THE CALIFORNIA TO HAWAII ANCHOVY TRANSPORT PROJECT

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ABSTRACT

The skipjack tuna fishery in the State of Hawaii has had limited growth partially because of inefficient and time-consuming methods of capturing bait. The baitfish resource in Hawaii is limited in quantity and experiences fluctuation during peak fishing periods, adversely affecting the catches of the local Hawaiian skipjack tuna (aku) fishing vessels.

Supplying a substitute or alternative bait could significantly reduce the fishing pressure on the limited local bait supply and provide an abundance of live bait during the summer fishing season, affording greater fishing effort and efficiency.

In an effort to alleviate this problem, in 1973 the National Marine Fisheries Service Southwest Fisheries Center in Honolulu, Hawaii designed and developed an anchovy transport project to import baitfish from California to Hawaii. This project was carried out with the aid of an advisory ad hoc baitfish committee comprised of representatives from Federal and State Governments, industry, and the University of Hawaii.

The 4-yr project experienced both failures and successes. The shipments of baitfish were accomplished via Matson Navigation Roll-On/Roll-Off vessels originally based in Long Beach, California. Shipping trials were conducted early in hopes of providing the local tuna fleet with much needed baitfish along with experimentation. Testing and modifications of the systems were done during shipping trials.

After a year of unsuccessful shipping trials, shoreside experiments were conducted to determine optimum loading densities and preferred bait handling methods.

Poor quality bait and the moving of the Matson vessels' departure point to Oakland prompted moving the baitfish project to Tiburon. In Tiburon, a series of comprehensive studies were made and optimum loading densities and bait handling methods were produced. An evaluation of the problems with the transport tank unit was conducted. It was determined that inherent problems in the original tank design were too complex to correct, and a completely new transport system was designed and constructed.

A series of docksite experiments was conducted to study the new system and evaluate its carrying potential and the effectiveness of its life support systems. Experimentation with the new system proceeded with a high degree of success, but the project was eventually overwhelmed by the lack of a reliable bait supply in San Francisco Bay, and was terminated.

INTRODUCTION

The commercial skipjack tuna, Katsuwonus pelamis, fishing industry in the Hawaiian Islands and the central and western Pacific has been limited in growth and development by the scarcity of live bait. The Hawaiian skipjack tuna fishery, with an annual ex-vessel value of over $2 million, experiences fluctuations in landings ranging from 2.3 thousand metric tons (MT) to 7.5 MT with an average over the last 28 yr of 4.3 thousand MT. This fluctuation is the result of several factors, the most significant being the unreliability of a continuous supply of live bait during the peak months of the Hawaiian fishing season. The seasonal availability of the Hawaiian baitfish, nehu, Stolephorus purpureus, varies greatly during the fishing months and the supply is insufficient to allow maximum fishing effort by the existing skipjack tuna (aku) fleet. While skipjack tuna in the Pacific is basically an underutilized resource, further expansion and development of the fishery is dependent upon a substantial increase in the available bait supply.

DEVELOPMENT OF THE PROJECT

In 1973, the Honolulu Laboratory of the National Marine Fisheries Service, NMFS, Southwest Fisheries Center, began a feasibility study to determine if importation of an alternate baitfish, the California anchovy, Engraulis mordax, was possible physically and economically, and acceptable to the local Hawaiian pole-and-line fisherman as a supplemental bait. The main thrust of this program was to develop technology and ancillary requirements for successfully holding and transporting California anchovy to

Hawaii. The California anchovy was chosen as the supplemental baitfish to be utilized in Hawaii for several reasons. It is found off the California coast in great abundance, and has been proven to be a hardy baitfish. This bait is utilized extensively by west coast pole-and-line fishing vessels and sport boats with great success.

The development of the baitfish feasibility study program began in early 1973 in California with the gathering of information on bait abundance, seasonal availability, and bait suppliers. Inquiries (to California Department of Fish and Game) were made to determine possible legal drawbacks concerning our proposed project. None of the aforementioned became a problem, and the real problems of handling and shipping bait were approached.

Various methods of shipping the baitfish were explored. Barges, baitboats, and L.A.S.H. (Lighter Aboard Ship) ships were eliminated basically on cost factors, handling problems, and logistics. A form of containerized fish transport tank seemed the most feasible approach, and the Matson Navigation Lines Roll-On/Roll-Off (RO/RO) system looked the most promising. This system involved the use of a mobile trailer (in our case a tanker trailer) which could be loaded with fish and water at a dock area, loaded aboard a ship, and transported to Hawaii. The fish on arrival in Honolulu would be unloaded into holding pools at the NMFS facility at Kewalo Basin for distribution to local aku vessels for fishing trials. The transport trailer would then be returned to California on the same ship for the next shipment.

Matson Lines RO/RO vessels are the fastest freight ships available, having a transit time from California to Honolulu of only 4 days. Live baitfish could be shipped with fast-scheduled regularity.

DESIGN AND CONSTRUCTION OF THE TRANSPORT TRAILER

During the development of the baitfish transport system, bait in Hawaii was scarce, and increasing demands by industry to expedite shipping of baitfish from California were heard.

With the pressure from the fishing fleet for bait and with minimal initial funding, the first baitfish transport system was generated. For reasons of both economy and speed, it was decided by the members of the baitfish project team to utilize a ready-made tanker trailer and to modify it structually to accommodate live anchovy while providing it with a life support system.

The beginning search for ideas brought to light a similar effort undertaken by the NMFS Northwest and Alaska Fisheries Center, Seattle in the transport of live juvenile salmon (Smith and Ebel 1972).

Comparable systems were designed for our tanker trailer with the realization that, while salmon are considered to be very hardy fish that can withstand considerable amounts of handling with low mortality, we were dealing with an animal that is exposed to weakness through red tides, stress, and disease through loss of scales, and considerably more scale loss, effluent, and slime accumulation from handling and being held in captivity.

In 1973, a surplus 5,000-gal military fuel tanker trailer was acquired for the project. Research was conducted on the physiological requirements of the California anchovy and a detailed life support system was developed. It consisted of a recirculation pump, filter system, injected air and induced oxygen, interior lighting, and flowmeters.

The system had two modes: a closed circulation circuit for periods when the trailer was to be transported on the highway, and an open circulation circuit for periods when the trailer was at a dock area for experimentation and loading, or in transit to Hawaii aboard ship.

The transport trailer was divided into three major compartments by two separating bulkheads. These dividing bulkheads each had 20 in. holes in the center allowing water to flow between compartments. Three large hatches, two with small scuttle hatches and one with a large plastic viewing port, were installed over the top of the compartments for easy access and monitoring. The complete tanker trailer was sandblasted and coated with nontoxic primers and epoxy finishes. The interior paints were of a green color and the exterior was painted gloss white.

The interior lighting consisted of two low light level underwater bulbs tinted green, and mounted on the inside top portion of each compartment. Plumbing lines were constructed from polyvinyl chloride (PVC) when possible, and all components to the life support system were chosen for minimal toxicity. The system was mounted on the rear of the trailer on a specially-built platform. The transport trailer was essentially completed in late March 1974, and was tested by hauling

a load of threadfin shad, Dorosoma petenense, another experimental Hawaiian baitfish, from Wahiawa Reservoir to the facility at Kewalo Basin, a distance of approximately 20 mi. The test results were considered satisfactory.

On April 1, 1974, the tanker trailer was transported to the west coast via a Matson Lines RO/RO vessel with an accompanying attendant to check out the various systems and maximum water flows aboard ship. All systems proved operational under these trial conditions, and water flows could be maintained to 400 gal/min.

On April 6, 1974, the transport trailer arrived in Los Angeles and was taken to the Battelle Research Foundation dock in Long Beach. This Long Beach facility was selected as the site of our experiments because of its strategic location, being near the entrance to the harbor and the baiting area, while being secluded and protected from vandalism.

Simulated trial shipments

Simulated trip experiments were conducted at Battelle's dock prior to shipping the first load of baitfish to Hawaii. These experiments were conducted to uncover potential problems, and also to observe results of loading bait directly from the catcher vessel into the transport trailer, and "resting" the bait before shipping.

The method utilized to transfer the bait from the catcher vessel to the transport trailer was the traditional Hawaiian "bucket" system, in which a mixture of baitfish and water are dipped from the baitboat fish well, passed up by hand from the boat to the dock, then further up to the

top of the trailer and unloaded into the open hatch (a distance of approximately 20 ft at Battelle's).

Initial problems

During the first trip simulation experiments, several problems developed. The seawater pumping system for circulating the water through the transport tank was not powerful enough for the higher-than-anticipated head distance, and the final output was far lower than expected, producing poor circulation and a low rate of water exchange within the tank.

The first batches of baitfish, although healthy when loaded into the transport tank, developed the "red-nose" syndrome. This condition is caused by the fish inadvertently running into the sides of the tank and damaging their noses. This damage turns the nose red with blood and leaves the fish in a moribund condition.

Another problem was encountered during the loading of the fish from the catcher vessel on windy days. Considerable surge developed alongside the dock, and coupled with the height which the bait had to be lifted created a serious problem. Several times the bait dealer could not deliver because of the surge.

The transport trailer similar in design to the salmon unit utilized a suction screen located in the center of each compartment to clean the water, but only in the recirculation mode. Dead fish, feces, scales, and slime built up on the bottom of the tank compartments creating areas where fish could contract disease from foul water.

This problem was initially solved by using a swimming pool cleaning siphon system, which was moved around the bottom of the tank compartments by its long handle. Access to the inside was through the three large hatch openings at the top of the tank. At the time, this was sufficient to keep the bottom of the tank compartments clean.

It was readily noticeable while cleaning that the dead fish would accumulate in corner areas in "dead spots" caused by poor circulation and tank configuration.

Two simulated trip trials were conducted at Battelle's dock, each with fairly light loads of bait. Each trial lasted 4 days. The best trial utilized an estimated 160 kg (350 lb) of bait loaded into the tank and resulted in 64% survival.

Trial shipments from Long Beach

Six trial shipments were conducted from Long Beach to Honolulu between April 1974 and March 1975.

The first trial shipment

An estimated 250 kg (550 lb) of bait was bucketed into the transport trailer for the first shipment. These fish were loaded 2 days prior to shipping, giving them a "resting" period to settle them down and orient them to the tank. On April 18, the first shipment to Hawaii departed aboard the Matson Lines vessel, Matsonia. This load, deliberately made light to test the system, arrived in Honolulu on April 22. The trailer was hauled to our Kewalo Basin facility and unloaded, again using the bucket system.

An estimated 80 kg (180 lb) of bait survived the trip, and many of these fish showed signs of the "red-nose" syndrome.

During the trip, the overboard discharge screens were heavily clogged with fish scales thought to be lost during the loading period. On the trip from Battelle's dock to the vessel, the life support system operated on the closed system. The filter system became clogged with scales at that time, reducing the efficiency of the support system.

The return to California of the transport trailer was delayed as further work on it was carried out in Honolulu. It was fitted with an experimental bottom siphoning system to aid in removal of dead fish and detritus and increase water circulation. This experimental siphon unit was to be tested after returning the trailer to California.

The demand for baitfish by the local aku fleet was so great during these trial periods that bait could not be expended for testing the transport trailer in Hawaii.

The siphon system consisted of rerouting the overboard water discharge lines to a pickup point on the bottom of the tank compartments. The lines comprised a down pipe with a tee section at the bottom and two pipes leading off in opposite directions, the ends of which were plugged. Narrow slots were made in the bottom of these pipes to allow water and dead fish to be picked up with the circulating discharge water and removed from the tank.

Upon completion of this modification, the trailer was returned to California for another trial shipment.

The second trial shipment

Bait was again delivered to the transport trailer at Battelle's dock and bucketed directly into the tank. During the resting period of the fish prior to shipping, the new discharge line suction system became clogged with fish, causing overflowing of the tank.

Slots in the lower pipes were widened. Again problems developed, and the dead fish extractor proved to be a live fish extractor as well. The transport trailer was loaded with an initial 725 kg (1,600 lb) of bait 4 days prior to shipping, and topped off 1 day before shipping with an estimated 250 kg (500 lb) of fish.

The "red-nose" syndrome was again present, and with the siphon problems still not fully solved, the shipping trial was conducted.

On May 23, the transport trailer arrived in Honolulu. An estimated 33% of the bait survived the trip.

The third trial shipment

For the third shipment, engineers were consulted to improve the siphon discharge system in the tank. The bottom portion was replaced with large conical suction heads believed to cut down the suction force allowing just rotten material and dead fish to be ejected from the tank. Loading for this trial took place at a different and lower dock area. During the loading, the filter system again became plugged with scales and could not be cleared. This greatly reduced water circulation, and since the oxygen system relied on circulating water for distribution, it

could not function properly. After returning to Battelle's dock, the circulating seawater system was attached and the filter was flushed repeatedly. Bucketing of bait into the tank was resumed in increments at Battelle's dock over several days. During this period, large wattage lights were installed in an attempt to cure the "red-nose" syndrome. These lights were large bright bulbs which would allow the fish better visibility and hopefully prevent them from bumbping into the tank walls. The light bulbs were 100-W, 110 VAC, and potentially hazardous from electrical shock. Low amperage fuses were installed to protect personnel and fish in case of a direct short. The results of installing these larger bulbs indicated that a change of this nature was indeed in order.

The fish schooling behavior was much better and the lights had a salutary effect on the behavior of the fish. They no longer tried to jump out of the tank when the hatches were opened.

The "red-nose" syndrome appeared to be reduced significantly.

Unfortunately, the lighting system could not be kept on while the trailer was on the road, and the "red-nose" syndrome reappeared.

During the acquisition of the fish for this shipping trial, another problem became evident. This was the annual arrival of the California "red tide," an algae bloom that seemed to affect the health of the anchovy. Fish delivered during this aging period looked weaker than the previous loads, and were given less chance for survival.

Approximately 545 kg (1,200 lb) of baitfish were loaded into the transport tank during this trial and on arrival in Honolulu on June 27, an estimated 160 kg (350 lb) or 29% had survived.

Bait aging begun

It was finally concluded that because of high mortality rates during shipping, "aging" of the bait should be undertaken prior to shipping. Two tanks were installed at the end of pier C on the Coast Guard dock in Long Beach for this purpose. This location was also desirable since it was located on a restricted pier area away from the general public. This location was also in the same area as the bait dealers' dock, which allowed better communication.

The tanks were 24-ft swimming pools each holding 13,000 gal of water. The water supply was provided by a large submersible pump lowered into the water from the pier. This pump was powered by electricity and provided each tank with approximately 200 gal/min of seawater.

As determined after the third shipment, bucketing of bait was not an accurate method of measuring weights of fish, and the scoop method was used to load an estimated 900 kg (2,000 lb) of bait into the tanks for aging prior to the next shipment.

This method incorporates a long handled dipnet which is used to take bait out of the catcher boat baitwell in a semi-dry state, and transfer it into the aging tanks. Later, when the transport tank was loaded for shipment, the process was repeated.

It was determined that scooping gave a more accurate estimate of fish weight, and for the rest of the shipments this method of handling bait was used.

Care and feeding of the fish became a full-time problem. Once the fish were loaded into the aging tanks, tank cleaning became a continuous

chore. Dead fish, effluent, and scales began to collect on the bottom, and daily tank cleaning was necessary. After a few days, the seagulls found that we had built a natural feeding station for them, and from then on we were plagued with their presence. The bait aging station was attacked daily, and with the dive-bombing seagulls and their continuous defecation in the water, our fish quality dropped drastically. As the fish were attacked by the swooping birds, they were driven down to the bottom of the tanks into the foul water, exposing themselves to disease.

To protect the fish, plastic netting was stretched over the tanks to keep the birds away, but the birds landed on it, made holes, and resumed the attack. Plastic pool covers were purchased and installed. Within a few days, the covers were dirty and ripped around the edges. The fish were more protected, but not completely. With the tanks covered, underwater lights had to be installed in order to keep the fish from running into the sides. Two light bulbs were suspended in each tank at night, and this seemed to work satisfactorily.

The fourth trial shipment

The 900 kg (2,000 lb) of bait loaded into the holding tanks were aged for 3 wk. During the aging period, the fish were fed daily with #1 trout chow. After aging, the bait was transferred into the transport trailer by the scoop method. Random samples were weighed to determine the accuracy of our weight estimates, and an estimated 600 kg (1,317 lb) of bait was loaded into the transport trailer for the fourth shipment.

Prior to this shipment, the filter system was removed since it was continually clogging with scales and could not be made to function properly.

The unsatisfactory siphon system was also removed and bottom drain and top discharge systems were installed in each compartment to eliminate the effluent problem and remove dead fish as they accumulated on the bottom. This experimental system seemed to work satisfactorily although the configuration of each compartment made it impossible for the system to clean the bottom thoroughly.

The installation of a new lighting system had also been undertaken, consisting of a constavolt-type charging unit, batteries, and larger wattage light bulbs. This system was designed to operate continuously at all times while the transport trailer was holding fish.

When the transport tank was shipped for the fourth experimental trial, it was sent unattended during the ocean crossing.

Since the modifications were untested, and this was the only period for their trial, the top screens were cut open and rubber risers installed to prevent potential disaster. It had been noticed that during the first shipment, the other time these same screens had been used, they clogged when scale loss was heavy. If this were to happen at sea with the tank unattended, the tank would overflow flooding the inside of the ship.

During this shipment, the location on board ship for the transport tanker trailer had been changed for ease of parking and timing for loading. After loading the trailer on the vessel late in the evening, the power supply to the trailer was plugged in to the ship's outlet. The ship's outlet had been incorrectly wired and immediately a short circuit occurred causing the wiring to burn up. After repairing the system, the hatches were opened and it was discovered that the rear tank screen, including the rubber riser, was allowing fish to be discharged from the tank at a rapid rate. The new

location on the ship had changed the trailer level, and the water seeking a new level rose above the rear discharge screen. Without any available repair equipment or any time for corrective action before sailing, the shipment departed on August 7, discharging fish overboard during the 4-day crossing to Honolulu. On arrival in Honolulu, about 410 lb of fish were unloaded from the transport trailer. The surviving fish appeared to be in excellent shape. The bottom of the tank was not covered with dead fish and debris, indicating that a partial correction of the problems had been made.

It appeared that the rest of the fish had been ejected over the side during the transhipment. Since an attendant did not accompany the trailer during the crossing, it was not possible to determine if the discharged fish had been dead or alive.

Optimum density studies begun

After the conclusion of the fourth shipment of anchovies, it was decided that density studies should be undertaken to determine the optimum carrying capacity of the baitfish transport system. During the same period, aging of bait in the holding tanks would be done to eliminate much of the variation in the quality of the bait before proceeding with further trial shipments to Honolulu.

For 3 mo, aging and density experiments were conducted. Problems encountered during these experiments were diseased fish attributed to red-tide, foul water in the pools, and continued harrassment by sea gulls. The density experimentation studies resulted in a survival model relating input of anchovy to output or survival during a 4-day simulated shipment. Three experiments conducted in the transport tanker developed eight data points, which were considered sufficient to graph the desired survival model.

These points are shown in Figure 1 and indicate that optimum loading occurs at 795 kg (1,750 lb) input with yield (survival) of 500 kg (1,100 lb) of live fish after a 4-day simulated trip.

The fifth trial shipment

Upon conclusion of the density experiments, trial shipping experiments were resumed. Trial shipment #5 left Los Angeles on November 30 with the tank unit loaded with 743 kg (1,634 lb) as measured by the scoop method, or slightly less than the determined optimum loading density. During the 3 mo of bait aging experiments, the bottom experimental screen drain system was used. Afterwards, while transporting the trailer to the ship for loading, the front bottom screen unit broke loose as electrolysis disintegrated the hold-down weight bolt. Live fish were sucked through the closed circuit recirculation pump and pulverized, contaminating the water with a red scaly fish soup. The problem was discovered after the 45-min trip from the dock to the ship during the loading period. The results were again a poor shipment; the tanker arrived in Honolulu with only 23 kg (50 lb).

The sixth trial shipment

The sixth and final shipment to leave the Long Beach area commenced February 10, and arrived in Honolulu on March 17, 1975.

It became obvious that the recirculation pumping system was inadequate. Due to the poor shape of each compartment, a larger pumping system would still not solve the problems.

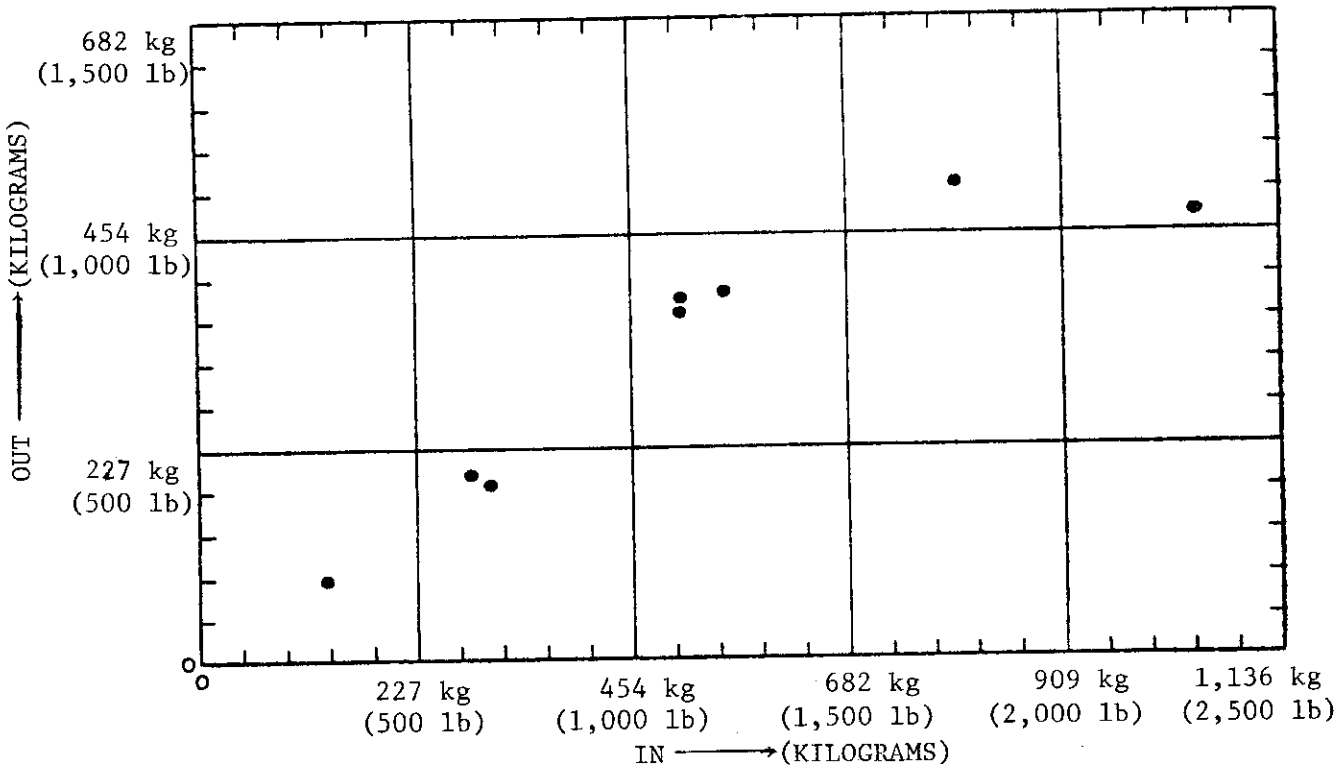

Figure 1.--Output compared to input in bait transport tank after 4-day simulated operation (individual compartment totals converted to full tank-load equivalents).

Table 1.--Synopsis of bait aging experience.

Dates loaded	Input kg	Input lb	Date unloaded	Output kg	Output lb	Survival rate (%)	Remarks	Disposition
1974								
9/10, 11	1,364	3,000	9/17	91	200	7	Red tide; poor bait quality	Experiment in tanker
10/9	909	2,000	10/15	909	2,000	100	Healthy bait	Experiment in tanker
10/16	682	1,500	10/15	91	200	13	Disease; poor quality bait	Dumped
10/21	682	1,500	10/27	356	784	52	Disease; many jack mackerel	Experiment in tanker
10/28	909	2,000	10/31	91	200	10	Disease; poor quality bait	Dumped
11/8	909	2,000	11/14	768	1,690	85	Good bait; covered pools	Experiment in tanker (switched off; bait died)
11/15, 18	950	2,090	11/21	448	985	47	Fair quality bait	Experiment in tanker
11/25	1,000	2,200	11/30	728	1,601	73	Fair quality bait	Shipped; lost in transit
1975								
2/18, 21, 24	1,920	4,225	2/27	0	0	0	Fair quality bait; power outage	Dumped
3/3, 13	2,045	4,500	3/17	788	1,734	39	Poor quality bait at shipping time	Shipped 743 kg (1,634 lb); delivered 261 kg (574 lb) to Honolulu
Totals	11,370	25,015		4,270	9,394	416		

The existing pumping system was removed, and 10 air stones were installed in the bottom of the transport tank. A complete set of screens fastened to the bottom was installed to drain off the muck from the bottom of the tanker. With the water going out both the top and the bottom, this provided better circulation within the system.

Prior to shipping, the first batch of hardy, well-aged anchovies were inadvertently killed the night before shipping. Another load of bait was delivered for aging, but the quality of this batch of bait was not as good, and during aging mortality was comparatively high. A total of 743 kg (1,634 lb) of this "less than perfect" bait was loaded into the tanker for shipment; 261 kg (574 lb) were delivered live in Honolulu.

Baitfish transport experiments moved to Tiburon

Continued problems with high mortality of the baitfish at the aging station in Long Beach contributed to the failure of the transport project up to this point. Poor bait and poor water quality appeared to have been the major causes of this mortality.

In April 1975, the baitfish committee recommended withholding further aging and shipping trials until the actual causes of the heavy mortality could be investigated. This would be done at the NMFS dock area in Tiburon, California, located on San Francisco Bay. The water quality in this location is far superior to that of Los Angeles Harbor, and an abundance of small anchovy is reported to occur there during the summer months.

During this same period, Matson Navigation Company informed the NMFS that their RO/RO vessels were to be moved from Los Angeles Harbor to the new Matson shipping terminal at Oakland.

By August 1975, the aging station in Long Beach had been moved to the NMFS Tiburon dock area. This new station was composed of two large 13,000-gal plastic-lined swimming pools, and a complex of twelve 400-gal aluminum holding tanks in which the experiments were to be conducted. Seawater was supplied to the pools and tanks by two submersible pumps providing separate water supplies to each system. A lighting system was installed above each tank to avoid the reoccurrence of the "red-nose" syndrome, and predator screens were fastened over the tops.

On September 4, 1975, the tank farm was completed, and factorial experiments which had been designed earlier were begun in order to assess the effects of bait quality, oxygen levels, salinity, handling methods, and loading densities on survival rates.

From September 15 through November 4, 1975, a series of five experiments were conducted. During this period, batches of bait that were captured and delivered by local bait boats varied greatly as to size and quality. Three methods were tested to handle the fish: pump, dry scoop, and the Hawaiian bucket system. The bucket handling method caused less scaling and was preferred over the other two, although it allowed a greater margin of error when estimating the weight of the fish being transferred.

Based on the density experiments, optimum holding density with the least mortality in a 400-gal test tank was 0.08 kg (0.18 lb) fish/gallon. Details on the above may be found in a preliminary report on the baitfish transport project by Stanley Smith and Robert Hoffman, 1975.

After the completion of this series of experiments, further experimentation was curtailed until after the winter season, November through March. With the seasonal drop in water temperatures and salinity, the fish are apparently weaker and more susceptible to stress. Further experimentation in the winter was not considered representative of normal conditions since shipments would be made from April through September, which is during the skipjack tuna fishing season in Hawaii.

BAITFISH PROJECT 1976--NEW MANAGEMENT, NEW METHODS

In January 1976, the baitfish project was reactivated, this time under new management and direction. It was apparent that the basic transport tank system needed extensive modification. Tank configuration, lighting, oxygen, circulation, dead fish extraction, and loading systems all had to be restructured. Previous bait handling methods such as bucketing, scooping, and pumping caused stress and loss of scales to the fish. These methods were also time-consuming and labor-intensive. Bait transfer methods needed to be simplified. Feeding would have to be reduced or eliminated completely. Aging would have to be eliminated or substantially reduced to keep fish from becoming contaminated or diseased prior to shipping. Holding fish on the closed-circuit mode prior to shipping had to be minimized. With these requirements in mind, a completely new baitfish transport system was developed.

Development of the new baitfish transport system

The baitfish project was reactivated under a three-part development scheme: (1) design construction, (2) experimentation (loading and density studies), and (3) shipping trials.

Design theory

The first problem was to develop a new concept in loading procedures which would eliminate virtually all handling of the baitfish. Research into the engineering aspects of the problem resulted in a completely new approach to loading bait into shipping tanks.

It was hypothesized that two large circular tanks could be constructed with a combined carrying capacity equal to that of the previous system. These tanks could be lowered into the water one at a time, loaded with live fish and water in one movement similar to the bucket system, and replaced on the trailer ready for shipment.

If this were possible, the concept of holding bait in an open, free circulating bait barge could be used, allowing the fish to utilize natural feed and oxygen. This barge could then become the loading vehicle into which the tanks could be lowered. The fish could be transferred directly from the water into the tanks for shipping. If this method were feasible, handling of the bait would be kept at an absolute minimum and survival rates at their maximum.

Tank design and construction

An extensive review of the problems encountered with the previous transport system aided in the development of the new transport tank design. Tank configuration, circulation, sludge build up, and loading methods were analyzed and made the basis for the development of the new tanks. Two 2,500-gal circular tanks were designed with conical bottoms and tops for maximum self-cleaning capabilities. Inlet and discharge water systems were incorporated to provide good circulation throughout

the entire tank. Lighting and oxygen system were also integrated into the tank system to provide maximum life support for the baitfish. The tanks were designed to be lifted fully loaded, each weighing 14 tons.

In early May 1976, preliminary drawings were submitted to a structural architect and engineer for review and analysis. A duplicate set of working drawings was made and distributed to commence construction of the tanks.

During June and July 1976, the transport tanks underwent construction in Hawaii, complete with contractor delays and material acquisition problems. The tank shells arrived in Tiburon im mid-August and installation of the various life support systems and plumbing commenced. By mid-September the majority of the construction had been completed with one tank finished and tested. All systems worked well and water flow through the single tank was measured at 150 gal/min.

Trailer

For carrying the tanks, a used, heavy-duty military trailer was located in California and delivered to the Tiburon Laboratory for modification. The trailer was stripped of its excess metal parts and modified to accommodate the plumbing, circulating water, lighting and oxygen systems, and flow meters. The front of the trailer became the housing area for a diesel generator which powered a submersible pumping system mounted on the rear. The generator and pumping units enabled the trailer and tanks to be self-contained at all times and provide a continuous flow of water to the fish. The generator also provided electrical power to the battery charging unit which, in turn, powered

the 12-VDC lighting system. This system utilized two 12-V batteries connected by long cables to the tanks, allowing the interior lighting of the tanks to be on continuously.

The oxygen supply cylinders were also housed in the front section of the trailer and, similar to the lighting system, were connected by long hoses to the tanks, providing a continuous supply of oxygen as required. A recirculation pump was also mounted in this area, which provided water flow through the tanks during the closed-circulation mode periods.

Bait receiver barge

A bait receiver barge built for holding anchovies was located in San Diego and made available to the project on a lease basis. A tug boat towed the barge to San Francisco and delivered it to our Tiburon Laboratory pier where a specially designed mooring had been placed. To gain maximum water flow through the barge for good circulation, it was located on the end of the pier in a current area. The mooring was so placed as to keep the barge away from the pier and safe from damage. The barge was rigged with underwater lights which operated from a power source on the pier. These lights promoted schooling behavior in the fish prior to their being loaded into the tanks and also alleviated the chance of their developing the "red-nose" syndrome. The barge was also outfitted with predator grates on the top, keeping the birds away from the fish. Loading and crowder nets were designed to fit within the barge to capture the bait for loading into the tanks.

EXPERIMENTATION

Experimentation with the new baitfish transport system was designed as a four part scheme. The first part was the development of general procedures involving bait acquisition, tank and net handling, and loading techniques.

It was decided that a commercial bait boat would capture the bait, wet brail the fish into its baitwells, and transport them to the bait barge moored at Tiburon. The bait would then be unloaded by a flume method, which allows bait and water to flow out of the baitwell into the barge with little damage to the fish. After holding the bait for a short time (aging) to observe their physical condition, the barge would be moved to a position alongside the dock at the Tiburon Laboratory for transfer of the bait to the transport tanks. The two transport tanks situated on the trailer would be positioned on the dock adjacent to the bait receiver barge. A large crane would lower the tanks, one at a time, into the barge to be loaded with bait. While lowering a tank into the barge, a water supply hose would be attached, and also, the end of a holding net into which all the fish were manuevered would be attached around the open side door. After the net was attached, the tank would be lowered into the water, and as the water rose to the door, the fish would be crowded toward the entrance. While the tank was being lowered, water would be pumped in to aid in its submersion. Once the water filled the tank within 6 in. of the door opening, the tank would be lowered rapidly allowing fish and water to enter through

the open door. During this process, the net containing the bait would be drawn tight toward the door permitting all the fish to flow into the tank.

After the tank received the fish, the inner door would be closed and the tank filled completely with water. The net and water supply hose would be removed, the outer door closed, and the tank operated on the closed-circulation mode with lights and oxygen being supplied from the trailer. The filled tank would then be lifted from the barge and relocated on the trailer. The open-circulation mode would then be applied, giving the confined fish adequate life support. After duplicating the operation for the second tank, the baitfish transport system would then be ready for an experimental period at the Tiburon dock, or be ready for loading aboard ship.

The second area of concern was the critical estimating of the weights of fish to be loaded into each tank. Since the new system did not incorporate bucketing or dipnetting of the bait, visual weight estimation was to be used. To accomplish this, the fish were crowded into a holding net in half of the barge. The fish in the net were then split into two parts by sectioning the net, which involved raising a chain placed across the bottom of the barge. After the chain was drawn up and the fish divided, each section of the net was drawn up (drying up the net) and the weight estimated. By lowering the dividing chain, the fish could be adjusted to approximately equal portions on either side. Each half of the fish would be loaded into each tank. After several experimental trials, weight estimation would become more accurate.

The third portion of the scheme was a series of 4- to 5-day experimental simulated shipping trials at the Tiburon dock. These trails were designed to analyze the tank system for performance to allow modifications to be made if necessary prior to actual shipping trials. During these loading trials, dissolved oxygen, water flows, fish swimming behavior, and physical condition of the fish would be monitored.

The fourth and most critical experimentation to be done in the scheme was density loading of the fish. Progressive density studies were to be carried out during the experimental trials to realize the maximum sustainable density loading of the fish required for shipment from Oakland to Hawaii.

Preliminary baitfish acquisition problems

During the baitfish tank experiments at Tiburon in 1975, it became evident that there was a tremendous amount of rivalry between the only two baitfish dealers located on San Francisco Bay. While engaging in the experimental tank farm loading and density studies, the participating bait dealer indicated that if we accepted bait from the other firm, he would not make further deliveries to the tank complex.

The following year, to commence experiments with our new transport system, the same bait dealer was notified to begin delivery to our bait receiver barge. For many days, in spite of repeated efforts, he would not make contact with Laboratory personnel. Finally, it was decided to contact the second bait dealer to see if he would be more

cooperative and supply our needs. He, too, indicated that he would deliver bait, but if we went back to the previous dealer he would cancel his obligation to us.

Our second bait dealer supplied us with baitfish on time during the 1976 period of the transport trailer experimentation.

1976 Simulated shipping trial

In mid-September 1976, to expedite the project, it was decided to conduct the first experiment with the one completed tank. The barge had been filled with baitfish from the dealer's catcher vessel, and an estimated 635 kg (1,400 lb) of aged anchovy were available to conduct this experiment.

On September 22, the barge was positioned for loading fish, and the large crane manipulated the transport tank. Except for some minor adjustments with hoses and lines, the first loading of fish into the tank proceeded with little interruption. The actual loading time took 20 min. After the tank was returned to the trailer, it was shifted from the closed to the open-circulation mode to commence a simulated 4-day crossing from Oakland to Honolulu.

Since this experiment was the first time a visual weight estimation of this type was to be conducted, our weight estimation was considerably in error. To insure an accurate accounting of all fish that were loaded into the system, a fine mesh net captured all fish that were were discharged from the tank. This procedure was utilized during all the experiments. Upon completion of the experiment, all remaining

live fish were weighed dry in a bucket, and combined with the weight of the discharged fish to give the final results.

A total of 200 kg (440 lb) of anchovy survived the one tank experiment with only a 2.2% mortality.[1] The condition of the fish was satisfactory with no "red-nose" syndrome or disease in evidence.

After loading the bait from the barge into the tank for the experiment, a second load of anchovy was ordered and an estimated 900 kg (2,000 lb) delivered.

During the week of aging in the seawater-filled barge, the fish showed signs of weakness and disease. This load was discarded and another load was delivered to the barge. Again, this time the next day, the bait was weak and sick looking. It was concluded that this was the beginning of the period when anchovy become stressed easily because of annual physiological changes. The decision was made to mothball the program until spring, when the fish would be more viable and actual shipping would be undertaken.

Simulated trials, trial shipment, and termination

The baitfish project was resumed in March 1977 with the demothballing of the baitfish receiver barge at Tiburon. The large iron grates were reinstalled, and the lighting system replaced making the barge ready to receive bait.

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[1]Memo, from Donald Aasted to Richard Shomura, Director, Honolulu Laboratory, dated October 7, 1976, Subject: Report on the first trial run of a simulated bait shipment to Honolulu from San Francisco.

The bait dealer was notified both verbally and in writing stating our intentions to continue the baitfish project. He agreed that bait delivery would be made on the same basis as the previous year, and delivery would be made as soon as bait became available. Personnel from the Tiburon Laboratory made repeated contact with the bait dealer as to bait availability, size and location, and expected delivery dates, and although other sources indicated that bait was available, we did not have a delivery. Finally, in June, our bait dealer indicated he could deliver bait, and with this notification, the baitfish transport system was again readied for experimentation on the Tiburon dock. Again, we waited for our first delivery of baitfish. Finally, on July 27th, 5 mo after our initial contact with the bait dealer, we received the first load of baitfish for the year.

First simulated shipping trial[2]

After 1 wk of aging bait, the first experiment was conducted on August 2, 1977. During the crowding portion of the loading operation, it was noticed that the amount of bait within the barge was considerably less than what was estimated delivered the previous week.

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[2]Memo, from Tom Barnes, Tiburon Laboratory, to Director, Honolulu Laboratory, dated August 9, 1977, Subject: Progress report, first bait holding trial, 1977.

A loose plank was discovered on the bottom of the barge allowing predators to swim in and baitfish swim out of the large hole. Since the amount of fish left in the barge did not warrant the use of two tanks for an experiment, the forward tank was filled with fish and water, and the rear tank filled with water and used as control to monitor oxygen and temperature levels. The forward tank was loaded with 312 kg (687 lb), and 291 kg (641 lb) or 93% survived the 5-day simulated shipping trial. Loading problems were minor and easily adjusted. The condition of the fish was excellent, with no 'red-nose' syndrome or disease present.

Second simulated shipping trial[3]

On August 23, our second delivery of bait for the year arrived, and again the fish appeared in good condition and were aged for 1 wk. Two modifications were made for this trial: one was a different fish guard over the bottom discharge area where live fish were being caught in the discharge collecting system. The second modification was an increase in plumbing diameters to increase water flow to their maximum. Water flow increased from 150 to 195 gal/min in each tank providing an ideal flow for the system and for fish swimming speeds.

It was decided to load both tanks although the amount of bait in the barge again appeared considerably less than the 909 kg (2,000 lb) delivered. The density in each tank would not be as great as required

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[3]Memo, from Tom Barnes, Tiburon Laboratory, to Director, Honolulu Laboratory, dated September 16, 1977, Subject: Progress report, second bait holding trial, 1977.

for a density study, but prior to this we had not used both tanks, and felt it necessary to go through the entire loading procedure testing both tanks under loaded conditions.

Both tanks were loaded with 343 kg (755 lb) divided equally between them and the survival rate was 99% during the 5-day experimental period. The excellent survivial rate was attributed to the light density load in each tank, and although still not perfected, to the modified bottom fish guard.

Third simulated shipping trial[4]

On September 11, 1977, an estimated 909 kg (2,000 lb) of bait was loaded into our receiver barge. To try and eliminate an escapement from the barge and gain knowledge as to length of time needed for aging, the fish were loaded into the transport system 3.5 days after delivery to the barge. Again, the amount of fish in our barge, when crowded into the loading net, appeared much less than what was estimated delivered. The loading crew estimated that we had 455 kg (1,000 lb) captured in the net. This amount was determined to be ample for a maximum density loading for one tank, so the front tank was filled with 432 kg (953 lb) of live fish. A calculated 406 kg (894 lb) survived the trial period with an outstanding 94% survival rate.

During this trial period, a few live fish were still being discharged daily from the bottom fish guard. Further design and experimentation were necessary.

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[4]Memo, from Tom Barnes, Tiburon Laboratory, to Director, Honolulu Laboratory, dated September 23, 1977, Subject: Progress report, third bait holding trial, 1977.

Table 2.--Synopsis of simulated shipping trials.

Trial Period	Input (kg)	Tank used	Output (kg)	Remarks (% survival/condition)
1976				
9-22/26	204	Tank 1	200	98% - excellent health
1977				
8-2/7	312	Tank 1	291	93% - excellent health
8-31/9-6	343	Both	340	99% - excellent health
9-13/19	432	Tank 1	406	94% - excellent health

Trial shipment and termination of project[5]

Because we lacked a reliable supply of anchovy in San Francisco Bay, the decision was made to terminate the baitfish project at the end of September.

On September 18, the bait dealer delivered an estimated 909 kg (2,000 lb) of anchovy into our bait barge. Originally, this bait was intended for a fourth experiment prior to actual shipping trials to Honolulu, but in light of the impending termination, it was held for use during the trip returning the transport tank system and equipment to Hawaii. It was decided to make one attempt to ship a load of baitfish to Hawaii although the system was not yet perfected. The bait dealer was asked to "top off" the bait in the barge prior to departure. He was unable to accommodate us, and the shipment was made with only a partial load of bait.

During this period, our generator unit arrived and was installed. This unit was the key to making our transport trailer mobile and self-supporting. It also allowed the installation of the needed dual recirculation pumps, but since time was now short and funding limited, this circulation system was not installed.

The open-circulation submersible pump was mounted on the trailer suspended from a large davit, and the various other components were made ready for the shipment to Hawaii.

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[5]Memo, from Donald Aasted to Richard Shomura, Director, Honolulu Laboratory, dated October 31, 1977, Subject: Baitfish project: final report.

On September 30, 1977, the baitfish transport trailer, the partially loaded bait receiver barge, and personnel moved to the Matson shipping terminal where the fish were loaded into one transport tank. The weight of the fish loaded into the front tank was estimated at 500 kg (1,100 lb). The second tank was filled with seawater to act as control while monitoring the system.

Loading at the Matson dock proved to be a simple operation, and the baitfish transport trailer remained self-contained for 5.5 h before it was finally loaded onto the ship. Mortality during this period was minimal; three fish were ejected from the discharge system. During the loading of the transport trailer on the ship, the recirculation pump delivered only 50 gal/min through the bait filled tank (this system was to be replaced with the dual high-volume pumping system), not enough to create good circulation within the tank. After loading, the ship's seawater system was connected, and an estimated 1,000 gal of stale, contaminated water ran through the tank system. This seawater system was reportedly used prior to our shipment, but unfortunately, it was a different hose connection used further aft in the ship, and it did not flush out the plumbing in the forward section of the ship where the trailer was located.

With the poor circulation during loading and the poor quality water circulated through the tanks, the fish began to die and continued throughout the night at a rate of at least 23 kg/h (51 lb/h). Surviving the following day was about 212 kg (468 lb) of bait, and after the

4-day crossing to Hawaii, 204 kg (450 lb) was delivered in Honolulu from the one tank.

Reasons for lack of adequate bait supply

As indicated in early 1977, our new bait dealer did not deliver bait to our receiver barge for several months. It was learned later that this was a result of several factors, chief among them being a change in environmental conditions in California, believed to affect the amount of bait available within San Francisco Bay. This change had also undermined the dealer's primary business of freezing bait for sale. During the summer, delivery to our barge was again put off due to the large number of albacore boats entering San Francisco Bay requiring bait from our dealer. Since both of these operations provided considerably more profit for fish delivered, the California to Hawaii baitfish project suffered from low priority.

Baitfish transport shipment costs examined

Costs incurred during the shipment from Oakland to Hawaii originating on September 30, 1977 are as follows:

Purchase of live bait	$ 400.00
Tugboat services - Tiburon to Oakland and return (move barge)	825.00
Crane service at Matson	375.00
Shipment to Hawaii	1,750.00
Rider on ship	267.00
Crane service in Honolulu	395.00
	$4,012.00

Crane and tug services can be reduced significantly if the whole operation is conducted in the Richmond/Oakland area. Matson Lines has indicated that utilization of their giant overhead cranes might be possible for loading and unloading of the tanks. The suggestion was also made to help defray shipping costs by loading the tanks with a return cargo. Lobsters, fish, and other live or manufactured products could be exported to the west coast via these tanks.

Matson has also proposed a renegotiation of shipping charges to aid in making this specialized shipping a viable operation.

CONCLUSION

The final design for a baitfish transport system to import live anchovy from California to Hawaii, as evidenced by the few simulated trials conducted, appeared to function well.

Optimum loading density is still an amount which has not been verified, but 455 kg (1,000 lb) per tank seems to be a realistic figure, with 90% survival rate or better. The simulated trials never approached thresholds that would cause mortality in the anchovy. Further experimental examination of the system will produce more conclusive results.

Bait weight estimation without direct handling is a serious problem. Even experienced bait dealers are not as accurate as they would have you believe. Estimating the weight of fish within the loading net appears to be the easiest method and the least harmful to the fish. Only practice and net markings will refine this method of weight estimating. Undoubtedly a sophisticated electronic unit is or can be

devised to count fish and give accurate weights without handling, but at present such a system would be very costly or would require capital expenditures. A large crane is at present the only method available to lower the tanks into the bait barge for filling. Matson has indicated there is a possibility of using their large container cranes to load and unload the tanks of fish. This would solve this problem and also reduce the cost of shipping. If this system is used, it gives rise to the possibility that all loading and unloading of the baitfish could be conducted at the Matson container yards at both ends of the shipment, making it necessary to hold the baitfish on the closed-circulation mode for only a few minutes. Problems solved during the development of the new transport system were directly related to the decrease in mortality of the bait. Eliminated were direct handling, the 'red nose' syndrome, and diseased fish which attributed to the greater mortality rates.

The great distances and length of time fish had to be held on the closed-circulation system were reduced to a few minutes. Aging of the bait was reduced to a few days, and this was finally just an inspection period to evaluate the health and condition of the bait. Labor-demanding tank cleaning, fish feeding, and bucketing of the bait were also totally abolished.

Given good tank configuration, circulation, lighting, and a clean environment, the capturing, holding and shipping of anchovy in containers appear feasible. Only further experimentation and shipping trials will provide conclusive evidence to this theory.

This report does not reflect a detailed economic feasibility analysis. Any such study will require an in-depth analysis of three major components: (1) the supply or availability of bait on the west coast, (2) the capital and operating costs of the transport system, and (3) the demand for the delivered product in Hawaii. Such an analysis is an entirely separate report in itself and should be undertaken after the baitfish transport system is proven a viable system for transporting baitfish from California to Hawaii.

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LITERATURE CITED

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APPENDIX

Ad Hoc Baitfish Committee

The California to Hawaii baitfish project was advised by an ad hoc baitfish committee composed of representatives from:

National Marine Fisheries Service

Pacific Tuna Development Foundation

Pacific Island Development Commission

Hawaii State Department of Planning and Economic Development

Hawaii State Division of Fish and Game

Hawaii Institute of Marine Biology, University of Hawaii

Department of Economics, University of Hawaii

Marine Programs, University of Hawaii

Sea Grant Programs, University of Hawaii

Tuna Boat Owners Association

Bumble Bee Sea Foods

Hawaiian Tuna Packers

United Fishing Company

This committee reviewed the progress of the baitfish project, advising the National Marine Fisheries Service project members as to course and direction to be taken during the project.