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MAPPING AND MONITORING KELP RESOURCES IN MEXICO

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ABSTRACT

Kelp, often called Giant Kelp, is a brown seaweed of the species Macrocystis pyrifera which forms dense floating beds along the west coast of the Peninsula of Baja California, México. Extensive Kelp beds have been shown to be a valuable resource for a number of reasons, including their function as habitat for other species and the income derived from the kelp harvesting industry. These characteristics make kelp an important renewable resource to be mapped and monitored in order to obtain information on its distribution and abundance and on the variations in the availability of the resource due to natural and induced fluctuations. Remote Sensing technology may play a significant role in satisfaying these information requirements, given the implicit difficulty in collecting on site data all along the large geographic area (more than 800 km) in which kelp beds are distributed. After considering different remote sensing techniques it was decided to implement a computer-assisted multispectral approach to mapping and monitoring kelp resources. This paper presents the results and conclusions of applying such an approach. Results of classifications of aircraft and Landsat multispectral scanner data are presented. Their characteristics and applicability are analized. The methodology followed to obtain a base line inventory of kelp resources and to construct a geographically referenced data base is discussed. Some examples of output products are given. And the initial steps for establishing a geographic information system of kelp resources are described.

I. INTRODUCTION

The purpose of this paper is to present the results and conclusions of a project for the application of machine processing of multispectral data to the mapping and monitoring of Kelp resources off the coast of the Peninsula of Baja California, Mexico. The project was conceived by the Dirección General de Geografía (DGG), the official cartographic agency of Mexico, in response to the information requirements about Kelp presented by the Ministry of Fisheries, which is responsible for the management of the resource. In the following years, this ministry expects an increase in the demand of raw Kelp from chemical industries outside of Mexico and the need to install a national processing industry to obtain primary chemical products from kelp. This will imply increased ecological pressures on the resource and the need to expand the areas presently open to exploitation. To date, the ministry has no available complete sources of infomation on the distribution, abundance and condition of the resource on which to base its management decisions. Therefore, they required information from the DGG on the geographic location and areal extent of the kelp beds distributed along am 800 km strip of the west coast of Baja California, from the US Border (32°15' N) to a point known as Punta Abreojos(26°30' N). The required products of this first inventory were to include 1:100 000 scale maps showing the distribution of Kelp,and tables containg the estimated areas and geographic positions of each kelp bed detected with an area of more than four hectares. After analizing several kinds of remote sensing data, such as different types and scales of aerial photography and Landsat data, it was concluded that digital analysis of multispectral data would be more satisfactory to fill the informational requirements mentioned above, considering the large area that had to be covered and the timeliness with which the output products were desired. The following sections deal with some biological and economic aspects of kelp and detail the steps taken to complete this application project.

II. GENERAL BIOLOGY OF KELP

Large areas of the offshore zone in the Peninsula of Baja California support a complex ecosystem dominated by Kelp. Kelp, often called Giant Kelp, is a brown seaweed of the species Macrocystis pyrifera which forms dense floating beds along the west coast of continents. Its growth form is shown in Figure 1 (1). There is a long branching stalk, which arises from a ramifying basal attachment system, and the upper ends of the branches bear rows of leafy laminae, each of which has a small swolen bladder (pneumatocyst) at its base. By means of these bladders, which are gas-filled, the fronds are kept floating at the surface of the sea. In view of their great size these seaweeds can have their rooting portion at depths of 20-30 meters, though they achieve their best growth in depths about 15 meters. Kelp is the fastest growing plant on Earth, averaging 45 cm per day. It thrives as an aquatic forest nurtured by cold, nutrient laden waters found primarily along the west coast of continents. In America, Kelp has a wide distribution, and to the north it extends from Baja California to Alaska. Its southern limit being set approximately by the 20°C water isotherm of the warmest month. This algae are unable to spread into warmer waters because at temperatures higher than 18-20°C the plants do not form any reproductive bodies. When viewed from above, the dense surface canopies of the beds give the impression that the Kelp forms an impenetrable, tangled mass. The canopies may extend one to two cm above the ocean surface, which makes Kelp suitable for remote sensing inventory (2).

III. IMPORTANCE OF KELP

For Mexico, Kelp is a renewable, marketable resource. The Kelp beds found in Baja California are so well developed that commercial exploitation is carried out on some of them for the production of the valuable phycocolloid Algin and its derivatives. Algin is an amazingly versatile hydrophylic colloid which has recently found numerous uses in idustry. As emulsifying, stabilizing and suspending agents alginates serve in the manufacture of a great variety of products such as pharmaceutical jelly, film emulsions, textile sizings, paints, oil well drilling muds, battery plate separators, etc. The harvesting of Kelp is accomplished by cutting the floating parts of the Kelp a short distance (approx. 1.20 m) below the surface with a large mowing machine installed in a barge, upon which the cut Kelp is piled for transport to the factory. National gross sales of raw Kelp to chemical industries outside of the country were, according to the Ministry of Fisheries, on the order of one million dollars for the year of 1981.

IV. FEASIBILITY STUDY

The first step of this application project was a study for establishing the feasibility of making Kelp inventories through computer-aided analysis of multispectral data. The specific objective of the study was to determine whether kelp could be distinguished from other landscape features based on its spectral, temporal and/or spatial variations. The input data were aircraft and Landsat multispectral scanner (MSS) data as described below (3).

A. AIRCRAFT MSS DATA

These data were collected using a Daedalus DS-1280 five-channel scanner. This instrument has a spatial resolution of 0.54 mr which produces from an altitude of 35 000 ft a ground resolution of 33.18 m^2. The spectral range covered by the scanner is from 0.5 to 1.1 micrometers (um); with two channels in the visible (0.54-0.59; 0.62-0.67 um) and three in the infrared (o.74-0.80; 0.84-0.94; 0.95-1.06 um). Prior studies of the spectral properties of Kelp have indicated that Kelp has a spectral response basically similar to that of orange-brown vegetation (4). Field spectroradiometric measurements showed that in the visible region the absorbtion of the green radiation by chlorophyll is about 10 percent, with a slightly greater reflectance in the red. In the infrared region, Kelp reflects from 60-70 percent of the incident radiation. In this latter region water absorbs most of the energy, producing a good object to background contrast. Within the visible region the effects of bottom reflection and turbidity may provide a background against which Kelp can be discriminated.

To confirm these observations, some classifications were made of an image taken on July 4th, 1981, over a test site near the city of Ensenada. These were made using different sets of channels and unsupervised classification techniques on a portion of 512 x 512 pixels in which a Kelp bed approximately 1.5 Km long was present. The spectral separability of Kelp from its water and land context was assessed by comparing the classification results to digitized ground truth data obtained from aerial photographs taken simultaneously with the multispectral scanning. These analyses, which included divergence and spectral plot analyses, showed that the maximum spectral separability between Kelp and water was present in channel 4 (centered at 0.89 um), and between Kelp and land in channel 2 (centered at 0.64 um). Figure 2 shows the result of a classification made using this set of channels. Notice how well it was possible to discriminate Kelp (in dark), water (no pattern) and a group of spectral classes categorized as land (dotted). Some spectral confusions of Kelp were in the latter category in zones of tiny cloud shadows, in which the attenuated spectral responses of shadowed brown vegetation and dry soil appear as that of Kelp. A test of the performance of this classification gave an overall accuracy of more than 95 percent. However, it was observed that even though in this set of channels the maximum separability of Kelp from its context was attained, the poor water penetration capability of channel 4 resulted in misclassifications of submerged portions of Kelp with water whithin and in the margins of the bed, which could produce underestimates in the computations of areas occupied by kelp.

On the other hand, a classification made using channels 2 and 3 (centered at 0.77 um) provided better detection of submerged portions of Kelp due to the greater water penetration capability of channel 3. Some of these portions were in zones in which Kelp was removed to depths of more than one meter by the mowing machine of a harvesting barge. And other portions were in zones in which Kelp was submerged by the action of waves and currents. The use of these channels permited detection of these portions, but did not permit distinghishing them from the emerged Kelp, thus both were classified in the same class. A test of the performance of this classification resulted in an overall accuracy of more than 91 percent. The reduction in the performance of this classification in relation to that previously described was caused by an increase in the spectral confusions between Kelp and zones of cloud shadows and shallow water near the beaches. Nevertheless, when the performance for Kelp was specifically analized within the bed it was found to be greater than 96 percent. A close comparison with aerial photographs showed that this classification better represented the shape, extent and distribution of the Kelp bed and several dispersed patches present within the test site. These results suggested that even though it is possible to better discriminate Kelp from its context using channels 2 and 4, for some inventory purposes it could be more adequate to use channels 2 and 3, since these may provide more precise descriptions and area estimates of Kelp beds. The problem of the increased spectral confusions of Kelp observed using this latter set of channels could be alleviated by limiting the analized area to the immediate surroundings of the beds.

The results of the classifications mentioned above led to the following partial conclusions :

1) It is possible to spectrally discriminate Kelp form its water and land context through machine processing of aircraft MSS data.

2) Since it is possible to spectrally discriminate Kelp, and the capacibility for collecting and processing aircraft MSS data exists, then it is feasible to conduct a Kelp resources inventory project.

Further considerations on the possible realization of such an inventory project make it clear that due to the high spatial resolution of the DS-1280 scanner it would be necessary to obtain very large amounts of data to cover relatively small areas. For instance, to cover an area of 18.5 x 18.5 Km it would be necessary to collect and store data in five channels from approximately 1×10^7 resolution elementes, far more than the total number of pixels (7×10^6) that comprise one Landsat image of 185 x 185 Km. In the case of complete coverage of the 800 Km long area of interest, the amount of data would be unmanageable. These considerations and the fact that the spectral coverage of the DS-1280 scanner is basically coincident with that of the Landsat MSS, indicated that the analysis of Landsat images would be a more cost-effective option for making Kelp resource inventories.

B. LANDSAT MSS DATA

The considerations that led to the use of Landsat MSS data were further confirmed when it was realized that the acquisition of aircraft MSS imagery would bw very expensive because of the aircraft operation costs, and difficult to acquire on a regional basis due to cloud or fog so common along the cold water coast of Baja California. Since Landsat imagery is repetitively acquired ($\leq$ 18 days), it was considered that this data collection system would provide a higher probability of complete coverage of the area of interest. Reviewing the literature it was also found that the application of machine processing of Landsat imagery to extract Kelp information has been successfully conducted (2).

At the time of selecting an input Landsat image, it was observed that for this type of data considerations on the temporal variations of Kelp come to be of prime importance for selecting an image in which Kelp beds are well represented and the interference of clouds is minimal. Following this reasoning and considering some reports in the literature on the biology of Kelp (5) and on the applications of aerial photography to seasonal surveys of Kelp (6), it was concluded that the dates best suited for obtaining Landsat imagery are in the July to October period, in which Kelp beds reach their maximum growth and the atmospheric interference is at a minimum, since the rainy seasson in Baja California is in the winter.

For this part of the study a Landsat image acquired on September, 25th, 1975 (ID 8224617375500), was used as input. As in the case of the aircraft data, the analysis of this image was conducted making several unsupervised classifications using different sets of channels on a test site of 512 x 512 pixels that included the site in which the aircraft data analysis was made.

The analyses of the results of these clasifications showed that it is possible to locate and estimate the areal extent of Kelp beds with Landsat data. The set of channels that produced the maximum spectral separability of Kelp from its context was that of channels 4, 6 and 7. A test of the performance using these channels gave an overall classification accuracy of 96 percent.

One further advantage of the use of Landsat images is that they may be easily georeferenced, thus making it feasible to determine the geographic position of Kelp beds.

Another concern was the accuracy of the area estimates of Kelp beds obtained with Landsat.For this study no retrospective information was available to evaluate the results of the estimates,however, a prior study in which acreage estimates obtained with Landsat were compared to others obtained with aerial photography concluded that although the results of both inventory methods were hihly correlated, Landsat estimates tended to consistently underestimate the areas of the beds (2). Consulted about this particular, the Ministry of Fisheries indicated that, in despite of this limitation, Landsat-based inventories of Kelp resources would be valuable since they would provide precise information on the distribution of Kelp and useful approximations to the actual areas of the beds.

This study demonstrated the feasibility of using Landsat MSS digital data and aircraft MSS data to locate and estimate the areas of Kelp beds.

Considering the differences in coverage and resolution of the two systems it was recommended that the Landsat MSS data would be used to obtain large area inventories of Kelp and the aircraft MSS data would be used to meet more specific or localized information requirements.

V. KELP RESOURCES MAPPING PROJECT

Once the feasibility study was completed, an application project was started for the utilization of machine processing of Landsat data in a complete inventory of Kelp bed resources.

A. OBJECTIVES

The specific objetives of the project were:

1) To locate and estimate the areal extent of the Kelp beds distributed along an 800 Km strip of the west coast of Baja California, between 26°30' N and 32°15' N.

2) To obtain 1:100 000 maps showing the distribution of Kelp.

3) To obtain tables containing the geographic positions and estimated areas of all Kelp bed detected with areas of four hectares or greater.

B. LANDSAT INPUT DATA

The input data for this project were 21 sets of Landsat CCT's that correspond to nine frames which cover the entirety of the area of interest. The dates of these images were selected applying the criteria established in the feasibility study.

C. DATA PROCESSING SYSTEM

The digital images for this project (as those for the feasibility study) were processed at the image processing facility of the DGG in Mexico City. DGG's computer system includes two PERKIN-ELMER 8/32 minicomputers and their standard peripheral devices, two on-line COMTAL image processing systems and two off-line VERSATEC electrostatic printer/plotters. The computer software utilized is the Earth Resources Laboratory Applications Software (ELAS), developed at NASA/NSTL/Earth Resources Laboratory (7).

D. METHODOLOGY

The methodology for mapping Kelp ressources was designed as a basic sequence of operations to be applied to each image used as input for the project. These operations are described below.

D.1. <u>Preprocessing</u>. This operation basically consists of reformating the CCT's into a disk file compatible with the analysis software, and correcting for the sixth scan line radiometric anomaly.

D.2. <u>Screening The Data</u>. During this operation the analyst decides whether it is worthwhile to undertake the following steps of the analysis on a particular image. Examining the data on a display device, he looks at the entire image, enlarges and reduces selected portions and swithches from band to band looking for significant extentions of Kelp that can be used in the collection of training sta tistics. At the same time, he checks for cloud cover, bad data lines and other anomalies which could degrade the quality of the data.

D.3 Developing Training Statistics. This operation has proven to be the critical one of the analysis sequence, because the final quality of a classification depends on obtaining representative training statistics. This operation is accomplished by 1) selecting a set of channels, and 2) collecting training statistics.

Even though in the feasibility study a set of channels was defined in which the maximum separability of Kelp from its context was attained, the experiences gained in the development of this project soon demonstrated that the changing conditions in which each image is acquired make it necessary to define such a set of channels for each image in particular.

Bearing in mind that the number of pixels representing Kelp within an image is relatively small compared to the total number of pixels that comprise the image, and considering the fact that the project attempted to obtain information about only three earth features (Kelp, water and land), it was decided to use a modified-supervised approach (8) for the collection of training statistics. This approach was preferred over the strictly supervised approach because the training fields need not be completely homogeneous and therefore,can be defined faster and with less analyst involvement. The strictly unsupervised approach was considered inadequate for this application since the entire image, containing large unimportant areas of water and land, would have to be processed. This modified-supervised approach is accomplished by supervised extraction (using a display device) of several polygons representing the information categories of interest. The polygons are well distributed within the scene to obtain a more representative sample of the naturally-occurring variations in spectral response within the scene. When it is observed that spectral confusions exist between Kelp and other features, such as clouds and inshore zones, polygons representing these are also extracted. The data of these polygons are then individually clustered, selectively merged and a final set of statics automatically prepared. The analyst controls the procedures of clustering and merging of statistics by manipulating program input parameters.

D.4. Classifying The Data During this operation the statistics developed by the training strategy described above are applied to the data by a maximum likelihood algorithm. The first step of this operation consists in a classification of a portion sampled from the image. Classification results are evaluated and, if unsatisfactory, the causes of misclassification are ascertained and the previous operation is re-entered at the proper step until a representative set of statistics is prepared. Once a set of statistics is obtained, the classification is extended to the whole image. The classified output is then analized on the display device and the spectral classes are identified.

D.5. Postprocessing. This operation consists in removing the logic errors committed during the classification process due to spectral confusions and the presence of noisy data. This is accomplished in two ways : automatically and manually. In the former, the image is smoothed by an algorithm which passes a 3 x 3 pixel window through the data and replaces the value of the centermost pixel with the value of the class most frequently occurring if there are not at least N pixels of the same class within the window. In this project the number N has been specified as 3. The objective of this procedure is to remove excessive detail from the final image by approximateing a 0.75 hectare minimum representable unit. The latter consist in the manual editing of the image for removing obvious comission errors, such as the confusions of Kelp with land and clouds.

D.6. Geo-referencing the data. This operation is accomplished by locating several points within the data through use of the image processing system and locating the corresponding points on DGG topographic maps. The element and scan coordinates are related to the corresponding map coordinates, so a geometric transformation equation is derived for registering the digital data to a 50 x 50 m north-oriented UTM grid. For this project, the procedure of extracting control points is straightforward since the uneven coast line of Baja California permits the location of many precise points. Most of the images have been corrected to a rms error of nearly 50m.

D.7. Integrating Information Categories.- In this operation the spectral classes resulting from the classification process are grouped into three information categories:

1) Kelp
2) Water
3) Land

D.8. Locating and Estimating Areas of Kelp Beds. This operation is accomplished by locating fields of contiguous pixels categorized as Kelp and counting the total number. The geographic positions of these fields are determined by calculating their central coordinates. This information can be obtained in two modes: - automatic and manual. In the former the categorized image is input to a program - instructed to search through the data for contiguous fields of an extent equal to - or greater than 16 pixels (4 hectares) of the Kelp category. Once a field of these characteristics is located the program -- computes its area and determines its central coordinates. In the manual mode the analyst, using a display device, draws a polygon around an specific area in which the presence of Kelp beds is observed.The data of this polygon are then input to a program that determines the frecuency of occurrence of the classes within the de-- signated area . Geographic positions are determined by positioning the cursor of - the screen on the central point of the -- bed and reading the coordinates.

Considering that in previous opera-- tions most of the misclassifications have been removed, in this project the automatic mode is predominatly used since it ac coplishes the operation in one step, is - more precise and requires less analyst in volvement.

D.9. Obtaining Output Products. The dis-- tribution and abundance of Kelp is geographically represented with maps at an scale of 1:100 000. These maps represent only three categories: Kelp, water and land. They are in UTM projection, with a grid - represented at increments of 10 Km and -- their limits are specified by the user by supplying, in either metric or geographic coordinates, the northeast and southwest limits of the desired area. Figure 3 ---- shows an enlarged portion of a map of a region located about 30 Km to the south of the city of Ensenada (central coordinates: 31°33' N; 116°36' E). Notice the remarkable extent of the Kelp beds of this area. The semicircular bed near the bottom of - the figure is about 6 Km long and has an - estimated area of 202 ha. Although the - scale specified for these maps was 1: --- 100 000, they also have been obtained at 1: 75 000 and 1: 50 000 scales.

As a complement to, or independently of cartographic products, tabular pro---- ducts can be obtained. These consist of computer printouts containing the geographic positions in UTM and geographic co-- ordinates, and the estimated area in hectares of each Kelp patch of more than --- four hectares detected within a user-specified area. These tables also contain a summary of the total area occupied by --- Kelp.

D.10 Field Verification. To date, a com-- plets verification of the results of this mapping project has not been conducted. A preliminary verification in which some -- output cartographic products were taken - to the field and, by means of aerial re-- connaissance, directly checked with ---- ground observations, showed that the de-- tection of Kelp beds was correct in more than 80 percent. Errors of omission were more frequent than errors of commission.An extensive verification is planned at the - end of the project.

VI. KELP RESOURCES MONITORING PROJECT

The end product of the mapping pro-- ject will be a base line inventory of Kelp resources. It is planned to subsequently aquire new satellite coverage of the area of interest, process the data, produce new inventory information and, by means of digital overlaying and change detection algorithms, to observe and record fluctuations in the distribution and abundance of Kelp. Considering that for some areas of Baja California the availability of data is scarce, it has been determined that complete - coverage of the areas of interest is not - likely more frequently than every two ---- years.

VII. A GEOGRAPHIC DATA BASE FOR KELP RESOURCES

The inventory project will provide -- the means to determine the distribution -- and abundance of Kelp resources through -- time.This will require development of a methodology to establish and rapidly store, retrieve and analyze large amounts of data on Kelp. The first step of such a project is to integrate a digital data base to be used as input for a geographic information system. When the need to construct a data - base was detected, a first conception was of a data base compiled with data for the entire Baja California coast. Further analyses demonstrated that Kelp is not continuously distributed along the coast, ins-- tead it is discontinuously distributed, -- restricted to zones in which submarine --- rock outcrops are present. With this in -- mind, it was considered better to integrate a data base only for some selected portions of the coast. This data base will - be integrated by digital mosaicking of geographically referenced and categorized multitemporal landsat data of adjacent frames. Since this data base will not be intensively consulted it was considered wasteful to maintain it in a mid-term memory device -- such as a disk pack. For this reason, this data base will be tape-oriented, with the information organized to be stored in ta-- pes which will correspond to the different regions in which the data base will be divided. The software needed to retrieve and analyze this information already exists.

VIII. KELP RESOURCES GEOGRAPHIC INFORMATION SYSTEM

The applications software used in --- this project, ELAS, is not only a pattern recognition system that allows the acces-- sing, processing and, classification of -- georeferenced multispectral data, it is - also a geobased information system that - allows storage, retrieval and analysis of the resulting information in conjunction with different types of information, such as digitized maps.

One objective of this project is to take advantage of these capabilities for implementing a Kelp resources information system. The first step taken to meet --- this objective was to design a user inter face with the system. This consists of a set of ten instructions that directs the interaction of the user with the machine in natural language. When the user in--- puts one of these instructions, he makes reference to a canned runstream of ELAS - directives that are executed by the capa- bility of this software to accept input - from external I/O routines. These routi- nes make execution of reoutine operations transparent to the user, and when input - is requested from him, he is prompted for it in his natural language (Spanish),thus making it a straightforward process to -- consult the data base. Since at this time the data base only containg the informa-- tion of the base line inventory of Kelp, instructions for the storage, retrieval - and analysis of information of one date - are the only ones available.

IX. CONCLUSIONS

1. Pattern recoguition techniques al low to spectrally discriminate Kelp from its water and land context.

2. It is feasible to conduct mapping and monitoring projects of Kelp resources through machine processing of aircraft MSS and Landsat MSS data.

3. Although Landsat-based inventories of Kelp are not a complete substitute of on-site studies, shen the principal con-- cern is the location and area estimation of Kelp beds, they can provide a cost-ef- fective option to map the large and inac- cesible areas in which Kelp beds are dis- tributed.

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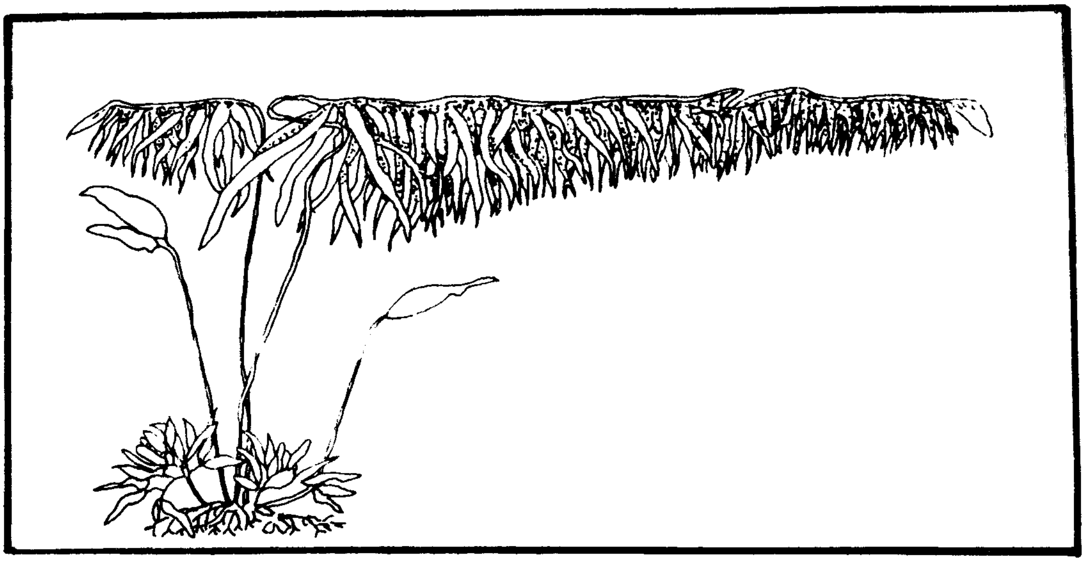

Figure 1. Giant Kelp of California (Macrocystis Pyrifera).

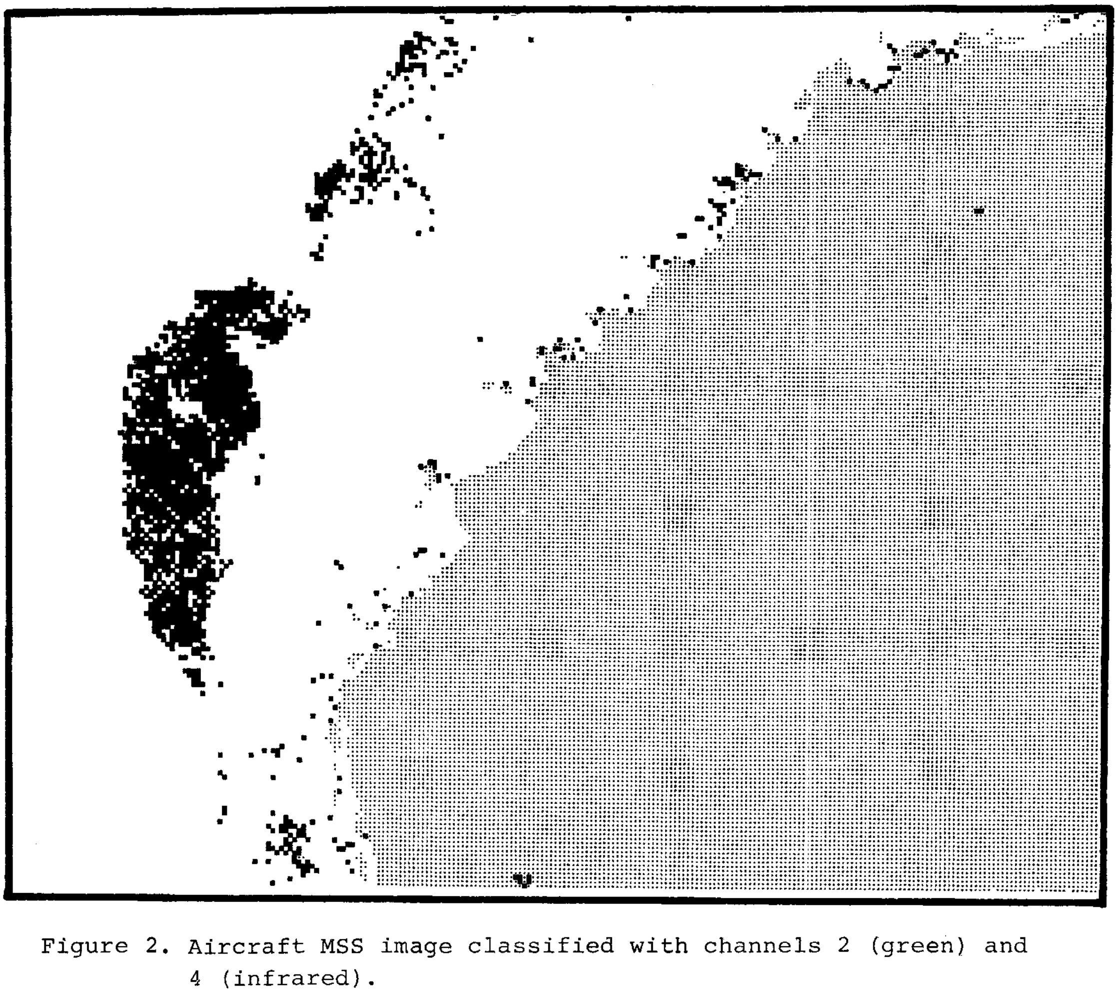

Figure 2. Aircraft MSS image classified with channels 2 (green) and 4 (infrared).

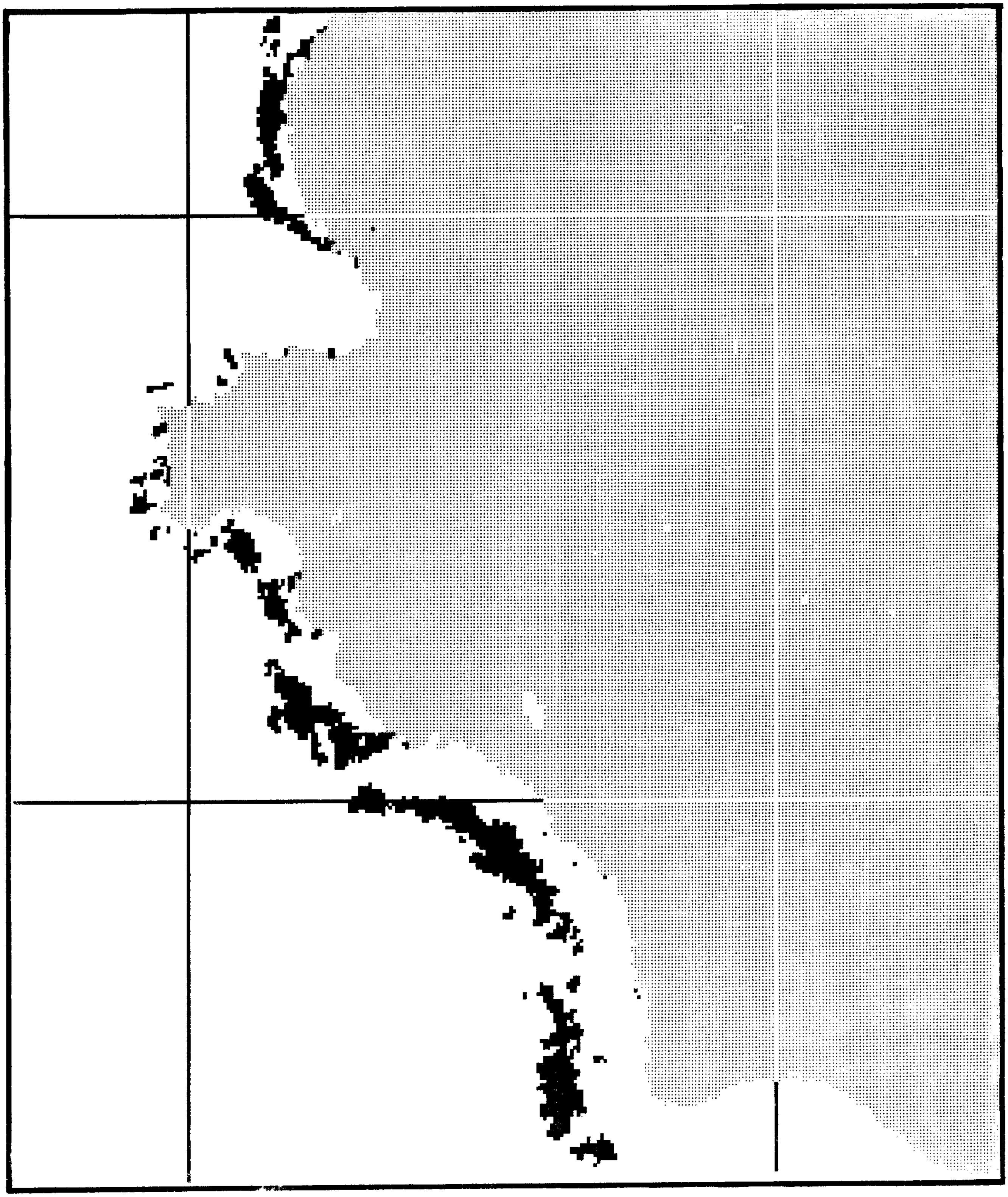

Figure 3. Enlarged portion of a map at original scale of 1:100 000. Grid spacing = 10 Km.