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Geomorphological and Biological Monitoring of Sensitive Intertidal Flat Environments

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ABSTRACT

Intertidal flats are very sensitive coastal environments. They support large communities of highly specialised fauna and flora and are subject to physical processes that combine hydrodynamic and sedimentary processes that are highly sensitive to change. An added factor to the difficulty of studying and monitoring intertidal flats and their environment is that they may be situated near a human settlement that requires protection from flooding or inundation. Monitoring sensitive intertidal flat ecosystems to obtain precise and updated information on its geomorphological and biological state is a challenging task for coastal scientists, managers and engineers, who have to deal with both, the conservation of the environment and human demands.

This paper describes a monitoring programme designed to establish, for a sensitive intertidal flat, the state of a comprehensive number of environmental factors prior, during and after the construction of sea defences. The rigorous assessment of environmental impact has been the backbone of the design and implementation of this monitoring programme based in Newtownards, at the Northern end of Strangford Lough in Northern Ireland. The Lough is a major wildlife and scientific resource that is subject to several domestic conservation designations as well as being considered, under European Community Directives, as a site of importance for nature conservation. The individual components of the intervening forces and responses have been identified and studied on a high-resolution spatial basis whilst not interfering with the fragile ecosystem. Biological and geomorphological parameters were identified for monitoring. Surveys comprised plant ecology, spatial distribution of density and type of vertebrates and invertebrates, sedimentological analysis (both historical and contemporary), hydrodynamic controls and topographic evolution as well as salt marsh shoreline monitoring. A wide range of technologies have been implemented to achieve a monitoring programme that that can be fully integrated in a Geographic Information System minimising post-processing times for interpretation and data-base access. Some of the techniques include the use of an ATV mounted DGPS with sub-centimetre accuracy for topographical and biological surveys, colour infrared digital airborne image acquisition using the Kodak DCS460 and image analysis, as well as numerical wave modelling of wave propagation. A virtual monitoring centre is being created as the main outcome of this project. The participating institutions (research, management and the public) will be able to access the electronic libraries and maps via an integrated web-based database. This project has been approached as a research and development programme that serves as a model for integrated coastal zone management in sensitive tidal flat ecosystems.

ADDITIONALINDEX WORDS: *morphodynamics and sedimentology of tidal flats, biomass spatial distribution.*

INTRODUCTION

Intertidal flats are generated in geographical areas where wave action is moderate and river input is small. They are the manifestation of progradation of sediments derived from a marine sediment source and can occur in lateral accreting tidal-dominated estuaries or wave-dominated inner parts of estuaries.

These environments are a rich source of food for secondary consumer species, which are attracted to estuaries by the large, productive populations of primary consumers. The latter, in turn, are dependent on plant and detritus production, which are maintained by the ability of estuaries to trap nutrients and food particles. The secondary consumers consist of birds such as wildfowl, waders and gulls, fish such as flounder (*Platichthys flesus* L.) and invertebrate predators such as the shore crab (*Carcinus maenus* L.). Primary consumers which include suspension or filter feeders e.g. mussels (*Mytilus edulis* L.), and deposit feeders e.g. lugworms (*Arenicola marina* L.), whose main source of food is detritus which abounds in the water column and on the bottom of the estuary, and which is replenished by the tide and freshwater inflow. Primary producers in the estuarine environment include salt marsh plant species found above the upper shore, and intertidal eelgrasses, filamentous algae, epibenthic algae and phytoplankton (McLUSKY, 1989). Seagrasses are considered to be an important aspect of estuarine ecosystems having an impact on the structure and function of many estuarine ecosystems throughout the world (HECK *et al*., 1995). Wildfowl and waders play an important role as consumers in estuarine ecosystems and as such may act as indicators of their productivity and health. Communities of eelgrasses and their consumers may be inter-linked directly i.e. herbivorous wildfowl that feed directly on *Zostera* spp. and other species may be indirectly affected through productivity and other geomorphological or biological interactions.

Strangford Lough, in common with estuaries throughout the UK and elsewhere, has been greatly influenced by man. Reclamation of land occurred during the 19th century when the northern saltmarshes were reclaimed for agricultural use (ANON, 1891). Construction of causeways and fords to islands has also occurred altering tidal flows and sedimentation patterns, e.g. from the mainland to Island Reagh and Mahee Island (KIRBY *et al*. 1993). Sea defences have also been constructed, most extensively to protect the reclaimed land at the northern end of the Lough, and have been upgraded at various times in the past (WHATMOUGH, 1995). These structures inevitably will have had an affect on the tidal regime and energy levels of the mudflats they abut (CARTER, 1988), though the overall impact of these on Strangford Lough is not known. Strangford Lough has seen an increase in the populations of its coastal towns, particularly since the 1960s, and there has been a rise in recreational activities and commercial enterprise (BROWN, 1990; DAVISON, 1991). Currently the Lough is used for a wide range of recreational and enterprise purposes. Recreational pastimes include wildfowling, dog-walking, sailing and general leisure activities while commercial activities include fishing, dredging, shellfish farming, shellfish gathering and bait digging. Waste disposal with sewage outfalls of varying degrees of treatment are located all around Strangford Lough, including Newtownards, Greyabbey and Quoile (DAVISON, 1991).

Figure 1. Location of Strangford Lough and Newtownards intertidal flats. Northern Ireland.

At the same time, Strangford Lough is designated for its nature conservation and ecological importance at national and international levels. In 1995 the subtidal areas of the Lough were designated a Marine Nature Reserve (MNR). The intertidal areas were designated as an Area of Special Scientific Interest (ASSI) in 1988 and 1989. This designation covers most of the intertidal area and much of the coastal fringe. The Strangford Lough area was designated an Area of Outstanding Natural Beauty in 1972 and there are five National Nature Reserves on or around the Lough which date from the mid 1970s. The area is also recognised as a potential Ramsar site and Special Protection Area (SPA) under the EC Birds Directive and has recently been confirmed as a Special Area of Conservation (cSAC) under the EEC Habitats Directive (WHATMOUGH, 1995).

The necessity for hard engineering solutions to protect the town of Newtownards is particularly sensitive as reclaimed land lies below mean sea level. A complex scenario is introduced here, where the major reconstruction of a 1.5 kilometre sea wall has to address all this issues without damaging the geomorphological and biological environment of the tidal flat. The intertidal flats immediate to the sea defences are also a delicate ecological setting that requires extreme attention because of its rich biological diversity. At the same time, the design of the new sea wall has to embrace the latest advances to reduce wave energy reflectivity because of its potential effects on the sedimentation of the tidal flats. The conflict must then be resolved by serving public demands for protection against flooding and ecological long term damage.

A monitoring programme was designed for the intertidal flats of Newtownards to establish the state of a comprehensive number of environmental factors prior, during and after the construction of the sea defences. The rigorous assessment of environmental impact has been the backbone of the design and implementation of this monitoring programme based in Newtownards, at the Northern end of Strangford Lough. It was recommended in the Environmental Impact assessment report on Strangford Lough Sea Defences at Newtownards (BINNIE BLACK and VEATCH, 1997) and the work has been undertaken on behalf of the Rivers Agency jointly by the University of Ulster at Coleraine and Queen’s University of Belfast. Since its beginning in 1997, the monitoring programme commenced with an 18 month pre-construction phase. The construction phase took over the monitoring programme in spring 1999, when refurbishing works commenced. The sea wall reconstruction was finalised in spring 2001 and since then the post-construction phase has been operational until its finalisation scheduled by 2004.

The aim of the pre-construction phase monitoring programme was to record conditions previous to the refurbishing of the sea defences, and provide baseline information on the biological and geomorphological processes involved in he study area. These data would allow an understanding of any changes that might occur and help to address directly the problem of anecdotal evidence of change in sediment composition. A fundamental part of the assessment was the regular and formal interaction between landowners, conservation bodies, the regulating authority and the project engineering staff. The outcome of this phase contributed to the design of the operational phase of seawall modification. Because of the regular discussion with all interested parties, agreement was reached on the strategy before construction commenced.

A second phase of monitoring was introduced for the construction phase, during which the impacts of operational activities could be monitored and any impact on the natural environment could be determined. Two locations within Strangford Lough were introduced as reference sites for topographic and sedimentological monitoring during the construction phase: Greyabbey Bay and Cross Island Bay. The locations were chosen for study on the basis of their position within the Lough and orientation with respect to the predominant wind and wave direction (Figure 1). Both sites are close to the Newtownards tidal flats, situated at the northern end of the Lough, but not directly affected by the refurbishing of the sea defences, so that other largely naturally occurring changes in the environment can be detected.

Following the end of the construction works in spring 2001, a further three year phase of post-construction monitoring was established to identify significant changes in the biological or sedimentological system and detect any potential long-term effects of the presence of the upgraded sea defences. New information will be added to the databases of the pre-construction and construction phases.

The individual components of the intervening forces and responses acting in the intertidal flats of Newtownards have been identified and studied on a high-resolution spatial basis whilst not interfering with the fragile ecosystem. Biological and geomorphological parameters were identified for monitoring. Surveys comprised plant ecology, spatial distribution of densities and type of vertebrates and invertebrates, sedimentological analysis (both historical and contemporary), hydrodynamic controls and topographic evolution as well as salt marsh shoreline monitoring.

The intertidal flats at Newtownards, as most areas in Strangford Lough, have been the subject of relatively few and mostly unpublished studies. These have dealt with management-related topics and/or biological factors acting on the shores of Strangford Lough. The geomorphological characteristics and the geomorphological processes taking place on the tidal flats of Strangford Lough have not been studied in detail in the past and, therefore, the current study involves the collection and analysis of novel data.

The method introduced in this article combines high resolution topographic DGPS surveys, advanced digital imagery orthophotographic surveys to monitor vegetation development, tidal and meteorological recording, faunal and floral empirical measurement and numerical modelling of wave induced processes. The databases are integrated using GIS and results, both cartographic and statistical.

The results demonstrate that the innovative methodological approach used in the study is sufficient to define the variables acting on the biological and geomorphological dynamics of the tidal flats. The analysis yield an understanding of tidal flat sedimentary and biological processes that enable the establishment of baseline conditions and can track changes induced by the new design of the sea defences in a highly homogeneous/low energy environment.

This paper outlines the key geomorphological and biological issues of the ongoing monitoring programme at Newtownards intertidal flats, in Co. Down, N. Ireland. Both the geomorphology, hydrology, biology and engineering aspects are contemplated and the relationships of the variables show how a multidisciplinary study carried out by independent research teams can benefit coastal management and decision making. The programme arose from the recommendations of the Environmental Impact Assessment report on Strangford Lough Sea Defences at Newtownards, and was undertaken jointly by the University of Ulster at Coleraine and Queen's University of Belfast, on behalf of the Rivers Agency (Department of Agriculture and Regional Development for Northern Ireland).

STUDYAREA

Main monitoring site: Newtownards intertidal flats

Newtownards intertidal flats are located at the northern end of Strangford Lough (Figure 1). The Lough is a large marine inlet on the East Coast of County Down, Northern Ireland, covering approximately 150 km^2 and is some 24 km long and 8 km wide at its broadest part. It is virtually land locked, being connected to the Irish Sea at its southern end by a narrow channel, call "the Narrows", some 8 km long, through which strong currents of up to 7 knots flow. The Lough has a semi-diurnal tidal regime with a tidal range varying from 3.5m (spring) to 2.0m (neaps).

The body of the Lough is a drowned drumlin field, with numerous islands and "pladdies" (eroded drumlins exposed at low tide) which are more extensive on the western than the eastern shore. There is relatively little freshwater input to the Lough, though there is a tidal flow of some 350 million cubic metres with every tide (DAVISON, 1991) through "the Narrows" at the southern end of the Lough. The Lough is therefore fully saline except near the Quoile and Comber rivers. The hydrodynamics of the Lough are complex, but generally there is a reduction of current strength from the Narrows to the north of the Lough. Extensive intertidal flats occur where the shore is protected from currents and the prevailing westerly winds, and therefore predominate in the north and particularly on the north-western shores. However, there are also extensive flats on the eastern shore, where shelter is offered by the islands around Greyabbey. The sediments of the Lough appear to be principally derived from the erosion of bed material and the re-distribution of earlier deposits, especially the winnowing out of glacial material, with the existing rivers and streams discharging little additional material into the Lough and having little influence on sediment distribution (DAVISON, 1991).

The shores of Strangford Lough are physically diverse, ranging from semi-exposed rocky shores in the "Narrows" to sheltered mud and boulder shores within the body of the Lough (WILKINSON *et al*., 1988). The Lough is also biologically diverse, with 72% of all sublittoral marine species reported for Northern Ireland occurring within it; 28% of these are found only in Strangford Lough (DAVISON, 1991). The islands of the Lough support breeding populations of birds. The Lough is also very important for numerous overwintering bird species, which utilise the Lough for much of the winter (PORTIG, 1997). Greatest concentrations are found in the northern half of the Lough where the mudflats are most extensive. Most notable of these overwintering birds visitors is the Pale Bellied Brent Goose (*Branta bernicla hrota* Müller) which breeds in Greenland and arctic Canada. This population overwinters almost exclusively in Ireland, with some two-thirds of the total population occurring on Strangford Lough in the early winter months (FOX *et al*., 1990; O'BRIAIN and HEALY, 1991). Redshank (*Tringa totanus* L.) and Knot (*Calidris canutus* L.) also occur in numbers that are of international importance (1% or more of the total flyway population) as well as many other species which occur in numbers of Irish and UK importance (BROWN, 1990).

Reference sites: Greyabbey Bay and Cross Island Bay

The two reference sites are located in Strangford Lough, close to the main monitoring area, but not directly affected by the renovation of the sea wall at Newtownards.

Greyabbey Bay is situated about 10 km. south of Newtownards tidal flats on the east coast, which receives strong wave attack The embayment of Greyabbey has a semicircular shape and comprises an area of about 1.3 km^2. It is bounded by land on the eastern and northern shores, and by the Mid and South Islands on the western side, leaving only its southern end open to direct wave attack. At low water vast tidal flats are exposed. Sediments of the intertidal area are characterised generally by a thin layer of sand overlaying the pladdies that are present throughout.

Cross Island Bay is located at the western shore of Strangford Lough, opposite Greyabbey. It is a small embayment extending about 250m at its widest distance

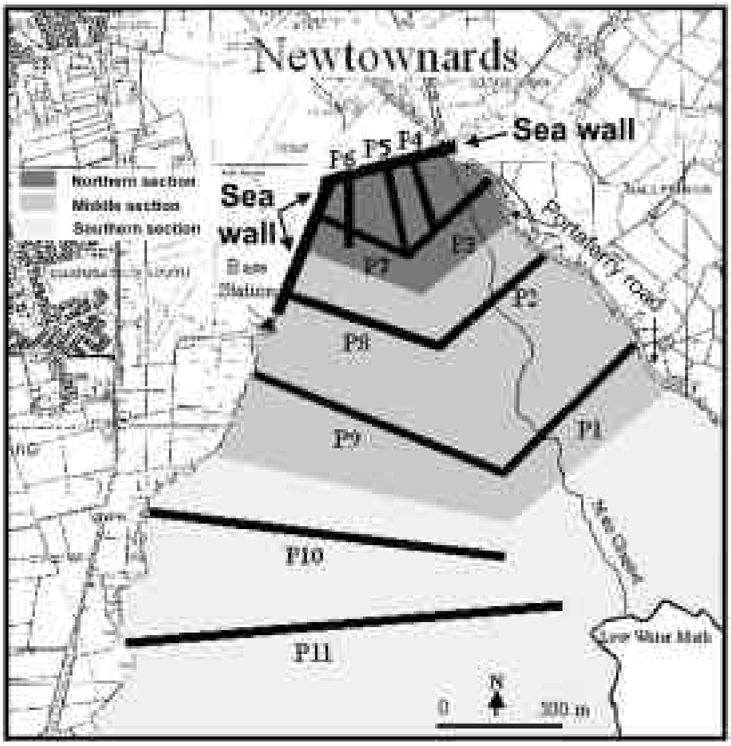

Figure 2. Location cross sectional profiles for regular monitoring and the three main sections into which the Newtownards intertidal flats was divided for analysis of monitored data.

north to south, and less than 500m at its longest distance from high to low water mark. The embayment forms between Reagh Island at the northern and western shores, and Cross Island and the causeway that links both islands at the southern shore, leaving only the eastern side of the embayment open to the incoming waves. Even this area open to the Lough is protected from direct wave attack by Mahee Island, creating an environment of lower wave and tidal energy when compared to the opposite eastern shore.

METHODS

Geomorphological and biological surveys were carefully design to achieve a detailed coverage of possible variations on the intertidal flats of Newtownards, with high frequency (bimonthly) during the establishing of baseline conditions during pre-construction phase, and twice a year (spring and autumn) during construction and post-construction phases, coinciding with the seasonality of the ecosystem (MALVAREZ *et al*., 2000; NAVAS *et al*., 2002). The reference sites monitoring is being carried out every 6 months since the beginning of the construction phase, during spring and autumn, coinciding with the main monitoring at Newtownards tidal flats.

Topographic surveys were carried out using an ATV mounted Differential Global Positioning System Trimble 4400Ssi (DGPS) with real-time sub-centimetre accuracy survey capability and a range of 10km. The DGPS base stations (at Newtownards and reference sites) were set and levelled with local benchmarks. In Newtownards, elevation measurements are taken along eleven fixed transect lines (Figure 2) that extend from high to low water line covering the extent of the intertidal flats seaward of the existing flood defences. After surveys, data is downloaded into a computer, individual profile lines selected, plotted and added to previous surveys to allow comparison of elevations along each fixed transect line.

Topographical monitoring of the reference sites has been carried out throughout the construction and post-construction periods. Fixed transect lines were designed to make possible repeatability of surveys and hence topographical comparison. Greyabbey has six cross sectional profile lines disposed in a radial pattern to better suit the shape of the embayment (Figure 3). Profile lines converged at a point located at the centre of the bay, reachable only during very low water periods. From this central point and along the described profile lines, topographical elevations are recorded using the same methods as those described from the main survey at Newtownards intertidal flats. Cross Island (Figure 3) has

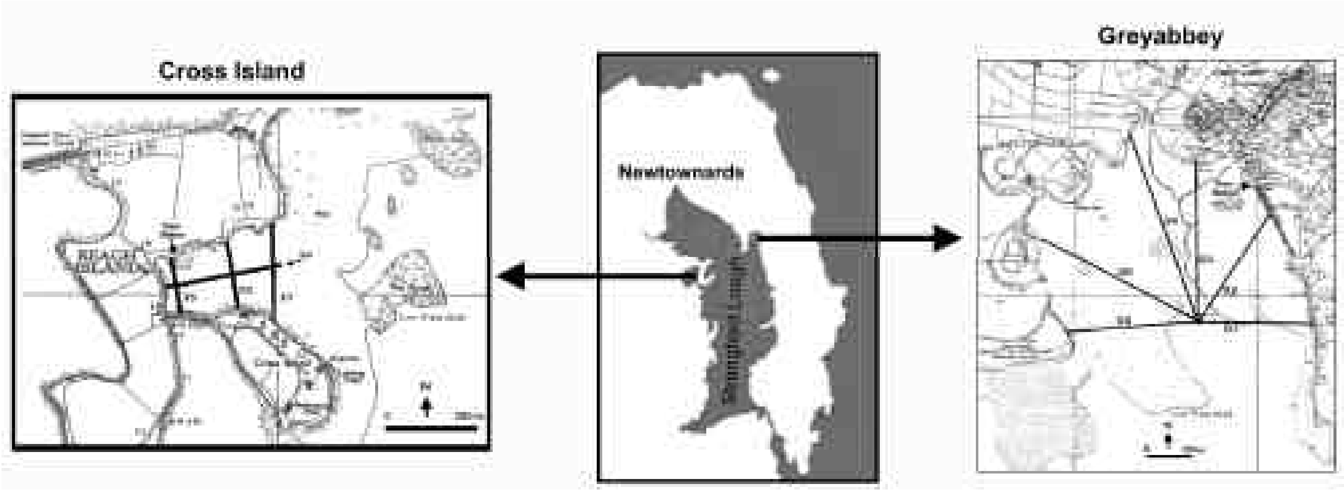

Figure 3. Location reference sites (Greyabbey and Cross Island) in Strangford Lough, and position of profile lines for reference site monitoring (maps modified from 1:10000 O.S.N.I).

four transect lines in a grid-like shape, and due to the soft nature of the sediments, surveys are made using the DGPS by hand instead of mounted on the ATV. For both reference sites, topographic raw data is archived and available if needed for future reference.

A series of sediment samples are collected from the Newtownards intertidal flats during the geomorphological surveys for subsequent textural analysis as an aid to interpretation of potential geomorphological changes on the tidal flats. Sediment samples are collected from the surface 5cm of the tidal flat along the transact lines and the sampling stations are geo-referenced using DGPS. Sediment samples are bagged, labelled and returned to the laboratory for analysis. Textural analysis of the samples was carried out in the laboratory following a stepwise approach. Each sample was thoroughly mixed in the laboratory and splits approximately in halve. One part was stored in the plastic container for future use if needed. The other half was wet-sieved through a 0.063 millimetres screen to remove the mud component which was dried at 100°C and weighed. This was recorded as a percentage dry weight of the total sample. The remaining sediment was dried at 100°C and dry-sieved through a 2 millimetre screen which removed the coarser fraction from the sand. When existent, coarser fraction was recorded as a dry-weight percentage of the total sample. The textural characteristics of the sand fraction were analysed by settling tube. This sedimentation method of size analysis is supported by many authors since the technique more nearly approaches natural conditions of deposition and by which hydraulically related size parameters can be obtained (POOLE, 1957; TAIRA and SCHOLLE, 1979). The settling tube computer program calculates grain size parameters based on the formulae for graphical statistical analysis obtained from BULLER and McMANUS (1979). Results from the settling tube were plotted showing the distribution of the percentage in each sediment size category as well as median, mean grain size (in φ and mm), sorting and skewness. These outputs were calculated using both graphical and moment statistics. As divisional points for sorting and skewness the verbal limits suggested by FOLK and WARD (1957) were used (table 1). As neither mud nor gravel constituted a sizeable proportion of any of the sediment samples, the sand component's statistical parameters may be considered representative of the entire sample.

For both reference sites, sediment samples are collected during field surveys along the profile lines in fixed points. Samples are labelled and stored in a cool room. This data would be available if needed for future analysis and interpretation.

Salt marsh shoreline monitoring was undertaken driving the ATV with the DGPS mounted, along the salt marsh edge. After each survey positions are plotted and overlaid with previous shorelines, creating a composite salt marsh shoreline map where precise measurements of erosion and accretion are carried out using Arc/View computer package. The monitoring of the salt marsh shoreline is accompanied by fixed-point ground photography of the northern most segment of the marsh-edge, as well as assessment of the state of its vegetation with the CIR imagery obtained after each aerial survey.

Airborne colour infra red digital images are acquired to monitor vegetation growth on the tidal flat and areas saltmarsh before, during and after the construction of the new seawall. This technique, coupled with calibration by ground truth, enable computerised analysis of the spatial distribution growth and health of vegetation over the tidal flats.

Aerial surveys were carried out every six moths during pre-construction and construction phases, coinciding with low tides at spring and autumn. During post-construction a yearly aerial survey was schedule to take place every autumn. The Kodak DCS 460 CIR digital camera used for the aerial surveys is a high resolution digital camera systems and has 3060 photosites on its horizontal axis and 2036 photosites on its vertical axis, delivering on output an effective resolution of over six million pixels per image (KOH and EDWARDS, 1996; MASON *et al*., 1997). The digital camera is mounted on a Piper Aztec aircraft and linked to a Trimble Ensign XL Global Positioning System (GPS) so each image would contain the latitude, longitude, time and date of capture for later analysis. The spatial resolution of digital camera images refers to the size of the actual scene portrayed by any single pixel. However, with conventional photography spatial resolution refers to the scale of the photograph (size of the area captured by the photo compared to actual image size). Scale in aerial digital images depends directly on the altitude above the surface.

Flight paths were designed to fly over the Newtownards intertidal flats as well as over the reference sites, and the survey was undertaken at an altitude commensurate with an image pixel resolution of 30cm. The control system uses an intervalometer to trigger the digital camera at uniform intervals. Each time the camera is triggered, the system records the time, GPS position and image information. Faster exposure times than conventional film are achieved with this digital camera system creating less image blurring during low altitude surveys. It is capable of recording one image every 10 seconds. Images are stored onto removable PCMCIA cards within the camera that could hold up to 81 images per card. When acquired for viewing and image analysis, the image size is 18.5Mb.

Distortions caused by tilt, topography and camera lenses are removed from the images during post-processing and these are ortho-rectified and geo-referenced using ERDAS Imagine software. The images are then utilised for various purposes, from map of the intertidal vegetation extent, class and health after supervised classification (with ERDAS Imagine) to expert analysis of the changes in morphology (i.e. channels) or positioning of the salt marsh from one set of photos to the next.

Immediately after or during aerial surveys, ground truthing was performing over the flown area. The purpose in acquiring ground truth is ultimately to aid in the calibration and interpretation of remotely recorded surveys by checking out realities from within the scene. That way computerised supervised classification can be performed.

Water levels and wind speed and direction were recorded nearby using equipment deployed for the study. Water level data collection involved the installation of an automated water level recording system (Dobie, NIWA) and the retrieval of water level records at 15-minute intervals. The data was used in subsequent wave modelling to provide water levels at which simulations would be conducted. The records also provided information on tidal elevation from predicted levels (residuals) resulting from variations in weather conditions during the monitoring period.

Wind direction and speed were recorded at 30-minute intervals at Newtownards using a Weather Wizard III station. A data logger recorded real time wind speed and direction and these were downloaded via modem or directly to a laptop computer. The records were used to hindcast wave heights in the Lough, analyse the effects in local wave propagation and to interpret tidal variability additional to that predicted from tide tables.

A numerical wave propagation model (HISWA) was used to aid in the interpretation of wave energy distribution (HIncasting of Shallow Water wAves, HOLTHUIJSEN *et al*, 1989, BOOIJ *et al*; 1993) and to analyse spatial distribution of wave-related hydrodynamic parameters. The package uses gridded bathymetric information and parametric deep-water wave data. This enables calculation of wave characteristics in shallow waters and at the shoreline. Gridded output of the model was plotted and tabulated for interpretation.

A recompilation of the sedimentary history of the tidal flats at Newtownards was included as part of the construction phase. Historical changes in surface sediment composition in the Newtownards intertidal were assessed semi-quantitatively through historical publications, aerial photography, maps and charts.

Three different techniques were used during the monitoring of the Newtownards intertidal area to identify the spatial and temporal variability of floral and faunal species. The biological characterisation was spatially referenced using common points with the geomorphological survey.

Bird population was monitored on a weekly basis. The survey consisted of three components: a) counts of birds present feeding in the intertidal area, b) counts of birds present using the surrounding land during high tide chiefly roosts, and c) observation of the bird's behaviour. Feeding counts lasting six hours were made of wildfowl and waders utilising the study area. These covered varying stages of the tidal cycle. Roost counts were made during the period when the tide covered the intertidal area during the above counts. These were supplemented by additional, specific counts on particular roosts. The behaviour of birds was observed generally throughout the course of these counts. In addition to the actual counts, records were kept of any anthropogenic or natural forms of disturbance that may or may not have affected the behaviour of the birds.

A coarse macro-invertebrate survey was conducted in the intertidal area. It involved the digging of a 50cm deep by $0.25m^2$ quadrant and hand sorting the visible macro-invertebrates from the sediment. Three randomly placed quadrants were located at more than 100 points distributed along transects. Macro-invertebrates were identified and the number and biomass of each species recorded. Data was collated for the three quadrants at each sample point.

A finer resolution survey investigated macro-invertebrates at a finer scale than the coarse survey above. Three replicates of a 15cm deep by 10cm diameter core were taken and sieved with a 0.5mm mesh to remove sediment. These samples were preserved and stained for subsequent analysis. Identification of all species was made and numbers and biomass of all invertebrates found was recorded. This investigation supplements the coarse survey which examined the larger macroinvertebrates found in the intertidal area that would not be well recorded in this type of survey.

Zostera spp. survey investigated the biomass and distribution of *Zostera* spp. in the intertidal area and was carried out with the fine survey. Three replicate samples were taken at each sample point consisting of a 15cm deep by 20.5cm diameter core. Samples were sieved to remove sediment and frozen for subsequent analysis. Analysis consisted of separation of *Zostera* into above and below ground fractions. These were oven dried at 70°C for 48 hours and dry weight of each fraction recorded.

A meiofaunal survey investigated microscopic invertebrates and consisted of three replicate core samples of 5cm deep by 1.5cm diameter taken at each sample point. Samples were split into the top 2cm and bottom 3cm portions were meiofauna were identified and numbers recorded in each fraction.

An organic and Chlorophyll-a survey was carried out at each sample point taking three replicate samples of sediment (top 1cm). In the laboratory these samples were analysed for Chlorophyll-a (pigment involved in photosynthesis) and organic content (measure of detrital material available).

All data obtained during the monitoring periods will be organised in electronic libraries. A virtual monitoring centre will be created for that data to be access by the participant institutions.

RESULTS

The pre-construction and construction phases of the monitoring program have provided a database with the results from the surveys carried out periodically on the intertidal flats of Newtownards. As the post-construction phase is still ongoing, results are not yet available for description or discussion. The database is GIS compatible and updateable when new data is collected. Results from the pre-construction and construction phases for both the geomorphology and biology surveys are presented below.

The topography of the tidal flats was measured along transects and results grouped in three main sections: northern, middle and southern, corresponding to areas closer and farther from the sea defences respectively (Figure 2). The northern section of the monitored area (closer to the sea defences) showed small variations overtime on elevation of the profiles. Average maximum variation was about 5cm. coinciding with the areas around the channels. The rest of the section, more stable, is mainly flat. Some areas described convex shape towards the low water mark (towards the south), where elevations tend to be higher than at the start of profile (towards the north). In the middle section, elevations showed small variation throughout the surveyed period, with an average maximum variation less than 10cm. Some cross sections here described a flat profile that extended about 600m along the western shore from the sea wall towards the middle of the flats, describing only at the very end, a slight change of slope. In the southern part of the middle section profiles show three changes in slope that can be seen defining two convex topographies divided by a flatter area around the middle of the profile (approximately between 550m and 700m). Vertical variations are most visible on the upper and middle areas, with an average maximum mobility of about 9cm. Also in these areas topography of spring surveys is higher than that of autumn surveys. The southern section (approximately 1000m from the sea defences) is represented by cross sections located at the western shore of the tidal flats starting from the salt marsh extending about 1600m across the western tidal flats. The first 200m of these cross sections depicts concave morphologies changing in slope towards the low water mark with a morphology sloping westwards that drops from over 1m in elevation to just below -0.3m in about 1200m. Variation in elevations along the profile is greater at the upper and lower ends of the profile (about 7cm and greater around the channel). In general terms, topographic levels during the autumn surveys are lower than during spring surveys.

Granulometry analyses showed little spatial variation over the survey area. The range in sediment sizes was typically 0.12 to 0.22 mm. Finer particles were found near the sea wall and greater towards the low water mark. Grain sizes in the main tidal channels were characterised by 0.20 mm particles. There were few changes in sediment sizes over these two phases of the monitoring programme. The overall stability was characterised by a < 0.05mm temporal variation in particle size.

Three-dimensional surveys of the salt marsh edge measured during the monitoring programme showed the stability of its overall position. Some areas, however, showed localised retreat noticeable in some cases, (generally during the autumn surveys) followed by periods of accretion (generally during spring surveys), creating a seasonal behaviour. This was more acute at the northern and southern ends of the monitored salt marshes. Along the central area stability dominated up to the autumn 2000 survey when localised retreat of the shoreline could be appreciated.

Computer simulations of wave propagation indicated that the spatial distribution of potential wave activity (as indicated by wave bottom orbital velocity in m/s) was higher around the southern reaches of the sea wall with a significant concentration between profiles P7 and P8 (Figure 2). High values were also output along the south facing shores of the east (along the Portaferry road) to the southeast of the study area. The flat topography of the western shores induces a gradual shoaling of the waves that may result in re-suspension of sediments. Under storm conditions values of wave heights were low at the northern end due to shoaling and the highest values were predicted at locations around P8 (Figure 2).

Water levels recorded in Killinchy were corrected to local datum (using DGPS and local benchmarks) so that the results could be interpreted for conditions in Newtownards. Maximum variation between low and high water measurements was recorded at 4.39m. Average high water level was calculated at 1.86m, and average low water level at –1.96m OD. During the monitored period, although periods of strong winds and storms were depicted from the climatic data analysed for the studied period, no anomalies were noted between the recorded and the astronomical tides, predicted and available in published tables and computer models. This may be caused by directions not coinciding with tidal approach, orientation of the shoreline or timing with high/low tides during storms.

The most frequent wind speed values were between 0.4 m/s and 3.6 m/s where more than the 50% of the frequencies concentrate. Maximum values in rare occasions reached above 13 m/s (0.2 % of recorded period). Average values from the extensive data record have been calculated in order to continue monitoring and illustrate some of the seasonal patterns observed. Recorded average wind speeds were low, always below 6 m/s with an average velocity of 3.2 m/s. Gusts were also recorded with maximum values over 40 m/s and an average of 6.2 m/s. Winds affecting the flats were mainly from due west-south-west during the recording period. An average of around 10 % of total winds recorded showed prevailing conditions from western sectors.

Airborne remote sensing images (digital Colour Infra Red) were acquired flying over the tidal flats of Newtownards in a format suitable compatible with integration with a GIS. Two reference sites were also surveyed to enable comparison. The spectral signature of the different types of vegetation present on the intertidal

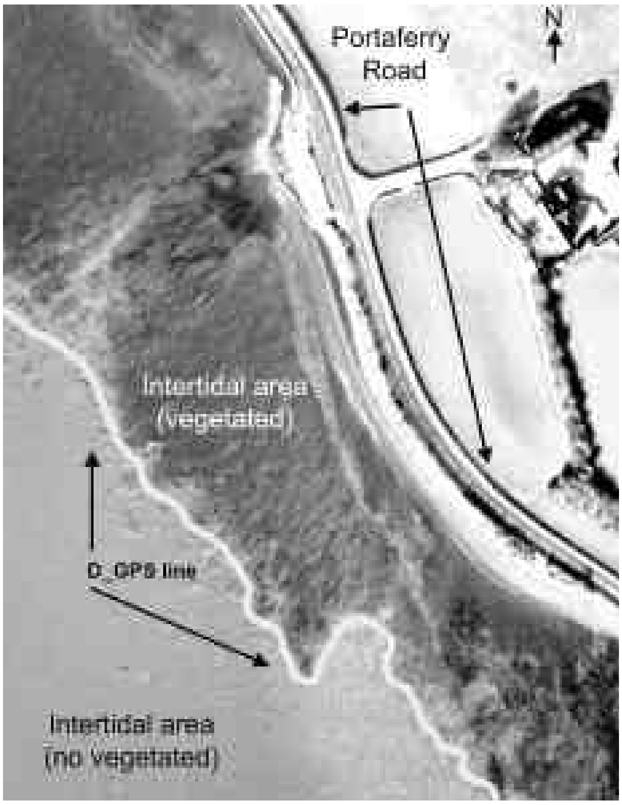

Figure 4. Digital colour infra red aerial image of the eastern shore of Newtownards tidal flats. Grey line represents the limit of the Zostera ssp from DGPS ground truthing data. Darker side of the line is intertidal vegetated area while the other is not vegetated.

flats was preliminary validated by field-based ground truthing using DGPS. Maps of outline and vigour of vegetation are readily available in case that comparison is required before and after the pre and construction phases (Figure 4).

The historical analysis of surface sediment composition showed that the Newtownards intertidal flats appears to have experienced alternating periods of sand and mud dominance over the past 200 years.

The results of the biological surveys show more definition near the sea wall. The fine survey, that investigated macroinvertebrates in high spatial resolution, showed that there is a general tendency towards lower numbers and biomass of species in Spring than in Autumn, which would be expected as many of these species are preyed heavily upon the Winter months.

The distribution of *Hydrobia ulvae* by both numbers and biomass in the intertidal area showed that this species is more or less ubiquitous with greater biomass found in the lower areas and peak biomass and numbers coincide. The distribution of Nepthys sp. by both numbers and biomass in the intertidal identified that numbers differs from that of biomass in that though numbers of this species are relatively widespread biomass is greatest in the mid to upper tidal areas. *Macoma balthica* and *Cerastoderma edule* (Cockle) clearly have a different distribution in the intertidal area. One explanation for this is that *Macoma balthica* prefer muddier areas of an estuary than *Cerastoderma edule*. However this was not confirmed statistically. Hydrobia ulvae between the April and September showed a similar spatial distribution though with much reduced biomass in April.

The coarse survey was carried out in March 1997, March 1998 and March 1999. The species found in these two survey chiefly represented a subset of the fine survey with only two additional species found *Hediste diversicolor* and *Lanice* sp.. The distribution of *Cerastoderma edule* between the three surveys shows the three years is similar with the cockle bed well established and so little expansion evident. It was also seen with comparison between the fine survey that the distribution in the fine survey is somewhat more extensive. This will be due to the fine survey "picking up" the smaller cockles missed in the coarse survey. The distribution of *Arenicola marina* between the fine survey in September 1997 and coarse survey 1998 showed a disparity between these two surveys and illustrates the limitation in the fine survey for examining the distribution of this species. The coarse survey compliments the fine survey in looking at the distribution of certain species.

The *Zostera* resource was surveyed from 1997 to 1999. The distribution of *Zostera* spp. was relatively uniform and had a lower limit within the study area during April's surveys. The distribution in September resulted in higher densities in all areas and the biomass distribution was not as uniform. The highest density areas in the September distribution were the wetter areas of the study area where growth of *Zostera* was better than in dryer areas.

The results of the bird counts showed maximum numbers of wildfowl and waders counted in the study area in each month. Numbers in May and June were very small with species present being in small numbers (juvenile Shelduck and occasional Curlew or Oystercatcher). Numbers increased over July and August with an influx of Redshank, Curlew and Oystercatcher. However, numbers increased significantly in September with Brent geese especially numerous at this time. Total numbers of wildfowl and waders remained relatively high for most of the winter period with in excess of 5,000 individuals utilising the area until February with a peak of over 10,000 individuals. Species composition changed over the winter period. Numbers declined from March onwards with few birds remaining in May. Variation in total numbers counted in consecutive counts was considerable which is also true of individual species. Peak numbers of Brent Geese utilising the intertidal study area in 1997/98 was 7067 individuals, though as explained above this should not be treated as an absolute figure. Maximum count in the winter of 1997/98 was somewhat lower at 5770.

During this study it became clear that birds utilise the study area in different ways. Apart from seasonal changes birds utilise the area differently at various times of the tidal cycle. This information is important for any future study of the area. Redshank utilise the area in constant numbers fairly consistently throughout the tidal cycle. Other species, such as Dunlin and Pintail, do not utilise the intertidal flats at low water and only use the area as the tide floods or ebbs. Brent Geese showed a variation in usage as they are roosting on the water. This highlights the care that is needed in comparing counts form year to year in that there are many factors influencing the distribution of birds.

DISCUSSION AND CONCLUSIONS

Coastal defences are a controversial element of coastal zone management and frequently elicit negative responses from a variety of sources (NORDSTROM, 2000). There are instances where human infrastructure is such that there is no viable option other than sea defences. In such instances, the means by which the defence is designed and constructed should take account local concerns as expressed through relevant authorities or groupings. If this does not take place, conflict may arise between various interest groups.

The alteration of existing sea defences at Newtownards took place in a highly sensitive ecosystem and required a careful assessment of both the engineering design and ecological implications of engineering works both during and after the construction phase. The major areas of concern related to geomorphological/sedimentological changes on the tidal flats and associated ecological changes. Since links were already inferred to exist between the geomorphology and ecosystem that may interact with each other, a pre-construction phase assessment of these linkages was conducted over an 18 month period. An integral part of this assessment was the regular and formal interaction between landowners, conservation bodies, the regulating authority and the project engineering staff. The outcome of this phase contributed to the design of the operational phase of seawall modification and identified periods during which no work was to be conducted due to high numbers of migratory birds. It also informed decisions regarding patterns of access to the tidal flat and the type and duration of vehicles that should access the intertidal area. Because of the regular discussion with all interested parties, agreement was reached on the strategy before construction commenced. Following the pre-construction phase assessment, which established a monitoring baseline, a second phase of monitoring was introduced for the construction phase during which the impacts of operational activities could be monitored and any impact on the natural environment could be determined. A third phase -still in operation- that commenced when the reconstruction of the sea defences was finished was designed to take into account any potential long-term effects of the presence of the new defences. Since the area is highly visible for adjacent roads and is heavily utilised by a variety of recreational users, it had high public awareness and any interference with traditional recreation had to be considered. The participation of interested parties in the monitoring group, meant that due regard could be given to potential recreational impacts during the construction phase and interference was minimised and alternatives suggested.

This exercise in environmental assessment and monitoring demonstrated a linked approach to establishing baseline conditions, taking account of legitimate environmental and recreational concerns, and designing sea defence works accordingly. Since this process was ongoing from the inception phase, public concerns were allayed and due regard was given to findings of pre-construction phase investigations. The process serves as a model for development in ecologically sensitive, high profile coastal areas and it enabled the combined needs for enhanced sea defences and maintenance of a viable habitat to be met.

Geomorphological and biological surveys of the intertidal flats of Strangford Lough were undertaken, prior to engineering works for the refurbishment of the sea defences of Newtownards and ran from April 1997 to March 1999. The intertidal area carries large overwintering populations of Brent geese and waders, part of the reason for the designation of the area as Special Protection Area and Marine Nature Reserve. The monitoring programme was recommended in the Environmental Impact Assessment report on Strangford Lough Sea Defences at Newtownards (BINNIE BLACK and VEATCH, 1997). The work has been undertaken on behalf of the Rivers Agency jointly by staff of the University of Ulster at Coleraine and Queen's University of Belfast.

The geomorphological and biological monitoring programme of Newtownards intertidal flats included: a) Regular topographic surveys along a series of cross sectional profile lines at the main study area and at two reference sites that help to describe and understand the geomorphological and biological patterns of the intertidal flat environment. b) Sediment collection and analysis to assess possible variations in particle size over the study area. Results concluded in limited spatial and temporal variation to date. c) Water levels recording assess tidal patterns and provide first hand information with which wave modelling simulations could be conducted. No anomalies were noted between predicted and recorded tides. d) Meteorological monitoring to interpret geomorphological and biological episodes, as well as tidal variations from the expected behaviour predicted in tide tables and to help analyse the effects in local wave propagation. Prevailing wind directions and averaged velocities of main winds and gusts are updated regularly. e) Wave propagation modelling to identify spatial distribution of potential wave activity and allow interpretation of sediment size distribution. f) Aerial surveys to obtain digital colour infra red imagery to assess vegetation growth and biomass density on the intertidal areas and saltmarsh regularly. Ground truth calibrations and image post-processing, classification and interpretation are also included. g) A sedimentary history of the tidal flats to localise and describe changes in surficial sediments of Newtownards intertidal area. Although the reasons for such changes remain unclear, it may involve climatic, biological or human forcing factors, or a combination of these potential influences. h) Intertidal *Zostera* spp. Distribution, growth and biomass of eelgrass were investigated. There was major temporal and spatial variability in peak biomass of *Zostera* spp due to grazing by the Brent geese in winter. i) Distribution and abundance intertidal invertebrates. These animals which support many other birds and fish were examined using widespread, extensive sampling, and other more, detailed and intensive surveys. community composition of invertebrates was found to be relatively uniform, which may in part be due to a similar uniformity in sediment size composition. j) Bird populations. The distribution and abundance of the intertidal plants and invertebrate animals confirm the view that the study area is an important area for overwintering wildfowl and waders as birds utilise the area for feeding an as a roost site. The behaviour of the overwintering wildfowl and waders can be related to their use of the area and their major food preferences.

All data produced can be integrated in a Geographic Information System, minimising post-processing times for interpretation and database access. A virtual monitoring centre will be available at the end of the monitoring programme, so resulting data from the monitoring programme can be accessed by the participating institutions (research, management and the public) via the Internet.

The whole monitoring process carried out in the intertidal flats of Newtownards serves as a model for development in ecologically sensitive, high profile coastal areas and it enabled the combined needs for enhanced sea defences and maintenance of a viable habitat to be met.

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