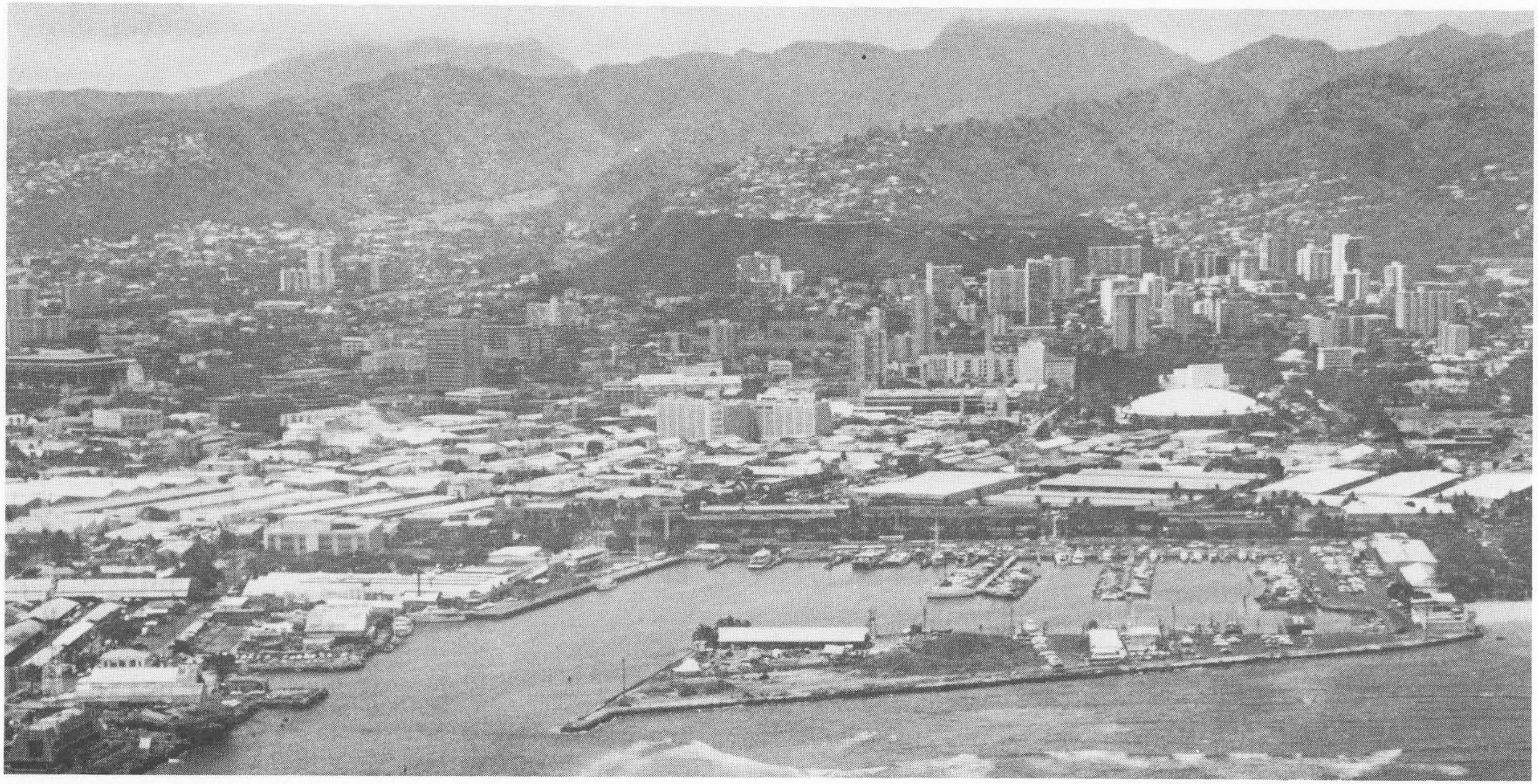
U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL MARINE FISHERIES SERVICE
SOUTHWEST FISHERIES CENTER
HONOLULU LABORATORY

KEWALO RESEARCH FACILITY



AUGUST 1979

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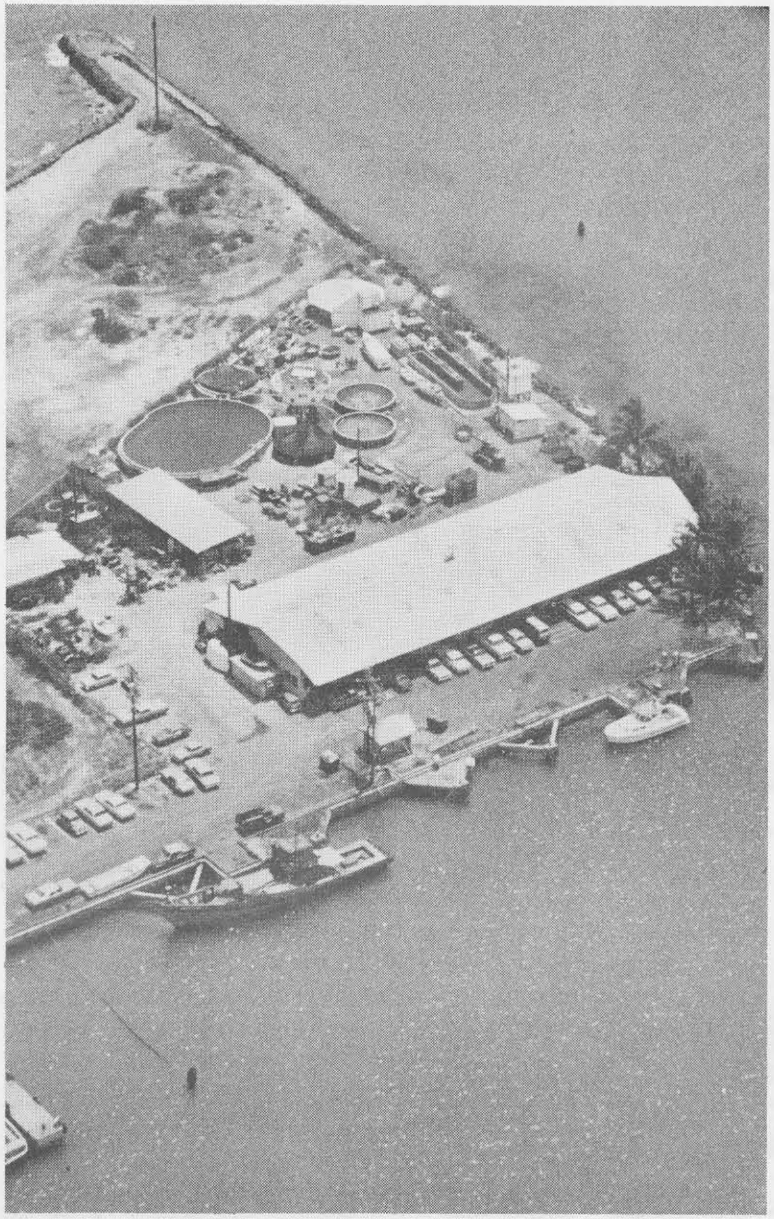
ADMINISTRATIVE REPORT H-79-11

FORWARD

In the important commercial tuna fisheries of the world a major biological problem is the prediction of the distribution and abundance of the various species of tunas comprising the resource. Analyses of environmental data in the Pacific over the years have provided correlations between skipjack tuna distribution and various oceanographic and meteorological variables but the mechanisms determining the distribution, availability, and migration of tunas are not completely known. Temperature, oxygen, salinity, and food availability all influence tuna movements and limit their vertical and horizontal distribution. The Kewalo Research Facility of the Honolulu Laboratory is in the midst of an ongoing program to examine the effects of the most important environmental parameters on the behavior and physiology of tunas, and thus ultimately, their effects on the distribution, availability, and movements of tunas. This knowledge will be a major contribution to the science of fishery prediction.

The Honolulu Laboratory foresees the future role of the Kewalo Research Facility as an international gathering place for scientists of varied backgrounds and disciplines. The past two decades of quality research and the uniqueness of its facility have engendered an enviable reputation for the Kewalo Research Facility throughout the world. During this period many respected scientists from around the world have taken the opportunity to work with tunas under laboratory conditions at our facility.

To continue the high quality work and to press forward in more innovative research will require researchers possessing a high degree of specialization in various disciplines including physiology, biochemistry, hydromechanics, and electronics. Without doubt the many attributes of the Kewalo Research Facility will continue to attract well qualified scientists to its doors in the future.



THE KEWALO RESEARCH FACILITY

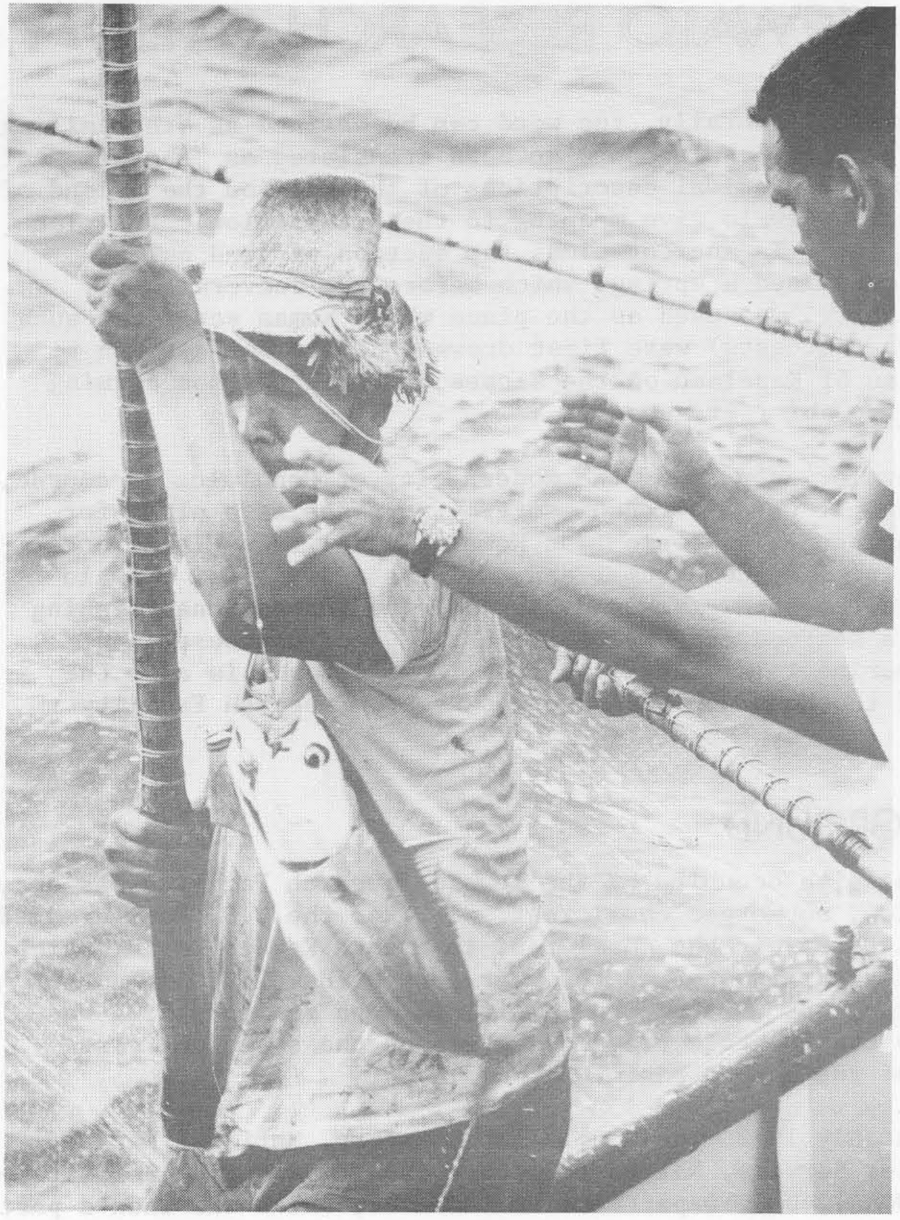
Kewalo--literally, the word can be defined as "the calling" (as an echo). Kewalo has also been translated as "the place of wailing." Historical descriptions of the area on the island of Oahu called Kewalo give meaning to the translation, "the place of wailing." In ancient times the section of land called Kewalo contained a spring, which before the conversion to Christianity, was used as the place where human scrifices such as kauwa (outcasts) were first drowned before being taken to the Heiau of Kanelaau on the slopes of Punchbowl for burning in the imu ahi (fire oven).

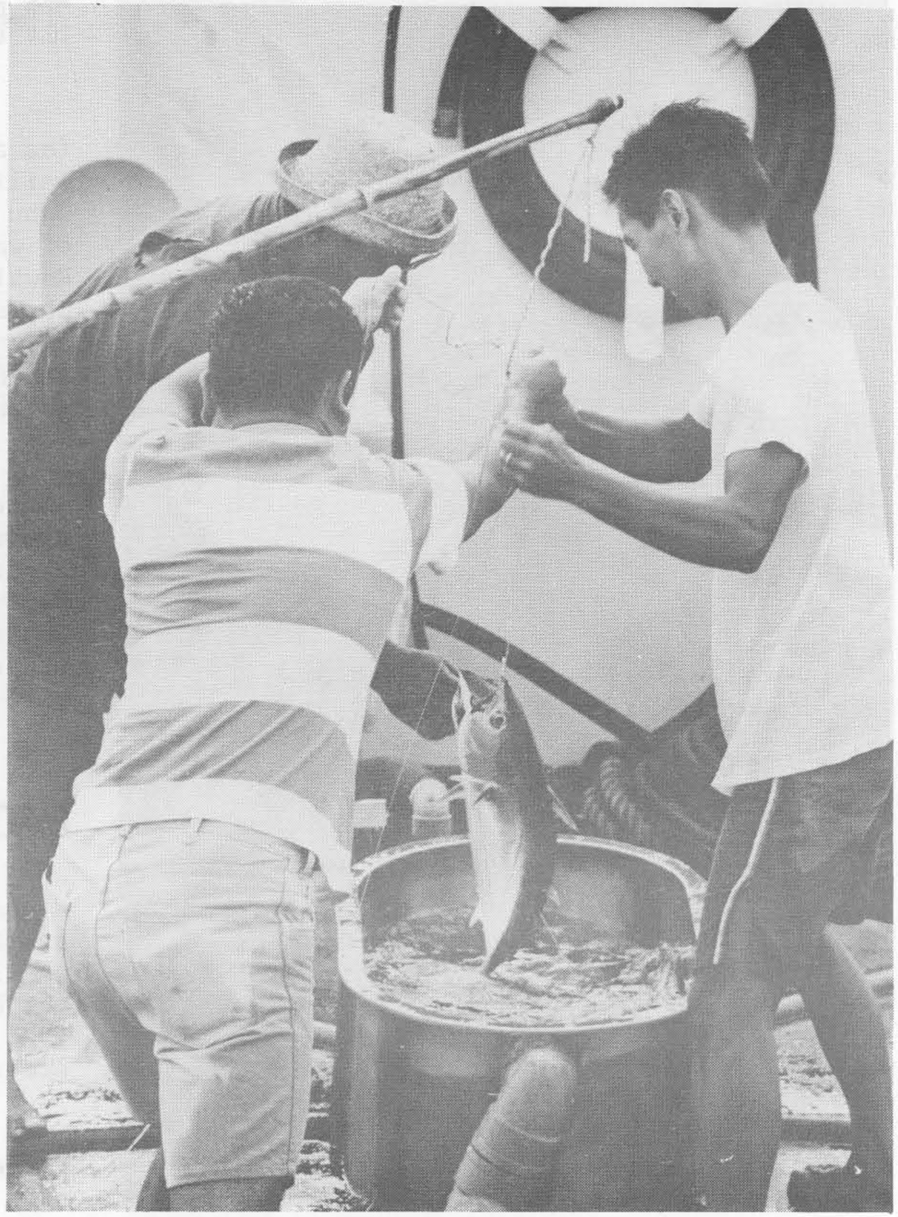
Kewalo, as part of the modern city of Honolulu, of course, is no longer used for such esoteric purposes as a place for drowning people. Kewalo (and Kewalo Basin) today is an area supporting many commercial and business activities. Kewalo Basin is the home of many commercial and recreational fishing boats, a seafood cannery, a fresh fish auction house, and other marine related enterprises. Kewalo Basin is also the site of the Honolulu Laboratory's Kewalo Research Facility.

BACKGROUND

The site occupied by the Kewalo Research Facility was once a shallow, submerged coral reef. In 1945 the U.S. Navy dredged a small harbor in the coral reef to create Kewalo Basin, which was later turned over to the Territory of Hawaii. Subsequently, the harbor was enlarged and artificial and sanitary fill was used to create protecting land areas on the south and east sides of the harbor basin.

In July 1958, the Honolulu Laboratory, National Marine Fisheries Service, National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce, which was then a part





of the Fish and Wildlife Service, U.S. Department of the Interior, negotiated a lease to the grounds and building on the spit of artificially created land at the southeast entrance of Kewalo Basin to establish the Kewalo Research Facility. The facility has a low profile and goes unnoticed by the many surfers and fishermen that frequent the area. But within the 0.4 hectare (0.98 acre) area is a truly remarkable research facility. The main building has over 1,003.4 m^2 (10,800 sq ft) of space and houses offices and laboratories tailored for various research activities, a machine shop, and storage areas. On the adjoining grounds has been dug a saltwater well that has the capacity to produce over 3,785 liters (1,000 gal) per minute of high quality coral filtered seawater. The filtered seawater is pumped to an aerator to be oxygenated and then distributed to various tanks including a series of five 75,706-liter (20,000-gal) circular pools that can be observed from a tower, a 757,060-liter (200,000-gal) oceanarium, and specially designed experimental tanks of various sizes.

The Kewalo Research Facility still remains today as it did soon after it was first established as the only research center in the world that is able to collect and maintain live tunas throughout the year for use in behavioral and physiological research. Indeed, this international reputation has attracted and still attracts established scientists of diverse backgrounds and expertise to this facility where experiments requiring live tunas as laboratory animals can be conducted.

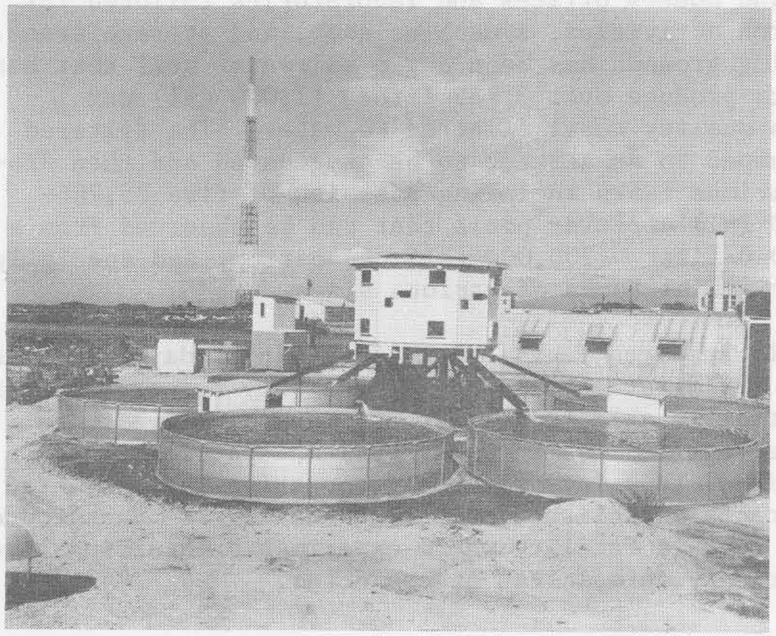
RESEARCH ACTIVITIES

Early Work

Tunas are widely distributed in the world oceans and are the bases of many important commercial fisheries. Despite their wide distribution and economic value very little research had been done with live specimens, probably in part because of

Specially designed fiberglass transport tanks are used at sea in collecting tunas for use in experimental behavioral and physiological studies in shoreside tanks. The transport tanks are designed so that tunas caught on pole and lines using barbless hooks can easily be dropped in them without being handled. When the vessel returns to Kewalo Basin with a load of live tunas, a mobile crane lifts the 1,893-liter (500-gal) tank and delivers it over the short distance to the holding tanks. There the special design of the transport tanks allows the fish to swim out freely into the shoreside holding tanks. This handling technique which has evolved over the years minimizes shock to the fish, thus assuring a higher survival rate.

Live tunas are also collected by cooperating commercial pole-and-line fishermen. Using similar capturing and handling techniques, the commercial fishermen bring back live tuna in their vessel's bait holding tanks. At dockside the fish are dipped with plastic lined dip nets from the baitwells to the transport tanks and then transported to the holding tanks.



Much of the early tuna behavioral experiments were conducted in the tank-observational tower complex. The observation tower houses equipment to record behavior, water temperature, and light. It also has two windows facing each tank. Food to reinforce desired behavioral responses is tossed to the fish from one of the windows and the other window is used to observe the tuna. Observation windows cut into the side of the tanks and covered by protective huts also allow undetected observation of the tuna. A portable keyboard connected to a 20-channel event recorder in the tower is used in the hut to record behavioral data.

the difficulty in keeping them alive in captivity. Because of the limited knowledge available on live tunas as experimental animals, the early research was aimed at collecting data that would serve as the foundation for future investigations. This early work produced interesting facts about tunas.

- Tunas are heavier than water and must continuously swim to (1) keep afloat and (2) breathe by passing oxygen rich water over their gills. Tunas would sink and suffocate if they stopped swimming.

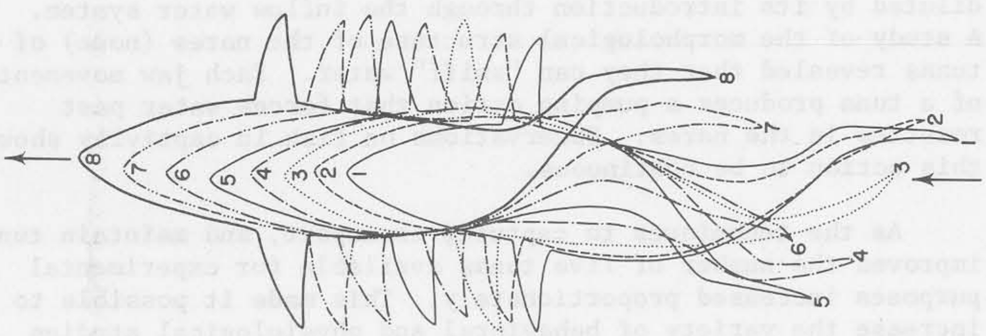
- The basal swimming speed of tunas is dependent upon the lifting area of fins and the density of the fish, and is not a function of respiration or a search for food.

- All tunas have made the following adaptations for continuous basal swimming: (1) a high hemoglobin level in their blood to carry more oxygen and nutrients to maintain continuous muscle activity; (2) compared to other fishes, possess a larger proportion of dark muscle that is specialized, like muscles of the heart, for continuous contractions; (3) possess a streamlined body shape to reduce drag.

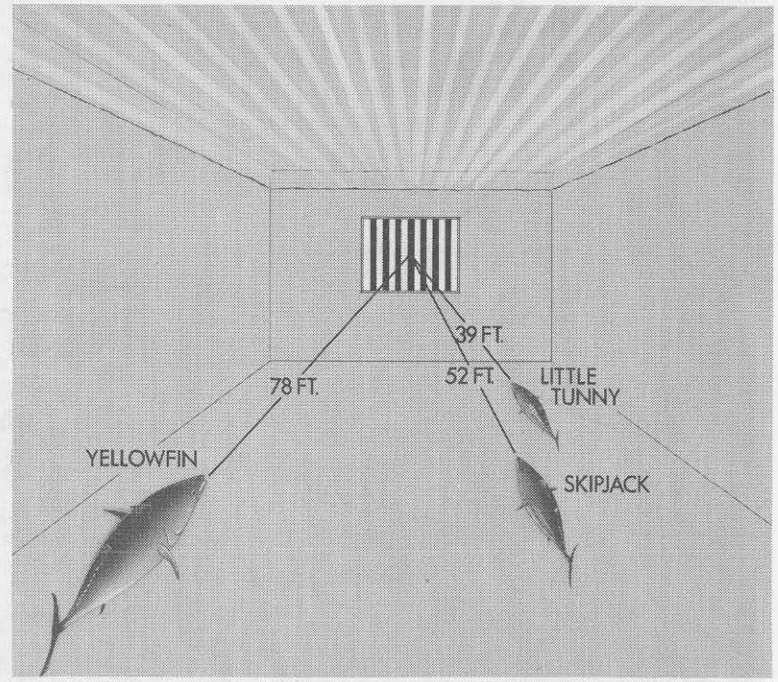
- In larger species of tunas, two morphological features evolved to reduce energy required to keep afloat. First, pectoral fins got larger to produce more lift; second, when the pectorals were insufficient, gas bladders developed to decrease density. Although gas bladders are very effective in reducing density of fish, they limit the streamlined tuna to the deeper layers of the ocean. A fast vertical ascent to the surface would cause large changes in volume and in the extreme, burst the gas bladder.

Other early experiments with tunas were designed to determine their sensory abilities--how well they can smell, taste, hear, and see. The rationale for these studies was that a basic understanding of the behavior and sensory capabilities of tunas should be useful in the future design of fishing gear and fishing methods and in locating tuna.

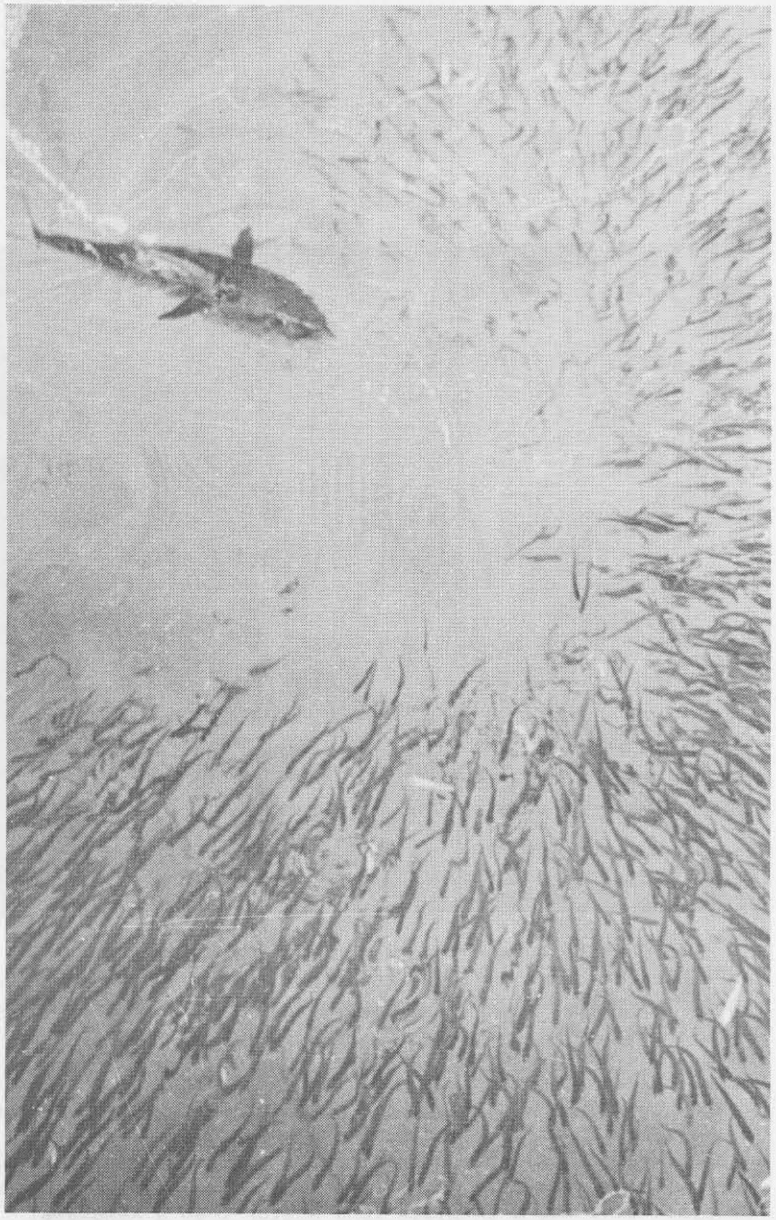
To determine how well tunas can see, studies were conducted on their visual acuity (the ability to see clearly the fine details of objects). Of three tunas tested, it was determined that yellowfin tuna could see better than skipjack tuna, and the latter better than kawakawa. Further experiments on the optical system of restrained tuna showed that they are probably color blind and are most sensitive to blue light.



The facilities at Kewalo made it possible to closely observe captive fish and produced the first high-speed movies of swimming kawakawa. The analysis of the film provided intimate details of swimming speed, tail beat rates, body postures and flexures, and how the changing positions of fins and finlets provide drag reduction features. It was determined that the tail provided nearly 100% of the forward thrust and that the fish attained burst speeds of twice that of nonscombrid fish. The line drawing shown here was traced from successive ciné frames (camera speed 100 frames per sec) for one complete caudal fin beat cycle of a kawakawa. The swimming speed of this fish was 8.2 body lengths per sec which was produced by a tail beat frequency of 14.3 tail beats per sec.



To measure tuna's reaction to various sensory stimuli, an observer must be able to detect the fish's response to these stimuli. It was found that tunas can be trained to perform a specific act in response to stimuli if they were rewarded. To measure how well they can see, tunas were trained to respond differently to vertical and horizontal bars that were projected onto an underwater screen by giving rewards (food) or punishment (electric shock). These experiments showed that at constant brightness, a yellowfin tuna sees details of an object better than a skipjack tuna and a skipjack tuna better than a kawakawa.

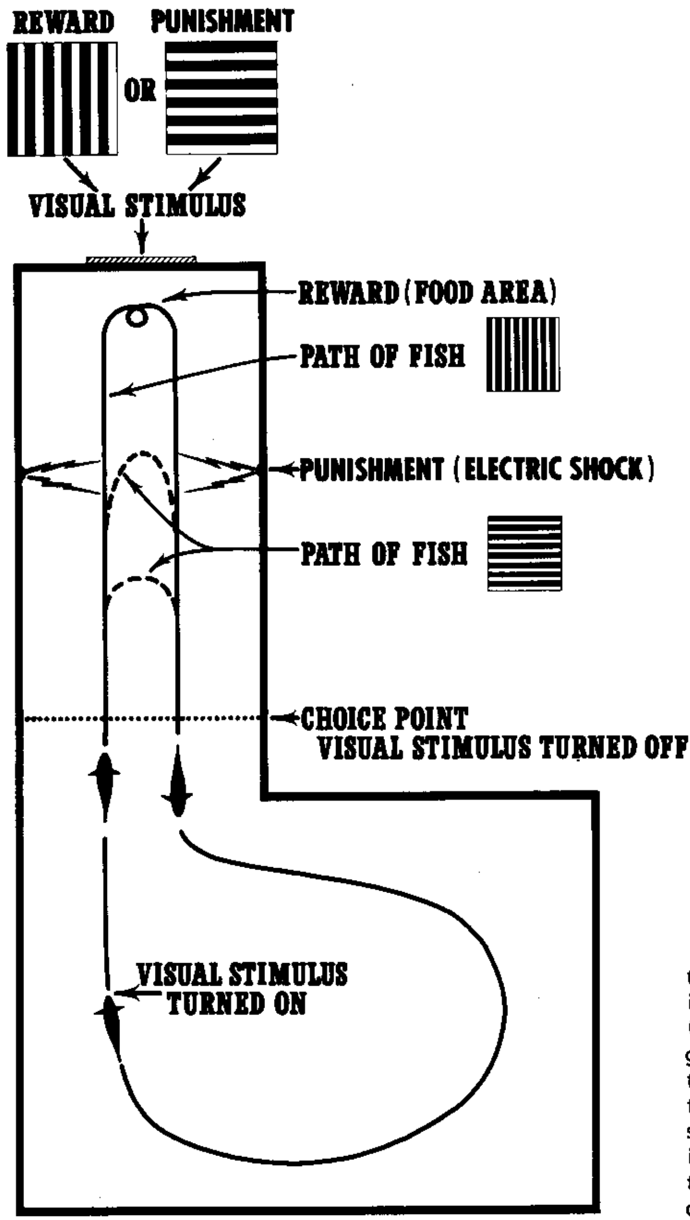


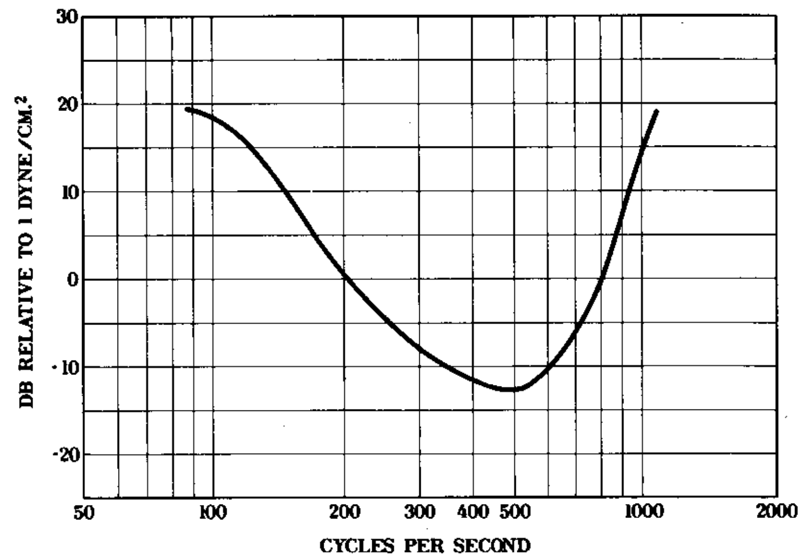
Experiments to define the hearing ability of tunas made it possible to construct a hearing curve for a tuna, the first ever for a scombrid, and to determine their auditory thresholds (the lowest level of sound that can be heard at a specific frequency). It was determined that the hearing range of yellowfin tuna is from about 200-2,000 Hz and that its hearing is most acute at 500 Hz.

Our experiments showed that tunas have a highly developed sense of smell. When a liter (1.06 qt) of water in which a small fish (a smelt weighing 10 g or 0.4 oz) had been dipped for 10 sec was introduced, a strong response was elicited from a school of kawakawa in the tank. It should be noted that the response was elicited even though the rinse water was further diluted by its introduction through the inflow water system. A study of the morphological structure of the nares (nose) of tunas revealed that they can "sniff" water. Each jaw movement of a tuna produces a pumping action that forces water past rosettes in the nares. Observations on fish in captivity showed this action to be continuous.

As the techniques to capture, transport, and maintain tunas improved the number of live tunas available for experimental purposes increased proportionately. This made it possible to increase the variety of behavioral and physiological studies such as those on the feeding and digestive rates of tunas. Food or forage organisms usually are not homogeneously distributed in the ocean but are found in patchy concentrations in space and time. Consequently, tunas and other oceanic apex predators exist in a "feast or famine" situation and the periods between feedings may be long. And knowledge of the digestive and feeding rates of fishes existing in such environments as tunas can be of practical use to commercial fishermen.

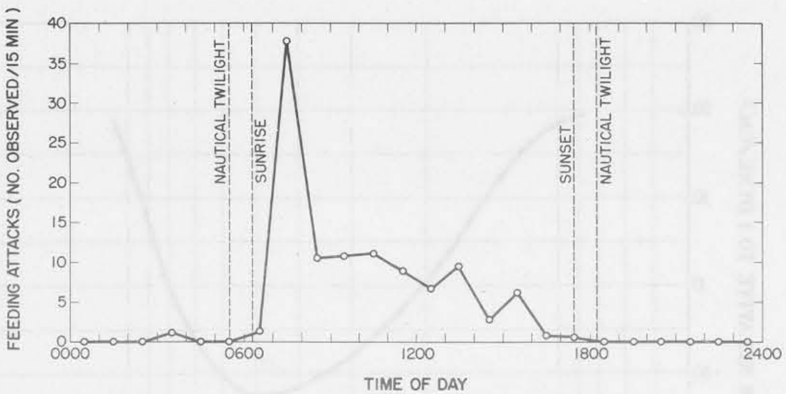
In this photograph a kawakawa is making an aggressive move towards a school of nehu in a shoreside research tank. Kawakawa has proved to be a good laboratory research animal and is readily available in Hawaiian waters.



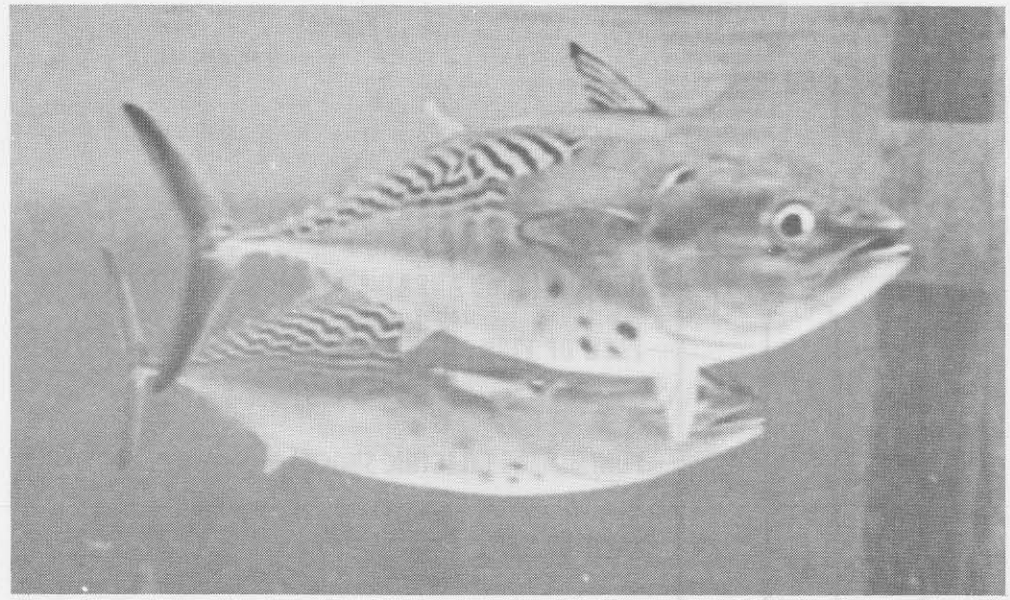


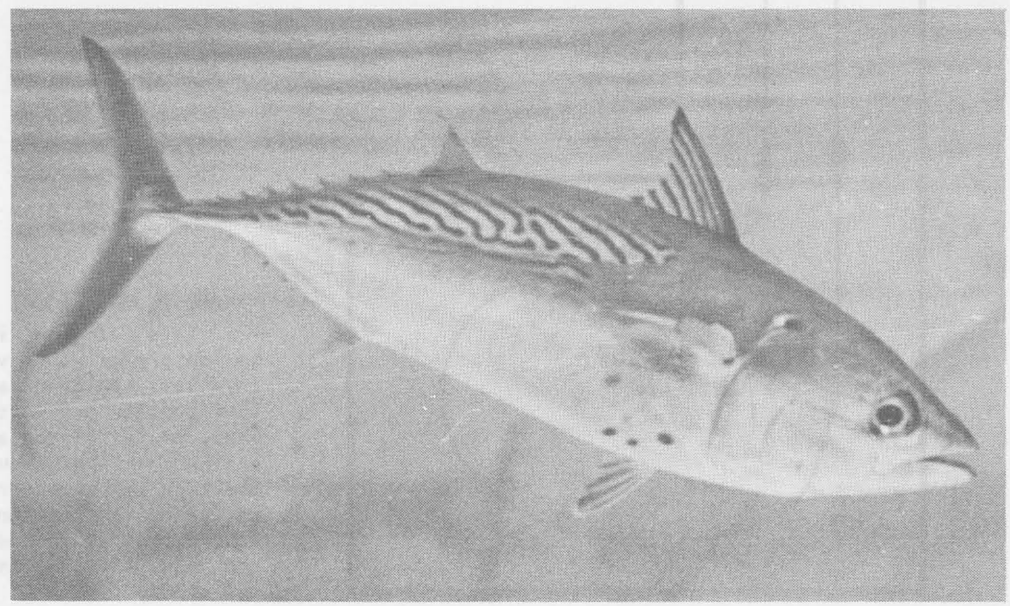
Experiments to determine the hearing ability of tunas were conducted in a pool specially constructed to insulate the fish from outside sounds and electronic interference. The test fish were first trained to recognize a pure "white" sound and then to react to the sound stimulus by swimming through a maze for a reward. The yellowfin tuna best hears sounds that are near 500 Hz as shown by the dip at that frequency in the hearing curve. Sounds near this frequency are common in the ocean, as for example, the sound produced by the swimming of a school of small fish.

This diagram illustrates the experimental method used to determine the visual acuity of tunas. The method involves training a fish to respond to a visual stimulus (horizontal or vertical stripes), projected on an opal glass plate placed against a tank window. The fish is trained so that when the stripes are vertical it swims down the tank to a food-drop area where it is rewarded; when the stripes are horizontal the fish is trained to turn before it reaches the food-drop area and return to the far end of the tank. If the fish fails to turn it receives an electrical shock.

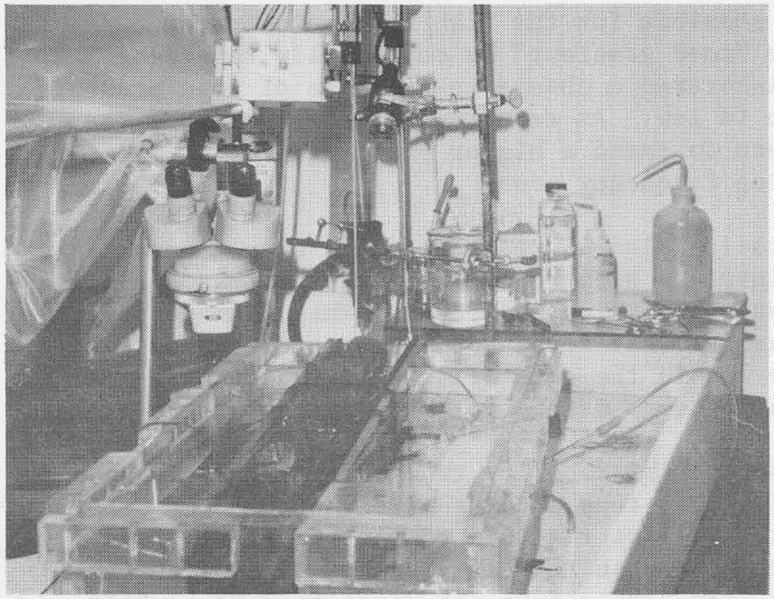


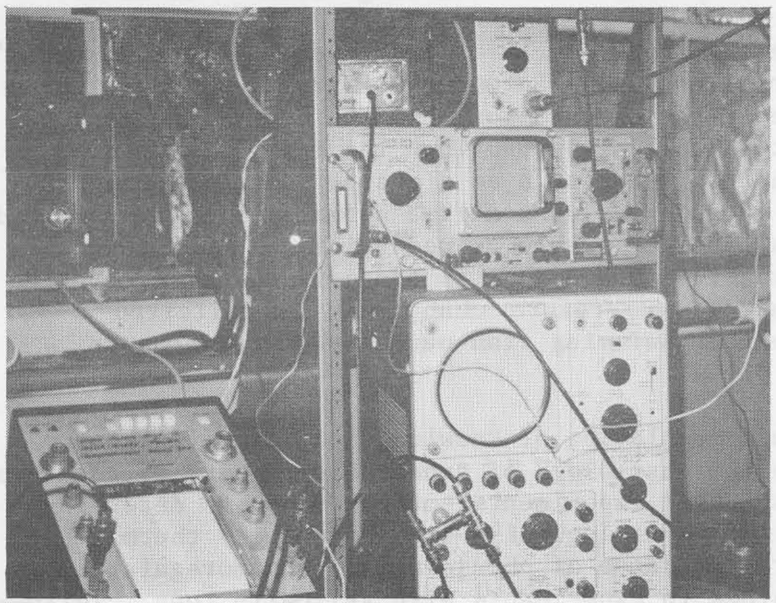
The changes in the feeding activity of kawakawa during a 24-h period as shown in this graph is typical for all tunas. When tunas in captivity were provided with a constant supply of food, feeding motivation was highest at early morning followed by a rapid decrease through noon and two smaller peaks at midafternoon. They showed no attempts to feed at night. This behavior is consistent with the high consumption and digestion of tunas which is from two to five times faster than that of other fish. When tunas are fed continuously, an equivalent of 15% of body weight or two times their stomach volume is eaten. The drive to attack prey is dependent on the amount of food in the stomach. Intense feeding always occurs in the morning when the stomach is empty. However, the stomach is not filled to capacity at the first feeding frenzy and the fish feeds throughout the day. Feeding slows when the stomach is 80% filled.





Upon swimming into an odor cloud of prey or other food items, tunas will typically increase their swimming speed, break the school swimming formation, and display the various color patterns associated with feeding. Kawakawa (pictured) display ventral spots and dorsal stripes; skipjack tuna exhibit lateral vertical bars and a dorsal white stripe and yellowfin tuna show the same color pattern as skipjack tuna plus a dark dorsal coloration.





Present Work

Current work at the Kewalo Research Facility includes an effort to determine a model of the energy requirements of skipjack tuna. Such a model will enable scientists to better explain and predict the distribution of the various species of tunas by answering questions such as, what are the limiting environmental conditions in the apparently energy-poor pelagic tropical seas for active fishes like the tunas to thrive in, and what are the dimensions of the tunas' apparent ability to conserve heat and thermoregulate. Already, much of the data collected over the past two decades have been used in the model and the preliminary results indicate that the growth rate of fish less than 11.8 kg (26 lb) is governed by food consumption while growth rate of fish larger than 15.0 kg (33 lb) is limited by the biological demands of activity and metabolism. Laboratory experiments have indicated that the distribution of small fish is dependent on the availability of food and the distribution of large fish is dependent on environmental conditions, of which temperature plays a major role.

Current behavioral and physiological studies include work to test the hypothesis that a tuna will recognize a "food gradient" and position itself in the densest portion of the gradient. To do this a doughnut-shaped tank which has instrumentation to detect if the fish is swimming clockwise or counterclockwise was constructed. Each lap that the fish swims would advance or reverse a looped tape which determines frequency of food presentation ranging from a high to a low rate.

Tests to determine various physiological functions of a quiescent fish are accomplished by restraining a fish in a cradle. The fish is kept alive by forcing aerated water past its gills (photo 1).

An electrode is placed in the brain and the fish's reactions to various stimuli are then monitored visually on an oscilloscope and graphically on a recorder. This technique has been used to determine the reactions of tunas to a range of colors, odors, and muscle stimuli (photo 2).

This makes it possible for the fish to remain in the densest portion of the "food gradient" by continually reversing itself once it had discovered a change in the rate of food presentation from high to low. As expected, the fish altered its swimming pattern to spend a higher proportion of its time in the high feeding frequency area.

Recent studies also showed that tunas have a remarkable ability to maintain a higher body temperature than the temperature of the water in which they swim. This is made possible by a heat exchanger that retains the heat produced by metabolic activity within the core of the body whereas in most other fishes all excess metabolic heat is lost at the gills.

As a predator, this ability to maintain an elevated body temperature gives the tuna an extreme advantage over other fishes in that it allows the tuna to operate at higher activity levels. Depending on the activity and size of the fish, maximum excess body temperature can range from 8° to 21°C.

Two new experiments have been designed to determine tunas' ability to perceive changes in water temperature. One experiment makes use of the observation that the heart beat rate of a restrained tuna will slow down when the fish is presented with an external stimulus such as a change in water temperature. In the other experiment a free swimming fish is rewarded with food each time it is able to recognize a temperature difference when water from a spigot is added to the tank. In the restrained fish a temperature change of 1°C elicited a response. The free swimming fish perceived a temperature difference of 0.1°C.

The large accumulation of knowledge on the effects of temperature on the physiology of tunas allowed work to continue on more sophisticated experiments such as those to determine whether tunas can physiologically or behaviorally thermoregulate. The first evidence of physiological thermoregulation in tunas was obtained in experiments with yellowfin tuna. Yellow-

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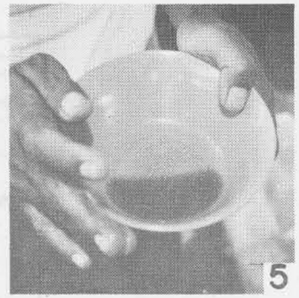

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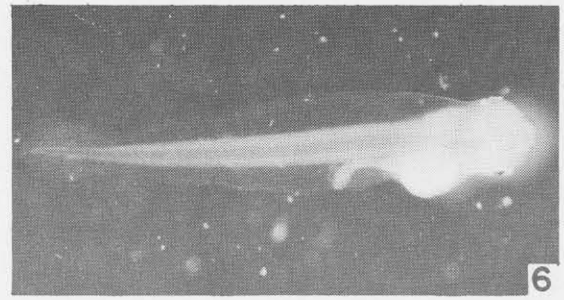

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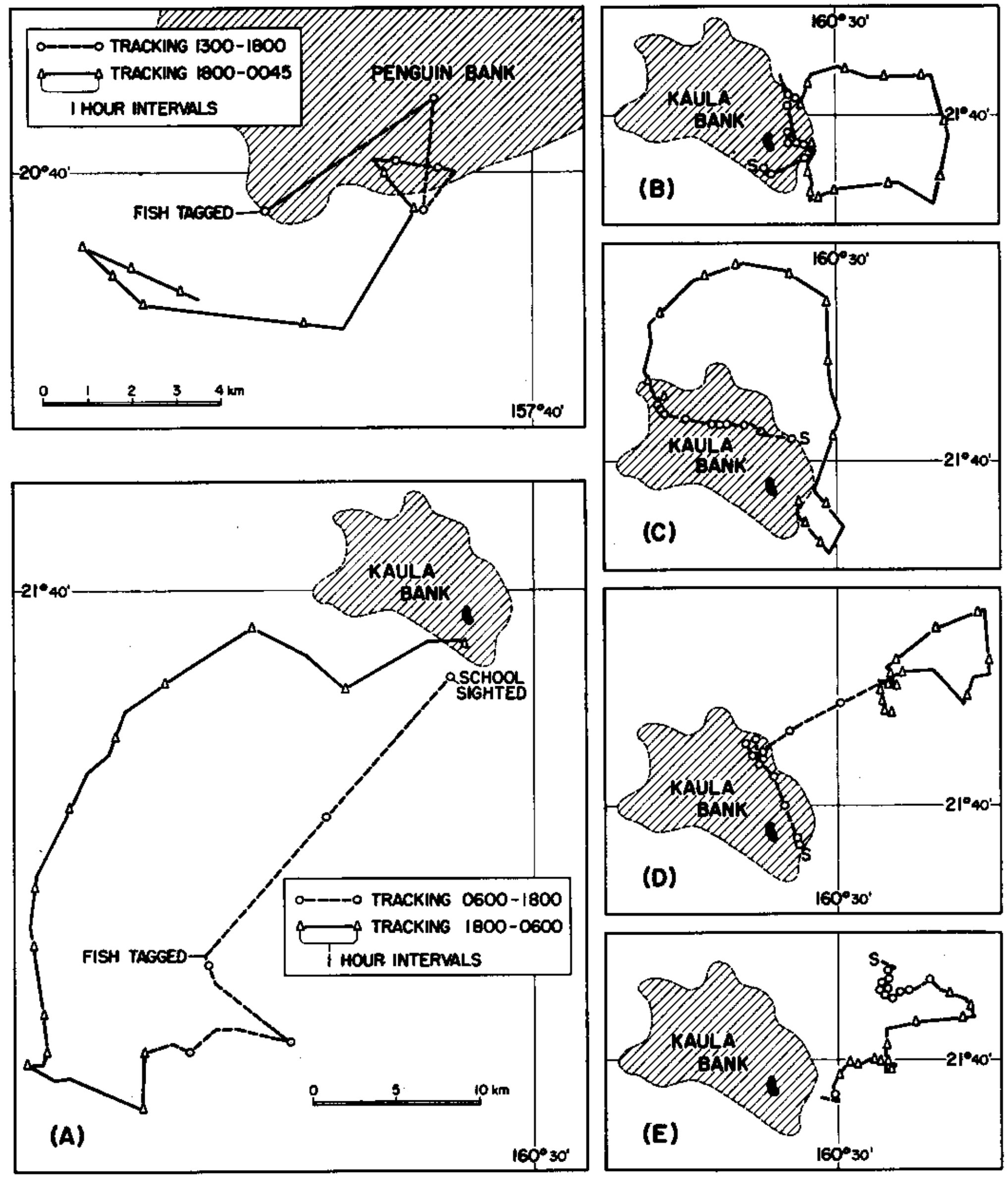
The first successful attempts at artificially inducing spawning in captive tuna were accomplished at the Kewalo Research Facility. The technique involved a periodic biopsy of the tunas to determine the developmental stage of the eggs in the ovaries. After the eggs attain a critical size, hormone treatments are administered to the fish to induce spawning. In the summer of 1979, kawakawa treated with hormone spawned for the first time in the shoreside holding tanks.

This series of photographs shows a kawakawa being guided into a funneling device to entrap it (photo 1) and then strapped into a "straitjacket" (photo 2). The biopsy or the hormone injection is then effected while the fish is immobilized in the "straitjacket" (photo 3). Within 12 h after the final hormone treatment, the fish were ready to spawn and eggs were stripped from the female (photo 4). The ripe eggs were fertilized with milt which was stripped from a ripe male, and the fertilized eggs were then placed in temperature controlled aquaria to hatch (photo 5). The eggs hatched in about 24 h and the yolk sacs of the larvae were absorbed in about 2 days. At this stage a baby tuna (in this case kawakawa) is forced to fend for itself and forage for food (photo 6).

The Honolulu Laboratory was one of the pioneers in the use of sonic tags to track tuna in the open ocean. Tags are now being developed to transmit biological and environmental data such as muscle activity (heart and tail beat rates), temperature (of the fish and water), and depth, in addition to the usual data on location of the fish.

These figures show the tracks of skipjack tuna tagged with sonic tags near Penguin Bank and Kaula Bank. (Track of tagged skipjack tuna at Kaula Bank: (A) from 1452, August 30, to 0600, August 31; (B) from 0600, August 31, to 0600, September 1; (C) from 0739, September 3, to 0600, September 4; (D) from 0600, September 4, to 0600, September 5; (E) from 0600, September 5, to 0730, September 6.)

These results confirmed for the first time that skipjack tuna are temporarily territorial and remain in a given area for some time in Hawaiian waters. Also of interest is the fish's repeated returns to the same area each morning, which implies that skipjack tuna can navigate and have a sense of time.



fin tuna placed in the doughnut tank were able to alter their body temperature physiologically, or thermoregulate, when the water temperature was changed at 6-h intervals. This ability to physiologically thermoregulate, however, has not been demonstrated as yet in all species of tuna.

The other form of thermoregulation, behavioral thermoregulation, involves a fish's ability to select and remain in water of a preferred temperature range. To test the hypothesis that fish of a given size would gravitate to water of a preferred temperature range and stay there, a special two-tank system was devised. The two tanks, 7,571 liters (2,000 gal) each in capacity, are connected by a short tunnel and contain water differing in temperature. If the fish swam from the cooler tank to the warmer tank, the temperature of both tanks would rise. Conversely, if the fish swam from the warmer tank to the cooler tank, the temperature of both tanks would fall. In this way, the fish could control its environmental temperature. These data will provide clues to the preferred temperature range of tunas in the ocean and provde valuable information to commercial fishermen.

Relation with University of Hawaii

The Honolulu Laboratory through its Kewalo Research Facility (and in other ways) maintains a special relationship with the University of Hawaii. There is free dialogue and exchange of information among scientists in the University's Department of Zoology, Physiology, and Biochemistry and the Kewalo Research Facility. The Honolulu Laboratory has provided part-time employment for University of Hawaii undergraduates and support for master's and doctor's degree candidates by providing laboratory space, experimental tuna, and monetary grants. Laboratory scientists have also served on graduate student theses committees. These activities have provided enrichment to the mutual benefit of the University of Hawaii and the Honolulu Laboratory.

BASE FOR RESEARCH VESSELS

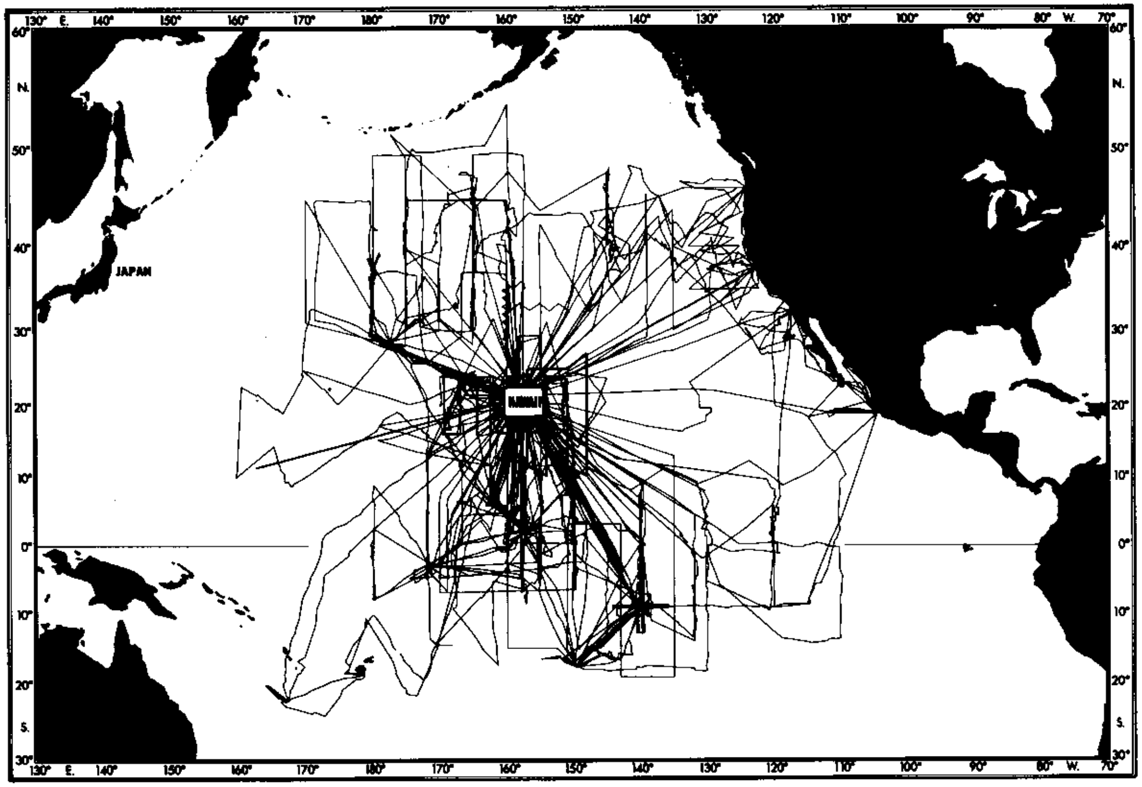
The Kewalo Research Facility has also served as the base for research vessels operated by the Honolulu Laboratory. At one time or another, the research vessels Hugh M. Smith and Charles H. Gilbert have docked at the shoreside facilities of the Kewalo Research Facility in the placid waters of Kewalo Basin. Presently, this facility is the home base of the NOAA vessel Townsend Cromwell, which has been assigned to the Honolulu Laboratory for fishery related work in the central Pacific Ocean. A few of the scientific achievements resulting directly from research cruises of vessels operated by the Honolulu Laboratory include:

- The discovery and delineation of the easterly flowing Equatorial Undercurrent (Cromwell Current). Its discovery solved one of the major oceanographic puzzles of our time, the great imbalance of the amount of water flowing westward in the Pacific Ocean as compared to the amount flowing to the east.

- The discovery of a concentration of large, deep-swimming tunas in an equatorial band and determining their relationship to the oceanographic and meteorological features of the Pacific Ocean.

- The preparation of an atlas of the oceanography of the central Pacific Ocean. This description provides basic environmental information of the world of the pelagic fishes, information that is essential to the exploratory and developmental stages of a fishery.

Currently, the Townsend Cromwell is deeply involved in a 5-yr study of the fishery and other biological resources of the Northwestern Hawaiian Islands. The study is being conducted under the provisions of an agreement for a Cooperative Study for the Assessment of the Living Resources of the Northwestern



The research activities of the Honolulu Laboratory cover a wide reach of the tropical and subtropical Pacific Ocean. From 1950 to the present, research vessels of the Honolulu Laboratory sailed over 1 million nautical miles on oceanographic and fishery cruises. Currently, the 48.2 m (158-ft) NOAA vessel Townsend Cromwell is under assignment to the Honolulu Laboratory for its use. In the past the Honolulu Laboratory operated the Henry O'Malley, John R. Manning, Hugh M. Smith, and the Charles H. Gilbert.

Hawaiian Islands involving the National Marine Fisheries Service (Honolulu Laboratory), the U.S. Fish and Wildlife Service, and the State of Hawaii (Hawaii Division of Fish and Game and various departments of the University of Hawaii). The Cromwell serves as the primary research platform for this study.

This research program has already provided payoffs in the form of the discovery of valuable spiny lobster and demersal fish resources in the Northwestern Hawaiian Islands. As a result of this discovery, a small fishery for spiny lobsters has developed. With proper management, the Northwestern Hawaiian Islands spiny lobster fishery should contribute to the economic well-being of Hawaii for many years to come.

APPENDIX 1

List of Visiting Investigators

Investigator	Affiliation	Specialty
DR. JELLE ATEMA	Marine Biological Laboratory Boston University Woods Hole, Massachusetts	Olfaction
DR. JOHN E. BARDACH	Resources Systems Institute East-West Center Honolulu, Hawaii	Olfaction
DR. GRANT R. BARTLETT	Laboratory of Comparative Biochemistry San Diego, California	Blood biochemistry
DR. WILLIAM P. BRAKER	John G. Shedd Aquarium Chicago, Illinois	Aquarist
DR. RICHARD W. BRILL	Department of Zoology University of British Columbia Vancouver, B.C., Canada	Thermal and muscle physiology
DR. PHYLLIS H. CAHN	Department of Zoology Stern College for Women Yeshiva University New York, New York	Behavior
DR. FRANCIS G. CAREY	Woods Hole Oceanographic Institution Woods Hole, Massachusetts	Thermal physiology

Investigator	Affiliation	Specialty
DR. JEAN L. CRAMER	Department of Animal Sciences University of Hawaii Honolulu, Hawaii	Thermal physiology
DR. F. E. J. FRY	Department of Zoology University of Toronto Toronto, Ontario, Canada	Thermal physiology
DR. MALCOLM S. GORDON	Department of Biology University of California Los Angeles, California	Muscle physiology
DR. MICHAEL GUPPY	Department of Zoology University of British Columbia Vancouver, B.C., Canada	Muscle biochemistry
DR. ISAO HANYU	Laboratory of Fish Physiology University of Tokyo Tokyo, Japan	Visual perception
DR. FRANCOIS HAVARD-DUCLOIS	Centre National pour L'Exploitation des Oceans Brest, France	Olfaction
DR. PETER W. HOCHACHKA	Department of Zoology University of British Columbia Vancouver, B.C., Canada	Muscle biochemistry
KIM HOLLAND	Monell Chemical Senses Center University of Pennsylvania Philadelphia, Pennsylvania	Olfaction

Investigator	Affiliation	Specialty
DR. C. S. HOLLING	Institute of Animal Resource Ecology University of British Columbia Vancouver, B.C., Canada	Behavior
DR. WILLIAM C. HULBERT	Department of Zoology University of British Columbia Vancouver, B.C., Canada	Muscle biochemistry
WALTER N. IKEHARA	Hawaii Institute of Marine Biology University of Hawaii Kaneohe, Hawaii	Olfaction
DR. JOHN W. KANWISHER	Woods Hole Oceanographic Institution Woods Hole, Massachusetts	Physiology, tag design
DR. CALVIN M. KAYA	Department of Zoology Montana State University Bozeman, Montana	Endocrine physiology
DR. JAMES F. KITCHELL	Department of Limnology University of Wisconsin Madison, Wisconsin	Bioenergetics
DR. JOHN J. MAGNUSON	Department of Limnology University of Wisconsin Madison, Wisconsin	Thermal physiology
MICHAEL A. MC COY	Micronesian Maritime Authority Kolonia, Ponape Eastern Caroline Islands	Turtle behavior

Investigator	Affiliation	Specialty
DR. JOHN M. MILLER	Department of Zoology University of North Carolina Raleigh, North Carolina	Larval ecology
ELIZABETH A. MONCKTON	Department of Zoology University of Hawaii Honolulu, Hawaii	Behavior
DR. BARRY S. MUIR	Marine Ecology Laboratory Bedford Institute of Oceanography Dartmouth, Nova Scotia, Canada	Physiology
DR. A. EARL MURCHISON	Naval Undersea Center Kailua-Kona, Hawaii	Behavior
DR. CLAUDE M. NAGAMINE	Institute of Marine Resources University of California Davis, California	Endocrine physiology
DR. WILLIAM H. NEILL	Department of Wildlife and Fisheries Sciences Texas A&M University College Station, Texas	Thermal physiology
DR. ARTHUR J. NIIMI	Canada Centre for Inland Waters Burlington, Ontario, Canada	Metabolism
DR. HIROSHI NIWA	Department of Fisheries Nagoya University Nagoya, Japan	Visual perception

Investigator	Affiliation	Specialty
DR. ELMER R. NOBLE	Department of Biological Sciences University of California Santa Barbara, California	Ectoparasites
LINDA M. PAUL	Department of Zoology University of Hawaii Honolulu, Hawaii	Lobster behavior
DR. DOUGLAS G. PINCOCK	Department of Electrical Engineering University of New Brunswick Fredericton, New Brunswick, Canada	Tag design
DR. WARREN P. PORTER	Laboratory of Limnology University of Wisconsin Madison, Wisconsin	Bioenergetics
DR. JOHN H. PRESCOTT	Oceanarium, Inc. Palos Verdes Estates, California	Courtship behavior
DR. MARTIN D. RAYNER	Pacific Biomedical Research Center University of Hawaii Honolulu, Hawaii	Muscle physiology
DR. TERENCE A. ROGERS	John A. Burns School of Medicine University of Hawaii Honolulu, Hawaii	Muscle and blood biochemistry
DR. BRYANT T. SATHER	Department of Zoology and Physiology Rutgers University Newark, New Jersey	Muscle and blood biochemistry

Investigator	Affiliation	Specialty
DR. EDWARD D. SCURA	Aquatic Farms Kahaluu, Hawaii	Aquaculture
DR. GARY D. SHARP	Inter-American Tropical Tuna Commission La Jolla, California	Thermal physiology
SHERRY STEFFEL	Laboratory of Limnology University of Wisconsin Madison, Wisconsin	Thermal physiology
DR. E. DON STEVENS	Department of Zoology University of Guelph Guelph, Ontario, Canada	Thermal physiology
LEN STUTTMAN	Stuttman Productions East Lansing, Michigan	Television production
DR. E. E. SUCKLING	Downstate Medical Center State University of New York Brooklyn, New York	Neural physiology
DR. J. A. SUCKLING	Department of Zoology Hunter College of the City University of New York New York, New York	Neural physiology
DR. TAMOTSU TAMURA	Agriculture Fisheries Laboratory Nagoya University Nagoya, Japan	Visual perception

Investigator	Affiliation	Specialty
DR. VLADIMIR WALTERS	Department of Zoology University of California Los Angeles, California	Locomotion
DR. DANIEL WEIHS	Department of Aeronautical Engineering Technion-Israel Institute of Technology Haifa, Israel	Hydrodynamics
DR. THEODORE Y. WU	Department of Engineering California Institute of Technology Pasadena, California	Hydrodynamics
MINATO YASUI	Shizuoka Prefectural Fisheries Experimental Station Yaizu, Shizuoka, Japan	Thermal physiology

APPENDIX 2

List of Scientific Publications and Manuscripts Resulting from Research at the Kewalo Research Facility

ATEMA, J., K. HOLLAND, and W. IKEHARA.
Chemical search image: Olfactory responses of yellowfin tuna (Thunnus albacares) to prey odors. Manuscr.

BARKLEY, R. A., W. H. NEILL, and R. M. GOODING.
1978. Skipjack tuna, Katsuwonus pelamis, habitat based on temperature and oxygen requirements. Fish. Bull., U.S. 76:653-662.

BARRY, M.
1979. Behavioral response of yellowfin tuna, Thunnus albacares, and kawakawa, Euthynnus affinis, to turbidity. M.S. Thesis, Univ. Hawaii, Honolulu.

BONE, Q.
1978. III. Myotomal muscle fiber types in Scomber and Katsuwonus. In G. D. Sharp and A. E. Dizon (editors), The physiological ecology of tunas, p. 183-205. Acad. Press, N.Y.

BRILL, R. W.
1978. V. Temperature effects on speeds of muscle contraction and stasis metabolic rate. In G. D. Sharp and A. E. Dizon (editors), The physiological ecology of tunas, p. 277-283. Acad. Press, N.Y.

1979. The thermal physiology of tuna. Ph.D. Thesis, Univ. Hawaii, Honolulu, 215 p.

In press. The effect of body size on the standard metabolic rate of skipjack tuna, Katsuwonus pelamis. Fish. Bull., U.S.

BRILL, R. W., and A. E. DIZON.
1979. Effect of temperature on isotonic twitch of white muscle and predicted maximum swimming speeds of skipjack tuna, Katsuwonus pelamis. Environ. Biol. Fish. 4.

In press. Red and white muscle fibre activity in swimming skipjack tuna, Katsuwonus pelamis (Linnaeus). J. Fish Biol.

BRILL, R. W., D. L. GUERNSEY, and E. D. STEVENS.
1978. IV. Body surface and gill heat loss rates in restrained skipjack tuna. In G. D. Sharp and A. E. Dizon (editors), The physiological ecology of tunas, p. 261-276. Acad. Press, N.Y.

BROWN, C. E., and B. S. MUIR.
1970. Analysis of ram ventilation of fish gills with application to skipjack tuna (Katsuwonus pelamis). J. Fish. Res. Board Can. 27:1637-1652.

CAHN, P. H.
1967. Some observations on schooling of tunas (motion picture). (Abstr.) Am. Zool. 7:199.

1972. Sensory factors in the side-to-side spacing and positional orientation of the tuna, Euthynnus affinis, during schooling. Fish. Bull., U.S. 70:197-204.

CHANG, R. K. C., B. M. ITO, A. E. DIZON, and W. H. NEILL.
Temperature independence of metabolism and activity in skipjack tuna, Katsuwonus pelamis. Manuscr.

CHANG, R. K. C., and J. J. MAGNUSON.
1968. A radiographic method for determining gas bladder volume of fish. Copeia 1968: 187-189.

DIZON, A. E.
1977. Effect of dissolved oxygen concentration and salinity on swimming speed of two species of tunas. Fish. Bull., U.S. 75: 649-653.

DIZON, A. E., and R. W. BRILL.
1979. Thermoregulation in tunas. Am. Zool. 19:249-265.

In press. Thermoregulation in yellowfin tuna, Thunnus albacares. Physiol. Zool.

DIZON, A. E., R. W. BRILL, and H. S. H. YUEN.
1978. III. Correlations between environment, physiology, and activity and the effects on thermoregulation in skipjack tuna. In G. D. Sharp and A. E. Dizon (editors), The physiological ecology of tunas, p. 233-259. Acad. Press, N.Y.

DIZON, A. E., T. C. BYLES, and E. D. STEVENS.
1976. Perception of abrupt temperature decrease by restrained skipjack tuna, Katsuwonus pelamis. J. Therm. Biol. 1:185-187.

DIZON, A. E., W. H. NEILL, and J. J. MAGNUSON.
1977. Rapid temperature compensation of volitional swimming speeds and lethal temperature in tropical tunas (Scombridae). Environ. Biol. Fish. 2:83-92.

DIZON, A. E., and G. D. SHARP.
1978. II. Perspectives: The past, present, and future of tuna physiology. In G. D. Sharp and A. E. Dizon (editors), The physiological ecology of tunas, p. 451-458. Acad. Press, N.Y.

DIZON, A. E., E. D. STEVENS, W. H. NEILL, and J. J. MAGNUSON.
1974. Sensitivity of restrained skipjack tuna (Katsuwonus pelamis) to abrupt increases in temperature. Comp. Biochem. Physiol. 49A: 291-299.

FIERSTINE, H. L., and V. WALTERS.
1968. Studies in locomotion and anatomy of scombrid fishes. Mem. South. Calif. Acad. Sci. 6:1-31.

GOODING, R. M.
1963. The olfactory organ of the skipjack Katsuwonus pelamis. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, Calif., 2-14 July 1962. FAO Fish. Rep. 6, 3:1621-1631.

GOODING, R. M., and W. H. NEILL.
Oxygen uptake and low-oxygen tolerance

limits in unrestrained skipjack tuna, *Katsuwonus pelamis*. Manuscr.

GORDON, M. S.

1968. Oxygen consumption of red and white muscles from tuna fishes. Science (Wash., D.C.) 159:87-90.

1972. Comparative studies on the metabolism of shallow-water and deep-sea marine fishes. I. White-muscle metabolism in shallow-water fishes. Mar. Biol. 13:222-237.

1972. Comparative studies on the metabolism of shallow-water and deep-sea marine fishes. II. Red-muscle metabolism in shallow-water fishes. Mar. Biol. 15:246-250.

GUPPY, M., and P. W. HOCHACHKA.

1978. Controlling the highest lactate dehydrogenase activity known in nature. Am. J. Physiol. 234:R136-R140.

1978. II. Skipjack tuna white muscle: A blueprint for the integration of aerobic and anaerobic carbohydrate metabolism. *In* G. D. Sharp and A. E. Dizon (editors), The physiological ecology of tunas, p. 175-181. Acad. Press, N.Y.

1979. Pyruvate kinase functions in hot and cold organs of tuna. J. Comp. Physiol. 129: 185-191.

HANYU, I., T. TAMURA, and H. NIWA.

1973. Electroretinograms and retinal ganglion cell responses in the skipjack tuna. Bull. Jpn. Soc. Sci. Fish. 39:265-273.

HOCHACHKA, P. W., W. C. HULBERT, and M. GUPPY.

1978. I. The tuna power plant and furnace. *In* G. D. Sharp and A. E. Dizon (editors), The physiological ecology of tunas, p. 153-174. Acad. Press, N.Y.

IKEHARA, W., J. ATEMA, A. BRITTAIN, J. BARDACH, A. DIZON, and K. HOLLAND.

1978. Reactions of yellowfin tuna to prey scents. (Abstr.) Pac. Sci. 32:97.

IVERSEN, R. T. B.

1966. Hearing in tunas with special reference to *Euthynnus yaito* Kishinouye. (Abstr.) Abstracts of Papers Related with Fisheries, Marine and Freshwater Science, Divisional Meeting on Fisheries Sciences, p. 25. Proc. 11 Pac. Sci. Congr., Tokyo, 1966, vol. 7.

1967. Response of yellowfin tuna (*Thunnus albacares*) to underwater sound. *In* W. N. Tavolga (editor), Marine bio-acoustics 2: 105-119, discussion, p. 119-121. Proc., Second Symposium on Marine Bio-Acoustics held at the American Museum of Natural History, New York, April 13-15, 1966. Pergamon Press, Oxford and New York.

1969. Auditory thresholds of the scombrid fish *Euthynnus affinis*, with comments on the use of sound in tuna fishing. *In* A. Ben-Tuvia and W. Dickson (editors), Proceedings of the FAO Conference on Fish Behaviour in Relation to Fishing Techniques and Tactics, Bergen, Norway, 19-27 October 1967. FAO Fish. Rep. 62, 3:849-859.

IVERSEN, R. T. B., and J. O. PUFFINBURGER.

1977. Capture, transportation, and pumping of threadfin shad, Dorosoma petenense. In R. S. Shomura (editor), Collection of tuna baitfish papers, p. 127-136. U.S. Dep. Commer., NOAA Tech. Rep. NMFS Circ. 408.

KITCHELL, J. F., J. J. MAGNUSON, and W. H. NEILL.
1977. Estimation of caloric content for fish biomass. Environ. Biol. Fish. 2:185-188.

KITCHELL, J. F., W. H. NEILL, A. E. DIZON, and J. J. MAGNUSON.
1978. III. Bioenergetic spectra of skipjack and yellowfin tunas. In G. D. Sharp and A. E. Dizon (editors), The physiological ecology of tunas, p. 357-368. Acad. Press, N.Y.

MAGNUSON, J. J.
1963. Tuna behavior and physiology, a review. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species, La Jolla, Calif., 2-14 July 1962. FAO Fish. Rep. 6, 3:1057-1066.

1964. Activity patterns of scombrids. (Abstr.) Proc. Hawaiian Acad. Sci., 39 Annu. Meet., 1963-1964, p. 26.

1964. Tuna behaviour research programme at Honolulu. In Modern Fishing Gear of the World 2:560-562. Fish. News (Books) Ltd., Lond.

1965. Tank facilities for tuna behavior studies. Prog. Fish-Cult. 27:230-233.

1966. A comparative study of the function of continuous swimming by scombrid fishes. (Abstr.) Abstracts of Papers Related with Fisheries, Marine and Freshwater Science. Symposium on Biological Studies of Tunas and Sharks in the Pacific Ocean, p. 15. Proc. 11 Pac. Sci. Congr., Tokyo, 1966, vol. 7.

1966. Continuous locomotion in scombrid fishes. (Abstr.) Am. Zool. 6:503-504.

1969. Digestion and food consumption by skipjack tuna (Katsuwonus pelamis). Trans. Am. Fish. Soc. 98:379-392.

1969. Swimming activity of the scombrid fish Euthynnus affinis as related to search for food. In A. Ben-Tuvia and W. Dickson (editors), Proceedings of the FAO Conference on Fish Behaviour in Relation to Fishing Techniques and Tactics, Bergen, Norway, 19-27 October 1967. FAO Fish. Rep. 62, 2:439-451.

1970. Hydrostatic equilibrium of Euthynnus affinis, a pelagic teleost without a gas bladder. Copeia 1970:56-85.

1973. Comparative study of adaptations for continuous swimming and hydrostatic equilibrium of scombroid and xiphoid fishes. Fish. Bull., U.S. 71:337-356.

1978. Locomotion by scombrid fishes: Hydromechanics, morphology, and behavior. In W. S. Hoar and D. J. Randall (editors), Fish physiology, vol. VII, p. 240-315. Acad. Press, N.Y.

MANAR, T. A.
1965. Tuna behavior: A growing field for research. Pac. Fisherm. 63(11):9-11.

MARR, J. C.
1967. Research programme of the U.S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii. Proceedings of the Symposium on Scombroid Fishes, Mandapam Camp, S. India, January 12-15, 1962, Part III, p. 1154-1157. Mar. Biol. Assoc. India.

MONCKTON, E. A.
1979. Stress in captive skipjack tuna, Katsuwonus pelamis. M.S. Thesis, Univ. Hawaii, Honolulu.

MUIR, B. S., and C. E. BROWN.
1971. Effects of blood pathway on the blood-pressure drop in fish gills, with special reference to tunas. J. Fish. Res. Board Can. 28:947-955.

MURCHISON, A. E., and J. J. MAGNUSON.
1966. Notes on the coloration and behavior of the common dolphin, Coryphaena hippurus. Pac. Sci. 20:515-517.

NAKAMURA, E. L.
1960. Confinement of skipjack in a pond. (Abstr.) Proc. Hawaiian Acad. Sci., 35 Annu. Meet. 1959-1960, p. 24-25.

1962. Observations on the behavior of skipjack tuna, Euthynnus pelamis, in captivity. Copeia 1962:499-505.

1964. A method of measuring visual acuity of scombrids. (Abstr.) Proc. Hawaiian Acad. Sci., 39 Annu. Meet., 1963-1964, p. 26-27.

1964. Salt well water facilities at the Bureau of Commercial Fisheries Biological Laboratory, Honolulu. In J. R. Clark and R. L. Clark (editors), A collection of papers on seawater systems for experimental aquariums. U.S. Fish Wildl. Serv., Res. Rep. 63:169-172.

1966. Fiberglass tanks for transferring of pelagic fishes. Prog. Fish-Cult. 28:60-62.

1968. Visual acuity of two tunas, Katsuwonus pelamis and Euthynnus affinis. Copeia 1968: 41-49.

1969. A review of field observations on tuna behavior. In A. Ben-Tuvia and W. Dickson (editors), Proceedings of the FAO Conference on Fish Behaviour in Relation to Fishing Techniques and Tactics, Bergen, Norway, 19-27 October 1967. FAO Fish. Rep. 62, 2:59-68.

1969. Visual acuity of yellowfin tuna, Thunnus albacares. In A. Ben-Tuvia and W. Dickson (editors), Proceedings of the FAO Conference on Fish Behaviour in Relation to Fishing Techniques and Tactics, Bergen, Norway, 19-27 October 1967. FAO Fish. Rep. 62, 3:463-468.

1972. Development and uses of facilities for studying tuna behavior. In H. E. Winn and B. L. Olla (editors), Behavior of marine animals. Current perspectives in research, vol. 2: Vertebrates, p. 245-277. Plenum Publ. Corp., N.Y.

NAKAMURA, E. L., and J. J. MAGNUSON.
1965. Coloration of the scombrid fish Euthynnus affinis (Cantor). Copeia 1965: 234-235.

NEILL, W. H., and T. C. BYLES.
1972. Automatic pellet dispenser for experimental feeding of fishes. Prog. Fish-Cult. 34:170.

NEILL, W. H., R. K. C. CHANG, and A. E. DIZON.
1976. Magnitude and ecological implications of thermal inertia in skipjack tuna, Katsuwonus pelamis (Linnaeus). Environ. Biol. Fish. 1:61-80.

NEILL, W. H., J. J. MAGNUSON, and G. D. CHIPMAN.
1972. Behavioral thermoregulation by fishes: A new experimental approach. Science (Wash., D.C.) 176:1443-1445.

NEILL, W. H., and E. D. STEVENS.
1974. Thermal inertia versus thermoregulation in "warm" turtles and tunas. Science (Wash., D.C.) 184:1008-1010.

RAYNER, M. D., and M. J. KEENAN.
1967. Role of red and white muscles in the swimming of the skipjack tuna. Nature (Lond.) 214:392-393.

SATHER, B. T., and T. A. ROGERS.
1967. Some inorganic constituents of the muscles and blood of the oceanic skipjack, Katsuwonus pelamis. Pac. Sci. 21:404-413.

SHARP, G. D., and A. E. DIZON (editors).
1978. The physiological ecology of tunas. Acad. Press, N.Y., 485 p.

SHARP, G. D., and W. J. VLYMEN III.
1978. II. The relation between heat generation, conservation, and the swimming energetics of tuna. In G. D. Sharp and A. E. Dizon (editors), The physiological ecology of tunas, p. 213-232. Acad. Press, N.Y.

STEFFEL, S.
1973. Temperature discrimination thresholds in a tuna, the kawakawa (Euthynnus affinis), as determined by operant conditioning. M.S. Thesis, Univ. Wisconsin, Madison, 52 p.

STEFFEL, S., A. E. DIZON, J. J. MAGNUSON, and W. H. NEILL.
1976. Temperature discrimination by captive free-swimming tuna, Euthynnus affinis. Trans. Am. Fish. Soc. 105:588-591.

STEVENS, E. D.
1972. The effect of changes in ambient temperature on spontaneous activity in skipjack tuna. Comp. Biochem. Physiol. 42A: 803-805.

1972. Some aspects of gas exchange in tuna. J. Exp. Biol. 56:809-823.

STEVENS, E. D., and F. E. J. FRY.
1971. Brain and muscle temperatures in ocean caught and captive skipjack tuna. Comp. Biochem. Physiol. 38A:203-211.

SUCKLING, E. E.
1965. Mode of action of the lateral line organ receptors in fish. (Abstr.) Physiologist 8:283.

1967. Electrophysiological studies on the trunk lateral line system of various marine and freshwater teleosts. In P. H. Cahn (editor), Lateral line detectors, p. 97-103. Indiana Univ. Press, Bloomington.

SUCKLING, J. A.
1967. Trunk lateral line nerves: Some anatomical aspects. In P. H. Cahn (editor), Lateral line detectors, p. 45-52. Indiana Univ. Press, Bloomington.

TAMURA, T., I. HANYU, and H. NIWA.
1972. Spectral sensitivity and color vision in skipjack tuna and related species. Bull. Jpn. Soc. Sci. Fish. 38:799-802.

TESTER, A. L.
1959. Summary of experiments on the response of tuna to stimuli. In H. Kristjonsson (editor), Modern fishing gear of the world, p. 538-542. Fish. News (Books) Ltd., Lond.

WALTERS, V.
1966. On the dynamics of filter-feeding by the wavyback skipjack (*Euthynnus affinis*). Bull. Mar. Sci. 16:209-221.

YASUI, M., and A. E. DIZON.
Thermal inertia of the cooling and heating in restrained yellowfin tuna, *Thunnus albacares*. Manuscr.