SURVEYING COASTAL ZONE TOPOGRAPHY WITH AIRBORNE REMOTE SENSING FOR BENTHOS MAPPING

Jacques Populus[1], Astrid Laurentin[2], Claire Rollet[1], Mickaël Vasquez[1], Brigitte Guillaumont[1] and Chantal Bonnot-Courtois[3]

1. Ifremer, Département Environnement Littoral, BP 70, 29280 Plouzané, France; jpopulus(at)ifremer.fr
2. 13, avenue de Rambouillet, 44500 Saint-Herblain, France
3. CNRS, Boulevard de la Mer, 35000 Dinard, France

ABSTRACT

This paper addresses the need for a finer description of coastal zone relief that is currently of interest for benthic habitat mapping. For example, the distribution of seaweed species in the tidal zone will mostly depend on the terrain's hypsometric level, slope and orientation. These parameters can be used in predictive distribution models, or more simply merged with 2.5/3D imagery to enhance interpretation. Since the required accuracy is of the order of 20-30 cm, two remote sensing techniques, lidar and photogrammetry, were examined and conditions for their application were assessed.

Lidar surveys have been shown to provide such accuracy in all instances, whatever the substratum and vegetal cover type, as well as with the slope values currently encountered in tidal zones. Photogrammetric techniques were compared with lidar. They could achieve the required accuracy, provided that two conditions were met: a) the availability of a sufficient number of high quality ground control points, and b) the textural content of the ground observed. Tidal sedimentary areas clearly lack both of these assets, resulting in dramatically reduced accuracy. In mixed zones with hard and soft substrata, a strategy has to be implemented whereby methods are adapted locally to the specific needs of benthos and biodiversity mapping, while keeping in mind the constraints and costs incurred.

Keywords: Coastal zone topography, photogrammetry, benthos mapping, laser scanning

INTRODUCTION

The need for inventory and monitoring of coastal marine biocenoses is constantly growing. These data are important for assessing and understanding the changes brought about by human activities (chronic or accidental pollution, impact of developments or uses) or by climate change. Already, some requirements (OSPAR/biodiversity, Natura 2000, Water Framework Directive) involve the mapping of habitats over vast territories. The need is not only to draw up distribution maps of habitats and their related biocenoses resulting from detailed observations, but also maps of distribution probability for these habitats. These could be predicted from known habitat distribution preferences according to some structuring parameters like bathymetry and type of bottom. Other parameters like temperature, salinity, turbidity, exposition, etc. could also be considered. Developing spatialised data bases for these parameters, as well as the tools to interpolate and aggregate the data (including GIS which can use fuzzy logic), will make these spatialised productions possible. Several products, of varying forms and resolutions, are being defined, particularly for endangered or declining habitats in the OSPAR framework.

In France, the « Rebent » benthic network (1), currently being developed over all coastal areas, also needs these probability maps. It requires formalised rules of knowledge taken from literature or biosedimentary data acquired on sites and sectors, and determining the aggregation procedures to be used. In addition to producing these probability maps, the approach should also make it possible to i) foster understanding of benthic habitat distribution and development in the coastal fringe, so that expectations can be compared with reality and ii) improve the sampling stratification and data interpolation procedures still necessary for detailed maps.

Topographic mapping requirements for benthos cartography

The distribution of subtidal and intertidal species and hence, of habitats, is thought to result from a combination of physical and biological factors. Physical factors include i) bottom depth and type, ii) hydrodynamic parameters such as wave exposure, water circulation, iii) hydrological parameters such as water clarity, water nutrient content etc. (2,3). In the tidal zone, altitudes and topography are all the more necessary for accurate computation of water dynamics.

In sedimentary areas, exposure to hydrodynamic forces is crucial and the morphology is the result of these factors. Although landforms are usually visible on planimetric media alone (such as photographs or images), relief information can significantly improve the topographic signature. In rocky areas, due to the smoothing effect of the seaweed cover, the landscape is more homogeneous when viewed from ground level, and all the more so from above, and terrain forms may be partly hidden from view, which makes the knowledge of the relief even more relevant. In salt marshes whose overall topography does not exceed a 2 m range, the micro-relief drives the distribution of species even more subtly (4). In general, with haline vegetation, the dominant species corresponds rather closely to a certain combination of the three above-mentioned topographic variables. So it should be possible to use this combination for prediction purposes, especially when identification by classical means is difficult.

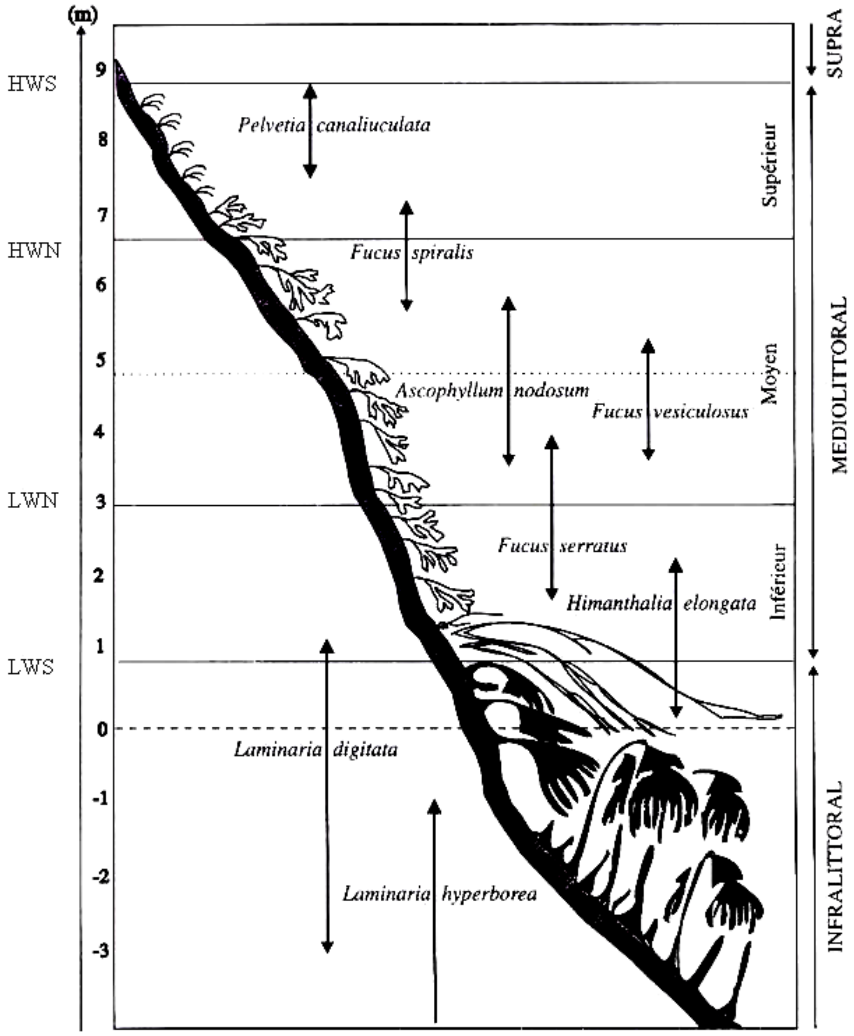

Figure1: Distribution of main seaweed species in the intertidal zone; adopted from (5) with modifications

Figure 1 shows the vertical distribution of seaweeds covering rocky substrata between low to high water levels in spring. So far, only planimetric data has been used to delineate the main groups. However, this task has always suffered from the insufficient discriminating power of most easily available remote sensing data, such as satellite imagery and aerial photography. These topographic variables need to be described on a greater scale to fully understand their predictive relevance. On the Atlantic coast of France, there is hardly a metre's difference in height between the LAT (Lowest Astronomical Tide) level and the low water spring level. Given the standard deviation of the species distribution, it appears that accuracy of about 20-30 cm should be sought.

TOPOGRAPHIC MAPPING METHODS

The study sites

The first study site is a rocky shore on Le Croisic peninsula, just north of the Loire Estuary (Figure 2a,b). The geology of the area is a leucogranite base with shiny mica flakes. Beach patches spread at the higher levels, followed downwards by a gently sloping granite plate covered by *Ascophyllum nodosum* seaweed, quickly becoming mixed with Fucales. Around half tide level are large slabs of rocks covered with cirripedes (*Balanus sp.*) and oysters. Then red seaweed types are seen, and finally *Laminaria spp*. at spring low tide level. The highest astronomical tide amplitude is 6.3 m.

The second site is the Aiguillon cove in Charente-Maritime, on the central Atlantic coast of France (Figure 2a,c). This 40 km² bay is mostly made up of tidal flats (called “slikke”). Their lower levels are used for shellfish farming activities (mussel poles). The upper part is occupied by salt marshes ("schorres"), shown in darker blue on Figure 2c. Salt marshes are limited landward by dykes approximately 3 m high, which protect the polders from invasion by the sea. The general slope of the bay is about 1-2 %.

Two height references are commonly used in the coastal zone: the French “IGN69” terrestrial altitude reference line and the LAT line (Lowest Astronomical Tide). In Le Croisic, the latter lies 2.86 m below the former.

Laser scanning: material and methods

Laser scanning has been documented by many authors (6,7) as a way of rapidly mapping the topography of vast expanses of land. Indeed, in the coastal area, this technique can overcome the constraints encountered over tidal zones, where both hydrographic and topographic field surveys can be difficult to implement. However, the need to operate at low water and the need for reasonably good weather conditions remain severe constraints (8). Due to generally gentle slopes and smooth terrain, the accuracy reached in the coastal zone is quite high. According to Huising and Pereira (6), and Populus (8), it is better than 15 cm on bare tidal flats and deteriorates to roughly 30 cm on schorres.

A survey was conducted on 23 September 2002 in Le Croisic. The flight lasted two hours during the low water period of a small spring tide. The low water level was –1.70 m with reference to IGN69. The scanning density chosen was at least 1 point per 3 m², deemed sufficient for benthos mapping purposes. The density was twice as much on flight lines overlaps. This was compatible with the specifications of the instrument and the flying parameters recommended by the operator. The laser scanning system was an ALTM 2025, with a frequency of 25000 Hz, a scanning rate of 28 Hz, a scan angle of 40° and a footprint of 25 cm². The flight altitude was 1000 m and the operating swath 700 m, which yields an effective swath of 500 m, due to the 30% flight line overlap.

The lidar data was acquired, delivered and processed in the newly adopted Lambert 93 system, which uses the IAG-GRS 80 ellipsoid. All filtering operations were performed by the operator, providing three types of output files, i.e. first pulse, last pulse and ground data (after filtering vegetation and buildings). To compare the two types of data, given the higher lidar density, the choice was made not to alter the photogrammetric grids, and rather to map the higher resolution lidar onto this grid, i.e. the Lambert 2 system based on the Clarke 1880 ellipsoid with elevations referenced to the IGN 69. (Note that this system is currently being replaced by the Lambert 93 based on the IAG-GRS80 ellipsoid). The Circé software from IGN (Institut Géographique National) was used to transform WGS84 heights into IGN69 altitudes (9).

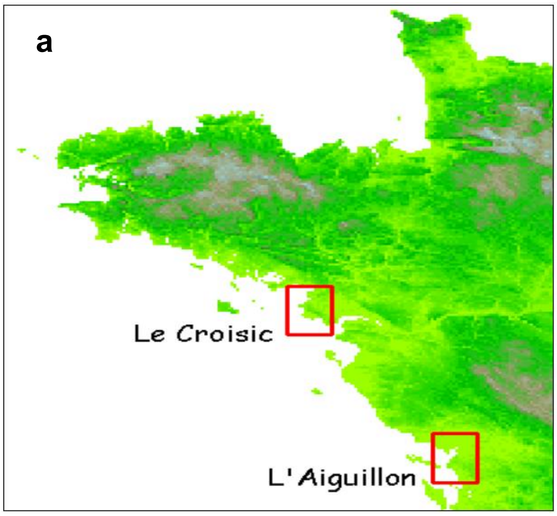

Figure 2a: The study sites of Le Croisic peninsula and Aiguillon cove, France.

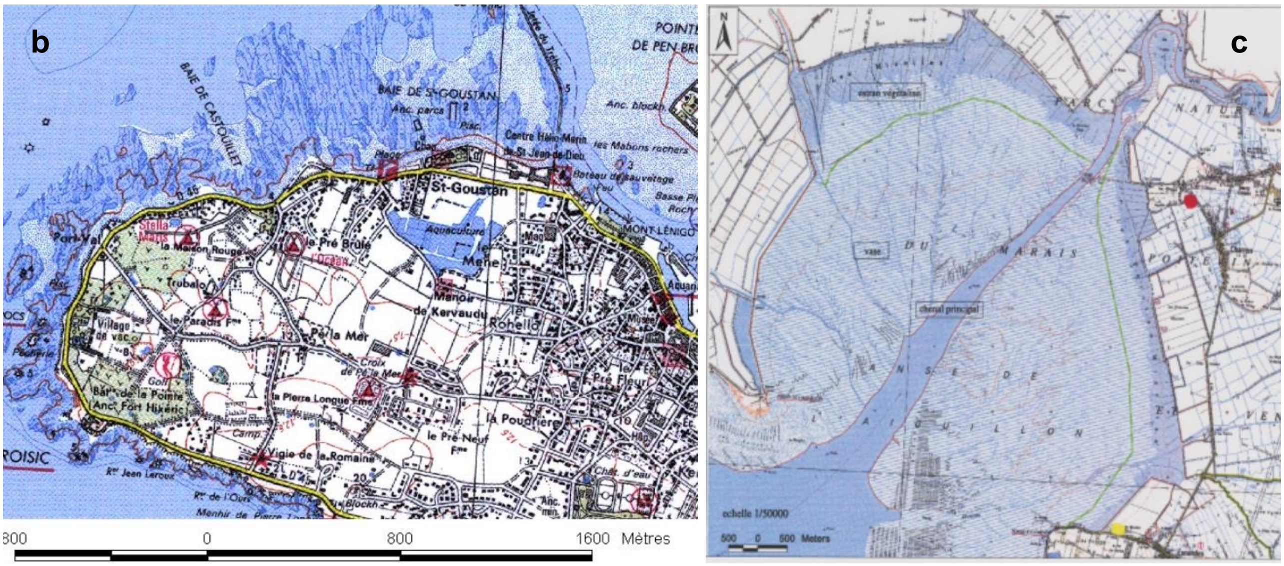

Figure 2: Le Croisic peninsula (b) and Aiguillon cove (c), Atlantic Coast, France.

Lidar data accuracy

Lidar ground data were compared with field measurements. Several control zones were surveyed using a high precision kinematic dGPS: a beach and a rocky tidal area (Figure 3), as well as a soccer field.

Co-location better than 1 m was ensured between the pairs of field points and neighbouring lidar points. This means that pairs of such points may randomly differ by the amount of relief occurring within 1 m on the ground. This amount is almost negligible on this sort of non-rugged terrain, with a slope not exceeding 2%.

High accuracy was found when validating lidar data against the soccer field measurements (Table 1), a flat surface where no topographic signal affects the pairs of points. The slight bias of 4 cm may be due to the presence of grass. The comparison on the sandy reference zone (with 774 pairs less than 1 m apart) yielded an almost nil mean difference, which could be expected on this type of bare soil. The standard deviation remains quite moderate, seeing that a small topographic contribution, the result of a random height difference induced by the local ruggedness, also affects it.

Figure 3: Control zones in Le Croisic; left: rocky zone; right: sandy flat (orthophotograph, August 31, 2000)

Table 1: Elevation discrepancies between lidar and field values (Z_{lidar} *-* Z_{field}*)*

Control zone	Number of pairs	Mean height difference (m)	Std deviation of difference (m)
Soccer field (Z_{lidar}– Z_{field})	665	0.04	0.10
Beach (Z_{lidar}– Z_{field})	774	-0.02	0.13

These figures show that lidar data are within the specifications given by the operator (15 cm on flat, smooth terrain) and usually found in the literature (6). De Joinville (10) also compared the results of a laser scanner survey with the 35 points of a control zone known with accuracy of 2 mm. After calibration, he obtained a bias of 2 cm and a standard deviation below 10 cm.

Photogrammetry: material and methods

Photogrammetry was based on a 1/25000 colour aerial photography survey carried out in 2000-2002 over the whole French coastal area, called the “Orthopho littorale” survey. Over the study areas, the survey took place in August 2000. One great advantage of this method is the low cost of the data: the photographs are free of charge and available to the general public. The original photographs were scanned at a resolution of 0.5 m. The full restitution process is described in Laurentin (11). After stereo-preparation and aero-triangulation (12) had been performed, DTMs were produced by automatic correlation using the Socet Set software from LH Systems. DTM points were generated in two modes called the “TIN “and “GRID” modes. The former usually gives a better account of reality, since the density of points can be adapted to the local ruggedness to retain only significant points. This is not the case with the latter, which yields elevations on a regular mesh (13). The accuracies expected with 1/25000 aerial photographs on such terrain are given by IGN (14) as 0.50 m in planimetry and 0.53 m in altimetry.

The restitution was performed on a 5 m grid in the original mapping system used for the photographs, i.e. Lambert 2.

Photogrammetric accuracy on a high texture site: Le Croisic peninsula

The results of the comparison between photogrammetric restitution from pairs of aerial photographs and field survey data over the Le Croisic area are summarised in Table 2. Besides the sandy flat, a rocky zone featuring either bare substratum or boulders or rocks covered with seaweed (Figure 3) was also surveyed. It can be seen that on 124 pairs on sandy ground, photogrammetry systematically reads below the reality, with a bias of 12 cm. This bias is most likely linked to operational artefacts. The standard deviation of the difference amounts to 39 cm, a very encouraging figure, given that a small topographic part of it may be due to the small slope between two points (average slope 2-3%). This is somewhat better than the theoretical precision mentioned above.

The results of the rocky zone survey on 401 pairs are also reported in Table 1. Although the bias is reduced to a very low value (probably random variability), the standard deviation increased as expected, reaching 62 cm. This is mostly due to the random height discrepancy occurring within 1 m of distance separating the two points, which of course increases in a rocky environment and may reach 30 cm or more.

It should be remembered that the quality of photogrammetry is highly dependent on the quality of the local correlation of the two photographs. Therefore, less accuracy is expected in low texture areas such as sedimentary flats in general. It is noteworthy that on the sandy zone here, in spite of its lower texture, no significant loss of accuracy occurs.

To further evaluate these results on a higher number of points, an assessment against lidar data was carried out in the same way over the whole tidal zone (i.e., between elevations of –1.7 m and +3 m). Lidar was considered a good enough reference to allow this procedure. Computation of over 17,000 pairs of points (with co-location better than 1 m) from both data sets yielded a bias of 31 cm.

In conclusion, photogrammetry seems to read below real values and the comparison with lidar seems to indicate a maximum bias of about 30 cm. The root mean square is in the range 30-70 cm.

Table 2: Elevation discrepancies between a) photogrammetry and field values (Z_{photo} – Z_{field}), b) photogrammetry and lidar values (Z_{lidar} – Z_{photo}),

Control zones	Number of pairs	Mean difference (m)	Standard deviation (m)	RMS
(a) Sandy zone ($Z_{photo} - Z_{field}$)	124	-0.12	0.39	0.41
(a) Rocky zone ($Z_{photo} - Z_{field}$)	401	-0.04	0.62	0.62
(b) Whole tidal area ($Z_{lidar} - Z_{photo}$)	17459	0.31	0.65	0.72

Photogrammetric accuracy on a low texture site: the Aiguillon cove

Laurentin (11) exploited a set of aerial photographs taken in August 2000 on the Aiguillon cove site and processed an area of about 30 km² (Figure 4), providing photogrammetric elevations on a 5 m mesh. The accuracy could not be assessed against a true reference such as dGPS field data, too difficult to collect on such terrains.

Therefore, it was decided to assess them against an experimental lidar survey that had been conducted there in May 2000 (8). The accuracy of these measurements had been evaluated at 11 cm, by using three reference zones with a surface area of one hectare, located at the periphery of the surveyed area. This accuracy only concerned bare soil and was not assessed on the schorre, due to insufficient ground truth data. The results are shown in Table 3. The photogrammetry still reads 10-30 cm below lidar values on average. The lowest accuracy of 1.22 m was obtained on tidal flats. This can be considered as realistic, since the reference lidar on this target is reliable. The accuracy improves to 70 cm when more texture is present, as is the case in the upper left block (tidal zone including schorre plus farmland). Note that the Socet Set “TIN” restitution mode was used here. In the case of a small subset of schorre (right hand part of tile 332_334/147_149), the rms is only 48 cm, but a high bias of 31 cm appears, which is most likely due to high lidar readings on vegetation. Given the lower lidar accuracy on such targets, the latter result should be regarded with caution.

Figure 4: Orthophotograph of Aiguillon cove (August 2, 2000) and extensions of photogrammetric DTM calculations. Coordinates are in the metric Lambert system.

Table 3: Elevation discrepancies ($Z_{lidar} - Z_{photo}$) between lidar and photogrammetry on three different zones in the Aiguillon cove

Zone (see Figure 4)	Mode	Number of pairs	Bias (m)	Standard deviation (m)	RMS (m)	DTM mesh size
332_334/2147_2149 (schorre only)	grid	20437	0.31	0.37	0.48	5
326_330/2149_2153 (various targets)	tin	20950	0.04	0.70	0.70	10
330_332/2149_2151 (mud flats)	grid	160000	0.09	1.22	1.22	5

Conclusion on photogrammetric accuracy

It was very difficult to gather enough field data to truly assess the photogrammetric accuracy on various targets. To summarise, a photogrammetric accuracy of roughly 30-60 cm can be expected on targets with enough texture to ensure both proper aero-triangulation and correlation. This was the case for the rocky substratum as well as for the schorre type ground. Over bare tidal flats, with no control points and poor correlation, accuracy drops to less than 1 m, which of course is insufficient for most applications. In terms of average readings, photogrammetry seems to constantly yield values below reality, the bias ranging from 10-30 cm. If the cause of this bias could be better understood and corrected, then rms could be kept lower.

ASSESSING TOPOGRAPHIC VARIABLES OVER THE CROISIC TIDAL AREA

Over the Croisic test site, a ground survey was organised in September 2002 covering an area of about 2.5 km² shown in Figure 5, where all land cover units, with plant covering or bare substratum, were delineated. The class called "Mixed", referring to a mixture of *Fucus* with cirrepede-covered rocks and patches of sand, will be disregarded. The "*Ascophyllum* dominant" class refers to patches where *Ascophyllum* is present with other species, mostly *Fucus sp*.

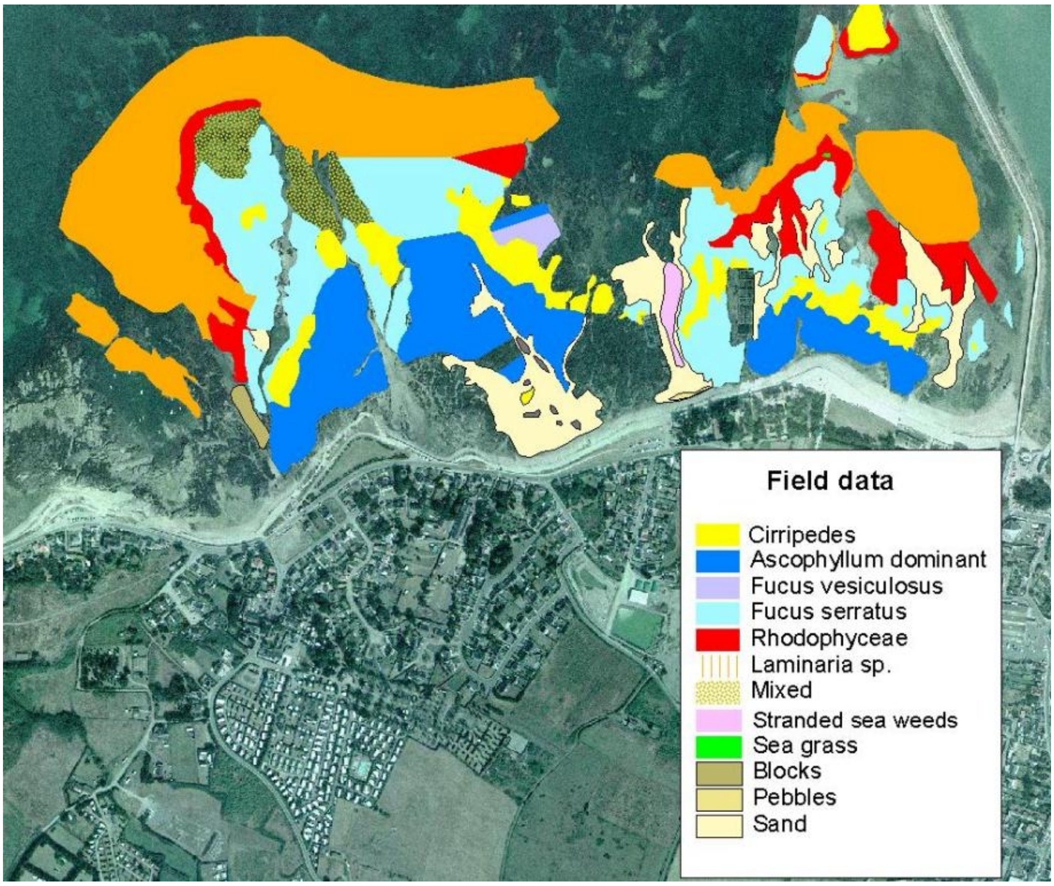

Figure 5: Le Croisic main intertidal units recorded during September 2002 field survey

Lidar and photogrammetric elevations were respectively available on 1 m and 5 m mesh gridded files. The area for comparison was limited to down to –1.70 m (i.e., 1.16 m above Lowest Astronomical Tide level), the lowest value reached by lidar data. Photogrammetric cells for comparison were chosen according to the availability of lidar cells less than 1 m away.

Next, a "summarising" function (Arcview TM) allowed the computation of statistics on these two elevation files for each of the ground truth polygons. The results for elevations are shown in Table 4. The smallest classes should be disregarded, as they do not represent a sufficient number of pixels. For instance, there were only 15 "photogrammetric" pixels for pebbles (i.e., 375 m²) and 39 for stranded seaweed.

These statistics are compatible with those computed above on the whole tidal zone, which yielded a 0.31 m bias (refer Table 2). Only Ascophyllum dominant and bare rocks are beyond this value.

When looking at whether the two methods could differentiate between seaweed classes, it must be remembered that the lowest lying classes, namely *Laminaria* and *Rhodophyceae*, cannot be characterised in terms of elevation. This is because the bottom threshold of elevations is –1.70 m here, which is above their theoretical highest altitude (Low water at spring level). The standard deviations of most classes are quite similar. This means that, provided the photogrammetric bias could be either explained or locally corrected, this method would be as effective as lidar in differentiating between classes.

Table 4: Statistics of lidar (1 m mesh size) and photogrammetric heights (5 m mesh size) as well as their difference for each field class.

Class	Area (m²)	Lidar Height (m)		Photogrammetric height (m)		$Z_{lidar} – Z_{photo}$
		Mean	standard deviation	mean	standard deviation	mean
Bare rocks with Cirrepedes	39350	-0.25	0.61	-0.67	0.52	0.42
Rhodophyceae	5175	-1.35	0.24	-1.52	0.16	0.17
Fucus serratus	74500	-0.81	0.73	-0.97	0.65	0.16
Laminaria sp.	10425	-1.36	0.22	-1.52	0.21	0.16
Ascophyllum dominant	80575	0.36	0.74	-0.11	0.76	0.47
Sand	31350	0.07	0.95	0.03	1.00	0.04
Fucus vesiculosus	2825	-1.28	0.29	-1.35	0.18	0.07
Boulders	2125	-0.85	0.33	-1.07	0.22	0.22
Stranded seaweed	1250	-1.31	0.35	-1.19	0.38	-0.12
Pebbles	375	1.57	0.22	1.70	0.24	-0.13

Table 5: Statistics of lidar and photogrammetric slopes (%) per field class, for a 5 m mesh size

Class	Lidar		Photogrammetry	
	mean (%)	standard deviation	mean (%)	standard deviation
Cirripedes	3.02	1.84	1.43	0.75
Rhodophyceae	1.40	1.16	0.92	0.54
Fucus serratus	2.06	1.40	1.35	0.78
Laminaria sp.	0.94	1.05	1.08	0.71
Ascophyllum dominant	2.10	1.30	1.42	0.91
Sand	1.79	1.64	1.62	1.41
Fucus vesiculosus	1.53	1.06	1.19	0.55
Cobbles	0.96	0.62	0.82	0.44
Stranded seaweed	1.15	0.72	1.65	0.71
Pebbles	5.67	0.57	6.00	0.69

The same computation was run for slopes, which are an important factor for seaweed drainage capacity. Since the slope has more relevance at lower scales, a 5 m mesh size was chosen for both lidar and photogrammetric data. The 5 m lidar file was obtained by a moving average of all individual measurements. As expected, the agreement (Table 5) is best on smoother surfaces such as sand, pebbles, cobbles. The photogrammetric method seems to underestimate the slopes of most seaweed categories. However, this should be confirmed on sites showing more ruggedness.

DISCUSSION ON DIGITAL TERRAIN MODELS (DTMS) PRODUCTION FEASIBILITY

Figure 6 shows the 1 m mesh lidar and the 5 m mesh photogrammetric DTMs. A very high level of detail can be seen on the lidar DTM, where a set of derelict concrete ponds less than 1 m high are clearly visible on the right hand side.

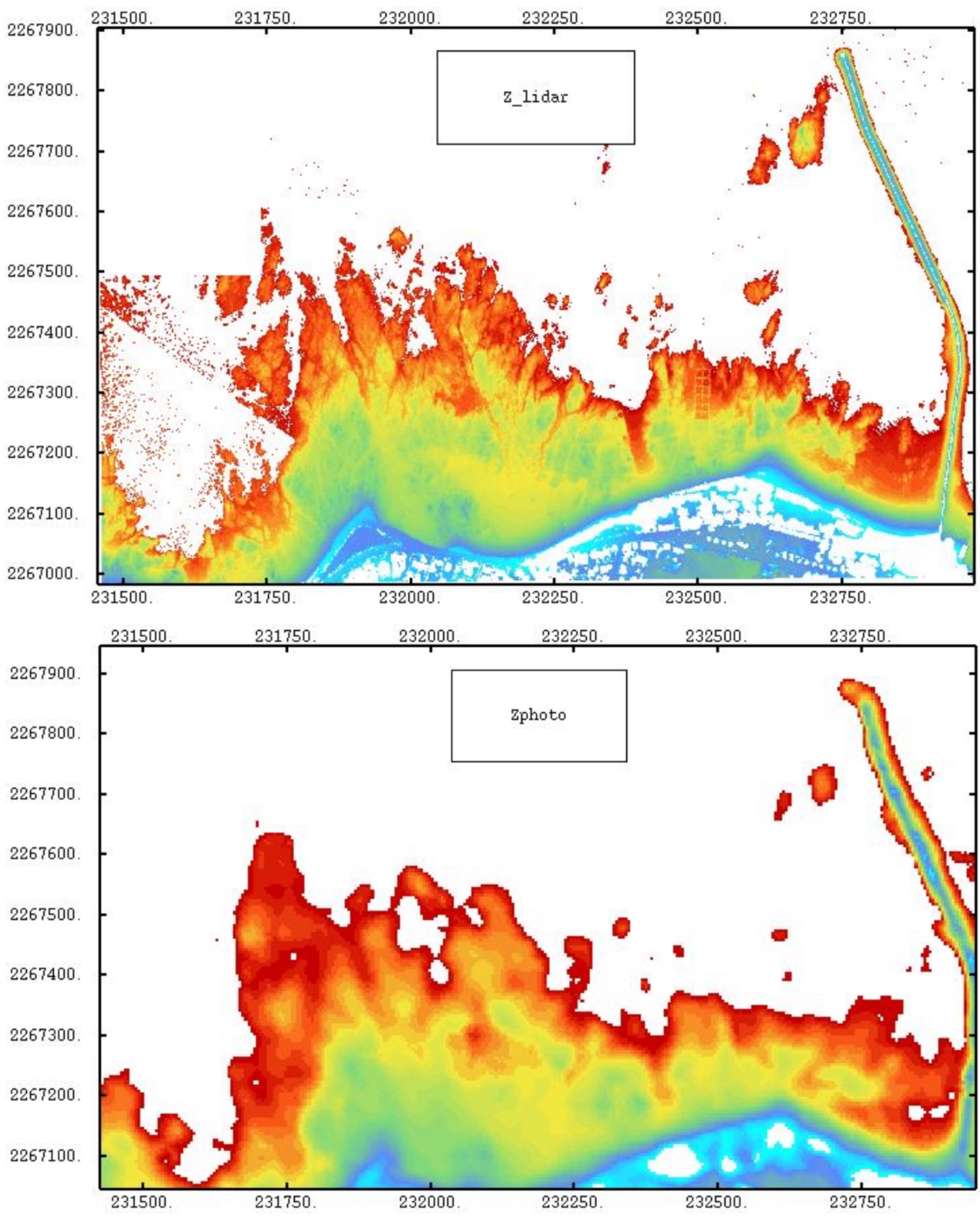

Figure 6: Lidar (top, 1 m mesh size) and photogrammetric elevations (bottom, 5 m mesh size) over Le Croisic. Elevations are referenced to the IGN69 datum.

However, not all applications require such a level of detail. In the case of benthos mapping, where a scale of 1/ 25000 is considered, a 3 to 4 m mesh is probably a good trade-off. When addressing other needs such as coastline defence mapping and monitoring, then a higher resolution is needed.

When using laser scanners such as the current ALTM generation, there is no dramatic increase in cost with point density. Therefore, it is recommended to survey at high density (almost 1 point per m²), hence allowing a wider range of applications in the range 1/5000 to 1/25000. In the case of photogrammetry, the cost of producing a fine mesh increases dramatically in terms of computing time. Also, automatic correlation degrades with decreasing mesh size. This led us to adopt a 5 m resolution in this study, which was reasonable in view of mapping on a 1/25000 scale and with regard to the limited accuracy of the process.

It has been shown above what degree of accuracy can be expected in mapping the topography of the coastal zone with both the laser scanning and photogrammetric techniques. The French benthos network specifications include the capacity to monitor some key units of the tidal zone over a limited number of sectors encompassing full coastal diversity, with a view to giving long-term trends. In Brittany, the total extent of these sectors amounts to 1,000 km². On rocky substratum, two main units to be covered are the *Lamanaria sp*. unit (spring low water level) and the "Fucals" group, which stretches over the medio-littoral range (see Figure 1). This means the boundaries of these units must be delineated with the highest reliability, making full use of both planimetric and topographic data. Inside these boundaries, appropriate indices can be built to monitor seaweed cover regularly and repeatedly.

For rugged zones such as Le Croisic, it is recommended that aerial photography be used and elevations computed by the photogrammetric method. No loss of accuracy occurs on smaller sedimentary units enclosed within the hard substratum area. Likewise, schorre units display enough "grain" to ensure good correlation and acceptable accuracy. Conversely, when vast expanses of tidal flats are not surrounded by higher texture zones, then accuracy drops to unacceptable levels and alternative mapping methods such as laser scanning must be considered.

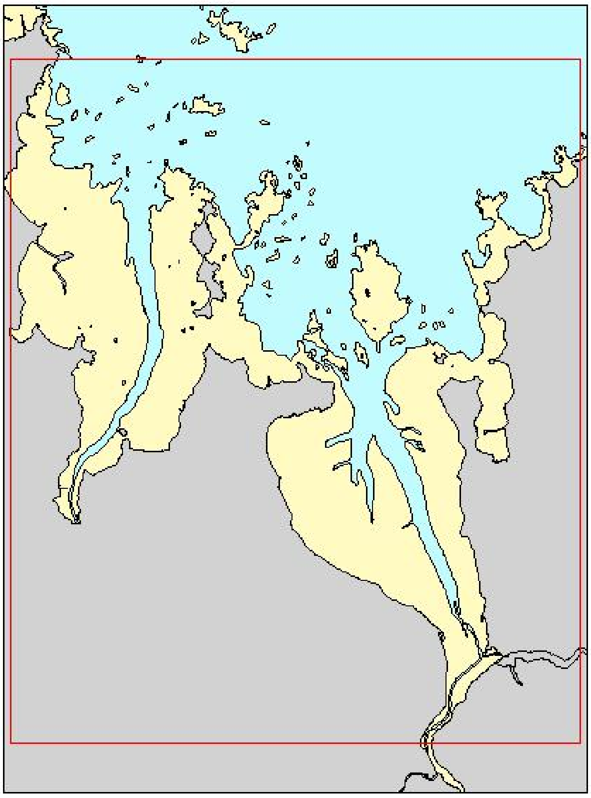

Figure 7: Baie de Morlaix, with tidal zone (size of the area approx. 110 km²)

To illustrate this, the economic feasibility of producing DTMs was investigated for the baie de Morlaix in Brittany, whose tidal zone covers an approximate 130 km² (Figure 7). The morphology of the outer bay is a rocky exposed type. Landwards, the bay becomes fully estuarine, with two rivers and large mudflats bordering them. As the width of these two estuaries does not exceed 2-3 km, and given the fact that some rocky outcrops lie in the way, the aero-triangulation is likely to remain of good quality. The bay was covered with about 20 aerial photographs on a scale of 1/25000. Bearing in mind that this coverage is freely available, the main tasks to be achieved are then: stereo-preparation, aero-triangulation and computation of the 5 m mesh size DTM.

The latter only involves computer time. Under these conditions, the cost per km² was evaluated with the help of a chartered surveyor at € 60-80. These figures should be re-assessed for a higher output resolution on the order of that of the lidar.

This figure cannot be directly compared with laser scanning costs, which are around € 350 per km² for medium size sites (200 km²), for a resolution of approximately 1 point per 3 m².

When designing a surveying strategy, sites to be surveyed have to be split into sub-units according to their land cover. Laser scanning could be reserved for larger (>20 km²) regularly sized sedimentary units, whereas photogrammetry would be suitable for all other sub-units, including tidal marshes. Joinville (10) also discussed cost aspects and concluded that to update IGN's BD Topo (of metric accuracy), a laser scanning survey flown at 3000 m would be competitive with photogrammetry.

CONCLUSION AND PERSPECTIVES

Beyond their elevation, seaweed development and distribution are to a certain extent a function of their frequency of inundation. This frequency varies with the tidal amplitude, which itself ranges on French shores from about 6 m on the Atlantic coast to twice that much in the Channel. To apply a single formula all along the coast, elevations have to be converted into immersion times. This can be done by inverting the tidal curve for each homogeneous tidal zone (as defined by the Hydrographic Office). This was already done in a local application to oyster growth in the Marennes-Oléron region of France (15). It could be generalised to all areas where the elevations are known.

Elevation and slope were the factors examined here. Orientation is the second most relevant factor to habitat distribution. After the statistics per ground unit have been refined for each method, a predictive approach should be explored by combining elevation and orientation, along with the texture contained in the orthophotographs, to model the presence of the various classes. The results should then be assessed against ground truth.

Mapping the topography of the coastal zone is a very costly operation, which means that strategy should be well thought-out. Sufficient accuracy is achievable at low cost with photogrammetry on hard substratum (more stable). Sedimentary zones, which are also the most prone to change, could then be dealt with using the laser scanning technique

ACKNOWLEDGMENTS

This study has been carried out with the sponsorship of the "Fondation d'Entreprise Total pour la Biodiversité et la Mer".

REFERENCES

1. Guillaumont B, D Hamon & C Hily, 2001. Réseau Benthique (REBENT), Développement d'un pilote Breton, Elaboration de l'Avant Projet, Rapport IFREMER.

2. Bickers A N, 2003. Cost Effective Marine Habitat Mapping from Small Vessels using GIS, Sidescan Sonar and Video. In: Coastal GIS 2003: An integrated approach to Australian coastal issues, edited by C D Woodroffe and R A Furness. Wollongong papers on Maritime Policy, 14.

3. Baxters K J, 2003. Broad scale classification and prediction of marine habitats: integrating GIS and rule based modelling. In: Coastal GIS 2003: An integrated approach to Australian coastal issues, edited by C.D. Woodroffe and R.A. Furness. Wollongong papers on Maritime Policy, 14.

4. Barreau G & J Populus, 2001. Apport de l'altimétrie par laser aéroporté à la cartographie d'estran: expérimentation de l'anse de l'Aiguillon. Revue XYZ, 87: 23-28

5. Feldmann J, 1978. Les algues. In: Précis de Botanique. Les végétaux inférieurs. (Masson, Eds.), 95-320.

6. Huising E J & L M Gomes Pereira, 1998. Errors and accuracy estimates of laser data acquired by various laser scanning systems for topographic applications. ISPRS Journal of Photogrammetry and Remote Sensing, 53: 245-261

7. Van de Kraats E, 1999. Airborne laser scanning: an operational remote sensing technique for digital elevation mapping in coastal areas, in: Geomatics and Coastal Environment. Actes de Colloques, edited by J Populus and L Loubersac, (Editions de l'Ifremer, Brest, France) 149-158

8. Populus J, G Barreau, J Fazilleau, M Kerdreux & J L'Yavanc, 2001. Assessment of the lidar topographic technique over a coastal area. CoastGIS'01, Second International Symposium on GIS and Computer Mapping (Halifax) June 2001.

9. IGN - http://www.ign.fr

10. Joinville O, B Ferrand & M Roux, 2002. Levé laser aéroporté: état de l'art, traitement des données et comparaison avec des systèmes imageurs. Bulletin SFPT, 166: 72-81

11. Laurentin A, 2002. Etude de faisabilité de topographie d'estran par photogrammétrie. Rapport Ifremer. DEL/AO (Brest) 56 pp.

12. Egels Y, 2001. Utilisation du GPS en aérotriangulation, Photogrammétrie numérique. ENSG (Editions Hermès), 136-142.

13. CNIG, 1997. Modèles numériques de terrain, aspects techniques. Fiche technique du CNIG n°58 (Conseil National de l'Information Géographique, Paris)

14. CNIG, 1993. Proposition de spécifications générales pour les prises de vue aériennes destinées à des levés photogrammétriques réguliers. (Conseil National de l'Information Géographique, Paris)

15. Populus J, L Loubersac., J Prou, M Kerdreux, O Lemoine, 2003. Geomatics for the management of oyster culture leases and production. In: Coastal and Marine Geo-Information Systems, edited by D.R. Green and S. D. King (Kluwer Academic Publishers, The Netherlands) 261-274