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PROGRESS IN TUNA AND TUNA-RELATED STUDIES OF THE SOUTHWEST FISHERIES CENTER, HONOLULU LABORATORY, FROM OCTOBER 1973 THROUGH SEPTEMBER 1974

TUNA ASSESSMENT AND DEVELOPMENT INVESTIGATIONS

Design, Construction, and Testing of a Bait Transport System a Major Undertaking at the Honolulu Laboratory This Past Year

A limited supply of skipjack tuna baitfish has curtailed the growth of existing tuna fisheries and the establishment of new fisheries in areas of the Indo-Pacific. The SWFC Honolulu Laboratory is testing the feasibility of transporting baitfish from an area of plenty to one of limited supply. In a project under the leadership of Fishery Biologist Roger E. Green, the Laboratory developed a plan to augment the local bait supply in Hawaii by bringing the northern anchovy *Engraulis mordax* from California to the Hawaiian Islands using a transport tank via roll-on/roll-off freighter.

Late in October 1973 they acquired a surplus 5,000-gallon fuel tank and trailer, and began the design and construction necessary to modify it into a baitfish carrier. Tank modification and repairs were completed in January, as were final plans for the dual life support system, construction and installation of which were finished in March. The transporter was first tested with 45 buckets of threadfin shad, successfully carried from Wahiawa Reservoir to the Honolulu Laboratory's Kewalo Basin facility.

It was shipped to Long Beach in early April for its first load of anchovy. About 100 pounds of fish died during the crossing, but an estimated 500 pounds were delivered to Honolulu alive and well. A discharge system for the removal of dead fish and a new tank draining system were installed after the first load was removed.

For the second shipment the tank was loaded with an estimated 1,300 pounds of anchovy--later determined to be an overestimate. Fishery scientists in Honolulu had determined that a break-even payload should be a minimum of 700 pounds of baitfish. Loss during the second trial shipment was 450-500 pounds, removed dead and alive by the "vacuum cleaner" system of dead bait removal.

First results of live anchovy as skipjack tuna bait in Hawaii were reported by the skipjack tuna fishing vessel Anela. The anchovy were used to chum and fish 20-pound yellowfin tuna successfully but were felt to be too large for the 5- to 7-pound skipjack tuna in the islands at the time. The vessels selected to receive the second trial shipment reported excellent results chumming 8- to 15-pound skipjack tuna.

The third load delivered to Hawaii was small--the problem of accurately estimating the amount loaded becoming increasingly obvious.

In July a temporary baitfish aging facility was set up by SWFC and Southwest Region personnel in the Long Beach Harbor area, and about 2,000 pounds of strong, healthy baitfish were available for the fourth shipment. Of the 224 scoops of fish placed in the transport tank, 17 were weighed and a calculated mean weight estimated at 1,317 pounds. At the completion of the unmonitored voyage to Honolulu, over 400 pounds of anchovy in excellent condition were removed from the tanker. It was estimated that at least 800 pounds were lost overboard during the shipment, probably being expelled live through the after water outlet as the result of a greatly increased pressure head created by the angle of the tanker aboard the Matsonia.

Modifications to the tanker are presently underway in Long Beach, as are bait density tests being conducted by Messrs. Green and Aasted.

The South Pacific Albacore Fishery Provided Material for Various Studies Throughout the Reporting Year

The Fishery Analysis Program under the leadership of Dr. Robert Skillman continued the assessment of the South Pacific albacore fishery using data collected at the canneries in American Samoa. With the receipt of the final CY 1972 data, a total albacore catch for 1972 was determined to be 20,168 metric tons, less than the 1970 and 1971 catches of 23,876 and 22,193 metric tons, respectively. Effort expended by the fleet based in American Samoa increased slightly.

Dr. Skillman's group also worked on an analysis of the albacore size-frequency data collected from that part of the South Pacific albacore fishery based in American Samoa. These data were used to separate areas of homogeneous-sized fish in order to describe the size structure of the catch and to convert Japanese catch data in numbers to catch in weight. This analysis revealed a significant latitudinal effect on average size of albacore, with the largest fish occurring in the 15° to 20°S latitudinal band.

A sensitivity study of a recently developed generalized production model for the South Pacific albacore fishery was completed during the year. Data used in the study were the catch data from the fishery based in American Samoa, the non-Samoan catches for Japan as recorded in "Annual report of effort and catch statistics by area on Japanese tuna longline fishery," and refined estimates of the non-Samoan catches for Korea and Taiwan. This study concluded that the MSAY (maximum sustainable "average" yield) for the South Pacific albacore fishery as it is now carried out is about 35,000 metric tons.

Techniques of Otolith Reading Developed and Applied to Tuna Otoliths in Growth Rate Studies

Skills and techniques of otolith reading were developed in the first part of the reporting year with the reading of the presumed daily growth layers in sagittae of nehu, Stolephorus purpureus, from Pearl Harbor and Kaneohe Bay. Techniques thus developed were applied to the reading of otoliths taken from skipjack and yellowfin tunas of the central Pacific to determine early growth rates of these species. Skipjack tuna otoliths from the Papua New Guinea region were also examined in order to compare the growth rates of the geographical population from that area and the one from the central Pacific. Preliminary results suggest a slower growth rate for skipjack tuna from the Papua New Guinea area. A manuscript dealing with this subject is in preparation.

Expansion of Skipjack Tuna Fisheries in the Southwest Pacific and Around Adjacent Indian Ocean Islands Described After Extensive Literature Search

Fishery Biologist Richard Uchida completed an extensive literature search for data and information on the development or potential development of skipjack tuna fisheries, particularly in the southwest Pacific and around the islands of the Indian Ocean which are contiguous to the southwest Pacific. Gathered was catch, effort, and catch per effort information that was subsequently used to describe the expansion of the skipjack tuna fisheries in these areas.

Two Skipjack Tuna Tagged and Released in Eastern Pacific Recovered Near Hawaii

A tagged 8.38-kg skipjack tuna was recaptured in Hawaiian waters by the MV Sunfish on June 21, 1974. The fish had been tagged and released by IATTC on June 5, 1973 at lat. 22°00'N, long. 111°25'W. On August 30, 1974 about 30 miles south of Honolulu, the MV Buccaneer recovered a tagged skipjack tuna weighing 9.68 kg and measuring 75.0 cm FL. This second animal had been released at lat. 22°18'N, long. 111°39'W on June 8, 1973, at which time it measured 47 cm and weighed an estimated 2.03 kg (by Magnuson 1973 regression). The growth of the second skipjack tuna closely approximates the growth curve for skipjack tuna in the central Pacific derived from Honolulu Laboratory measurements of skipjack tuna otoliths.

Prediction of the 1974 Skipjack Tuna Catch in the Hawaiian Fishery

In April Dr. Robert Skillman issued the 1974 Hawaiian skipjack tuna catch prediction of 3,800 metric tons. This estimate was based on a multiple linear regression model combining two earlier models, one based on the change in salinity from January 1 to March 1 of the year the catch is made, and the other on the time of minimum sea-surface temperature, all values collected at Koko Head, Oahu. Estimated cumulative state landings through September 16 were 2,596 metric tons.

FISH-ENVIRONMENT INVESTIGATIONS

Design and Construction of the Tuna Behavioral Thermoregulation System (the Doughnut Tank) Completed During the Reporting Period

During the reporting period Drs. William H. Neill and Andrew E. Dizon of the Honolulu Laboratory continued development of a unique apparatus for the study of tuna behavior in gentle temperature gradients like those encountered in much of the open sea. This apparatus, termed the tuna behavioral thermoregulation system, consists of a doughnut-shaped tank (8,000 liters) whose temperature is controlled automatically by a tuna's direction and speed of swimming in the circular channel. By reversing swimming direction in the tank, the tuna can keep the water within a preferred range of temperature. Anticipated results of these studies include the behavior of tunas in different temperature regimes and tunas' preferred temperatures, a set of parameters with high potential value in predicting tuna distribution in the ocean.

Construction of the system was completed in February except for two undelivered components, the refrigeration unit and the heater-switching assembly. During May the thermoregulation system's temperature-controlling parts were installed and tested.

First Output Obtained From a Simulation Model for the Responses of Fishes to Temperature

The long-range goal of the Honolulu Laboratory's program on Life Studies of Tuna and Tunalike Fishes is to generate a predictive model of tuna distribution, abundance, and availability to fisheries. The basis of the model is to be the joint physiological and behavioral responses of tunas to environmental variables, as determined in part through experimental work with captive fishes.

To explore the potential value of such a modeling approach and to provide an objective framework for further experimental work, Drs. William H. Neill and Andrew E. Dizon have developed a simulation model for the responses of fishes to temperature, a variable of recognized importance in the ecology not only of tunas but also of fishes in general.

The procedure used in constructing the model was 1) to create a hypothetical tunalike fish (based on skipjack tuna) endowed with a simple set of capabilities and responses, all well recognized or reasonably deducible from extant experimental results; 2) "follow" the fish in computer-generated one-dimensional environments with temperature the only variable; and 3) look for consistencies between distributional features of the hypothetical fish and those reported for real tunas in real heterothermal environments. Physiological acclimation, accumulation and decay of thermal "doses" leading to lethal-temperature mortality, temperature preference, gradient perception, and basal swimming speed were treated deterministically; perception-contingent increases in swimming speed and the tendency to change swimming direction were modeled stochastically as a biased random walk with constant step-time (10-min., in most simulations).

First runs of the model (without any a posteriori manipulation of process functions or input parameters) suggested a number of similarities between the behavior of the model and that of real tunas as observed at sea:

Hypothetical 50 cm long fish weighing 2 kg

1) tended to "seek out" and remain within a few degrees of their preferred temperatures in a linear gradient as steep as 1°C/km but to randomly disperse in gradients of 0.1 or 0.01°C/km until encountering temperatures near the upper or lower lethal limits;

2) tended to "aggregate" at randomly encountered thermal fronts, regardless of temperature;

3) would tend to become "trapped" and concentrated in areas of unfavorable temperature under certain conditions of temporal change in the distribution of temperature; similarly, would tend to be absent from areas of favorable temperature under certain conditions of temporal change in the distribution of water temperature;

4) would tend to be distributed within narrower thermal limits than conspecific fish of smaller size.

Doughnut Tank Experiments Investigate the Activity of Tunas in Rapidly Cooling Water

One notion implicit in the simulation model is that the likelihood of fish responding to a gradient of temperature depends both on the level and the rate of change of temperature. The faster the rate of change of temperature ($dT/ds \cdot ds/dt = dT/dt$) and the nearer the temperature to the lethal, the more likely is the fish to respond.

Drs. Dizon and Neill conducted a series of cooling experiments in the doughnut tank to establish such responses for tunas. Water temperature was decreased from 27°C at about 0.05°C min^{-1} while swimming speed and turning tendency of the tunas were monitored.

Experiments with eight skipjack and two yellowfin tunas have been conducted. Both species consistently and dramatically increased their rate of turning when tank temperature decreased to 21.5°-20.5°. However, swimming speed of skipjack tuna tended to be almost constant between 27° and 19°C, whereas yellowfin tuna swam slower ($Q_{10} \cong 2.2$) as the water cooled.

Implications of Thermal Physiology on Distribution of Skipjack Tuna

In June Dr. William H. Neill of the Honolulu Laboratory reported construction of a tentative energy budget for central Pacific skipjack tuna; development of the budget was a collaborative effort by Drs. James F. Kitchell and John J. Magnuson of the University of Wisconsin and Dr. Neill. The energetics model suggested the following ecological proposition: Skipjack tuna smaller than about 12 kg are growing at rates substantially less than maximal, being limited by availability of food and/or predatory efficiency; skipjack tuna larger than about 15 kg obtain a maximum daily ration but are limited in further growth by a physiological constraint of large size coupled with an effective mechanism of heat retention--overheating of the muscle mass, especially during bursts of feeding activity.

Dr. Neill has now completed a preliminary analysis of the overheating problem. If it is assumed that 35°C is the temperature at which skipjack tuna muscle breaks down when exposed over a period of time, then it is possible to calculate maximum water temperatures at which skipjack tuna can safely operate (without regulation of heat exchange efficiency). At minimum activity, the red muscle of skipjack tuna metabolizes at about 1 mg-O_2 g^{-1} hr^{-1}; the corresponding rate of demand for maximum activity is about 7 mg-O_2 g^{-1} hr^{-1}, part of which must be met anaerobically.

The preliminary analysis suggested the following conclusions: Skipjack tuna larger than 12.5 kg cannot indefinitely sustain minimum activity in waters warmer than 30°C. At 5 kg, the critical temperature for minimum activity is about 31.5°C. But of more concern are the water temperatures critical for normally active fish, whose red muscle may metabolize at about 3 mg-O_2 g^{-1} hr^{-1}: 30°C at 1 kg, 25°C at 5 kg, and 20°C at 12.5 kg.

These calculations imply that large fish must seek out cooler waters if they are to be as active as smaller fish. This could be achieved by large fish living at higher latitudes or at greater depths than smaller fish. Low rates of heat exchange in large skipjack tuna permit forays of several minutes' duration into surface waters warmer than the critical temperature if the fish is initially at thermal equilibrium with deeper, cooler water.

Prequisite to serious consideration of fish-energetics problems is accurate estimation of tissue caloric yields for the subject species. To complement construction of an energy budget for skipjack tuna, Drs. Kitchell, Magnuson, and Neill completed a caloric analysis of whole body, red muscle, and white muscle of just-caught and 10-day starved skipjack tuna.

Just-caught skipjack tuna, weighing 1.5 kg, had whole body averages of 1.46 kcal g-wet^{-1}, 5.00 kcal g-dry^{-1}, and 5.63 kcal g-ash-free-dry^{-1}, with water constituting 70.8% of wet weight. Skipjack tuna of similar size and history but starved for 10 days in captivity had whole body averages of 1.18 kcal g-wet^{-1}, 4.64 kcal g-dry^{-1}, and 5.36 kcal g-ash-free-dry^{-1}, with water constituting 74.7% of wet weight. Red muscle and white muscle showed the same trends as whole body, but decreases in kcal g-dry^{-1} and kcal g-ash-free-dry^{-1} for the two muscle tissues were only 25% in red muscle, and 5% in white muscle, as great as for whole body. Priority utilization of high-energy materials (fats) stored in the viscera presumably accounted for the dramatic changes in whole-body energy content during starvation.

Thus, skipjack tuna tissues yield substantially more than 1 kcal g-wet^{-1}, and, upon starvation, skipjack tuna not only metabolize their energy stores, in order of decreasing energy yield, but also hydrate.

Effects of Temperature on Routine Metabolism of Skipjack Tuna

Productivity of the seas in terms of tuna flesh must depend on whether food supplies are adequate to provide the energy required by tunas for activity and growth. Research Assistants Randolph Chang and Bernard Ito, under the supervision of Dr. William Neill, all of the Honolulu Laboratory, are extending previously completed experiments on routine metabolism of skipjack tuna at a single temperature (24°C) to temperatures throughout the skipjack tuna's zone of thermal tolerance. This will permit estimation of the energy required for minimum activity in skipjack tuna at all temperatures where the fish are likely to occur.

Experiments at 18°, 24°, and 29°C have now been completed. Results can be summarized as follows:

Temperature (°C)	Number of tests	Respiration rate ($mg\text{-}O_2 \, g^{-1} \, hr^{-1}$)	
		Median	Range
18	14	0.66	0.42-1.03
24	6	0.71	0.58-0.79
29	10	0.78	0.64-1.25

Thus, routine metabolism of skipjack tuna appears only weakly temperature-dependent, the Q_{10} value being between 1.1 and 1.2.

Physiological Data Suggest Definition of Limits of Skipjack Tuna Habitat

Physiological data obtained recently in experiments and simulation studies conducted by the Life Studies Program of the Honolulu Laboratory are being used to shape answers to the long standing question of why there are no big skipjack tuna in the eastern Pacific Ocean. These data are being used to define the geographic areas the skipjack tuna can be expected to inhabit on the basis of extremes in tolerance. Results so far indicate that the smaller skipjack tuna, less than 3 kg or 50 cm in size, can inhabit virtually all of the eastern tropical Pacific above the oxycline. Areas from which larger fish are excluded increase in size with the size of the fish. Fish weighing 8 kg, 70 cm long, are excluded from an area which extends from Cabo Corrientes or San Blás to 145°W, 10°N, and from there to Panama. Fish of intermediate size are excluded from most of this area, but can move north-south along a 100-mile corridor slightly offshore of Mexico, between the Gulf of Tehuantepec and the Gulf of California. This corridor probably closes seasonally, and may close entirely in some years.

TUNA BAITFISH WORKSHOP

Tuna Baitfish Workshop Held at SWFC Honolulu Laboratory

An invitational tuna baitfish workshop co-sponsored by the National Marine Fisheries Service and the University of Hawaii Sea Grant Program, was held at the NMFS Honolulu Laboratory June 4-6.

A major purpose of the workshop was to bring together all information gathered thus far on baitfish, with emphasis on tuna baitfish of the central and western Pacific, and to explore some of the basic questions needing clarification in the face of the proposed development and expansion of skipjack tuna live-bait fisheries in these areas of the Pacific.

Thirty-seven participants from the mainland United States, Hawaii, Japan, and islands of the western Pacific met first in general session, where they considered the essentials of a suitable baitfish for skipjack tuna pole-and-line fishing. These criteria were organized as "fisherman-related" and "tuna-related," and the final product of the session, chaired by Honolulu Laboratory Director Richard S. Shomura, was a comparison to one another of the more important baitfishes presently in use in various parts of the Pacific.

Workshop sessions dealt with natural stocks; cultured species; and baitfish transport, holding, and substitutes, with a discussion of the economics of each method of providing the bait necessary to a particular fishery.

The session on natural stocks was conducted by Dr. R. E. Kearney, Principal Biologist with the Department of Agriculture, Stock and Fisheries, Konedobu, Papua New Guinea. This group identified the principal natural baitfish resources of the Pacific as falling into three categories: the large stocks of Engraulis found in the eastern and extreme western Pacific--as off the mainland United States west coast and off Japan--adequate for local fisheries and in addition available for transport; smaller stocks of other baitfishes, mainly Stolephorus, currently supporting modest stable or growing local skipjack tuna fisheries (included here is the Hawaii fishery, where nehu, S. purpureus, is the principal baitfish); and stocks known to be poor or not well enough known to be evaluated accurately. The group recommended improved bait handling and holding techniques, and intensified acquisition and exchange of information on naturally occurring stocks.

The session on cultured baitfish species, under the leadership of Mr. Shomura, aimed at providing guidelines for subsequent actions in the development of baitfish culture. The complexity of the subject was noted, and long- and short-range proposed approaches were aired. The group prepared a chart outlining the principal factors to be considered in the culture of known tuna baitfish.

Honolulu Laboratory Fishery Biologist Tamio Otsu opened the session on baitfish transport, holding, and substitutes stressing the need to establish direction and guidelines for ongoing baitfish transport studies presently being conducted by the NMFS Honolulu Laboratory. Discussion of problems of the experimental bait transport system centered on heavy mortalities experienced and on the importance of aging the bait before shipping. The group approved of HL's approach to bait transport, and recommended a third trial shipment in the existing tank before undertaking an evaluation of tank design. Cost factors clearly affect the design and construction of a tank of "ideal" configuration.

In the final general session, participants established an order of priority for further studies: for Hawaii, the anchovy transport system; for American Samoa, the culturing and sea trials of mollies; initiation of Apogon studies by the Trust Territory of the Pacific Islands; and for other areas, the development of cultured baitfish and natural stocks.

The 35 contributed working papers constitute a valuable collection of current baitfish knowledge, and proceedings and selected working papers of the workshop will be published.

Attachment

September 17, 1974

HONOLULU LABORATORY PUBLICATIONS ON TUNA AND TUNA-RELATED STUDIES

October 1973 through September 1974

TUNA AND TUNA-RELATED PUBLICATIONS

Hester, Frank J. 1974. Some considerations of the problems associated with the use of live bait for catching tunas in the tropical Pacific Ocean. U.S. Natl. Mar. Fish. Serv., Mar. Fish. Rev. 36(5):1-12. (MFR paper 1060.)

Matsumoto, Walter M. 1974. The skipjack tuna, *Katsuwonus pelamis*, an underutilized resource. U.S. Natl. Mar. Fish. Serv., Mar. Fish. Rev. 36(8):26-33. (MFR paper 1077.)

Neill, William H., and E. Don Stevens. 1974. Thermal inertia versus thermoregulation in "warm" turtles and tunas. Science (Wash., D.C.) 184:1008-1010.

IN PRESS

Dizon, Andrew E., E. Don Stevens, William H. Neill, and John J. Magnuson. Sensitivity of restrained skipjack tuna (*Katsuwonus pelamis*) to abrupt increases in temperature. Comp. Biochem. Physiol.

TRANSLATIONS

Federation of Japan Tuna Fisheries Co-operative Associations and Japan Tuna Fisheries Federation. 1972. Study of bait problems in the skipjack tuna and tuna fisheries (Katsuo-maguro gyogyo no jiryo taisaku). Federation of Japan Tuna Fisheries Co-operative Associations and Japan Tuna Fisheries Federation (Katsuo to Maguro) 126:4-8. February 1972. (Translated from Japanese by T. Otsu, 1974, 6 p.)

Horikawa, Akio. 1974. Japan's tuna production (Waga kuni no maguro gyogyo seisan). Suisan Shūhō (The Fishing and Food Industry Weekly) 707:16-19. March 25, 1974. Suisansha K.K. (Translated from Japanese by T. Otsu, 1974, 7 p.)

Katsuo-Maguro Nenkan. 1973. Japanese skipjack tuna fishery development in foreign areas (Katsuo kaihatsu--kaigai katsuo-zuri gyogyo). Katsuo-Maguro Nenkan (Skipjack-Tuna Yearbook). Suisan Shinchōsa K.K., Tokyo, p. 151-158. (Translated from Japanese by T. Otsu, 1974, 12 p.)

Kikawa, Shoji. 1971. Shunyo Maru's third bait survey in the Papua New Guinea area (Shunyo Maru ni yoru dai-san-ji Papua New Guinea jiryogyo chosa). Proceedings of the 1970 Japanese Tuna Fishery Research Conference, Shimizu, Japan, February 3-5, 1971, p. 255-262. Fisheries Agency of Japan, Far Seas Fisheries Research Laboratory. (Translated from Japanese by T. Otsu, 1974, 10 p.)

Kinki University Fishery Experimental Station. 1974. Artificial fertilization and rearing experiments conducted on tunas in 1973...A progress report (Showa 48-nendo maguro-rui fuka shi-iku gijutsu kaizen shiken hōkoku-sho). Preliminary progress report prepared for a special meeting of cooperating agencies working on tuna culture research, Shimizu, Japan, February 26, 1974, 23 p. (Mimeogr.) (Translated from Japanese by T. Otsu, 1974, 18 p.)

Suisan Sekai. 1973. Tuna longliner No. 18 Nankai Maru [408 tons] earns a record 300 million yen [$1.15 million] in a single trip... breaks record formerly held by the No. 5 Fukuhisa Maru [404 tons]. Suisan Sekai 22(2):46-50, February 1973. (Translated from Japanese by T. Otsu, 1973, 2 p.)

1973. No. 7 and No. 8 Otoshiro Maru (Mie Prefecture) make good albacore landings. Suisan Sekai 22(7):48-51. July 1973. (Translated from Japanese by T. Otsu, 1973, 5 p.)

Suisan Shūhō. 1973. The slow progress in skipjack tuna live-bait development (Nakanaka susumanai katsuo no esa kaihatsu). Suisan Shūhō (The Fishing and Food Industry Weekly) 693:30-31. October 5, 1973. (Translated from Japanese by T. Otsu, 1973, 4 p.)

Tohoku Regional Fisheries Research Laboratory. n.d. Atlas of skipjack tuna fishing grounds in southern waters, 1973 fishing season (July 1973-May 1974) (Showa 48 nendo nanpō katsuo gyokyō). [Five pages text, 14 charts.] (Translated from Japanese by T. Otsu, 1974, 22 p.)

Urabe, Shiro (interviewer). 1974. There's a keen interest in developing new skipjack tuna fishing grounds (Shingyojo no kaihatsu ni iyoku wo moyasu). Suisan Sekai 23(1):84-93. [Interview with two brothers, both fishing masters on vessels belonging to the Abekane Suisan K.K.] (Translated from Japanese of selected portions of article by T. Otsu, 1974, 17 p.)