MAPPING INVASIVE SPECIES

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Abstract:
Hyperspectral Data International Inc. (HDI) did trial work in the Mediterranean Sea (southern France & Monaco), which was the first known use of hyperspectral data used to map a potential invasive species. The client, The Museum of Oceanography in Monaco, was able to detect an invasive species called *caulerpa taxifolia,* an aggressive form of algae. HDI did subsequent and larger surveys using CASI technology, which lead to major scientific publications on the topic. The mapping of the invasive algae attracted the attention of both CNN and the BBC who produced network stories on the situation.

In Canada at Dalhousie University, Dr. Robert Scheibling discovered Nova Scotia has an invasive species problem as well. HDI mapped a section of the Nova Scotia coastline with the same CASI technology used in Southern France. The preliminary results clearly demonstrate this invasive algae, *codium fragile*. There is also interest in using this methodology to map invasive species elsewhere.

Assessing the impact of species invasions on coastal ecosystems using remote sensing

Invasive species are typically introduced to the marine environment through ship's ballast water. Marine legislation around the world has begun to address the flushing of ballast water in foreign waters, however once a species has been introduced into a new, hospitable environment, the damage has already been done.

Through the use of remote sensing, research facilities are now able to photograph and document coastal regions on such a large scale that previously was both impractical from a time perspective and prohibitive from a cost perspective.

Up until this decade, marine divers would survey a small region of coastline, typically videotaping the algae growth and individual plants. This method was suitable for small regions and micro-analysis, but was highly ineffective for large coastlines and failed to provided an overview of an entire region for year-over-year analysis.

Current research has turned to remote sensing by satellite and airborne sensors to map and monitor coastal habitats. The Compact Airborne Imaging Spectrometer (CASI) is a hyperspectral imaging sensor capable of acquiring high resolution spatial and spectral data in the visible to near infrared regions of the electromagnetic spectrum, and can be easily deployed from a small fixed wing aircraft. CASI hyperspectral photography has proved to be ideal for providing baseline mapping, determining the extent of invasion and is also acknowledged as being more cost effective and time-sensitive than diving.

In the past four years, HDI has conducted two major pioneering airborne surveys using their CASI system in the southern France coastal Mediterranean waters. HDI, in conjunction with the Observatoire Océanologique Européen based at the Centre Scientifique de Monaco, has developed a methodology for employing hyperspectral data for this purpose.

Background on the Nova Scotia Situation

Within the past decade, a series of species invasions has dramatically altered the structure and dynamics of the coastal ecosystem off Nova Scotia. Luxuriant kelp beds that once dominated the rocky subtidal zone have been displaced by an alien green alga, *Codium fragile*. This shift in algal dominance is associated with pronounced changes in benthic habitat and community structure, and an overall decrease in biodiversity. These invasions, which have progressively destabilized the coastal ecosystem, limit the predictive capacity in managing marine resources. Considering the potential for serious negative impacts on ecosystem goods and services associated with this phase shift, it is essential that a rapid and effective method of mapping and monitoring *Codium* and other invasive species be established.

A coordinated program of hyperspectral remote-sensing and undersea ground-truthing to map benthic habitat and invasive species is ideal. The Compact Airborne Spectrographic Imager (CASI), and integrated navigational and data assimilation software, was the key enabling technology for this project. CASI was deployed from a small plane to map successive sections of the southwestern shore of Nova Scotia, along an invasion gradient. The high spectral and spatial resolution of CASI optimized conditions for mapping the distribution of *Codium* and detecting small-scale heterogeneity in benthic vegetation. To calibrate CASI imagery and classification algorithms, various indicative habitat units (e.g. *Codium* meadows, kelp beds, coralline barrens) was accurately mapped on the seabed using proven video sampling methods and geographic positioning systems. Other ground-truthing procedures allowed accurate corrections for water column attenuation.

Field-work has begun and will continue over three years, spanning approximately 200 km of coastline. Fully classified maps of benthic habitat and vegetative types over this range is being produced. Operational mapping procedures that target particular habitat types (e.g. kelp beds) or species (e.g. *Codium*) are also being developed. The application of hyperspectral remote sensing enables researchers and managers to track changes in marine habitats and invasive species at ecologically relevant, spatial and temporal scales. Subtidal habitat maps, when merged with other DFO data-bases, provide a valuable tool for empirical and modeling approaches to fisheries and coastal zone management.

Hyperspectral data will provide the basis for generation and analysis of subtidal habitat classification maps and developing operational mapping procedures for invasive algae (*Codium fragile*) and key habitat types (e.g. kelp, *Laminaria* spp.).

The Importance of Monitoring Benthic Vegetation

Marine scientists and resource managers have long recognized the importance of benthic vegetation (seaweeds and seagrasses) to the structure and function of coastal ecosystems and the fisheries they support. Marine plants play a fundamental ecological role as primary producers in coastal areas, supporting both grazing and detrital food webs. Benthic vegetation provides critical habitat and nursery areas for commercially important finfish and invertebrates, such as cod and lobster. It also serves to moderate erosion by storms and to reduce nutrient loading and other forms of coastal pollution. With rising concern over the impact of human activities in coastal areas, the need for accurate mapping and monitoring of marine vegetation has become increasingly obvious and urgent for coastal zone management.

The Coastal Marine Ecosystem off Nova Scotia

The coastal ecosystem alternates between two distinct phases based on the abundance of sea urchins (*Strongylocentrotus droebachiensis*), the dominant grazers: luxuriant kelp beds (mainly *Laminaria* spp.) where urchins are few, and so-called "barrens" dominated by coralline red algae with high densities of urchins. Sporadic introductions of an alien pathogen (*Paramoeba invadens*) cause mass mortalities of urchins, which drive the ecosystem dynamics. Release from grazing pressure enables the establishment of kelp beds that persist for decades until urchins repopulate the shallow subtidal zone and destructively graze kelp to form barrens again.

Two invasive species have disrupted urchin-kelp dynamics. An epiphytic bryozoan *Membranipora membranacea*, which encrusts kelp fronds causing fragmentation and loss, has repeatedly decimated kelp beds along the Atlantic coast of Nova Scotia. By removing the dominant canopy species, *Membranipora* has facilitated the invasion of the Asian green alga, *Codium fragile* spp. *tomentosoides*. *Codium* is a coarsely-branching seaweed that forms low lying, bushy stands. Kelps, on the other hand, have large strap-like fronds suspended by a stipe, a growth form that creates distinct canopy (1-2 m high) and understory microhabitats.

In view of the detrimental effects of the *Codium* invasion on marine resources in eastern Canada, it is essential that a rapid and effective method of monitoring and mapping this and other invasive species be established. The only extensive survey of marine vegetated habitats along the Atlantic coast of Nova Scotia was conducted using SCUBA, and took over two years to cover about 400 km (straight-line distance) of Atlantic coast. While providing accurate data on the distribution and abundance of benthic vegetation at point locations, diving surveys are extremely labour intensive and time consuming. This approach is far too slow, arduous and limited in scope to effectively track the spread of invasive species or transitions between the kelp bed and barrens phases of the subtidal ecosystem. The application of remote sensing provides researchers with synoptic maps of large areas of seabed, which can be acquired at regular, predetermined intervals to track changes in marine habitats at relevant ecological scales.

Another potential application of remote sensing in Atlantic Canada lies in mapping healthy kelp beds in sea urchin harvesting areas. A habitat-based management scheme has been instituted in Nova Scotia to conserve sea urchin and kelp resources along the Atlantic coast. This process is expensive and labour intensive, both for the urchin harvesters and DFO, and only allows for sporadic spot checks given the scale of the coast and the degree of isolation of many lease-holds. Remote sensing would provide a cost-effective means of monitoring kelp and sea urchin resources over large areas.

Increased observational and modeling capacity

The use of remote-sensing technology for the mapping and monitoring of invasive species along the Atlantic coast of Nova Scotia will significantly increase the observational and modeling capacity. The production of the first coastal-scale synoptic maps of the shallow subtidal zone will represent a quantum leap in our knowledge base for fisheries and coastal zone management.

This technology is fully compatible with Geographic Information System (GIS) technology, which is widely recognized as a key element in the management, analysis, and planning aspects of map and map-related data. A fully classified coastal zone map, when combined with ecological, environmental, and fisheries data in GIS format, provides an invaluable tool for empirical and modeling approaches to management. The combination of technology (GIS) and data (high resolution habitat maps) enables a range and depth of analysis. Typical activities that are possible using an information system include:

1. Determining the relationship between habitat type and fisheries yield
2. Assessing effects of habitat fragmentation on regional biodiversity and fish stocks
3. Estimating productive capacity of the coastal ecosystem and assessing the impact of ecosystem phase shifts
4. Development of habitat-based management models (e.g., the sea urchin fishery)
5. Selection of aquaculture sites and assessment of aquaculture impacts

Development of new expertise and technological innovation

A key innovation is the development of operational and analytical procedures that enable the acquisition of cost effective, high resolution image-based data for mapping subtidal habitats. Such methodological and technological advances significantly enhance the capacity to produce maps with sufficient ecological definition to allow accurate and rapid assessments at spatial scales relevant to regional and national needs.

Preliminary analysis of CASI data shows good penetration of the imaging system to at least 10 m depth (below mean lowest low water) under conditions of clear sky, calm sea state, low sun angle (to limit sea glint), and high water clarity. *Codium* presently extends to a depth of only 8 to 10 m, with the greatest abundance of plants at 2-6 m.

The high spectral and spatial resolution of CASI optimizes conditions for mapping the distribution of *Codium* and detecting small-scale heterogeneity in benthic vegetation. The sharp interface between kelp beds and urchin barrens (where coralline algae form a pink crust over the rocky bottom) are resolved by CASI throughout the depth range of most kelps.

Specifics of Remote Sensing

The HDI CASI is maintained in a state-of-the-art configuration with the latest upgrades and constant calibration. The integrated navigation platform, sensor configuration and data assimilation software package represent key enabling technology. It is a proprietary configuration unique to HDI , developed over many years of application in temperate and tropical marine environments.

CASI is readily deployed from a small plane and can provide high spatial resolution (1 m per pixel) depending on flight altitude. CASI is capable of simultaneous recording of radiance in up to 19 user-selected channels over the wavelengths (400-950 nm) necessary to detect marine vegetation and correct for water-column attenuation. These attributes make CASI particularly useful in distinguishing vegetation types in a heterogeneous assemblage of subtidal vegetation and along a gradient of water depth. Variation in the pigment composition of different types of seaweed (Red, Green, and Brown Algae) allows for spectral discrimination between them. An advantage of CASI is the ability to adjust sensor bands to the desired wavelength to selectively distinguish specific plant types (e.g. *Codium*).

Preliminary analysis of CASI images taken at high spatial resolution reveals detailed bottom features indicative of different vegetated habitat types (established by video surveys).

Future

The goal is to produce fully classified maps of the area, and expand the mapping to a broader coastal scale. These maps will be converted to a Geographical Information System format enabling final quantification of the distribution and abundance of *Codium*, kelp and other types of marine vegetation. The spatial and temporal patterns that emerge will enable inferences to be drawn about the spread and impact of invasive species on the benthic ecosystem.

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