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BEHAVIOR AND NATURAL REACTIONS OF THE NORTHERN ANCHOVY, *ENGRAULIS MORDAX* GIRARD, UNDER THE INFLUENCE OF LIGHT OF DIFFERENT WAVE LENGTHS AND INTENSITIES AND TOTAL DARKNESS

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I. INTRODUCTION

It has been known from times immemorial that certain fishes respond positively to artificial light and aggregate within illuminated zones. This peculiar behavior of fish has long been extensively exploited by fishermen. Torches and bonfires (still in use in some areas) were the first sources of artificial light for attracting the schools of fishes into nets and fish traps. With advancing technology, these light sources gave way to petrol and acetylene lamps and electricity, especially to the latter because of its applicability for underwater illumination (Verheijen, 1958). With underwater illumination possible, a new trend in commercial fishing has been developing since the end of World War II (Ellson, 1953), particularly in the Soviet Union

(Borisov, 1950; Borisov and Protasov, 1959; Leskutkin, Nikonorov and Patëev, 1955; Nikonorov, 1955, 1956, 1958, 1959a, 1959b; Terentiev, 1957). Instead of using conventional gear such as nets or traps, new, so-called "netless" fishing equipment has been introduced in certain fisheries. It consists of submerged electric lamps and the "fish pump." The fish attracted by the light at night are sucked into the pump funnel and pumped directly into the vessel's hold. In this technique, experiments have been made also to apply an electrical field within the illuminated zone so that the aggregated fish would be forced to swim toward the pump funnel, which is made the positive pole (Nikonorov and Patëev, 1959; Smith, 1955).

More and more species of fishes and other aquatic organisms have been reported in the literature as reacting positively to sources of artificial light under laboratory conditions or in the natural environments. Considerable research has been done on the structure and function of the fish eye (Baburina, 1955, 1958; Brett, 1959; Tamura, 1959; Vilter, 1950), on the ability of the fish to discriminate colors, and on innate preferential selectivity of monochromatic lights (Arora and Sperry, 1958; Breder, 1959; Bull, 1957; Kawamoto, 1959; Loukashkin and Grant, 1959), on the ability of fish to respond differently to different intensities of artificial light (Breder, 1959; Privolnev, 1956, 1958), and on many other specific problems related to fish behavior as it is affected by natural and artificial lights.

Out of the voluminous literature on the subject published in recent years and of special interest to the writers, only a few papers are selected and mentioned below. Borisov (1950) recorded 42 species and subspecies of fishes which responded positively to electric light. His list includes marine, anadromous and freshwater fishes found in the USSR; in 1955, he listed more than 60 forms. In 1954, Radovich and Gibbs reported 44 species of marine fishes from the waters of California and western Mexico which responded positively to electric light under natural conditions.[1] Baranov (1955) listed 17 species for the northwestern Pacific, and Parin (1958) mentioned 54 marine fishes collected at night light stations during oceanic exploration of the Pacific in 1954–55.[2]

Among pelagic fishes of commercial importance, the clupeids, or herring-like fishes, have been found the most responsive to artificial light, and

[1] Since the date of Radovich and Gibbs' report (1954), many more species of the fishes from the same area have been found to respond positively to electric light in the open sea (a continuously expanding unpublished list has been maintained by the California State Fisheries Laboratory at Terminal Island). While on research cruises of the California Fish and Game M/V *Alaska* in Mexican territorial waters in 1958 and 1961, the senior author recorded 20 species as supplementary to Radovich and Gibbs' list of 1954. These fishes are as follows: *Astroscopus zephyreus*, *Auxis* sp., *Carcharhinus lamiella*, *Cetengraulis mysticetus*, *Chloroscombrus orqueta*, *Cynoscion parvipinnis*, *Harengula thrissina*, *Menidia starksi*, *Mugil cephalus*, *Mugil* sp., *Nectarges nepenthe*, *Oligoplites* sp., *Polynemus* sp., *Pseudophallus starksii*, *Raja* sp., *Sphyraena* sp., *Sphyrna zygaena*, *Synodus lucioceps*, *Trachurops crumenophthalmus*, and *Upeneus* sp.

[2] A complete list of the fishes collected at night light stations by Parin in the Pacific Ocean during the 1954–1960 oceanological expeditions aboard the research vessel *Vitiaz* will be published by him and is in press.

most of the references herein cited refer to this family. Species displaying a strong positive taxis to artificial light, readily aggregating in masses within illuminated zones, are as follows: sardines—*Sardinops caerulea* (Radovich and Gibbs, 1954; Rasalon, 1959), *Sardinops sagax melanosticta* (Borisov, 1955; Yudovich and Kolegov, 1956), *Sardina pilchardus sardina* (Verheijen, 1957, 1958; Nikonorov, 1959), *Sardinella macrophthalma* (Breder, 1959), *Sardinella aurita* (Verheijen, 1958); herrings—*Clupea pallasii* (Gristchenko, 1951; Radovich and Gibbs, 1954; Baranov, 1955; Borisov, 1955; Nikolaev, 1957), *Clupea harengus harengus* (Craig and Baxter, 1952; Borisov, 1955; Blaxter and Parrish, 1958; Radakov and Soloviev, 1959; Tihonov, 1959; Zaitsev and Azhazha, 1959), *Clupea harengus membras* (Borisov, 1950, 1955); Caspian shads—*Alosa brashnikovi brashnikovi, Alosa brashnikovi agrachanica, Alosa caspia caspia, Alosa kessleri kessleri,* and *Alosa kessleri volgensis* (Borisov, 1955; Chugunova, 1955); Caspian sprats "kil'ka"—*Clupeonella delicatula caspia, Clupeonella engrauliformis,* and *Clupeonella grimmi* (Eremtstov and Nikonova, 1949; Tokarev, 1949; Borisov, 1950, 1955; Bondarenko, 1951; Prihodko, 1951, 1957a, b; Leskutkin and Prihodko, 1951; Safronov, 1952; Evtëev, 1953; Leskutkin, Nikonorov and Patëev, 1955; Lovetskaya, 1955, 1958; Nikonorov, 1955, 1956a, b, 1958, 1959a, b; Chugunova, 1955; Terentiev, 1957; Borisov and Protasov, 1959); sprats—*Sprattus sprattus sprattus* (Blaxter and Parrish, 1958), *Sprattus sprattus balticus,* and *Sprattus sprattus phalericus* (Borisov, 1950, 1955); Pacific round herring—*Etrumeus acuminatus* (Radovich and Gibbs, 1954); Pacific thread herring—*Opisthonema libertate* (Radovich and Gibbs, 1954); Atlantic dwarf herring—*Jenkinsia lamprotaenia* (Breder, 1959); and zunasi herring—*Harengula zunasi* (Sasaki, 1959).

Among other commercially important pelagic fishes which are known to respond strongly to artificial light are the following: anchovies—*Engraulis mordax, Anchoa delicatissima,* and *Anchoa compressa* (Radovich and Gibbs, 1954), *Engraulis japonica* (Borisov, 1950, 1955; Baranov, 1955; Parin, 1958), *Engraulis encrasicholus* (Verheijen, 1958), *Engraulis encrasicholus pontica* and *Engraulis encrasicholus maeotica* (Borisov, 1950, 1955; Safianova, 1952, 1958; Kirillov, 1955; Radakov, 1956); mackerels—*Scomber scombrus* (Blaxter and Parrish, 1958), *Pneumatophorus diego* (Radovich and Gibbs, 1954), and *Pneumatophorus japonicus* (Borisov, 1950, 1955; Baranov, 1955; Parin, 1958) jack-mackerels or horse-mackerels—*Trachurus symmetricus* (Radovich and Gibbs, 1954), *Trachurus japonicus* (Parin, 1958, Sasaki, 1959), and *Trachurus trachurus* (Borisov, 1950, 1955; Safianova, 1952, 1958; Radakov, 1956; Protasov, 1957; Blaxter and Parrish, 1958; Borisov and Protasov, 1959); saury—*Cololabis saira* (Pochekaev, 1949; Radovich and Gibbs, 1954; Baranov, 1955; Borisov, 1955; Yudovich, 1956; Parin, 1956, 1958; Gristchenko, 1957; Pokrovsky, 1957; Fukuhara, 1959); tunas—

Neothunnus macropterus and *Euthynnus yaito* (Hsiao, 1952; Tester, 1959); cod-like fishes—*Gadus morhua morhua* (Borisov, 1950, 1955; Lagunov, 1955), *Gadus morhua macrocephalus* (Baranov, 1955), *Melanogrammus aeglefinus, Odontogadus merlangus euxinus,* and *Boreogadus saida* (Borisov, 1955).[3] The behavioral studies conducted at the California Academy of Sciences have been confined to four species of marine pelagic fishes: Pacific sardine, *Sardinops caerulea* (Girard); northern anchovy, *Engraulis mordax* Girard; Pacific mackerel, *Pneumatophorus diego* (Ayres); and Pacific jack mackerel, *Trachurus symmetricus* (Ayres). The behavior and reactions of the sardine under the influence of white and colored lights and darkness have already been explored (Loukashkin and Grant, 1959). The present paper sums up the results of the study of the behavior and reactions of the northern anchovy stimulated by artificial light of different wave lengths and intensities and by darkness. In essence, it is a continuation of the earlier experimental work on sardines. The equipment, facilities, and methods (fig. 1) used in the laboratory experiments for the larger part of the study were exactly the same as described earlier for the sardine; therefore, to avoid unnecessary repetition the reader is referred to that report. However,

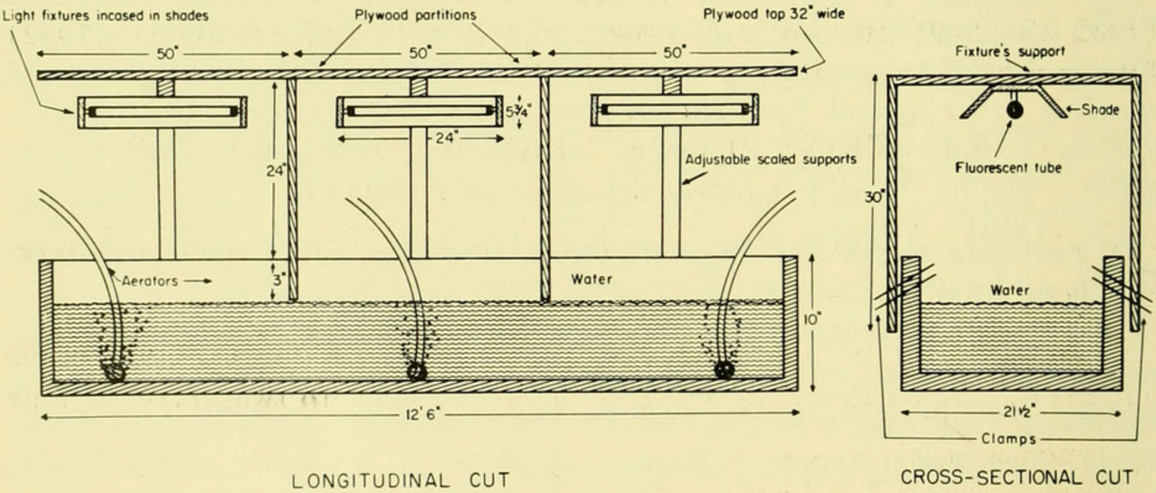


Figure 1. Sketch drawing of the experimental tank divided into three light zones for testing the anchovy's ability to discriminate colors of the light and intensities of white light. (After Loukashkin and Grant, 1959.)

changes in technique or equipment are noted and full information is presented in appropriate sections below.

For measuring light intensities, a Weston Illumination Meter, model 756, was used. This model is visual and cosine corrected, with direct dial read-

[3] The size of the present report excludes the possibility of listing all the other marine and freshwater fishes whose phototactic responses to artificial light have been tested in recent years. Readers interested in this subject will find more information in the accounts by Baranov (1955), Blaxter and Parrish (1958), Borisov (1950, 1955), Parin (1958), Pochekaev (1949), Privolnev (1958), Protasov (1957, 1958), Radovich and Gibbs (1954), Sasaki (1959), and especially in the Verheijen report (1958) in which a review of the literature on fish responses to light is included.

ings on the scales ranging from 0 to 500 foot-candles. The illumination meter was manufactured by the Weston Electrical Instrument Corporation of Newark, New Jersey.

This account is based on the experiments carried out on two large schools of adult anchovies kept in the display tanks of the Steinhart Aquarium, California Academy of Sciences, at different times (approximately two years apart). The majority of the experiments were devoted to the investigation of the ability of the anchovy to discriminate the same monochromatic lights, white light and darkness, which had been successfully applied in the experiments with the Pacific sardine (fig. 2). The second portion of the study involved the use of ultraviolet and infrared wave lengths and observations on the reactions of the anchovy to different intensities of the white light. As with the stock of the Pacific sardine used in earlier experiments, the northern anchovy schools were kept in a 1,000-gallon display tank illuminated with an ordinary 300-watt incandescent lamp which was suspended two feet above the water surface. Therefore, the fish used in the study can be considered "light-adapted" animals.

The scientific names of most of the fishes mentioned in the text are based on Roedel (1953) for the California and Mexican species, and on Berg (1932–33, 1949), Borisov and Ovsiannikov (1951), and Svetovidov (1952) for the fishes of the USSR.

II. REACTIONS OF NORTHERN ANCHOVY TO LIGHT WAVE LENGTHS AND INTENSITIES

(1) Preferential reactions to monochromatic lights, white light, and darkness.

The ability of the anchovy to react differently to different light wave lengths was tested in a tank which could be divided into two, three, or four

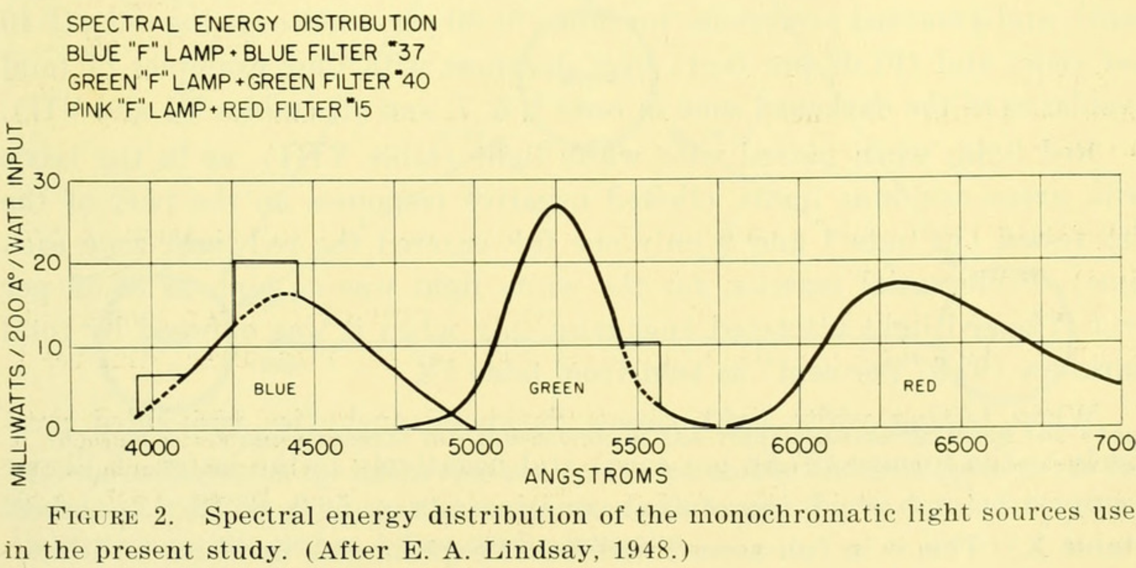


Figure 2. Spectral energy distribution of the monochromatic light sources used in the present study. (After E. A. Lindsay, 1948.)

zones and equipped with electric light sources of contrasting illumination. Results of the experiments of two-zone tests are presented in tables I–XI, those of the three-zone tests in tables XII and XIV, and of the four-zone tests in table XIII. In the two-zone tests different groups of six fish were subjected to the effect of a given pair of lights or of light and darkness. Each combination was used in two experiments consisting of six tests with 100 recorded observations, totalling 7,200 fish. Altogether, 79,200 fish are grouped in eleven tables for comparison of natural preference reactions to one type of illumination, or another. In testing the ability of the anchovy to distinguish green light from other colors, it was found that when this light was paired with white light, 5,424 fish out of 7,200 moved to or remained in the green-light zone, displaying definite preference for this light (74.34 per cent) over the white light (24.66 per cent), as seen from table I. When green and red lights were paired, this preference for green light rose to 97.86 per cent. The highest degree of negative reactions to red light in tests 2, 6, and 12 was manifested by total avoidance of the red light zone, as shown in table II. When green light was presented along with blue light, anchovies were able to differentiate these two lights in contrast to the Pacific sardine, which was unable to do so (Loukashkin and Grant, 1959). As seen from table III, anchovies reacted preferentially to green light; 73.18 per cent of the individuals which were tested selected the "green zone," compared to 26.82 per cent which showed preference for the "blue zone." When paired with a darkened zone, the green-light zone was frequented by 6,918 fish (96.08 per cent), while only 282 (3.92 per cent) made occasional movements of short duration into the darkened zone. In tests 1 and 5, avoidance of the darkened zone was total (table IV).

When testing the blue light paired with white light or red light or darkness, fish responded favorably to the blue light. Table V shows a slight preference for blue (52.15 per cent) over the white light (47.85 per cent), and a marked preference for blue (81.60 per cent) over the red (18.40 per cent) and (97.03 per cent) over darkness with four examples of total avoidance of the darkened zone in tests 1, 6, 7, and 12 (tables VI and VII).

Red light, when paired with white light (table VIII), as in the trials with green and blue lights, elicited negative responses on the part of the fish tested (in tests 1 and 9 only one fish entered the red light zone each time). Preferential reaction for the white light was as high as 88.39 per cent. The red light attracted anchovies only when it was opposed by total darkness (92.97 per cent) as seen from table IX.

When testing white light versus darkness, anchovies responded positively to the former (97.88 per cent) and negatively to the latter (2.12 per cent) with total avoidance of that zone in tests, 4, 5, 6, 8, 10, 11, and 12 (table X). This is in full accord with other experiments in which an illuminated zone was presented with the darkened one (tables IV, VII, and IX).

Diagrammatic interpretation of the relationship in the effects of different lights on the anchovy's discriminating ability tested in pairs is shown in figure 3.

To evaluate the significance of the apparent preference responses of the fish to monochromatic lights, the same groups of anchovies, either before or after experiment, were kept in a two-zone tank under a white light of the same intensity. The results obtained are presented in table XI, and they clearly display a normal distribution of 7,200 fish very close to a 50:50 ratio; however, the relationship varied from test to test. The average distribution of anchovies for 12 tests was found to be 50.06 per cent for one zone, and 49.94 per cent for the other. These tests were considered as controls.

After completing the series of experiments in a two-zone tank, anchovies were subjected to experiments in three-zone and four-zone tanks. In these experiments light intensities were maintained at a uniform level for all lights as in the two-zone experiments, or they were presented in different values. The latter modification was intended to see if the increment in light intensity would elicit a change in response because of brightness of illumination regardless of the color of light. The results of these experiments are presented in tables XII and XIII. The first four experiments in a three-

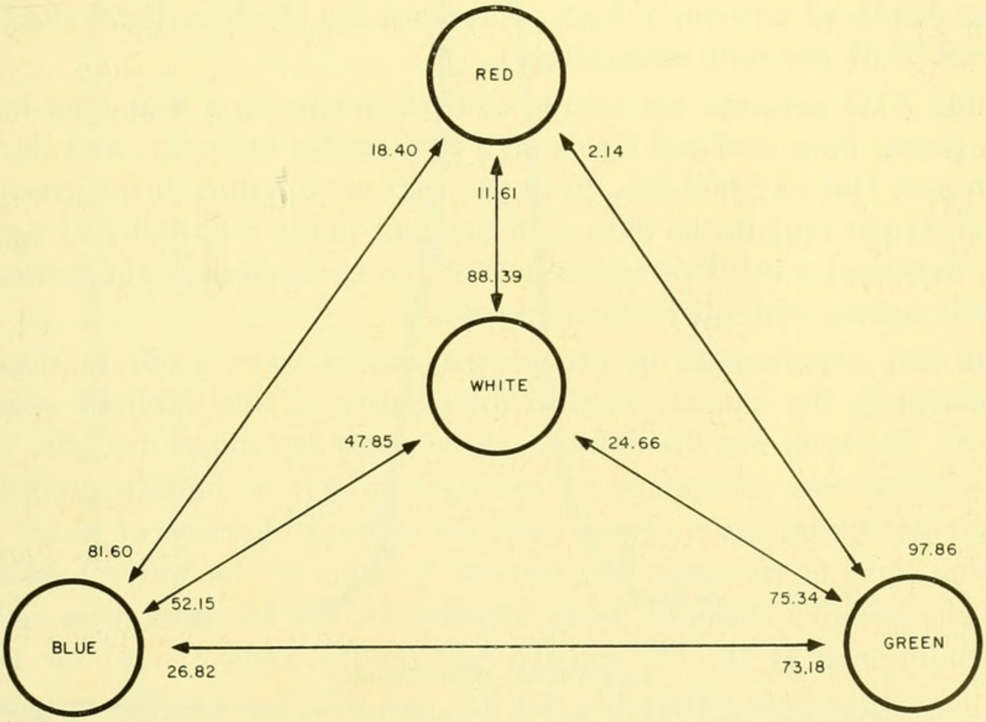


FIGURE 3. Diagrammatic interpretation of the relationships between the effects of different lights on the anchovy's discriminating ability tested in pairs in the two-zone tank. Positive and negative reactions are expressed in per cent. All sources of light were maintained at 9 foot-candle intensity.

zone tank illuminated with white, green, and red lights, regardless of variation in intensities, demonstrated overwhelming preference of the anchovies for the green light. The positive preference responses in these experiments for the green light averaged as high as 66.33 per cent (14,400 fish), though in separate cases this preference varied from 56.0 per cent to 72.0 per cent. Negative responses to the other two lights were as follow: 19.63 per cent for white light and 14.04 per cent for red light. These results are in full agreement with those obtained for the green light when tested in pairs with the others in a two-zone tank. In experiment WGD (table XII) the intensity of the green light was reduced to 6 foot-candles, while the white-light intensity was increased up to 30 foot-candles. The third zone was darkened. Again, anchovies responded in favor of the green light (69.33 per cent). In another experiment RDW (table XII) red and white lights were presented in intensities of 30 foot-candles with the middle zone darkened. As anticipated, the white-light zone was frequented most of all (50.34 per cent), and red-light zone least of all (19.33 per cent). The reason why more fish were found in the darkened zone than in the red-light zone may have been that the white light penetrated the darkened zone. In other experiments, DBR-1 and DBR-2 (table XIII), the blue and red lights were applied, the third zone having been darkened. In both experiments with uniform intensities of 9 foot-candles and with contrasting intensities (4 foot-candles for the blue light, and 30 foot-candles for the red light) anchovies displayed extremely high preference for the blue light (93.16 per cent and 98.67 per cent respectively).

Table XIII presents the results of experiments in a four-zone tank in which green, blue, and red lights of 9 foot-candle intensity, and darkness were tested. Out of 9,600 fish, 80.19 per cent were found in the green-light zone, 15.34 per cent in the blue, 2.56 per cent in the red, and 1.91 per cent in the darkened zone. This preference of the anchovies for the green light perfectly agrees with all previous results.

The last experiments in the present series were made to duplicate approximately the natural vertical distribution of the sunlight spectrum in water. The tank was divided into three zones as follow: daylight (white light with normal percentage of red light in it)[4] to imitate surface and near-surface illumination; green light for a deeper horizon of water mass; and blue light to represent the deepest horizon of the water medium in which the anchovy is found. In experiment DGB-1 the intensities of lights were maintained at 16, 7.8, and 0.5 foot-candles respectively; for DGB-2 these intensities were reduced to 6.0, 3.0, and 0.25 foot-candles respectively (table XIV). The results of 12 tests with a group of nine anchovies in each of the two experiments show the same preferential tendency of the fish

[4] General Electric 20-watt "Daylight" fluorescent tube 24 inches long, ordering symbol F20T12/D.

toward the green light as in all other experiments in which various combinations of monochromatic and white lights were applied. This preference for the green light was found to be 48.57 per cent, in the experiment DGB-1, and 44.79 per cent in DGB-2 compared to 30.01 per cent and 30.24 per cent respectively for the daylight and 21.42 per cent and 25.40 per cent for the blue light.

(2) Responses to ultraviolet wave length.

In this series of experiments, low and high intensity sources of ultraviolet radiation were used. In the first set of experiments a "black light" 20-watt fluorescent tube (24 inches long) manufactured by the General Electric Company (trade symbol F20T12/BLB) was used. Its spectrographic characteristics are shown by the curve in figure 4, from which it is seen that this lamp emits a certain amount of visible light, too. This source

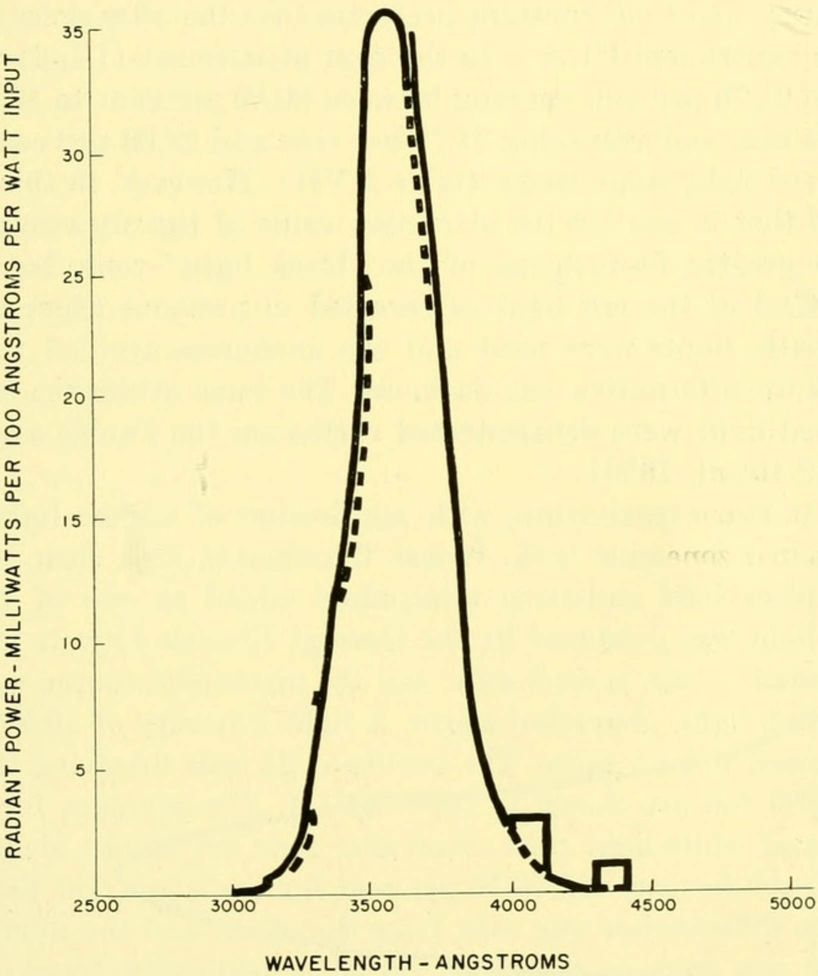


Figure 4. Spectral energy distribution of the "Black Light Integral Filter Fluorescent Lamp" manufactured by the General Electric Company. Official drawing on file with the Company based on 40-watt lamp is reproduced here with written permission of the manufacturer. The curve is also typical for the 20-watt lamp (F20T12/BLB) used in the present study.

of ultraviolet radiation was first tested paired with monochromatic lights, using the same colored fluorescent tubes and filters as in the preceding series. Because of the extremely low intensity of the "black light," the other lamps were masked to reduce the intensity of colored lights to the level of the former, which was as low as 0.2 foot-candle. The results of six experiments covering the distribution of 57,600 fish are tabulated in tables XV–XVII.

Paired with blue light, the ultraviolet wave length had no specific effect upon behavior of the anchovies. The average figures show a 50:50 distribution ratio (table XV). The ultraviolet-green combination revealed slight preferential reactions toward the green light (54.79 per cent). This tendency was observed in all of the 24 tests (table XVI), while in ultraviolet-blue combination fish responses varied considerably from test to test, especially in experiment UL-1.

In experiments using ultraviolet light and red light, anchovies at first displayed very slight but constant preference for the ultraviolet zone (52.25 per cent in experiment UL-5.). In the next experiment (UL-6) this preference rose to 91.70 per cent varying between 80.50 per cent to 100.0 per cent from test to test, and averaging 71.79 per cent and 28.03 per cent for ultraviolet and red light respectively (table XVII). However, in this case it can be assumed that it was not the attractive value of the ultraviolet rays that resulted in greater frequenting of the "black light" zone, but rather the repelling effect of the red light as revealed in previous experiments when monochromatic lights were used and the anchovies avoided the red-light zone unless the alternative was darkness. The same avoidance reactions toward the red light were demonstrated earlier on the Pacific sardine (Loukashkin and Grant, 1959).

The next two experiments, with application of higher light intensity, were made in a two-zone tank. It was illuminated with clear light, and a source of ultraviolet radiation alternately added to one of these zones. The white light was produced by the General Electric 15-watt incandescent lamp ("frosted"), one in each zone, and the ultraviolet source was the same 20-watt "black light" described above. A light intensity of 10.5 foot-candles was maintained in both zones. The results of 24 tests involving the distribution of 19,200 fish are shown in table XVIII. The averages for the white-light zone and white-light plus ultraviolet zone are almost identical: 49.84 per cent for the former, and 50.16 per cent for the latter. The fish seemed to be unable to differentiate one zone from the other, and the numbers of fish frequenting one zone or the other varied considerably from test to test, especially in experiment UL-7.

Following this, an ultraviolet source of very high intensity was tested. For this purpose a "New Black-Ray Model B-100 (3660Å)" equipped with 100-watt mercury spotlight bulb, ballast, and ultraviolet-transmitting Kopp

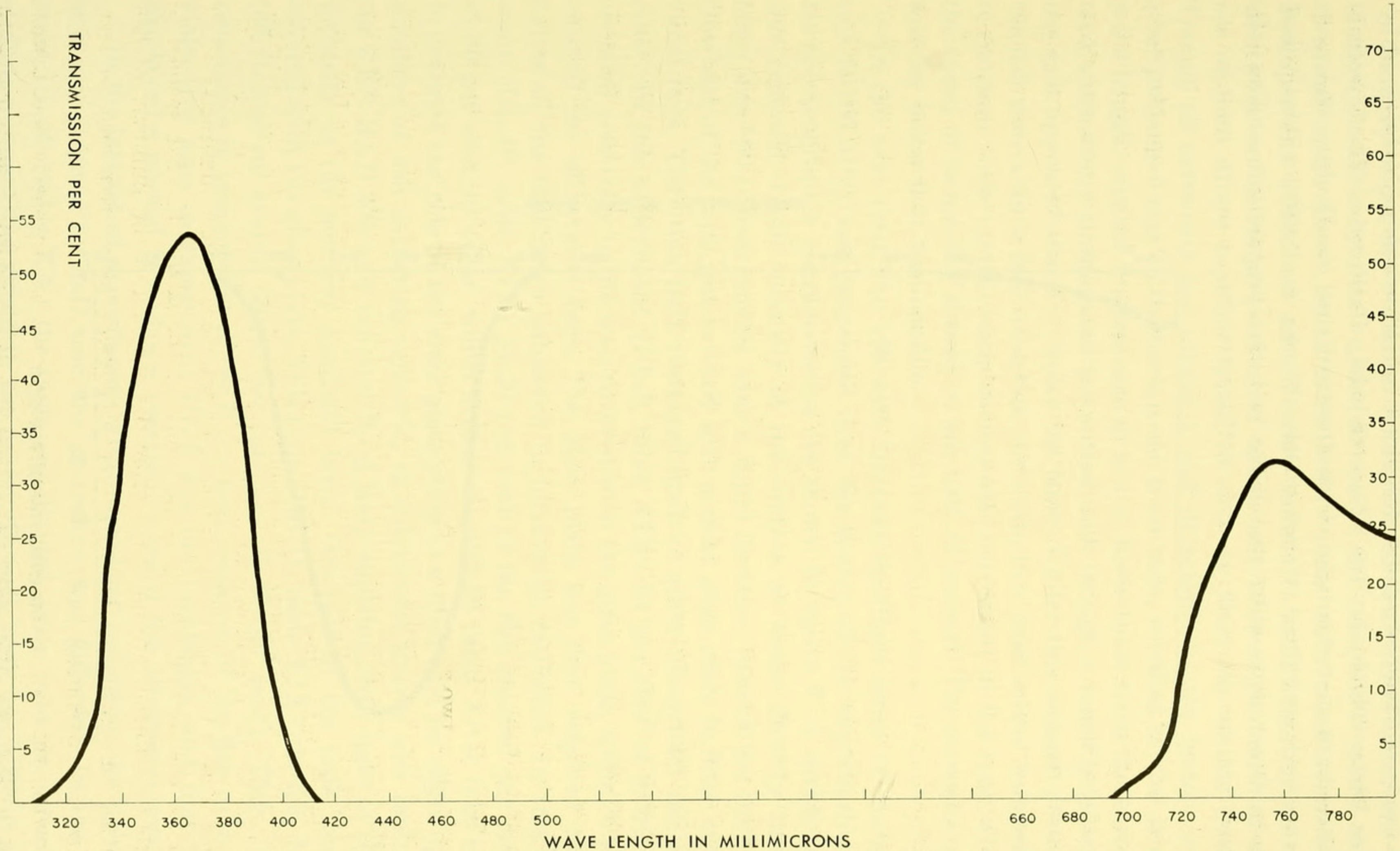


FIGURE 5. Spectral properties of the ultraviolet transmitting filter "Kopp no. 41" as used on the "New Black-Ray Model B-100 (3660Å)" lamp manufactured by the Ultra-Violet Products, Inc., San Gabriel, California. Courtesy of the manufacturer.

41 filter was used. This source of ultraviolet radiation was manufactured by the Ultra-Violet Products, Inc., San Gabriel, California. The spectral-energy distribution of this lamp, with filter attached, is shown in figure 5. In addition, an extra filter (Corning Glass Works, no. 5840) was acquired in order to filter out most of the visible rays. Its properties are shown in figure 6.

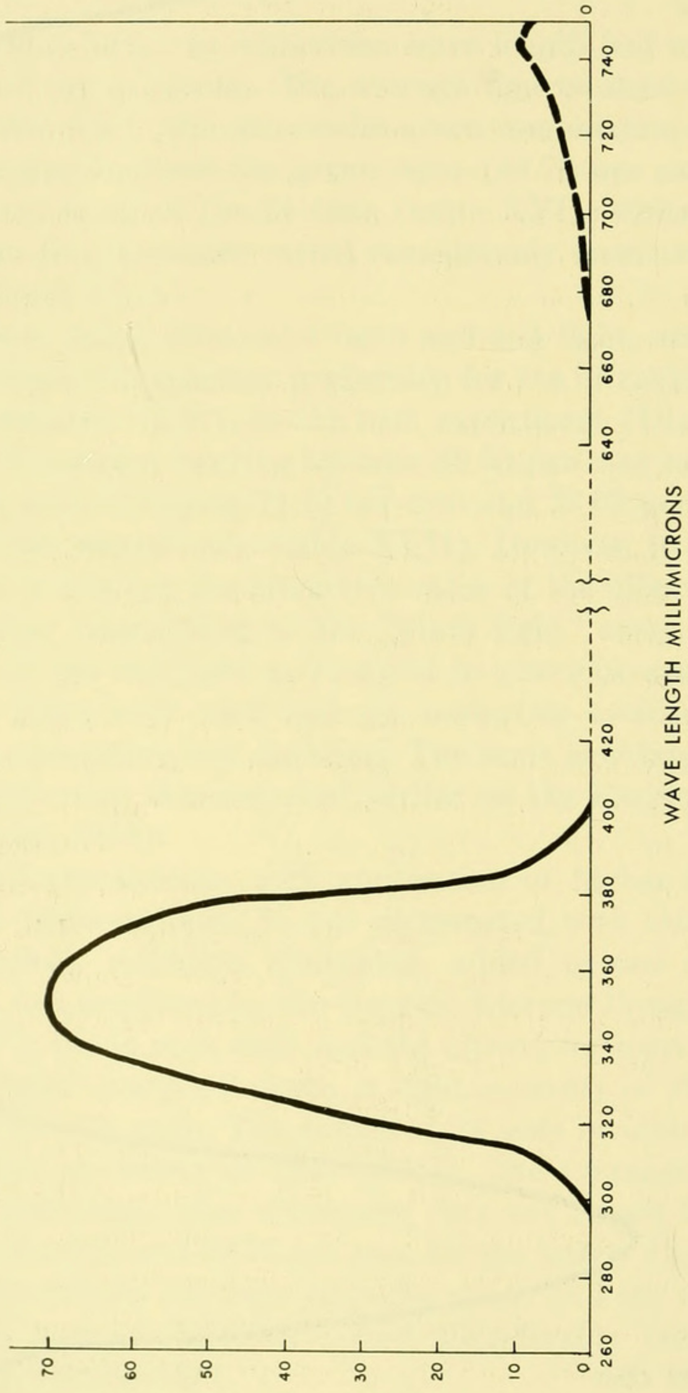


FIGURE 6. Spectral properties of the ultraviolet-transmitting filter no. 5840 (7–60) of the Corning Glass Works. Courtesy of the manufacturer.

At first, attempts were made to test the effect of ultraviolet wave lengths in total darkness by placing this source in one zone and keeping the other zone darkened. These, as all other tests herein reported, were carried out in a specially built dark room in the Steinhart Aquarium. Despite all possible efforts, the investigators had to abandon this experiment because the use of both filters together failed to entirely filter out visible light rays. Though of extremely low intensity and detectable by the human eye only after prolonged stay in the dark room, these rays, fortified by the ultraviolet wave length, created fluorescence in water. Reflections from the bottom and tank sides dimly illuminated the entire tank though a much brighter glowing spot appeared directly under the lamp. Under this meager illumination the fish were able to still orientate and swim in a loose school formation and to continue their typical counter-clockwise movement in the tank. However, the speed of swimming slowed to one-half of normal. The intensity of light was far below 0.01 foot-candle.

In the next trial, the 100-watt mercury spotlight lamp (General Electric H-100-SP4) was suspended over the center of the experimental tank. Its spectrographic characteristics are shown in figure 7. A dividing shield was removed. Light intensity at the surface of water directly under the lamp was 500+ foot-candles with a rapid decrease toward the tank's ends. One-half of the tank was covered with a clear glass plate to filter out ultraviolet rays. The other half remained open to allow ultraviolet radiation to enter. In this experiment (UL-9, table XIX) 64 per cent of 8,000 fish responded positively to the zone covered with the glass plate, while 36 per cent entered the ultraviolet zone. The glass plate was then removed and both halves of the tank were subjected to ultraviolet radiation. In this experiment (UL-10, table XIX) 52.20 per cent of the fish entered one zone, and 47.80 per cent the other, which is close to a 50:50 ratio. After this, in order to evaluate the role of the clear-glass plate as a filter and its effect upon the numbers of fish gathering under it, an ultraviolet source was replaced by the KEN-RAD 300-watt reflector flood lamp emitting clear light of the same intensity as the mercury spotlight lamp. One-half of the tank was again covered with the glass plate. This time (UL-11, table XIX) the fish distributed themselves evenly (50.45 per cent and 49.55 per cent). Thus, it seems reasonable to assume that the 64.0 per cent response of the fish to the ultraviolet-free zone in experiment UL-9 was not incidental, and that the fish displayed a normal "avoidance reaction" toward the ultraviolet zone.

In the last set of experiments with ultraviolet radiation, the light intensity was reduced by half, and the procedure was different. In the experiment UL-12 (table XX) the tank was divided again into two zones by installing a separating shield in the center. In each zone one KEN-RAD 300-watt reflector flood lamp emitting white light of 225 foot-candle intensity

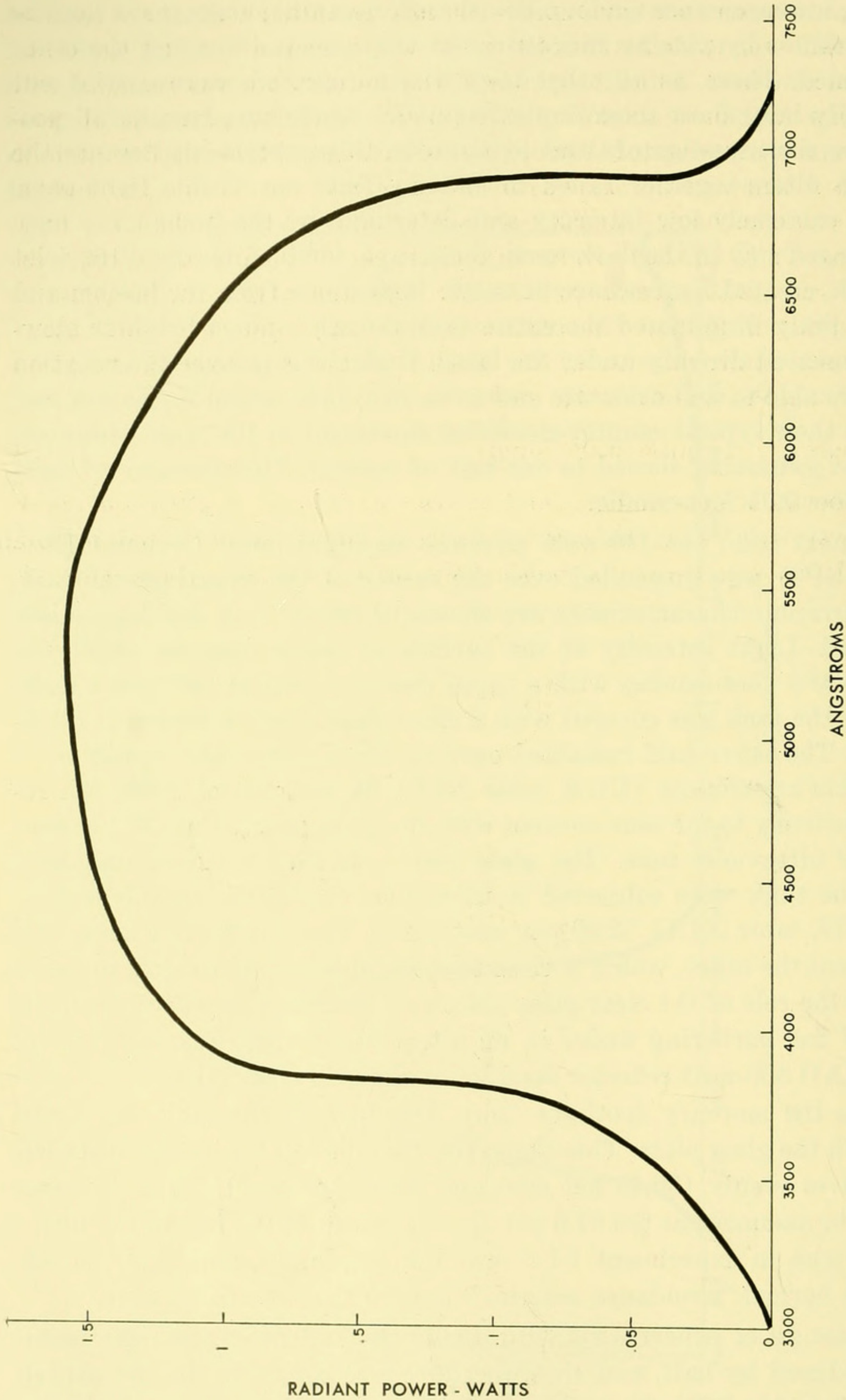


Figure 7. Spectral energy distribution of the General Electric 100-watt mercury reflector spotlight lamp (near-ultraviolet region of the spectrum) No. H-100-SP4 (Black Light) based on the data published by the manufacturer. [The pamphlet "Mercury Lamps and Transformers," LS-103, second printing, dated January 1958.] Courtesy of the General Electric Company.

was installed. In ten tests involving 6,000 fish, as anticipated, there resulted a more or less even distribution of fish (48.47 per cent and 51.53 per cent). In experiment UL-13 (table XX), one of the white lights was replaced with 100-watt mercury spotlight lamp (ultraviolet), and the positions of these two sources were alternated during the experiment. The intensity of light in both zones remained the same as in the previous experiment. Throughout all ten tests, the anchovies consistently preferred the white-light zone. Their responses for the white-light zone varied between 60.0 per cent to 100.0 per cent from test to test, averaging 72.1 per cent and displaying negative or avoidance reaction toward the ultraviolet zone (27.9 per cent) once again. Diagrammatic interpretation of the anchovy reactions toward the ultraviolet wave length is shown in figure 8.

(3) Responses to infrared wave length.

In this series of experiments the first tests were made in a two-zone tank; one zone was exposed to infrared radiation, the other remained in total darkness. Instead of being six inches deep, as in all other experiments, the

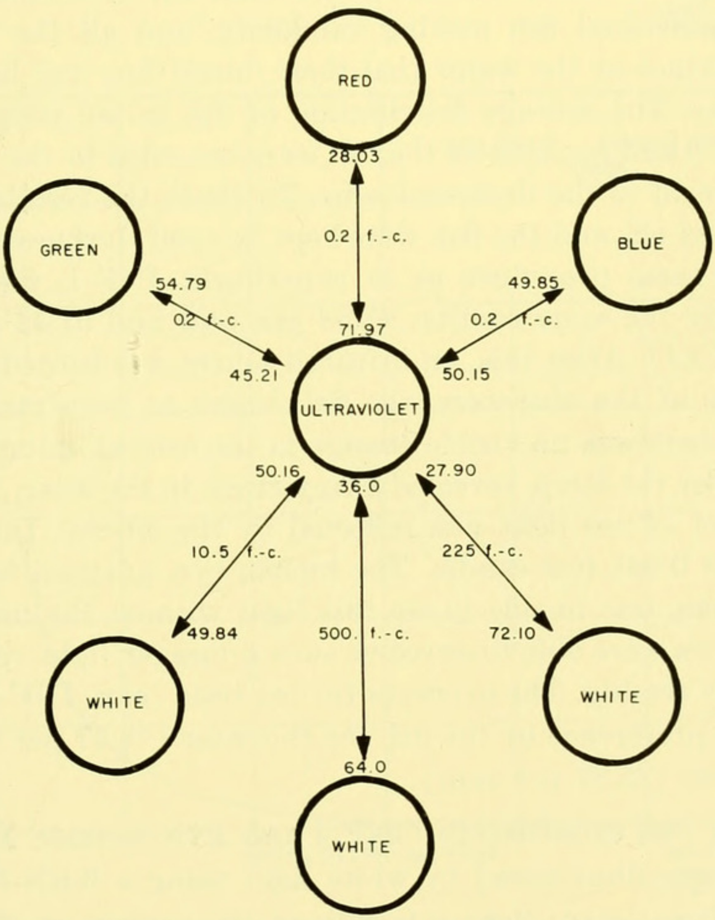
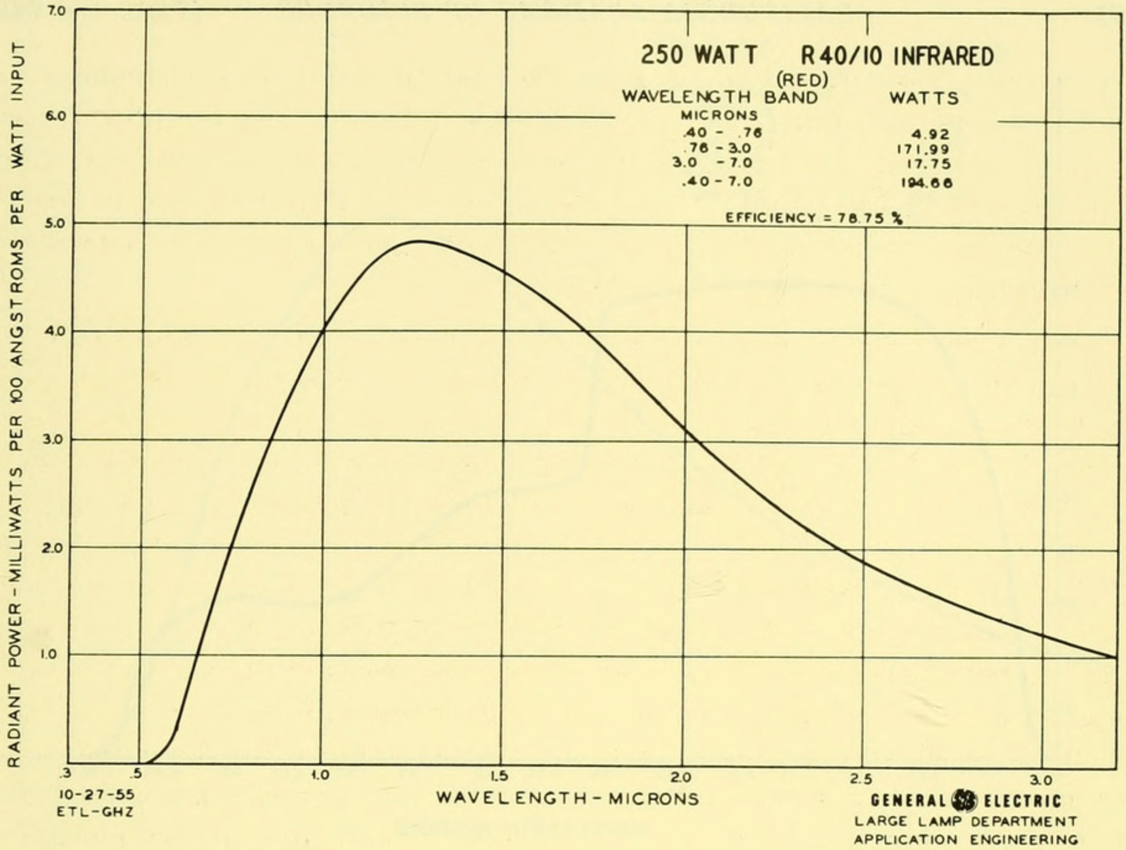


Figure 8. Diagrammatic interpretation of the anchovy's reactions toward the ultraviolet wave length in relation to opposing monochromatic and white lights. Positive and negative reactions are expressed in per cent.

water level was lowered to three inches and the lamp was suspended six inches above its surface. A G.E. 250-watt reflector heat lamp with red coating provided the source of the infrared radiation (its spectrographic features are shown in figure 9). A Corning filter no. 2540 was used to absorb all visible rays, transmitting infrared rays alone. Figure 10 shows the spectrographic properties of this filter.

Eight anchovies were placed in an experimental tank two hours prior to testing and were kept there in total darkness. A recording of fish distribution was made every ten minutes with the aid of dimmed ruby-red flashlight; this operation required not more than two or three seconds and only the fish in one zone were counted at a time. Altogether ten tests each of 30 recorded observations were made covering the distribution of 2,400 fish. The results of experiment INF-1 are shown in table XXI. From the very start, it was clearly evident that the fish did not respond to infrared radiation. In both darkened and infrared zones, they behaved in exactly the same manner as did the Pacific sardine in total darkness (Loukashkin and Grant, 1959). The school was broken up; fish were scattered throughout the tank; swimming speed was slowed almost to a "stand still"; orientation was completely lost, individual fish moving randomly, and all the fish moved so close to the surface of the water that their dorsal fins and backs projected above the water. The average distribution of fish in ten tests was found to be about even: 51.33 per cent of the fish were recorded in the infrared zone, and 48.67 per cent in the darkened zone. To check the results, the infrared lamp was turned off, and the fish were kept in total darkness in both zones. Following the same procedure as in experiment INF-1, the investigators obtained exactly the same results: 48.58 per cent and 51.42 per cent (exp. INF-2, table XXI). After this, an infrared source was turned on again, and to the surprise of the observers, the fish began to concentrate under the lamp, though there was no visible change in the over-all situation. The mirror, placed under the lamp, revealed a tiny crack in the filter, through which just a pin point of red light was reflected by the mirror. Intensity of this light was about 0.001 foot-candle. The human eye, adapted to the darkness of the dark room, was unable to see this light without the use of a mirror, but the anchovies were able to perceive such a meager light value and to respond to it very readily. The averages for ten tests (exp. INF-3, table XXI) show a definite preference by the fish for this zone (74.17 per cent) over the zone of darkness (25.83 per cent).

In the next two experiments (INF-4 and INF-5, table XXII), one of the two zones was illuminated by white light using a KEN-RAD 300-watt reflector floodlight lamp; light intensity at the surface of the water measured 500 foot-candles. The other zone was illuminated with a G.E. 250-watt reflector heat lamp without red coating, which emitted both white light and



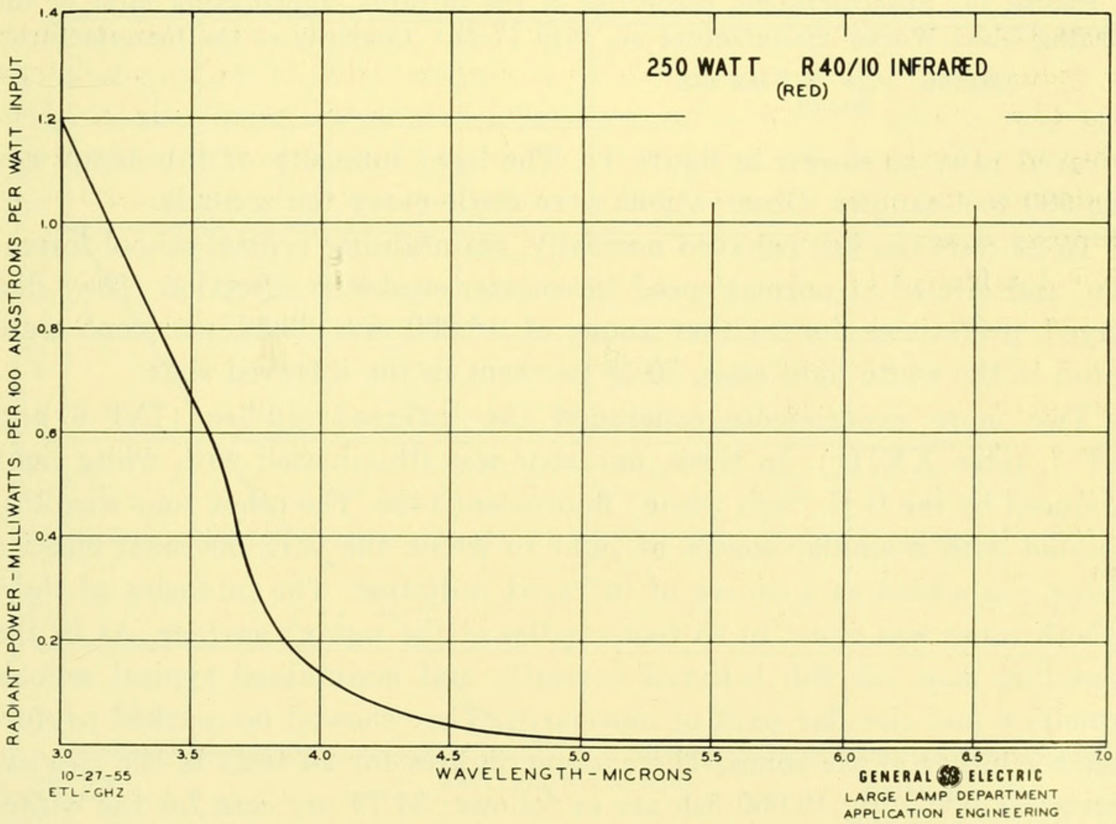


FIGURE 9. Spectral energy distribution of the 250-watt reflector heat lamp with red coating (infrared) manufactured by the General Electric Company. These graphs are official manufacturer's copies reproduced here with the Company's written permission.

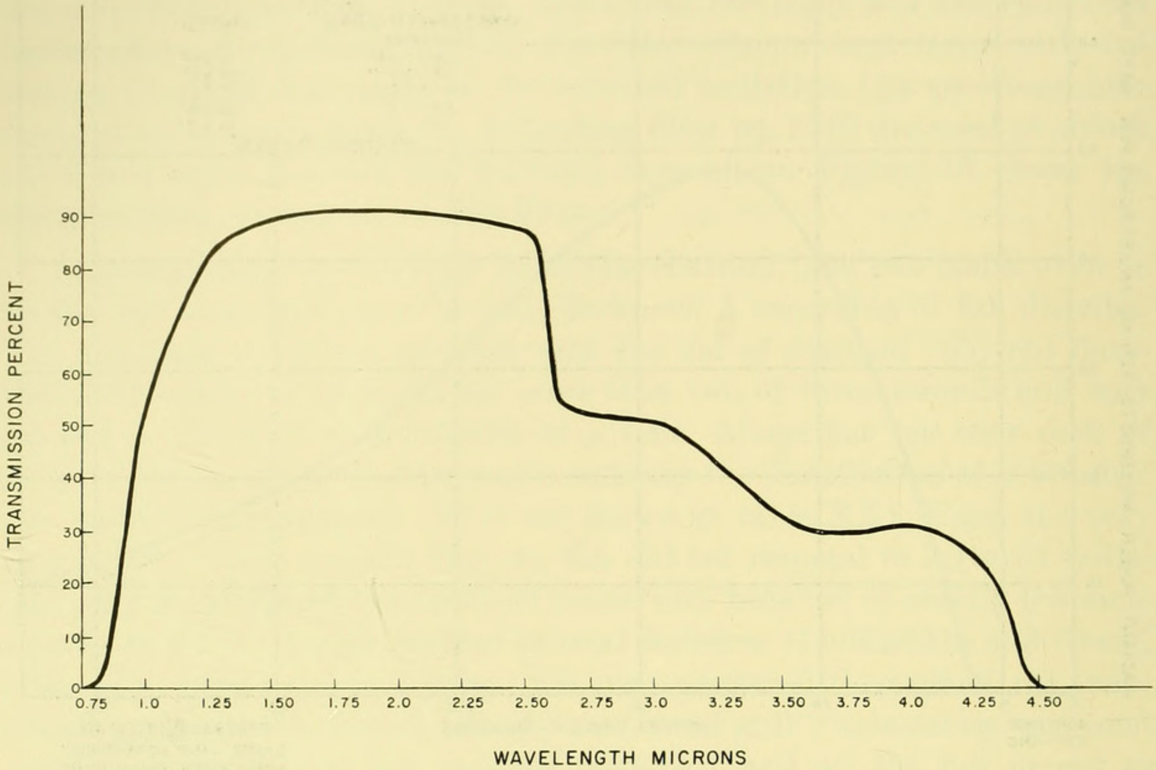
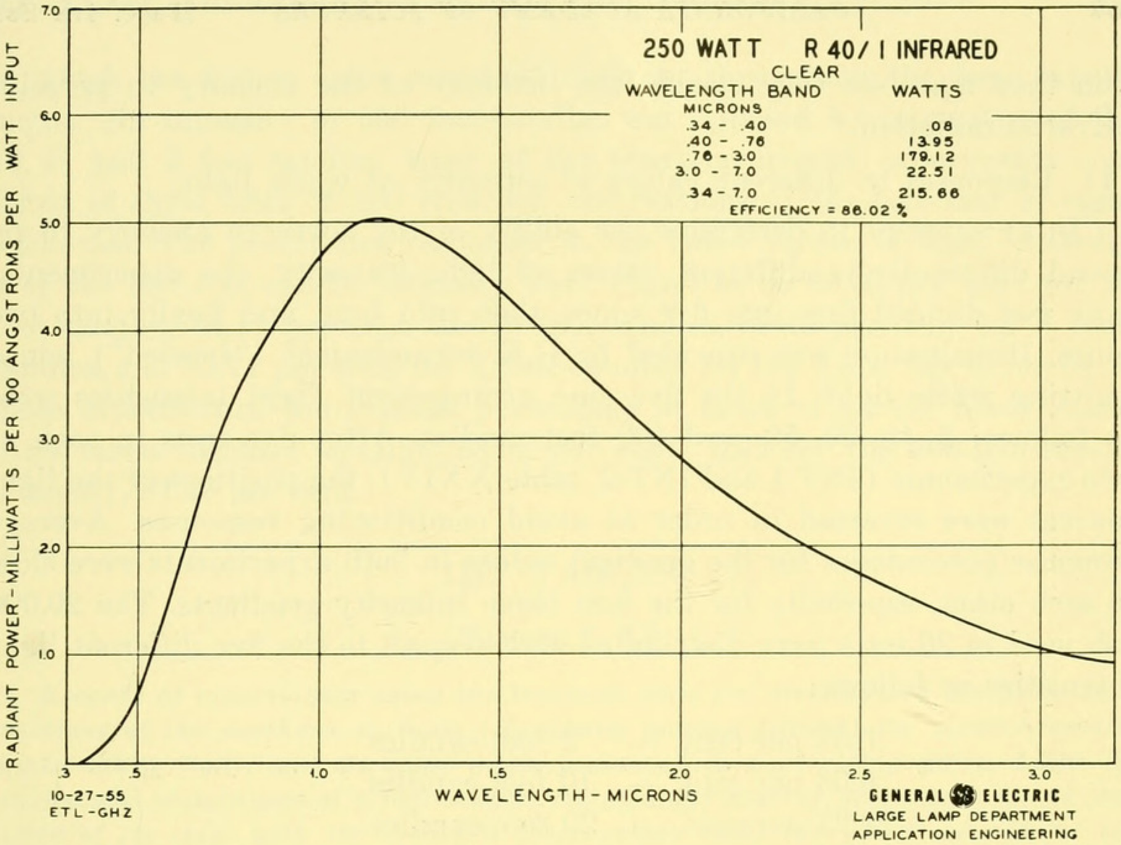


Figure 10. Spectrographic properties of the infrared transmitting filter of the Corning Glass Works' manufacture no. 2540 (7–56). Courtesy of the manufacturer.

infrared rays, as shown in figure 11. The light intensity of this lamp was also 500 foot-candles. Observations were made every ten seconds.

In 24 tests the fish behaved normally, maintaining typical school-formation, and circled at normal speed in counter-clockwise direction. They displayed preference for neither zone; of 19,200 fish 49.52 per cent were found in the white light zone, 50.48 per cent in the infrared zone.

Two more experiments concluded the infrared studies (INF-6 and INF-7, table XXIII). In these, one zone was illuminated with white light produced by the G.E. "soft white" fluorescent tube. The other zone was illuminated with a similar source of light to which the G.E. 600-watt electric heater was added as a source of infrared radiation. The intensity of light in both zones was equal to 25 foot-candles at the water's surface. As in the preceding case, the fish behaved normally and maintained typical school-formation and circular path of movement. They showed no marked preference for either of the zones. The average figures for 24 tests in the two experiments involving 19,000 fish are as follows: 51.79 per cent for the white-light zone and 48.21 per cent for the white-light-plus-infrared-wave-length zone. For all practical purposes these figures show an even distribution of the fish, and as in all other experiments with application of infrared radia-



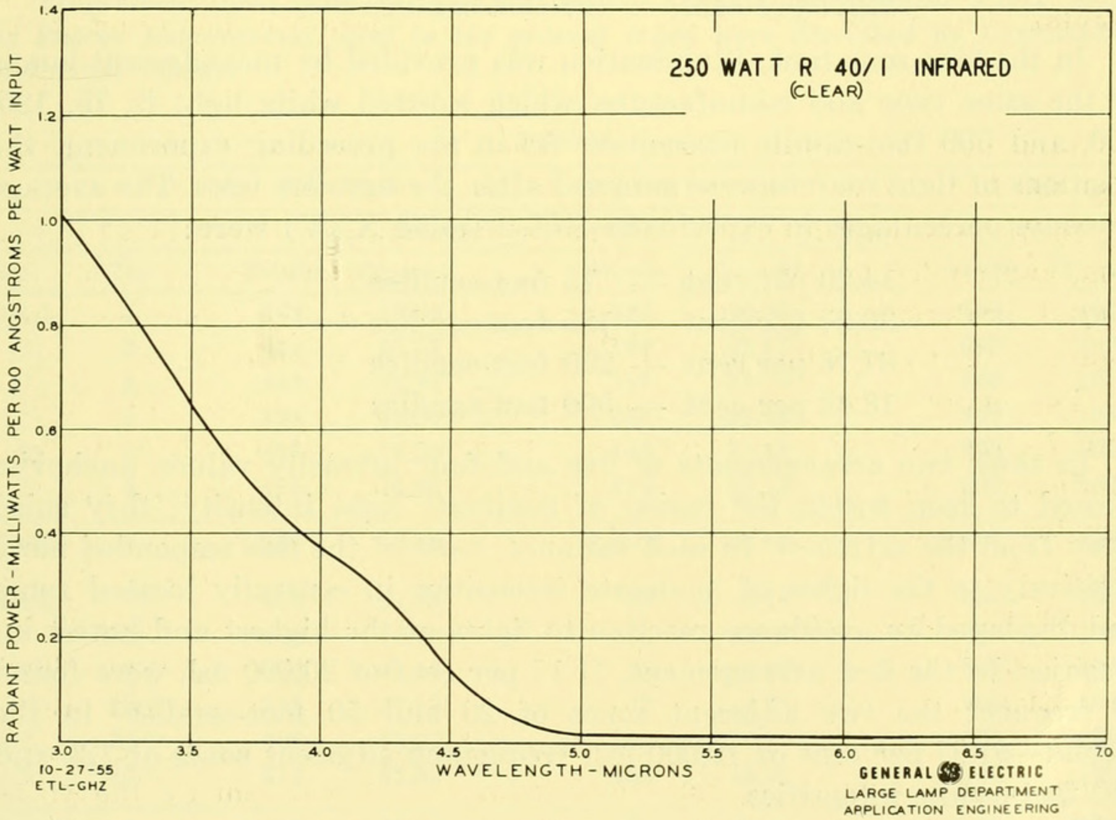


Figure 11. Spectral energy distribution of the 250-watt reflector clear heat lamp (infrared) manufactured by the General Electric Company. These graphs are official copies of the manufacturer. Courtesy of the General Electric Company.

tion they manifest very clearly the inability of the anchovy to perceive infrared radiation.

(4) Responses to different values of intensity of white light.

In an attempt to determine the ability of the northern anchovy to respond differently to different values of light intensity, the experimental tank was divided first into five zones, then into four, and finally into two zones. Illumination was provided by G.E. incandescent ("frosted") lamps emitting white light. In the five-zone arrangement, light intensities were as follows: 2, 10, 20, 50, and 100 foot-candles. After five tests in each of two experiments (INT-1 and INT-2, table XXIV), the positions of the light sources were reversed in order to avoid conditioning responses. Average response percentages for the gradient values in both experiments were close to each other, especially for the first three intensity gradients. The 20,000 fish used in 20 tests were distributed with respect to the five different light intensities as follows:

0.53 per cent — 2 foot-candles
6.03 per cent — 10 foot-candles
29.23 per cent — 20 foot-candles
41.94 per cent — 50 foot-candles
22.27 per cent — 100 foot-candles

In the four-zone tank, illumination was provided by incandescent lamps of the same type and manufacture, which emitted white light in 75, 125, 250, and 500 foot-candle intensities. As in the preceding experiment, the positions of light sources were reversed after the first five tests. The average response percentages in experiment INT-3 (table XXV) were:

14.20 per cent — 75 foot-candles
30.21 per cent — 125 foot-candles
37.16 per cent — 250 foot-candles
18.43 per cent — 500 foot-candles

In these two arrangements of five and four intensity values, anchovies seemed to keep within the region of moderate light intensity; they shied away from the extremes. In each instance, most of the fish responded more positively to the lights of moderate intensities in centrally located zones and displayed an avoidance reaction to lights of the highest and lowest intensities. In the first arrangement, 71.17 per cent of 20,000 fish were found to frequent the two adjacent zones of 20 and 50 foot-candles; in the second—67.37 per cent of 10,000 fish frequented adjacent zones of 125 and 250 foot-candle intensities.

The most striking example of avoidance by anchovies of the brighter zone was demonstrated in experiments INT-4, INT-5, INT-6, and INT-7, when intensities of white light were presented in sharply contrasting pairs, in which the higher value remained constant throughout the four experiments. An intensity of 500 foot-candles was opposed by intensities of 20, 10, 5, and 2 foot-candles. Each of the above-mentioned experiments consisted of three tests of 100 recorded observations of the behavior of eight anchovies. The preference responses to the lower values of light intensity over the 500 foot-candle intensity were found to be 65.50 per cent for 20 foot-candles, 64.71 per cent for 10 foot-candles, 60.42 per cent for 5 foot-candles, and 83.71 per cent for 2 foot-candles. Of the 9,600 fish involved in these experiments, the average percentage in favor of all the lower intensities taken together equalled 68.52 per cent; that for the 500-foot-candle intensity, 31.48 per cent.

III. TABLES

TABLES I–XI

Records of experiments using the two-zone tests for determining the preference reactions of the northern anchovy (Engraulis mordax *Girard) for monochromatic lights, white light, and darkness when presented in contrasting pairs. Light intensity was maintained at 9 foot-candles for all light sources. Each experiment consisted of six tests with 100 recorded observations made every ten seconds for six anchovies subjected to the effect of the light.*

Fluorescent tubes, manufactured by General Electric, and gelatine filters, made by Rascoe Laboratories, used in the present study were described by Loukashkin and Grant (1959).

Table I

		Green Light		Soft White Light		Total	
		Frequency of Occurrence					
Exp.	Test	Number	Per cent	Number	Per cent	Number	Per cent
GR-1	1	468	78.00	132	22.00	600	100
"	2	404	67.33	196	32.67	600	100
"	3	443	78.83	157	26.17	600	100
"	4	399	66.50	201	33.50	600	100
"	5	453	75.50	147	24.50	600	100
"	6	425	70.83	175	29.17	600	100
Total	6	2,592	72.00	1,008	28.00	3,600	100
GR-2	7	551	91.83	49	8.17	600	100
"	8	468	78.00	132	22.00	600	100
"	9	582	97.00	18	3.00	600	100
"	10	523	87.17	77	12.83	600	100
"	11	396	66.00	204	34.00	600	100
"	12	312	52.00	288	48.00	600	100
Total	6	2,832	78.67	768	21.33	3,600	100
Grand Total	12	5,424	75.34	1,776	24.66	7,200	100

Table II

		Green Light		Red Light		Total	
		Frequency of Occurrence					
Exp.	*Test*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
GR-3	1	597	99.50	3	0.50	600	100
"	2	600	100.00	0	0.00	600	100
"	3	561	93.50	39	6.50	600	100
"	4	593	98.83	7	1.17	600	100
"	5	597	99.50	3	0.50	600	100
"	6	600	100.00	0	0.00	600	100
Total	6	3,548	98.56	52	1.44	3,600	100
GR-4	7	598	99.67	2	0.33	600	100
"	8	599	99.83	1	0.17	600	100
"	9	591	98.50	9	1.50	600	100
"	10	514	85.67	86	14.33	600	100
"	11	596	99.33	4	0.67	600	100
"	12	600	100.00	0	0.00	600	100
Total	6	3,498	97.17	102	2.83	3,600	100
Grand Total	12	7,046	97.86	154	2.14	7,200	100

Table III

		Green Light		Blue Light		Total	
		Frequency of Occurrence					
Exp.	*Test*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
GR-5	1	433	72.17	167	27.83	600	100
"	2	429	71.50	171	28.50	600	100
"	3	383	63.83	217	36.17	600	100
"	4	381	63.50	219	36.50	600	100
"	5	480	80.00	120	20.00	600	100
"	6	465	77.50	135	22.50	600	100
Total	6	2,571	71.42	1,029	28.58	3,600	100
GR-6	7	563	93.82	37	6.17	600	100
"	8	419	68.33	181	31.67	600	100
"	9	280	46.67	320	53.33	600	100
"	10	505	84.17	95	15.83	600	100
"	11	441	73.50	159	26.50	600	100
"	12	490	81.67	110	18.33	600	100
Total	6	2,698	74.94	902	25.06	3,600	100
Grand Total	12	5,269	73.18	1,931	26.82	7,200	100

Table IV

		Green Light		Darkness		Total	
		Frequency of Occurrence					
Exp.	*Test*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
GR-7	1	600	100.00	0	0.00	600	100
"	2	454	75.67	146	24.33	600	100
"	3	557	92.83	43	7.17	600	100
"	4	597	99.50	3	0.50	600	100
"	5	600	100.00	0	0.00	600	100
"	6	594	99.00	6	1.00	600	100
Total	6	3,402	94.50	198	5.50	3,600	100
GR-8	7	594	99.00	6	1.00	600	100
"	8	559	93.17	41	6.83	600	100
"	9	592	98.67	8	1.33	600	100
"	10	583	97.17	17	2.83	600	100
"	11	594	99.00	6	1.00	600	100
"	12	594	99.00	6	1.00	600	100
Total	6	3,516	97.67	84	2.33	3,600	100
Grand Total	12	6,918	96.08	282	3.92	7,200	100

Table V

		Blue Light		Soft White Light		Total	
		Frequency of Occurrence					
Exp.	*Test*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
BL-1	1	180	30.00	420	70.00	600	100
"	2	464	77.33	136	22.67	600	100
"	3	373	62.17	227	37.83	600	100
"	4	333	55.50	267	44.50	600	100
"	5	367	61.17	233	38.83	600	100
"	6	318	53.00	282	47.00	600	100
Total	6	2,035	56.53	1,565	43.47	3,600	100
BL-2	7	379	63.17	221	36.83	600	100
"	8	289	48.17	311	51.83	600	100
"	9	237	39.50	363	60.50	600	100
"	10	280	46.67	320	53.33	600	100
"	11	234	39.00	366	61.00	600	100
"	12	303	50.50	297	49.50	600	100
Total	6	1,722	47.83	1,878	52.17	3,600	100
Grand Total	12	3,757	52.15	3,443	47.85	7,200	100

Table VI

		Blue Light		Red Light		Total	
		Frequency of Occurrence					
Exp.	Test	Number	Per cent	Number	Per cent	Number	Per cent
BL-3	1	474	79.00	126	21.00	600	100
"	2	591	98.50	9	1.50	600	100
"	3	353	58.83	247	41.17	600	100
"	4	390	65.00	210	35.00	600	100
"	5	438	73.00	162	27.00	600	100
"	6	523	88.83	77	11.17	600	100
Total	6	2,769	76.95	831	23.05	3,600	100
BL-4	7	597	99.50	3	0.50	600	100
"	8	576	96.00	24	4.00	600	100
"	9	403	67.17	197	32.83	600	100
"	10	526	87.67	74	12.33	600	100
"	11	499	83.17	101	16.87	600	100
"	12	505	84.17	95	15.83	600	100
Total	6	3,106	86.28	494	13.72	3,600	100
Grand Total	12	5,875	81.60	1,325	18.40	7,200	100

Table VII

		Blue Light		Darkness		Total	
		Frequency of Occurrence					
Exp.	Test	Number	Per cent	Number	Per cent	Number	Per cent
BL-5	1	600	100.00	0	0.00	600	100
"	2	538	89.67	62	10.33	600	100
"	3	578	96.33	22	3.67	600	100
"	4	565	94.17	35	5.83	600	100
"	5	578	96.33	22	3.67	600	100
"	6	600	100.00	0	0.00	600	100
Total	6	3,459	96.08	141	3.92	600	100
BL-6	7	600	100.00	0	0.00	600	100
"	8	594	99.00	6	1.00	600	100
"	9	592	98.67	8	1.33	600	100
"	10	560	93.33	40	6.67	600	100
"	11	581	96.83	19	3.17	600	100
"	12	600	100.00	0	0.00	600	100
Total	6	3,527	97.97	73	2.03	3,600	100
Grand Total	12	6,986	97.03	214	2.97	7,200	100

Table VIII

		Red Light		Soft White Light		Total	
		Frequency of Occurrence					
Exp.	Test	Number	Per cent	Number	Per cent	Number	Per cent
RD-1	1	1	0.17	599	99.83	600	100
"	2	40	6.67	560	93.33	600	100
"	3	8	1.33	592	98.67	600	100
"	4	48	8.00	552	92.00	600	100
"	5	89	14.83	511	85.17	600	100
"	6	81	13.50	519	86.50	600	100
Total	6	267	7.42	3,333	92.58	3,600	100
RD-2	7	13	2.16	587	97.84	600	100
"	8	104	17.33	496	82.67	600	100
"	9	1	0.17	599	99.83	600	100
"	10	209	34.83	391	65.17	600	100
"	11	233	38.83	367	61.17	600	100
"	12	9	1.50	591	98.50	600	100
Total	6	569	15.80	3,031	84.20	3,600	100
Grand Total	12	836	11.61	6,364	88.39	7,200	100

Table IX

		Red Light		Darkness		Total	
		Frequency of Occurrence					
Exp.	Test	Number	Per cent	Number	Per cent	Number	Per cent
RD-3	1	570	95.00	30	5.00	600	100
"	2	594	99.00	6	1.00	600	100
"	3	454	75.67	146	24.33	600	100
"	4	583	97.17	17	2.83	600	100
"	5	600	100.00	0	0.00	600	100
"	6	581	96.83	19	3.17	600	100
Total	6	3,382	93.94	218	6.06	3,600	100
RD-4	7	569	94.83	31	5.17	600	100
"	8	520	86.67	80	13.13	600	100
"	9	593	98.83	7	1.17	600	100
"	10	537	89.50	63	10.50	600	100
"	11	588	98.00	12	2.00	600	100
"	12	505	84.17	95	15.83	600	100
Total	6	3,312	92.00	288	8.00	3,600	100
Grand Total	12	6,694	92.97	506	7.03	7,200	100

Table X

		Soft White Light		Darkness		Total	
		Frequency of Occurrence					
Exp.	Test	Number	Per cent	Number	Per cent	Number	Per cent
WH-1	1	594	99.00	6	1.00	600	100
"	2	566	94.33	34	5.67	600	100
"	3	589	98.17	11	1.83	600	100
"	4	600	100.00	0	0.00	600	100
"	5	600	100.00	0	0.00	600	100
"	6	600	100.00	0	0.00	600	100
Total	6	3,549	98.58	51	1.42	3,600	100
WH-2	7	543	90.50	57	9.50	600	100
"	8	600	100.00	0	0.00	600	100
"	9	554	92.33	46	7.67	600	100
"	10	600	100.00	0	0.00	600	100
"	11	600	100.00	0	0.00	600	100
"	12	600	100.00	0	0.00	600	100
Total	6	3,497	97.14	103	2.86	3,600	100
Grand Total	12	7,046	97.88	154	2.12	7,200	100

Table XI

		Soft White Light		Soft White Light		Total	
		Frequency of Occurrence					
Exp.	Test	Number	Per cent	Number	Per cent	Number	Per cent
CON-1	1	263	48.83	337	56.17	600	100
"	2	286	47.67	314	52.33	600	100
"	3	349	58.27	251	41.73	600	100
"	4	350	58.33	250	41.67	600	100
"	5	228	38.00	372	62.00	600	100
"	6	371	61.83	229	38.17	600	100
Total	6	1,847	51.31	1,753	48.65	3,600	100
CON-2	7	384	64.00	216	36.00	600	100
"	8	238	39.67	362	60.33	600	100
"	9	302	50.33	298	49.67	600	100
"	10	224	37.33	376	62.67	600	100
"	11	318	53.00	282	47.00	600	100
"	12	291	48.50	309	51.50	600	100
Total	6	1,759	48.86	1,841	51.14	3,600	100
Grand Total	12	3,604	50.06	3,596	49.94	7,200	100

TABLE XII

Records of experiments using the three-zone tests for determining the preference reactions of the northern anchovy in monochromatic and white lights of equal and different intensities. Each experiment is based on six tests of 100 recorded observations, with six anchovies used in each test.

Exp.	Soft White Light		Green Light		Red Light		Total	
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
	Light Intensity 9 f.-c.		Light Intensity 9 f.-c.		Light Intensity 9 f.-c.			
WGR-1	1,158	32.17	2,016	56.00	426	11.83	3,600	100
	Light Intensity 30 f.-c.		Light Intensity 9 f.-c.		Light Intensity 9 f.-c.			
WGR-2	516	14.33	2,496	69.33	588	16.34	3,600	100
	Light Intensity 30 f.-c.		Light Intensity 6 f.-c.		Light Intensity 30 f.-c.			
WGR-3	432	12.00	2,448	68.00	720	20.00	3,600	100
	Light Intensity 30 f.-c.		Light Intensity 30 f.-c.		Light Intensity 30 f.-c.			
WGR-4	720	20.00	2,592	72.00	288	8.00	3,600	100
Total	2,826	19.63	9,552	66.33	2,022	14.04	14,400	100
			Other combinations in three-zone tests					
	Soft White Light Intensity 30 f.-c.		Green Light Intensity 6 f.-c.		Darkness Intensity 0 f.-c.			
WGD	804	22.33	2,496	69.33	300	8.34	3,600	100
	Red Light Intensity 30 f.-c.		Darkness Intensity 0 f.-c.		Soft White Light Intensity 30 f.-c.			
RDW	696	19.33	1,092	30.33	1,812	50.34	3,600	100
	Darkness Intensity 0 f.-c.		Blue Light Intensity 9 f.-c.		Red Light Intensity 9 f.-c.			
DBR-1	186	5.17	3,354	93.16	60	1.67	3,600	100
	Darkness Intensity 0 f.-c.		Blue Light Intensity 4 f.-c.		Red Light Intensity 30 f.-c.			
DBR-2	48	1.33	3,552	98.67	0	0.00	3,600	100

TABLE XIII

Records of experiments using the four-zone tests for determining the preference reactions of the northern anchovy for monochromatic lights and darkness. Each of the two experiments is based on six tests of 100 recorded observations, with eight anchovies used in each test.

Exp.	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
	(Darkness — 0 f.-c.; Lights — 9 f.-c. intensity)									
	Darkness		Red Light		Blue Light		Green Light		Total	
DRBG-1	123	2.56	204	4.25	849	17.69	3,624	75.50	4,800	100

Table XIII — Cont.

Exp.	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
	(Darkness: 0 f.-c.; Lights — 9 f.-c. intensity)									
	Darkness		Green Light		Blue Light		Red Light		Total	
DRBG-2	60	1.25	4,074	84.88	624	13.00	42	0.87	4,800	100
	Darkness		Green Light		Blue Light		Red Light		Total	
Total	183	1.91	7,698	80.19	1,473	15.34	246	2.56	9,600	100

Table XIV

Records of preference reactions of the northern anchovy (Engraulis mordax *Girard) to white and monochromatic lights arranged so as to approximately duplicate vertical distribution of sunlight spectrum in water mass. Nine fish were used in each test.*

		Blue Light		Green Light		Daylight		Total	
		Intensity — 0.5 f.-c.		Intensity — 7.8 f.-c.		Intensity — 16 f.-c.			
		Frequency of Occurrence							
Exp.	Test	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
DLGB-1	1	245	27.22	422	46.87	233	25.89	900	100
"	2	216	24.00	448	49.78	236	26.22	900	100
"	3	207	23.00	435	48.73	258	28.67	900	100
"	4	216	24.00	411	45.67	273	30.33	900	100
"	5	175	19.44	432	48.00	293	32.56	900	100
"	6	186	20.67	434	48.22	280	31.11	900	100
"	7	201	22.33	416	46.22	283	31.45	900	100
"	8	188	20.89	407	45.22	305	33.89	900	100
"	9	151	16.78	435	48.33	314	34.89	900	100
"	10	162	18.00	469	52.11	269	29.89	900	100
"	11	156	17.33	472	55.45	272	30.22	900	100
"	12	210	23.33	455	50.56	235	26.11	900	100
Total	12	2,313	21.42	5,246	48.57	3,241	30.01	10,800	100
		Reduced intensities:							
		Blue — 0.25		Green — 3.00		Daylight — 6.00			
DLGB-2	1	275	30.56	400	44.44	225	25.00	900	100
"	2	281	31.22	402	44.67	217	24.11	900	100
"	3	246	27.33	396	44.00	258	28.67	900	100
"	4	275	30.56	336	37.33	289	32.11	900	100
"	5	231	25.67	379	42.11	290	32.22	900	100
"	6	226	25.11	416	46.22	258	28.67	900	100
"	7	199	22.11	428	47.56	273	30.33	900	100
"	8	203	22.56	406	45.11	291	32.33	900	100
"	9	210	23.33	425	47.22	265	29.45	900	100
"	10	221	24.55	421	46.78	258	28.67	900	100
"	11	157	17.44	386	42.89	357	39.67	900	100
"	12	219	24.33	396	44.00	285	31.67	900	100
Total		2,743	25.40	4,791	44.36	3,266	30.24	10,800	100

Tables XV–XVII

Records of experiments using the two-zone tests for determining the preference reactions of the northern anchovy (Engraulis mordax *Girard) to monochromatic lights (blue, green, and red) and black light (ultraviolet radiation) presented in contrasting pairs. A light intensity of 0.2 foot-candle was maintained for all light sources applied. Two experiments were run using each contrasting pair of lights; each experiment consisted of twelve tests of 100 recorded observations of distribution of eight anchovies subjected to testing. Fluorescent tubes of General Electric manufacture 24″ long and gelatine filters of Rascoe laboratories as sources for the blue, green, and red lights used in the present study were the same as described by Loukashkin and Grant (1959) in their experiments with the Pacific Sardine.*

For ultraviolet radiation a fluorescent "black light" tube of the same length as the monochromatic light tubes was used (General Electric, F20T12/BLB).

Table XV

		Blue Light		Ultraviolet Radiation		Total	
		Frequency of Occurrence					
Exp.	Test	Number	Per cent	Number	Per cent	Number	Per cent
UL-1	1	507	63.37	293	36.63	800	100
"	2	554	69.25	246	30.75	800	100
"	3	509	63.63	291	36.37	800	100
"	4	584	73.00	216	27.00	800	100
"	5	507	63.37	293	36.63	800	100
"	6	420	52.50	380	47.50	800	100
"	7	394	49.25	406	50.75	800	100
"	8	285	35.63	515	64.37	800	100
"	9	400	50.00	400	50.00	800	100
"	10	264	33.00	536	67.00	800	100
"	11	321	40.13	479	59.87	800	100
"	12	308	38.50	492	61.50	800	100
Total	12	5,053	52.62	4,547	47.37	9,600	100
UL-2	13	423	52.87	377	47.13	800	100
"	14	415	51.87	385	48.13	800	100
"	15	417	52.12	383	47.88	800	100
"	16	388	48.50	412	51.50	800	100
"	17	397	49.63	403	50.37	800	100
"	18	383	47.88	417	52.12	800	100
"	19	363	45.38	437	54.62	800	100
"	20	389	48.63	411	51.37	800	100
"	21	359	44.88	441	55.12	800	100
"	22	331	41.38	469	58.62	800	100
"	23	322	40.25	478	59.75	800	100
"	24	332	41.50	468	59.50	800	100
Total	12	4,519	47.07	5,081	52.93	9,600	100
Grand Total	24	9,572	49.85	9,628	50.15	19,200	100

Table XVI

		Blue Light		Ultraviolet Radiation		Total	
		Frequency of Occurrence					
Exp.	*Test*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
UL-3	1	432	54.00	368	46.00	800	100
"	2	441	55.12	359	44.88	800	100
"	3	422	52.75	378	47.25	800	100
"	4	432	54.00	368	46.00	800	100
"	5	468	58.50	332	41.50	800	100
"	6	427	53.37	373	46.63	800	100
"	7	470	58.75	330	41.25	800	100
"	8	426	53.25	374	46.75	800	100
"	9	419	52.37	381	47.63	800	100
"	10	470	58.75	330	41.25	800	100
"	11	432	54.00	368	46.00	800	100
"	12	426	53.25	374	46.75	800	100
Total	12	5,265	54.84	4,335	45.16	9,600	100
UL-4	13	462	57.75	338	42.25	800	100
"	14	449	56.12	351	43.88	800	100
"	15	467	58.37	333	41.63	800	100
"	16	386	48.50	414	51.50	800	100
"	17	428	53.50	372	46.50	800	100
"	18	436	54.50	364	45.50	800	100
"	19	462	57.75	338	42.25	800	100
"	20	449	56.12	351	43.88	800	100
"	21	467	58.37	333	41.63	800	100
"	22	386	48.50	414	51.50	800	100
"	23	428	53.50	372	46.50	800	100
"	24	436	54.50	364	45.50	800	100
Total	12	5,256	54.75	4,344	45.25	9,600	100
Grand Total	24	10,521	54.79	8,679	45.21	19,200	100

Table XVII

		Red Light		Ultraviolet Radiation		Total	
		Frequency of Occurrence					
Exp.	*Test*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
UL-5	1	387	43.38	413	51.62	800	100
"	2	365	45.63	435	54.37	800	100
"	3	327	40.88	473	59.12	800	100
"	4	360	45.00	440	55.00	800	100
"	5	386	48.25	414	51.75	800	100
"	6	337	42.13	463	57.87	800	100
"	7	375	46.88	425	53.12	800	100
"	8	351	43.88	449	56.12	800	100
"	9	358	44.75	442	55.25	800	100
"	10	471	58.87	329	41.13	800	100

Table XVII — Cont.

		Red Light		*Ultraviolet Radiation*		*Total*	
		Frequency of Occurrence					
Exp.	*Test*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
"	11	444	56.50	356	44.50	800	100
"	12	423	52.87	377	47.13	800	100
Total	12	4,584	47.75	5,016	52.25	9,600	100
UL-6	13	89	11.13	711	88.87	800	100
"	14	93	11.62	707	88.38	800	100
"	15	136	17.00	664	83.00	800	100
"	16	117	14.62	683	85.38	800	100
"	17	156	19.50	644	80.50	800	100
"	18	109	13.62	691	86.38	800	100
"	19	35	4.38	765	95.62	800	100
"	20	25	3.12	775	96.88	800	100
"	21	6	0.75	794	99.25	800	100
"	22	10	1.25	790	98.75	800	100
"	23	0	0.00	800	100.00	800	100
"	24	21	2.62	779	97.38	800	100
Total	12	797	8.30	8,803	91.70	9,600	100
Grand Total	24	5,381	28.03	13,819	71.97	19,200	100

Table XVIII

Records of preference reactions of the northern anchovy (Engraulis mordax *Girard) to white light and ultraviolet rays presented simultaneously in a two-zone tank. Eight fish were used in each test.*

		White light zone		*Ultraviolet zone*		*Total*	
		Two G.E. 15-watt incandescent lamps. Intensity 10.5 foot-candles		*Two G.E. 15-watt incandescent lamps and 1 fluorescent G.E. "Black light" tube. Intensity 10.5 f.-c.*			
		Frequency of Occurrence					
Exp.	*Test*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
UL-7	1	282	35.25	518	64.75	800	100
"	2	240	30.00	560	70.00	800	100
"	3	316	39.50	484	60.50	800	100
"	4	325	40.63	475	59.39	800	100
"	5	328	41.00	472	59.00	800	100
"	6	302	37.75	498	62.25	800	100
"	7	482	60.25	318	39.75	800	100
"	8	520	65.00	280	35.00	800	100
"	9	546	68.25	254	31.75	800	100

TABLE XVIII — CONT.

		White light zone		*Ultraviolet zone*			
		Two G.E. 15-watt incandescent lamps. Intensity 10.5 foot-candles		*Two G.E. 15-watt incandescent lamps and 1 fluorescent G.E. "Black light" tube. Intensity 10.5*			
		Frequency of Occurrence					
Exp.	*Test*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
"	10	480	60.00	320	40.00	800	100
"	11	484	60.50	316	39.50	800	100
"	12	434	54.25	366	45.75	800	100
Total	12	4,739	49.37	4,861	50.63	9,600	100
UL-8	13	463	57.87	337	42.13	800	100
"	14	427	53.37	373	46.63	800	100
"	15	416	52.00	384	48.00	800	100
"	16	474	59.25	326	40.75	800	100
"	17	459	57.37	341	42.63	800	100
"	18	436	54.50	364	45.50	800	100
"	19	366	45.75	434	54.25	800	100
"	20	373	46.63	427	53.37	800	100
"	21	371	46.38	429	53.62	800	100
"	22	358	44.75	442	55.25	800	100
"	23	331	41.38	469	58.62	800	100
"	24	378	47.25	422	52.75	800	100
Total	12	4,852	50.54	4,748	49.46	9,600	100
Grand Total	24	9,591	49.84	9,609	50.16	19,200	100

TABLE XIX

Records of preference reactions of the northern anchovy (Engraulis mordax *Girard) to white light and ultraviolet rays presented in pairs in a two-zone tank. Eight fish were used in each test.*

		General Electric 100-watt mercury spot-light lamp suspended over the middle of the tank. Intensity 500+ foot-candles					
		Zone "A" covered with clear glass to filter out ultraviolet rays		*Zone "B" free for ultraviolet radiation*		*Total*	
		Frequency of Occurrence					
Exp.	*Test*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
UL-9	1	663	82.87	137	17.13	800	100
"	2	704	88.00	96	12.00	800	100
"	3	639	79.85	161	20.15	800	100
"	4	569	71.12	231	28.88	800	100
"	5	347	43.38	453	56.62	800	100

TABLE XIX — CONT.

		General Electric 100-watt mercury spotlight lamp suspended over the middle of the tank. Intensity 500+ foot-candles					
		Zone "A" covered with clear glass to filter out ultraviolet rays		*Zone "B" free for ultraviolet radiation*		*Total*	
		Frequency of Occurrence					
Exp.	*Test*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
"	6	421	52.62	379	47.38	800	100
"	7	418	52.25	382	47.75	800	100
"	8	402	50.25	398	49.75	800	100
"	9	388	48.50	412	51.50	800	100
"	10	569	71.12	231	28.88	800	100
Total	10	5,120	64.00	2,880	36.00	8,000	100
		Clear glass filter removed, both zones under effect of ultraviolet radiation					
UL-10	1	361	45.13	439	54.87	800	100
"	2	375	46.88	425	53.12	800	100
"	3	361	45.13	439	54.87	800	100
"	4	448	56.00	352	44.00	800	100
"	5	428	53.37	372	46.63	800	100
"	6	440	55.00	360	45.00	800	100
"	7	441	55.12	359	44.88	800	100
"	8	450	56.25	350	43.75	800	100
"	9	416	52.00	384	48.00	800	100
"	10	456	57.00	344	43.00	800	100
Total	10	4,176	52.20	3,824	47.80	8,000	100

To check the role of the glass filter in experiment UL-9, it was introduced again, but instead of 100-watt mercury spotlight (ultraviolet) KEN-Rad 300-watt reflector flood light (white) lamps were installed in each zone. Light intensity was 500+ foot-candles. The results are shown below.

		Zone "A" covered with glass		*Zone "B" open free*		*Total*	
UL-11	1	432	54.00	368	46.00	800	100
"	2	431	53.87	369	46.13	800	100
"	3	398	49.75	402	50.25	800	100
"	4	393	49.12	407	50.88	800	100
"	5	408	51.00	392	49.00	800	100
"	6	404	50.50	396	49.50	800	100
"	7	371	46.38	429	53.62	800	100
"	8	420	50.25	380	49.75	800	100
"	9	371	46.38	429	53.62	800	100
"	10	408	51.00	392	49.00	800	100
Total	10	4,036	50.45	3,964	49.55	8,000	100

TABLE XX

Records of preference reactions of the northern anchovy (Engraulis mordax Girard) *to white light and ultraviolet rays presented in pairs in a two-zone tank. Six fish were used in each test. Experiment UL–12 shows typical distribution of the fish when white light alone was applied, and experiment UL–13 shows change in distribution after replacing the white-light lamp in one of the zones with a lamp producing ultraviolet radiation.*

Exp.	*Test*	*Zone "A"*		*Zone "B"*		*Total*	
		Frequency of Occurrence					
		Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
		KEN-RAD 300-watt reflector flood light lamp (white) Intensity 225 f.-c.		*KEN-RAD 300-watt reflector flood light lamp (white) Intensity 225 f.-c.*			
UL-12	1	240	40.00	360	60.00	600	100
"	2	263	43.84	337	56.16	600	100
"	3	270	45.00	330	55.00	600	100
"	4	280	46.67	320	53.37	600	100
"	5	300	50.00	300	50.00	600	100
"	6	240	40.00	360	60.00	600	100
"	7	280	46.67	320	53.37	600	100
"	8	340	56.67	260	43.33	600	100
"	9	335	55.83	265	44.17	600	100
"	10	360	60.00	240	40.00	600	100
Total	10	2,908	48.47	3,092	51.53	6,000	100
		KEN-RAD 300-watt reflector flood light lamp (white) Intensity 225 f.-c.		*G.E. 100-watt mercury spotlight lamp (ultraviolet). Intensity 225 f.-c.*			
UL-13	1	600	100.00	0	0.00	600	100
"	2	477	79.50	123	20.50	600	100
"	3	387	64.50	213	35.20	600	100
"	4	404	67.33	196	32.67	600	100
"	5	372	62.00	228	38.00	600	100
"	6	380	63.33	220	36.67	600	100
"	7	400	66.67	200	33.33	600	100
"	8	420	70.00	180	30.00	600	100
"	9	480	80.00	120	20.00	600	100
"	10	406	67.67	194	32.37	600	100
Total	10	4,326	72.10	1,674	27.90	6,000	100

Table XXI

Records of preference responses of the northern anchovy (Engraulis mordax *Girard) to infrared radiation and total darkness in a two-zone tank. Eight fish were used in each test.*

Exp.	*Test*	*Infrared Radiation*		*Total Darkness*		*Total*	
		G.E. 250-watt reflector heat lamp with red coating and Corning infra-red transmitting filter.		*Absolute Darkness*			
		Frequency of Occurrence					
		Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
INF-1	1	167	69.58	73	30.42	240	100
"	2	135	56.25	105	43.75	240	100
"	3	135	56.25	105	43.75	240	100
"	4	106	44.17	134	55.85	240	100
"	5	162	67.50	78	32.50	240	100
"	6	96	40.00	144	60.00	240	100
"	7	98	40.83	142	59.17	240	100
"	8	74	30.84	166	69.16	240	100
"	9	153	63.75	87	36.25	240	100
"	10	106	44.17	134	55.83	240	100
Total	10	1,232	51.33	1,168	48.67	2,400	100
		Total Darkness		*Total Darkness*			
INF-2	1	170	70.83	70	29.19	240	100
"	2	124	51.67	116	48.33	240	100
"	3	105	43.75	135	56.25	240	100
"	4	116	48.33	124	51.67	240	100
"	5	120	50.00	120	50.00	240	100
"	6	95	39.58	145	60.42	240	100
"	7	96	40.00	144	60.00	240	100
"	8	86	35.83	154	64.17	240	100
"	9	150	62.50	90	37.50	240	100
"	10	104	43.33	136	56.67	240	100
Total	10	1,166	48.58	1,234	51.42	2,400	100
		Infrared: Visible Red. Corning filter cracked and began to transmit visible red in the intensity about 0.001 f.-c.		*Total Darkness*			
INF-3	1	124	51.67	116	48.33	240	110
"	2	183	76.25	57	24.75	240	110
"	3	170	70.83	70	29.17	240	100
"	4	166	69.17	74	30.83	240	100
"	5	166	69.17	74	30.83	240	100
"	6	192	80.00	48	20.00	240	100
"	7	196	81.67	44	18.33	240	100
"	8	201	83.75	39	16.25	240	100
"	9	192	80.00	48	20.00	240	100
"	10	190	79.17	50	20.83	240	100
Total	10	1,780	74.17	620	25.83	2,400	100

TABLE XXII

Records of preference reactions of the northern anchovy (Engraulis mordax *Girard) to white light and infrared radiation in a two-zone tank. Eight fish were used in each test.*

Exp.	*Test*	*Clear Light*		*Infrared Radiation*		*Total*	
		KEN-RAD 300-watt reflector flood light lamp. Light intensity - 500 f.-c.		*G.E 250-watt reflector infrared (heat) industrial lamp (white bulb). Light intensity - 500 f.-c.*			
		Frequency of Occurrence					
		Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
INF-4	1	377	47.13	423	52.87	800	100
"	2	352	44.00	448	56.00	800	100
"	3	370	46.25	430	53.75	800	100
"	4	363	45.38	437	54.62	800	100
"	5	365	45.63	435	54.37	800	100
"	6	352	44.00	448	56.00	800	100
"	7	406	50.75	394	49.25	800	100
"	8	399	49.88	401	50.12	800	100
"	9	393	49.13	407	50.97	800	100
"	10	480	60.00	320	40.00	800	100
"	11	441	55.12	359	44.88	800	100
"	12	413	51.62	387	48.38	800	100
Total	12	4,711	49.07	4,889	50.93	9,600	100
INF-5	13	415	51.87	385	48.13	800	100
"	14	405	50.62	395	49.38	800	100
"	15	413	51.62	387	48.38	800	100
"	16	471	58.87	329	41.13	800	100
"	17	401	50.12	399	49.88	800	100
"	18	442	55.25	358	44.75	800	100
"	19	388	48.50	412	51.50	800	100
"	20	379	47.38	421	52.62	800	100
"	21	344	43.00	456	57.00	800	100
"	22	385	48.13	415	51.87	800	100
"	23	364	45.50	436	54.50	800	100
"	24	389	48.63	411	51.37	800	100
Total	12	4,796	49.96	4,804	50.04	9,600	100
Grand Total	24	9,507	49.52	9,693	50.48	19,200	100

Table XXIII

Records of preference reactions of the northern anchovy (Engraulis mordax *Girard) to white light and infrared radiation plus visible light in a two-zone tank. Eight fish were used in each test.*

Exp.	*Test*	*White Light*		*Infrared Radiation*		*Total*	
		Fluorescent tube "Soft White" light; Intensity 25 f.-c.		*Fluorescent tube "Soft White" light, and G.E. 600-watt electric heater. Intensity 25 f.-c.*			
		Frequency of Occurrence					
		Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
INF-6	1	374	46.75	426	53.25	800	100
"	2	390	48.75	410	51.25	800	100
"	3	373	46.63	427	53.37	800	100
"	4	406	50.75	394	49.25	800	100
"	5	389	48.63	411	51.37	800	100
"	6	404	50.50	396	49.50	800	100
"	7	438	54.75	362	45.25	800	100
"	8	459	57.37	341	42.63	800	100
"	9	410	51.50	390	48.50	800	100
"	10	434	54.25	366	45.75	800	100
"	11	429	53.62	371	46.38	800	100
"	12	425	53.12	375	46.88	800	100
Total	12	4,931	51.36	4,669	48.64	9,600	100
INF-7	13	419	52.37	381	47.63	800	100
"	14	458	57.25	342	42.75	800	100
"	15	420	52.50	380	47.50	800	100
"	16	387	48.38	413	51.62	800	100
"	17	415	51.87	385	48.13	800	100
"	18	388	48.50	412	51.50	800	100
"	19	394	49.25	406	50.75	800	100
"	20	449	56.12	351	43.88	800	100
"	21	402	50.25	398	49.75	800	100
"	22	435	54.37	365	45.63	800	100
"	23	416	52.00	384	48.00	800	100
"	24	429	53.62	371	46.38	800	100
Total	12	5,012	52.21	4,588	47.79	9,600	100
Grand Total	24	9,943	51.79	9,257	48.21	19,200	100

TABLE XXIV

Records of preference reactions of the northern anchovy (Engraulis mordax Girard) to light gradient tests using five-zone tank and white light (G.E. incandescent lamps) ranging in its intensity from 2 to 100 foot-candles. Ten fish were used in each test.

		Zone "A"		Zone "B"		Zone "C"		Zone "D"		Zone "E"			
		2 f.-c.		10 f.-c.		20 f.-c.		50 f.-c.		100 f.-c.		Total	
		Frequency of Occurrence											
Exp.	Test	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
INT-1	1	4	0.40	143	14.30	390	39.00	312	31.20	151	15.10	1,000	100
"	2	3	0.30	83	8.30	247	24.70	390	39.00	277	27.70	1,000	100
"	3	1	0.10	95	9.50	261	26.10	337	33.70	306	30.60	1,000	100
"	4	15	1.50	62	6.20	271	27.10	370	37.00	282	28.20	1,000	100
"	5	2	0.20	43	4.30	332	33.20	374	37.40	249	24.90	1,000	100
"	6	2	0.20	54	5.40	250	25.00	385	38.50	309	30.90	1,000	100
"	7	0	0.00	9	0.90	315	31.50	424	42.40	252	25.20	1,000	100
"	8	1	0.10	26	2.60	253	25.30	406	40.60	314	31.40	1,000	100
"	9	19	1.90	52	5.20	242	24.20	394	39.40	293	29.30	1,000	100
"	10	2	0.20	50	5.00	315	31.50	367	36.70	266	26.60	1,000	100
Total	10	49	0.49	617	6.17	2,876	28.76	3,759	37.59	2,699	26.99	10,000	100
INT-2	11	3	0.30	23	2.30	258	25.80	532	53.20	184	18.40	1,000	100
"	12	1	0.10	28	2.80	265	26.50	486	48.60	220	22.00	1,000	100
"	13	7	0.70	75	7.50	264	26.40	511	51.10	143	14.30	1,000	100
"	14	2	0.20	37	3.70	346	34.60	436	43.60	179	17.90	1,000	100
"	15	1	0.10	93	9.30	297	29.70	486	48.60	123	12.30	1,000	100
"	16	26	2.60	78	7.80	339	33.90	447	44.70	110	11.00	1,000	100
"	17	2	0.20	61	6.10	306	30.60	418	41.80	213	21.30	1,000	100
"	18	9	0.90	68	6.80	242	24.20	425	42.50	256	25.60	1,000	100
"	19	3	0.30	65	6.50	359	35.90	418	41.80	155	15.50	1,000	100
"	20	4	0.40	62	6.20	293	29.30	470	47.00	171	17.10	1,000	100
Total	10	58	0.58	590	5.90	2,969	29.69	4,629	46.29	1,754	17.54	10,000	100
Grand Total	20	107	0.53	1,207	6.03	5,845	29.23	8,388	41.94	4,453	22.27	20,000	100

TABLE XXV

Records of preference reactions of the northern anchovy (Engraulis mordax *Girard) to light gradient tests using four-zone tank and white light (incandescent lamps) ranging in its intensity from 75 to 500 foot-candles. Ten fish were used in each test.*

		Zone "A"		Zone "B"		Zone "C"		Zone "D"		Total	
		75 f.-c.		125 f.-c.		250 f.-c.		500 f.-c.			
		Frequency of Occurrence									
Exp.	Test	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
INT-3	1	144	14.40	280	28.00	396	39.60	180	18.00	1,000	100
"	2	167	16.70	275	27.50	360	36.00	198	19.80	1,000	100
"	3	175	17.50	218	21.80	362	36.20	245	24.50	1,000	100
"	4	137	13.70	291	29.10	365	36.50	207	20.70	1,000	100
"	5	170	17.00	356	35.60	377	37.70	97	9.70	1,000	100
"	6	178	17.80	289	28.90	377	37.70	156	15.60	1,000	100
"	7	116	11.60	308	30.80	380	38.00	196	19.60	1,000	100
"	8	111	11.10	301	30.10	326	32.60	262	26.20	1,000	100
"	9	133	13.30	356	35.60	363	36.30	148	14.80	1,000	100
"	10	89	8.90	347	34.70	410	41.00	154	15.40	1,000	100
Total	10	1,420	14.20	3,021	30.21	3,716	37.16	1,843	18.43	10,000	100

TABLE XXVI

Records of preference reactions of the northern anchovy (Engraulis mordax *Girard) to different intensities of white light presented in sharply contrasting pairs in a two-zone tank. Eight fish were used in each test.*

		Zone "A"		Zone "B"			
		Frequency of Occurrence					
Exp.	*Test*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
		(A)	500 f.-c.	20 f.-c.			
INT-4	1	256	32.00	544	68.00	800	100
"	2	297	37.11	503	62.89	800	100
"	3	275	34.38	525	65.62	800	100
Total	3	828	34.50	1,572	65.50	2,400	100
		(B)	500 f.-c.	10 f.-c.			
INT-5	1	319	39.88	481	60.12	800	100
"	2	302	37.75	498	62.25	800	100
"	3	226	28.25	574	71.75	800	100
Total	3	847	35.29	1,553	64.71	2,400	100
		(C)	500 f.-c.	5 f.-c.			
INT-6	1	335	41.88	465	58.12	800	100
"	2	334	41.75	466	58.25	800	100
"	3	285	35.63	515	64.37	800	100
Total	3	954	39.58	1,446	60.42	2,400	100
		(D)	500 f.-c.	2 f.-c.			
INT-7	1	210	26.25	590	73.75	800	100
"	2	127	15.88	673	84.12	800	100
"	3	54	6.75	746	93.25	800	100
Total	3	391	16.29	2,009	83.71	2,400	100
Grand Total	12	3,020	31.48	6,580	68.52	9,600	100

IV. DISCUSSION

(1) On responses of the northern anchovy to monochromatic lights in relation to reactions of other species.

As stated in the introduction, the experiments described in the preceding pages were carried out as a part of the general study on color vision in certain species of the marine pelagic fishes of the Pacific Ocean. The first stage of this study was published in 1959 by the present investigators. At that time they studied the Pacific sardine to determine the influence of monochromatic and white lights and darkness as environmental stimuli for elucidation of behavioral changes in schooling patterns and conversely to determine the ability of the sardine to discriminate colored and white lights qualitatively. Those experiments demonstrated clearly that different lights and darkness do affect school behavior and schooling patterns; also shown was the ability of the sardine to discriminate between lights on the basis of wave length. The sardines were attracted most of all by green light; they were repelled by both red light and total darkness (Loukashkin and Grant, 1959).[5]

The results of recent experiments with the northern anchovy, to determine their ability to discriminate among differently colored lights and darkness, are strikingly similar to those obtained in the experiments with the Pacific sardine. The anchovy, however, was able to differentiate green light from the blue, while the sardine failed to do so. In choice experiments in which the blue and white lights were presented responses of the anchovy in favor of the blue light (52.15 per cent) were lower than those of the sardine (73.05 per cent). Comparative data on the responses of these two species are assembled in the table XXVII.

Table XXVII

Comparison of preference reactions of the northern anchovy and Pacific sardine to monochromatic and white lights in a two-zone tank.

Description	Responses in per cent	
	Light source	*Light Source*
	Green	*White*
Anchovy	75.34	24.66
Sardine	78.63	21.37
	Green	*Red*
Anchovy	97.86	2.14
Sardine	95.25	4.17
	Green	*Blue*
Anchovy	73.18	26.82
Sardine	49.17	50.83
	Blue	*White*
Anchovy	52.15	47.85
Sardine	73.05	26.95
	Blue	*Red*
Anchovy	81.60	18.40
Sardine	97.26	2.74
	Red	*White*
Anchovy	11.61	88.39
Sardine	12.43	87.57

[5] Verheijen (1956, 1958, 1959), speaking of the mass gathering phenomena of certain clupeids under the light at night at sea, disqualifies the interpretation of these phenomena in terms of "positive phototaxis," "being attracted," "intensity preferendum," or "light optimum." He considers all of them unsatisfactory and he attributes the above phenomena merely to a "mass photic disorientation" of the fish.

In the series of experiments comparing the effects of green, blue, red, and white lights in a two-zone tank (tables I, II, III, V, VI, VIII) only 2,315 fish or 10.72 per cent out of 21,600 fish responded positively to red light, and 19,285 fish or 89.28 per cent responded positively to the other lights. The negative reaction of the sardine toward red light was stronger: of 36,000 fish, 2,300 or 6.67 per cent were found in the red-light zone, and 33,610 fish or 93.33 per cent in the other light zones. Comparative data are shown below to better illustrate the preferential responses of the anchovy and sardine to colored and white lights.

Table XXVIII

	Description	*Responses in per cent*	
		Anchovy	*Sardine*
(A)	Green	82.13	74.35
	Blue, Red, White together	17.87	25.65
(B)	Blue	53.52	73.71
	Green, Red, White together	46.48	26.29
(C)	Red	10.72	6.67
	Green, Blue, White together	89.28	93.33
(D)	White	53.63	45.30
	Green, Blue, Red together	46.37	54.70

In the three- and four-zone tank (tables XII, XIII, and XIV) green light was found to have the same effect as in the two-zone tank. The anchovies consistently responded in favor of the green light regardless of the intensities of the opposing lights. As was true for sardines (Loukashkin and Grant, 1959), anchovies were attracted mostly by the blue-green region of the spectrum. They showed a preference for green light over blue, for green over red, and for green over white. A preference for blue, in the absence of green, over red and white was also evident. Similar results were obtained by Breder (1959) in his experiments using monochromatic lights of low intensities (2 foot-candles) on *Sardinella macrophthalma*, *Jenkinsia lamprotaenia*, and some other fishes. He observes that, when contrasting colored lights are presented in pairs, "a general tendency is evident for fishes to respond more definitely toward the shorter wave lengths (the blue and greens) and much less toward the longer wave lengths (reds)."

The attractive value of the blue-green region of the spectrum was demonstrated in experimental studies by several Japanese behaviorists on young marine fishes, such as *Oplegnathus fasciatus*, *Stephanolepis cirrhifer*, *Scomberomorus niphonius*, *Fugu niphobles*, *Fugu rubripes*, *Mugil cephalus*, *Girella punctata*, *Pempheris japonica*, *Trachurus japonicus*, and the freshwater *Oryzias latipes* (Kawamoto, 1959; Kawamoto and Konishi, 1952; Kawamoto and Takeda, 1950, 1951; Ozaki, 1951).

Protasov (1957) investigated the responses of several species of the Black Sea fishes to monochromatic and white lights in the seaquaria of the Sebastopol Biological Station. He found that the ombre, *Corvina umbra,* responded positively to violet, blue, light blue, green and white lights, and even to ultraviolet rays. The juvenile sturgeon "sevriuga," *Acipenser stellatus,* was found to be phototatic to all types of lights applied but the responses were rather quantitative in character. The fish reacted positively only to higher intensities of the light, regardless of color. The horsemackerel "stavrida," *Trachurus trachurus,* displayed indifference to the blue-green region of the spectrum, but when the intensity of the light was increased ($\times 5$) the fish reacted negatively. This fish responded less positively to white light than to red, especially when water temperature was lowered.[6]

A year later, Protasov (1958) published the results of his studies on the sensitivity of the fish eye to different wave lengths of light, establishing boundaries of the visible spectrum for certain marine and freshwater fishes, as shown in the following table:

Species	*Limits in millimicrons*		
Trygon pastinaca	≈ 420	—	≈ 620
Acipenser stellatus	≈ 420	—	≈ 700
Mugil auratus	≈ 430	—	≈ 700
Scorpaena porcus	≈ 400	—	≈ 600
Silurus glanis	≈ 500	—	≈ 700
Cyprinus carpio	≈ 480	—	≈ 700
Squalus acanthias	≈ 400	—	≈ 620

He also tested the ability of the fish to discriminate monochromatic lights regardless of their intensities, applying the electrophysiological method suggested by Bongard (1955) and Bongard and Smirnova (1959). This study revealed that *Mugil auratus* could distinguish blue, green, red, and orange lights from one another, but failed to distinguish blue from the violet and "extreme red" from red. *Scorpaena porcus* could discriminate red, yellow, orange, green, blue, and light-blue lights, but was unable to discriminate violet from the blue and "extreme red" from the red. The Black Sea turbot, *Rhombus maeoticus,* could distinguish blue, light blue, green, yellow, orange, and red lights, but could not differentiate violet from the blue.[7]

[6] The rather unusual reaction of the Black Sea horsemackerel (in view of the Kawamoto experiments with the Japanese horsemackerel) had been reported earlier by Safianova (1952), who demonstrated preferential reactions of this fish to the orange-red illumination.

[7] Protasov's studies would have been more complete had he determined the ability of his fishes to react preferentially to certain wave lengths as well.

As to the responses of marine fishes to monochromatic lights in experiments under natural conditions in the open sea, there are several reports of interest to be mentioned in connection with the present study. Pochekaev (1949), testing the effects of overhead and submerged electric lights in the inshore waters of Sakhalin Island as possible attractants in local fisheries, obtained positive phototactic reactions as follows: (1) of the pond smelt, *Hypomesus olidus;* saury, *Cololabis saira;* and Eastern dace *Leuciscus brandti* (all three in juvenile stage) to white, yellow, and violet lights; (2) adult dace, to white and yellow (violet light was not used); and (3) trout "kundzha," *Salvelinus leucomaenis,* pond smelt and saury (all adult), to white light (the other two sources were not used).[8]

In addition to Pochekaev's data on pond smelt, Baranov (1955) found this fish also responded readily to and aggregated in quantities around submerged electric lamps emitting blue, red, and white light, the latter appearing to be the more effective attractant. As to the saury, Yudovich (1956) and Gristchenko *et al.* (1957) described the effectiveness of the blue and red lights in experimental saury catches in the northwestern Pacific. The blue light was used to attract the fish to the vessel (up to forty 500-watt incandescent lamps were installed along one side of the vessel); the red light (not more than four 500-watt incandescent lamps on the opposite side of the vessel) was used for operational purposes. When an aggregation would form in the blue light zone, the light would be extinguished and the red lamps would be turned on. The fish aggregation then would move from the darkened zone into the new dimly illuminated red zone where conical lift nets or blanket nets were installed. Upon lifting the nets, the red lights would be turned off and the blue lights turned on. This procedure would be repeated several times at one night light station.[9]

Experiments carried out by Japanese fishery biologists in the open sea revealed the effectiveness of other monochromatic lights in attracting saury. Light of 4,000 angstroms (violet) wave length was found to be most effective, and that of 6,000 angstroms (red) the least effective (Takayama, 1956).

[8] Pochekaev indicated that violet light attracted the squid, *Ommastrepes sloani pacificus,* in great masses. A marked preference for violet light over both yellow and white lights was displayed by an instant phototaxis following switching on of the violet lamp and in a short time by the mass aggregation of the squid schools within the illuminated zone. The other two lights were found to be good attractants too, but to a much lesser degree. Positive phototaxis toward white light was recorded for the California squid, *Loligo opalescens,* by Radovich and Gibbs (1954) and for the Mediterranean squid, *Loligo vulgaris,* by Verheijen (1958).

[9] The use of a two-light arrangement as described by Yudovich (1956) and Gristchenko (1957) was introduced in the saury fisheries industry of Japan in the years following the end of World War II: it has been highly appreciated by the fishermen whose catches have rapidly increased (Parin, 1956; Pokrovsky, 1957). The total annual landings of saury in prewar years (1936-1939) in Japan, before the use of artificial lights, amounted to less than 10,000 metric tons. With introduction of light attractants, the catch in 1947 reached 22,900 metric tons; in 1950, 126,400 metric tons; and in 1954, 292,700 metric tons (Rass, 1956). By 1957 the number of fishing vessels with electric-light equipment employed in saury fisheries exceeded 2,000; the annual catch for the same year reached 375,000 metric tons (Fukuhara, 1959).

In experimental studies of natural visual responses of the yellowfin tuna, *Neothunnus macropterus,* and little tunny, *Euthynnus yaito,* in the Hawaii Marine Laboratory of the University of Hawaii, electric lights of white, blue, green, orange, red, and yellow colors were applied. The fish responded to colored and white lights, but "green light appeared to attract tuna" (Hsiao, 1952; Tester, 1959).

According to Nikonorov (1956a), the Caspian anchovy-like sprat "kilka," *Clupeonella engrauliformis,* in its natural environment "prefers" white light emitted by the submerged electric lamp when this light was presented paired with green or red lights. When green and red lights were presented together, the fish concentrated near the green lamp. In studying another Caspian sprat, *Clupeonella delicatula caspia,* under identical environmental conditions and using monochromatic and white lights, Borisov (1955) found out that the most effective attractant was ordinary white light. The results of his trials, expressed in per cent, are shown below:

Catches made with application of:	white light	57.2
	yellow light	27.6
	orange light	5.9
	blue light	5.0
	green light	3.8
	red light	0.5
	no light	0.0
	Total	100.0

In evaluating the results of his exploration, Borisov observed, "Here, apparently, is reaction to the intensity of light but not to the color of light." From this remark it could be assumed that light intensities of the lamps used by Borisov and his associates were not uniform, and therefore the results he obtained were not conclusive.[10]

During the present investigation, two other species of schooling marine fishes, occasionally available for comparative study, were subjected to the influence of lights. One of them, the topsmelt, *Atherinops affinis* (Ayres), was kept in captivity for quite a long time; the second, the Pacific herring, *Clupeaa pallasii* Valenciennes, had been captured at the end of the spawning season and was used in tests following the fish's initial adaptation to an artificial environment in the 1000-gallon display tanks of the Steinhart Aquarium. The results obtained with these fishes are shown in tables below:

[10] Borisov never mentioned either light intensity figures or spectrographic values of his monochromatic lights in his report. This is also true for most of the Russian works cited in the present paper.

TABLE XXIX

Records of responses of the topsmelt to monochromatic and white lights and darkness. Each experiment consisted of five tests of 100 recorded observations on a group of eight fish. Light intensity was maintained at the 5 foot-candle level.

Experiment number	Pair of contrasting light zones					
	Zone "A"		Zone "B"		Total	
	Frequency of distribution					
	Number	Per cent	Number	Per cent	Number	Per cent
Top-1	Green light		Red light			
	3,970	99.25	30	0.75	4,000	100
Top-2	Blue light		Red light			
	3,610	90.25	390	9.75	4,000	100
Top-3	Blue light		White light			
	3,400	85.25	590	14.75	4,000	100
Top-4	Red light		Darkness			
	2,536	63.40	1,464	36.60	4,000	100

As seen from this table, the preference responses of the topsmelt were toward the green and blue lights. As in the case of the Pacific sardine and northern anchovy, the red light had no attractive value, except when it was opposed by darkness.

TABLE XXX

Records of responses of the Pacific herring to monochromatic and white lights. Each experiment consisted of five tests of 100 recorded observations on a group of six fish. Light intensity was maintained at the 10 foot-candle level.

Experiment number	Pair of Contrasting light zones					
	Zone "A"		Zone "B"		Total	
	Frequency of distribution					
	Number	Per cent	Number	Per cent	Number	Per cent
Hrg-1	Blue light		Red light			
	2,115	70.50	885	29.50	3,000	100
Hrg-2	Green light		Red light			
	1,591	53.10	1,409	46.90	3,000	100
Hrg-3	White light		Red light			
	1,524	50.80	1,476	49.20	3,000	100

Possibly, because of the physical and physiological condition of the herring captured during spawning season (in fact, a few females spawned on the tank's walls soon after delivery of the captured fish), their responses to monochromatic and white lights are quite different from those of the anchovy and topsmelt. Only in one of the three experiments did the herring display strongly negative reactions to red light and preferentially positive reaction to the contrasting light (blue). Gristchenko (1951) and Nikolaev (1957), speaking of the Pacific herring, and Tihonov (1959)—of the Atlantic herring, state that in experiments conducted in the open sea they found seasonal changes in phototactical behavior of this fish to the artificial lights. During the fattening period, both herrings reacted positively to light, and readily aggregated in masses in the illuminated zone. During the spawning season they became phototactically negative.[11] This may well explain the confusing results shown in the table XXX.

In closing this discussion on color vision in fishes, a few words should be said about the results of certain experiments in which "training" techniques have been successfully applied (*e.g.*, feeding responses associated with a stimulus of restricted wave length). In the classical work of Reeves (1919) the sunfish, *Lepomis gibbosus*, and horned dace, *Semotilus atromaculatus*, were trained to discriminate light of longer wave lengths from light of shorter wave lengths and from clear light. *Blennius pholis*, used in experiments reported by Bull (1957) in which he applied differential conditioning, displayed unusual ability to qualitatively discriminate monochromatic lights. One of the most interesting studies on color vision in fishes recently published is that of Arora and Sperry (1958). These investigators applied training techniques too. *Astronotus ocellatus* was used as an experimental animal. They found that this fish was able to distinguish red, blue, yellow, and green lights, and painted objects from each other and from various shades of grey. After training, the optic nerve was sectioned; the fish became blind. Regeneration of the sectioned optic nerve and restoration of vision took from 36 to 40 days; upon recovery of vision the fish displayed an ability to discriminate among the colors without further training. A fish which had not been trained prior to the blinding, by sectioning of the optic nerve, learned color discrimination as fast as normal fish. In the opinion of Arora and Sperry, the fish were able to discriminate between colors qualitatively rather than merely because of variation in intensity. In the much earlier work of Brown (1937), who worked with large-mouth black bass, it was concluded that, "in general, and excepting the violet, the degree of difference of different colors to bass is a function of difference in wave length." Puchkov (1954) states, "the ability of the fish to distinguish colors undoubtedly exists." Discussing the results of von Frisch's (1933) experiments, Puchhov observed, "if the fish were color blind, it would per-

[11] Similar seasonal peculiarities in the behavior of certain marine fishes were recently reported by several Russian investigators: Parin (1956) in regard to saury; Safianova (1952, 1958) and Radakov (1956) concerning the Black Sea anchovy, *Engraulis encrasicholus pontica*, and horsemackerel, *Trachurus trachurus*; and Lovetskaya (1958) about the Caspian sprat, *Clupeonella delicatula caspia*.

Of the freshwater fishes, adult bream, *Alburnus alburnus*, in experimental studies in the laboratory carried out by Privolnev (1956) displayed phototactical periodicity with a change four times a year.

ceive the red color as grey, and thus it would mistake red cups for the grey ones of corresponding brightness. However the fish always distinguished red cups from the grey ones of different degrees of brightness." Walls (1942) flatly concluded that "no reasonable student of the problem [of the color vision in fishes] any longer doubts that fishes—all duplex teleosts at least—can experience hue as a sensation-quality apart from brightness." Fifteen years later, Brett (1957) recognized Walls' statement as the best formulated conclusion to the problem.

As to the present study of the innate ability of the northern anchovy to react differently to light of different wave lengths, the authors are inclined to consider the anchovy's perception of the applied lights strictly as a function of wave length apart from the intensity of the light, in accordance with their earlier report on color vision in the Pacific sardine (Loukashkin and Grant, 1959).

(2) On responses of the northern anchovy to ultraviolet wave length in relation to reactions of other species.

Illumination of the aquatic media differs from that of the aerial environments both quantitatively and qualitatively. Clark (1954) said that the sunlight upon entering water undergoes many changes. First of all, about 10 per cent or more of the light is lost because of reflection at the surface or beneath it. Traveling downward, the light is further modified not only in its intensity but also in its spectral and other properties.[12]

Baburina (1955) states that infrared rays are absorbed in the first meter layer of water. Ninety per cent of the red rays disappear within a depth of five meters; and ninety per cent of the green region of sunlight spectrum is absorbed before reaching thirteen meters of depth. Only violet and ultraviolet rays reach a depth of five hundred meters. The ultraviolet rays were detected 1,000 and more meters below the ocean surface. In conformity with this she maintains that "the eye of the fish is less sensitive to the red and more sensitive to the yellow, green, blue, and violet rays than the human eye, but in contrast with the human eye it is also sensitive to the ultraviolet region of the spectrum." Craig and Baxter (1952), speaking of the physiological importance of the ultraviolet component of natural light in aquatic environments, observed that "in the sea water there is differential absorption so that the centre of maximum intensity is displaced somewhere towards shorter wave lengths, the precise effect depending upon depth and the nature of the sea water. We should not, therefore, be surprised to find marine creatures sensitive to a range including a portion of ultraviolet spectrum." These theoretical reasonings concerning the ability of the fish

[12] For instance, Boden *et al.* (1960) found that in the Bay of Biscay sunlight passing through water "becomes steadily bluer with depth until at 400 meters the spectrum peaks sharply between 475 and 480 millimicrons."

eye to perceive ultraviolet wave lengths appear to be well founded and correct as has been demonstrated by recent experiments in both the open sea and in the laboratory.

Protasov (1957), who applied an electrophysiological method in the investigation of vision in a number of marine fishes, obtained definite proof that the Black Sea ombre, *Corvina umbra*, could respond to ultraviolet rays as positively as to the rays of the visible spectrum.[13]

With facilities, sources of radiation, and techniques used in the present study, natural responses of the anchovy to ultraviolet rays seemed to be misleading because the fish responded inconsistently to ultraviolet light in various combinations with opposing wave lengths of light. These responses were found to vary from indifferent and negative to highly positive. Because of this seemingly individualistic and confusing behavior of the anchovy in response to the ultraviolet radiation, further experimentation is necessary, especially in total darkness with the application of better filters totally isolating the wave lengths of the visible region of the spectrum. Breder (1959), who experienced the same difficulties with his experimental fishes, in his very carefully worded conclusion states "there is some evidence to support the view that some fishes show a positive reaction toward ultraviolet wave length, but this requires extended analysis . . ." He found out that males of *Gambusia* sp. were ultraviolet positive, the females negative. In his experiments *Anoptichthys hubbsi* reacted positively, and *Anoptichthys jordani* negatively in one case; both species were slightly negative in another case. *Jenkinsia lamprotaenia* was found to be "ultraviolet positive to a very marked extent," and *Atherina stipes* showed an individualistic behavior toward the ultraviolet, being either attracted, or repelled, or indifferent. *Brachydanio rerio* displayed a strong positive reaction to the ultraviolet radiation.

As to the use of sources of ultraviolet radiation in tests in the open sea, only a few attempts have been made. A Netherlands research vessel carried out experiments along the Belgian coast but without success (de Boer, 1950). Craig and Baxter (1952), however, obtained immediate reactions of several species of marine fishes and other marine organisms to a submerged source of ultraviolet radiation (125-watt "black" ultraviolet lamp). They list the following fishes as influenced by ultraviolet rays: herring, mackerel, horsemackerel, dogfish, and whiting. Blaxter and Parrish (1958) also obtained positive aggregation of fish around the same source of radiation as used by Craig and Baxter, but they assumed that the reactions to the ultraviolet light might have been "due to the fluorescence from microorganisms in the water" rather than to the "black light" itself.

The inconclusive results of the experiments herein discussed prompt

[13] Of freshwater fishes, the trout and pike have been known to perceive ultraviolet wave lengths of light ("Reflector," 1949).

the authors to consider the data obtained as a preliminary step toward further experimentation using improved sources of radiation and applying perfected techniques in the study of behavioral responses of the marine fishes toward ultraviolet radiation.

(3) On responses of the northern anchovy to infrared radiation with reference to experiments of other behaviorists.

There was no evidence that they were attracted, repelled, or frightened by the radiation, which suggests that they did not perceive the infrared wave length. This conforms with work of Duncan (1956) who found that fingerling silver salmon, *Oncorhynchus kisutch,* failed to respond in any manner to infrared radiation. Breder (1959) has found no indicative evidence that fishes would respond differently to radiant heat (infrared radiation) and ambient temperature.

(4) On responses of the northern anchovy to different values of intensity of white light.

The experiments using white light of varying intensities in two separate arrangements (in one these intensities ranged from 2 to 100 foot-candles, in the other from 75 to 500 foot-candles) revealed a natural ability of the anchovy to respond positively to intensities of moderate values regardless of the order of light arrangement, and to react negatively to both the highest and the lowest intensities in the arrangement. On the other hand, in a series of experiments utilizing sharply contrasting light intensities presented in pairs, the anchovies always responded positively to the lower values and displayed a marked avoidance reaction toward the brighter illumination. The results obtained in the present preliminary study suggest other tests, to be made in near future, might disclose the degree of sensitivity of the fish eye to the changes in the intensity of illumination, as well as the specific adaptation of the eye to certain intensity values as earlier demonstrated by Privolnev (1958) on samples of young carp, *Cyprinus carpio,* and young tench, *Tinca tinca.* He had found both were able to differentiate intensities of white light when these intensities were 75 per cent to 85 per cent greater than those to which the experimental fish were originally adapted.

As with other species found suitable for training, the northern anchovy and Pacific sardine should not present any difficulty in training studies. Usually, the newly delivered wild anchovies and sardines began to take food after 5 to 7 days of acclimation to the artificial environment of the Steinhart Aquarium. Following this, the fish were trained to break up the school, to ascend to the surface, and to swim close to the position occupied by the feeding person. The training consisted of propelling a tablespoon in the water for 10–15 seconds prior to dropping live food (brine shrimp) into water. Both the sardines and anchovies became conditioned to the sound of propelling the spoon, developing a feeding reaction within three to five trials (once a day), and they retained this response permanently. This conditioned response was of great help to the investigators at times when they had to pick up a few live specimens from the 1,000-gallon tank.

V. SUMMARY

1. The present investigation was conducted in order to study experimentally the effects of various types of illumination on the northern anchovy, *Engraulis mordax* Girard, from the point of view of its ability to discriminate between different wave lengths of the light spectrum and different intensity values of the white light.

2. The discriminating ability of the anchovy in regard to different types of visible and non-visible light radiation was explored in the specially constructed dark room and an experimental wooden tank which was divisible into a number of light zones [in accordance with the nature of the experiment to be carried out].

3. In the two-zone experiments the following paired lights were tested: green-blue, green-red, green-white, green-darkness, blue-red, blue-white, blue-darkness, red-white, red-darkness, and white-darkness. Ultraviolet was tested in pairs with green, blue, red, white, and darkness; infrared with darkness or with white light.

4. In the three-zone experiments the following combinations of lights were tested: green-red-white, green-white-darkness, red-white-darkness, blue-red-darkness, and blue-green-white ("daylight").

5. In the four-zone experiments the green-blue-red-darkness combination was tried.

6. In the two-zone experiments with monochromatic and white lights, the intensity was maintained uniformly at the 9 foot-candle level; in experiments with monochromatic lights and ultraviolet rays the intensity was adjusted to the maximum intensity of the "black lamp" which was equivalent to 0.2 foot-candle. In other experiments using ultraviolet or infrared wave lengths and white light or darkness, the intensities varied from almost zero to 500+ foot-candles.

7. In the three- and four-zone experiments, the intensities of monochromatic and white lights tested were either uniform or of different values.

8. In all combinations of monochromatic and white lights, the effect of red light on the anchovy remained invariably negative in contrast to the sharply positive reaction of these fish toward other lights tested.

9. In two-zone choice experiments the positive reaction of the anchovy for green light was found to be 97.86 per cent over the red (2.14 per cent);

75.34 per cent over white (24.66 per cent); 73.18 per cent over blue (26.82 per cent). The preference for other lights, tested in pairs, was as follows: 81.60 per cent for blue light over red (18.40 per cent), and 52.15 per cent over white (47.85 per cent); and 88.39 per cent for white light over red (11.61 per cent).

10. In the three- and four-zone experiments, the anchovies consistently demonstrated positive responses toward the green light as they did in the two-zone experiments. Even a considerable increase in the intensities of the opposing lights could not alter the positive reaction to green light.

11. In the two-zone experiments using ultraviolet light paired alternately with green, blue, or red light, the anchovies displayed three conflicting responses. These responses were "indifference" in ultraviolet versus blue light (50.15 per cent – 49.85 per cent), "slightly negative" (45.21 per cent) when ultraviolet was contrasted with green light (54.79 per cent), and "highly positive" (71.97 per cent) when it was paired with red (28.03 per cent).

12. In the other two-zone experiments, when ultraviolet and white lights of much higher intensities were tested, the results were confusing as described above. With respect to the ultraviolet light, the responses of the anchovies varied from negative or avoidance (36:64), through indifference (50:50), to positive (72:28).

13. In experiments utilizing infrared radiation, the anchovies seemed totally unable to perceive it.

14. In experiments intended to test the ability of anchovies to differentiate among different white light intensity values they seemed able to do so as evidenced in the tests with four and five intensity zones, and even more markedly in the two-zone experiments.

15. In the five-zone test arrangement in which intensities of light ranged from 2 to 100 foot-candles, the fish responded preferentially to the moderate intensities of the central zones (29.23 per cent for the 20 foot-candle zone, and 41.94 per cent for the 50 foot-candle zone, or 71.17 per cent for both).

16. In the four-zone test arrangement of white light used in intensities of 75, 125, 250 and 500 foot-candles, the anchovies reacted toward the moderate intensities of 125 foot-candles (30.21 per cent) and 250 foot-candles (37.16 per cent).

17. In the two-zone test experiments involving sharply contrasting intensities of 500 foot-candles, as a constant value, paired with much lower values ranging from 2 to 20 foot-candles, the reaction of the anchovies was always in favor (60.42 per cent to 83.71 per cent, averaging 68.52 per cent) of the lower intensity values.

18. The experiments herein described and discussed reveal a few important factors in the reactions of the anchovy to light and darkness: (1) the an-

chovy is a phototactic animal; (2) it is capable of discriminating qualitatively between monochromatic (green, blue, red) and white lights; (3) it is able to distinguish green light from blue (the Pacific sardine failed to do so); (4) it shows a preference for green and blue lights over white; (5) it proved to react strongly negatively to red light. However, the fish tolerated this type of illumination when it was tested as an alternative to total darkness, and showed a highly positive response in such a case to the red light; (6) in its reaction toward the ultraviolet wave lengths it displayed a rather individualistic pattern of behavior; (7) it is unable to perceive infrared radiation; (8) it is capable of reacting differently to different intensities of white light ranging from 2 foot-candles to 500 foot-candles.

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