi-date studies. These corrections have been fully described by Mumby *et al.* (2000). They are performed either by using invariants (stable targets whose reflectance is known once and for all) and methods such as the ‘Empirical line method’ described by Karpouzli and Malthus (2003), or by using special software which takes the atmospheric content into account.

4. Current usage

Spot imagery is widely used throughout the world for coastal mapping. It is currently in operational use in France in the Rebent project to monitor large seaweed belts, namely fucoids and kelp. Comprehensive coverage of the north Biscay, Brittany and eastern Channel coasts is planned, with a repeat cycle of six years, in order to monitor changes in seaweed coverage. Owing to combined weather and tide constraints, however, it remains difficult to secure complete coverage of a region like Brittany. The planned scene coverage shown in Figure 2 had not been completed after a two-year period, which begs the advent of new satellites with more revisit capability.

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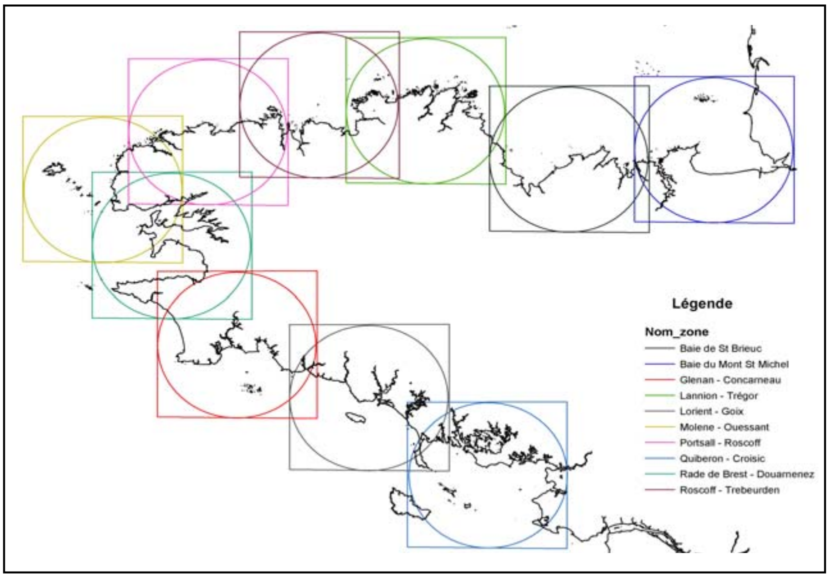

Figure 2. Spot scene coverage of the coastal zone of Brittany within the seaweed monitoring strand of the French benthic network, Rebent.

It is anticipated that the next generation of high-resolution satellites (e.g. the Pléiades constellation or IRS) with a full-colour resolution of around 3 m will have these improved features. Problems with reduced low-water shooting windows, however, are likely to remain the main drawback in the future of satellite imagery. On the other hand, when imagery resolution improves, the ability of satellite imagery to map such underwater features as seagrass beds (currently done with aerial photographs) will be enhanced.

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