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THE KEWALO RESEARCH FACILITY
1958 TO 1983--25 YEARS OF PROGRESS

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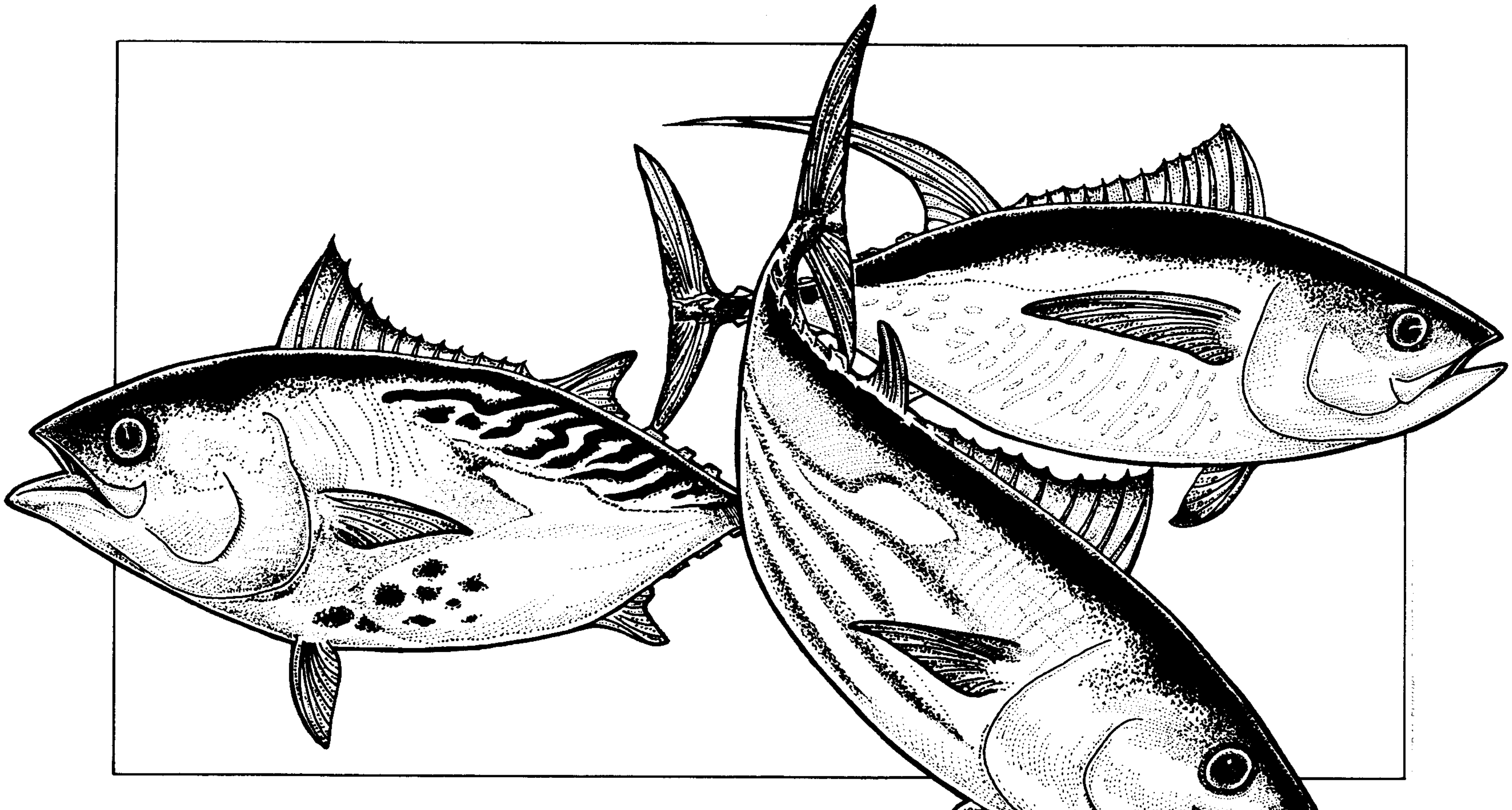

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FORWARD

Tuna stocks are distributed throughout the oceans of the world and form an important economic resource for many countries. In 1982, the estimated worldwide catch of all species of tuna was 2.5 million metric tons (2,205 pounds per metric ton) which was valued at $2.8 billion. The United States alone processed 540 million pounds of canned tuna which was valued at $885 million.

In the important commercial tuna fisheries of the world, prediction of the distribution and abundance of the various species of tunas that comprise the resource is a major biological problem. Analyses of environmental data from the Pacific over the years have provided correlations between tuna distribution and various oceanographic and meteorological variables, but the mechanisms determining the distribution, availability, and migrations of tunas are not completely known. Temperature, oxygen, salinity, and food availability all influence tuna movements and limit their vertical and horizontal distributions. The Kewalo Research Facility of the Honolulu Laboratory is in the center of ongoing research programs designed to examine the effects of the most important environmental parameters on the behavior and physiology of tunas. These programs will ultimately allow fishermen and fisheries scientists to predict how environmental factors affect the distribution, availability, and movements of tunas.

The Honolulu Laboratory sees the role of the Kewalo Research Facility also as an international gathering place for scientists of varied backgrounds and disciplines. The uniqueness of this facility and past 25 years of quality research have engendered an enviable reputation for the Kewalo Research Facility throughout the world. During this period many respected scientists have taken the opportunity to study tunas under the controlled laboratory conditions available only at the Kewalo Research Facility.

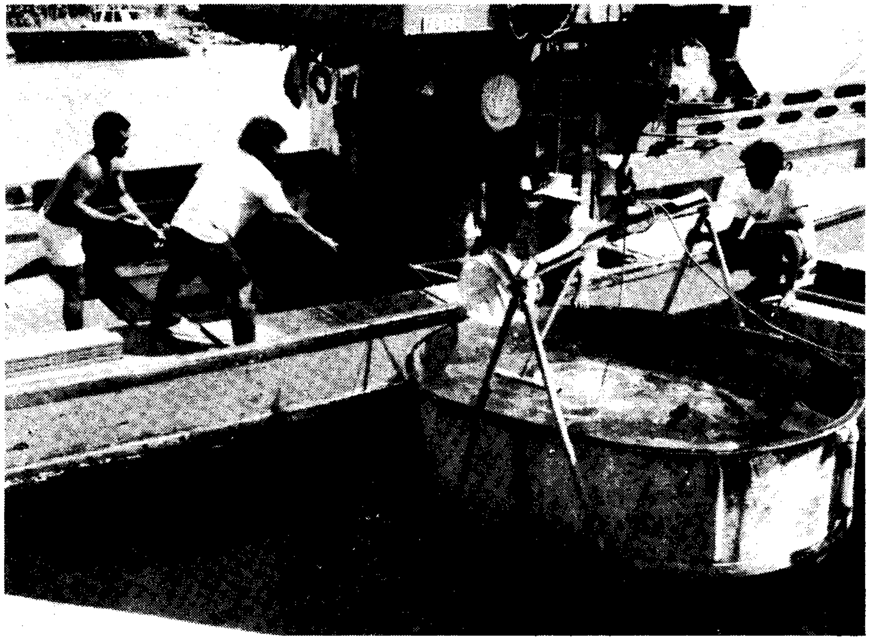
THE KEWALO RESEARCH FACILITY

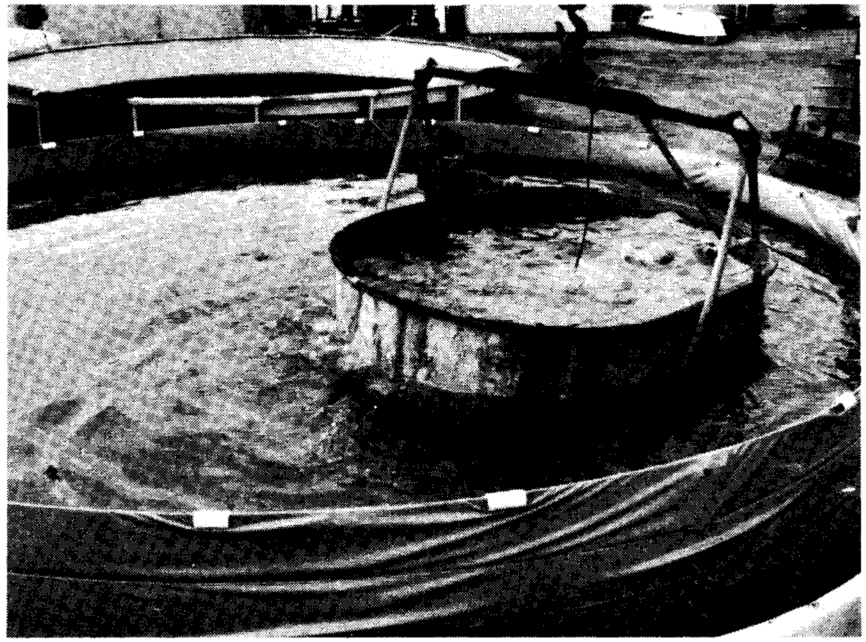
"Kewalo" has been translated as "the place of wailing." Historical descriptions of the area on the Island of Oahu called Kewalo give meaning to the translation. In ancient times the section of the land called Kewalo contained a spring, which before the conversion to Christianity, was used as a place where human sacrifices, such as <u>kauwa</u> (outcasts), were first drowned before being taken to the Heiau of Kanelaau (temple) on the slopes of Punchbowl Crater for burning in the <u>imu</u> <u>ahi</u> (fire oven).

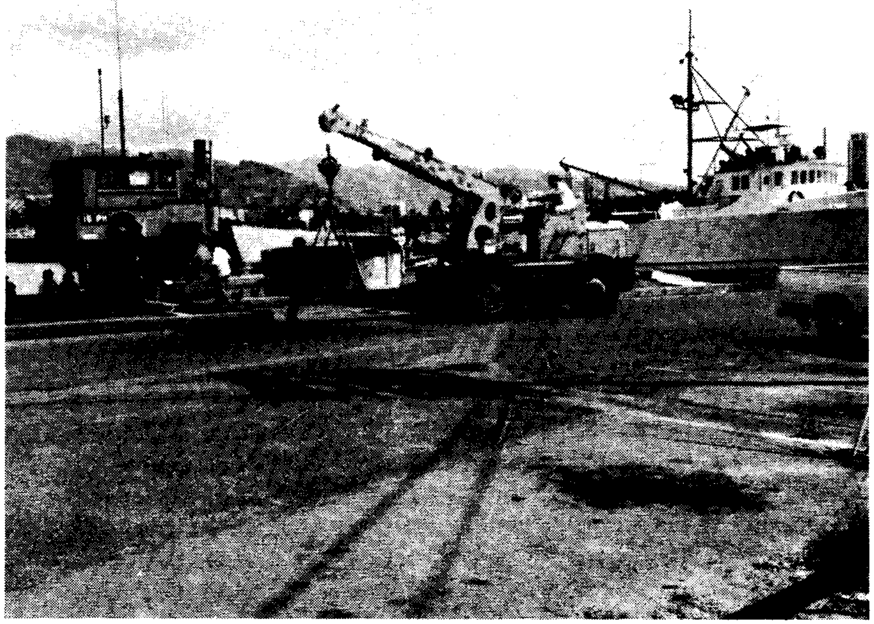
Kewalo Basin, as part of the modern city of Honolulu, is of course no longer used for such purposes. Today, Kewalo Basin is the home of many commercial and recreational fishing boats, a seafood cannery, a fresh fish auction house, and other marine related enterprises. Kewalo Basin is also the site of the Honolulu Laboratory's Kewalo Research Facility.

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 of the National Marine Fisheries Service, then a part of the Fish and Wildlife Service, 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 tourists, 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







Live tunas are presently collected by cooperating commercial pole-and-line fishermen. The fish are caught with barbless hooks and dropped into the vessel's bait holding tanks. When the vessel returns to Kewalo Basin, the fish are transferred into a waiting transfer tank with a chamois-lined dip net. The transfer tank is then transported with a crane and lowered into a holding tank in which the fish freely swim. This handling technique, which has evolved over the years, minimizes injury to the fish.

building has over 1,003.4 m^2 (10,800 ft^2) of space and houses offices, laboratories tailored for various research activities, a machine shop, and storage areas. A saltwater well on the adjoining grounds has the capacity to produce high quality coral filtered seawater at a rate of over 3,785 liters (1,000 gal) per minute. The filtered seawater is pumped to aerators to be oxygenated and then distributed to various tanks including a series of five 75,706-liter

(20,000-gal) circular pools, a 757,060-liter (200,000-gal) oceanarium, and specially designed experimental tanks of various sizes.

The Kewalo Research Facility is today, as it has been since its inception, the only research center in the world that is able to maintain live tunas in captivity throughout the year for use in behavioral and physiological research. Indeed, the Facility's international reputation continues to attract established scientists of diverse backgrounds and expertise to this unique laboratory where experiments requiring live tunas can be conducted.

RESEARCH ACTIVITIES

Early Work

Despite the worldwide distribution and high economic value of tuna stocks, very little research had been done with live specimens before 1958. The initial goals of the Kewalo Research Facility were to develop a program to maintain live tunas in captivity as experimental animals. Because there was little information available on live tunas, the early research was aimed at collecting data that would serve as the foundation for future investigations. This early work uncovered interesting facts about tunas.

- Tunas are heavier than water and must continuously swim to keep from sinking. Tunas breathe by simply opening their mouths so that water is forced over their gills as they swim. Tunas sink and suffocate if they stop swimming.

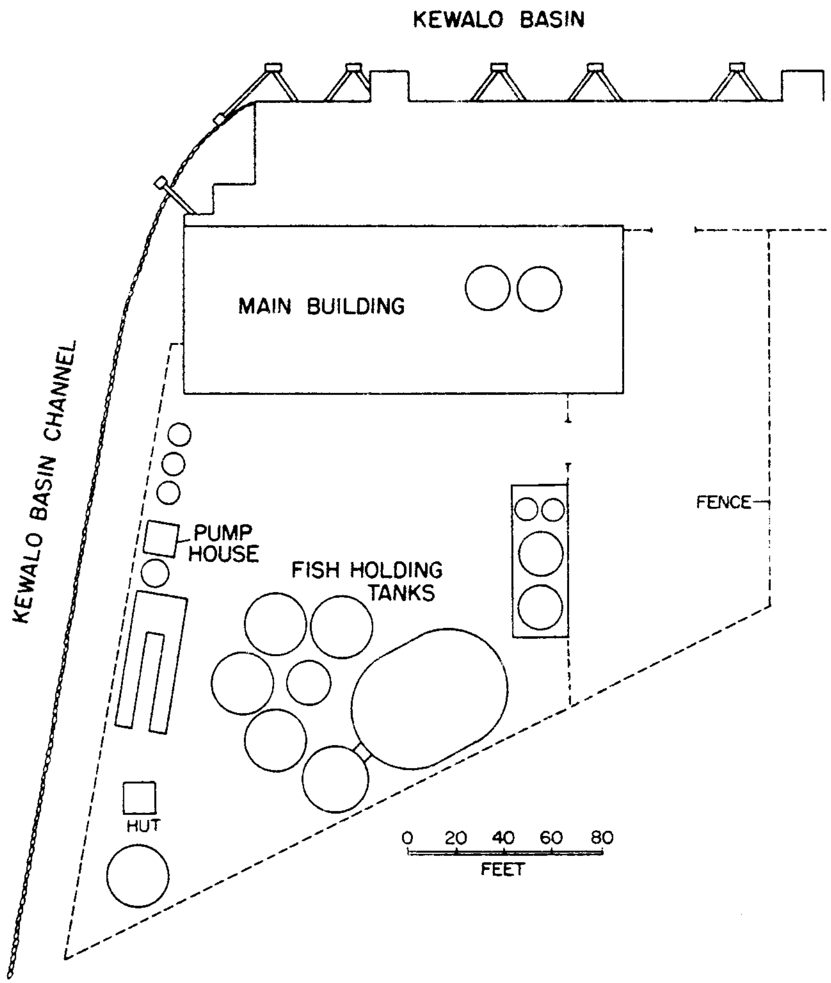
- The basal swimming speed of tunas is dependent upon the lifting area of fins and the density of the fish, and is not a function of either respiratory requirements or the search for food.

- All tunas have the following adaptions for continuous swimming: 1) a high hemoglobin level in the blood to carry sufficient oxygen to maintain continuous muscle activity; 2) a large proportion of the muscle made up of red muscle fibers that are specialized, like muscles of the heart, for continuous activity; and 3) a streamlined body shape to reduce hydrodynamic drag.

- In larger species of tunas, two morphological features evolved to reduce the energy required to keep from sinking. First, pectoral fins became larger to produce more lift; second, gas bladders developed to decrease density. Although gas bladders are very effective in reducing the density of fish, they limit the tuna's vertical movements. A fast vertical ascent to the surface can cause large changes in volume and, in the extreme, burst the gas bladder.

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

To determine how well tunas can see, studies were conducted on their visual acuity (the ability to see the fine details of objects). Of the three species tested, it was determined that yellowfin tuna, _Thunnus albacares_, could see better than skipjack tuna, _Katsuwonus pelamis_, and the latter better than kawakawa, _Euthynnus affinis_. Further experiments on

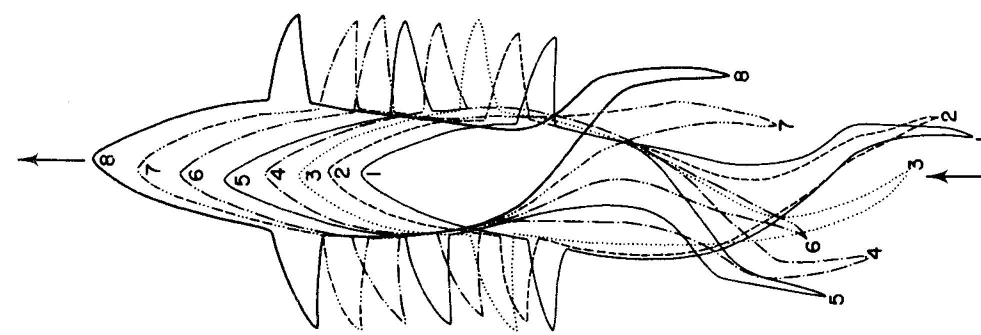


The Kewalo Research Facility is able to obtain and maintain tuna in captivity because of several conditions unique to its site. Commercial live bait tuna fishing boats dock literally at the laboratory's front door. Also, because the facility was built over a filled-in coral reef, and because of Hawaii's mild climate, the saltwater well is able to provide clean seawater at appropriate temperature for holding tunas the year round.

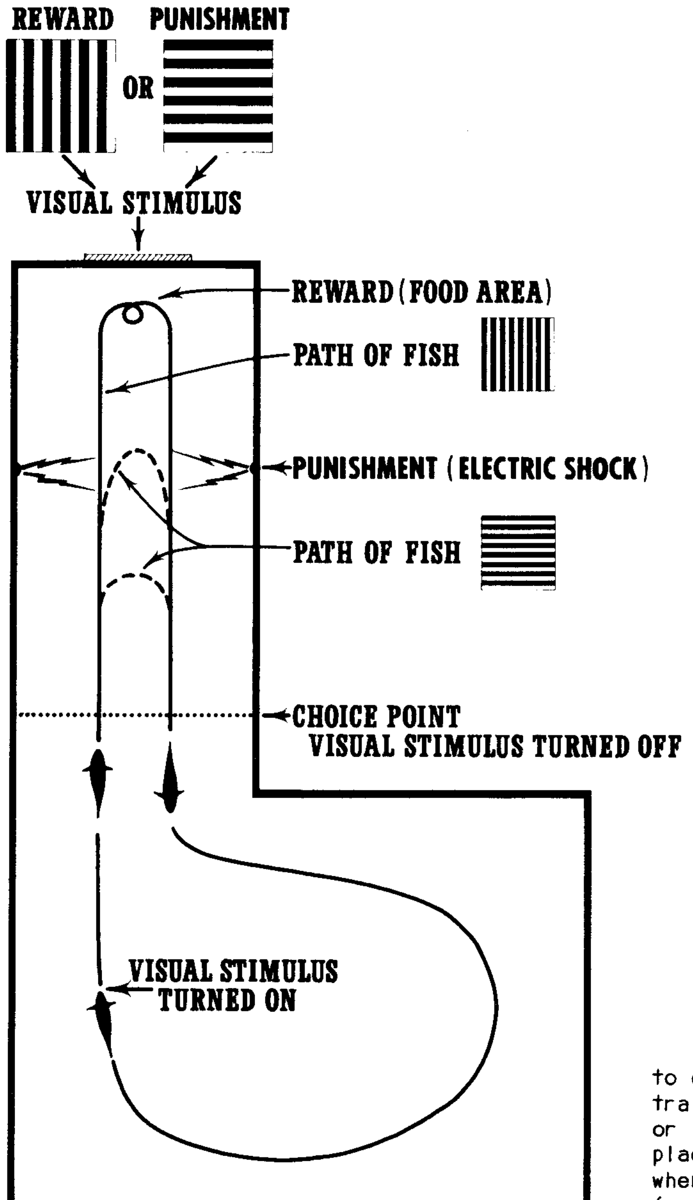
the optical system of restrained tuna showed that they are color-blind and are most sensitive to blue light.

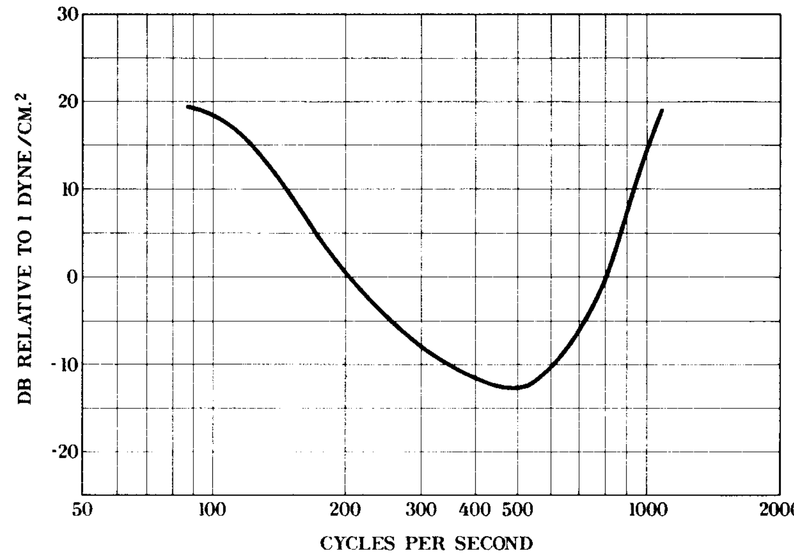
Experiments to define the hearing ability of tunas made it possible to construct a hearing curve for a tuna, the first ever for a scombrid, and to determine their auditory thresholds (the lowest level of sound that can be heard at a specific frequency). It was determined that the hearing range of yellowfin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

Experiments at the Kewalo Research Facility also showed that tunas have a highly developed sense of smell. A strong response was elicited from a school of kawakawa when a liter (1.06 qt) of water in which a



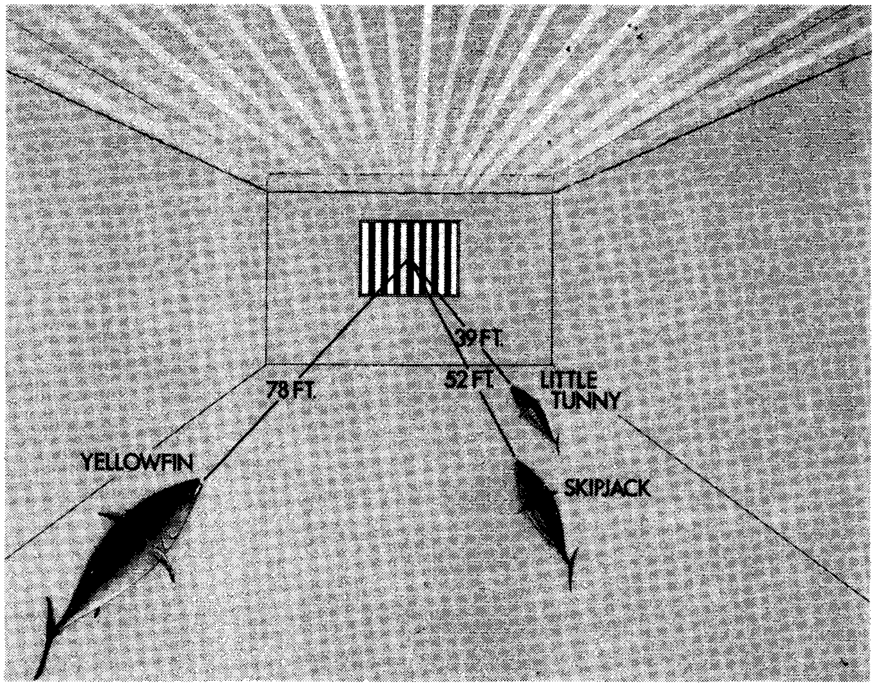
The facilities at Kewalo made it possible to closely observe captive fish and produced the first high-speed movies of swimming kawakawa. The analysis of the film provided intimate details of swimming speed, tail beat rates, body postures and flexures, and how the changing positions of fins and finlets 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 cine frames (camera speed 100 frames per second) for one complete caudal fin beat cycle of a kawakawa. The swimming speed of this fish was 8.2 body lengths per second which was produced by a tail beat frequency of 14.3 tail beats per second.





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.



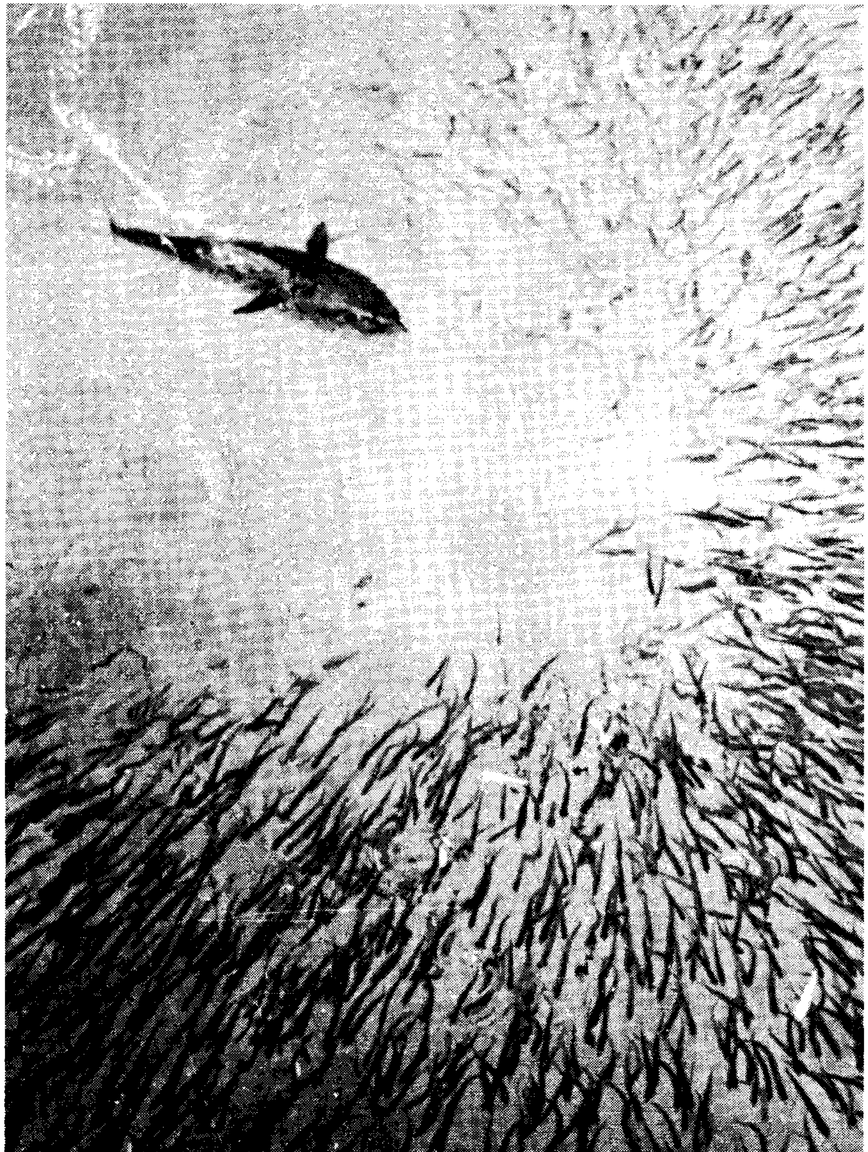
To measure tuna's reaction to various sensory stimuli, an observer must be able to detect the fish's response to these stimuli. It was found that tunas can be trained to perform a specific act in response to stimuli if they were rewarded. To measure how well they can see, tunas were trained to respond 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 a constant brightness, a yellowfin tuna sees details of an object better than a skipjack tuna and a skipjack tuna better than a kawakawa.

small fish (a smelt weighing 10 g or 0.4 oz) had been dipped for 10 seconds was introduced to their holding tank. It should be noted that the response was elicited even though the rinse water was further diluted by its introduction through the inflow seawater system. A study of the morphological structure of the nares (nose) of the tunas revealed that they can "sniff" the water. Each jaw movement of a tuna produces a pumping action that forces water past their nasal rosettes (odor receptors). Observations of fish in captivity showed this pumping action to be continuous.

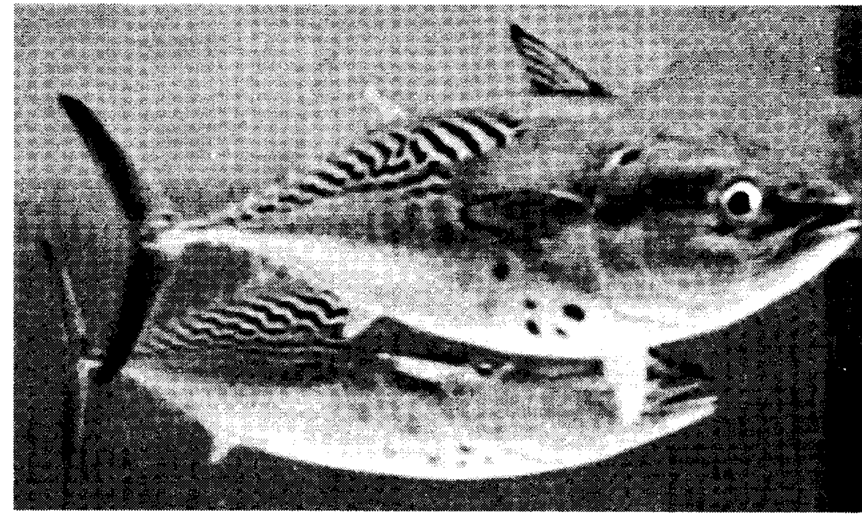
Two other research projects were designed to determine tunas' ability to perceive changes in water temperature. One experiment made use of the observation that the heart rate of a restrained tuna slows when the fish is presented with an external stimulus, such as a change in water temperature. In the second experiment a free swimming fish was rewarded with food each time it was able to recognize a temperature difference when cooler or warmer water was added to the tank. In restrained fish, a temperature change of 1°C elicited a response. Free swimming fish were able to perceive a temperature difference of as little as 0.1°C.

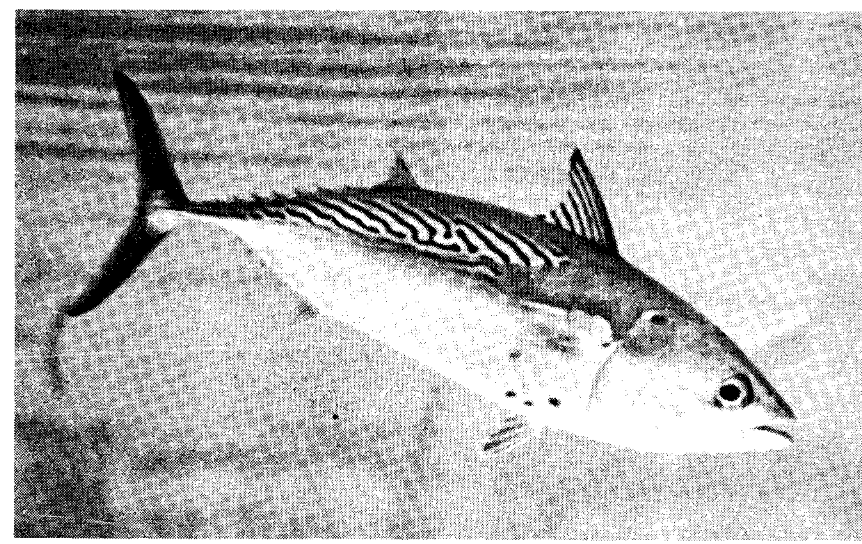
Other early work in the feeding and digestion rates of tunas showed that these fish can digest a meal several times faster than other fish species. Prey organisms are not homogeneously distributed in the open ocean, but are found in patchy concentrations in space and time. Tunas, thus, exist in a "feast or famine" situation and must eat whenever they find food. Knowledge of digestion and feeding rates of fishes adapted to such environments is important for the understanding of growth and the worldwide distribution of tunas and can be of practical value to commercial fishermen.

As techniques for capture, transport, and maintenance of tunas improved, the number of live tunas available for experimental purposes increased proportionately. This has made it possible to increase the variety of behavioral and physiological studies conducted at the Kewalo Research Facility.

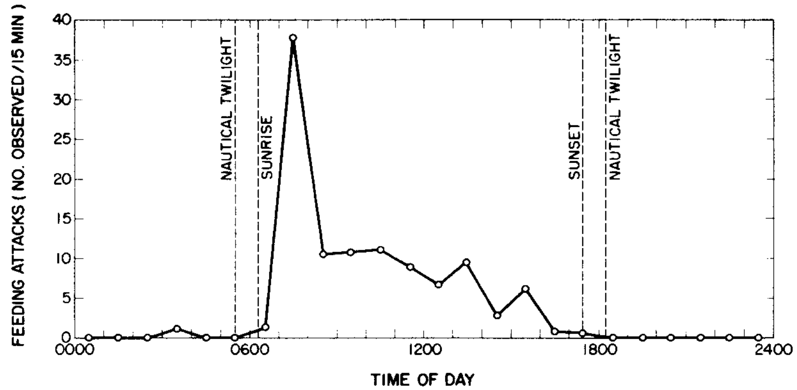


In this photograph a kawakawa is making an aggressive move towards a school of nehu in a shoreside research tank. Kawakawa has proved to be a good laboratory research animal and is readily available in Hawaiian waters.





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.



The changes in the feeding activity of kawakawa during a 24-hour 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.

Later Work

More recent work at the Kewalo Research Facility has included efforts to develop a mathematical model of the energy requirements of skipjack tuna. Such a model enables scientists to better explain and predict the abundance and maximum sustainable yields of all species of tunas. Much of the data collected over the past quarter century have been used in this model. Results indicate that the growth rate of skipjack tuna less than 11.8 kg (26 lb) is governed by food consumption, whereas the growth rate of fish larger than 15.0 kg (33 lb) is limited by the energetic demands of activity. Other work, using data from laboratory experiments on tuna combined with oceanographic information, indicated that the distribution of small fish is dependent on the availability of food whereas the distribution of large fish is dependent on environmental conditions, of which temperature and oxygen levels play major roles.

Additional studies at the Kewalo Research Facility confirmed that tunas have a remarkable ability to maintain body temperatures higher than the temperature of the water in which they swim. This ability is attributable to vascular countercurrent heat exchangers that retain the heat produced by metabolic activity within the muscles. In other bony fishes metabolic heat is lost into the surrounding water via the gills and body surface.

As a predator, the ability to maintain an elevated body temperature probably gives tunas an advantage over other fishes because it allows the tuna to operate at higher activity levels. Depending on the activity and size of the fish, muscle temperature can range from 2° to 21°C above ambient water temperature.

The accumulation of knowledge on the effects of temperature on the tuna physiology allowed work on more sophisticated experiments, such as those designed to determine whether tunas can physiologically or behaviorally thermoregulate. The first evidence of physiological thermoregulation in tunas was obtained in experiments with yellowfin tuna. Yellowfin tuna placed in a doughnut-shaped tank were able to alter their body temperature independently of swimming speed (that is physiologically thermoregulate) as the water temperature was changed at 12-hour intervals. This ability to physiologically thermoregulate, however, has not yet been demonstrated in all species of tuna.

Current Work

Tuna Bioenergetics

Tuna metabolic rates present an interesting paradox. Tunas are more energetic than other fishes yet they inhabit a very food-poor environment: the tropical oceans. How do tunas obtain the energy for so much activity when they live in a virtual desert? Anyone seeing the sleek, streamlined shape of a swimming tuna is impressed with its design for speed. Each of five swimming fins can be withdrawn into a slot or recess, leaving the body surface perfectly smooth. Despite their hydrodynamically designed bodies, tunas require more energy to swim at their cruising speed than do other fishes when forced to swim at the same speeds. Shouldn't tunas be more efficient? The measurement of tuna metabolic rates has a long history at the Kewalo Research Facility. Past projects included measurement of standard metabolic rate (metabolic rate at zero activity), and studies of the effects of size, temperature, and speed on active metabolic rate.

Current work is designed to reexamine earlier results based on oxygen consumption (respirometry), by directly measuring changes in whole fish energy content (calorimetry). To determine the relationship between speed and energy consumption, wild skipjack tuna, kawakawa, and yellowfin tuna are being compared with experimentally manipulated fish caught from the same schools.

Answers to the paradox of high metabolic rates may come from the advantages a high metabolic rate provides with respect to agility and mobility in hunting and capturing prey. The data indicate that tunas become more efficient than other fishes at higher swimming speeds. For tunas, high metabolic rates at low activities may be a physiological necessity for greater efficiency at high swimming speeds during feeding or when escaping from predators. The unique ability of tunas to conserve metabolic heat may also turn high metabolic rates to advantage by keeping the tuna's swimming muscles warm when they penetrate cold, deep water in pursuit of prey.

Investigators are working at the Kewalo Research Facility to determine the characteristics of muscle physiology needed to link data on tuna bioenergetics with mathematical hydrodynamic models of power output. Aside from providing basic insight into the physics of swimming, these models, derived in cooperation with researchers from the University of Wisconsin and California Institute of Technology, should provide a useful tool for predicting energy consumption at the population level. Such predictions will, in turn, permit better estimates of tuna abundance and productivity for eventual applications to fishery management.

Olfaction

Work conducted 20 years ago at the Kewalo Research Facility established that tunas have an excellent sense of smell that is capable of detecting the very dilute odor of their prey. Recent research with captive and wild tuna indicates that they can distinguish between odors of different types of prey, and that some prey odors cause stronger search behavior than others. These data indicate that tuna probably use their sense of smell to detect prey before they come within visual range.

Current research is aimed at analyzing the chemical structure of the prey odors and testing various synthetic prey odors for eliciting a feeding response. Eventually, it may be possible to use these natural and synthetic odors to enhance the effectiveness of traditional fishing techniques. If an inexpensive synthetic odor can be formulated, it could be used in the live-bait and the handline tuna fisheries to increase catch success and decrease the dependency on expensive natural bait.

Spawning

The first successful attempts to artificially induce spawning in captive tuna were accomplished at the Kewalo Research Facility. The technique involved a periodic biopsy of kawakawa to determine the developmental stage of the eggs in the ovaries. After the eggs attained a critical size, hormone treatments were administered to the fish to induce spawning. Today, because of recent advances in techniques and knowledge, hormone treatments are no longer used and (during the summer months) skipjack tuna routinely spawn in our shoreside facilities shortly after arrival. This has enabled researchers to investigate the techniques needed to rear larval pelagic fish.

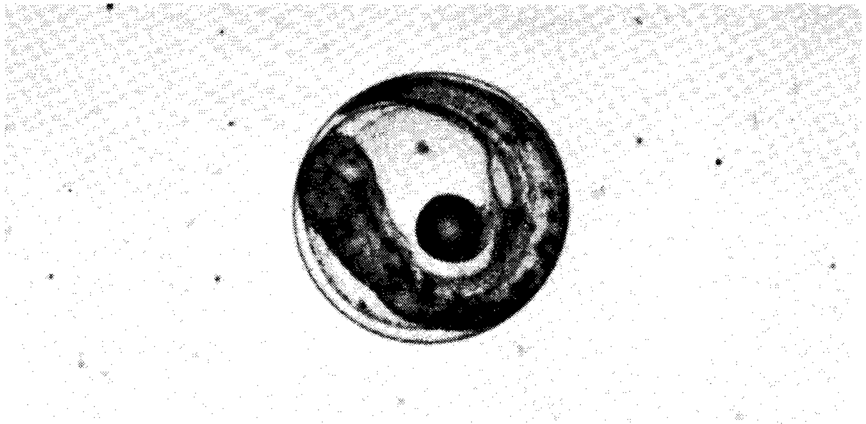
Tuna eggs hatch about 24 hours after fertilization and the yolk sacs of the larvae are absorbed in about 2 days. At this critical stage, the larval tuna must forage for food. To meet the nutritional requirements of larval tuna, the Kewalo Research Facility maintains a culture system for species of phytoplankton, rotifers, and copepods. These foods are of different sizes and nutritional values and must be present at each critical stage of the tuna's development. The technology developed to rear larval tuna is opening new fields of research that will focus on the previously unobservable day-to-day development and early life history of pelagic fish. Currently, larval tuna are the subjects of studies designed to determine their growth, development, behavior, neuroanatomy, energetics, and development of geomagnetic sensitivity.

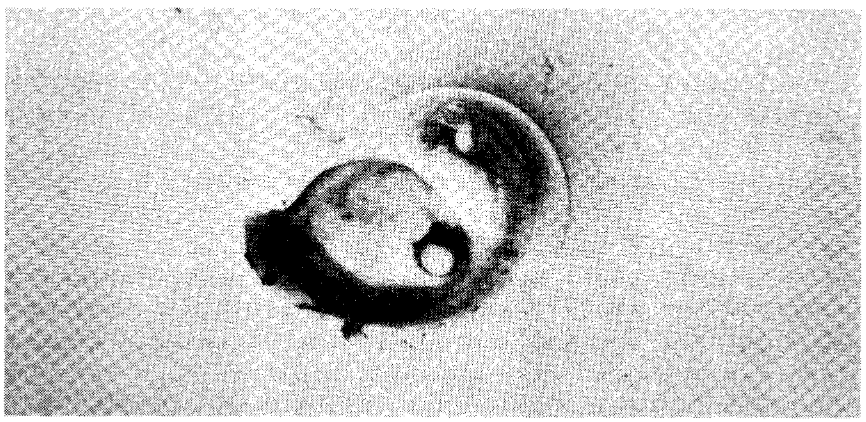
Geomagnetic Sensitivity

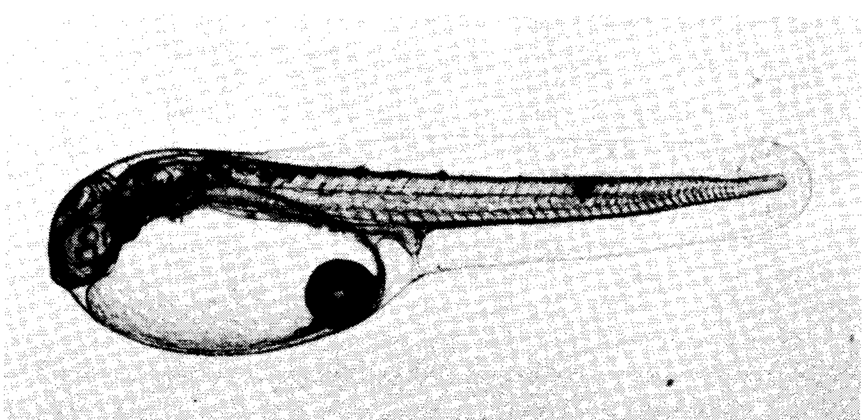
Tunas are among the most highly migratory fishes. An understanding of migration is central to an understanding of the distribution of tuna stocks. Migration represents a substantial investment of energy for migrating fish, and it might be expected that there has been intense evolutionary pressure on the sensory systems responsible for guiding migration. However, no special abilities useful in navigation have been detected among the commonly recognized sense systems (vision, smell, taste, etc.) of tunas. One exciting possibility is that tunas possess a magnetic compass sense capable of guiding their migrations.

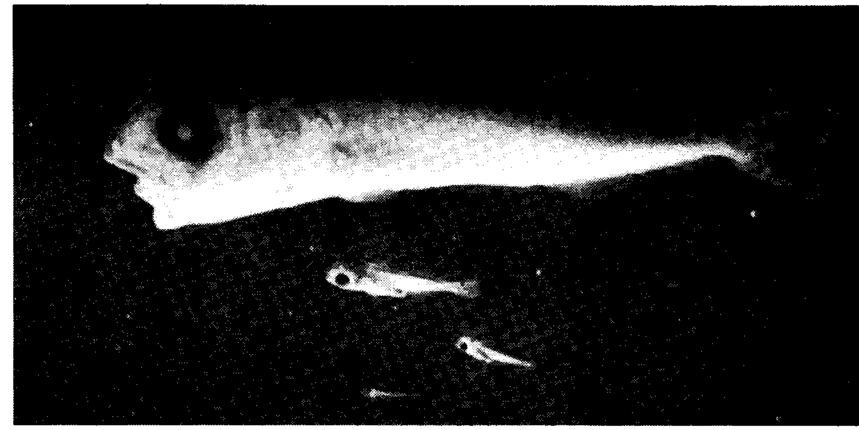
Studies are currently underway to test the ability of yellowfin tuna to discriminate between different magnetic fields. The fish are pretrained to perform a conditioned response (swimming through a hoop) at a consistent rate. The fish are then tested by rewarding them with food when one magnetic field is present in the tank and by punishing them (by withholding food) when the second field is present. If the fish are able to detect the difference between the two magnetic fields, maintaining a high rate of response during positively reinforced trials will maximize food rewards, whereas a low rate of response during negatively reinforced trials will minimize the cost of responding. Thus, discrimination is measured as a difference in the rates at which the fish swim through the hoop in anticipation of positive or negative reinforcement.

Results show that yellowfin tuna can learn to use magnetic field information to make appropriate decisions about their experimental situation. The first conclusion from these studies is that yellowfin tuna possess a magnetic sense which probably could be





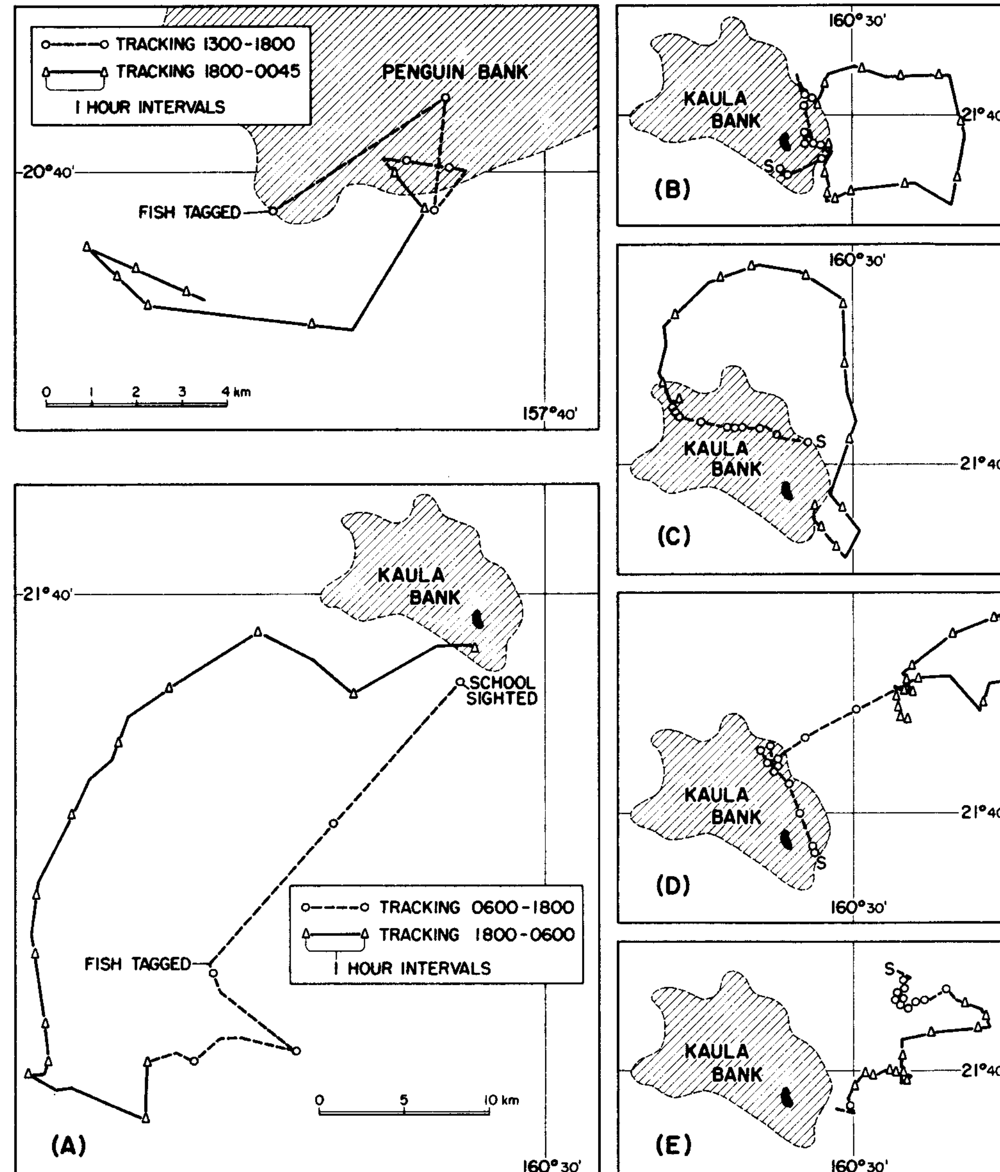




The different stages of development of skipjack tuna spawned at the Kewalo Research Facility are shown in this series of pictures. The first picture is of an egg that has been nurtured in the laboratory for about 16 hours since fertilization. The second picture catches a larvae just hatching, about 21 hours after fertilization. The third picture is of a larvae less than 24 hours old. The large yolk sac will be absorbed about 48 hours after hatching, and the fish must then actively forage for food. The fourth picture shows the rapid growth in the early life of a skipjack tuna. The ages from the largest to the smallest are 35, 20, 18, and 3 days old.

used for navigation. Continuing studies are testing for magnetic sensitivity in kawakawa and skipjack tuna.

Related studies are aimed at determining whether the fish use crystals of magnetite (lodestone) as the basis for their magnetic sense. A yellowfin tuna has been shown to contain up to 10 million crystals of magnetite. The fish produce the magnetite under very closely controlled conditions of size, shape, and chemical composition in a tissue within the ethmoid bones of the skull. A large branch of the anterior lateral line nerve ramifies in the area of the ethmoid bones of tunas. It is therefore possible that a



The Honolulu Laboratory was one of the pioneers in the use of sonic tags to track tuna in the open ocean.

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.)

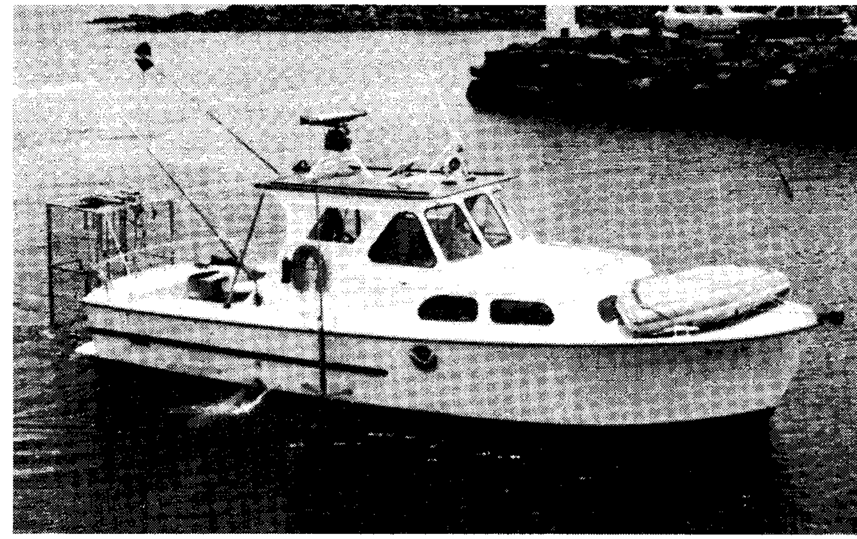
These results confirmed for the first time that skipjack tuna are temporarily territorial and remain in a given area for some time in Hawaiian waters. Also of interest is the fish's repeated returns to the same area each morning, which implies that skipjack tuna can navigate and have a sense of time.

branch of this nerve may be associated with the magnetite crystals, forming a magnetoreceptor organ. Work is continuing on the structure and anatomy of the magnetite-bearing tissue contained in the ethmoid bones.

Physiological Laboratory

The Kewalo Research Facility has a laboratory specifically designed for neurophysiological, cardiovascular, and general physiological experiments on tunas. The laboratory contains a vibration-free operating table with running seawater. Tuna can be effectively restrained on the table in a padded Plexiglas[1] trough or box and often will survive in excess of 8 hours in this situation.

The laboratory is currently being used to investigate the neurophysiological responses of tunas to odors and to changes in the Earth's magnetic field. A series of experiments to measure the rate of oxygen uptake of quiescent fish (the so-called "standard metabolic rate") is also in progress. The physiological studies on restrained tuna are specifically designed to complement the data obtained from free swimming fish's responses to various odor and magnetic stimuli and measurements of the metabolic rate.



The RV Kaahele'ale is pictured leaving on a dual mission to confirm results of experiments conducted at the Kewalo Research Facility. In addition to the normal fishing, navigational, and oceanographic equipment on board, a hydrophone is mounted at the bottom of the vertical pole located amidship. After a tuna is successfully tagged with an ultrasonic transmitter and released, the receiver is lowered into the water and the horizontal and vertical movements of the fish are then recorded. On the stern of the vessel is secured a shark cage from which divers will observe the behavioral reactions of fish to natural and synthetic prey odors.

BASE FOR RESEARCH VESSEL

The Kewalo Research Facility has also served as the base for research vessels operated by the Honolulu Laboratory. At various times, the research vessels Hugh M. Smith, Charles H. Gilbert, and Townsend Cromwell have docked at the shoreside facility. The Townsend Cromwell is now docked at Snug Harbor (part of Honolulu Harbor); but, the Kewalo Research Facility still serves as a base of operation for research cruises.

The Kewalo Research Facility now has at its disposal the RV Kaahele'ale. This 33-ft vessel is capable of returning live specimens to the laboratory and is equipped with sophisticated electronics and navigational equipment to track the vertical and horizontal movements of tunas and billfishes carrying

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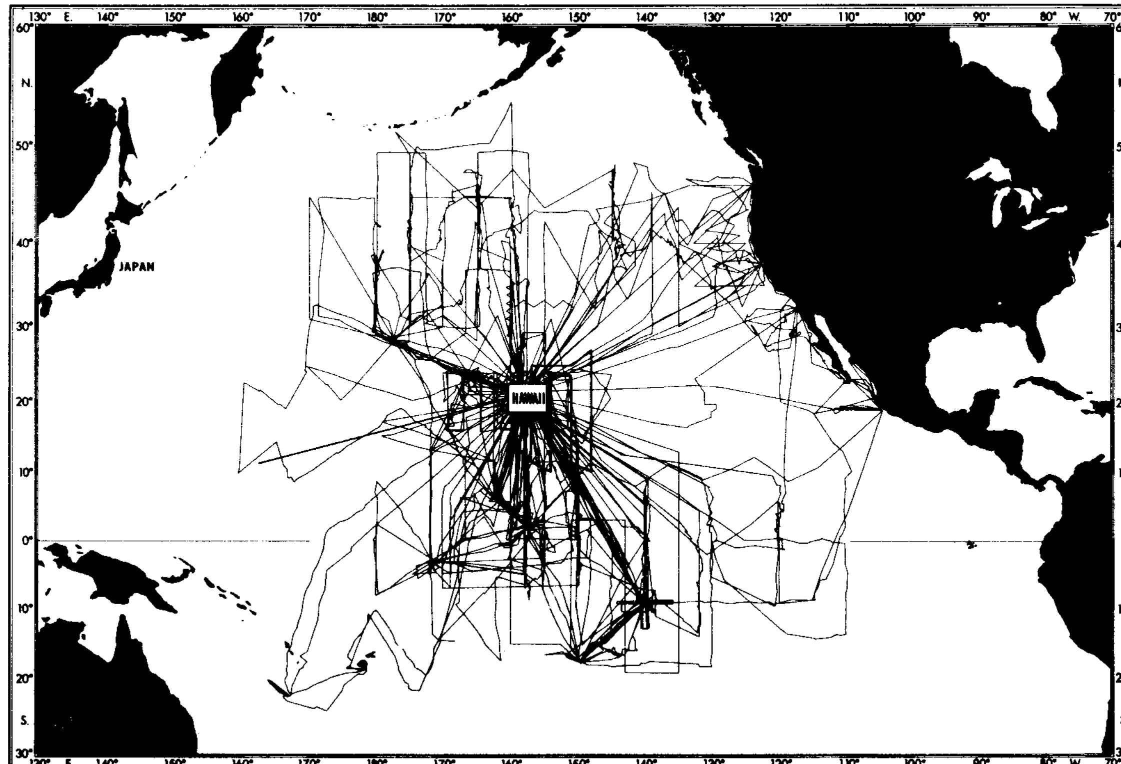
[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

ultrasonic transmitters. The vessel is an integral part of the Facility and is in constant demand to test the results of theoretical and experimental investigations conducted at the Kewalo Research Facility.



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.

RELATIONSHIP 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 Departments of Zoology, Physiology, Oceanography, Biochemistry, Nutrition, and Animal Sciences and researchers working at the Kewalo Research Facility. The Honolulu Laboratory has provided part-time employment for University of Hawaii undergraduates and support for master's and doctoral degree candidates by providing laboratory space, experimental tuna, and monetary grants. Laboratory scientists have also served as advisors on graduate student thesis committees. These activities have provided enrichment to the mutual benefit of the University of Hawaii and the Kewalo Research Facility.

Graduate students from the University of Hawaii (and other universities) who have earned advanced degrees that included research work at the Kewalo Research Facility have included:

Andrew Ayers	Department of Zoology University of Hawaii
C. Scott Baker	Department of Zoology University of Hawaii
Michael Barry	Department of Zoology University of Hawaii
Gordon Bauer	Department of Psychology University of Hawaii
Christopher Boggs	Laboratory of Limnology University of Wisconsin
Robert Bourke	Department of Animal Sciences University of Hawaii
Richard W. Brill	Department of Physiology University of Hawaii
Michael Guppy	Department of Zoology University of British Columbia
Sharon D. Hendrix	Department of Zoology University of Hawaii
Walter N. Ikehara	Department of Zoology University of Hawaii
Barbara A. Kuljis	Kewalo Basin Marine Animal Facility University of Hawaii
Elizabeth A. Monckton	Department of Zoology University of Hawaii
Robert Olson	Department of Biology San Diego State University
Linda M. B. Paul	Department of Zoology University of Hawaii
Anjanette S. Perry	Department of Oceanography University of Hawaii
John Salamonski	Department of Physiology and Pharmacology University of St. Andrews St. Andrews, Scotland
Sherry Steffel	Laboratory of Limnology University of Wisconsin

Anthony Sudekum	Department of Zoology University of Hawaii
Michael M. Walker	Department of Zoology University of Hawaii
Minato Yasui	Shizuoka Prefectural Fisheries Experimental Station Shizuoka, Japan

LIST OF VISITING INVESTIGATORS

The Kewalo Research Facility has hosted visiting scientists since its inception because it is the only laboratory in the world that routinely maintains live tunas specifically for behavioral and physiological research. (An operations and procedures manual for prospective visiting scientists at the Kewalo Research Facility is available as Southwest Fisheries Center Administrative Report H-83-7.) Visiting scientists of diverse backgrounds have come from around the world to work at the Kewalo Research Facility and have included:

Dr. Jelle Atema	Marine Biological Laboratory Boston University Woods Hole, Massachusetts
Dr. John E. Bardach	Resources Systems Institute East-West Center Honolulu, Hawaii
Dr. Grant R. Bartlett	Laboratory of Comparative Biochemistry San Diego, California
Dr. William P. Braker	John G. Shedd Aquarium Chicago, Illinois
Dr. Phyllis H. Cahn	Department of Biology C. W. Post Center Long Island University Grenvale, New York
Dr. Francis G. Carey	Woods Hole Oceanographic Institution Woods Hole, Massachusetts
Dr. Jean L. Cramer	Department of Animal Sciences University of Hawaii Honolulu, Hawaii
Dr. Charles Daxboeck	Pacific Gamefish Foundation Kailua-Kona, Hawaii
Dr. Brian Emmett	Department of Zoology University of British Columbia Vancouver, B.C., Canada
Dr. Christopher French	Department of Zoology University of British Columbia Vancouver, B.C., Canada
Dr. F. E. J. Fry	Department of Zoology University of Toronto Toronto, Ont., Canada

Dr. F. W. Goetz, Jr. — Department of Biology, University of Notre Dame, Notre Dame, Indiana

Dr. Malcolm S. Gordon — Department of Biology, University of California, Los Angeles, California

Dr. E. Gordon Grau — Department of Zoology, University of Hawaii, Honolulu, Hawaii

Dr. Isao Hanyu — Laboratory of Fish Physiology, University of Tokyo, Tokyo, Japan

Dr. Teruo Harada — Fisheries Laboratory, Kinki University, Wakayama, Japan

Dr. Alan R. Hargens — Department of Surgery, Veterans Administration Hospital, University of San Diego, San Diego, California

Dr. F. Havard-Duclois — Centre National pour l'Exploitation des Oceans, Brest, France

Dr. Peter W. Hochachka — Department of Zoology, University of British Columbia, Vancouver, B.C., Canada

Dr. Kim Holland — Hawaii Institute of Marine Biology, University of Hawaii, Kaneohe, Hawaii

Dr. C. S. Holling — Institute of Animal Resource Ecology, University of British Columbia, Vancouver, B.C., Canada

Dr. William C. Hulbert — Department of Zoology, University of British Columbia, Vancouver, B.C., Canada

Dr. Ian Johnston — Department of Physiology and Pharmacology, University of St. Andrews, St. Andrews, Scotland

Dr. John W. Kanwisher — Woods Hole Oceanographic Institution, Woods Hole, Massachusetts

Dr. Sergey M. Kashin — Institute of Oceanology, Academy of Sciences, Moscow, U.S.S.R.

Dr. Calvin M. Kaya — Department of Zoology, Montana State University, Bozeman, Montana

Dr. Robert E. Kearney — South Pacific Commission, Noumea, New Caledonia

Dr. James F. Kitchell — Department of Limnology, University of Wisconsin, Madison, Wisconsin

Dr. John J. Magnuson	Department of Limnology University of Wisconsin Madison, Wisconsin
Michael A. McCoy	Micronesian Maritime Authority Kolonia, Ponape Eastern Caroline Islands
Dr. John M. Miller	Department of Zoology University of North Carolina Raleigh, North Carolina
Dr. Shigeru Miyashita	Fisheries Laboratory Kinki University Wakayama, Japan
Dr. Thomas W. Moon	Huntsman Marine Laboratory Brandy Cove St. Andrews, N.B., Canada
Dr. Barry S. Muir	Marine Ecology Laboratory Bedford Institute of Oceanography Dartmouth, N.S., Canada
Dr. A. Earl Murchison	Naval Undersea Center Kailua, Hawaii
Dr. Claude M. Nagamine	Institute of Marine Resources University of California Davis, California
Dr. William H. Neill	Department of Wildlife and Fisheries Sciences Texas A&M University College Station, Texas
Dr. Arthur J. Niimi	Canada Centre for Inland Waters Burlington, Ont., Canada
Dr. Hiroshi Niwa	Department of Fisheries Nagoya University Nagoya, Japan
Dr. Elmer R. Noble	Department of Biological Sciences University of California Santa Barbara, California
Dr. Kenneth R. Olson	South Bend Center for Medical Education Indiana University School of Medicine Notre Dame, Indiana
Dr. Steve Perry	Department of Biology McMaster University Toronto, Ont., Canada
Dr. Douglas G. Pincock	Department of Electrical Engineering University of New Brunswick Fredericton, N.B., Canada
Dr. Warren P. Porter	Laboratory of Limnology University of Wisconsin Madison, Wisconsin
Dr. John H. Prescott	Oceanarium, Inc. Palos Verdes Estates, California

Dr. Martin D. Rayner	Pacific Biomedical Research Center University of Hawaii Honolulu, Hawaii
Dr. Terence A. Rogers	John A. Burns School of Medicine University of Hawaii Honolulu, Hawaii
Dr. Bryant T. Sather	Department of Zoology and Physiology Rutgers University Newark, New Jersey
Dr. Edward D. Scura	Aquatic Farms Kahaluu, Hawaii
Dr. Gary D. Sharp	Inter-American Tropical Tuna Commission La Jolla, California
Dr. E. Don Stevens	Department of Zoology University of Guelph Guelph, Ont., Canada
Dr. E. E. Suckling	Downstate Medical Center State University of New York Brooklyn, New York
Dr. J. A. Suckling	Department of Zoology Hunter College of the City University of New York New York, New York
Dr. Tamotsu Tamura	Agriculture Fisheries Laboratory Nagoya University Nagoya, Japan
Dr. Vladimir Walters	Department of Zoology University of California Los Angeles, California
Dr. Daniel Weihs	Department of Aeronautical Engineering Technion-Israel Institute of Technology Haifa, Israel

PARTIAL LIST OF SCIENTIFIC PUBLICATIONS RESULTING FROM RESEARCH AT THE KEWALO RESEARCH FACILITY

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