Determining the sensitivity of SPOT XS imagery for monitoring intertidal and sublittoral vegetation of Otago Harbour

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1. Executive Summary

INVESTIGATION SUMMARY

The University of Otago Department of Surveying conducted a remote sensing survey using an existing SPOT image of the Otago Coast. The ability of SPOT multispectral data to detect different intertidal and shallow subtidal habitats was examined using a classification accuracy assessment. Potential remote sensing applications to provide information supporting coastal conservation and coastal management strategies were identified. Eelgrass *(Zostera novazelandica)* beds were the focus of this case study.

OBJECTIVES

- To determine the sensitivity of SPOT imagery for classifying coastal vegetation using eelgrass as a case study.
- To show the benefits of incorporating satellite imagery into management strategies.
- To identify costs involved in performing remote sensing analysis of the Otago coast.
- To identify the factors that need to be considered to ensure remote sensing data obtained is suitable for coastal observation.

METHODS

- A February, 1994, SPOT image of the Otago Harbour and surrounding coast was analyzed for this project. Field surveys of Otago Harbour tidal flats were performed to determine thematic classes based on substrate, vegetation and shore level. Supervised image classifications were used to determine the image sensitivity to similar cover types. An accuracy assessment was performed.
- Relevant literature was reviewed to determine how satellite imagery supports coastal management strategies.
- The cost associated with digital image analysis was estimated based upon minimum functionality.
- Acquisition techniques were assessed to determine optimum conditions for performing coastal analysis.

RESULTS

- The overall classification accuracy was 87% for intertidal and subtidal vegetation. Most of the confusion among classes occurred where a low density of *Zostera* was difficult to distinguish from the bare substrate. For example, the class of low density *Zostera* on high sandbanks was often confused with the unvegetated sandbank class.

- SPOT satellite imagery can provide managers with useful information by facilitating the development of a regional inventory of coastal habitats such as eelgrass. Changes in the area or quality of these habitats can be monitored and quantified using multi-temporal images.

- Output covertypes are in an electronic raster format. The electronic format of these areas of interest readily supports a variety of databases. These databases may be shared between organizations with similar territorial interests.

- The direct real costs of this image analysis including the hardware/software platform and satellite imagery was $7 650 for mapping 929 hectares. However, if the full 360,000 hectare image were being analyzed the cost would only increase to $10 950. These values do not include overheads or reporting costs.

CONCLUSIONS

- SPOT imagery does possess the spectral and radiometric sensitivity to distinguish the difference between a variety of intertidal and sublittoral covertypes.

- The information which SPOT provides on the distribution and extent of different habitat types allows a better assessment of their regional significance.

- Using SPOT to monitor changes in the health and distribution of eelgrass provides a practical means of assessing the effect that coastal activities and discharges are having on the habitat.

- Image analysis and electronic databases such as GIS (geographic information systems) are interrelated. Attributes collected from image analysis can be compiled into other databases. Specifically, this analysis can be used as a baseline to quantify future coastal vegetation changes.

- The system costs are significant but may be offset by cooperation between users of the image data and databases.

RECOMMENDATIONS

- For analysis of large area coastal vegetation, satellite image classification should be used in conjunction with field surveys. The resulting information will provide bench marks for other non-image observations and research.

- Surveys should be performed at regular discrete intervals. These intervals should take the dynamic nature of the physical and biological environment into account.

- Since the information contained within an image can have a wide variety of applications and the output from analysis can be project specific, the Otago Conservancy should develop partners to share resources and facilities.

- An electronic layered database should be developed because it would enable easy access to image and other spatial attribute data.

2. Introduction

Electronic collection and storage of spatial (both image and non-image) data, provides a fast, flexible means to monitor large geographic areas. Satellite platforms such as the French Systeme Pour l'Observation de la Terre (SPOT) and American Landsat Thematic Mapper (TM) collect reflective information from a variety of spectral bands between 0.4 and 12 μm of the electromagnetic spectrum. Coastal nearshore and intertidal characteristics can be mapped, analyzed and quantified from satellite observations using a wide variety of image analysis and mapping software (Jensen et al. 1990, Augenstein 1991, Deysher 1993, Guillaumont et al. 1993 and Race 1994). Landuse attribute databases allow the user to merge a broad range of spatial and non-spatial target characteristics in a common file structure. This offers the flexibility to support a number of municipal organizations with different responsibilities and functions within the same geographic area.

This paper will demonstrate the application of remote sensing techniques to provide cost effective information on the regional distribution and extent of the coastal eelgrass *(Zostera novazelandica)* habitat. A review of the use of satellite remote sensing for coastal inventory and management is included. The cost associated with environmental monitoring using image analysis will be identified. Important considerations for obtaining consistent and useful results from coastal land use surveys will be described.

Seagrasses are ideally suited to mapping from remote platforms and have been a focus of studies considering the application of remote sensing to study the coastal environment (Kirkman 1990, Kelly 1991). Seagrass habitats are recognised worldwide for their productivity and diversity (Zieman and Wetzel 1980). The eelgrass beds within Otago Harbour contribute to the production of organic detritus making them an important component of the ecosystem (ORC & DCC 1991). However, there have been few studies exploring the demography and productivity of the New Zealand seagrasses *(Zostera novazelandica* and *Z. capricorni)* despite their role in estuary and inlet ecology. An estimate of minimum detritus production for eelgrass in Pauahatanui Inlet based on the maximum summer above ground weight and assuming the loss of this material over winter was 90 gram dry weight/m^2 (DSIR 1980). Even at this conservative estimate the annual production from the 38 hectares of eelgrass within the Inlet amounted to 34 tonnes annually and it was suggested that the loss or reduction of eelgrass beds could be disastrous for the filter feeding cockle populations. Other studies show that eelgrass can have a considerably higher number of crop rotations per year (eg Kerr and Strother 1989).

Using the eelgrass *Zostera novazelandica* habitat as a case study also demonstrates the immediate management benefits that may be gained through incorporating remotely sensed information into resource planning strategies. The Resource Management Act 1991 (RMA) requires Regional Councils to produce coastal plans to assist in the management of coastal resources. Rules within these plans determine the status of an activity in the coastal marine area and whether a resource consent is required. In considering the management of the coastal marine area, the Otago Coastal Plan must recognise the different sensitivities of the various areas of Otago's coast and provide an appropriate framework to consider the effects of all activities and uses (section 5.2, ORC 1994).

The report of the Ecosystems and Physical Systems Working Group for the Otago Harbour Planning Study (ORC & DCC 1991) emphasised the need for detailed information on the location and extent of major benthic habitat and community types within the harbour including eelgrass. Such information would aid understanding of how the Harbour ecosystem functions in terms of the transfer of energy between different components. Without such an understanding there is no way of predicting how the Harbour ecosystem might respond to environmental change (ORC & DCC 1991). Management areas have been suggested for the Harbour in the proposed Coastal Plan despite this recognition of limited knowledge (ORC 1994). However, the ORC intend to monitor the extent to which the foreshore and seabed is altered, and the effects of alterations on the coastal environment (section 17.2, ORC 1994).

Satellite imagery can provide an effective means of acquiring environmental data (Kelly 1991). Since timely Landsat data are currently unavailable for New Zealand, analysis issues will be restricted to SPOT data. Data from this source have the spectral sensitivity, minimum resolution and coverage suited for environmental monitoring and are currently available. To fully exploit the image to target area relationships, field surveys should be conducted near the time of image acquisition.

3. Objectives

- To determine the sensitivity of SPOT imagery for classifying coastal vegetation using eelgrass as a case study.

- To investigate the possible benefits of incorporating satellite imagery into management strategies.

- To identify costs involved in performing remote sensing analysis of the Otago coast.

- To identify considerations to ensure useful results are obtained from remote sensing data.

4. Methods

4.1 SENSITIVITY ANALYSIS

The SPOT satellite is in sun-synchronous orbit and passes over New Zealand at approximately 11:00 am. The imagery has 3 spectral bands observing light in the green (0.5 - 0.59 μm), red (0.61 - 0.68 μm) and near infrared (0.79 - 0.89 μm) portions of the electromagnetic spectrum. SPOT image data have a 20-metre spatial resolution and a 60 x 60 kilometre ground coverage. The image analysed for this project was acquired during low tide on 26 February 1994.

4.1.1 Image Pre-processing

This analysis step was performed prior to any field work. The SPOT image was registered to the New Zealand Map Grid.A local area of interest was extracted from the 60 km x 60 km image using ERDAS/Imagine software. From the area of interest, upland features were masked[1] from processing. The masking reduced confusion between terrestrial and hydrographic features.

4.1.2 Unsupervised Image Classification/Cluster Analysis

In this procedure, the image is reduced to a number of categories specified by the user. Pixel values are assigned to these categories based upon an iterative procedure of comparing the pixel's response in each spectral band to the statistics of each category. The statistics of each category are updated after each pixel's assignment. When either the number of iterations reaches a maximum or the number of pixels changing categories is minimized, an image is produced showing the unsupervised classes that have been selected.

Unsupervised classifications were performed both before and after the field surveys. Prior to the survey, the procedure provided an understanding of the spatial distribution of different categories. Sites possessing significant areas of a particular category could then be identified for investigation during the field survey. After the survey, unsupervised classifications were performed to determine how covertypes observed in the field relate to the image categories.

[1] The ERDAS/Imagine software allows the analyst to exclude any areas from analysis. This allows analysts with different objectives to process identical images for their respective projects.

4.1.3 Field Surveys

It should be noted that fieldwork was undertaken in April 1995, over a year after the SPOT data were acquired. Two Otago tidal-flat sites were visited at low tide by a marine biologist and a digital image analyst from the Surveying Department. A member of the Department of Conservation staff accompanied the university team. The first site was within Otago Harbour and included the extensive eelgrass beds adjacent to Harwood.The second site was within Papanui Inlet (Figure 1). Low tide provided comparatively easy access to the sites and also enabled the vegetation to be viewed while site conditions were similar to those present during image acquisition. Subtidal Harwood habitats were explored using snorkel gear on a subsequent visit. During the field surveys, large homogeneous areas were photographed. Locations that presented extensive examples of each intertidal and sublittoral covertype observed in the area of interest were identified on a printed copy of the image.

4.1.4 Supervised Image Classification

Supervised classification was performed after the field surveys. Several test areas were selected for each homogeneous covertype identified from the field survey. This accounted for the possibility of identical covertypes having a slightly different sensor response owing to environmental influences such as water content and sediment type at the different locations. Differences might also be the result of biological features such as epiphyte growth or collection of dead plant material.

After the homogeneous test areas were selected, approximately 2/3 of the sample pixels for each covertype were selected as training data and 1/3 were held as test data.This enabled the classification accuracy to be assessed without a bias of testing and training on identical samples. Three classifications were produced. Each classification contained a different set of test pixels.

4.2 MANAGEMENT APPLICATIONS

To consider the potential benefits of incorporating remotely sensed data into coastal management strategies some past applications were reviewed. In addition, existing management issues relating to the eelgrass habitat were identified. The resolution of SPOT imagery was considered in relation to the types of changes expected in response to the existing threats to eelgrass habitat. The potential to utilise geographic information systems (GIS) for monitoring environmental change was also investigated in relation to coastal management. The information obtained through analysis of *Zostera* distribution at Harwood was used to demonstrate the immediate benefit remote sensing offers to those responsible for coastal planning.

4.3 SYSTEM COSTING

Two strategies for costing were employed. The strategies were based on procuring a system and performing all image analysis within the Department of

Conservation or hiring the expertise and existing systems from an external organization. In both cases, the Department of Conservation would need to purchase all imagery at a cost of NZ$4 200 per image.[2] Also, it was assumed that labour rates, overheads and productivity for in-house and contracted analysis were identical.

For the in-house solution, a system was designed based upon minimum cost with functionality. For the contractual solution, contractor costs were identified. The expected contractor costs *do not* represent an actual quote for work performed by the University of Otago Surveying Department.

4.4 DATA ACQUISITION ASPECTS

The main factors that ensure data obtained are suitable for investigating coastal habitats were reviewed.

5. Results and Discussion

5.1 COVERTYPES IDENTIFIED

During the field survey at Harwood the following ten covertypes were identified.

- **Shell** - a high bank of shell material (Figure 2) occurred at the edge of the extensive *Zostera* beds south of Harwood. This bank appeared to be mobile as it extended onto existing outer *Zostera* beds.

- **Low sand** - low sand areas were sand flats with a low profile, generally located near low tide level (Figure 3). There was a variable amount of shell material and the sand appeared quite dark, possibly due to the high moisture content.

- **High sand** - the sand banks extending north from Harwood were composed of well sorted quartz sand and contained very little shell material (Figure 4).

- **Low density *Zostera*** - a low density and stunted *Zostera* growth form (Figure 5) that appeared to be associated with the high sand (Figure 4).

- **Dry *Zostera*** - These areas had a significant cover of *Zostera* plants but were well drained at low tide. They were generally higher on the shore.

- **Shell *Zostera*** - shelly areas with a significant cover of *Zostera*. These areas were generally lower on the shore.

[2] SPOT imagery is distributed in New Zealand by Landcare and this price is valid as of 6 June 1995.

- **Dense *Zostera*** - areas of dense *Zostera* growth which often had complete *Zostera* cover. These areas were generally poorly drained with surface water remaining beneath the eelgrass canopy (Figure 6). A test area taken from the Papanui Site of Dense *Zostera* was analyzed with the information taken from the Harwood site (Figure 8).

- **Wet *Zostera*** - shallow pools or sublittoral fringe areas where *Zostera* grew luxuriantly. The underlying sediment was seldom visible through the canopy but only some of the *Zostera* blades broke the surface (Figure 7).

- **Shallow red algae** - in the shallow subtidal area red seaweeds *(Plocamium* sp., *Polysiphonia* sp., *Brongniantella australis)* occurred as patchy beds.There were some subtidal beds of *Zostera* with blades up to 30cm in length where the red seaweeds appeared to be an epiphytic sub-canopy. The subtidal vegetated area was treated collectively as a single class.

- **Shallow shell/sand** - a subtidal bank of shell and sand forms a distinct feature against the extensive areas of patchy sublittoral vegetation.

A brief field survey of the Papanui eelgrass habitat provided one additional covertype:

- ***Ulva*/filamentous algae** - a peripheral area of Papanui Inlet with a reasonably continuous mat of opportunistic algae.

However, the time that had elapsed since the SPOT data were collected together with the transient nature of algal mats prevented the selection of reliable test sites for this feature.

5.2 SENSITIVITY OF SPOT IMAGERY FOR CLASSIFYING COASTAL VEGETATION

The overall classification accuracy was 87% for the case study (Figure 9). The accuracy exceeds the expected user accuracies for coastal vegetation analysis with an airborne multispectral imager (Curran 1995). In each classification there was no confusion between eelgrass and red seaweed. In fact, the only minor problem was quantifying the relative amounts of eelgrass. Some crossover was evident between eelgrass classes. This stems from the randomness in the natural environment rather than any procedural error.

An area of known eelgrass from Papanui Inlet was also chosen as a test case in all the classifications. The Papanui sample sets were included in the analysis as dense *Zostera* because they corresponded to the denser beds observed in the Inlet. The goal was to determine how well a small sample set would characterise other small scale environments of the Peninsula. The area of eelgrass from Papanui Inlet was classed into 3 low density eelgrass categories. This result agrees with the group's expectation that the Papanui Inlet eelgrass was less vigorous than the eelgrass at Harwood (Figure 8). Even though the species were the same, local variations in the environment yield significantly different results.

A map of *Zostera* that represents the results of a Supervised Classification is shown in Figure 10. The dense, wet, dry, and shell *Zostera* classes have been combined. Low density *Zostera* has not been included in this map due to its confusion with high sand (Fig.9). It should be noted that algae such as *Ulva* may also be included in the areas shown.

The accuracy of subtidal classes (Fig. 9 - red algae, subtidal sand/shell) shows there is promise for further evaluation. It was also noted in unsupervised classifications that the classes identified within Portobello Bay followed bathymetric contours. Engelbrecht & Preu (1993) have shown that SPOT data can be used to discriminate shallow bottom types at different depths by using a bathymetric model that is based on the ability of different SPOT bands to penetrate water.

5.3 BENEFITS OF INCORPORATING SATELLITE IMAGERY INTO MANAGEMENT STRATEGIES

Race (1994) considered the most important aspects of applying remote sensing data to conservation management to be:

1. Identifying major management issues

2. Selecting appropriate remote sensing and analysis techniques to provide the relevant information

3. Considering the data source in relation to identification of thematic classes significant to ecology and management, how these classes are spatially distributed, and how well the composition of the thematic classes is represented in the spectral data

This section identifies major management issues related to the eelgrass habitat and considers how well SPOT data are suited to providing the relevant information. Management applications for remote sensing of the coastal environment were considered in two parts. Firstly, an inventory of coastal habitat types is required to provide a basis to assess the role and regional importance of different habitats. Secondly, there is an increasing need to monitor changes, particularly with regard to cumulative impact assessment requirements of the RMA.

5.3.1 Inventory

A number of New Zealand studies have used aerial photography to map the distribution of coastal habitats (Ballantine et al. 1973, DSIR 1980, Nature Conservation Council 1984, Walls 1987, Davidson & Moffat 1990, Davidson 1992a, 1992b). Particular benefits of using aerial photography were:

1. The ability to identify and map isolated coastal wetlands (Walls 1987).

2. A means to assess relationships between habitat components (DSIR 1980).

3. Observation across legislative boundaries (Ballantine et al. 1973).

The main focus of this study has been to determine whether SPOT is a useful tool for coastal inventory. For this task, distinguishing even a limited number of thematic classes that are significant to ecology will provide an improved assessment of the regional distribution and extent of these coastal habitats. The thematic classes identified in this study demonstrate that SPOT imagery shows promise for investigating both substrate type and vegetation. The distinctive infrared reflectance of different intertidal features meant there was considerable sensitivity for detecting different intertidal classes. There was also a distinct subtidal class' that included extensive, though sometimes patchy, red algae beds.

Subtidal and intertidal vegetation is likely to have a considerable influence on Harbour benthic communities (Singleton 1993, Grove 1995). Aquatic vegetation is an important producer of organic detritus and can provide a nursery habitat for some fish and invertebrate species (Bell et al. 1988). A better knowledge of vegetation distribution would therefore assist in understanding and researching biological processes within the Harbour. Distinguishing between vegetated and unvegetated intertidal flats also allows an assessment of the distribution of macrophytes available for swan grazing. The clear difference between low-lying wet sandflats, higher sandbanks, and areas with considerable shell may allow a better interpretation of the foraging strategies of wading birds.

Mats of opportunistic algae and *Zostera* beds represent considerably different habitat types and distinguishing between these should be the focus for future evaluation. For this case study, it was difficult to select training areas for algal mats with any certainty due to the small sample size and the age of the image. In addition to the direct effects that algal mats have on benthos (Ford 1993), there has been some debate in the United Kingdom (UK) about secondary influences that algal mats may have on estuarine birds. Tubbs and Tubbs (1983) suggest a decline in some species of birds in Langstone Harbour due to their inability to penetrate weed mats. However, Soulsby et al. (1982) comment that the increased invertebrate biomass in high weed areas may support increased numbers of birds.

Knowledge of the distribution of different coastal habitat types can be invaluable for risk evaluation and management in the event of an oil spill (Jensen et al. 1990). It is also useful to be able to identify isolated coastal areas that may have a specific conservation value (Race 1994).

5.3.2 *Monitoring Change*

To establish whether remote sensing techniques can provide the relevant information for monitoring eelgrass habitat a more thorough analysis of the type and magnitude of likely changes to the eelgrass beds is necessary. This

[3] reflectance signal extinction is a function of water depth.

knowledge may also allow a distinction between the effects of human activities and variability due to other environmental influences.

While there has been very little study of *Zostera* habitat in New Zealand, temperate Australian seagrasses have a minimum winter and a maximum summer leaf growth. At one Australian site, the summer above-ground biomass of *Zostera mueleri* was shown to be 40 times greater than winter above-ground biomass (Kerr and Strother 1990).[4] Remote sensing may assist further evaluation of the beds with regard to their seasonal productivity and influence on benthic fauna.

Eelgrass and opportunistic algae are likely to show different seasonal patterns, so it will be important to differentiate between them in order to assess the natural variability in extent and density of eelgrass beds.

5.3.2.1 Threats to the eelgrass habitat

The influence of nutrient pollution
High levels of plant nutrients entering estuaries and inlets can have detrimental effects on eelgrass (Cambridge and McComb 1984, Orth and Moore 1983). Declines attributed to nutrient enrichment in Cockburn Sound, Western Australia, were much more extensive than damage caused by dredging or causeway construction (Cambridge and McComb 1984). Nutrient enrichment is also a possible threat to eelgrass health in New Zealand coastal waters (Walls 1987). Agricultural runoff is a major source of nutrients entering the coastal environment (Gabric and Bell 1993). Otago Peninsula is predominantly agricultural land and there is a particular risk of high nutrient levels in Papanui Inlet where the entire catchment is farmland.

Light attenuation caused by the algal and phytoplankton growth stimulated by high nutrient levels is the likely cause of such declines (Dennison et al. 1993). Epiphytes growing on seagrasses are generally cropped by grazers but seagrass growth can be reduced when high nutrient levels coincide with low numbers of grazers (Williams and Ruckelshaus 1993, Neckles et al. 1993). Coleman & Burkholder (1994) showed nitrate enrichment coincided with changes in the micro-epiphytic community structure. Diatoms and blue-green algae stimulated by nitrate enrichment could be too small for herbivores to consume, and build up of a thick, dense epiphyte layer can significantly reduce macrophyte photosynthesis (Coleman & Burkholder 1994). Bach (1993) modelled eutrophication to include variations in the growth of the eelgrass *Z. marina* in Denmark with good results. Water transparency (dependent on phytoplankton growth), water temperature and depth/topography were found to be the important factors in explaining variation (Bach 1993).

High nutrient levels were directly implicated in seagrass decline when extensive mats of green algae suffocated 10 hectares of eelgrass in Langstone Harbour by causing long term anaerobic conditions (den Hartog 1993). Ford (1993) studied the influence of algal mats on macrofauna within Otago Harbour. It was noted that sediments under algae mats in Papanui Inlet were anoxic and that algal mat settling was more common in summer (Ford 1993).

[4] Zostera novazelandica was formerly considered a subspecies of *Z. muelleri.*

Considerable seasonal and interannual variability in algal biomass may be related to a number of environmental factors (Piriou and Menesguen 1992, Josselyn and West 1985).

Another threat to the eelgrass *Zostera marina,* widely distributed throughout the Atlantic, is the occurrence of a wasting disease caused by a slime-mould like protist, *Labyrinthula* (Short et al. 1988). *Zostera marina* almost completely disappeared in North America and Europe during an epidemic in the 1930's (Short et al. 1988). An occurrence of *Labyrinthula* sp. which led to the decline of Auckland Harbour *Zostera* beds was reported by Armiger (1964). While eelgrass die-off due to the wasting disease phenomenon is distinct from pollution-related declines it has been acknowledged that eelgrass populations under stress of pollution may be predisposed to this disease (Short et al. 1988).

Remote sensing is being used increasingly to monitor changes due to nutrient enrichment in sensitive coastal environments. In the UK remote sensing and GIS will be important components of the multidisciplinary approach to address problems caused by an increased amount and extent of algal mats in the lowerYthan (Green, 1995). Dennison et al. (1993) recommend a habitat approach involving observation of the condition of submerged vegetation as the best monitoring option to guide water quality improvements in Chesapeake Bay. To be most useful a remote sensing technique that can differentiate between eelgrass and opportunistic algae is necessary.

Sediment movement and altered hydrology

There is a considerable natural movement of sediment into the Otago Harbour (Kirk 1980). The relatively homogeneous nature of sediments is consistent with the dominant Clutha source of the material (Kirk 1980). Changes to Harbour currents brought about by structures, reclamations and dredging may cause changes in the distribution and health of beds. For example, construction of a causeway led to scouring of some Australian seagrass beds (Cambridge and McComb 1984). In Auckland Harbour tide deflectors were believed to be responsible for the disappearance of *Zostera* beds in Stanley Bay (Hounsell 1935). Such losses are local when compared to the widespread changes associated with effluent discharges (Cambridge and McComb 1984). Scott and Landis (1975) suggested that eelgrass was aiding in the development of sandbanks in the Otago Harbour. In addition to possible modification of sediment due to reduced current flow over eelgrass, current velocity over a meadow has a role in structuring the eelgrass bedform (Fonesca et al. 1983).

Changes to water flow can have long term effects on coastal vegetation. The retreat of salt marsh in Maketu Estuary is possibly linked to the diversion of Kaituna River nearly forty years ago (Bergin 1994).

Silt and sediment influx can be detrimental to eelgrass beds (Walls 1987). Direct smothering may occur after floods or slips. The loss of eelgrass beds in Ahuriri estuary has been attributed to smothering by silt following floods (Mr Clinton Duffy, personal communication). Silt resulting from the construction of waterside roads and railway embankments was believed to be an important factor in the decline of Auckland Harbour beds (Hounsell 1935, Dromgoole and Foster, 1983).

Other impacts on eelgrass beds

Black swans *(Cygnus atratus)* were present at both sites visited. Three hundred and forty-four swans were counted in Papanui Inlet during the April 1995 Fish and Game census and numbers in the Harwood area can exceed 200 (Mr R. Soulsby personal communication, Fish and Game Council records). A recent figure for daily consumption of eelgrass per swan, based on research at Hawkesbury lagoon, (Mitchell and Wass, in press) is 1.4 kg fresh weight. Further material may be uprooted without being eaten. Swans may therefore have considerable influence on the beds, and the distribution of detritus and nutrients. Byrom and Davidson (1992) noted that swans feeding on *Zostera* at Farewell Spit and Whanganui Inlet were never seen grubbing eelgrass by the roots and their observations of the eelgrass further suggested that the swans were merely cropping the leaves. Based on the field survey for this project, there is evidence that swans in the harbour do grub the plants, creating holes in the *Zostera* bed. A study of some eelgrass *Zostera marina* beds identified wildfowl grazing to be the single most important factor in the reduction of below ground biomass (Portig et al. 1994). They suggest that wildfowl selection of eelgrass rhizome material may be influenced by the nature of the sediment. Though grazing by wildfowl may contribute to seasonal density changes (Portig et al. 1994), other factors contribute to the loss of above ground material and it would be difficult to attribute distribution and density changes detected using SPOT images to the activities of swans. Furthermore, it may be difficult to use percentage cover to estimate changes in biomass as grazing pressure is unequal between above and below-ground material (Portig et al. 1994).

Mechanical damage of eelgrass beds by moorings has been demonstrated using aerial photographs and GIS in Western Australia (Hastings et al. 1995). Assessing the changes of seagrass distribution over a period of industrial development in a Western Australian sound, Cambridge and McComb (1984) found that losses caused by moorings, anchors and dredging were local in nature. In areas where *Zostera* is exposed to high current levels such damage may lead to further erosion of the beds (Hastings et al. 1995). Small areas of erosion (less than 20 m in diameter) exhibited significant recolonisation compared to more extensive areas (Hastings et al. 1995).

Small study areas may best be served by utilizing aerial rather than satellite platforms. Consideration must be given to the management objectives, the attributes of interest to be mapped and the relative costs. Bamber (1990), for example, recommends the use of aerial photography to provide information required for the environmental impact assessment of coastal development projects.

5.3.2.2 GIS capabilities for monitoring environmental change

Photographs and satellite imagery can be used in conjunction with Geographic Information systems (GIS) to improve data manipulation, to overlay ancillary information and to analyse and query the dataset. GIS is an important tool for assessing environmental impact by aiding the quantification of rates of regional resource loss (Johnston et al. 1988). A classic example of the use of GIS for marine mapping was a study investigating the effects of boat moorings on seagrass distribution (Hastings et al. 1995). Both the timing of and pattern of changes to the beds identified from four sets of photos spanning 51 years indicated that moorings were the most likely cause of seagrass destruction. Remote sensing coupled with GIS allowed efficient collection and analysis of data on changes in kelp bed size and location (Deysher 1993). Change detection, size of foraging sites and proximity to Wood Stork colony were analysed using GIS algorithms to obtain Wood Stork foraging habitat statistics (Hodgson et al. 1988). The information gained related well to observed Wood Stork population trends and allowed potential conservation strategies to be identified. Watson (1992) used the GIS MapInfo to store and display survey information for the purpose of establishing a coastal management plan for the Portobello area. The GIS was found to provide quick visually assimilated access to information but was limited in terms of available data sets (Watson 1992).

Electronic storage and manipulation is a major advantage of resource monitoring using remote sensing. Electronic databases allow the user to merge spatial data with ancillary information such as elevation and property ownership. A single database of land/water covertypes or resources may be shared by multiple institutions. These institutions would share the costs. Maps created from small individual mapping exercises may be incorporated into a large central databases. Therefore, future habitat mapping exercises can be compared quantitatively with previously obtained information. A pilot Marine Protected Area (MPA) information system using data from Paterson Inlet confirmed the usefulness of GIS technology in supporting planning and management of MPA's (Wong, 1989).

5.3.3 *Utility of Project Observations*

This case study demonstrated the value of satellite data by providing information pertinent to present coastal planning needs. A form of zoning has been introduced by the Proposed Otago Regional Coastal Plan (ORC 1994) which will provide legislative guidance for up to 10 years. Three different types of management areas provide recognition of different values associated with them. This requires the ORC, when considering applications for consents within these different coastal areas, to give priority to avoiding adverse effects on the values associated with the area. All estuarine areas along the Otago coast have been designated as Coastal Protection Areas (CPA). However, a considerable portion of the Otago Harbour has been designated as a Coastal Development Area (CDA) which gives a higher recognition to facilities and the infrastructure associated with them. The proposed boundary between the Harbour CDA and the Otakou CPA falls within the Harwood study area. Mapping eelgrass occurrence at the Harwood site highlights the need for information on habitat distribution. The dense and most extensive areas of the ecologically important eelgrass habitat occur within the CDA. Furthermore, the proposed boundaries indicated in the plan do not follow natural environmental boundaries.

In addition, an application for a resource consent under the RMA legislation requires an assessment of effects (section 88(4)). The definition of effects in the RMA includes any cumulative effects (section 3d). Monitoring changes to coastal habitats such as eelgrass should allow early identification of areas that may be under threat due to cumulative influences (Dennison et al. 1993).

5.4 COST OF REMOTE SENSING ANALYSIS

5.4.1 *Purchasing a System and Performing Analysis In-house*

The following are quotes from Eagle Technologies, the distributor for both ERDAS/Imagine Image analysis software and ArcInfo Geographic Information Systems software. The assumption here is that the hardware is an existing DOS platform with 32 megabytes of RAM and a large amount of disk space. UNIX platforms provide the greatest amount of power and flexibility in the software; however, they also require a dedicated system administrator. A UNIX platform would significantly increase costs both of hardware and labour.

5.4.1.1 *NT Imagine 8.1* **(Production)**

US$6 000 excluding GST
Maintenance : US$1 500 per annum
Probably the best all-round environmental image analysis package available with a minimum functionality for a wide variety of users. Less expensive image analysis software exist but do not contain the classification routines required for most resource investigations.

5.4.1.2 *VgaErdas 7. 5* **(DOS 8bit)**

US$2 400 excluding GST
Maintenance : US$1 000 per annum
The financial savings do not recover the loss in functionality.

5.4.1.3 *PCArcInfo* **(All modules except TIN)**

NZ$8 500 excluding GST (No future upgrades)
Maintenance : NZ$500 phone support
A software application that allows for the storage and analysis of a wide range of spatial data.

5.4.2 *Contractor Costs*

- Equipment rate : NZ$300 per day

- Computer time required for this investigation 3 days: This is the direct interface time between the analyst and computer. The analysis was spread over a 2-week interval. This would also include the minimum time to export the classified and raw datafiles into a format that can be read by most GIS packages.

- Data storage: The commercial price for storing electronic data on a compact disk is approximately NZ$300. This is a good option for stable long-term storage. CDs hold 600 megabytes of data which is more than enough for most data analysis projects. Alternatively, 5 gigabytes can be stored on magnetic tape at a cost of approximately NZ$25. Magnetic tape is not as stable as CD for long term storage; however, it is more than adequate for distribution between isolated computers.

5.4.3 *Cost of This Image Analysis (929 hectares)*

Cost of Image	$4200
1.5 equivalent people field days	$750
3 equivalent people computer processing days	$1800
3 equivalent days of computer processing time	$900
TOTAL	$7650

5.4.4 *Additional Cost of Analysing Entire Image (360 000 hectares)*

3 additional equivalent people field days	$1 500
2 additional people days of image processing	$1 200
2 additional computer days of image processing	$600
TOTAL additional costs	$3 300

5.5 CONSIDERATIONS INVOLVED WITH OBTAINING USEFUL RESULTS FROM REMOTE SENSING ANALYSES

For all remote sensing applications, planning is the most important aspect. SPOT imagery observes a given area of the Earth every 4 to 5 days. [5] Ordering imagery from Landcare, SPOT's New Zealand distributor, is a simple task. However, to ensure that imagery of the required quality is obtained the following characteristics should be specified:

1. Low cloud cover. Generally, this is specified as being less than 10%. SPOT is a passive sensor and does not receive any information through clouds.

2. Collect the image during low tide. This is important for improving spectral resolution in order to separate opportunistic algae and different densities of eelgrass.

3. Obtain imagery during the peak growth season. Vegetation vigour will vary depending upon season.

4. Plan to visit the study site at short notice as soon after the acquisition date as possible. This reduces the amount of variation that can occur at the site.

It will be beneficial to provide a number of dates when low tide for the geographic area of interest coincides with the 11:00 am sun synchronous orbit of SPOT. The larger the number of dates, the greater the chance of obtaining useful imagery. Note the general weather conditions at 11:00 am during these periods.

[5] This is mainly due to its pointability across its orbital track.

6. Conclusions

Preliminary assessment shows SPOT imagery can provide reliable information about the distribution and extent of habitats over a large area.

More test sites with known cover of opportunistic algae such as *Ulva* and *Enteromorpha* need to be assessed with a near simultaneous image in order to determine the separability of green seaweed from low density eelgrass classes. However, more specific information may not be necessary to achieve some management objectives. Determining the distribution of dense beds alone allows the most significant localities of eelgrass production to be identified and monitored. A map of the regional distribution of combined intertidal and sublittoral fringe vegetation classes would be sufficient to evaluate coastal macrophytes available for grazing by swans.

Further assessment of intertidal sand brightness and its relationship to moisture content will provide a better understanding of physical characteristics of the sandflats and may allow a more precise determination of eelgrass density.

Distinct subtidal classes show that SPOT data may also be useful for inventory of habitats in the shallow waters of harbours, inlets and estuaries.

Remote sensing provides managers with useful information by enabling regional habitat distribution to be mapped and changes in habitat condition to be monitored.

> **Mapping** information about the location and area of special, rare or threatened habitats can provide direction for steps taken to ensure their protection. This information can also provide a focus for process studies to identify the important biological attributes of different habitats. The spatial information together with knowledge of the biological significance of the habitat types will allow modelling of the interaction between different ecological components.
>
> **Monitoring** changes to coastal habitats such as eelgrass allows early identification of areas that may be under threat due to cumulative influences. Monitoring also allows those responsible for the management of coastal areas to evaluate the success of policies and rules made to mitigate or avoid adverse effects. Furthermore, knowledge of the natural variability in condition and extent of habitat types over time may provide important information for management of associated wildlife values.

SPOT compatibility with GIS software provides great potential for monitoring applications. In particular GIS allows images obtained on different dates to be compared electronically. It is also useful to be able to add attribute data to derived spatial classes. The system costs are significant but may be offset given functional cooperation between users of the image data and databases.

7. Recommendations

7.1 For analysis of large area coastal vegetation, satellite image classification should be used in conjunction with field surveys. These surveys provide bench marks for other non-image observations and surveys.

7.2 Surveys should be performed at regular discrete intervals. These intervals should take the dynamic nature of the physical and biological environment into account.

7.3 The Department of Conservation should weigh the advantages of long term benefits of electronic databases against costs. The additional resources required to input data from environmental study sites into electronic media are negligible compared to the cost of the analysis and the cost of possible additional surveys due to lost data.

7.4 There is a large amount of data in an image and the outputs from analysis can be project specific so the Otago Conservancy should develop partners to share resources and facilities. This would reduce costs.

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