CONCLUSIONS

Like any other sort of military terrain intelligence, the aim of military coast and beach analysis from aerial photography is merely the production of complete and detailed "scientific information expressed in military terms so that it may be of use in the field" (Wilson (6)). It is achieved by a fine blending of photogrammetric and photographic interpretation techniques with scientific knowledge in geography, geology, vegetation, soils and engineering, tempered with a thorough understanding of amphibious tactics. This collaboration of civil and military science has proven beneficial to both; while it is true that photographic intelligence was vital to the success of World War II Amphibious Operations, it is equally true that wartime development has stimulated greater peacetime employment of aerial photography. The accomplishments of amphibious photographic intelligence have emphasized the known value of aerial photography in coastal and oceanographic investigations in soils analyses, in erosion studies and in certain types of vegetation research and have provided impetus for its more extensive employment in these fields in the future.

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AERIAL PHOTOGRAPHIC INTERPRETATION OF VEGETATION FOR MILITARY PURPOSES

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THERE are four important ways in which vegetation may affect military operations: (1) it may facilitate or impede the movement of foot soldiers and motorized equipment; (2) it may accentuate or conceal evidence of military activity; (3) it may determine the ease with which clearings can be made for the construction of airfields and roads; and (4) it may serve as a source of construction material, fuel, or food. It follows that detailed information as to the type, density and distribution of vegetation within areas of contemplated military operations is essential to the intelligent planning and execution of such operations. Aerial photographs are an excellent source, and for enemy-held territory frequently the only detailed source, of this vital information.

Most of the examples given in the following pages are from tropical or subtropical regions wherein the density and complexity of plant growth are very great, thus perhaps offering greater problems to both the photographic interpreter and the military commander than does vegetation in other parts of the world.

In recognizing vegetation types on aerial photos, the photographic interpreter relies on such characteristics as size, shape, tone, texture, shadow, and topographic location. Stereograms appearing in Figures 1 and 2 well illustrate the use of these characteristics in identifying wild and cultivated types of vege-

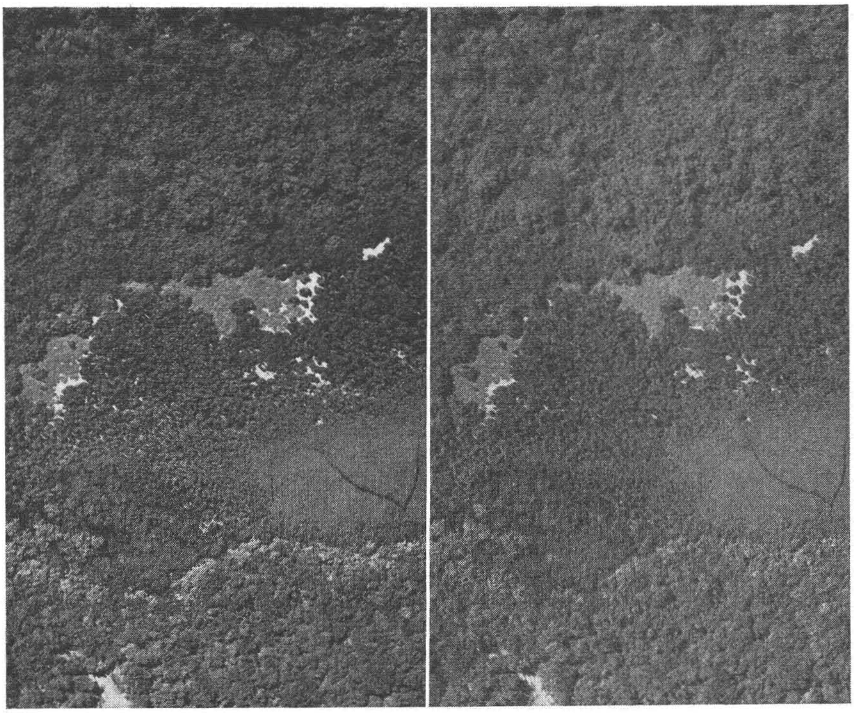

FIG. 1. Stereogram showing variety of wild vegetation types, all readily recognizable by trained aerial photo interpreters.

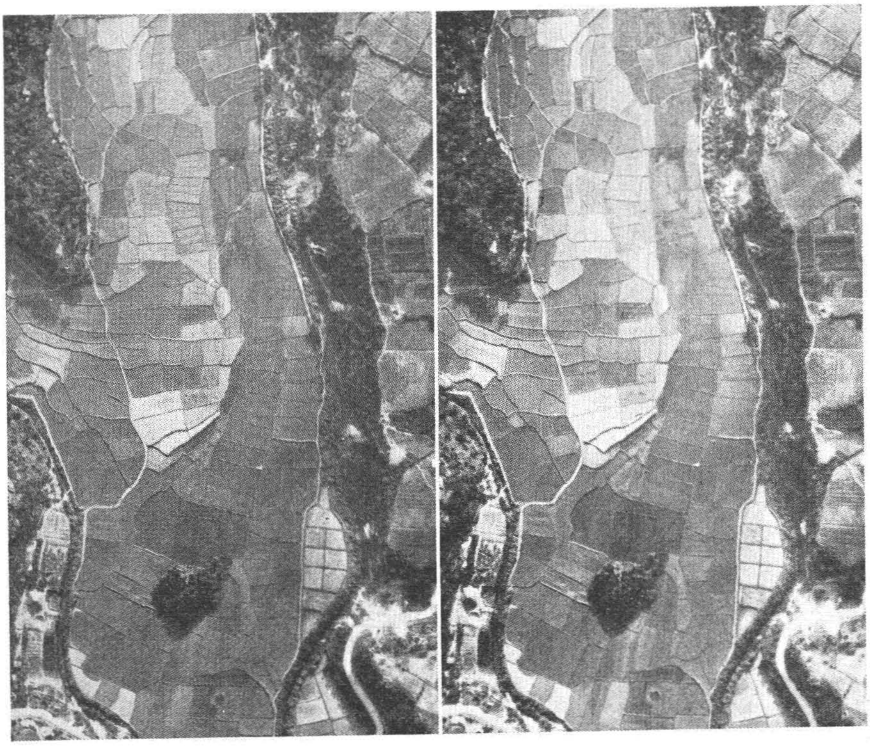

FIG. 2. Stereogram of an intensively cultivated area in which type of crop largely determines trafficability.

tation. The reader is encouraged to study the illustrations stereoscopically, as several important features discussed below will not otherwise be discernible.

Proceeding from top to bottom of the stereogram in Figure 1, the following vegetation types are easily recognized by virtue of one or more of the identifying characters just listed: (1) rainforest with dense undergrowth, (2) an abandoned clearing reverting to secondary growth, (3) clusters of wild palms with narrow crowns and very long stems, (4) mangroves and related swamp species, and (5) rainforest with little undergrowth. That each of these vegetation types presents unique problems from the military standpoint is apparent from stereoscopic study of Figure 1, especially to the photo interpreter who, as a part of his field training, has examined comparable areas on the ground.

If Figure 2 be studied stereoscopically, the ease with which topographic features can be recognized will be seen to greatly facilitate the distinction between paddy crops in the valleys and dryland crops on the surrounding high ground. Tone and texture differences make it possible for the experienced interpreter to further differentiate flooded rice paddies which have only recently been planted, those in which the grain is nearly mature, and those in which the grain has just been harvested. Each represents entirely different conditions of trafficability. The water-filled bomb crater at bottom center of the stereogram confirms the interpretation of poor drainage in this area. On the high ground, dryland sugar cane is consistently distinguishable by its coarser texture from fields of sweet potatoes and other dryland crops. Trees at the center left of the stereogram are identifiable as conifers instead of hardwoods from a study of their shadows which reveal the excurrent branching habit of coniferous trees. The approximate length and diameter of tree stem suitable for construction purposes can also be estimated on the photos, either from shadows or by other means which have recently been devised for use in connection with aerial timber surveys.

The very dark-toned low-lying vegetation on the knoll near the bottom center of Figure 2 is readily distinguished as a dense gorwth of cycads by the photographic interpreter familiar with such an area. He is also aware that cycads characteristically occupy limestone deposits having a thin soil mantle which prevents the limestone from becoming casehardened and difficult to work. Thus he can inform the military engineer, charged with developing the area after its seizure from the enemy, that this knoll probably contains very near to its sufface an easily worked deposit of limestone ideal for the surfacing of roads and airfields.

It is apparent from the foregoing that not all the characteristics of any given vegetation element are of equal value in its photo identification. Sugar cane is identified primarily by virtue of its velvety texture, cycads by their dark tone, mangroves by their proximity to brackish water. Confirmatory characteristics must of course be used also, but there are usually one or two salient features that are of greatest diagnostic value in the identification of any given vegetation element, not necessarily because they are more conspicuous than other features, but because they are more unique, thus better serving to differentiate one type of vegetation from all of its associates.

In some cases, those features which are of greatest value for identification purposes may be overlooked because attention is drawn to somewhat more conspicuous features. For example, one of the best ways of differentiating nipa palm from sago palm is by noting the uniform height of nipa palm stands as compared with the somewhat variable height of trees in a sago palm stand. More apparent on aerial photos than this feature, however, is the frond type of leaf, but since this is common to both palms, it does not serve to differentiate one from the other. On the other hand, the *arrangement* of the fronds, another subtle feature likely to be overlooked by the untrained eye, is of value since the fronds form a rosette pattern discernible from the air in the case of sago palms, but are without a definite pattern in the case of nipa palms.

Just as in taxonomic botany or zoology, these salient aids to identification can be set forth in a key to the population being classified. Such a key for the photo identification of vegetation was published in the June 1946 issue of PHOTOGRAMMETRIC ENGINEERING, page 159. With the aid of a key directing attention to the most important characteristics, one can learn the photo identification of vegetation in certain areas very rapidly. It is most successfully used in conjunction with annotated stereograms of the various vegetation elements. Even more rapid progress can be made if it is also possible to study the photos in the field and to compare the appearance on the photos with the appearance of the same area on the ground.

In planning the seizure of enemy-held territory, it is sometimes highly desirable to know in advance how troops and mechanized equipment will react to certain vegetation barriers within the area of contemplated military operations. For example, if there is a large amount of swampland of a certain type within the probable battle area, it may be very important to know, long in advance of the battle, the ease with which swamps of this type can be traversed by foot soldiers and by such equipment as weasels, ducks, amtraks, tanks, and jeeps. Such information may largely dictate the type of mechanized equipment, clothing and other materiel to be procured for the operation. From a careful study of aerial photos of both the enemy-held territory and similar territory held by our own forces, it usually is possible to pick comparable vegetation and terrain conditions in the two areas with great accuracy. Preliminary tests with men and equipment can then be made on the comparable site in friendly territory.

The inflammability and other fuel characteristics of various vegetation types located in a prospective battle area may be of importance. The ease with which fires can be started by incendiary air attack or by other means, the rate of spread of fires through the vegetation, and the intensity of heat generated may have military significance in both offensive and defensive planning. Here again, a careful comparative study of aerial photos may permit the selection of a comparable area in friendly territory on which preliminary tests can be made.

The species identification of vegetation frequently is of great military value. *Casuarina equisetifolia* is a hardwood tree normally confined to firm sandy beaches ideally suited for amphibious landings; *Nipa fruticans* is a swampland palm which grows in such dense stands as to constitute an almost impenetrable barrier to troop movements; *Hevea brasiliensis*, the rubber tree, was the object of intensive search on aerial photographs of the Amazon jungle during World War II in an effort to augment our supply of natural rubber; *Cinchona* (*sp.*), a tree from the bark of which quinine is extracted, was needed for use in combatting malaria.

Most of the aerial photography from which identification of vegetation was attempted during World War II was taken with panchromatic film at scales smaller than 1/10,000. On such photography, identification of individual species of vegetation can be done only in special instances. It so happens that throughout rather extensive areas of the Pacific there is only one species of casuarina, one cycad, one brackish water palm, and one wild sugar cane. The photo identification of each of these elements is readily made on conventional aerial photography and is the equivalent of species identification. At the other extreme is the tropical rainforest in which 20 or more species of trees may be intermingled with virtually none of them identifiable as to species on small scale panchromatic photography. At least 3 possible improvements in type of photography suggest themselves: (1) increase in scale of photography, (2) use of color photography, and (3) use of photography obtained simultaneously from two or more cameras each employing a different film-filter combination.

Increasing the scale of photography to somewhat greater than 1/10,000 has in certain instances permitted the use of a tree's branching characteristics, has accentuated textural differences in foliage, or has brought out other features not ordinarily discernible at smaller scales. This facilitates species identification especially of trees in the larger size classes. However, it has by no means completely solved the problem. As an extreme attempt in this direction, aerial photography at scales of 1/500 and larger has been obtained with the Sonne camera in the hope of identifying tree species from leaf characteristics. These tests have met with only limited success. In the large scale Sonne stereogram, Figure 3, individual leaf characteristics, together with a knowledge of principal

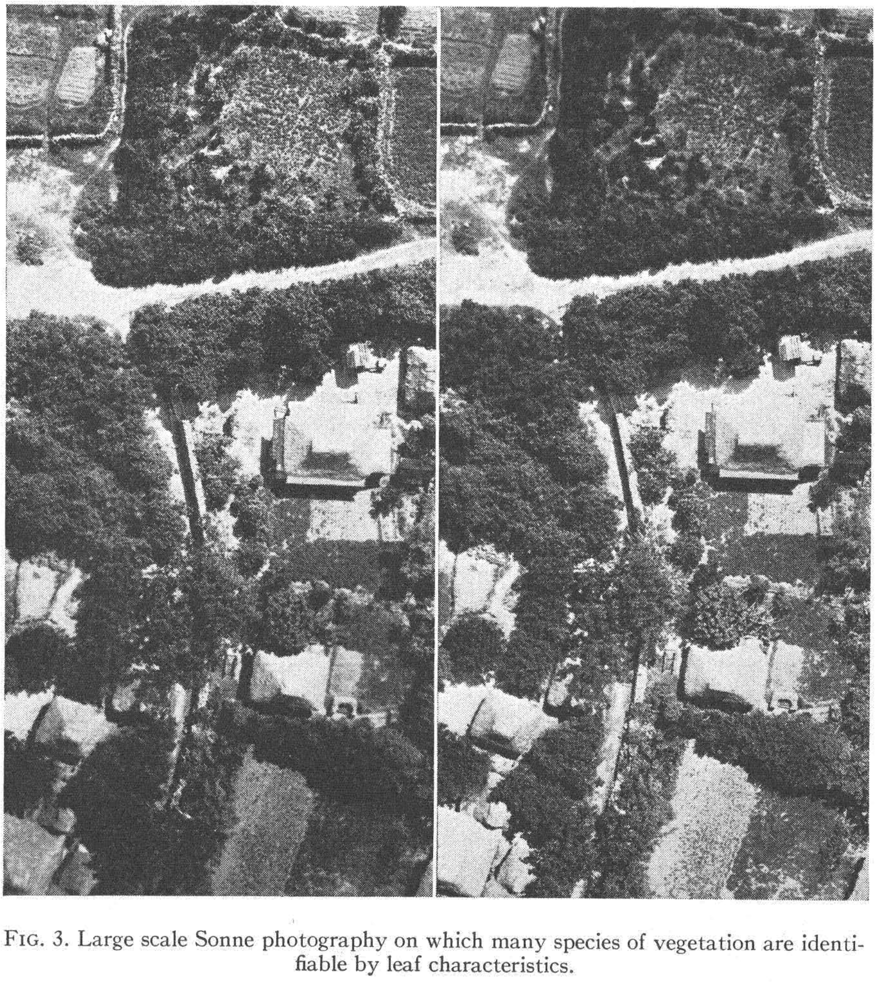

FIG. 3. Large scale Sonne photography on which many species of vegetation are identifiable by leaf characteristics.

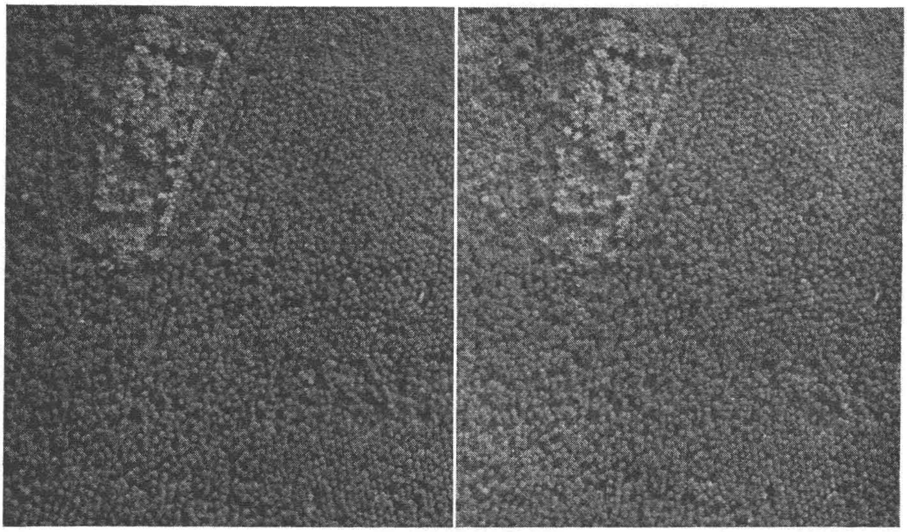

FIG. 4. Stereogram showing value of tone in differentiating coconut from betelnut palms.

species native to the area, permit identification of banana, bamboo, pandanus, castor bean, fig and cycads on the original photos, but leave most of the larger trees still unidentifiable as to species.

The use of color photography likewise has been only partially successful. Since practically all vegetation is one shade or another of green, interpretation of vegetation types usually is as much a problem of differentiating between tones of green on color photography as it is of differentiating between tones of grey on black and white photography. Other aids to species identification, such as texture, shape and size, usually are no more apparent on color than on black and white photographs.

There are exceptional instances in which color is of considerable diagnostic value in species identification, particularly if the photography is obtained at the proper season of the year to exploit flower color or the autumnal coloration of foliage. Such instances are of limited military application, however, because they require photography taken at precisely the right time of year. A further complication lies in the fact that not all trees of a given species in a given area are in the same seasonal state at exactly the same time. For these reasons greater success has been obtained from black and white photography which accentuates tonal contrasts between species by capitalizing on differences in their foliage reflectance spectra (i.e. differences in the intensity with which the green foliage of these species reflects certain wave lengths of light). A familiar example is the use of infrared sensitive film for differentiating hardwood trees from conifers in certain areas. This uses to advantage the fact that the hardwood species reflects much more infrared light to the camera than do the coniferous species, thus producing a sharp tonal contrast between the two groups on infrared photography. Within the visible part of the spectrum, however, differences in the intensity with which light is reflected by these hardwoods and conifers are less pronounced and accordingly there is much less of a tonal contrast on either panchromatic or color photography than on infrared.

In many cases, tone must be very largely relied upon in effecting species separation because in all other respects discernible from aerial photographs the species look essentially alike. For example, in Figure 4, coconut and betelnut palms are shown growing side by side. They appear sufficiently similar in size, shape, texture, arrangement of fronds and topographic location to render distinction between the two very difficult on the basis of these characteristics. However, tone alone readily permits a means for tree separation of these two species if a proper combination of film and filter has been used, as shown in Figure 4. The dark-toned trees in the plantation are coconut; the light-toned trees, betelnut.

This leads to consideration of a third approach to the problem of species identification, namely that of using aerial photography obtained simultaneously from two or more cameras each employing a different film-filter combination. By way of illustrating the possible use of this method, let us assume that a forest is composed of just 3 species, A, B, and C, each having somewhat different foliage reflectance spectrum than the other two, as determined spectroscopically in the laboratory. The proper selection of two different film-filter combinations, I and II, by permitting only selected wave lengths of light to activate the two photographic films, might capitalize on these known differences in foliage reflectance spectra so as to produce the following photographic tones:

Species	Film-Filter Combination	
	I	II
A	light	light
B	dark	dark
C	light	dark

Once the above relationships had been established and confirmed by checks made on the ground, the two types of photography might be comparatively studied on a tree by tree basis. Those trees appearing light in tone on both types of photography would be recognized as species A; those appearing dark on both types as species B; and those appearing light on I and dark on II as species C.

The method is of course predicated on the assumption that foliage reflectance is a function of species. While in general this is true, the difference between reflectance spectra of various species of foliage is not great, as might be expected from the fact that the green pigment, chlorophyll, is common to them all. The assumption also is made that all trees of a given species will have the same photographic tone. This ignores the fact that there are many other factors, such as angle of the sun, position of the tree image on the photo, age and vigor of the tree, etc., which may affect its photographic tone. Despite these limitations, recent experiments indicate that considerably more can be done as regards species identification from such a comparative study of two types of photography than from a study of either type alone. Conceivably, from examination of the reflectance spectra of all the species of trees to be identified in a mixed stand composed of many species, further film-filter combinations might be indicated which would permit identification of many more, if not all, of the species represented. Color photography might also be included.

As a number of film-filter combinations is increased, this method will of course become both costly and complicated. However, for instances in which detailed advance information as to the exact species of vegetation in enemy-held territory has considerable military importance, such a method might be justifiably used. Although the example given pertains to the species identification of trees, it would be equally applicable to the identification of agricultural crops and other forms of vegetation.

It should not be construed from the foregoing that a detailed knowledge of species is always of vital military importance. A feature of rainforests which is usually of greater military importance than its exact species composition is the completeness of closure of the overhead crown canopy, as this largely determines the amount of light striking the forest floor and therefore the density of growth of low-lying vegetation which might impede military movement. Comparison of the portions of a rainforest appearing at the top and bottom of Figure 1 indicates how easily this important feature usually can be determined from aerial photos, there being much more undergrowth at the top of the stereogram than at the bottom.

It is often on the basis of type of barrier to the conduct of military operations that vegetation is classified on aerial photos for military purposes. Thus, in the Pacific during World War II, all wild grass species (exclusive of wild sugar cane) were ordinarily reported by the photographic interpreter simply as Short Grass or Tall Grass, regardless of species, depending upon whether they were shorter than a man's head or taller, thus limiting his visibility. Swamp Forest, Moss Forest, and Savannah were similarly treated as units, each representing particular conditions for the conduct of military operations regardless of its species composition.

In the temperate zone, vegetation may be logically classified for military purposes into the following broad groups: conifer, hardwood, brush, bushy herbs, grass, swamp, cultivated. These ordinarily can be readily distinguished on aerial photos. In any local area of operation, further subdivisions usually will be both desirable and feasible.

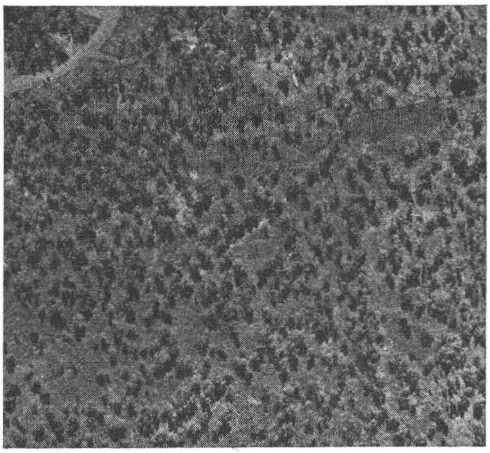

FIG. 5. Vertical aerial photograph of Savannah in which grass accentuates evidence of military track activity.

The example of Savannah shown in Figure 5 shows its typical appearance on aerial photographs. Visibility from the air of activity taking place in such an area is good, as is readily apparent from the illustration. This is attributable both to the wide spacing and sparse foliage of the trees and to the fact that the ground cover of grass is only 2 to 4 feet high. Since the grass is readily bent to the ground and is slow to regain an upright position, track activity is greatly accentuated as shown in Figure 5, where in several instances tracks formed by the single passage of a jeep are easily discerned. The inflammability of this grass at various seasons of the year may be of military importance as previously mentioned. Visibility from the ground is good in a Savannah since the trees are small-stemmed and widely spaced and the grass is shorter than a man's head. Obviously a Savannah is one of the easiest areas in which to make clearings for the construction of roads and airfields. The porous well-drained soil which is characteristic of a Savannah and the ready availability of logs may further facilitate such construction.

Since many features of a Savannah are thus seen to have great bearing upon the effectiveness with which either offensive or defensive warfare can be waged, detailed advance information as to the nature and distribution of this vegetation type within an area of contemplated military activity is of manifest importance for military planning. A similar analysis of all vegetation types within the area, expressed in terms of the 4 factors listed at the beginning of this article, may largely dictate the whole plan of battle.

Figure 6 illustrates ways in which the interpretation of underwater vegetation may be of military significance in planning an amphibious landing. The distribution of phytobenthon (attached underwater plants) indicates portions of the ocean bottom which are rocky, since seaweed of this type normally is anchored by one end to a rock. Such areas may cause difficulties during an amphibious landing because of both rock hazards and the possible fouling of boat screws by the seaweed. In following a channel to the beach which will avoid these difficulties, local currents may be of importance. The direction of "streaming" of the free ends of the seaweeds, as shown in Figure 6, indicates underwater current directions. Depths of water throughout the area also can be obtained from aerial photos, thus completing the hydrographic information needed for planning an amphibious landing.

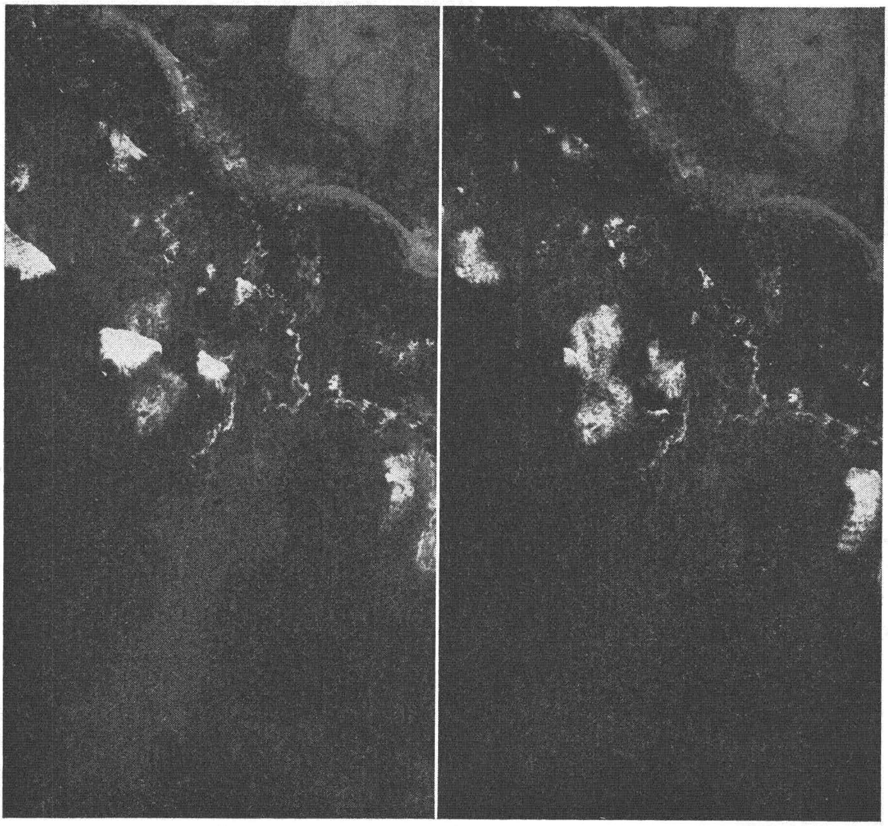

FIG. 6. Rockiness of the ocean bottom and direction of current are indicated by seaweed in this stereogram.

The use of vegetation in an effort to conceal evidence of military activity is a common device. For the aerial photographic interpreter, such attempts frequently accentuate rather than conceal the evidence. If green branches are cut to cover an installation, the foliage soon turns from green to brown, and the consequent change in photographic tone often serves to highlight the installation on aerial photos. Painting either the dead foliage or the installation itself with a green paint, which to the naked eye seems to match the surrounding green foliage, may still further highlight the attempt at camouflage. The use of a special type of color film, known as Camouflage Detection Film, usually permits the photo interpreter readily to distinguish green painted objects from the natural green foliage, and even panchromatic photography with a suitable filter often suffices for this purpose.

FIG. 7a. Stereogram of a recently constructed barbed wire entanglement rapidly being overgrown by vegetation.

Living vegetation, however, is among the most effective of all camouflage materials for deceiving the aerial photographic interpreter. This is particularly true if sufficient time has elapsed since the construction of a military installation for the vegetation to have covered it through normal growth processes. The ability of living vegetation to conceal evidence of military activity is well illustrated in Figures 7a and 7b, two stereograms of the same barbed wire entanglement taken little more than a month apart. Shortly after Figure 7b was taken, the entanglement could scarcely be detected from the ground, let alone from aerial photographs. Even coast defense guns and other sizeable installations can thus be hidden, often in a surprisingly short period of time. For this reason it is highly desirable to obtain periodic photo coverage of the enemy's territory while he is constructing defenses so that each installation can be detected and pinpointed before vegetation has had time to grow over it and perhaps obscure it forever from the eyes of the aerial photographic interpreter.

FIG. 7b. Portion of the same entanglement a few weeks later, almost completely obscured by vegetation.