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Remote Sensing Techniques for Kelp Surveys

Color infrared aerial photography, Landsat digital imagery, aircraft X-band radar, and Seasat L-band radar are evaluated.

Abstract: *The economic significance of kelp makes it an important renewable resource to be carefully managed throughout the 1980's. The physiographic and spectral nature of giant kelp (*Macrocystis pyrifera*) are reviewed to identify the role remote sensing may play in providing accurate kelp information. A multispectral approach to monitoring kelp resources is reported. Four dates of high altitude color infrared aerial photography (1:125,000), four dates of Landsat digital imagery, and two dates of aircraft X-band radar imagery were analyzed, which yielded kelp acreage estimates for beds along the Southern California Bight. These estimates were compared with statistics compiled by a private photogrammetric engineering firm responsible for monitoring Southern California beds. In addition, recently processed Seasat L-band radar imagery is examined. The practicality of monitoring kelp by using these remote sensing systems is discussed.*

Introduction

The reader is probably asking two fundamental questions. First, what is Kelp? Second, why is it important that kelp be surveyed? Kelp is defined here as a specie of seaweed of the genus *Macrocystis*, often called Giant Kelp. *Macrocystis pyrifera* is the fastest growing plant on the Earth, averaging 18 inches per day. It thrives as an aquatic forest nurtured by cold, nutrient laden waters found primarily along the west coast of continents (Druehl, 1969). *M. pyrifera* is given primary attention in this study versus other specie because (1) it is dominant whenever it occurs, (2) it is an economically important crop, and (3) its growth form permits it to be observed from aerial platforms in greater detail than species which do not form a surface canopy.

The growth form of *M. pyrifera* is shown in Figure 1 (Neushul, 1968). Plants usually attach to rock substrate on the ocean floor by a holdfast structure. Stipes (analogous to branches) rise vertically from the holdfast, bouyed up by gas filled pneumatocysts at the base of each leaf-like blade. The length of individual fronds vary, but healthy adult fronds may extend horizontally up to twenty feet on the water surface. When viewed from above, the relatively dense surface canopy gives the illusion that the kelp forms an impenetrable, tangled mass. The canopy may extend 1 to 2 cm above the ocean surface, which makes kelp amenable to aerial inventory.

North (1971) recognized three distinct trends in different Kelp populations. First, certain Giant Kelp beds such as those near

Photogrammetric Engineering and Remote Sensing,
Vol. 46, No. 6, June 1980, pp. 743-755.

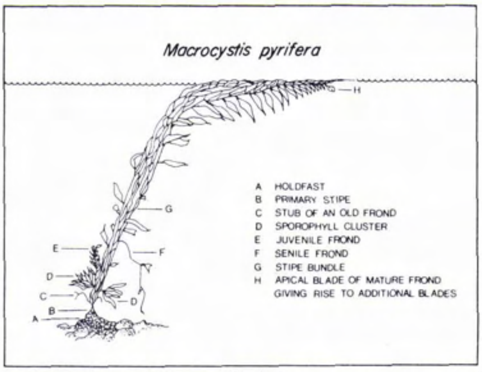

FIG. 1. Growth form of adult *Macrocystis pyrifera* (after Neushul, 1968).

Santa Barbara tend to have larger holdfasts, more fronds, and consistently longer life-spans. These plants are relatively stable through time in the absence of high waves. Conversely, other beds appear and disappear in cycles. The mechanisms triggering such fluctuations have not been completely identified. However, it is known that high water temperatures can disturb the specie as in 1957-58 when California's beds were severely damaged by water temperatures just a few degrees above normal. A third situation is where beds vanish indefinitely for no apparent reason. Once removed from an area, *Macrocystis* may not be able to recolonize the substrate before other species form a cover inhibiting sunlight penetration.

Kelp Economic Significance

Kelp is a renewable, marketable resource. Austin and Adams (1978) noted that "increasing demands upon raw seaweed as raw material for the growing extractives industry has indicated the need for gathering accurate and complete inventory data upon abundance and harvestability of particular seaweed (macroalgal) species." Algin is the most important substance extracted from *M. pyrifera*. It is used as an emulsifying agent to bind water with oily fluids, stabilize emulsions, and hold them in suspension. A small percentage of kelp is also used for human consumption or as meal for animal feed. In 1975, California gross sales for *M. pyrifera* derivatives exceeded 20 million dollars, making it one of California's most valuable coastal zone marine industries (Ashkenazy, 1975).

Research by the American Gas Association to demonstrate the feasibility of growing and harvesting kelp in the open ocean for energy purposes also has significant economic potential (North, 1976; Solar Energy Research Institute, 1979). Conversion of kelp biomass to methane gas can follow several paths. The emphasis is currently on the development of a biological conversion process using anaerobic digestion. California Giant Kelp was selected as the marine biomass because of its very high growth rate, its reproductive capacity, and its ability to regenerate after being harvested (American Gas Association, 1977). Also, in the open ocean there is no competition for space, a major problem for terrestrial biomass conversion concepts.

The kelp beds also are significant to the nearshore sport fishing industry as an integral part of the food chain. Charles Darwin, as early as 1834, recorded his fascination with the multitude of organisms present in South American beds:

> "The number of living creatures of all orders whose existence intimately depends on the kelp is wonderful . . . Often as I recurred to a branch of kelp, I never failed to discover animals of a new and curious structure . . . I can only compare these great aquatic forests of the southern hemisphere with the terrestrial ones in the intertropical regions. Yet, if in any country a forest was destroyed, I do not believe nearly so many species of animals would perish as would here from the destruction of the kelp."

North (1971) reported 128 plant species and over 700 species of animals in Southern California beds. Consequently, the California sport fishing industry is heavily dependent on continued well being of the beds. Certain beds are now officially designated as protected areas to insure stability of kelp ecosystems.

Monitoring Requirements and Strategies

The demand for algin derivatives, food supplements, and methane gas will increase the demand for harvested kelp during the 1980's. Effective management of kelp beds is necessary to meet these demands. Management responsibility for California beds falls primarily on two agencies; the California Department of Fish and Game and the Bureau of Land Management.

The California Department of Fish and Game is mandated to monitor kelp harvesting in California. The department uses hand-held 35 mm cameras to obtain oblique aerial photography of central and southern California beds. Widespread geographic distribution of the beds makes this type of inventory fragmentary and uneconomical. The Department anticipates a time when high altitude aircraft or satellite monitoring can be carried out economically on a quarterly basis. Information from such surveys would be of benefit in determining the impact of harvesting, rehabilitation, and transplantation projects (Haaker, 1975). Given timely information, the Department has the authority to stop harvesting a particular bed for up to one year (Fish and Game Code, 1975).

The Bureau of Land Management collects kelp bed statistics as part of its Outer Continental Shelf Program. In an attempt to obtain a base line inventory on a quarterly basis, the Bureau contracted with ESCA-tech Corporation for a 1975-1977 areal extent inventory of Southern California beds. The study used 70 mm large scale (1:24,000) color and color infrared vertical aerial photography. The data were placed in a geographic information system for statistical analysis (Mel, 1976). Results of this survey represent the ground (sea) truth against which high-altitude photography, Landsat, and microwave inventories were judged.

The Spectral Nature of *M. Pyrifera*

Based on analysis of *in situ* spectroradiometer measurements, healthy *M. pyrifera* has a spectral signature similar to terrestrial orange-brown vegetation (Figure 2). In the visible region, chlorophyll absorption in the green is apparent with slightly greater reflectance in the blue and red. *M. pyrifera* reflects 60 to 70 percent of the incident radiant flux in the region between 700-1100 nm. In contrast, water absorbs most all infrared radiant flux in this region, providing a good object to background contrast between kelp and water. Sensors sensitive to the spectral difference between kelp and water include normal color and color infrared aerial photography and certain multispectral scanning systems (e.g., Landsat).

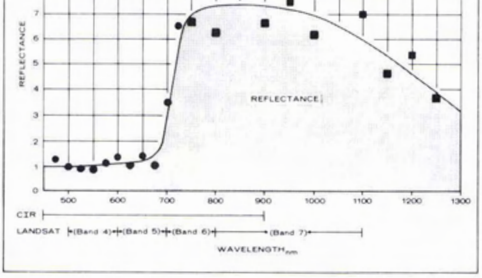

Fig. 2. Spectroradiometer measurements made on twenty interlayered *M. pyrifera* blades. Radiometer bandwidths were 30 and 60 nm for the visible and infrared regions respectively. Kelp was sampled from bed 26 offshore Goleta, California.

Aerial Photography Kelp Surveys

Numerous kelp inventories have been conducted using aerial photography (Table 1). If the canopy is on the surface, color infrared photography (hereafter referred to as CIR) is generally preferred. Unfortunately, beds may be submerged by strong local currents. If submerged, color photography is generally superior due to its water penetration capability in the blue-green region. Most studies used relatively large scale aerial photography, which is expensive to acquire on a repetitive basis. Such photography provides high spatial resolution and usually includes the coastline, making it valuable for numerous coastal planning functions. These attributes continue to make large scale aerial photography inventories attractive. If, however, the areal extent of *M. pyrifera* is the dominant concern, it may be possible accurately to inventory beds from high altitude platforms. Initially such data may come from high altitude aircraft photography and eventually from large format metric cameras onboard platforms such as Space Shuttle or other satellites (Doyle, 1978).

An experiment was conducted to examine the utility of small scale (1:125,000) high altitude CIR photography versus large scale (1:24,000) CIR photography for inventorying *M. pyrifera* acreage. Beds 26 and 27 offshore Goleta, California were inventoried using four separate dates of CIR (1:125,000) imagery obtained by NASA U-2 aircraft. The dates of high altitude photography were chosen to be as close as possible to ESCA-tech's large scale inventories; however, fog and flight scheduling hampered complete agreement. Maps from these analyses are shown in Plate 1. Table 2 reveals the relatively small discrepancy between ESCA-tech's statistics and those of the high altitude inventories. When the high altitude inventory is regressed against ESCA-tech statistics (Figure 3), it is obvious that there is very high agreement between the inventory methods (r = 0.99, significant at the 0.1 level). In fact, there is no significant difference between methods ($t = 0.47$, when $t_{0.05,\,7} = 2.37$). These results suggest analysis of high altitude CIR aerial photography can provide accurate measurement of kelp areal extent when photography is available. In the 1980's, satellite photography may provide a similar function.

TABLE 1. SELECTED AERIAL PHOTOGRAPHY STUDIES

Author	Location	Film	Scale	Species	Remarks
Cameron, 1950	Nova Scotia	B&W, Color	1:15860	Laminaria	
Scolfield, 1960	California	B&W IR	Various	Macrocystis	Statewide inventory
North *et al*, 1963	California	CIR+#25, B&W IR	Not given	Macrocystis	Evaluated surface canopy only
Kelly and Conrold, 1969	Bahamas	Color	1:4000-1:50000	Thalassia Diplanthara	Classification based on density and substrate.
Welch, 1969	Monterey Peninsula	CIR+#12 Color+#12	Various	Macrocystis, Nereocystis, Others	Color infrared was superior
Pirie and Murphy, 1975	Point Sal	CIR+#12 Color+#12	1:10000 1:20000	Macrocystis	Minus-blue color was superior because of depth penetration.
Mel, 1976	Southern California	Color+#12 CIR+#12 CIR+#25	1:24000-1:36000	Macrocystis, Egregia, Others	Color superior for evaluation of sub-surface. CIR superior for surface vegetation.
Austin and Adams, 1978	Georgia Strait, N.E. Pacific	Color+ CIR+#12 Water Pene-tration	1:10000 various	I. Cordata others	Color superior for subsurface. Color and CIR good for surface vegetation. Water penetration poor.

B&W = Black and White Panchromatic
CIR = Color Infrared, Kodak type 2443
Color = Kodak type 2448, or 2445+
B&W IR = Black and White Infrared, Kodak type 2424
Water penetration = Kodak SO-224
Filter #12 = Yellow (minus-blue)
Filter #25 = Red (minus-blue, partial green)

LANDSAT KELP SURVEYS

One might ask the question, Why bother with Landsat if large or small scale aerial photography can perform the task satisfactorily? Aerial photography is expensive to acquire because of aircraft mobilization costs and difficult to acquire on a regional basis due to stratus or fog so common along cold water coasts. Landsat imagery is obtained on a repetitive basis, ≤18 days, depending on the number of satellites functioning in orbit at a given time. This provides a higher probability of complete regional coverage on a seasonal basis.

One might also be concerned whether the 56 by 79 m spatial resolution of Landsat and relatively broad band spectral resolution (see Figure 2) are sufficient for accurate kelp acreage estimation. To evaluate these considerations, a supervised classification was performed on four Landsat dates using all four bands on each date to extract *M. pyrifera* acreage statistics (Figure 4). Classification maps are shown in Figure 5. The acreage statistics from these maps were compared with ESCA-tech statistics in order to assess inventory performance. The results are shown in Table 2 and plotted in Figure 3. The Landsat estimate was highly correlated with the aerial photography inventory (r = 0.98; significant at the 0.01 level) but, unfortunately, it consistently underestimated. In fact, there was a significant difference between the survey methods as documented by a t-statistic of 2.97 ($t_{0.05,\ 7} = 2.37$). By utilizing the regression equation it is possible, however, to scale future Landsat derived underestimates to approximate those obtained from photographic surveys. The difference in acreage estimates appears to lie with a photointerpreter's ability to identify less dense kelp areas on high resolution aerial photography. The integrating nature of a Landsat pixel causes low density regions within a bed to exhibit ocean spectral characteristics.

Numerous interesting phenomena came to light while conducting the Landsat image processing. The spectral nature of kelp and ocean were remarkably consistent in their clustering for three of the four Landsat images (Figure 6). Kelp was separable from

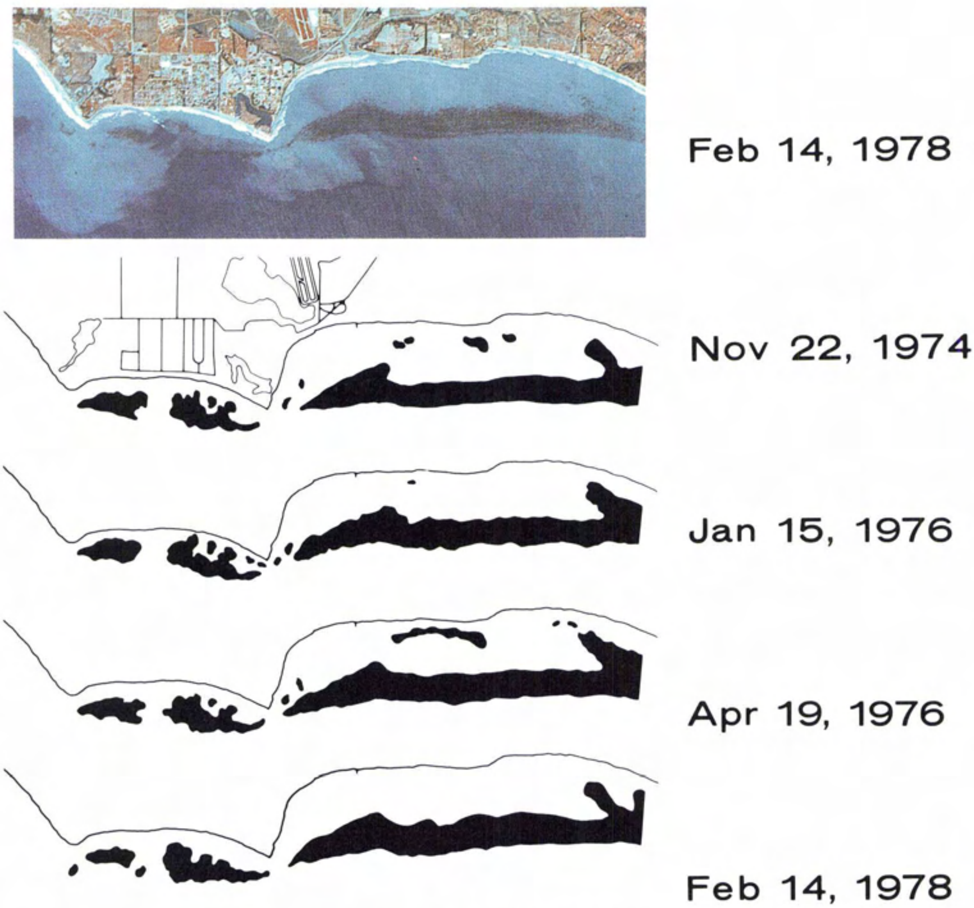

PLATE 1. An example of high altitude CIR photography (original scale 1:125,000) and manually interpreted keep acreage surveys on four dates.

ocean primarily due to the return of radiant flux in the red and infrared bands (5, 6, 7). On the 21 April 1978 image, however, the separation of kelp from ocean was due solely to the water penetration capability of band 4. Bands 6 and 7 did not provide any significant kelp information on this date. Analysis of the 21 April 1978 image revealed turbidity due to a recent storm (Figure 4). The suspended particulate matter severely decreased the spectral separation distance between kelp and water in the infrared bands (6 and 7). In band 4, however, the turbid water evidently provided an improved background against which the kelp could be sensed. This is the first known instance where kelp was quite visible in band 4 (Figure 4) and appears to be due to both the water penetration capability of band 4 (Hammack, 1977) and the turbid nature of the background ocean water.

There was misclassification between beach and kelp in early analyses using only Landsat bands 6 and 7 in the classification procedure because both classes reflect much of the incident infrared flux (Jensen *et al.*, 1976). When bands 4 and 5 are included in the procedure, however, the spectral difference between kelp and beach is sufficient to allow correct classification. Beach materials reflect almost all blue, green, and red flux whereas kelp absorbs much of the blue, green, and red, causing the spectral separation (Figure 6).

Cloud stratus covered part of bed 26 on 7 July 1977 (Figure 4) causing severe underestimation of kelp acreage although the spectral plots show no apparent problem (Figure 6C). Beach and cloud training statistics were lumped together on this date, which produced the spurious spectral plot. The as-

Table 2. Aerial Photography, Landsat and Microwave Kelp Surveys Compared to ESCA-tech Verified Statistics
High Altitude Color Infrared Aerial Photography Survey

Date	Flight & look direction	Bed No. 26 Inventoried/Verified		Bed No. 27 Inventoried/Verified		System
22 Nov 1974		597	603	173	200	
15 Jan 1976		634	678	170	193	
19 Apr 1976		739	680	201	195	
14 Feb 1978		692	675*	177	202	
		Landsat Survey				
21 May 1974		564	603	161	200	
6 Jun 1976		643	655	228	208	
7 Jul 1977		565	671	198	216	
21 Apr 1978		611	675*	128	202	
		X-band Radar Survey				
19 May 1976	W-E, S	720	680	181	195	APS
19 May 1976	N-S, W	640	680	161	195	APS
19 May 1976	W-E, S	764	680	219	195	COR
19 May 1976	N-S, W	713	680	208	195	COR
17 Apr 1977	W-E, S	665	688	230	240	APS

* Estimate based on two years of field verified data.

sumption that beach and cloud cover exhibit similar spectral characteristics was erroneous. One must train on beach and cloud cover separately to maximize discrimination between kelp and these classes.

Results suggest Landsat digital data may provide accurate kelp acreage estimates when a linear equation is used to scale consistent underestimates. Also, Landsat repetitive coverage may provide timely data acquisition on a regional basis.

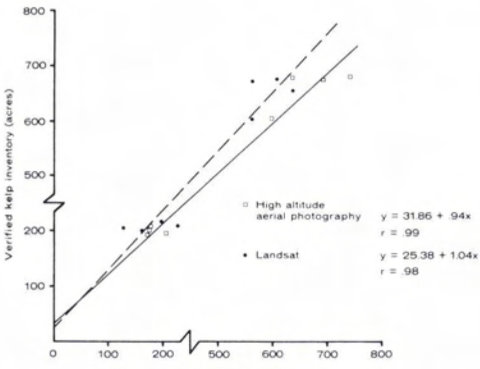

Fig. 3. High altitude CIR photography and Landsat imagery kelp acreage estimates regressed with large scale photogrammetric estimates provided by ESCA-tech Corporation.

Microwave Kelp Surveys

Aerial photography and Landsat imagery are useless when coastal zones are shrouded in dense fog for extended periods of time. Microwave sensors, however, may image through fog, providing an all-weather monitoring capability. Unlike other sensor systems, radar does not record the spectral nature of kelp and ocean. Rather, signatures are the result of complex interactions between materials and actively produced microwave energy. Specifically, signatures are determined by the wavelength and depression angles of the radar beam and by the dielectric constant and surface roughness of the materials. Therefore, in order to discriminate kelp from ocean or any other class of materials, there must be a significant difference in either surface roughness or dielectric constant between classes. Generally, rougher surfaces relative to the size of the incident wavelength energy will produce stronger radar reflections and be recorded as brighter tones on the imagery. *M. pyrifera* exhibits a vertical relief of approximately 1 to 2 cm above the water surface while calm, glassy ocean attains a surface relief of about 0.1 to 0.3 cm. It is hypothesized that this difference in surface roughness is sufficient to discriminate between kelp and water at certain radar wavelengths.

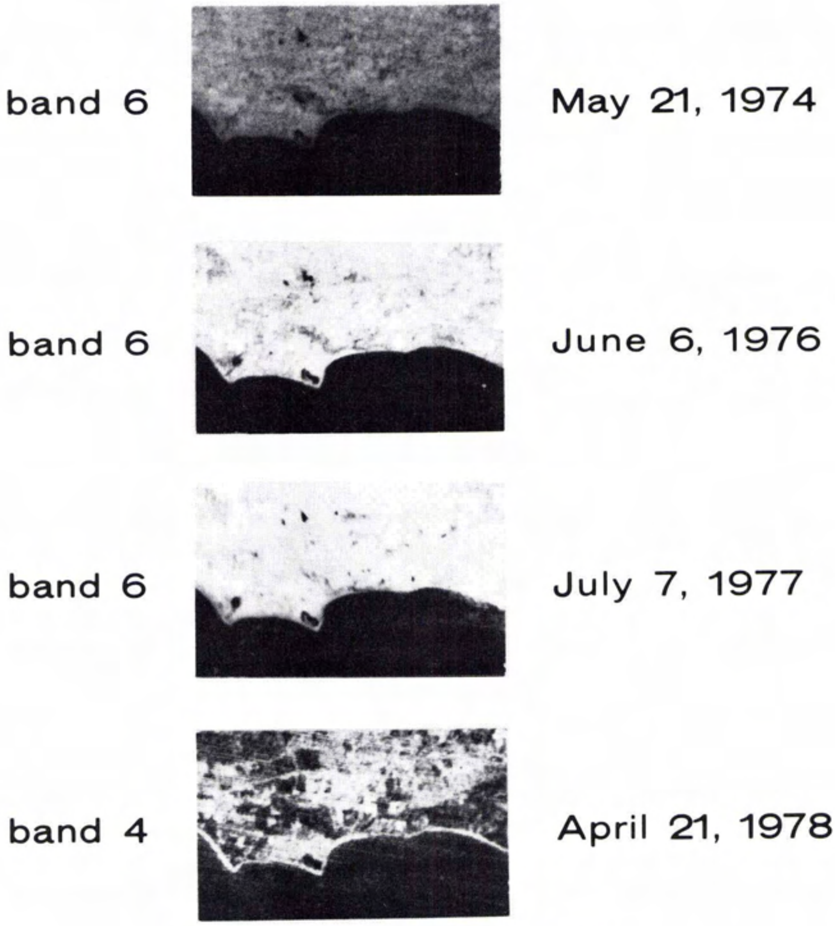

FIG. 4. The four dates of Landsat imagery.

An extensive radar survey of marine targets took place on 19 May 1976 near Goleta, California. An AN/APS-94D real-aperature X-band horizontally polarized radar was flown over the study area at approximately 6500 feet. A vertically polarized X-band coherent-on-receive (COR) synthetic aperature system was also flown simultaneously at approximately 5500 feet. The systems were equipped with 16 ft and 8 ft antenna, respectively. Both systems imaged the study area from a number of different flight and look directions (Figure 7) operating at a 0-25 km range. The antennae depression angle, γ, for each system was approximately 40 degrees at the kelp beds for runs flown east to west, looking south. For a complete description of experiment characteristics see Kraus *et al.*, 1977. The real aperature system was also flown on 17 April 1977.

Based on these parameters and criteria established by Peake and Oliver (1971), it was possible to predict the tonal response of kelp, ocean, and land at a 3 cm wavelength, λ, using the equations

$$h_{\text{smooth}} < \frac{\lambda}{25 \sin \gamma}$$

$$h_{\text{rough}} > \frac{\lambda}{4.4 \sin \gamma}$$

where h_{smooth} and h_{rough} establish the limiting boundaries in centimetres for smooth and rough surfaces. Table 3 identifies the limiting boundaries and suggests tonal signatures for kelp, ocean, and land. The prediction held true (Table 3B), resulting in a relatively high contrast between kelp and water (Figure 7). When evaluating the imagery, however, remember that responses of the radar systems were calibrated to enhance ocean backscatter; hence, the rougher land surface

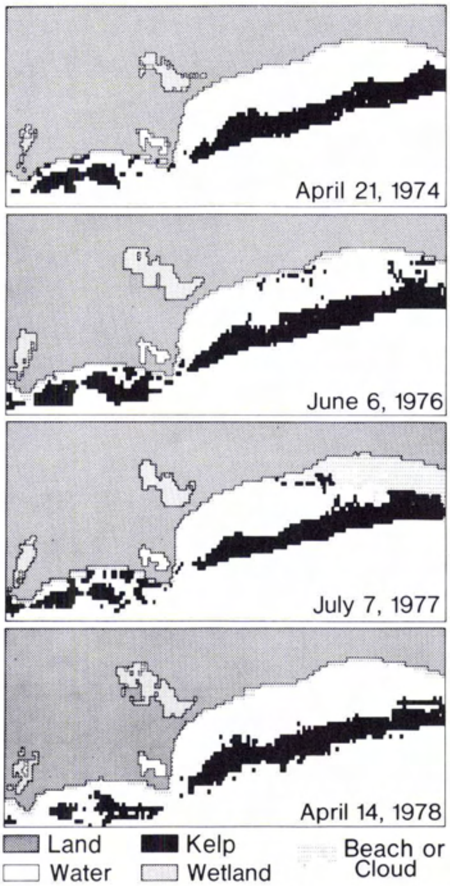

FIG. 5. Kelp acreage surveys derived from four dates of Landsat image processing. Kelp acreage was derived by equating each pixel to 1.1478 acres, i.e. the classification maps were at a scale of 1:24,000 (91.83 acres inch²) with 80 pixels inch². Other land covers were classified for comparative purposes (see Figure 6).

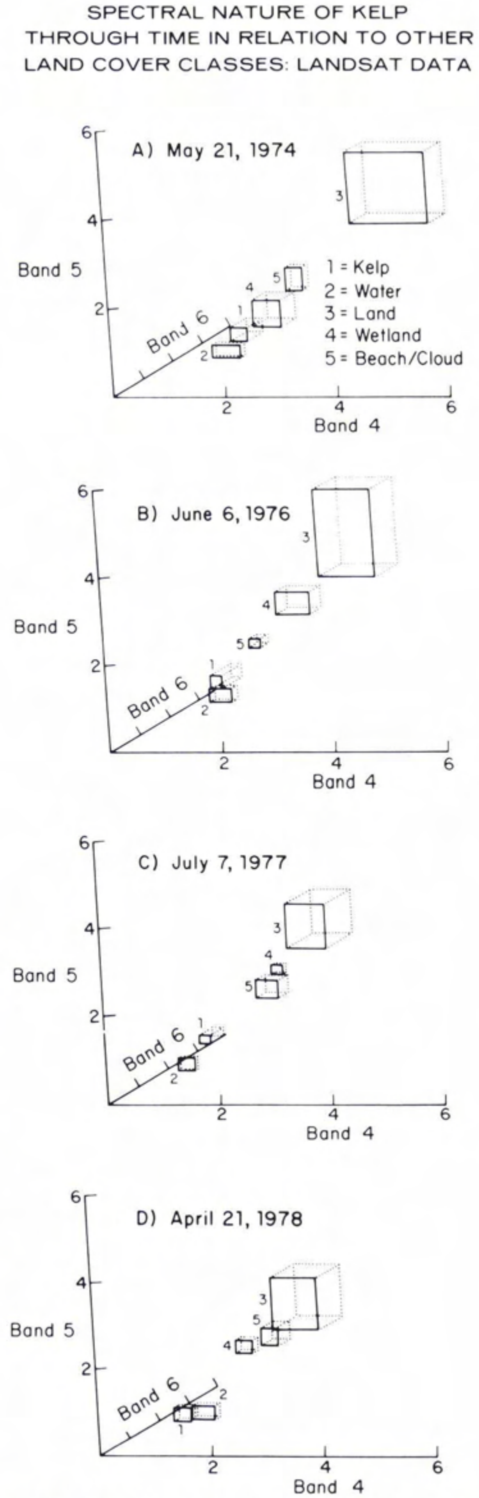

FIG. 6. The spectral nature of kelp through time depicted in three dimensions.

appears extremely bright. Similar contrast between kelp and ocean was found in an oil detection study by Mauer and Edgerton (1976) using an X-band system.

Kelp acreage statistics obtained from manual interpretation of X-band radar imagery are shown in Table 2. Both radars provided relatively accurate estimates of *M. pyrifera*, although the synthetic aperature system consistently yielded overestimates while the real aperature system yielded underestimates. No one look direction was particularly well suited. The ocean surface and interior of kelp beds were devoid of highly oriented phenomena which cause many land-use classes to image differently

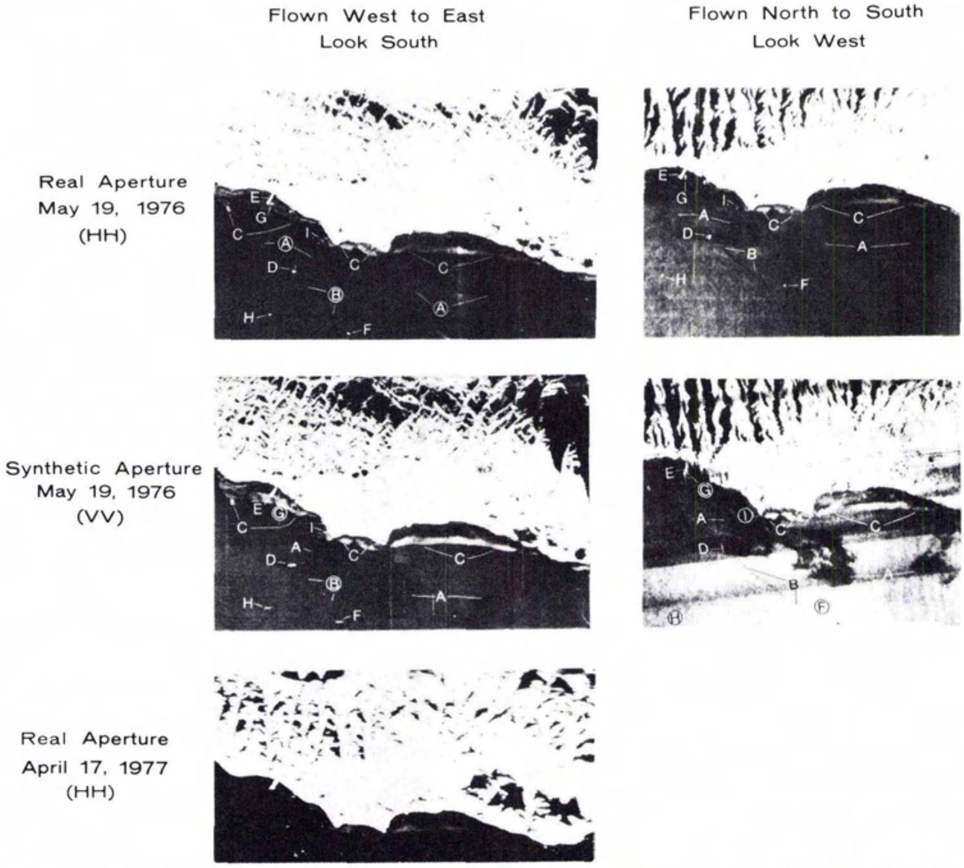

FIG. 7. Two dates of X-band radar imagery over Goleta, California. Annotated targets include: (A) natural seep oil slick; (B) oleyl alcohol slick; (C) kelp beds; (D) platform Holly; (E) oil support pier-1900′; (F) USCG cutter *Pt. Judith* -83 ft; (G) aluminum crewboat -61 ft; (H) fiberglass sailboat -40 ft; (I) 5 point mooring and radar reflector buoy. Circle with a letter indicates the target was not detected.

TABLE 3. A) LIMITING VALUES OF VERTICAL RELIEF (h) FOR SURFACE ROUGHNESS CATEGORIES WITH A DEPRESSION ANGLE (γ) OF 40 DEGREES

roughness category	X-band (3 cm)	predicted signature
smooth	$h < 0.19$ cm	dark
intermediate	$h = 0.19$ to 1.06 cm	intermediate
rough	$h > 1.06$ cm	bright

B) X-BAND RESPONSE OF DIFFERENT VALUES OF VERTICAL RELIEF WITH DEPRESSION ANGLE (γ) OF 40 DEGREES

material	h (cm)	observed signature	predicted signature
ocean	<0.2	dark	dark to intermediate
kelp	1.5–2.0	bright	bright
land	>5.0	bright	bright

when viewed from various look directions (Bryan, 1979). Consequently, the difference in surface roughness between kelp and ocean produced adequate contrast between classes irrespective of look direction.

Having established the utility of X-band imagery for discriminating kelp from ocean and water, a relevant question is whether sensing in other microwave wavelengths can provide similar if not superior results. A tentative answer to this question was obtained by analyzing Seasat L-band imagery of the study area. Seasat-A was launched on 26 June 1978 into a circular orbit approximately 800 kilometres above the Earth (Eberhart, 1978). A synthetic-aperture radar (SAR) with a 10.7 metre antenna provided the equivalent of a brute force conventional radar antenna 14.8 kilometres long. Seasat transmitted L-band (25 cm) microwave pulses of energy at a depression angle, γ, of approximately 70 degrees (20.6 degrees off nadir). An 18 July 1978 Seasat image (Revolution #308; ascending mode) of the Goleta

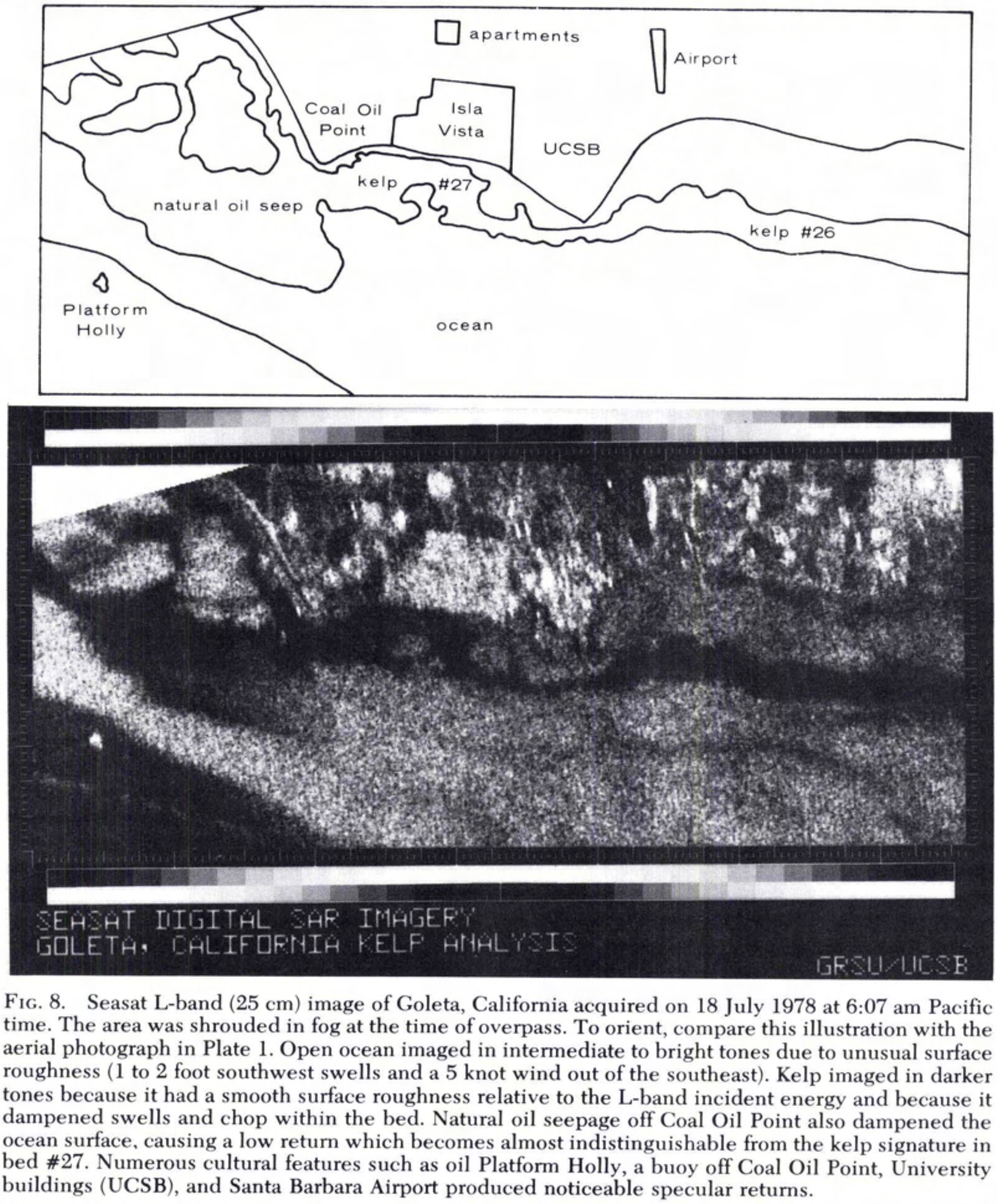

FIG. 8. Seasat L-band (25 cm) image of Goleta, California acquired on 18 July 1978 at 6:07 am Pacific time. The area was shrouded in fog at the time of overpass. To orient, compare this illustration with the aerial photograph in Plate 1. Open ocean imaged in intermediate to bright tones due to unusual surface roughness (1 to 2 foot southwest swells and a 5 knot wind out of the southeast). Kelp imaged in darker tones because it had a smooth surface roughness relative to the L-band incident energy and because it dampened swells and chop within the bed. Natural oil seepage off Coal Oil Point also dampened the ocean surface, causing a low return which becomes almost indistinguishable from the kelp signature in bed #27. Numerous cultural features such as oil Platform Holly, a buoy off Coal Oil Point, University buildings (UCSB), and Santa Barbara Airport produced noticeable specular returns.

TABLE 4. A) LIMITING VALUES OF VERTICAL RELIEF (*h*) FOR SURFACE ROUGHNESS CATEGORIES WITH A SEASAT DEPRESSION ANGLE (γ) OF 70 DEGREES

roughness category	L-band (25 cm)	predicted signature
smooth	h < 1.07 cm	dark
intermediate	h = 1.07 to 6.05 cm	intermediate
rough	h > 6.05 cm	bright

B) L-BAND RESPONSE OF DIFFERENT VALUES OF VERTICAL RELIEF WITH DEPRESSION ANGLE (γ) OF 70 DEGREES

material	*h* (cm)	observed signature	predicted signature
ocean	2–10	intermediate to bright	intermediate to bright
kelp	1.5–2.0	dark	dark intermediate
land	>5	intermediate to bright	intermediate to bright

study area is shown in Figure 8. This digitally processed image was rotated and contrast stretched to enhance interpretation. No conventionally derived kelp acreage statistics were available for comparison; consequently, this discussion will concentrate on the radar signatures of kelp, ocean, and land and the potential for conducting accurate kelp surveys.

The most striking difference between X- and L-band imagery is the signature reversal between kelp and ocean. In the X-band image kelp is bright and water is dark (Figure 7). The situation is reversed in the L-band image (Figure 8). Table 4 shows the observed and predicted signatures for ocean, kelp, and land when using L-band radar. This information and the data for the X-band study are plotted graphically in Figure 9 to identify those limiting values (height in cm) which cause the same object to image differently on X- and L-band radars. Prominent in this discussion are the environmental variables which modulated the radar returns (Henderson, 1979). For instance, on the day of the Seasat overpass, the ocean surface was rough, averaging 2 to 10 cm of chop. This was dramatically different from the calm and glassy sea-state present on the days of the X-band overflights. Therefore, as suggested in Table 4 and Figure 8, the ocean imaged as intermediate to bright tones on the Seasat image. Kelp lay 1.5 to 2 cm in height above the ocean surface, which resulted in relatively dark intermediate signatures (Figure 8). Additional environmental factors present on this day increased the contrast between kelp and ocean in one instance and decreased the contrast in another. First, it is a documented fact that kelp dampens capillary waves and surface chop. This resulted in even lower returns from water inside kelp areas, hence a darker tone. Secondly, seepage from natural oil seeps at Coal Oil Point also dampened the ocean surface in certain areas and intermingled with kelp in bed #27. This dampening made it impossible to discriminate kelp in bed #27 from the oil

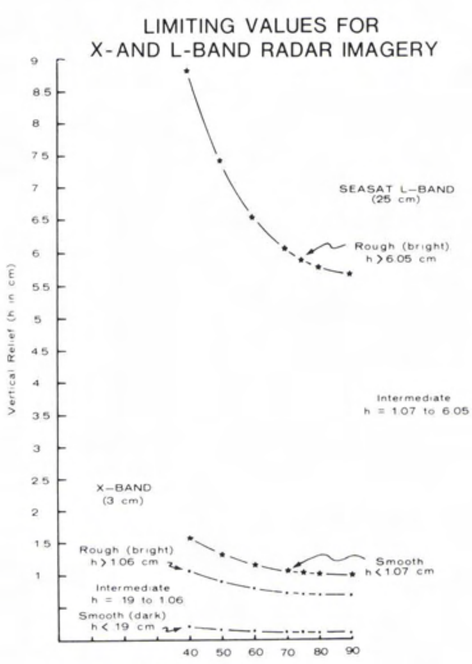

FIG. 9. Limiting values for X- and L-band radar imagery. Depression angles for the X- and L-band imagery in this study were 40 and 70 degrees, respectively. At X-band wavelengths kelp (1.5 to 2 cm in height) should image as bright while at L-band wavelengths it should image in the dark portion of the intermediate region.

dampened ocean nearby (Figure 8). Although interesting, this is not a serious concern to most kelp surveys because natural oil seepage is rare. What is significant is the possibility that, without substantial ocean surface roughness, kelp may not be distinguishable from ocean at L-band wavelengths. Additional research must determine if this assumption is true. The land's extreme range of surface roughness produced both the intermediate and brightest signatures as expected.

Conclusion

The survey and monitoring of kelp resources is becoming more important as the demand for energy and food resources escalate. High altitude color infrared photography and X-band radar imagery can provide areal extent data on *Macrocystics pyrifera* at approximately the same level of accuracy as conventional large scale inventories. L-band satellite radar imagery exhibited potential for kelp monitoring. However, additional L-band research must document if kelp can be discriminated from ocean under calm sea-states. Landsat data may provide accurate statistics if consistent underestimation is offset using a simple linear equation. Given these results, multispectral sensors in the 1980's offer potential for operational monitoring of renewable kelp resources.

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Received 24 September 1979; accepted 8 January 1980; revised 27 January 1980)

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