https://doi.org/10.17895/ices.pub.9191

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SPECTRAL BANDS OF SUBMARINE SOLAR RADIATION IN THE NORTH PACIFIC AND ADJACENT INSHORE WATERS.

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Introduction.

RECOGNITION of the great importance of the magnitude and distribution of solar radiation beneath the surface of the ocean as a fundamental factor in maintaining marine life dates back several years. It was natural to attempt to obtain quantitative information on the subject, and early experimenters made use of visual and photographic observations. While their results were of great value and aided materially in establishing a foundation for further work, they did not yield quantitative data.

In the last few years W. R. G. Atkins and H. H. Poole, using a photoelectric cell connected in a potentiometer circuit, have made many measurements of the transparency of ocean waters. George L. Clarke and co-workers at Woods Hole, Massachusetts, have made many determinations of the transparency of ocean waters in the mid Atlantic and on the east coast of the United States employing apparatus similar to that of Atkins and Poole. Recently Hans Pettersson has made use of photoconductivity cells in making measurements of the transparency and the scattering of subsurface solar radiation. Other workers have used different types of cells and current measuring circuits following the same general procedure of W. R. G. Atkins and H. H. Poole.

In planning for the work on the Pacific Coast, it was decided to use a photoconductivity cell in the submarine photometer. There are several different photoconductivity cells of similar characteristics available. One cell of this type is the Weston Photronic and while much of our earlier work was done with a Photronic, other types seem to possess certain advantages. The Photronic cell produces a current of 130 microamperes for an illumination of approximately 100 foot candles, (1.2 lumens), if the resistance of the external circuit does not exceed 400 ohms. The current output is fairly linear with illumination under this condition but departs from linearity with increasing external resistance. The spectral response approximates the visibility curve of the human eye with the maximum response at 5800 A.

The Lange cell is the equivalent of the Photronic in its relative spectral sensitivity, with possibly a slightly lower response in the ultra violet. It excells the Photronic in current output, giving about 400 microamperes per lumen. It has a linear output when used in circuits of low external resistance.

The Electrocell produces a current which is directly proportional to illumination at low light intensities. The current output is approximately 450 microamperes per lumen. The relative spectral sensitivity shows a maximum response at about 5800 A with a high response over a fairly wide spectral band. The sensitivity of this cell can be increased approximately 30 % by the application of a low unidirectional voltage.

At the time of writing, the General Electric Company announces a new cell of the Selenium type. The spectral sensitivity curve for this cell, with a maximum at 5600 A, compares favourably with that of the Electrocell except that it has a lower relative response on the long wave length side. The relative response is less than 5 % at 7000 A. The cell, in combination with a filter which is to be provided, gives a relative response comparable to the spectral visibility curve of the human eye. The filter, however, reduces the response of the cell in daylight by approximately 43 %. This cell produces a current of 140 microamperes with an illumination of 20 foot candles when the external resistance is 100 ohms. The cell has a relatively high current variation with increasing external resistance for constant illumination.

The photoconductivity cell does not require the use of accelerating potentials and thus does away with the troublesome leakage currents and insulation difficulties which arise on work at sea. The early photoconductivity cells had considerable fatigue effect, although this seems to be less in the later types.

Apparatus.

In order to measure the transparency of the water to various spectral bands of solar radiation, the submarine photometer shown in Fig. 1 was constructed.

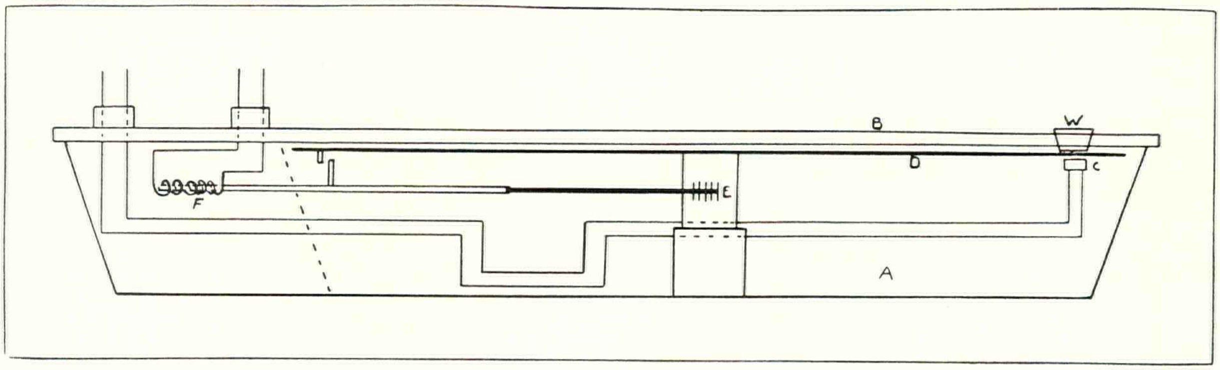

Fig. 1. Schematic Arrangement of the Cell, Color Filters and Filter Shifting Device.

A nickel steel casting, *A*, with a boiler plate cover, *B*, formed the case for lowering the cell and color filters into the sea. A calibrated cell, *C*, was mounted directly beneath a glass window, *W*, and between the window and the cell, with the least possible clearance, was a thin aluminum disk upon which were mounted the color filters. This disk was mounted on a drum which was actuated by means of an electromagnet. The drum was so designed that for each excitation of the electromagnet the disk rotated about a vertical axis through exactly 45 degrees, thus permitting the use of eight color filters on the disk. The cable from the cell and from the electromagnet passed through water tight seals in the boiler plate and terminated on an instrument panel in the ship laboratory. This panel contained two Rawson multimeters, a Leeds and Northrup marine galvanometer, ammeters, voltmeters, rheostats, etc.

One multimeter was connected to a deck photometer for which a duplicate set of color filters were provided. The current from the submerged cell, for relatively high light intensities, was measured with a second multimeter while for lower light intensities it was measured by means of the marine galvanometer. The galvanometer, which was provided with electromagnetic field coils and dynamically balanced, had a very rugged suspension. Its sensitivity was .00118 microamperes. The galvanometer and the multimeters were frequently calibrated.

The cell was calibrated with two sources, sunlight and a 200 watt tungsten lamp. The light from the lamp when filtered through Roundel glass differs from sunlight in its spectral distribution by a very small amount in the violet portion of the spectrum. The calibration was made for each filter by means of a Kingsbury flicker sight box with a special Lummer-Brodhun cube.

The photometer shown in Fig. 2 was constructed to measure the scattering of the light at

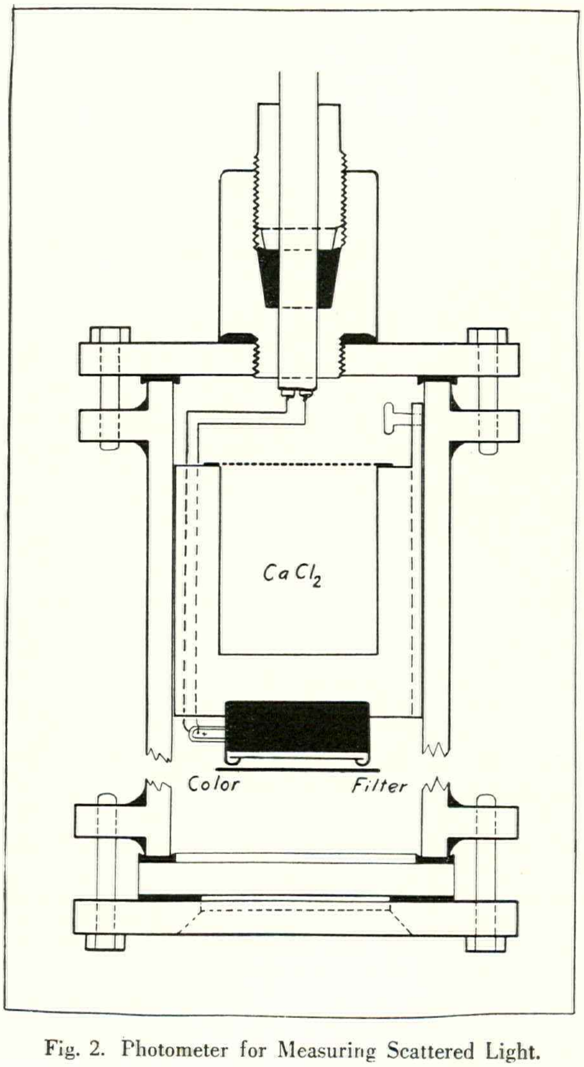

Fig. 2. Photometer for Measuring Scattered Light.

various depths. It consists of a cylindrical steel tube provided with a flange at each end and closed at the upper end with a piece of boiler plate. The other end was closed by means of a glass window, a duplicate of the window used in the photometer described above. The cell was mounted on an adjustable support in such a way that the color filters could be placed between the cell and the window.

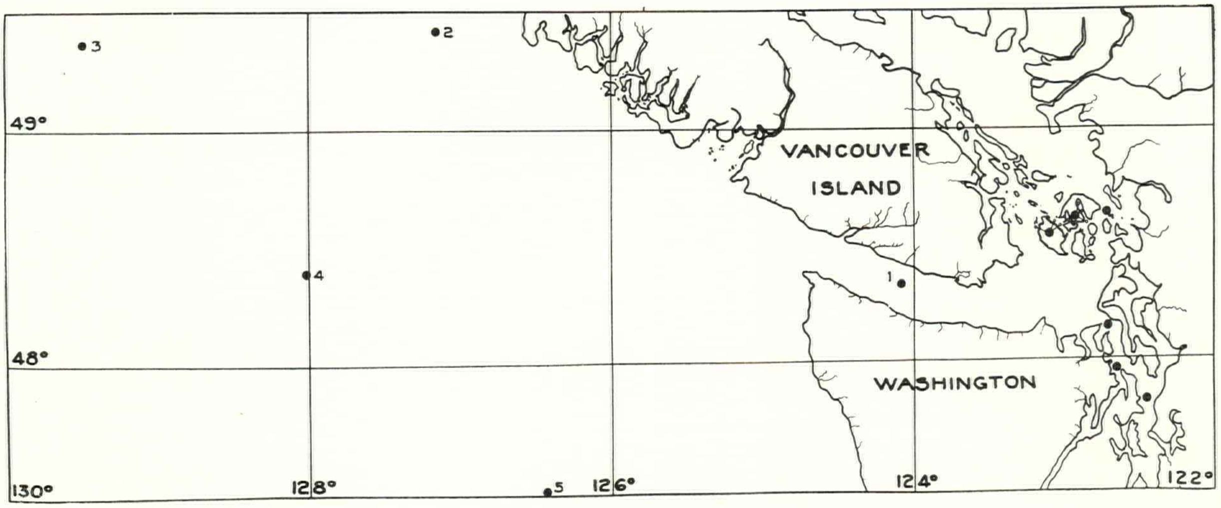

Fig. 3. Northwestern United States and Southwestern Canada.

Seven color filters were used in most of the observations on transmission while but three were used on the scattering observation reported in this paper. Each filter, with the exception of the yellow one, was chosen to give as narrow a transmission band as possible. The transmission band of the yellow filter was rather wide, extending somewhat into the red and slightly into the violet. An effective wave length has been arbitrarily assigned to each filter. Former experiments show that the absorption in the inshore and near shore waters is least in the central portion of the spectrum so the effective wave length of any filter will shift towards the center of spectrum with increasing depth unless, by chance, the effective wave length of a particular filter happens to be that of least absorption of the water. The shifting of the transmission band is quite marked in the extreme red and extreme violet. However, each transmission band is to be considered as designating a small region of the spectrum rather than an exact effective wave length. The wave lengths assigned to the color filters are: 4600 A, 4800 A, 5150 A, 5300 A, 5650 A, 6000 A and 6600 A.

Observations on submarine radiation have been made at many stations in the Pacific northwest. The stations occupied during the last three years include the following regions: The San Juan Archipelago, which is located between the mainland of the state of Washington and Vancouver Island, British Columbia; the Strait of Juan de Fuca between Cape Flattery and Port Angeles; Puget Sound; the waters of the inside passage to Alaska; the north Pacific Ocean between the 47th and 50th parallel approximately 150 miles from the shore line of Canada and the United States; and the Pacific Ocean off the Oregon and California Coast. The distribution of the submarine radiation at these stations has been computed and tabulated but only characteristic results will be treated in this paper.

The location of many of the stations where observations have been made in the San Juan Archipelago and the Pacific Ocean are shown in Fig. 3 while the location of some Alaska stations is shown in Fig. 4.

The small solid circles in the Figs. 3 and 4 refer to the location of places of observation.

The work here reported may be divided for convenience into three parts. (a) One part consists in a study of the transmission of light through the water in the several different locations. The photometer shown in Fig. 1 was used for all measurements of this type. (b) Monthly observations of the transmission of several spectral bands of light through the water have been carried out during 1934 and 1935 and are being continued throughout 1936. In 1934, one station was located in the Strait of Juan de Fuca about twenty-five miles in from Cape Flattery and another in Hood Canal near the junction of the Canal with Puget Sound. During 1935 the observations were continued at the station in the Strait but not at the one in Hood Canal. The 1936 measurements are being made at the same locations as were those of 1935. (c) Measurements on the scattering of light were made at selected stations in the San Juan Archipelago.

Measurements of Penetration into the Water.

The penetration of light into the water is indicated in this paper by a quantity, k, which may be called a total vertical absorption coefficient for a narrow spectral band of radiation and which may be defined by

$$I = I_o \, e^{-kx}$$

Where I_o is the intensity of illumination of a particular color just beneath the surface, and I is the intensity x meters vertically downward.

As the numerical value of k is in part determined by scattering by the water and by suspended matter it is not a true absorption coefficient but refers to the removal of radiation by the water for whatever causes may be operative. Atkins and Poole have given an excellent discussion of this coefficient and have found that consistent results could be obtained by its use. Their conclusions have been verified by the writer.

When a series of measurements were to be taken, the photometer, which was attached to a cable wound on an electrically operated drum, was lowered just beneath the surface of the sea. The light filters were then successively placed between the window and the photoconductivity cell and the current produced by the light transmitted through each filter was recorded. As the measurements were made to determine the absorption coefficients for each band of light this condition was taken as the initial one and illuminations at greater depths were compared to this. The photometer was lowered to greater depths and the current, for each filter again recorded.

The thickness of the layer of water between successive positions of the photometer was chosen by a consideration of the light intensity at the surface at the time and by a consideration of the characteristics of the water.

The electromagnet, used for operating the aluminum disk upon which the filters were mounted, permitted very rapid shifting of the filters. It has been possible to make a series of 180 observations in less than sixty minutes. Under conditions where it is desirable to measure the relative intensities at five or ten meter intervals, the time occupied in a series of observations is relatively short. This is of considerable importance in that it affords almost simultaneous measurements on various colors at each depth and a very small time interval between observations at different depths. Thus the illumination due to each color may be obtained under comparable conditions.

Southeastern Alaska.

The topographical features of the islands of southeastern Alaska are similar to those of the mainland to the east of them but less elevated. The islands are high, rough and broken. The higher summits are quite irregular and show but little modification by erosion. The lower summits are usually rounded and covered with a dense growth of timber. The midsummer snow line is at an average altitude of 1000 meters. Glaciers are found in many of the gorges and, in the northern part of the archipelago on the continental shore, attain a great size many of which reach to the water. The steep inclines and narrow gorges are continued below sea level and form a complex system of narrow straits which extend from Puget Sound to Cape Spencer.

The prevailing winds are from the southwest in the early summer and from the northwest in July and August. Southeast winds are usually accompanied by rain while northeast winds bring snow. The prevailing winds are clearing winds. In the inlets opening from the ocean, fog is frequent in July, August and September. The fogs, which come after midnight, are usually dispelled by clearing winds before noon.

The results of observations at several stations in southern Alaska are shown in Table 1. With the exception of the station off Cape Spencer, they were all made in the waters of the inside passage to Alaska. All of these waters show considerable evidence of layering of foreign matter which probably results from land drainage and, in some instances, from glaciers.

The water, in some cases, is modified by the discharge of large rivers which have drained considerable land areas. This is especially true at the station off MacArthur Reef, in Sumner Strait, past which flows the discharge from the Stikine River. Here the water enters Sumner Strait over a mud flat which extends from the mainland to Mitkof Island on the west. The ebb makes out from the vicinity of Wrangel through Sumner Strait, Stikine Strait and Chichagof Pass, its velocity being materially augmented by the current from the Stikine River. There is a relatively high absorption in the upper four meters, from four meters to ten meters the absorption is very great while below ten meters the transparency increases. Net hauls at this station showed but little plankton.

A similar condition exists at the station off Watson Rock, which is near the mouth of the Skeena River. The absorption was very great and very little microscopic organisms were found.

Dixon Entrance forms one of the deep water inlets to southeastern Alaska from the sea. It is one of the connecting waters of the inside passage. It extends from Cape Muzon in a northeasterly direction a distance of 60 miles with an average

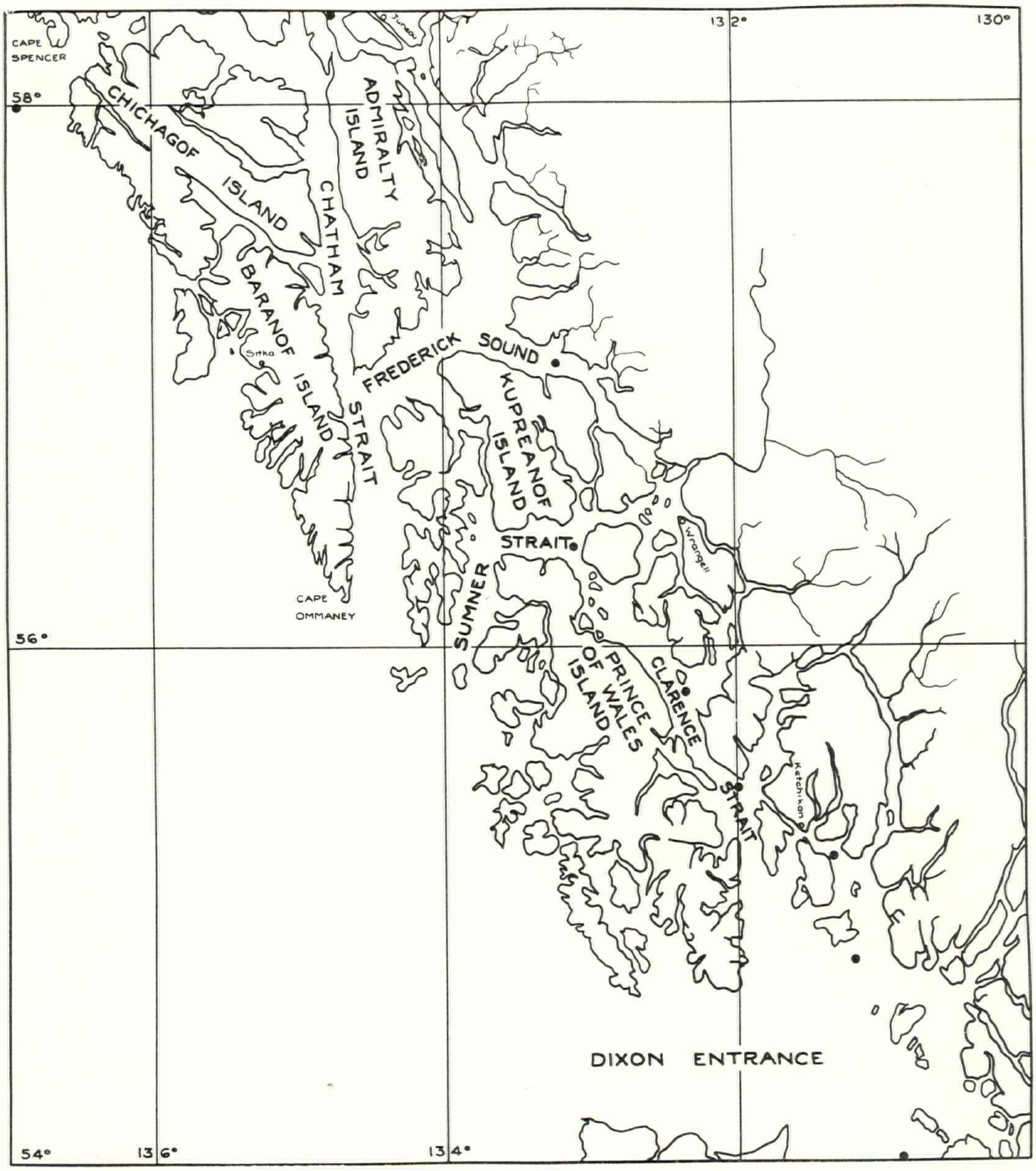

Fig. 4. Southern Alaska.

width of 30 miles. It then contracts to a width of 8 miles and continues with this width to the mouth of Portland Canal, a distance of 18 miles.

The water off Cape Spencer is much more transparent to blue light than are the inshore water. The sea is entered at the Cape by Icy Strait and Cross Sound. These are the northernmost channels connecting the inside passages. Glacial ice, from Glacier Bay is often seen fifteen miles seaward from Cape Spencer.

It will be noticed that in Hecate Strait, and to a lesser extent in Dixon Entrance, the transmission is greater in the blue region of the spectrum than it is in the inshore waters.

In general the transparency of the waters of the inside passage is less than any measured, with the maximum transmission in the green portion of the spectrum.

Table 1.
Per çent. of transmitted Ligth of three spectral Bands in the Waters of Southern Alaska.

Stations	Depth in meters	Per cent transmitted.			Temp. °C.	Cl ‰
		λ = 6000 A	5300 A	4800 A		
Hecate Strait	0	100	100	100	14.30	17.48
	10	0.24	25	19	13.35	17.59
	15	0.021	16	14	—	—
	20	0.0054	7.9	11	—	—
	25	0.0038	4.7	3.4	9.8	17.83
	30	0.0025	3.0	0.34	—	—
	35	—	1.5	0.068	—	—
Dixon Entrance ...	0	100	100	100	12.70	15.17
	5	18	35	26	—	—
	10	1.8	16	7.8	10.01	16.10
	15	0.53	7.6	3.9	—	—
	20	0.27	5.7	2.3	—	—
	25	0.015	1.9	1.0	9.60	17.25
	30	0.012	0.12	0.082	—	—
Off Walker Island.	0	100	100	100	15.00	11.98
	1	60	72	70	—	—
	2	41	65	53	—	—
	3	27	49	38	—	—
	4	18	41	28	—	—
	5	12	32	19	—	—
	6	7.8	25	13	—	—
	7	4.9	18	9.1	—	—
	8	3.1	13	6.0	—	—
	9	2.1	11	1.8	—	—
	10	1.5	9.0	0.33	10.25	15.42
	15	0.35	4.5	0.12	—	—
Off MacArthur Reef	0	100	100	100	10.21	14.25
	1	41	49	39	—	—
	2	21	30	20	—	—
	3	15	25	12	—	—
	4	9.6	18	9.1	—	—
	5	6.0	14	6.1	—	—
	10	0.046	0.28	0.96	8.81	16.62
	15	0.0072	0.13	0.026	—	—
	20	—	0.052	0.0074	—	—
	25	—	0.018	—	7.86	17.28
Portland Island ...	0	100	100	100	9.05	13.69
	5	13	23	18	—	—
	10	0.30	0.81	0.12	9.00	14.35
Watson Rock	0	100	100	100	9.65	10.20
	2	22	15	12	—	—
	4	0.0043	0.45	0.12	—	—
Off Cape Spencer..	0	100	100	100	—	—
	5	13	43	45	—	—
	10	1.7	18	20	—	—
	15	0.22	7.8	9.1	—	—

San Juan Archipelago.

The San Juan Islands form a part of the northwestern section of the state of Washington, lying west of the Washington mainland, and east of the south end of Vancouver Island, British Columbia, a short distance south of the 49th parallel. The San Juan Islands include large and small islands and rocks above high tide to a number of 428, of which 175 are large enough to warrant individual names. The archipelago includes a number of neighboring islands which are a part of the same general group. The islands are rocky and hilly. Though their surface is rocky there are considerable areas of glacial till and a number of swamp and peat areas. The islands have rocky shores though some are partly bordered by swamps.

The summers are usually dry and cool and the winters are rainy. The contours are such as to cut off the saturated winds from the ocean. The islands together with some portions of the mainland of Washington to the east and southwest and the southwestern portion of Vancouver Island have lower rainfall than that of other portions of western Washington and British Columbia.

A detailed survey of the transparency of the water has been made in this region during the last three years and some correlation suggested between the plankton distribution and growth and the transparency of the water. The data presented in Table 2 is characteristic of the location and illustrates the marked differences existing in one region.

East Sound, on the south shore of Orcas Island, extends northwest about 7 miles. It varies in width from 2 miles at the north to ½ mile about half way up the sound. The depths vary from 16 meters to 27 meters. In the summer East Sound is exceedingly rich in plankton. The water is a dark green color. The water here differs from all the other waters in the Archipelago in that it is not subject to turbulence. There is a very gradual exchange of water between the sound and neighbouring water bodies. The maximum plankton count is in May while after September it falls to an exceedingly low value. The water is warmer than neighboring waters in the summer and the phosphates, nitrates and silica are so low that no color reaction is obtained.

Pole Pass is between Crane Island and Orcas Island just west of East Sound. The plankton are not as abundant as in East Sound. The water averages about 40 meters in depth. The Pass itself is only 75 yards wide. The observation station was located north and west of the Pass well out from shoals which extend from the north shore of Crane Island.

Open Bay is located in Henry Island which lies in Haro Strait immediately westward of the northern point of San Juan Island and separated from it by a narrow strait. The water is about 100 fathoms deep and enters this region, directly from the Pacific, through the Strait of Juan de Fuca on the flood tide. The transparency of the water here is greater than that observed at any other locations in the Archipelago. Measurements at this station were made to a depth of 60 meters but for comparison the transmission is shown to 30 meters.

The North Pacific.

In the late summer of 1934 several series of measurements were made off the coast of Vancouver Island and off the coast of Washington. These measurements were repeated in the summer

Table 2.
Per cent. of transmitted Light of seven spectral Bands in the Waters of the San Juan Archipelago.

Depth in Meters	Per cent. transmitted						
	λ = 4600 A	4800 A	5150 A	5300 A	5650 A	6000 A	6600 A
				East Sound			
1	100	100	100	100	100	100	100
5	14	17	22	29	25	15	15
9	.45	.78	1.6	3.2	3.5	1.1	.27
13	.10	.12	.25	.70	.77	.16	.13
17	—	.043	.050	.20	.22	.023	—
21	—	—	.020	.080	.066	.009	—
				Pole Pass			
0	100	100	100	100	100	100	100
5	19	22	23	29	25	8.9	—
15	.77	1.1	1.9	2.7	1.8	.17	—
25	.04	.09	.93	.34	.23	.03	—
				Open Bay			
0		100		100		100	
10		11		15		1.4	
20		1.4		2.8		.043	
30		.15		.35		.0041	

of 1935, extending farther south, with comparable results. The stations, numbered 1, 2, 3, 4 and 5 on the map, are located as follows:

Station 1 is in the Strait of Juan de Fuca		
Station 2 is	49° 25′ N	127° 09′ W
Station 3 is	49° 22′ N	129° 29′ W
Station 4 is	48° 24′ N	128° 01′ W
Station 5 is	47° 26′ N	126° 26′ W

The absorption coefficients, for each spectral band, are recorded in Table 3. At stations 3, 4 and 5, where the water was a clear deep blue, the absorption of the shorter wave lengths was relatively low in the upper layers of the water, increased to a maximum around 50 meters and then decreased with increasing depths. At each of these stations the richest plankton hauls were made between 40 and 50 meters, a fact which may afford some bearing on the effect of light in controlling the diurnal migration of plankton.

It will be noticed that the absorption of all frequencies is very low compared with that of the inshore waters. Also the minimum absorption is in the short wave length end of the spectrum. This is especially true in the stations located farther to the westward. The average values of the coefficients for station 2, which was 28 miles off shore, are greater than the average values of the three stations to the west, while the average values in the Strait of Juan de Fuca are considerably greater than at station 2, but not as great as for the inshore waters of San Juan Archipelago.

Table 3.
Spectral Absorbtion Coefficients in the Strait of Juan de Fuca and in the North Pacific Ocean.

Station	Depth in Meters	Total Vertical Absorption Coefficient						
		λ = 4600 A	4800 A	5150 A	5300 A	5650 A	6000 A	6600 A
1	0—5	.434	.388	.320	.294	.344	.462	
	5—15	.412	.374	.328	.292	.290	.452	
	15—20	—	.332	.274	.266	.248	.354	
2	0—10	.202	.174	.149	.144	.206	.385	.574
	10—15	.138	.170	.136	.170	.166	.304	
	15—20	.137	.096	.144	.090	.108	.284	
	20—25	.060	.064	.088	.092	.132		
	25—30	.059	.060	.073	.080	.074		
	30—35	.058	.048	.072	.071	.096		
	35—40	.058	.072	.071	.068	.096		
	40—45	.024	.026	.072	.040	.140		
	45—50	.040	.036	.080	.086	.084		
3	5—10	.104	.054	.046	.062	.116	.306	.570
	10—20	.091	.086	.093	.105	.110	.286	
	20—30	.079	.065	.070	.076	.091		
	30—40	.059	.084	.090	.083	.092		
	40—50	.071	.062	.043	.072	.066		
	50—60	.047	.053	.055	.060	.096		
	60—70.5	—	.063	.070	.089	.089		
4	0—10	.054	.018	.033	.037	.100	.249	.451
	10—20	.041	.064	.035	.060	.083	.291	
	20—30	.130	.099	.105	.106	.109	.156	
	30—40	.162	.170	.146	.146	.149		
	40—50	.104	.101	.097	.106	.118		
	50—60	.118	.069	.085	.083	.095		
	60—72.5	—	.032	.030	.027	—		
5	0—10	.081	.088	.063	.094	.148	.338	.488
	10—20	.047	.041	.056	.049	.103	.226	
	20—30	.058	.039	.055	.055	.076	.167	
	30—40	.087	.099	.065	.089	.097		
	40—60	.090	.081	.079	.086	.081		
	60—72.5	.105	.081	.082	.095	.103		

Seasonal Variations in Absorption Coefficients.

During the year 1934 monthly measurements were made on the absorption of seven spectral bands of radiation. One of the two stations selected for these observations was Pillar Point which is located in mid channel of the Strait of Juan de Fuca, twentyfive miles in from Cape Flattery. This station is at the head of a submarine chasm which extends out from the Strait and through the Continental Shelf. Beyond the shelf there is considerable evidence of upwelling which with tidal and non-tidal currents produces a general turbulence and results in considerable mixing of the waters. The water is a greenish blue color with upper layers being somewhat like Puget Sound water, while the lower layers are more oceanic in character.

The other station is located at the junction of Hood Canal and Puget Sound. The water is about 125 meters deep, is of a dark greenish color and contains more organism and suspended matter than Pillar Point. The water has many of the characteristics of fjord water. During 1935 these monthly observations were repeated. However, a station in Puget Sound at Point No Point was studied instead of the one at Hood Canal, as it had been found difficult to reach the Hood Canal station at a time favorable for making radiation measurements. The water at Point No Point was similar in character to that at Hood Canal.

The variations in the absorption coefficients of three of the spectral bands at the Pillar Point station for the year 1934 are shown in Fig. 5. Of the data available on total plankton at this station there is some evidence of correlation with the transparency. There is more evidence of correlation of total plankton with transparency at the station in Hood Canal. The plankton study, at the time of writing, is not completed.

In Fig. 5 and Fig. 6 curves *A*, *B* and *D* show the absorption coefficients for the first 10 meters, while curves *C* and *E* show the absorption coefficients from 10 to 20 meters. *A* is for 6000 A, *B* and *C* are for 5300 A and *D* and *E* are for 4800 A.

The results of the 1935 study at Pillar Point show considerable differences when compared with those of 1934. A maximum absorption in the upper layer occurs each year. It was earlier in 1935 than in 1934. The 1934 maximum of absorption was coincident with a maximum in the total plankton. The curves for each year exhibit a minimum in December.

Since the values of the absorption coefficients are due to properties of inorganic matter as well as organic matter, the observed variation in coefficients is caused by changes in the amount and kind of matter present in the water.

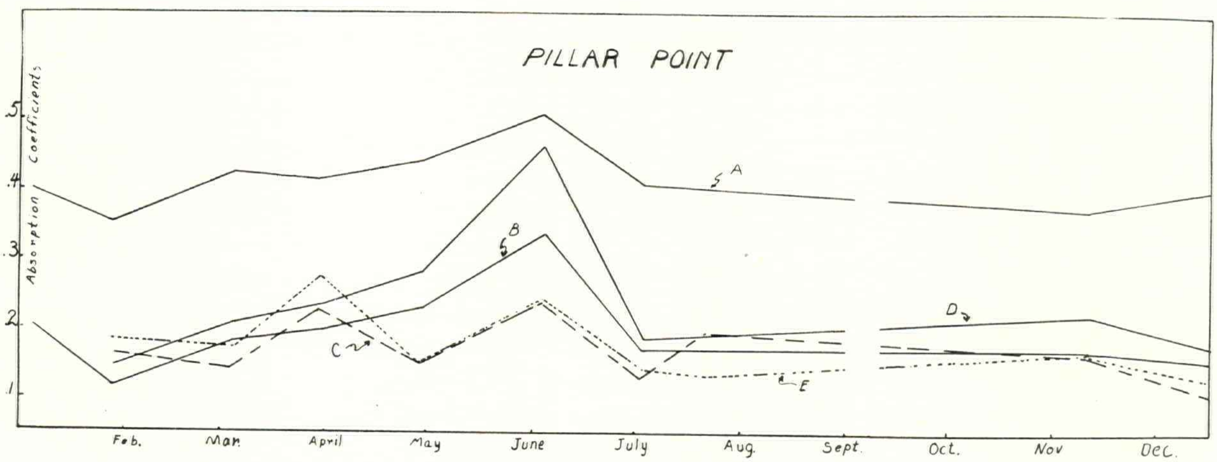

Fig. 5. Variation in Absorption Coefficients at Pillar Point during the Year 1934.

The observations were made to depths of 50 meters during most of the year but due to the exceedingly low intensity of daylight in the winter months, comparison data for the first 20 meters are shown. Some of the winter data were taken during fog or rain and on some days, the surface of the water was not as quiet as was often experienced in the inshore waters.

Scattering of Subsurface Radiation.

While a considerable number of observers have been concerned with the transmission of daylight through ocean waters, there has been very little work done on the light which is scattered at various depths.

In order to investigate the light scattered in certain spectral bands the photometer shown in

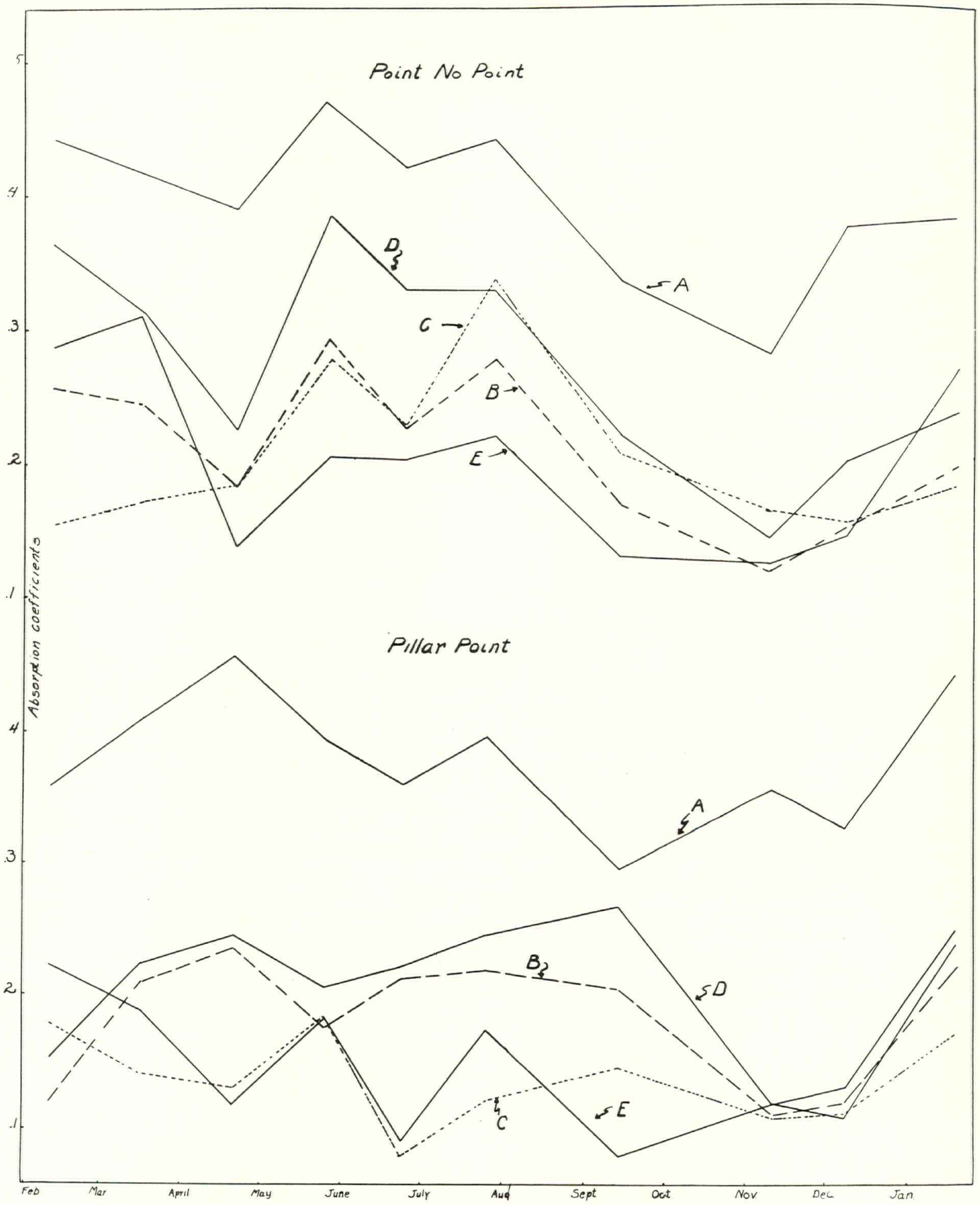

Fig. 6. Variation in the Absorption Coefficients at Point No Point and Pillar Point during the Year 1935.

Fig. 2 was constructed. The experiments reported here were conducted in the waters of the San Juan Archipelago in the late summer af 1935. A station was selected such that the depth of the water was approximately 40 meters.

With one of the filters between the cell and the window and with the window downward, the photometer, suspended by a cable, was lowered until the window was six inches beneath the surface of the water and the current measured. It was then lowered by 5 meter intervals as deep as the intensity of the upward scattered light could be accurately recorded. The photometer was next raised by the same 5 meter intervals and the current measurements repeated. The photometer was again suspended on the cable so that it was hanging vertically but this time with the window upward instead of downward as before. A similar series of measurements gave the relative intensity of the downward transmitted light at the same depths. These measurements were repeated for each of the filters and, at all times, simultaneous observations of the inntensity of the light incident upon the surface were made with the deck photometer, screened with the proper filter. The current measurements were made with a galvanometer which had a sensitivity of $98 \cdot 10^{-6}$ microamperes.

The relative intensities of the downward transmitted light and of the upward scattered light for each filter were plotted on a logarithmic scale and from these graphs the data for Table 4 were computed.

The intensity of the transmitted light and the intensity of the upward scattered light, at the different depths, was computed in terms of the 6 inch subsurface light and expressed as per cent. of that 6 inches below the surface. The values of the ratio of the scattered light to the transmitted light for each color are shown in Fig. 7.

The observations were made under very ideal conditions. There were no clouds in the sky and the intensity of the incident light was exceedingly constant during each series of measurements.

The comparison of scattered to transmitted light shows variations which, no doubt, are due to the nature of suspended matter and organisms in the water. The relatively low scattering of red light near the surface may be explained to some extent by the absence of organisms which are found at greater depths and which are known to reflect the longer wave lengths. It may also be explained, in part, by the fact that the longer wave lengths of the light transmitted through the red filter are absorbed largely near the surface.

Discussion of Results.

Since a thorough review of the literature has been made by Atkins and Poole and by Clarke and Oster, no detailed comparison of the work of other investigators will be presented in this paper.

There are certain possible sources of error to be considered in making submarine radiation measurements at sea. The shading caused by the ship might be considerable in the upper layers of water and can be lessened by having the photometer as far from the ship as possible with the ship away from the sun. The effect of the ship exists when observations are made with overcast skies. Many of the observations reported here were

Table 4.

Per cent. of transmitted and upward scattered Light of three spectral Bands.

Dept in Meters	λ = 4800 A Relative Intensity I	λ = 4800 A Log_e I	λ = 4800 A % of I at .15 m.	λ = 5300 A Relative Intensity I	λ = 5300 A Log_e I	λ = 5300 A % of I at .15 m.	λ = 6000 A Relative Intensity I	λ = 6000 A Log_e I	λ = 6000 A % of I at .15 m.
Downward traveling Light									
0.15	18500	9.83	100	72100	11.19	100	156000	11.96	100
5	6990	8.85	38	29300	10.29	41	15000	9.62	9.6
10	2620	7.87	14	11800	9.38	16	1980	7.59	1.3
15	992	6.90	5.4	4780	8.47	6.6	340	5.83	.22
20	372	5.92	2.0	1920	7.56	2.7	73.2	4.29	.047
25	141	4.95	0.76	781	6.66	1.1	19.9	2.99	.013
30	—	—	—	321	5.77	0.44	6.17	1.82	.0039
Upward traveling Light									
0.15	351	5.86	100	713	6.57	100	347	5.85	100
5	145	4.98	41	347	5.85	49	90.3	4.5	26
10	58.7	4.07	18	161	5.08	26	23.6	3.16	6.8
15	22.9	3.13	6.5	71.7	4.27	10	6.18	1.82	1.8
20	8.59	2.15	2.4	30	3.40	4.2	1.63	0.49	0.47
25	2.89	1.06	.82	12.1	2.49	1.7	—	—	—
30	0.91	—0.09	.26	4.81	1.57	0.67	—	—	—

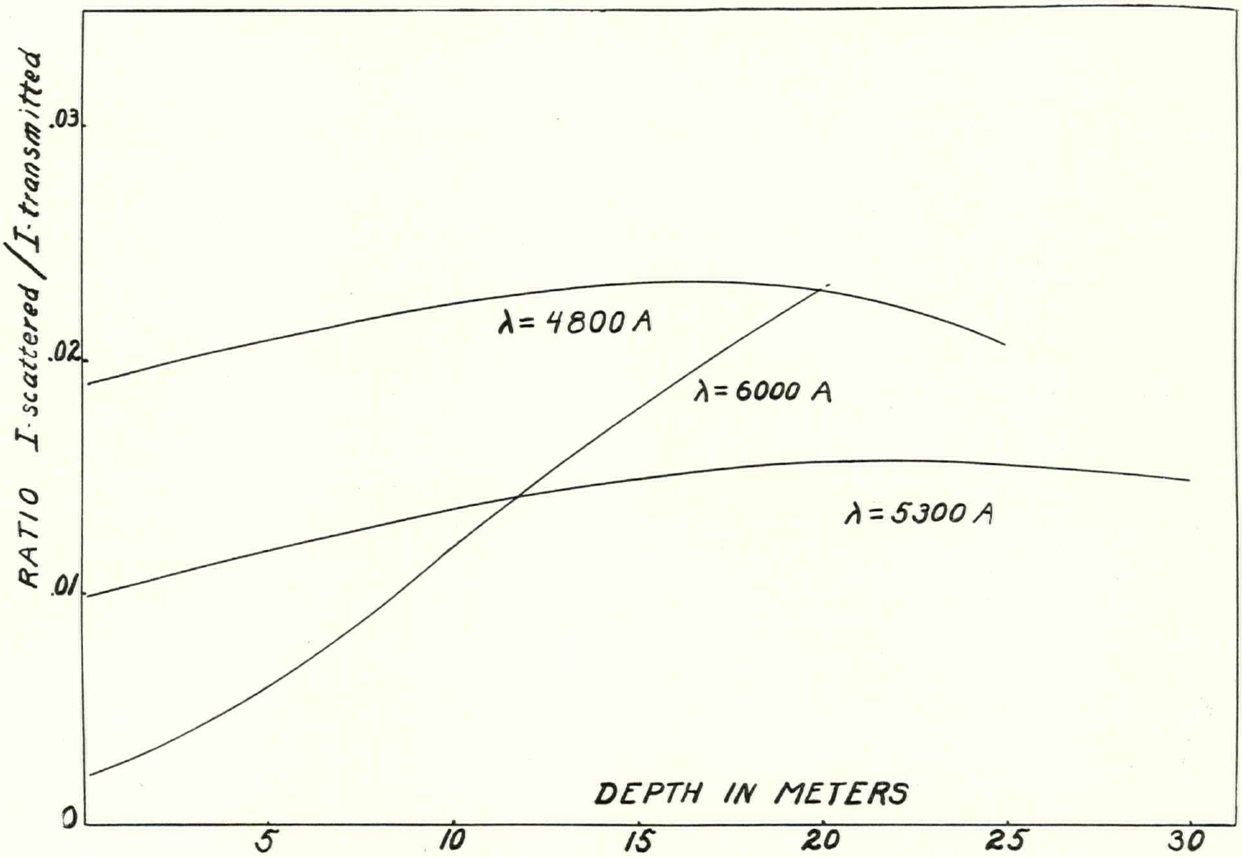

Fig. 7. Curves showing the Ratio of upward scattered Light to transmitted Light.

made when the incident light was well diffused and very constant, though of low intensity.

An error of considerable magnitude may be introduced by changing conditions in the water column above the photometer. This is especially serious in the inshore waters where tidal currents are experienced. It is, therefore, desirable to complete a series of observations in the shortest possible time, in order that the intensity of each color at the different depths may be determined under comparable conditions. Variations in surface reflections also afford a source of error. A large percentage of the observations reported here were made under ideal surface conditions. In the San Juan Archipelago, in Alaska and at times in the Pacific the surface was very smooth. When rough surfaces are encountered variations in the depth of the photometer due to the roll of the boat offer a source of uncertainty. This may be of considerable magnitude if the photometer is suspended a few meters out from the rail of the boat.

Since the extreme ends of the visible spectrum are more highly absorbed by water than the middle portion, there is a considerable variation in the spectral distribution of the light with depth and thus the values of absorption or scattering coefficients may depend greatly on the manner of making the measurements. The amount of energy transmitted through, or scattered by, a layer of water depends not only on the magnitude of the energy present, but on its spectral distribution and on the nature and amount of suspended matter in the water. Very different results will be obtained if the total energy is measured rather than the energy of narrow spectral bands.

Various statements are found in the literature suggesting some correlation between the abundance and distribution of plankton in the sea and the transmission of light, or a lack of such correlation. (Shelford and Gail; Atkins and Poole; Pettersson; Petterson, Höglund and Landberg; Clarke and Oster, etc.). Results of other investigators are matched by inconsistencies in our own data. It would appear obvious that the effect of plankton on light transmission would be a function not only of the amount of plankton present but also on its transmission and reflection characteristics. In certain cases, at least, the absorption attributed to plankton may be due to totally unrelated factors such as turbidity, etc.

In so far as the biological significance of submarine radiation is concerned two factors must be considered. First, the total illumination, both in character and intensity, is the effective factor in determining the growth and abundance of photosynthetic organisms. Second, the direction of the light as well as frequency and intensity is the effective factor in determining the distribution of those organisms whose movements are affected by subsurface radiation.

There are but little data available on the relative values of direct and scattered light. A very rapid examination of water bodies, repeated at regular intervals and including simultaneous observations of scattering and transmission of narrow spectral bands of radiation, will afford valuable information on the influence of light on growing organisms below the surface. An examination should, of course, include a simultaneous investigation of the number and kind of suspended particles and their optical characteristics with respect to the spectral distribution of the radiation at the depths where they are found.

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