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Investigations of the applications of ~~Scuba~~ SCUBA and free swimming techniques in fresh water and salt water fishery biology 1957

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INVESTIGATIONS OF THE APPLICATIONS OF SCUBA AND FREE SWIMMING TECHNICS IN FRESH AND SALT WATER FISHERY BIOLOGY

by

Donald A. Thomson

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Fisheries

January 1957

School of Natural Resources

University of Michigan

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Committee members:

Dr. Karl F. Lagler, Chairman
Dr. Gerald P. Cooper

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
FRESHWATER APPLICATIONS OF UST IN MICHIGAN LAKES	3
Sight identifications	4
Observed distribution and movement of game fish	6
Fish counts in Michigan lakes	8
Spearfishing	11
MARINE APPLICATIONS OF UST IN BERMUDA	14
A fish count on a coral reef	15
CRITIQUE OF DIVING EQUIPMENT	20
SUMMARY	23
TABLES 1 to 9	25
LIST OF SCIENTIFIC NAMES	36
LITERATURE CITED	37

LIST OF TABLES

Table		Page
1	Michigan lakes chosen for study with Secchi disc readings and number and duration of underwater observations	25
2a	Physical and chemical characteristics of Michigan lakes in UST studies (June 23 to Sept.12, 1955)	26
2b	Some ecological features of the study lakes: bottom types, vegetation density and game fish abundance	27
3a	Comparisons of species listed by UST and by regular survey technics (gill nets, seines, rotenone, and hook and line fishing)	28
3b	The evaluation of UST as a supplementary fish survey technic	29
4	Observations of smallmouth bass using brush shelters at Pratt Lake, Luce Co. (July 29 to August 3, 1955)	30
5	Comparison of relative abundance estimates: catch per standard gill net set with numbers of fish counted by divers per half hour	31
6	Fish count of a coral reef near Bermuda	32
7	Ledge count of 8 common reef fishes	33
8	Top of reef count of 8 common fishes	34
9	Comparison of fish counts by hydro-pak and snorkle	35

INTRODUCTION

The advent of the aqualung, patented in 1943 by Cousteau and Gagnan, caused a major revolution in man's attempts to explore the underwater frontier. With this self-contained underwater breathing appratus (SCUBA) man gained the freedom of a pseudo-fish, he was no longer burdened by bulky diving suits, helmets, heavily weighted shoes, and entangling air lines, and he no longer had to depend directly on the atmosphere for his air supply. The excitment of this discovery along with the raves of its supporters created skin diving enthusiasts throughout the world.

While skin diving as a sport was establishing itself in the United States and other parts of the world, practical professional men were discovering wide and varied applications for this new diving gear. There is little need for comment on the technics that the U. S. Navy developed with their frogmen or on the extensive uses that the scientists at Scripps Institute of Oceanography found for SCUBA. Many aquatic biologists soon took advantage of SCUBA in various aspects of research. Limbaugh and Rechnitzer (1955), through diving, have visually detected density continuities in the Pacific near California, while Banner (1955) actually saw the thermocline in the ocean off Hawaii. Walker (1955) was able to observe an experimental trawl in operation underwater, and Hassler and Villemonte (1953) observed the daily movement of perch in a Wisconsin lake. Brock (1954) devised a method for estimating reef fish populations by an underwater census. These are only a few examples of recently developed SCUBA technics.

This paper deals specifically with the uses and applications of SCUBA in connection with free underwater swimming technics (UST) in fisheries management and research.

The Institute for Fisheries Research under the supervision of Dr. Gerald P. Cooper sponsored the research in certain Michigan lakes. The marine study was sponsored by the Bermuda government and was part of a fisheries research program directed by Dr. John E. Bardach of the University of Michigan.

FRESHWATER APPLICATIONS OF UST IN MICHIGAN LAKES

To investigate the practical application of UST in lake surveys it was necessary to choose a random sample of lakes for study. It was decided that a number of lakes in the Upper Peninsula, Michigan, which were scheduled to be surveyed by the Institute for Fisheries Research during the summer of 1955 might be adequate. From June 20 to September 15 the survey crew (Merle Galbraith, Harold Huizinga, and Don Thomson) surveyed 14 lakes in 8 different counties. Along with the Institute's standard lake survey procedures the survey crew employed underwater diving equipment in an attempt to: (1) determine the supplementary value of several diving technics to lake surveys; (2) investigate certain underwater survey procedures; (3) make casual natural history observations; and (4) make comparisons of the results between underwater survey technics and standard lake survey methods.

The study lakes (Tables 1, 2a, 2b) ranged from 19 to 890 acres in size, with maximum depths of 8 to 50 feet. The lakes can be classified as mesotrophic with a tendency towards eutrophism (Welch, 1935). The average depth of the epilimnion was 17 feet. A thermocline was present in most of the lakes, its average thickness being 6 feet, with a lower limit averaging 24 feet. The average maximum depth at which oxygen was less than 4 ppm was 20 feet. The average methyl orange alkalinity at the bottom was 38 and the average pH of the surface waters was 7.5. The Secchi disc reading of the 14 lakes ranged from 4 to 18 feet, and the water color varied from colorless to light brown.

Since water transparency is an obvious limiting factor in underwater observations it was only possible to employ UST successfully in those lakes which had a Secchi disc reading of 10 feet or more, on in 11 of the 14 lakes surveyed. A limited amount of diving was feasible in 5 light-brown colored lakes. Only one lake, Mink Lake, Gogebic Co., was too turbid to allow any diving whatsoever. However, due to weather conditions and the amount of time allotted to each lake by the survey schedule, data could be collected from only 7 of the lakes.

Sight Identifications

It was relatively easy to identify most of the fish encountered underwater, with the possible exception of some of the minnows. The major problem, which was overcome through practice, was estimating their sizes. Soon all swimmers were able to estimate the size of at least the game fish to the nearest inch. Table 3a summarizes the fish that were identified underwater by lake, comparing these with the fish collected with survey methods (gill net, seine, rotenone, etc.), noting the unit effort in each case.

The fish most frequently misidentified by the swimmers were some of the minnows of the genus Notropis, and it is likely that some species of that genus were wrongly identified as "N. cornutus. Certain darters of the genus Etheostoma were missed by the swimmers, probably because little effort was made to search the bottom among the rubble and deadheads in the very shallow water, a favorable habitat for darters.

Although northern pike were present in fair numbers in 4 of the 7 lakes studied, pike were spotted underwater in only one of them. Most of the swimming was done in shallow weedy areas of the epilimnion where one might expect to find pike. Of the pike observed in Monacle Lake, none were larger than 20 in. and they were relatively easy to spot and approach. Perhaps the larger pike seek deep cool waters in the daytime moving to the shallows, where observations were concentrated, only to feed.

Bullheads were rarely seen in the daylight hours when most UST observations were made, although they were relatively numerous when sought at night with the aid of an underwater light.

Walleyes were occasionally seen in the daytime near the dropoffs, but such sight records were infrequent and probably accidental.

The remaining fishes which include the basses and sunfishes, the perch, and the suckers, were readily observed in the shoal areas and easily identified.

With reference to Table 3a, it is apparent that the total number of separate observations and the amount of time spent underwater are important to a reliable underwater survey of fishes present. In the last 3 lakes in Table 3a, McKeever, Grassy and Kingston, where a total of only 8 hours (average 2.6 hrs./lake) was spent diving, a known total of 17 species was not seen by the divers, whereas gill netting, seining, and rotenone missed only 3 species (identified by the divers). In the first 4 lakes where a sufficient amount of time was spent underwater ($40\frac{1}{2}$ hrs.) with an average of 10 hrs./lake, a total of only 9 species was missed, 7 of these were minnows difficult to identify in the field. However, it must be emphasized again that there was no intensive effort to search for the small forage fishes. Nevertheless, on the credit side, divers recorded 7 species that were not collected by conventional survey gear.

The value of UST in species listing is summarized in Table 3b. The data in this table indicate that UST as applied in this investigation is not sufficient in itself to provide a valid survey of the species present in a given body of water. However, it has definite value as a supplementary technic as demonstrated by the species that were not collected by fishing gear but were seen and positively identified by divers.

Observed Distribution and Movement of Game Fish

Diving gear enables one to locate and make direct observations on schools of fish in various depths and places. During the summer, the 3 divers made 59 individual observations with an average duration of 53 minutes per observation for a combined total of 3,150 minutes underwater. Most of the diving took place in water from 5 to 15 feet deep where the only necessary equipment was swim fins, a face mask and a snorkle. Depths of 15 to 30 feet were investigated with the aid of the Scott Hydro-pak.

The region most intensively surveyed was that layer of the epilimnion which had contact with the bottom. This included most of the shoals, the shoreline and the dropoffs. A rubber suit was required for excursions into the thermocline or hypolimnion; however descents into these layers were both infrequent and unproductive.

Centrarchids. There appeared to be no correlation between temperature of the water or depth with the locations of centrarchids in the epilimnion, but it was apparent that shelter was an important factor in their horizontal distribution. Smallmouth bass and rock bass were almost always associated with deadheads and brush pilings. Large schools of rock bass and immature smallmouths were frequently observed together under the shelter of fallen trees and logs. Likewise, adult smallmouth bass, estimated from 1 to 4 pounds in weight, were commonly seen under deadheads near the shoreline and along the dropoffs.

Bluegills, pumpkinseeds, and largemouth bass were regularly observed in regions of abundant vegetation. Bluegills and pumpkinseeds were infrequently seen near deadheads, however, largemouth bass would use deadheads for cover if emergent vegetation was lacking.

During the day the larger smallmouth and largemouth bass were nearly always found near deep water into which they would quickly descend when disturbed. A group of 6 largemouth bass estimated between 2-3 pounds in weight was observed in a dense bed of Nymphea odorata in a shallow bay (3-4 feet deep) at Petes Lake on one afternoon. These fish were at least 200 feet from the dropoff. Apparently they found "security" under the thick bed of lily pads. One of the bass was speared (16 in. 2½ lbs.) and when the diver came back to the same place about 15 minutes later the other bass had departed. It was not at all rare to find bass of this size in the very shallow water at midday (as many bass fishermen know).

Adults of both smallmouth and largemouth bass were rarely seen together in the same ecological niche. Bluegills and pumpkinseeds were frequently associated with largemouth or smallmouth bass, but rock bass were very seldom observed among schools of bluegills and pumpkinseeds. Green sunfish were rarely seen and there were no records of crappies in any of the lakes studied.

Percids. Yellow perch were commonly observed throughout the shoal areas and in the deep water. They were found among aggregations of centrarchids in shallow water and in large schools by themselves in or over the deeper waters. The daily movement of perch from deep water (20 to 25 feet) to shallow water at night (2 to 5 feet) was observed in Pratt Lake. During the day no perch were seen on the shoals, but large schools were observed near the bottom in 20 to 25 feet of water (still in the epilimnion in this lake). At night hundreds of perch were observed "sleeping" on the sand bars in the shallow water.

Other fishes. Northern pike were rarely seen by the divers even in lakes where they were known to be common. Their absence in sight records remains to be explained. The white sucker was present in fair numbers in almost all of the lakes surveyed. Few large individuals were seen in the shoals but gill netting indicated that more were present in deep water. Bullheads were never observed during the day but were quite commonly seen at night, while the investigator was swimming with the aid of an underwater flashlight. All of the remaining fish, which include the minnows and darters, were abundant in the shallow water and were not observed at the bottom in waters deeper than 5 feet.

Smallmouth Bass Movements in Pratt Lake

Pratt Lake is a circular single basin lake 24-acres in size with poor shoreline development and very sparse bottom vegetation. Brush shelters for fish had been installed a few years prior to our survey. To determine what fish, if any, were using the shelters, 12 selected brush shelters were marked with small wooden buoys and were checked daily for a week by a diver using a face-mask and snorkle. The only fish using the shelters were smallmouth bass, although there were yellow perch, bluegills and suckers in the lake. All of the smallmouth bass, with the exception of the young of the year, that were counted at the brush-shelter stations are listed in Table 4.

The total number of bass observed on each complete circuit of the brush shelters decreased steadily with repeated counts from day to day while the number of bass seen between shelters appeared to increase, although no careful counts were made of these wandering bass. It appeared that the bass were disturbed by the presence of the divers and either swam away when the swimmer approached or temporarily avoided using the brush shelters.

Fish Counts in Michigan Lakes

It is beyond the present methods of fishery science to obtain a reliable index of population estimate of a lake in a period of a few days. An oft used substitute, however, is an estimate of relative abundance. In lake surveys this is accomplished by gill net settings, seine hauls, casual observation and hook and line fishing. None of these methods is adequate in itself since each is selective for certain species.

The SCUBA method of estimating relative abundance is a fish count by direct observation. Counts of this type were performed in most of the lakes surveyed. Although the count was unbiased it was not at random since shoals to be traversed were chosen by the swimmer beforehand. This was done because it was desirable to count as many fish as possible in a short period of time. Promising spots were given priority over seemingly sterile ones. However, this should not make a difference in a relative abundance estimate as it would in an absolute population estimate.

All counts were made with the aid of a diving mask, a pair of fins and a snorkle. Rough surfaced plastic cards were employed in pencil tabulation of the data while underwater. The swimmer would swim at the surface of water 2 to 15 feet deep, diving toward or to the bottom if necessary to make an observation. The majority of the counts were executed along the dropoffs with the exception of expansive shoal areas in Monacle lake, and among brush shelters in Pratt and Ice lakes.

Useful interpretation of the count is possible only if the assumption is made that the shoals of the epilimnion (where the count was concentrated) are the habitats of the species of fish included in the count. Therefore, coldwater fish like trout and ciscoes and nocturnal fish, like bullheads and walleyes can not be included.

With the basic assumption that the areas chosen for counting are representative of the fish habitats of the lake, it is possible to equate the counts to a unit of effort and to compare them with other estimates. Since the average time spent in the water at any one time was $\frac{1}{2}$-hour, the counts will be averaged at a $\frac{1}{2}$-hour unit time. The gill net settings (experimental mesh) were overnight and were standard net sets, the catch being tabulated using the gill net index, catch/100 ft./24 hrs. (Moyle 1949), with the substitution of 125 ft. gill nets instead of 100 ft. nets. A comparison of the gill net catches with diving observations in 3 lakes comprises Table 5.

It has been shown that gill nets are very effective in sampling yellow perch, northern pike and walleyes (Carlander 1954), but it also is known that gill nets are poor gear for sampling centrarchid populations, especially the black basses. Thus it can be expected that relative estimates of bass abundance will be erratic and inaccurate from lake to lake if sampled by gill nets, while similar estimates of yellow perch populations would be more reliable. For example, the most abundant fish in Monacle L. was the yellow perch and this was borne out by both gill net and UST. Second in abundance was the rock bass which likewise checked out in both methods. The white sucker ranked even with the rock bass in gill net captures, but gill nets are much more efficient for suckers than for rock bass. USt listed the smallmouth bass third, whereas gill nets indicated that the walleye was next. Here we have a situation where the walleye is susceptible to gill nets and infrequently seen by divers, whereas the smallmouth bass is vice versa.

In Petes L. relative abundance estimates by the two methods we are comparing disagreed completely. The gill net results had smallmouth bass and the white suckers as the two most abundant fish in the lake, whereas UST showed the yellow perch and the rock bass to be present in relatively greater numbers. The great number of smallmouth bass (39) caught in gill nets, an unusual occurrence, accounted for this discrepancy in part. However, great numbers of yellow perch and rock bass were counted in the sole dense weed bed in the lake. This area was traversed more than once and repeated counts may have biased the estimate.

Since there is no practical way of checking these estimates the data must be evaluated subjectively trying to determine the limitations of the technics employed. First, the most important consideration in executing underwater fish counts is choosing good representative counting sites. Second, it is desirable to establish a minimum limit on the amount of time necessary to obtain a reliable estimate. This was not determined during the survey, but could be determined experimentally in large hatchery ponds with a known fish population. Third, time of the day and season of the year are important factors. There is need for more study on the effect of weather and available light on the movement and locations of species populations.

Since most of our counts were carried out with only a snorkle, the depth a diver could attain and accurately count fish was severely limited. However, this may not be as serious a defect as it seems since oxygen dropped off rapidly at 20 feet in most of the lakes and the greatest areas habitable to fish during the survey season were in less than 15 feet of water. It was not difficult to approach and count the fish, on the contrary, many of them were curious and swam out from their hiding places to inspect the swimmers.

Summarizing, UST appears to be applicable with a reasonable degree of accuracy to counts of large and smallmouth bass, bluegills, pumpkinseeds, rock bass and yellow perch. Underwater counts of walleyes, northern pike and white suckers have not been successful in this study.

Spearfishing

Saltwater skindivers have shown the underwater spear gun to be a deadly weapon against many species of fish. The use of this gear in fresh water has been somewhat limited, although it has been used by divers for rough fish control in certain designated waters. Michigan however, totally probibits the use of any mechanically powered speargun in its inland waters and the Great Lakes. Consequently, little is known about the effectiveness of the speargun as a fish-killer.

To determine the effeciency and effectiveness of the speargun as a collecting tool, or as fishing gear, an "Arbalete" single strand rubber propelled speargun was used. The divers, who had no previous experience with spearfishing, kept count of the numbers of times they "fired" their guns and the number of fish they killed. The kill by this means is summarized as follows:

Number of fish speared	Species	Size range (inches)
10	Largemouth bass	6 to 16
14	Smallmouth bass	4 to 18
5	Bluegills	5 to 7
3	Pumpkinseeds	4 to 6
12	Rock bass	3 to 11
14	Yellow perch	5 to 12
1	Walleye	15
5	Northern pike	5 to 20
2	White suckers	13 to 15
1	Brown bullhead	9

The 3 divers killed a total of 67 fish in 142 shots in a total of 39 "hunting" hours. The time involved is not at all indicative of unit effort since much of the spearfishing was selective for large fish, especially bass. Furthermore, a diver would sometimes carry a speargun along while taking fish counts and such shooting would be highly fortuitous.

The most effective spearhead was found to be three-pronged and triangular, (a trident). It worked well against large and small fish alike.

In the majority of the lakes surveyed the effective range of the speargun followed closely with the limit of visibility, a maximum of about 15 feet horizontally. However, most of the kills were made within 10 feet of the diver. On several occasions fish were hit with glancing blows and the head of the spear did not penetrate. Other times the spear penetrated the body musculature and the fish was able to free itself by violent struggling. Both such events were recorded as misses.

Practically all of the fish encountered were easily approached, if the diver took care not to make any quick motions. For this reason, it was sometimes difficult to aim the speargun since the slightest jerky movement would send the target fish scurrying. Many times the fish would swim so close to the diver that it was very awkward for the hunter to get in position for a shot. This happened quite frequently while hunting in areas of dense vegetation or brush pilings, where large curious bass often swam within 3 feet of the diver. Contrasting, in shallow water where cover was poor or altogether lacking, it was very difficult to get within shooting range of large fish.

The investigations of the survey party indicated that the speargun even in the hands of a novice can be an effective deadly weapon against game and rough fish alike. Whereas, it may not be practical to collect large quantities of fish in this manner, the speargun can be a useful tool to a biologist when only a few fish are needed in as short a time as possible.

MARINE APPLICATIONS OF UST IN BERMUDA

I had the opportunity to investigate the application of UST in salt water while at the Bermuda Biological station during the summer of 1956. In a research program directed by Dr. John E. Bardach and supported by the Bermuda government it was possible to do considerable diving in connection with research on the ecology and behavior of coral reef fishes. Most of the diving took place on the shallow outer reefs north of the islands where tagging experiments on reef fishes were being carried out.

The warm water (78 to 83°F) made it very comfortable for diving, while its high transparency (Secchi disc reading ranged from 50 ft. close to shore to 120 ft. beyond the reefs) provided ideal conditions for underwater observations. It is possible only to mention briefly some of the many ways in which diving aided marine research activities in Bermuda:

1. Snorkle-equipped divers were needed frequently to locate fish pots that had been lost among the coral heads. Divers also freed anchors, recovered lost gear, unfouled ship propellers, etc. Hand line fishing with a face plate and snorkle aided in the capture of certain fish for laboratory experiments.
2. A group of divers with lungs and snorkles poisoned a reef with rotenone by carrying down cans and jars of emulsified "Fish-Tox" and distributing it throughout the reef. The divers also collected the dead fish from the bottom, while snorkle-equipped swimmers helped pick up the dead fish from the surface.
3. Drs. Talbot Waterman and Richard Bainbridge studied, with the aid of the aqualung, the orientation movements of various micro-crustaceans in response to polarized light.

4. Dr. Donald Comb and this writer collected conchs in deep sand holes with the aid of a hydro-pak.

5. Dr. J. Bardach and this writer took movies and color photos respectively of several of the brilliantly colored coral reef fishes with UST.

6. Dr. Howard Winn and Mr. Clarence Smith used the arbalete speargun in collecting various species of fish for museum and classroom study Winn and Smith also collected small gobies and blennies underwater with the aid of a small aquarium net and vials. Smith earlier perfected this technic in Puerto Rico (Smith 1957).

There is little doubt that diving gear has become an indispensible tool to marine biology. The following pages demonstrate with data an important application of diving gear to marine fishery biology.

A Fish Count on a Coral Reef

An estimate of a standing fish population on a typical coral reef was required to supplement certain investigations of the Bermuda Fisheries Research Program. A solitary, circular reef was chosen for a fish count. This reef was a good representative of the off shore shallow reefs around Bermuda. It was almost circular in shape and about an acre in area. The average water depth over its upper surface at high tide was about 8 feet with a couple sand holes exceeding 20 feet. The margining ledges were quite abrupt and dropped off to a sand bottom 45-50 feet deep. The water was quite clear and it was possible to see the bottom in 50 feet of water while swimming at the surface.

The reef was divided (by divers) into 8 lanes ranging from 25 to 30 ft. in width with discarded black electrical wiring. The wires were either fastened down by weights or tied to the coral, and were marked by a float at each end. The lanes ran the width of the reef and were 200 to 250 ft. long.

The count was executed August 26, 1956, with the aid of some personnel from the biological station and two naval officers. It was decided that the count along the steep ledge of the reef be carried out first to avoid confusion and reduce disturbance to a minimum. This count was performed by two pairs of divers in hydro-paks. One diver took the bottom of the reef ledge (45 to 50 ft.) and the other swam directly above him near the surface of the reef. Each diver counted the fish below him and to his side. Each pair of divers started at the same time and place but proceeded in opposite directions so as they crossed they counted the area covered by the other pair. For this count, the divers were as follows: 1st pair, bottom- C. Smith, top- H. Winn; 2nd pair, bottom- Lieut. Commander R. Emerson, top- Lieut. Commander L. Rosekranz.

The top of the reef count employed four divers with hydro-paks and four snorkle-equipped swimmers, one to accompany each diver. Each pair of divers situated themselves at opposite ends of the reef and began swimming simultaneously in the same direction so that they would eventually meet and cross-over. The diver was instructed to count only the fish in his lane and those entering his lane from an uncounted lane. The snorklers would do the same and would follow behind their respective partners. In this manner the entire top of the reef would be counted four times. The paired divers were as follows: Hydro-paks....A- D. Thomson, B- J. Bardach, C- L. Sutcliffe, and D- W. Sutcliffe; Snorkles....A- H. Winn, B- C. Smith, C- R. Emerson, and D- L. Rosekranz. The complete count of the ledge and surface of the reef is listed in Table 6.

A cursory examination of the data in Table 6 will show considerable errors in the count of certain species. Many reef fishes spend most of the day hiding in holes and crevices among the coral. These include the rockfish, hamlets, hinds, conies, gags, yellow grunts and squirrel fishes. The squirrel fish, being the most nocturnal of the group, remains hidden most of the day and seldom ventures out, while the others stay close to their holes and retreat into them when disturbed. A complete count of such fish would be difficult to achieve. The grey snapper is fond of both shelter and shade, but because of its curious nature this fish was seen quite readily. The angel fish, doctor fish, spanish hogfish and parrot fishes are all herbivorous browsers. While the angel fish dart into holes when frightened, they quickly reappear and continue browsing. Studies by Bardach (unpublished) showed that none of these herbivores move about the reef to any great extent, nor are their activities greatly disturbed by the presence of divers. Yellow-tail snappers are transient species. The amount of time they spend on a given reef is not known. Since they are not secretive in habit they are readily seen. The remaining fishes occur in small numbers and are insignificant in the total count.

Table 7 compares the results obtained by the divers who were counting fish along the ledge. A total of 15 species were counted but only 8 of the commonest reef fishes will be discussed. Counts of angel fish and parrot fish checked fairly closely, indicating that these fishes were not driven away by divers. The discrepancy in the bottom count of a school of doctor fish was either due to the error of the observer or to movement of the fish. The second counts of the spanish hogfish and yellow grunt (bottom) were far lower than might be expected. However both of these fishes live in holes and were probably hiding after being disturbed by the first divers. Also, since the yellow grunts occurred in large clusters the divers may have miscounted them. The top and bottom counts of the grey snappers differed both times, and coincidently in the same proportion. Since this fish is curious and will sometimes follow divers, the presence of swimmers may have attracted some snappers from the surface of the reef. The hamlets and hinds stayed under cover most of the time. The count of these 2 serranids was far lower than predicted by tagging studies.

Excluding the variety of small fishes, 17 species were counted on the top of the reef by 8 divers. The commonest species are listed in Table 8. "A and B" were paired divers, as were "C and D" also. Together each pair covered the entire surface of the reef. The counts of one member of each pair are compared with their counterparts.

It becomes evident from Table 8 that considerable error arises in employing 8 divers. Each additional diver represents an additional variable increasing the standard error of the sample. In Table 9 the counts of each diver are combined with those of his partner and are treated as single counts. The combined counts of each pair of workers (Table 9) compare quite favorably in the angelfish, doctor fish, spanish hogfish and yellowtail snappers. The small differences are probably errors in counting or recording. The counts of the other 4 species (hamlet, hind, grey snapper, and parrot fish) are too inconsistent to be reliable.

The snorkle vs. hydro-pak counts appear to agree in the angel fish, doctor fish, spanish hogfish, hamlet (one count), and yellowtail snapper. The snorkle count was consistently higher than the count by hydro-pak in the parrot fishes, hinds, and grey snappers. Also note that the hydro-pak count was never substantially higher than the count by snorkle. A total of 261 fish were counted by the snorkle-equipped divers while the hydro-pak divers counted only 235. This substantiates but does not prove what had been expected, that the snorkle diver swimming at the surface was able to count more fish because of the wider range of vision.

The results of the reef count indicate that by UST a reasonably accurate count of a fish population in a given area is possible to attain if the right conditions prevail, if the workers are reliable and properly equipped, and if the proper species are chosen and controls are run.

CRITIQUE OF DIVING EQUIPMENT

The diving gear employed in this study consisted of Scott Hydro-paks, self contained underwater breathing apparatus with a demand-type two stage regulator. It is fitting and perhaps pertinent in a study of this kind to examine the disadvantages and shortcomings of the SCUBA used. Diving accessories such as swim fins, masks, snorkles depth gauges, rubber suits, etc. were utilized in various capacities, but their relative merits will not be discussed.

The hydro-pak might be compared to a similar diving lung of another type, the "Aqualung" or variations of it (Divair, etc.). In this discussion the term "aqualung" will refer to all lungs of this type and not necessarily the patented aqualung of Cousteau and Gagnan.

It is this writer's opinion after having used the hydro-pak for two summers in both fresh and salt water that this self contained diving lung has limited versatility and in many respects compares unfavorably with an aqualung. The major objections to the hydro-pak are as follows:

(1) The initial cost of the gear must be given consideration. The hydro-pak costs at least one hundred dollars more than any aqualung. The face mask of the hydro-pak is, of course, the most expensive item. It is constructed of a good quality neoprene rubber, but knowing that rubber is quite susceptible to the elements it must be given careful attention. While it would not be difficult to replace a mask used with an aqualung, it would be very costly to replace a hydro-pak mask.

(2) The air capacity of the single tank of the hydro-pak is insufficient for deep dives and inadequate for sustained work in shallow water. The construction of the aqualung allows for two or three extra tanks, the present hydro-pak can only fit one extra tank.

(3) While the harness of the hydro-pak is superior to most harnesses used with aqualungs the hydro-pak diver's freedom of movement is restrained by the short air supply hose which makes it difficult for the diver to turn his head to the right.

(4) The field of vision through a hydro-pak mask is not as wide as the field in a "Squale" face mask. Optimum lateral vision is important in underwater observations, especially in a fish count.

(5) Since the diver is breathing directly into the mask while using the hydro-pak the glass tends to fog up quicker than an ordinary face plate, even after preventive measures have been taken.

(6) While the hydro-pak mask fits more securely than an ordinary face plate it would be more difficult for a diver to refasten on if it would be knocked off while diving. An inexperienced diver would have more time to panic, for he would have to make a decision whether to try to get the mask back on, or to forget about it, and ascend to the surface to make adjustments.

(7) The exhaust valve on one of the hydro-pak masks used in Bermuda was known to clog when the diver was exhaling strongly, so that the air escaped along the seal of the mask. The writer, one one occasion, suffered a severe headache while dragging a weighty burlap sack of conchs along a shoal bottom.

(8) There has been some question about the safety of the hydro-pak at great depths (over 100 ft.). It has been postulated that carbon dioxide may accumulate in the mask and become toxic to the diver. This has not been shown to be so but it still is a possibility.

(9) The attachment of the air hose onto the nipple of the regulatory valve is a precarious fitting. Although this is supposedly a permanent attachment, the hose slipped off on one occasion and cut the diver's air supply. When this happens the diver has little choice but to jettison his

gear and surface. The position of this air supply nipple makes it exceedingly awkward to refasten the hose, although it can be done if the diver diagnoses the trouble immediately.

Aside from its disadvantages the hydro-pak was a useful tool especially in the marine study around Bermuda where the waters were clear and warm. In Michigan lakes where low temperature and turbidity were hindrances the hydro-pak was used to a limited degree. The snorkle was a much more valuable tool and could well replace SCUBA for much survey work in freshwater.

SUMMARY

1. By diving it was possible to make useful fishery observations in all but one of the 14 lakes surveyed in the Upper Peninsula, Michigan during the summer of 1955. However, unfavorable weather and a demanding schedule permitted the survey crew to employ actual diving gear in only 11 lakes; of these 11, only 7 provided meaningful data.
2. Underwater spot identifications are a definite aid to a fish survey in a lake. In the 7 study lakes, divers discovered a total of 10 species that were not collected with conventional fishing gear.
3. All of the fish observed by divers were in the epilimnion layer. No fish were seen while diving in the thermocline, however, dives into this layer or beyond were infrequent and inadequate.
4. The appearance of schools of fish as observed by divers can be correlated with cover, such as dense vegetation, brush pilings or deadheads.
5. Smallmouth bass showed an avoidance to divers after being disturbed daily by snorkle-equipped census takers.
6. A direct fish count underwater by snorkle divers appears to be reliable as an index of relative abundance of centrarchids and yellow perch but does not seem satisfactory for northern pike, walleyes and white suckers.
7. The speargun was an effective weapon for taking all the sufficiently large freshwater species encountered. Because of its effectiveness against black basses its sporting use in inland waters requires further study.
8. The uses of diving gear in saltwater are many and varied and the possibilities for its applications in marine fisheries research are by no means exhausted.
9. It is possible to estimate populations of fish on coral reefs by direct

underwater counts while diving. On shallow reefs it appears that counts by snorkle divers are more effecient than counts by mechanical-lung divers.

10. It is this writer's opinion that the Scott Hydro-pak, despite enthusiatic claims by its supporters, is not to be recommended for the versatile requirements of fisheries work; the aqualung seems better suited.

Table 1. Michigan lakes chosen for study with Secchi disc readings and number and duration of underwater observations.

Lake	County	Acres	Water Color	Secchi disc	Underwater Observations	
					Number	Duration
Clover	Gogebic	57	light brown	8 ft.	1	½ hr.
Mink	Gogebic	63	colorless	4 ft.	0	0
Ice	Iron	85	colorless	16 ft.	8	6 hrs.
Otter	Houghton	890	light brown	9 ft.	2	1 hr.
Monacle	Chippewa	146	colorless	16 ft.	13	19½ hrs.
Soldier	Chippewa	19	colorless	10 ft.	2	1½ hrs.
Pratt	Luce	24	colorless	18 ft.	8	8 hrs.
Petes	Schoolcraft	150	colorless	11 ft.	12	7 hrs.
Grassy	Schoolcraft	176	colorless	14 ft.	6	4 hrs.
McKeever	Schoolcraft	130	colorless	14 ft.	2	3 hrs.
Kingston	Alger	(250)*	colorless	12 ft.	3	1 hr.
Hascib	Marquette	41	light brown	11 ft.	0	0
Lowmoor	Marquette	36	light brown	11 ft.	2	1 hr.
Clear	Marquette	33	light brown	12 ft.	0	0

(*)estimated acreage

Table 2a. Physical and chemical characteristics of Michigan lakes in UST studies (June 23 to Sept. 12, 1955).

Lake	pH	MO (ppm)	Depth of layers (ft.) Ep	Th	Hp	O_2 limit*	Temperature of Ep
Clover	6.3-5.2	1-5	to 6	7-12	12-25	10	64.5-63.0
Mink	8.0-7.9	40-45-	to 4	4-7	.....	....	75.0-....
Ice	7.9-7.1	25-38	to 12	13-25	25-33	22	79.5-72.0
Otter	7.8-7.1	56-57	to 15	15-25	.....	20	75.5-74.0
Monacle	7.3-6.2	1-13	to 15	15-27	27-50	27	74.5-72.0
Soldier	6.5-6.1	1-2	to 15	15-17	.....	....	76.0-73.5
Pratt	7.0-6.0	3-12	to 25	25-32	......	28	79.5-72.0
Petes	8.1-8.0	97-105	to 24	24-29	29-30	26	75.0-72.4
Grassy	8.1-7.1	71-74	to 20	20-25	25-27	21	78.5-70.0
McKeever	8.2-6.7	50-59	to 18	18-30	30-54	23	77.0-70.0
Kingston	7.8-7.7	32-32	to 32	.....	.....	....	66.0-62.0
Hascib	7.1-6.1	5-11	to 16	16-23	23-49	23	64.0-....
Lowmoor	7.5-7.0	45-52	to 16	16-20	20-52	17	61.0-59.9
Clear	6.7-6.7	..-23	to 17	17-22	22-27	21	61.0-59.9

* O_2 less than 4 ppm
(Note: pH and MO data are read surface to bottom)

Legend

MO - methyl orange akalinity
Ep - epilimnion
Th - thermocline
Hp - hypolimnion

Table 2b. Some ecological features of the study lakes: bottom types, vegetation density and game fish abundance.

Lake	Bottom types	Vegetation density	Game fish in order of decreasing abundance
Clover	sand, gravel, pulpy peat.	medium	Bg, W, Np, Lmb, Yp.
Mink	sand, gravel, fibrous & pulpy peat	dense	Yp, Np, Ps.
Ice	rubble, sand, pulpy peat	sparse	Yp, W, Bg, Smb.
Otter	sand, red clay	medium	Yp, W, S, Np, Rb, Bg, Ps, Smb, Lmb.
Monacle	rubble, gravel, sand, pulpy peat	sparse	Yp, W, Rb, Np, Smb.
Soldier	sand, fibrous peat.	medium	Yp, ...
Pratt	sand, pulpy peat	sparse	Yp, Bg, Smb.
Petes	sand, marl pulpy peat.	sparse	Smb, Yp, Rb, Lmb, Np.
Grassy	sand, fibrous & pulpy peat	dense	Bg, Yp, Ps, Np, Lmb.
McKeever	sand, gravel, fibrous & pulpy peat	medium	Bg, Ps, Yp, Rb, Np, Lmb, Smb.
Kingston	sand, gravel, pulpy peat.	medium	Ps, Yp, Bg, W, Smb, Lmb.
Hascib	bedrock......	rare	Gs,........
Lowmoor	sand, gravel, pulpy peat.	medium	Bg, Lmb, Bt.
Clear	....	rare	Yp..........

Legend:
Lmb - largemouth bass
Smb - smallmouth bass
Bg - bluegill
Ps - pumpkinseed
Rb - rock bass
Gs - green sunfish
Yp - yellow perch
W - walleye
S - sauger
Np - northern pike
Bt - brook trout

Table 3a. Comparisons of species listed by UST and by regular survey technics (gill nets, seines, rotenone and hook and line fishing).

Species of fish	Lakes						
	Ice	Monacle	Pratt	Petes	Grassy	McKeever	Kingston
Largemouth bass	...	...	...	X	X	X	X
Smallmouth bass	X	X	X	X	...	X	X
Bluegill	X	...	X	...	X	X	X
Pumpkinseed	X	...	...	(U)	X	X	X
Rock bass	X	X	...	X	X	X	...
Green sunfish	...	...	...	...	(S)	...	X
Yellow perch	X	X	X	X	X	X	X
Walleye	X	X	...	...	...	...	(S)
Northern pike	...	X	...	(S)	(S)	(S)	...
White sucker	X	X	(S)	X	X	X	X
Johnny darter	...	X	...	...	(S)	(S)	(S)
Iowa darter	(U)	...	...	...	(S)	(S)	...
Least darter	...	...	...	...	...	(S)	...
Logperch	...	X	...	X	(U)	X	...
Brown bullhead	...	X	...	...	(S)	...	(S)
Mudminnow	...	...	...	...	...	...	(S)
Common shiner	(S)	(U)	...	(U)	X	(U)	...
Bluntnose minnow	...	(U)	(S)	X	...	X	...
Golden shiner	(U)	...	...	...	X	...	...
Creek Chub	...	...	...	(U)	...	...	(U)
Spottail shiner	...	(S)	...	...	...	...	...
Mimic shiner	...	(S)	...	(S)	(S)	...	(S)
Sand shiner	...	...	...	...	...	...	(S)
Pearl dace	(S)	...	(S)	...	...	...	(S)
Mottled sculpin	...	...	...	...	...	(S)	...
Hours of UST	6	$19\frac{1}{2}$	8	7	4	3	1
Gill net sets (24 hrs.)	8	23	18	24	24	6	21
Bag seine hauls	4	6	3	6	5	0	10
Rotenone	...	...	...	...	...	Used	...

Legend:

... - fish not observed by survey, or no data.
(S) - fish discovered by survey methods only.
(U) - fish discovered by UST only.
X - fish discovered by both UST and survey.

(Seine hauls averaged 50 ft. of shoreline.)

Table 3b. The evaluation of UST as a supplementary fish survey technic.

Lake	Total number of species found				
	Survey & UST	UST	Survey	UST (only)	Survey (only)
Ice	11	9	9	2	2
Monacle	13	11	11	2	2
Pratt	6	3	6	0	3
Petes	12	10	9	3	2
Total	42	33	35	7	9

Table 4. Observations of smallmouth bass using brush shelters at Pratt Lake, Luce Co. (July 29 to August 3, 1955).

		Number of smallmouth bass seen												
Stations: *		1	2	3	4	5	6	7	8	9	10	11	12	Total
Observations No.	Time													
1.	2:00 P.M.	6	1	0	0	0	2	0	5	4	2	2	4	26
2.	10:00 P.M.	0	...	...	...	...	...	...	...	...	...	...	...	....
3.	9:00 A.M.	2	0	1	0	0	...	7	1	3	2	0	0	16
4.	11:00 A.M.	3	0	2	0	0	0	...	2	1	0	0	0	8
5.	10:00 A.M.	0	0	0	0	0	...	0	0	3	0	0	0	3
6.	5:00 P.M.	2	1	0	0	0	0	0	0	0	0	0	0	3
7.	5:00 P.M.	0	0	0	0	0	0	0	0	0	0	0	0	0

* average depth of brush shelters 6 ft.

Table 5. Comparison of relative abundance estimates: catch per standard gill net set with numbers of fish counted by divers per half hour.

Lake:	Monacle		Petes		Grassy	
Depth range (gill net)	4 to 25 ft.		4 to 26 ft.		4 to 23 ft.	
Depth range (UST)	1 to 20 ft.		1 to 15 ft.		1 to 15 ft.	
Species	UST	gill net	UST	gill net	UST	gill net
Largemouth bass	....	....	1.43 (4)*	0.13 (5)	1.88 (5)	0.50 (5)
Smallmouth bass	0.69 (3)	0.17 (6)	8.93 (3)	1.62 (1)	....	....
Bluegill	....	....	....	....	50.0 (1)	2.29 (1)
Pumpkinseed	....	....	0.22 (6)	0.00 (0)	6.25 (3)	0.63 (4)
Rock bass	3.69 (2)	0.87 (2)	28.57 (1)	0.28 (4)	2.50 (4)	0.04 (7)
Yellow perch	5.77 (1)	2.30 (1)	17.86 (2)	1.29 (3)	18.75 (2)	1.25 (3)
Walleye	0.26 (5)	0.74 (4)	....	....	....	....
Northern Pike	0.13 (6)	0.39 (5)	0.00 (0)	0.08 (6)	0.00 (0)	0.46 (6)
White Sucker	0.62 (4)	0.87 (2)	0.72 (5)	1.42 (2)	0.25 (6)	1.79 (2)

( )* indicates order of relative abundance.

Table 6 . Fish count of a coral reef near Bermuda.

	Top of reef count						Ledge count	Total
Species *	Hydro-pak divers A&B	Hydro-pak divers C&D	Snorkle divers A&B	Snorkle divers C&D	Average (top of reef)	+	Average of 4 divers	= Average of top & ledge
Hamlet	7	0	7	5	5		4	9
Hind	20	12	24	21	19		4	23
Coney	3	5	0	0	2		1	3
Gag	0	1	0	0	1		1	2
Pudding-Wife	4	3	2	0	2		0	2
Angel fish	31	24	30	27	26		21	47
Doctor fish	7	12	9	13	10		17	27
Spanish hogfish	6	7	6	5	6		9	15
Parrot fishes	25	20	31	28	26		20	46
Grey snapper	14	16	24	19	18		60	78
Yellow grunt	2	7	1	5	4		347	353
Squirrel fish	0	0	0	1	1		1	2
Barracuda	1	0	4	0	2		0	2
Trunk fish	1	3	2	4	3		2	5
Porgy	2	0	2	0	1		0	1
Trumpet fish	1	0	0	0	1		1	2
Yellowtail snapper	8	6	8	6	7		3	10

* Scientific names of species of all fish in text and tables listed on p. 36.

Table 7. Ledge count of 8 common reef fishes.

Species	Top of ledge #1	Top of ledge #2	Bottom of ledge #1	Bottom of ledge #2	Top & Bottom Totals #1	Top & Bottom Totals #2
Angel fish	13	17	7	6	20	23
Doctor fish	1	1	19	12	20	13
Spanish hogfish	6	0	10	2	16	2
Parrot fishes	16	15	4	5	20	20
Hamlet	0	2	5	2	5	4
Hind	0	6	1	1	1	7
Grey snapper	23	42	23	41	46	83
Yellow grunt	47	49	342	255	389	304

Table 8. Top of reef count of 8 common fishes.

Species	Hydro-paks A + C		Snorkles A + C		Hydro-paks B - D		Snorkles B - D	
Angel fish	12	12	19	12	19	12	19	15
Doctor fish	2	6	6	9	5	6	5	4
Spanish hogfish	3	4	4	5	3	3	3	0
Parrot fishes	8	13	19	11	17	7	17	17
Hamlets	4	0	7	4	3	4	0	0
Hinds	12	8	18	8	8	4	6	13
Grey snapper	10	7	16	5	4	9	8	14
Yellowtail snapper	2	3	5	0	3	3	3	6

Table 9. Comparison of fish counts by hydro-pak and snorkle.

Species	Hydro-pak A + B	Snorkle A + B	Hydro-pak C + D	Snorkle C + D
Angel fish	31	30	24	27
Doctor fish	7	9	12	13
Spanish hogfish	6	6	7	5
Parrot fishes	25	31	20	28
Hamlet	7	7	0	5
Hind	20	24	12	21
Grey snapper	14	24	16	19
Yellowtail snapper	8	8	6	6

LIST OF SCIENTIFIC NAMES

Common Name	Generic and Specific
(Freshwater)	
Largemouth bass	Micropterus dolomieui
Smallmouth bass	Micropterus salmoides
Bluegill	Lepomis macrochirus
Pumpkinseed	Lepomis gibbosus
Rock bass	Ambloplites rupestris
Green sunfish	Lepomis cyanellus
Yellow perch	Perca flavescens
Northern pike	Esox lucius
Yellow walleye	Stizostedion v. vitreum
Sauger	Stizostedion canadense
White Sucker	Catostomus commersoni
Johnny darter	Etheostoma nigrum
Iowa darter	Etheostoma exile
Logperch	Percina caprodes semifasciata
Brown Bullhead	Ictalurus nebulosus
Mudminnow	Umbra limi
Common shiner	Notropis cornutus
Bluntnose minnow	Pimephales notatus
Golden shiner	Notemigonus crysoleucas
Creek chub	Semotilus atromaculatus
Spottail shiner	Notropis hudsonius
Mimic shiner	Notropis v. volucellus
Sand shiner	Notropis d. deliciosus
Pearl dace	Semotilus margarita nachtriebi
Mottled sculpin	Cottus bairdi
(Marine)	
Hamlet	Epinephelus striatus
Red Hind	Epinephelus guttatus
Coney	Cephalopholis fulvus
Gag	Mycteroperca tigris
Pudding-wife	Halichoeres radiatus
Angel fish	Angelichthys isabelita
Doctor fish	Acanthurus sp.
Spanish hogfish	Bodiannus rufa
Parrot fishes	Sparisoma sp
Grey snapper	Lutianus griseus
Yellow grunt	Haemulon sciurus
Squirrel fish	Holocentrus ascensionis
Great barracuda	Sphyraena barracuda
Trunk fish	Lactophrys tricornis
Porgy	Calamus sp.
Trumpet fish	Aulostomus sp.
Yellowtail snapper	Ocyurus chrysurus

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AIIM SCANNER TEST CHART # 2

Spectra

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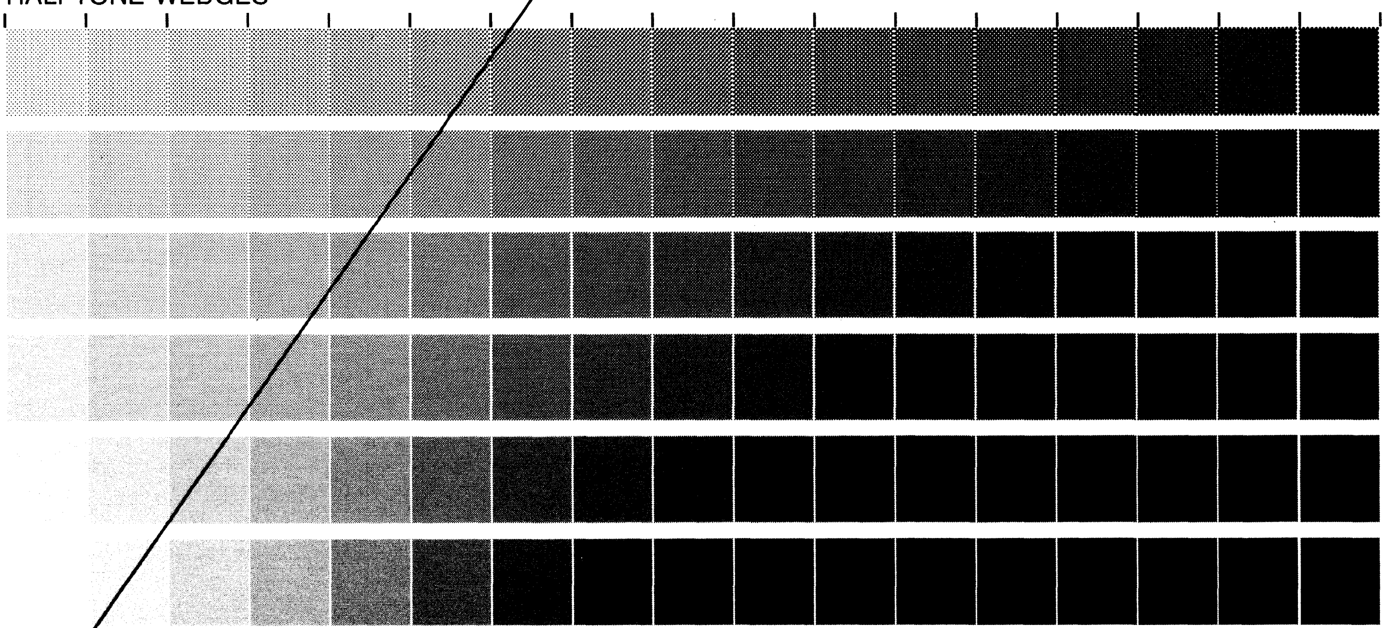

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