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# Aerial Color and Color Infrared Survey of Marine Plant Resources

Natural color proved to be the most useful for definition of submerged vegetation while color infrared and natural color together provided the best definition of above-water seaweed vegetation in an assessment carried out in the Georgia Strait area of the north-east Pacific.

Abstract: *Color, color infrared, and water penetration aerial photographs at various scales were assessed for identification, mapping, and inventory of macroalgal vegetation along extensive shoreline of Georgia Strait in the north-east Pacific. Natural color proved to be the most useful for definition of submerged vegetation to depths of 7 m, while CIR and natural color together provided the best definition of above-water intertidal seaweed vegetation. Using both films, exposed under rarely occurring optimum weather and tide conditions, and with the aid of ground data, a total of 11 vegetation units were classified and mapped at a scale of 1:10,000. Boundaries of the vegetation unit containing a valuable red seaweed resource,* Iridaea cordata, *could be defined equally well at a scale of 1:10,000 as at 1:2,500. A ground truth program was designed which revealed a close relation between the aerially mapped* I. cordata *vegetation units and field-observed vegetation units. Air photography with complimentary ground data collection was found effective in establishing baseline data for seaweed resource use, management, and conservation, and will be of value in environmental impact assessment.*

## Introduction

Increasing demands upon 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. Rapid and economical base-line surveys of wild plant resources are a prerequisite to policy decisions that ensure use is continued on a sustained yield basis. With seaweed resources, virtually unknown in distribution and developmental pattern, such pre-use surveys are even more vital.

As a result of the need for base-line information on marine plant resources of British Columbia in the north-east Pacific, the current program was designed to research, test, and apply a methodology for aerial mapping of seaweed communities and inventory of selected valuable species. The coast of British Columbia is deeply indented, in excess of 25,000 kilometers, and is fringed by rich populations of marine plants. Early shipboard seaweed surveys were inaccurate and dealt only with the larger floating kelps visible on the surface.

Aerial remote sensing, with a variety of color and color infrared (CIR) film, has been extensively used in surveys of terrestrial vegetation for quantifying distribution, biomass, and even plant vigor. Aerial photogrammetry has been used to survey aquatic vegetation in lakes (Lukens, 1968; Vary, 1971) and considerable attention is now being paid to aerial survey of inland and coastal marsh vegetation (Anderson and Wobber, 1973; Seher and Tueller, 1973; Klemas *et al.*, 1974; McEwen *et al.*, 1976). Similar surveys of rocky seashore, intertidal, and subtidal vegetation appear to be uncommon. Difficulties inherent in such surveys include the imaging of small and variably colored species, which occur on irregular terrain in heterogeneous bands of variable density and width. The vegetation is uncovered and covered to various depths depending upon the tides, thus severely limiting accessibility and photography. Through-water photography requires attention to problems associated with specular reflectance, water transparency, spectral transmittance, and scene reflectance.

However, a limited number of experimental studies have been made to assess and develop remote sensing as a tool in marine plant reconnaissance. Such studies were first documented in Scotland (Walker, 1950, 1954) and Nova Scotia (Cameron, 1950). Walker's lengthy (1946-1953) survey estimated quantities of *Laminaria*, a seaweed valuable for alginate extraction, and made observations on seasonal biomass fluctuations but gave no technical photogrammetric data and used photography only to differentiate seaweed beds from sandy areas. Three specific communities were differentiated, using minimal ground truth survey, in Cameron's (1950) survey, where the use of various filters constituted a pioneer, if primitive, attempt at multispectral photography. Dubois (1964), working on the French coast, made an interpretive key to imagery of several subtidal algal/seagrass associations and more recently Kelley and Conrod (1969), using both aerial and satellite photography, distinguished characteristics of seven communities on soft bottoms on the Bahamas Banks. Vadas and Manzer (1971) described aerial and CIR photography of intertidal biota affected by thermal effluents but used only small-format, hand-held cameras. The state of remote sensing imagery, as it applies to intertidal vegetation, was reviewed in 1972 by Jamison who used large-format color photography to map algal communities at a scale of 1:1,200 along short sections of coast in northern Washington.

Little use has been made of aerial photography for quantitative inventory of seaweeds and it was apparent that further detailed studies were required prior to extensive aerial survey work in the north-east Pacific. The major objectives of the current work were to assess various films at several photoscales for use in mapping seaweeds, to evolve systematic methods for ground data collection complimentary to the photo imagery, and to evaluate the accuracy of these procedures for resource inventory. The detailed mapping of such sensitive and productive vegetation will provide base-line data for resource use and management and will also serve to indicate the effects of long term perturbations impinging from both landward and seaward.

## METHODS

### AERIAL PHOTOGRAPHY

Mapping and inventory work was undertaken in the Strait of Georgia, British Columbia, where commercially valuable red algae were known to occur. The area (Figure 1) has a characteristic algal flora determined by the enclosed nature of the water mass, sheltered from open Pacific storms and swells. Gradually sloping shores provide

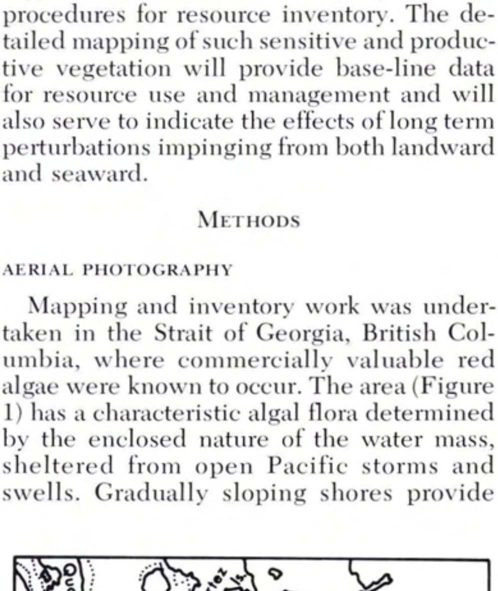

FIG 1. Map of area in Georgia Strait, British Columbia, encompassed by seaweed inventory.

wide intertidal expanses (Plate 3), which support populations of benthic algae on substrate composed primarily of surficial cobbles and rocks in sand, deposited by glacial action, with some protruding granitic bedrock. Maximum vertical tidal range is 6 m.

Along this coast two sensing flights, accompanied by ground data collection, were undertaken, one in 1972 and one in 1974.

The first exploratory (1972) flight used natural color, CIR, and panchromatic B/W film, at various altitudes. Aerial photographs of 23 cm format were taken at times, specifications, and weather conditions shown in Table 1. The photography was by Machair Company (Calgary) using a Wild RC8 camera with a 15 cm focal length lens, along a 45 km "test" coast (Elma Bay to Denman Island, Fig. 1) at a height of 1500 m (approximate photo scale = 1:10,000) with 60 percent forward lap. Color and CIR were exposed at additional scales of 1:5,000 and 1:2,500 in two 2.5 km test areas within this region.

The second (1974) photo mission was undertaken to extend the photo coverage to all coastal areas in northern Georgia Strait where dense beds of selected commercially valuable red seaweeds could potentially occur. Conditions of exposure also are shown in Table 1. Films and photo scales proven best for definition of this seaweed in the previous tests were used, and a total of 52 km of coast were photographed with Kodak aero-negative 2445 film. On the B.C. mainland shore near Powell River additional photography, for comparison with the natural color film, was taken using Kodak experimental color film for water penetration which has two emulsion layers covering the maximum water transmission spectra (Specht *et al.*, 1973).

### GROUND DATA COLLECTION

Interpretation of photographic imagery was accomplished using ground data collected for the definition of seaweed communities. Vegetation was surveyed along belt-transects to facilitate both the classification of vegetation units based on species composition and the location of their boundaries on air photographs used to produce vegetation maps. A total of 22 transects, averaging 500 m in length, were surveyed from May through August 1972 and 30 such transects were surveyed May through August 1974, to accompany photography in respective years. Prior to field work, transects were positioned at right angles to high water on existing standard B/W aerial photographs. The transects ran seaward, at intervals along the coast, on a variety of shore types having different substrates, exposures to wave action and currents, and degrees of steepness, embracing most major environmental conditions for seaweed growth.

In the field, the distance between boundaries of distinct seaweed communities were recorded, the bottom contour mapped, and seaweed samples collected along each transect at 50 m intervals. Position of transects in the field was accurately recorded with the aid of a field compass and sextant so that they could later be precisely located on the aerial photographs.

While such observations are commonplace and relatively easily obtained in terrestrial surveys (Kuchler, 1967), much of our data collection was carried out underwater and presented severe difficulties. When possible, transect observations were made by wading or using wet suits in shallow water at low tide. Observations were continued by SCUBA divers into the subtidal, where

TABLE 1. AERIAL PHOTOGRAPHY EXPOSURE PARAMETERS IN SEAWEED SURVEY FLIGHTS, 1972 AND 1974

DATE: August 6 & 7, 1972
TIME: 0830 – 1000 P.S.T. CLOUD: sunny, light high altitude haze
WIND: 5 mph TIDE: +0.6 m above chart datum

| Film Type | f. Stop | Exposure |
|---|---|---|
| Aerocolor 2334 | 5.6 | 1/400 |
| C.I.R. 2443 | 5.6 | 1/200 |
| B/W | 5.6 | 1/500 |

DATE: July 21, 1974
TIME: 1200 – 1300 P.S.T. CLOUD: broken cumulus, 40% overcast
WIND: 7 mph TIDE: +0.7 m above chart datum

| Film Type | f. Stop | Exposure |
|---|---|---|
| Aerocolor 2445 | 5.6 | 1/250 |
| Kodak Water Penetration | 5.6 | 1/200 |

weighted buoys were placed every 50 m out to a maximum depth of 10 m. A collapsible metal quadrat frame was dropped by a boat operator mid-way between the 50 m buoys and two divers were towed to a given site. Samples of all macroscopic seaweeds (except the smallest filamentous and encrusting forms) and notes on abundance were taken, within the large quadrat ($10m^2$), such that divers in low visibility waters explored associations sufficiently large to be resolved on the aerial photographs. The depth and substrate type at each quadrat site, the visible changes between sample quadrats, and the distances between distinct vegetation boundaries and the nearest buoy were also recorded for identification on aerial photographs.

Actual depth, relative to chart datum, was calculated for each sample site, as was the slope of shore between successive quadrats and the distances of vegetation boundaries from high water. Scale profiles of each transect were drawn (Figure 2) showing sample sites, the major vegetation zones, and tide levels. Distances on these profiles from high water to each vegetation boundary were transferred to the survey photographs.

Phytosociological methods of community analysis commonly used in terrestrial work were applied to the seaweed species data. The quadrat species lists were compiled with an IBM 360 computer, and a Zurich Montpellier sorting method was used which simultaneously groups species which cooccur in sample quadrats and groups sample quadrats with co-occuring species (Ceska and Roemer, 1971). The final sorted associations were used to help define and classify the vegetation units observed on aerial photographs prior to mapping.

### MAPPING

Seaweed vegetation maps for the entire study were prepared at the same scale (1:10,000) as the survey aerial photographs. Source maps for the survey coast were photographically enlarged to the desired 1:10,000 scale and the high water line (H.W.L.) was traced from the source-map onto transparent matte acetate. Boundaries of the vegetation units, the +0.6 m water line contour (low water line) and the H.W.L. debris-or storm-line were, with the aid of a stereoscope, outlined on the aerial photographs. These photographs (color and CIR, 1:10,000) were laid one after another underneath the acetate sheet, matching H.W.L. as closely as possible. The tracing from the source-map was corrected for the smaller H.W.L. features discernable on the air photographs and the boundaries of the major vegetation units and the +0.6 m water-line contour were traced from the photographs onto the acetate sheet. Whereas these maps were uncontrolled, they were sufficiently accurate for the representation of seaweed vegetation units and have been prepared similarly for lake vegetation (Lukens, 1968). Higher precision in drafting boundaries was not warranted because of the inherent gradation observed between many seaweed communities.

### FIELD VERIFICATION OF INVENTORY ESTIMATES

One species of commercially valuable marine plant was found in sufficient abundance and density to warrant inventory for commercial interests. This was a leafy ($0.1m^2$) red alga, *Iridaea cordata* (Turner) Bory, yielding an extract used widely in food processing and pharmaceutical products. The number of hectares occupied by dense *I. cordata* was measured planimetrically from the photographically prepared maps. Additional ground data were required, however, to estimate the accuracy of this area measurement and to make subsequent adjustments in order to derive a final estimate of the area covered by dense *I. cordata*. Such methods are used for inventories of terrestrial crops as outlined by Benson *et al.* (1971).

Ground truth data were sought to determine the relation between mapped boundaries of the *I. cordata* vegetation unit (I.V.U.) and field-observed I.V.U. boundaries. The mapped coastline of Georgia Strait was divided into roughly 2 km strata (sections) and within each, 3 to 10 transects, running nearly perpendicular to shore, were randomly positioned. Each transect was located to run through two clear landmarks (e.g., a house near high water and a large boulder in the intertidal) which could be identified both on aerial photographs and in the field. The distances from the landmarks to the landward and seaward I.V.U. boundaries were measured along each survey transect, both on the ground using survey instruments (± 1 percent error) and on the maps using dividers (± 3 percent average error). Because the *I. cordata* vegetation units were long and narrow, parallel to the coast, the widths of the mapped I.V.U. and field-observed I.V.U. were considered proportional to their respective areas. The ratio of these widths was used to adjust the mapped area by the formula

$$\hat{A}_a = A_m \times R$$

where $\hat{A}_a$ is the adjusted area estimate, $A_m$ is the I.V.U. area measured from the maps, and R is the ratio of the field-observed width measurements to the mapped width measurements. The variance of $R$ provided an estimate of the accuracy of the adjusted area.

The widths of mapped and field-identified I.V.U. and also *I. cordata* biomass were sampled along a total of 58 randomly located transects in 11 coastal strata. An average of two to three transects were surveyed per day by a crew of three SCUBA divers and a total of 25 days were required to complete the ground truth transects in this survey. Biological observations and biomass data have been reported elsewhere (Austin and Adams, 1973, 1974, 1975) and will not be included here.

## RESULTS AND DISCUSSION

### COLOR AND COLOR INFRARED PHOTOGRAPHY

Results of the exploratory study in 1972, using large format color and CIR photography taken at a scale of 1:5,000, can be seen in Plates 1 and 2 of Kye Bay, Vancouver Island. In this test area the cobble and sand shore was very extensive, having an intertidal width of 200-1200 m, and the photography at this scale imaged only the seaward edge of the intertidal and the upper portion of the subtidal marine vegetation. Dominant species and vegetation zones are illustrated in Figure 2. A ground level illustration of a red algal community, at low tide in Kye Bay, dominated by *Iridaea cordata* adhering to cobble substrates is given in Plate 3. A total of eleven major vegetation units between high water and −7 m were identified and mapped along the 45 km test coast in Georgia Strait.

Color and CIR photographs were infinitely superior to black-and-white (B/W) photographs for definition of the vegetation units both above and below the sea surface. With B/W films used during surveys by Cameron (1950) and Walker (1954), boundaries of beds were apparently noted to depths of 7 m. Similar depth penetration was achieved in our B/W prints but again only the boundary characteristics of plant associations could be determined.

A comparison of color and CIR for above-water imagery indicated that neither one was superior for definition of maximum numbers of communities, but they could be used together with advantage. In some shore areas the vegetation units dominated by brown species, especially *Sargassum*

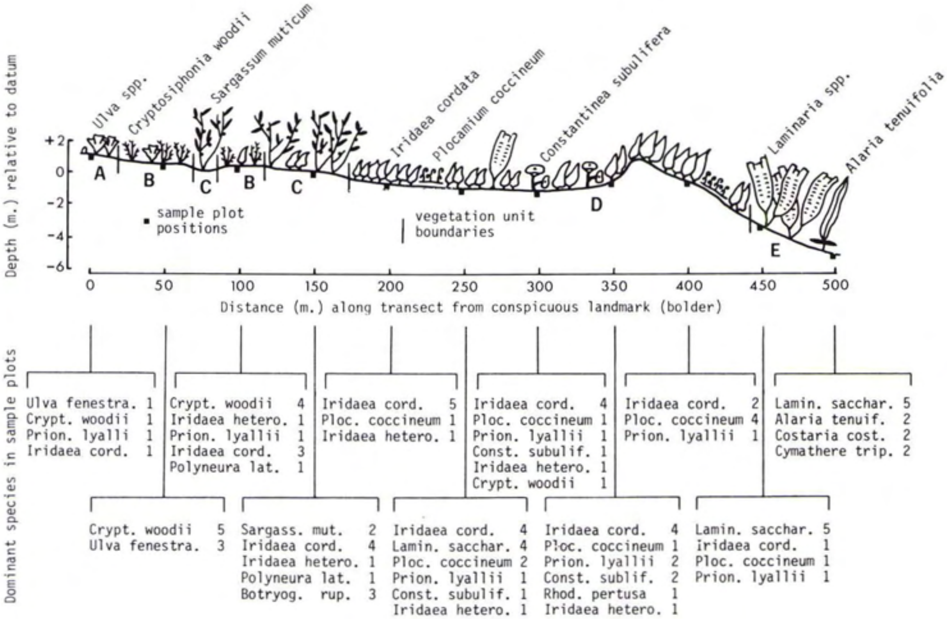

FIG 2. Typical profile of survey transect (Kye Bay) showing depth and distance scales, quadrat sample locations, cover of dominant species (abbrev.) in sample plots and vegetation boundaries, used as an aid to photo-interpretation. *Vegetation Units:* A = *Ulva* spp. B = *Cryptosiphonia woodii* C = *Sargassum muticum* D = *Iridaea cordata* E = *Laminaria groenlandica*. Species cover values: 1 = <5%; 2 = 5-25%; 3 = 25-50%; 4 = 50-75%; 5 = 75-100%.

PLATE 1. Portion of natural color (2445) print of intertidal and subtidal vegetation at low tide (Kye Bay, Vancouver Island) at scale of 1:5,000. Overlay indicates survey transect location and seaweed vegetation units defined from ground data. *Legend:* C = *Cryptosiphonii woodii* I = *Iridaea cordata* L = *Laminaria groenlandica* S = *Sargassum muticum* U = *Ulva* spp. Dashed line = water line (+0.6 m).

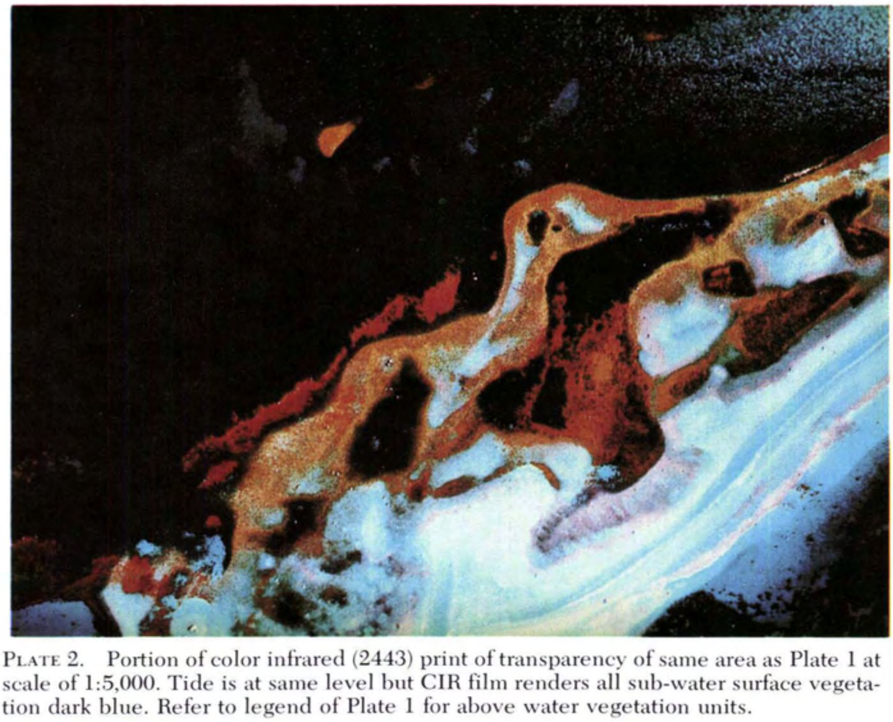

PLATE 2. Portion of color infrared (2443) print of transparency of same area as Plate 1 at scale of 1:5,000. Tide is at same level but CIR film renders all sub-water surface vegetation dark blue. Refer to legend of Plate 1 for above water vegetation units.

PLATE 3. Low intertidal shore area in Kye Bay with dense *Iridaea cordata* seaweed population adhering to cobble substrate.

PLATE 4. Portion of natural color print of B.C. mainland shore (near Powell River, B.C.) at low tide for comparison with water penetration film (Plate 5). Maximum depth penetration = 5 meters. Scale = 1:10,000. Yellow color is enhanced.

PLATE 5. Portion of Kodak experimental water depth penetration print made from transparency. Same location as Plate 4 for comparison.

*muticum* and *Fucus distichus*, were more readily distinguished on the CIR photographs as were living seaweeds in areas where sparse populations (especially *Fucus distichus* and *Ulva* spp.) contrasted little with underlying substrate on the color photographs. Vadas and Manzer (1971) also noted that CIR was superior for separating Phaeophytes (brown algae) from Rhodophytes (red algae). In some areas of our study, however, red species such as the *Cryptosiphonia woodii* vegetation unit were more readily differentiated from neighbouring vegetation on the natural color photographs.

Submerged seaweeds could not be differentiated on CIR taken in Georgia Strait, and the boundaries of vegetation units on these photographs could only be recognized in shallow water when surrounded by a reflective substrate such as sand. The maximum depth at which such boundaries could be discerned was 3 to 4 m, while across much of the CIR photograph little or no penetration was observed. The surface texture and color of seaweeds under water could not be discerned even in beach areas where there were very shallow drainage rivulets down the shore, much less in deeper pools where only sand could be differentiated from the dark blue colored algae. In this respect, CIR was good for locating the level of the tide and for locating areas of drainage. The floating seaweeds, *Sargassum muticum* and *Nereocystes luetkeana*, were very conspicous on CIR. However, in this survey, the lack of penetrance observed on CIR photographs severely limited their usefulness for subsurface definition.

The natural color film was found to give much better depth penetration in this survey, defining objects at depths of 7 m below the water surface. At depths to 2 m some red colors could still be discerned, and between 2 m and 7 m surface texture and boundary characteristics of plant associations could be seen. It is important that this color film be overexposed by one to two stops for greatest penetration (Anderson, 1971; Jamison, 1972).

Comparisons of photo-scales revealed considerably more land form detail at the large scale (1:2,500) than at the smaller test scale (1:10,000), but the depth penetration and definition of vegetation associations was only slightly better at the 1:2,500 scale. The distinctness of boundaries was not particularly better at the 1:2,500 scale than at the 1:10,000 scale due to the graduation inherent between our vegetation units. The main advantage of the larger scale was the increased ease in measuring the areas occupied by these vegetation units. Photo-scales smaller than 1:10,000 would probably show insufficient detail judging from our results, particularly when the algal communities are narrow, such as found on more steeply sloping shores. Furthermore, photographs of the study area at a scale of 1:5,000 often recorded only a portion of the shore between high water and the lower limit of depth penetration. In such areas imagery of the entire shore at a scale of 1:5,000 or larger would require two or more flight paths side by side with standard 30 percent sidelap, involving considerably more time, film, and cost than a single flight at a higher altitude. A further serious limitation of photography at larger scales was the difficulty of providing ground control for flights made entirely over shallow water areas with no coastline or high water line for reference.

Presence of scattered cumulus cloud between the sun and camera severely reduced seaweed community definition along portions of coast in the 1974 photographs. In these areas, contrast between seaweed communities was poor and maximum observed depth at which highly contrasting objects could be defined was only 1 to 2 m below the water surface. Additional factors observed to reduce seaweed definition in some photographs, even in cloud-free areas, were water turbidity and incorrect color enhancement in processing. More contrast between seaweed communities was obtained if yellow-red hues were enhanced during printing. Water transparency was greatest on an outgoing tide and also varied daily with storms and plankton blooms.

A comparison of the natural color photographs taken in cloud-free areas with Kodak water penetration film photographs (Plates 4 and 5) revealed little differences in the maximum depth (4 to 5 m) at which highly reflectant objects, such as sand, could be defined below the water surface. However, the contrast between different algal vegetation types and also between algal beds and bare, sandy bottoms was very poor on the water penetration film, both above and below the water surface. On this film, all features below the water surface retained a rather uniform, dull green tone which varied only slightly in density between the different seaweed populations. In comparison, the 2445 film showed a color range from deep blue to light red on below-surface details. Furthermore, above-water features showed a wider range of colors, while the water penetration film was limited to shades of green

TABLE 2. MEAN NUMBER OF DAYS ± S.E. PER YEAR WHEN DAYLIGHT LOW TIDES ARE COINCIDENT WITH SUITABLE WEATHER FOR PHOTOGRAPHY (WINDS ≤ 10 MPH AND CLOUDS < 1/10 CIRRUS AND 2/10 LOW CLOUD NOT OBSCURING SUN) IN GEORGIA STRAIT, B.C. CALCULATED FOR PERIOD 1966 TO 1975.

| Selected Restrictions | May | June | July | Aug. | Total per Year |
|---|---|---|---|---|---|
| Tide level <+ 1.0 m sun angle 35° to 60° | 1.1 ± 0.4 | 1.4 ± 0.5 | 2.1 ± 0.5 | 1.3 ± 0.3 | 5.9 ± 1.0 |
| Tide level < + 0.5 m sun angle 35° to 60° | 1.4 ± 0.2 | 0.7 ± 0.3 | 0.8 ± 0.3 | 0.3 ± 0.2 | 2.2 ± 0.4 |
| Tide level < + 1.0 m and sun angle 45° to 50° | 0.4 ± 0.2 | 0.5 ± 0.2 | 0.9 ± 0.4 | 0.9 ± 0.4 | 2.1 ± 0.5 |

and blue with some pink tones. Thus, both color and density characteristics could be used to greater advantage in defining and identifying seaweed populations, above and below the water surface, on the Kodak 2445 film. These results indicate that the water penetration film would not be as useful as the Kodak 2445 natural color film for defining red seaweed populations occupying the lower intertidal and upper subtidal with water conditions prevalent in Georgia Strait.

Weather, tide, and sun angle requirements for air-photography of marine algae within the intertidal and upper subtidal proved to severely restrict the time available for photography during summer in British Columbia. Wind should be less than 5-10 mph with cloud cover less than 10 percent cirrus and no low cloud (Lukens, 1968) as confirmed by our results. Hunter (1971) noted that specular reflectance is minimal and bottom illumination maximal when the sun is between 45° to 50 ° above the horizon. For color rendition of any subtidal vegetation, tides must be less than +1.0 m or, better, less than +0.5 m. Using wind, cloud, and tide data from Comox, Vancouver Island, averaged over 10 years, we have calculated the probability of the occurence of daylight low tides with suitable weather in Georgia Strait (Table 2). For tides less than +0.1 m and a sun angle of 45° to 50°, the probability was only 90 percent that one suitable day for aerial photography would occur during any one summer (May-August). We have not considered here the seasonal characteristics of many seaweed species, which would further limit photography if it had to be carried out during a restricted time when plant density was high. All of these parameters must be weighed carefully prior to a photo mission with the understanding that a flight may not be possible in any one year.

### VEGETATION MAPS

By using the Zurich Montpelier computer sorting technique, a total of ten species groups were differentiated which we considered to correspond closely with our intuitive definitions of species associations in the field. Table 3 lists the mean depth and substrate of each association calculated by averaging the depths of the quadrats which were grouped in each association. Eight of the ten vegetation units in Table 3 could be differentiated on air photos at a scale of 1:10,000. Two groups, *Desmarestia aculeata* and *Alaria tenuifolia,* were found in communities too small and too diffuse to be defined accurately on the air photos. In addition three other biological units were mapped including a small high intertidal red algal *Porphyra* spp. population, a deep subtidal floating *Nereocystes luetkeana* (kelp) population, and maritime vegetation consisting primarily of *Salicornia* sp. (glasswort). None of these three were sampled in quadrats but all were conspicuous on air photographs. In total, 11 seaweed vegetation units were mapped using the 1:10,000 scale color and CIR photos taken under close to ideal conditions (1972).

The minimum size vegetation unit mapped at the 1:10,000 scale was 500 m$^2$. Interpretation characteristics were not well defined in units smaller than this and moreover, in the field, small populations were often atypical and fragmentary in species composition compared to larger populations.

Plate 1 shows boundaries of algal vegetation units prepared from a selected air photograph and ground data. The color, surface texture, and boundary characteristics of seaweed beds, along with information concerning the littoral distribution and the major species associations of algae in the

TABLE 3. VERTICAL DISTRIBUTION AND TYPICAL SUBSTRATE OF MARINE PLANT ASSOCIATIONS SORTED FROM GROUND DATA SAMPLES IN GEORGIA STRAIT, B.C.

| Association | Mean Depth (m) | Range | Substrate |
|---|---|---|---|
| *Rhodomela larix*<br>*Gelidium sinicola*<br>*Crassostrea gigas*<br>*Mytilus edulis* | +2.8 | +2.0 to +3.9 | pebbles and sedimentary rock |
| *Fusuc distichus*<br>*Gigartina stellata* | +1.2 | −3.5 to +3.9 | boulders and sedimentary rock |
| *Enteromorpha intestinalis* | | | |
| *Gracilariopsis sjoestedii* | +0.3 | −2.0 to +3.2 | pebbles in sand |
| *Sargassum muticum* | +0.3 | −2.8 to +2.9 | cobbles in sand |
| *Cryptosiphonia woodii*<br>*Iridaea heterocarpa* | 0.0 | −2.5 to +2.2 | cobbles |
| *Iridaea cordata*<br>*Plocamium coccineum*<br>*Prionitis lyallii*<br>*Laminaria saccharina* | −0.6 | −6.3 to +2.9 | cobbles in sand |
| *Laminaria groenlandica* | −1.1 | −3.2 to +0.9 | cobbles |
| *Desmarestia aculeata*<br>*Agardhiella tenera* | −1.3 | −4.8 to +3.4 | pebbles in sand |
| *Alaria tenuifolia*<br>*Costaria costata* | −2.0 | −4.8 to +0.3 | large boulders |
| *Zostera marina* | −2.0 | −6.3 to +1.4 | sand |

study area, were used to interpret aerial-photographs and map the various vegetation units. However, both the littoral distribution and the color rendition of some algal units were observed to have considerable variation along the coast. Thus, generalized vegetation characteristics on aerial-photographs were used cautiously and ground-truth checks were sometimes necessary to confirm correct interpretation.

The maps prepared in this study were useful for the classification of shoreline on the basis of marine plant vegetation. For inventory purposes, large sections of coast, which did not contain sufficient densities of the resource-valuable plants, could be eliminated from more detailed surveys in which map accuracy and such biological parameters as vertical and horizontal biomass variation were estimated from ground-truth surveys.

Considerable emphasis was given the accurate mapping of the vegetation unit containing the principle resource-valuable alga *Iridaea cordata* along this coast in northern Georgia Strait. The total area covered by the *I. cordata* vegetation unit as measured on the 1:10,000 scale vegetation maps was 179 hectares. The area of the *I. cordata* unit on a test map of a portion of the coast, drawn using air photos at a scale of 1:2,500, varied only 5 percent from that area estimated from the 1:10,000 scale maps, suggesting that photo scale did not severely influence interpretation of this seaweed type.

### INVENTORY ACCURACY

The ratios of the field-identified *I. cordata* vegetation unit (I.V.U.) widths to the mapped I.V.U. widths were calculated for each coastal stratum to obtain area adjustment ratios (Benson *et al.*, 1971). The adjustment ratio ($\hat{R}$) was calculated by the formula:

$$\hat{R} = \frac{\sum_{i=1}^{n} W_{fi}}{\sum_{i=1}^{n} W_{m}}$$

where $W_{fi}$ are the individual field identified transect widths and $W_m$ are the corresponding mapped bed widths.

The correction factor $\hat{R}$ varied between 0.63 ± 0.15 and 1.32 ± 0.17 in different strata. A correction factor larger than 1.00 indicated that the mapped I.V.U. area underestimated the field-observed I.V.U. area in that stratum and a small correction factor (e.g., 0.63) indicated that the area of the mapped I.V.U. overestimated the field-observed I.V.U. in that stratum.

We must point out that the similarity in size of the mapped vegetation unit and the field-identified vegetation unit was not as important as the precision of the ratio between the two. In fact, the field boundaries may be as subjectively located as are the boundaries on the photographs. Biomass or other inventory data must, however, be collected in the field within a defined area which bears some calculable relation (map adjustment ratio) to the mapped area. In the Georgia Strait survey the mapped I.V.U. did correspond closely (3 percent smaller) to the field-identified I.V.U. when averaged for the entire 80 kilometers of coast mapped. The adjustment ratio averaged for the coast was 1.03 ± 0.06. When we applied the adjustment ratio of 1.03 to the mapped area, the sample error (coefficient of variance) was estimated to be 6 percent. This error in area measurement, obtained with the combined use of aerial photography and ground-truth data, represented a considerable improvement over many previous shipboard surveys.

## SUMMARY AND CONCLUSIONS

Procedures for mapping and inventory of seaweed vegetation using aerial photography and ground surveys were examined for coastline in Georgia Strait, British Columbia.

Ground data for classification of marine vegetation included collection of quadrat samples at 50 m intervals along transects positioned perpendicular to shore and these data (a) eliminated long stretches of coastline from the photographic surveys where potential resource-valuable plants were at low density, and (b) were used to interpret aerial photographs obtained along selected coastline.

Altogether, 11 vegetation units were defined in the intertidal and upper subtidal to 7 m below the water surface using large format natural color (Kodak 2445) and CIR (2443) photographs together. These vegetation units were interpreted on the aerial photographs according to their color, surface texture, boundary characteristics, substrate relations, and littoral distribution.

During trial surveys of intertidal and subtidal communities, CIR and color complimented each other, providing more interpretative information than use of one alone. For subtidal imagery, CIR was not useful and Kodak water penetration film was found to be less satisfactory than natural color. Better contrast was obtained on natural color prints by yellow-red enhancement. Optimum scale was determined to be 1:7,500 to 1:10,000. Scales larger than this (to 1:2,500) were not recommended, providing little advantage for the identification of major vegetation units but requiring more than one flight line, resulting in disproportionately high costs. Poor definition of the seaweed vegetation units would be provided by scales smaller than 1:10,000.

Photography of most seaweed was restricted to low tides; furthermore, suitable weather conditions during photography were critical. These requirements may hold photographic crews on standby for many days, which some agencies are unable to do. Only three to seven days with moderate to good photographic conditions are likely to occur during any one summer, with the possibility that no optimal days will occur in a particular year. Thus, survey programs must be designed to accomodate possible delays.

The use of vegetation maps prepared from aerial photographs for inventory of resource-valuable seaweeds was investigated using the red alga *Iridaea cordata* as a test species. The area of the vegetation unit containing this species varied little when mapped at 1:10,000 scale or 1:2,500 scale. When cost was balanced against accuracy, the 1:10,000 scale was considered to be the most suitable for mapping extensive stretches of coast.

Ground truth surveys were conducted to sample the width of the *I. cordata* vegetation unit and *I. cordata* biomass. The mapped unit corresponded closely with the field-observed unit. An adjustment ratio of 1.03 (calculated from the ratio of mapped to field-observed *I. cordata* vegetation unit widths) was applied to the mapped area and the sample error of the adjusted area was estimated to be ±6 percent. This error was low compared to those presented by many shipboard surveys.

The seaweed maps of the *I. cordata* vegetation unit prepared for 80 kilometers of coast will serve as an inventory base for potential commercial harvesting and regeneration of the resource but, more particularly, as a baseline condition of an extensive marine littoral biota from which environmental alteration can be detected.

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