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An Economic Analysis of the State of the Hawaiian Skipjack Tuna Fishery

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AN ECONOMIC ANALYSIS OF THE STATE OF THE HAWAIIAN SKIPJACK TUNA FISHERY

by

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FOREWORD

Public interest in the state of the Hawaiian skipjack tuna fishery appears to be disproportionate to its importance, either in gross value or in employment terms, to the state's economy. Yet, because of its relatively modest size and lack of growth in the face of a seemingly vast resource potential near the Hawaiian Islands, the state of affairs of this fishery appears incredulous to both the sophisticated and the casual observer.

There have been many studies dealing with the biological and technological aspects of this fishery and a great deal of financial and manpower resources have been expended in tackling the problems of the industry. These have contributed to a greater understanding of the physical characteristics of the industry. However, it is now time to look at the economic aspects of the industry. Two previous studies on costs and earnings and rates of return in the industry laid the foundation for further investigation in this area. This study is largely concerned with a production analysis of the industry. The statistical processing and analysis were undertaken during 1973-74 and the report was completed in mid-1975.

We believe this study provides greater clarification of the functioning of the industry and of the alternatives open to the participants. We hope this work proves useful to public officials in planning and formulating policies with regard to the role of this industry in the Hawaiian economy. We also hope that some of the methods and techniques presented in this study will be of some interest to the many researchers and analysts studying the live-bait pole-and-line skipjack fisheries of the world.

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INTRODUCTION

The purpose of this study was to undertake a comprehensive analysis of the nature and functioning of the Hawaiian skipjack tuna fishing industry. The fishing technique used by this industry is the pole-and-line method which, except in the eastern Pacific, is the method used by all other established skipjack fisheries in the Pacific Ocean. Hence, a thorough economic analysis of this industry will help to explain the outlook for all other skipjack fisheries using this method.

While there have already been two economic studies on the Hawaiian skipjack tuna industry (Shang, 1969; Ahsan et al., 1972), this study is justified on the basis that it examines the underlying production relationships of the industry using information which was not available to other researchers. Thus, this is the first study to utilize a production-function approach to explain the behavioral characteristics of the industry.

The production function for predicting catch levels for the industry gives fairly good predictions provided there is some reliable way of estimating skipjack stock availability at the beginning of a fishing year. Research efforts have been undertaken at the Honolulu Fisheries Research Center, National Marine Fisheries Service for making such reliable estimates. If successful, existing methods for predicting catch levels by industry and government researchers could be improved by injecting alternative levels of fishing effort into making a prediction.

The production function can be used to construct an "index of fishing effectiveness" for each vessel in the fleet. This improves on previous performance rankings of vessels (Ahsan et al., 1972) which looked only at catches without considering the number of trips made nor the qualitative characteristics, e.g., strategy of fishing and abilities of captain and crew, of the vessels themselves. This index can also be used to improve the fishing effort series for this particular industry (Uchida, 1967, 1970, 1974) since each vessel is assigned a unique index number based upon its overall fishing effectiveness. In fact, it was found that ranking vessels simply by size, upon which fishing effort series in this industry has largely been based, gives rankings different from the index of fishing effectiveness.

The production function can also be used to measure the relative contribution that labor and capital each make to the productive fishing process. These relative productivities can be compared with the respective shares of the catch proceeds going to the vessel owner and the crew. This analysis can be useful to the industry in determining whether the contractual shares, or returns to the respective factors of production, are adequate to keep incentives which are crucial to fishing at a maximum level.

Finally, an economic analysis of trends in selected series in this industry, together with the production function, can be used to construct a behavioral model which may be applied to all live-bait pole-and-line skipjack tuna fisheries. Essentially, the industry is inherently unstable due to its dependence on the availability of the traditional skipjack stocks.

THE HAWAIIAN SKIPJACK TUNA FISHING INDUSTRY

Background and Characteristics

Originally a subsistence fishery, the Hawaiian skipjack tuna fishery developed on a commercial basis as a result of the influx of Japanese immigrants at the turn of the 20th century. Consequently, the gear and fishing techniques used were strongly influenced by the Japanese pole-and-line fishery of the late 19th century. With the passage of time, mechanical power replaced sails, crew size increased, innovations more suitable for fishing in Hawaiian waters were introduced, and the local skipjack fishing vessel took on the unique characteristic known as the Hawaiian "aku sampan" (June, 1951). The aku fishing vessels, or sampans, are generally of wood construction and range between 58.3 and 80.5 feet in registered length and 27 and 77 gross registered tons. They carry six to 14 men per fishing trip.

Due to the limited capacity of the dried and fresh-fish markets to absorb the rapidly increasing catch, additional processing was required. Therefore, in 1917 a cannery was constructed on the island of Oahu. Although forced to curtail operations during World War II, by 1948 there were 32 vessels actively operating in the Hawaiian skipjack tuna fishing industry with annual landings running between 7.7 and 12.1 million pounds (Yamashita, 1958).

The Hawaiian skipjack tuna fishery is largely seasonal. On the average, more than 70 percent of the catch is made between May and September (Uchida, 1966).

The skipjack tuna (*Katsuwonus pelamis*), locally called aku, accounts for the bulk of the commercial marine fisheries catch in Hawaii. In 1972 these landings amounted to over three-fourths of the weight and more than one-half of the value of the total Hawaiian marine fisheries catch (Hawaii State Division of Fish and Game, 1973). Annual catches in the fishery, however, fluctuate quite widely. Between 1956 and 1972, the range was between 6.0 and 16.2 million pounds (Hawaii State Division of Fish and Game official records).

Commercial fishing for skipjack tuna in Hawaii is done exclusively with pole-and-line using live bait (Yamashita, 1958; Brock and Uchida, 1968; Uchida, 1966, 1970; and Uchida and Sumida, 1971). Baitfish, carried live in baitwells on the fishing vessels, are "chummed" into the water to attract a school of feeding skipjack. The objective is to excite the school of skipjack into a feeding frenzy and concentrate it around the boat by continued chumming of live bait. The fishermen, standing on a wide aft sponson (platform), use long bamboo poles to drag feather lures through the water. Fish biting the lures are rapidly swung aboard the vessel; the hook is quickly disengaged; and the lure is returned to the water for another catch.

The basic pole-and-line technique has shown little change over the years. Some innovations, however, have been adopted and proven successful in raising productivity. In 1931 the first flying bridge was installed and in 1935 a pump-spray system was added which forces seawater through nozzles located along the aft gunwales (June, 1951). The rain-like spray helps to induce the feeding frenzy of skipjack during fishing. In 1966, fishermen learned to "flip" fish off the hook, rather than catching each fish under the arm and removing the hook by hand (Uchida, 1966).

Since this is largely an inshore fishery, most of the commercial skipjack fishing in Hawaii is carried out within 56 km of the main island chain. Of the total catch, between 63 and 90 percent is taken within 37 km of the island chain (Uchida, 1970).

The main baitfish species used is a Hawaiian anchovy (*Stolephorus purpureus*), locally called nehu. The main sources of this bait are in the bays of the islands of Oahu and Maui. Each vessel catches its own bait--either during the day or at night--prior to leaving for the fishing grounds.

The fishery has shown signs of stagnation and even decline (Hawaii State Division of Fish and Game official records). Marginally productive vessels have dropped out of the fishery and new vessel construction has all but ceased since 1955. By 1972, there were only 14 of the original Hawaiian sampans still actively engaged in skipjack fishing. In that year, a new steel-hulled vessel of 136 gross registered tons, built under the vessel construction subsidy program, joined the fishing fleet. It is hoped that this vessel, which is capable of carrying large amounts of bait and remaining at sea for extended periods, will bring about a reversal in the decline of the industry (Uchida and Sumida, 1973).

Despite downward trends in both vessels and number of fishermen, total landings have remained relatively constant, subject only to seasonal and annual fluctuations. In 1972 the total skipjack catch amounted to 10.9 million pounds with a dockside value of $2.9 million (Hawaii State Division of Fish and Game, 1973), representing less than 1 percent of the total Hawaiian gross state product.

The Resource

Any production analysis of the Hawaiian skipjack tuna fishery must necessarily consider the extent and dynamic nature of the resource. The abundance of skipjack in Hawaiian waters, although completely exogenous to the Hawaiian skipjack industry at any point in time, has a great effect upon local skipjack landings. Oceanographic and biological conditions and perhaps the amount and type of effort by other Pacific fishing fleets may affect the availability and thus the market price of skipjack in Hawaii. It is proper then to briefly summarize existing knowledge on the extent of the skipjack resource and its harvest throughout the Pacific.

Various estimates of the potential yield of skipjack in the entire Pacific Ocean are listed in Hester and Otsu (1973). While estimates for specific areas, e.g., eastern Pacific and central Pacific, range anywhere from a doubling to an eightfold increase over present catch rates, recent Japanese estimates are between 1.5 and 2 million tons for the entire Pacific. This represents an increase of between five and seven times present catch rates. Because very little is known about the skipjack stocks in terms of numbers and sizes, any specific estimate of the potential yield is highly speculative. On the other hand, available evidence indicates that the potential yield is large when compared with recent catches (Sette and Rothschild, 1966; Suda, 1973).

Since 1966, skipjack landings in the Pacific Ocean have averaged close to 300 thousand metric tons compared with less than 250 thousand metric tons in prior years (FAO, 1972). This is mainly due to increased Japanese landings in the northwestern Pacific (Kawasaki, 1973) which have risen from about 61.5 percent to around 65 percent (FAO, 1972). Together with the figure for the United States, this represents approximately 85 percent of the total catch of Pacific Ocean skipjack. The Hawaiian skipjack tuna fishery accounts for less than 2 percent of these landings.

In 1974 skipjack tuna constituted about 30 percent of the total tuna catch and replaced yellowfin tuna as the dominant species caught (Matsumoto, 1974). Ex-vessel prices have shown a steady upward trend since 1967, reaching levels of over $500 per metric ton in 1973 and 1974. At these prices, the potential value of the Pacific skipjack resource to fishermen is between $400 million and $1 billion annually. In 1973, Hawaii's catch was valued at only $2.9 million.

Notwithstanding the potential abundance and value of this resource, studies have shown skipjack tuna to be widely distributed throughout tropical and subtropical waters. The latitudes of 40°N and 40°S provide generally accepted geographic boundaries; however, migratory patterns of subpopulations of skipjack and seasonal variations in stock abundance occur throughout this area and are apparently related to water temperature, salinity, and current patterns (Seckel, 1972; Seckel and Waldron, 1960; Rothschild, 1966; Rothschild and Uchida, 1968; Iwasaki, 1970; Fujino, 1970, 1972; Suda, 1971; Kawasaki, 1973; Hester, 1974). These dynamic resource patterns are reflected in yearly and seasonal variations in catch statistics for all Pacific skipjack fisheries, including Hawaii.

Marketing of Landings

Landings of the Hawaiian skipjack fleet are sold either on the fresh-fish market or to the local cannery. The fresh-fish market retails fresh, whole, and filleted skipjack as well as smoked and dried fish. Prevailing prices on the fresh-fish market are the result of supply and demand conditions for skipjack existing at any particular time, as well as prices of available competitive and substitute species.

Much of the skipjack is retailed as "sashimi," a raw fish delicacy highly prized by Hawaiian consumers, especially those of Japanese ancestry. The larger species of tuna, such as yellowfin (*Thunnus albacares*) and bigeye (*Thunnus obesus*), are most desirable for use as "sashimi." However, when supplies of these species are inadequate to fill the demand, skipjack provides a relatively low-priced substitute. With the increasing number of Japanese tourists visiting Hawaii, the demand for "sashimi" and thus the market for fresh tuna are expected to increase. "Sashimi" is in especially great demand during holiday periods, notably the Christmas and New Year season. Thus, although the market demand for fresh fish is greatest during the winter months, landings of skipjack are lowest during these months, as opposed to the summer months when fresh-fish demand is lowest and landings are highest. This situation, coupled with the perishable nature of the product, accounts for the considerable instability of prices on the fresh-fish market.

Any skipjack not sold on the fresh-fish market is purchased by the Hawaiian Tuna Packers cannery at prices which reflect conditions of major United States and Japanese markets. Since Hawaii produces a very small proportion of the total Pacific skipjack catch, fishermen selling to the cannery have no alternative but to accept the offered price, which is the world price less a differential for shipping cost. Tuna canned in Hawaii is exported to the mainland under the "Bumble Bee" brand and sold locally under the "Coral" label.

Problems of Development

The development problems of the Hawaiian skipjack tuna fishery appear to lie in two directions. One is the highly labor-intensive pole-and-line technique of fishing which makes it difficult to recruit the low-cost manpower needed for the crews of the vessels. The other involves the delicate nature of the baitfish nehu which limits the range of the fishing vessels even if these vessels could be technologically equipped with more powerful engines, greater holding capacities, freezing equipment, etc.

The average number of men hooking skipjack per trip has steadily declined over the years due to the inability of the industry to attract new recruits as old fishermen quit fishing or retire (Uchida, 1966). A study in 1972 indicated that a Hawaiian skipjack fisherman earns much less than persons engaged in alternative occupations, e.g., janitors, watchmen, or groundskeepers, despite the danger, intensive work, difficult living conditions aboard vessels, and inconvenience of spending much time away from the family (Ahsan et al., 1972). Due to this unattractive situation, the industry has turned to imported labor, primarily from Okinawa. It has been estimated that such labor comprises approximately half of the fishermen in the Hawaiian skipjack tuna industry.

In line with the need for labor-saving technological change, the Japanese have developed an automatic skipjack fishing machine which consists of a hydraulically operated fishing pole mounted on the side of the pole-and-line fishing vessel. Several hydraulic poles can be operated by a single fisherman, thus reducing the labor complement and increasing the share of the remaining crew. Although promising, this device has not yet proven to be completely successful (Suzuki Tekkajo Kabushiki Kaisha, 1970). Tests in the Hawaiian fleet were conducted in 1973 and 1974.

Under present conditions, the characteristics of the nehu bait most strongly influence the nature of the operations and future development of the Hawaiian skipjack tuna fishing industry. Studies have shown, for example, that fishermen may spend up to one-half of their time seeking and capturing bait, thus reducing the time available for skipjack tuna fishing (Brock and Uchida, 1968). It was also established that baitfish mortality typically averages about 25 percent per day after capture. The length of the fishing trip is thus usually restricted to one or two days of fishing after a one or two-day baiting period (Brock and Uchida, 1968).

In order to reduce the time needed to secure bait, as well as to reduce mortality rates, the Japanese have developed a separate bait fishery which supplies their western Pacific pole-and-line fleet with aged, hardy baitfish (Cleaver and Shimada, 1950). Attempts to develop a similar bait fishery to supply the Hawaiian skipjack fleet have not been successful (U.S. Bureau of Commercial Fisheries, 1969). In 1974-75, attempts have been made to supplement the Hawaiian baitfish supply by shipping live bait from California (National Marine Fisheries Service, Southwest Fisheries Center, "Proceedings of the Tuna Baitfish Workshop," June 4-6, 1974, in press). These experiments are continuing.

Other approaches to solving the bait problem have included the use of artificial bait (Tester et al., 1954), electrical stimuli (Miyake and Steiger, 1957), and dead nehu and tilapia (Yuen, 1969)--all with limited success. Also, efforts to decrease baitfish mortality through improved handling and transport have shown some positive results (Baldwin et al., 1971; Baldwin, 1969, 1970). However, for the most part, fishermen have been reluctant to adopt many of these techniques.

There have been several attempts to use more abundant and hardier species of culturable baitfish in place of the nehu. *Tilapia mossambica* was cultured and used as a supplement to nehu (Brock and Takata, 1955; King and Wilson, 1957; Uchida and King, 1962), but lack of fisherman acceptance precluded economically feasible production of this species. *Dorosoma petenense*, or threadfin shad, was also tried with some success (Iverson, 1971). A feasibility study for the rearing of threadfin shad (Shang and Iverson, 1971) showed that production of 3,660 buckets per 10-acre pond could be accomplished at reasonable prices, but fisherman resistance and lack of funds precluded further pursuit of this project. Also, experiments on the use of *Poecilia sphenops*, or sharpnose mollies, as skipjack bait are being conducted (Baldwin, 1974).

A comparison of the effectiveness of nehu with other baitfish species, e.g., tilapia, shad, northern anchovy (*Engraulis mordax*), and golden shiner (*Notemigonus crysoleucas*), shows that only the northern anchovy has a greater effectiveness than nehu in the quantity of tuna produced per kilogram of bait used (Hester, 1974). These findings tend to explain the intense interest in transporting the northern anchovy from California to Hawaii and the lack of interest in using other bait species by the Hawaiian skipjack tuna fishing industry.

Efforts at Non-Bait Technology

The use of gill nets and purse seines represents a possibility for circumventing both the labor and bait supply problems inherent in the pole-and-line method.

Gill nets

The gill net is a loosely hung piece of webbing which is set adrift near schools of feeding tuna. As fish attempt to swim through the mesh of the net, they are entangled.

In 1961-62 the Bureau of Commercial Fisheries in conjunction with the state of Hawaii conducted experimental gill net fishing for skipjack (Shomura, 1963). Although some fish were caught, the amount was insufficient for commercial purposes. Although crew size could be somewhat reduced; dependence upon live bait was not eliminated since best results were attained when live bait was chummed around the net as it was being set in the center of a school of feeding skipjack. Gill net experiments carried out in New Zealand waters have resulted in some success. Gill nets were used in conjunction with acoustic lures which were designed to broadcast the sounds of skipjack and bait in a predatory feeding frenzy (Avery, 1970). As yet both methods have not been tried in Hawaiian waters.

Purse seines

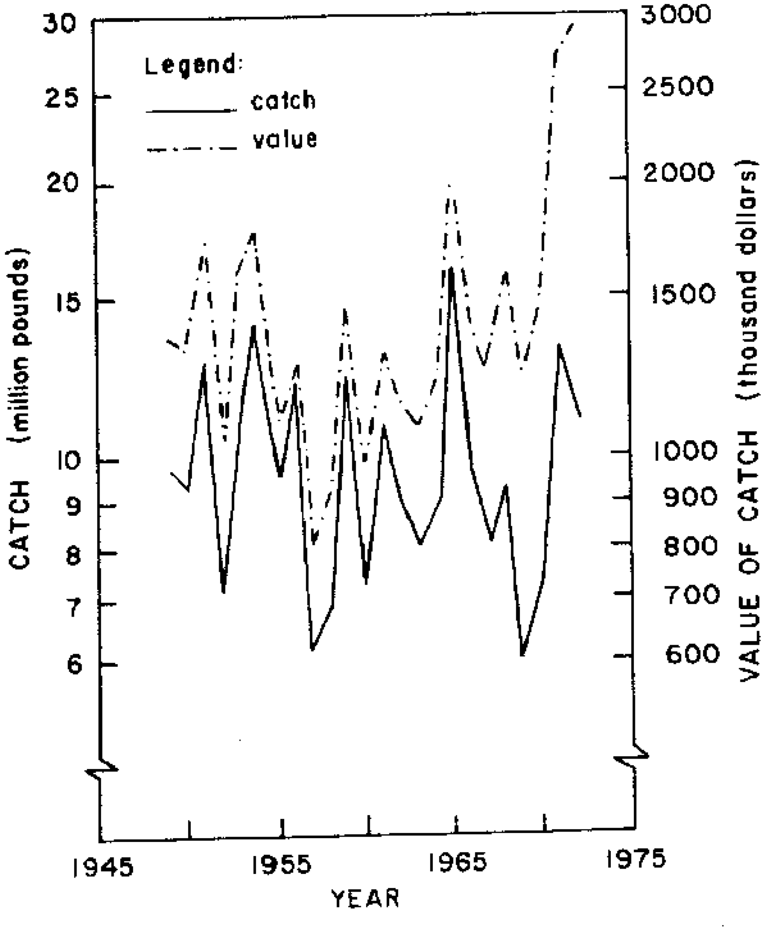
Purse seining involves the encirclement of tuna schools with a long, deep net which can be "pursed" or closed at the bottom. This highly capital-intensive, labor-saving method has been well perfected for use in the eastern Pacific where it accounts for a major portion of the skipjack catch (McNeely, 1961; Green et al., 1970b). In areas other than the eastern Pacific, however, seining methods have generally proven to be less than an overwhelming success. The Japanese have been experimenting with purse seining for skipjack in tropical waters since 1966; catches have not been outstanding (Watakabe, 1970; Inoue, 1971).

Purse seining was first tried in Hawaii during 1950-51 (Murphy and Niska, 1953). Trials were again conducted during the summer of 1970 (Hawaii State Division of Fish and Game and Bumble Bee Seafoods, 1970). As recent as 1972 purse seining experiments were carried out by a West Coast vessel in the Marquesas Islands (Cruise report, M/V *Kerri M.*, 1973). Lack of success in all of these trials has been attributed to the visibility of the net in the water, the depth of the thermocline, and the erratic movement of schools. Development of new, faster-sinking, finer-mesh, deeper nets, as well as the use of live bait to hold schools, may be solutions to some of these problems (Green et al., 1970a). However, until purse seining techniques are perfected for use in tropical waters the live-bait pole-and-line method will continue to be the dominant technology in all but the eastern Pacific skipjack fishery.

TRENDS OF SELECTED INDICATORS

Catch Levels

An examination of the catch statistics in the Hawaiian skipjack tuna fishery over a 24-year period revealed a rather high degree of variability from year to year (Figure 1). An attempt was made to derive



Note: Information obtained directly from the official records of the Division of Fish and Game, Department of Land and Natural Resources, State of Hawaii

Figure 1. Annual catch and value in the Hawaiian skipjack tuna fishery: 1949-72

a trend in the overall catch of the fishery[1] over the period 1956-72; it failed to show any statistical significance (Table 1). During this period, the annual catch ranged between 6.0 million and 16.3 million pounds with an average of 9.6 million pounds (Table 2).

TABLE 1. ANNUAL RATES OF GROWTH OF SELECTED INDICATORS IN THE HAWAIIAN SKIPJACK TUNA FISHERY

Item	1956-72	1966-72
Total Catch, pounds	.0052*	.0438*
Total Value, dollars	.0123	.1431
Vessels, number	-.0247	-.0342
Trips, number	.0112	-.0178*
Catch per Vessel, pounds	.0435	.0795*
Value per Vessel, dollars	.0890	.1822
Catch per Trip, pounds	.0051*	.0622*
Value per Trip, dollars	.0384	.1634
Trips per Vessel, number	.0487	.0162*
Average Price per Ton, dollars	.0437	.0951
Bait Catch, buckets	.0074*	.0424
Bait Mortality, percentage	.0137	.0098*
Bait Catch per Vessel, buckets	.0448	.0781
Skipjack Catch per Bucket of Bait Used, pounds	.0045*	.0051*
Skipjack Value per Bucket of Bait Used, dollars	.0484	.1008

*Not statistically significant at the 5 percent level

Note: Information obtained directly from the official records of the Division of Fish and Game, Department of Land and Natural Resources, State of Hawaii

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[1] Although there are some species caught together with skipjack, these actually make up only a small fraction of the total catch. For instance, in 1972 out of the total catch in the fishery, skipjack tuna accounted for approximately 99 percent while also accounting for slightly over 98 percent of the total value (Table 2).

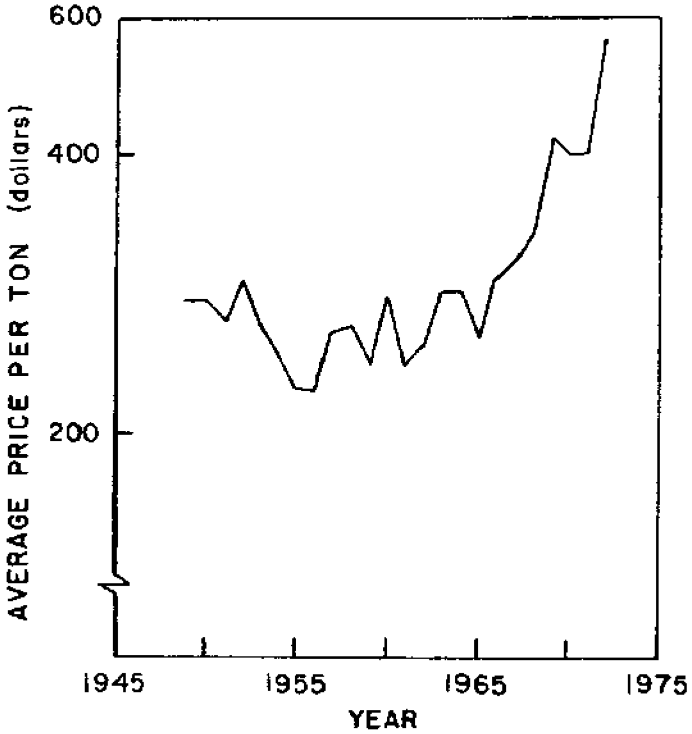
TABLE 2. HAWAIIAN SKIPJACK TUNA FISHERY DATA: 1949-72

Year	Total Catch (Thousand pounds)	Total Value (Thousand dollars)	Number of Trips	Number of Vessels	Total Catch Price Per Ton ($)	Total Catch Per Vessel (Thousand pounds)	Total Value Per Vessel (Thousand dollars)
1949	10,010	1,397	NA	26	280	385.0	53.7
1950	9.528	1,348	NA	27	284	352.9	49.9
1951	12,980	1,740	NA	28	268	463.6	62.1
1952	7.305	1,076	NA	28	294	260.9	38.4
1953	12,210	1,622	NA	27	266	452.2	60.1
1954	14,160	1,787	NA	27	252	524.5	66.2
1955	9,644	1,121	NA	28	232	344.4	40.0
1956	11.254	1,281	1,926	26	228	432.8	49.3
1957	6,341	825	1,656	25	260	253.6	33.0
1958	7,013	925	1,617	24	264	292.2	38.5
1959	12.514	1,495	1,871	21	238	595.9	71.2
1960	7.379	1,008	1.559	21	274	351.4	48.0
1961	10,976	1,323	1,792	21	240	522.6	63.0
1962	9.539	1.195	1,696	20	250	476.9	59.8
1963	8.245	1,117	1,742	20	272	412.3	55.9
1964	9.192	1,250	2,078	20	272	459.6	62.5
1965	16.295	2,042	2,288	19	250	857.6	107.5
1966	9.448	1,418	2,103	17	300	555.8	83.4
1967	8,174	1.283	2,050	18	314	454.1	71.3
1968	9.422	1,562	2,211	16	33.	588.9	97.6
1969	6,041	1,248	1,788	15	414	402.7	83.2
1970	7,380	1.511	1,914	15	410	492.0	100.7
1971	13.361	2,762	2,035	14	414	954.4	197.3
1972	11,018	2,996	1,881	15	544	734.5	199.8

Year	Catch Per Trip (Pounds)	Value Per Trip ($)	Trips Per Vessel	Skipjack Catch (Thousand pounds)	Skipjack Value (Thousand dollars)	Skipjack Price Per Ton ($)	Skipjack Catch Per Vessel (Thousand pounds)	Skipjack Value Per Vessel (Thousand dollars)
1949	NA	NA	NA	9,859	1,344	273	379.192	51.692
1950	NA	NA	NA	9,506	1,341	282	352.074	49.667
1951	NA	NA	NA	12,926	1,728	267	461.643	61.714
1952	NA	NA	NA	7,292	1,064	292	260.428	38.000
1953	NA	NA	NA	12,059	1,594	264	446.630	59.037
1954	NA	NA	NA	13,907	1,761	253	515.074	65.222
1955	NA	NA	NA	9,672	1,111	230	345.428	39.678
1956	5,843	665	74	10,920	1,227	225	420.000	47.192
1957	3,829	498	66	6.160	795	258	246.400	31.800
1958	4,337	572	67	6,781	880	260	282.546	36.667
1959	6,688	799	89	12,126	1,433	236	577.428	68.238
1960	4,733	646	74	7.178	964	269	341.810	45.905
1961	6,125	738	85	10,642	1,274	239	506.762	60.667
1962	5.624	704	84	9,188	1,136	247	459.400	56.800
1963	4.733	641	87	7.932	1,064	268	396.600	53.200
1964	4,423	602	104	9,031	1,219	270	451.550	60.950
1965	7,122	892	120	16,098	2,015	250	847.263	106.053
1966	4,492	674	124	9.357	1,398	299	550.412	82.235
1967	3,987	626	114	8,017	1,256	313	445.389	69.778
1968	4,261	706	138	9.264	1,525	329	579.000	95.312
1969	3.378	698	119	5,906	1,211	410	393.733	80.733
1970	3.856	789	128	7,307	1,487	407	487.133	99.000
1971	6,566	1,357	145	13,278	2,738	417	948.478	195.574
1972	5,858	1,592	125	10,896	2.943	540	726.400	196.200

Note: Information obtained directly from the official records of the Division of Fish and Game, Department of Land and Natural Resources, State of Hawaii

The value of the catch over the 24-year period had the same high degree of variability (Figure 1). This is reflected in the fact that the price per ton ranged from a low of $228 in 1956 to a high of $544 in 1972 (Table 2). The trend in the value of the catch over the period 1956-72 indicates that the value rose at a 1.2 percent compounded annual rate of growth, while during the more recent period, 1966-72, it rose at a 14.3 percent annual rate of growth. Both are statistically significant at the 5 percent level (Table 1). During these same periods, the price per ton of skipjack rose at 4.4 percent and 9.5 percent annual rates of growth, respectively. The sharp rise in the price of landed skipjack has been most pronounced since 1965 (Figure 2). In prior years the price fluctuated between a rather narrow range. Since 1965, the price per ton has more than doubled, causing a sharp rise in the ex-vessel value of landed skipjack tuna (Figure 1).

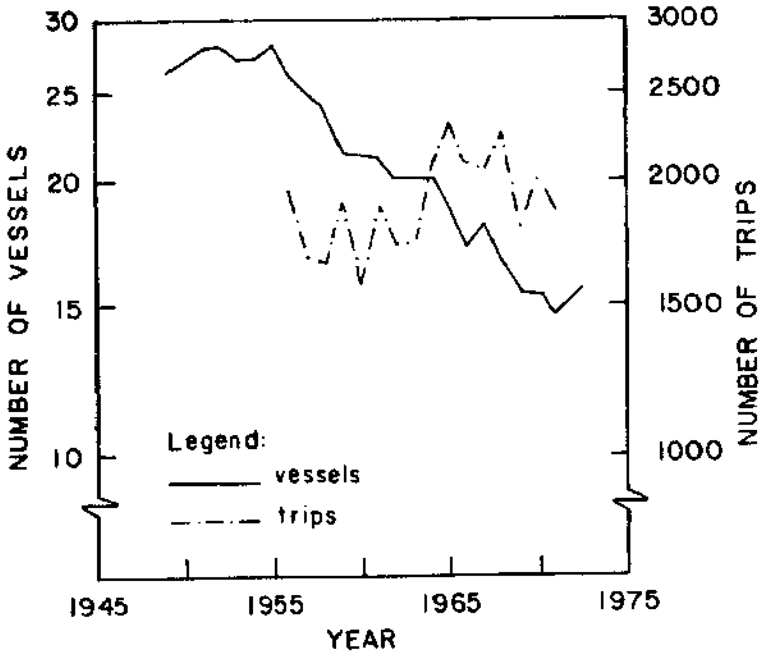


Note: Information obtained directly from the official records of the Division of Fish and Game, Department of Land and Natural Resources, State of Hawaii

Figure 2. Annual average price per ton of skipjack in the Hawaiian tuna fishery: 1949-72

Fishing Vessels

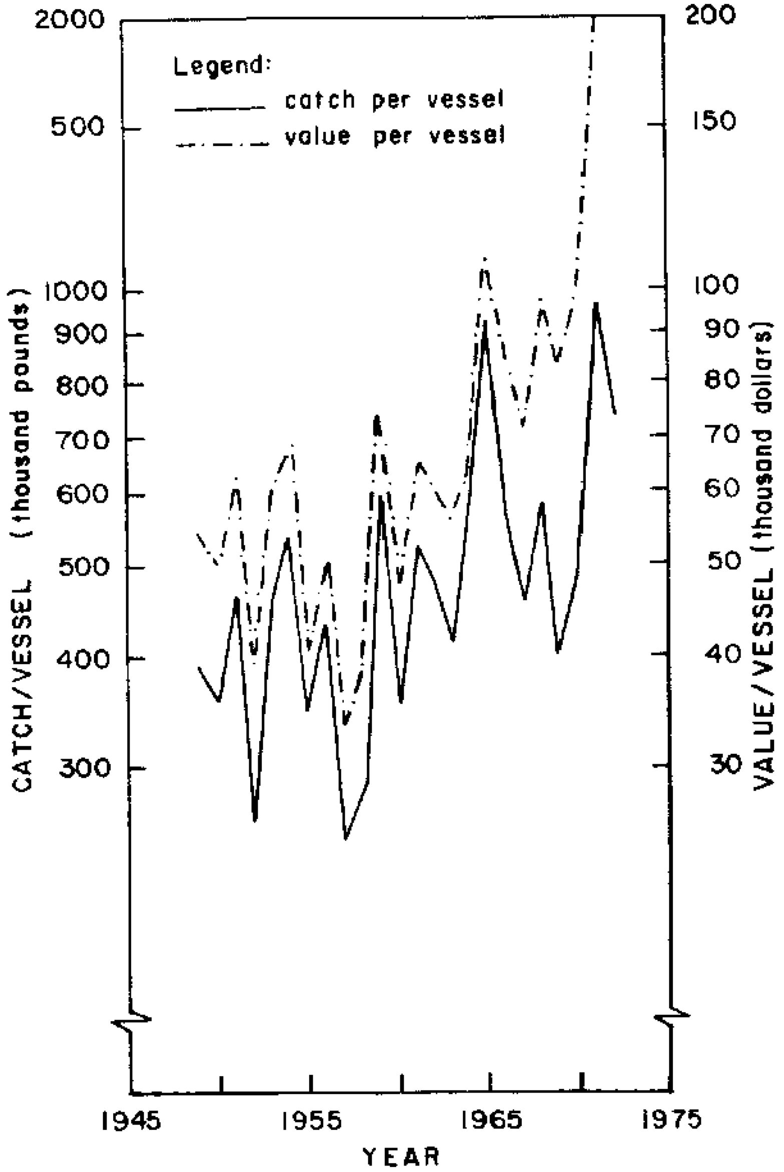
The trend in the number of full-time skipjack tuna fishing vessels has been steadily downward (Figure 3). From a high of 28 vessels in the early 1950s, the number has steadily declined to a point where the present fleet size is about one-half that number (Table 2). The compounded annual rate of decline over the period 1956-72 has been approximately 2.5 percent, with a slightly faster rate of decline of 3.4 percent in the more recent period, 1966-72. Both rates are statistically significant at the 5 percent level (Table 1).



Note: Information obtained directly from the official records of the Division of Fish and Game, Department of Land and Natural Resources, State of Hawaii

Figure 3. Annual fishing vessels and trips in the Hawaiian skipjack tuna fishery: 1949-72

The average catch per vessel has shifted upward as the number of vessels declined (Figure 4). The compounded annual rate of growth of the catch per vessel over the period 1956-72 was approximately 4.3 percent, which is statistically significant at the 5 percent level (Table 1). Because of the generally rising ex-vessel price of landed skipjack, the upward trend in the value of catch per vessel was even sharper (Figure 4). Over the period 1956-72, the compounded annual rate of growth was 8.9 percent, while during the more recent period, 1966-72, the annual average catch value per vessel increased at a remarkably high rate of 18.2 percent. Both rates are statistically significant at the 5 percent level.



Note: Information obtained directly from the official records of the Division of Fish and Game, Department of Land and Natural Resources, State of Hawaii

Figure 4. Annual catch per vessel and value per vessel in the Hawaiian skipjack tuna fishery: 1949-72

Reflecting both the highly variable catch and declining vessel conditions, the annual catch per vessel ranged from a low of 253.6 thousand pounds in 1957 to a high of 954.4 thousand pounds in 1971. At the same time, the value of the catch per vessel ranged from a low of $33 thousand in 1957 to a high of $199.8 thousand in 1972 (Table 2).

The decline of the number of skipjack tuna vessels has been proportionately greater for those based on the outer islands than on the island of Oahu (Table 3). Ten out of 27 vessels were based on the outer islands in 1954; in 1972 only three out of 15 vessels were based on the outer islands. Thus, the Hawaiian skipjack tuna fishing fleet has become even more reflective of the Oahu skipjack fleet.

TABLE 3. HAWAIIAN SKIPJACK TUNA VESSELS, BY BASE OF OPERATION: 1949-72

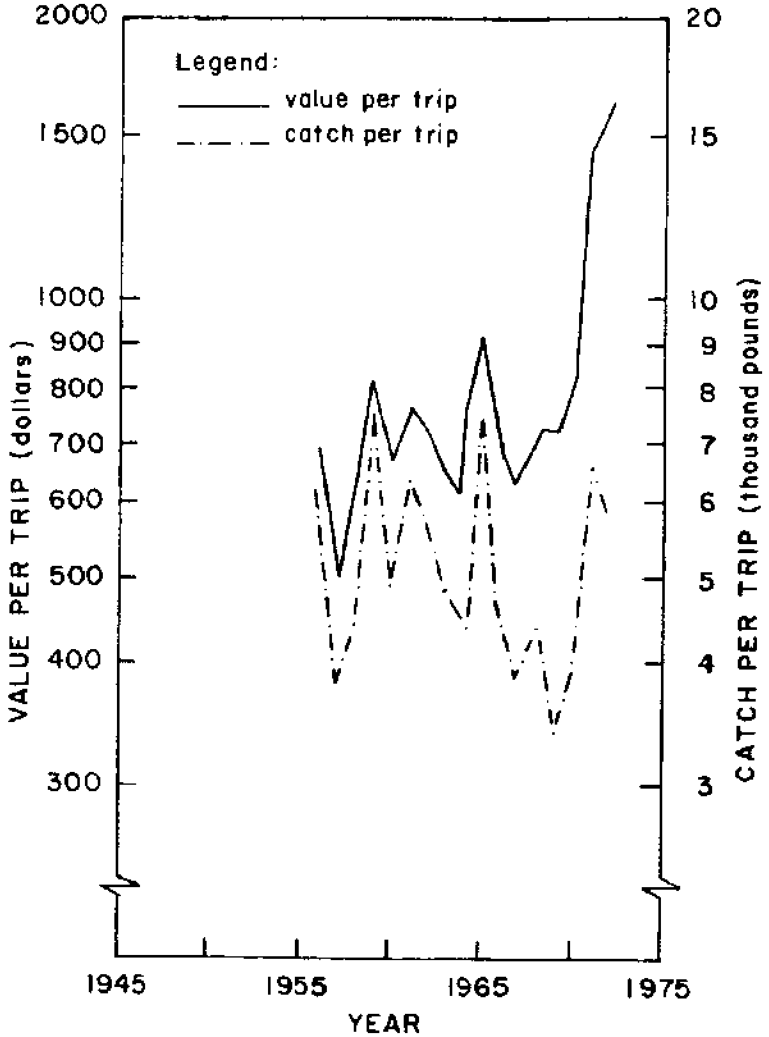
Year	Base of Operation				Total
	Oahu	Maui	Hawaii	Kauai	
1949	19	5	2	0	26
1950	18	5	2	2	27
1951	19	5	2	2	28
1952	19	5	2	2	28
1953	19	5	2	1	27
1954	17	5	3	2	27
1955	21	4	3	0	28
1956	19	5	2	0	26
1957	18	5	2	0	25
1958	16	6	2	0	24
1959	12	7	2	0	21
1960	14	5	2	0	21
1961	14	5	2	0	21
1962	12	5	3	0	20
1963	12	5	3	0	20
1964	12	5	3	0	20
1965	13	3	3	0	19
1966	13	2	2	0	17
1967	14	2	2	0	18
1968	12	2	2	0	16
1969	12	2	1	0	15
1970	12	2	1	0	15
1971	11	2	1	0	14
1972	12	2	1	0	15

Note: Information obtained directly from the official records of the Division of Fish and Game, Department of Land and Natural Resources, State of Hawaii

Fishing Trips

The annual number of fishing trips has shown only a moderate upward trend in the Hawaiian skipjack tuna fishery (Figure 3). The annual compounded rate of growth over the period 1956-72 was a little over 1 percent (Table 1). Since 1965, the trend, if anything, has been downward, although this is not statistically significant. The annual number of fishing trips for the Hawaiian skipjack tuna fleet ranged from a low of 1,559 in 1960 to a high of 2,288 in 1965 (Table 2). Since then, the annual number of fishing trips for the entire fishing fleet appears to converge around 2,000 trips (Figure 3).

The catch per trip for Hawaiian skipjack tuna vessels shows no discernible trend over the period 1956-72 (Figure 5). The compounded annual rate of growth for this period is not statistically significant (Table 1). There is some evidence of an upward trend in the catch per trip over the more recent period 1966-72, but this is not statistically significant. Over the years the catch per trip fluctuated from a low of 3,829 pounds in 1957 to a high of 7,122 pounds in 1965, averaging 5,116 pounds (Table 2).

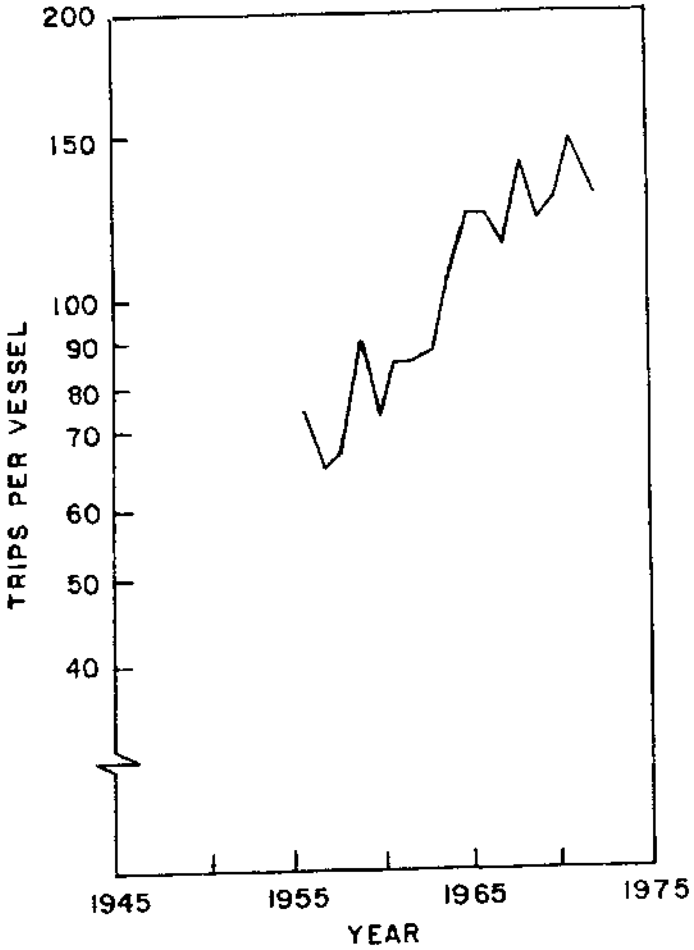


Note: Information obtained directly from the official records of the Division of Fish and Game, Department of Land and Natural Resources, State of Hawaii

Figure 5. Annual value per trip and catch per trip in the Hawaiian skipjack tuna fishery: 1949-72

Again, due to the rising ex-vessel price of skipjack, the catch value per trip has generally shown a rising trend. Over the period 1956-72, the value of the catch per trip rose at a compounded annual rate of 3.8 percent. The trend was much sharper over the period 1966-72, rising at a compounded annual rate of 16.3 percent. These rates are both statistically significant at the 5 percent level. The lowest gross receipts for a trip of skipjack over the period when data are available occurred in 1957 when the catch value averaged $498 per trip. This is contrasted with the $1,592 received for an average trip in 1972.

The average number of trips made per vessel has shown a rather consistent upward trend over the years (Figure 6). From a low of just 66 trips per vessel in 1957, the number of trips per vessel has approximately doubled, reaching a high of 145 trips in 1971 (Table 2). The compounded



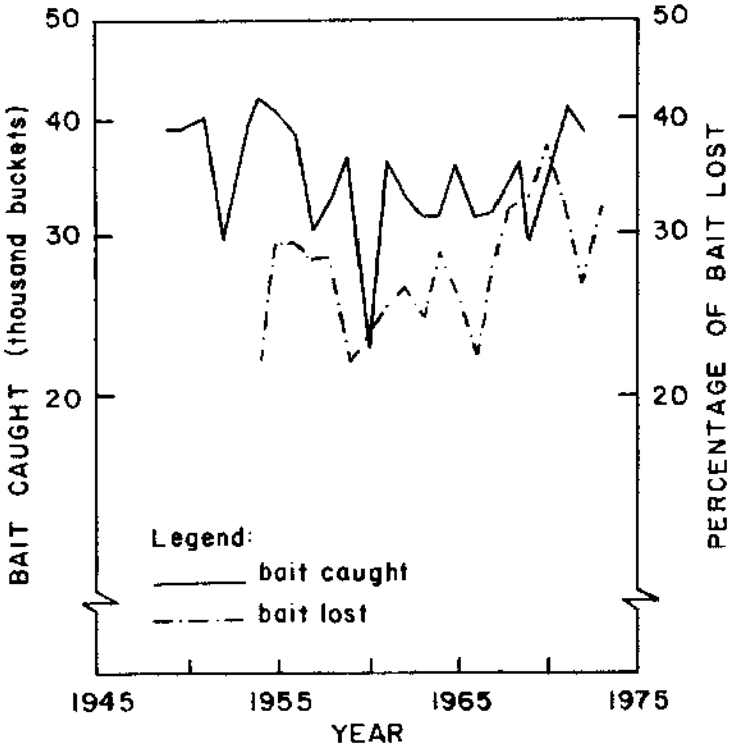
Note: Information obtained directly from the official records of the Division of Fish and Game, Department of Land and Natural Resources, State of Hawaii

Figure 6. Annual trips per vessel in the Hawaiian skipjack tuna fishery: 1956-72

annual rate of growth over the period 1956-72 was 4.9 percent which is statistically significant at the 5 percent level. During 1966-72, however, the rate of growth appears to have slackened (Table 1).

Bait supply

Generally speaking, the observable trends in the Hawaiian skipjack tuna bait fishery tend to reflect the overall trends in the primary production phase of the industry. Over a 24-year period, the annual number of buckets[2] of nehu caught by the Hawaiian tuna fishing fleet showed some degree of variability (Figure 7), although not as sharply as was the case with the skipjack catch (Figure 1). An attempt to derive a trend in the catch of baitfish over the period 1956-72, as with skipjack catch, failed to show any statistical significance (Table 1). During this period, the annual baitfish catch averaged 33.7 thousand buckets,



Note: Information obtained directly from the official records of the Division of Fish and Game, Department of Land and Natural Resources, State of Hawaii

Figure 7. Buckets of bait caught and percentage lost in the Hawaiian skipjack tuna fishery: 1949-72

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[2] The amount of baitfish in a bucket is approximately seven pounds.

ranging between 22.5 thousand and 42.4 thousand buckets (Table 4). During the more recent period, 1966-72, the baitfish catch rose at a 4.2 percent compounded annual rate of growth, which is statistically significant at the 5 percent level. New evidence suggests that this rise was largely due to a switch from night baiting to day baiting (Uchida, 1974).

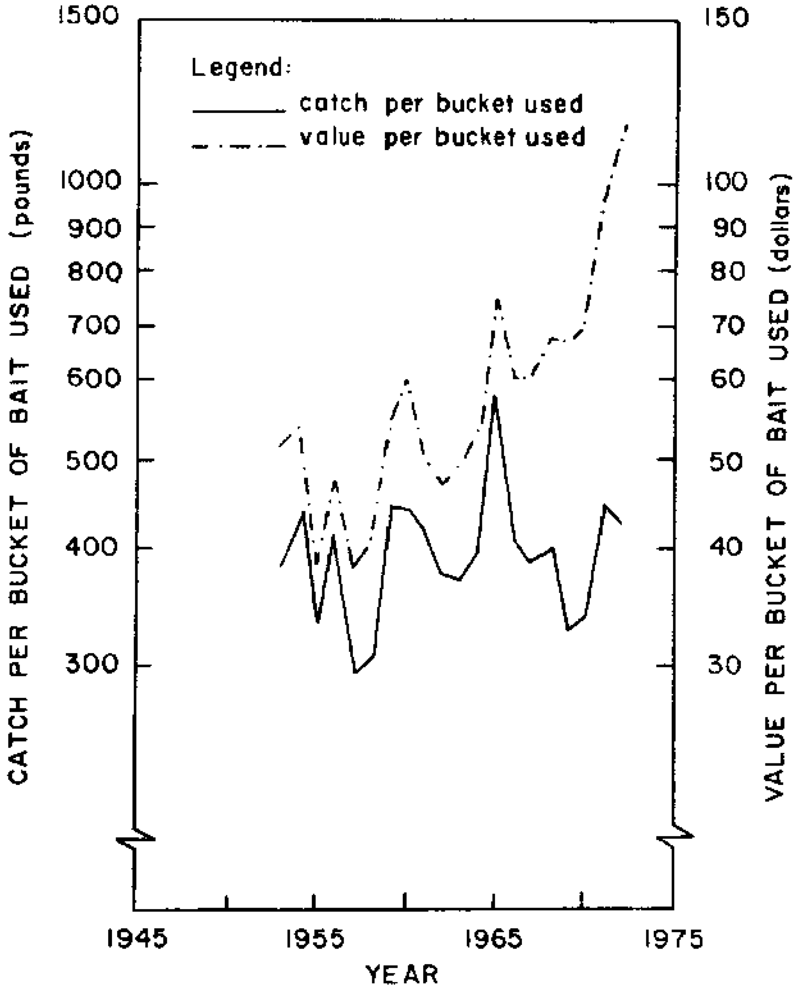
TABLE 4. HAWAIIAN SKIPJACK TUNA BAITFISH DATA: 1949-72

Year	Buckets Caught	Percentage of Buckets Lost	Buckets Caught per Vessel	Total Catch per Bucket Used (pounds)	Catch Value per Bucket Used ($)
1949	39,558	NA	1,521	NA	NA
1950	39,638	NA	1,468	NA	NA
1951	40,491	NA	1,444	NA	NA
1952	29,807	NA	1,065	NA	NA
1953	37,177	14.1	1,377	382	51
1954	42,354	22.1	1,569	429	54
1955	41,144	29.2	1,469	331	38
1956	38,250	29.5	1,471	417	47
1957	30,429	28.1	1,217	290	38
1958	32,782	28.6	1,366	300	40
1959	36,307	21.9	1,728	441	53
1960	22,517	25.0	1,072	437	60
1961	36,298	26.4	1,728	411	50
1962	33,522	24.4	1,676	376	47
1963	31,680	28.7	1,584	365	49
1964	31,677	25.9	1,583	391	53
1965	36,106	22.2	1,900	580	73
1966	31,508	25.8	1,853	404	61
1967	31,720	32.9	1,762	384	60
1968	35,389	32.9	2,212	396	66
1969	29,721	36.6	1,981	321	66
1970	33,451	33.8	2,230	333	68
1971	41,928	26.8	2,994	435	90
1972	39,273	32.1	2,618	413	112

Note: Information obtained directly from the official records of the Division of Fish and Game, Department of Land and Natural Resources, State of Hawaii

Baitfish mortality also tended to be highly variable over the period for which statistics are available (Figure 7), ranging from a low of 14 percent in 1953 to a high of almost 34 percent in 1970 (Table 4). It is difficult to explain the cause of this phenomenon except to note from Figure 7 that there appears to be an inverse relationship between bait caught and bait lost. This suggests that during high production years a high percentage of the bait carried on board is actually used to chum for skipjack tuna, while in low production years much time is spent searching for skipjack schools with the result that a larger percentage of the bait carried on board is left unused. The trend over the period 1956-72 showed a compounded annual growth rate of 1.4 percent; however, during the latter period, 1966-72, baitfish mortality showed no discernible upward trend (Table 1).

The skipjack catch per bucket of bait used appears to reflect the peaks and troughs of the industry itself (Figures 1 and 8). No discernible trend in this series appeared either over the period 1956-72 or in the more recent period 1966-72 (Table 1), again reflecting the similar pattern of the skipjack catch over these time periods.

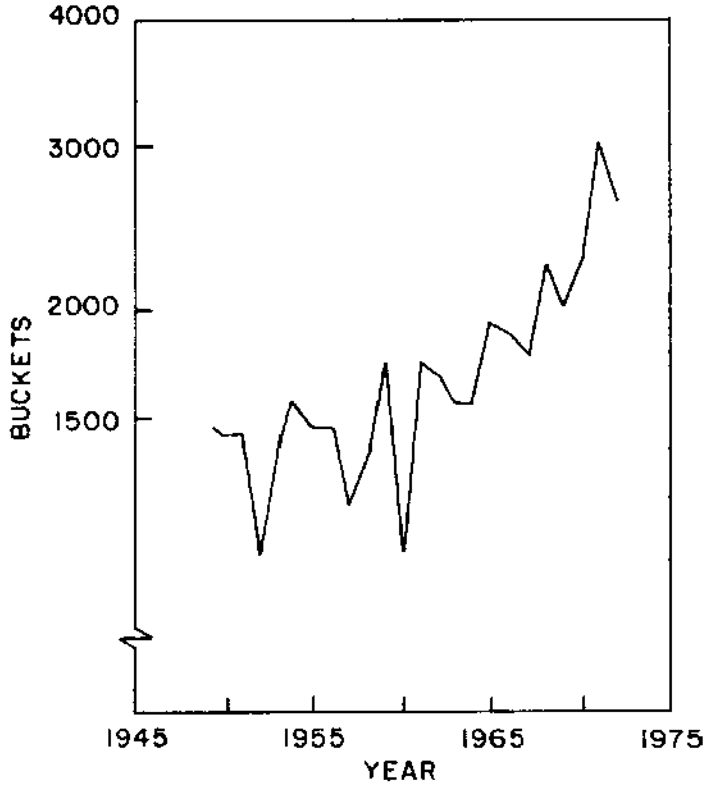


Note: Information obtained directly from the official records of the Division of Fish and Game, Department of Land and Natural Resources, State of Hawaii

Figure 8. Total catch and value of catch per bucket of bait used in the Hawaiian skipjack tuna fishery: 1953-72

Over the 17-year period, the skipjack catch per bucket of bait used averaged 394 pounds, ranging between 290 and 580 pounds (Table 4). The value of the catch per bucket of bait used, on the other hand, showed a significant upward trend, reflecting the rise in the price of skipjack tuna especially since 1965 (Figure 8). The trend in this series was quite significant, rising at a compounded annual rate of growth of 4.8 percent over the period 1956-72 and at a 10.1 percent compounded annual rate since 1965 (Table 1).

The buckets of bait caught per vessel in the Hawaiian skipjack tuna fishery showed a clearly discernible upward trend (Figure 9). Over the period 1956-72, the compounded annual rate of increase was 4.5 percent and during the period 1966-72 the annual increase was at a compounded rate of 7.8 percent (Table 1). These rates conform quite closely to the corresponding rates for skipjack catch per vessel, suggesting that in order for the skipjack catch to rise by some annual rate, the rate of baitfish catch will have to increase correspondingly.



Note: Information obtained directly from the official records of the Division of Fish and Game, Department of Land and Natural Resources, State of Hawaii

Figure 9. Buckets of bait caught per vessel in the Hawaiian skipjack tuna fishery: 1949-72

PRODUCTION-FUNCTION ANALYSIS

The use of production functions in fisheries economics research has been scarce in contrast with their wide use in agricultural economics research (Bell, 1967; Comitini and Huang, 1967; Carlson, 1970). Perhaps the main reason is that the underlying production data, which relate catches to some measure of effort expended (in terms of labor and capital) for individual vessels, are somewhat difficult to obtain. Normally, state fishery agencies require fishing vessel owners to report only catches landed and days fished, but is this information adequate for analyzing production relationships, or is knowledge of the number of fishermen on board and the size, or carrying capacity, of vessels also required? One way of testing this is to use both the foregoing type of data and also a set of data which includes days fished as well as estimates of labor and capital inputs in constructing a production function.

Since 1966, the State Division of Fish and Game has required fishing vessels in the skipjack tuna fishery to report catches landed, number of men aboard, and number of fishing trips[3] made in each year. Information has been obtained from the Southwest Fisheries Center of the National Marine Fisheries Service on the gross tonnages of each of the vessels in this fishery and also on the estimates of their capital values at a single point in time (Table 5). From these data production functions can be constructed relating catches to some measure of labor and capital inputs using alternative estimates of effort as a composite of labor and capital. The period covered by this data includes the years 1966-72. In order to compare their functional usefulnesses, alternative equations are used in an attempt (1) to estimate annual skipjack catches; (2) to construct vessel rankings as a measure of performance; and (3) to estimate the relative contribution of labor and capital in the production process.

Data Used for Estimation

Annual catches and fishing trips for each vessel in the Hawaiian skipjack tuna fishing fleet were compiled from records provided by the Southwest Fisheries Center (Honolulu Laboratory) of the National Marine Fisheries Service. In addition, the average number of men aboard each vessel were calculated from the same data source. In constructing the production function, two estimates of capital input were used. One was simply the gross tonnage of each vessel as a proxy for capital. There is precedence for the use of this variable as a measure of capital input in other production-function studies (Bell, 1967). The other estimate of capital made use of an annually depreciated value for each vessel by using the equation:

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[3] Days fished is the equivalent of number of trips made by each vessel in this fishery since, normally, a trip lasts one day.

$$K_n = K_g \cdot e^{-rt},$$

where K_n = net value of capital in each year; K_g = value of capital in year zero; r = rate of depreciation, and t = time, e.g., $t = 0, 1, 2, \ldots, 12$.[4]

TABLE 5. HAWAIIAN SKIPJACK TUNA VESSELS USED IN PRODUCTION-FUNCTION ANALYSIS

Vessel	Year Built	Gross Weight (Short tons)	Net Weight (Short tons)	Length (ft)	Baitwell Size (gal)	Estimated Value 1962 (x $1,000)
Angel	1955	56	36	74	1,004	70
Bonito*	1940	37	19	68	580	35
Buccaneer	1947	68	40	69	1,232	65
Corsair	1949	51	34	65	1,000	70
Electa	1938	47	23	72	854	50
Kilohana	1947	47	32	72	891	62
Kulakai	1947	77	52	80	1,297	70
Lehua	1947	45	31	73	1,127	50
Makanani*	1928	29	13	66	575	15
Marlin	1935	44	18	70	670	60
Neptune	1938	46	20	72	839	65
Orion	1946	52	23	77	1,064	55
Sailfish*	1931	51	35	74	1,135	30
Sea Queen	1950	46	27	72	845	38
Skipjack*	1928	39	19	72	785	22
Sunfish	1926	32	15	70	664	17
Tradewind	1950	54	34	73	873	50
Yellowfin	1928	33	17	59	576	22

*No longer fishing as of 1972.

Note: Information obtained directly from the official records of the National Marine Fisheries Service, Honolulu and the U.S. Coast Guard, Honolulu.

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[4] The relationship, $\alpha = e^{-\gamma n}$, was used to estimate r, where α = salvage fraction after n years, γ = writing-off exponent, and n = average lifespan. Converted to log form, results in $\gamma = \frac{\ln\alpha}{n}$ (Frisch, 1965).

To estimate n, the average age of vessels departing from the fleet was calculated and found to be 36.8 years, with a standard deviation of 4.4 years. From this information, subjective judgment was used in deciding the length of life of remaining boats based upon knowledge of the present vessels in the fleet. Generally, prewar-built vessels were given a lifespan of between 41 and 50 years, while postwar-built vessels were assumed to have an average lifespan of 37 years. Estimates of the salvage value remaining at the end of a vessel's useful life was based upon information provided by the Hawaiian Tuna Packers shipyard.

Estimating Procedure

Since the number of vessels in the fleet was relatively small--ranging from 18 down to 14 during 1966-72--it was possible to obtain data on all fishing vessels in each year. In order to have a significant number of observations and thus permit reliable estimates of the parameters, the cross sections and time series were pooled into one large sample.[5] To some extent, however, the information was incomplete due to the fact that some vessels habitually neglect to report data on men aboard. Thus, over the time period under study, the sample consisted of 72 observations when both labor and capital are used as inputs to the production process (Method I) and 110 observations when the number of trips (days fished) is used as a proxy for effort (Method II). A comparison of the number of observations included in Method I and Method II is shown in Table 6. In effect Method II includes all observations in the statistical population, while Method I includes a relatively high percentage of the total observations. Thus, this gives a high degree of confidence to the representativeness and reliability of the parameter estimates.

Method I

To express the functional relationships between variables, alternative forms of the production function were used. First, annual skipjack catch as simply a function of labor and capital inputs was specified:

$$C = f_1 (L, K), \tag{1}$$

where C is skipjack catch, L is the number of fishermen aboard each vessel, and K is the measure of capital input. However, it is apparent that annual catches are significantly affected by the number of fishing trips made by each vessel each year. Thus, to neutralize this effect, all variables were converted to a per trip basis:

$$C/T = f_2 (L/T, K/T), \tag{2}$$

where T is the number of fishing trips made by each vessel each year. For the production-function model, the familiar Cobb-Douglas form was used:

$$C/T = A(L/T)^{\alpha} (K/T)^{\beta}, \tag{3}$$

where A is the constant term and α and β are the parameters to be estimated.

In order to estimate the values of these parameters, equation (3) was converted into linear form through logarithmic transformation:

$$\ln C/T = \ln A + \alpha \ln L/T + \beta \ln K/T. \tag{4}$$

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[5] The assumption made is that the input coefficients do not vary over time and between cross sections.

TABLE 6. HAWAIIAN SKIPJACK TUNA PRODUCTION-FUNCTION DATA: 1966-72

Year	Vessels		Trips		Total Catch (x 1,000 lb.)		Total Value (x $1,000)	
	Method I	Method II	Method I	Method II	Method I	Method II	Method I	Method II
1966	8	17	1,190	2,103	5,877	9,448	906	1,418
1967	11	18	1,481	2,050	5,888	8,174	954	1,283
1968	11	16	1,616	2,211	7,082	9,422	1,142	1,562
1969	9	15	1,141	1,788	3,429	6,041	711	1,248
1970	12	15	1,842	1,914	7,018	7,380	1,463	1,511
1971	11	14	1,563	2,035	10,928	13,361	2,286	2,762
1972	10	15	1,142	1,881	6,124	11,018	1,795	2,996
Total	72	110	9,975	13,982	46,346	64,844	9,257	12,780
Percentage of Method I/ Method II	.655		.713		.715		.724	

Note: Information obtained directly from the official records of the National Marine Fisheries Service, Honolulu and the Division of Fish and Game, Department of Land and Natural Resources, State of Hawaii

Using the least squares regression procedure, the results of the estimates are as follows:[6]

$$\ln C/T = 5.471 + \underset{(4.870)}{1.039} \ln L/T + \underset{(2.429)}{0.154} \ln K/T; \tag{5}$$

$$R^2 = .346;\ F = 18.291$$

The figures in parentheses represent t-values; thus, both coefficients are significant at the 5 percent level. The F-test shows the entire relation to be significant at the 1 percent level.

It is interesting that the sum of the coefficients of labor and capital, being greater than one, implies increasing returns to scale. For example, a 10 percent increase in both labor and capital inputs would result in more than a 10 percent increase in skipjack catch. The elasticity of production of capital is also relatively low compared with that of labor, in fact, judging from the respective values of the coefficients, only 15 percent that of labor. If, however, changes in catches could have occurred not only due to labor and capital inputs, but also because of possible technological changes in the Hawaiian skipjack fishery over time, then these estimates of productivity would tend to be biased. Thus, in order to estimate the possible effects of technological change on catches in the industry a time trend variable, t, is included in the production function:

$$C/T = f_3\ (L/T,\ K/T,\ t). \tag{6}$$

In Cobb-Douglas form, the expression is:

$$C/T = A(L/T)^{\alpha}\ (K/T)^{\beta}\ e^{\gamma t}, \tag{7}$$

where t is specified as exponential to the base e and γ is the additional parameter to be estimated. The logarithmic transformation is then shown as:

$$\ln C/T = \ln A + \alpha \ln L/T + \beta \ln K/T + \gamma t, \tag{8}$$

where $t = 1, 2, \ldots, 7$. Estimating the coefficients using least squares regression results in the following:

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[6] Capital was measured in two ways: (a) as the gross tonnage of each vessel and (b) as the annually depreciated capital value of each vessel. Using the former measure, the estimates were as follows:

$$\ln C/T = 5.261 + \underset{(4.671)}{1.071} \ln L/T + \underset{(1.052)}{0.130} \ln K/T;$$

$$R^2 = .302;\ F = 14.913.$$

Since the coefficient of capital is insignificant, using gross tonnage as a proxy for capital input is an inferior measure to using depreciated capital value as shown in equation (5). Therefore, capital value, annually depreciated is used as the measure of capital input in all subsequent equations.

$$\ln C/T = 5.441 + \underset{(4.256)}{0.939} \ln L/T + \underset{(2.759)}{0.178} \ln K/T + \underset{(1.579)}{0.032}\, t; \tag{9}$$

$$R^2 = .370;\ F = 13.289.$$

The R^2 of equation (9) does not increase significantly over that of equation (5), suggesting that the addition of the time trend variable does not reduce the unexplained variation in catch per trip significantly. Furthermore, the coefficient of the time trend variable does not appear to be significantly different from zero, based on a t-test at a 5 percent level of significance. This is not surprising since there was no discernible technological improvements in the Hawaiian skipjack tuna fishery over the period 1966-72, either in fishing technique or new vessel construction.[7] Most of the vessels are of pre-World War II vintage, the oldest being 46 years and the average age being 29 years in 1972. The time trend variable was therefore dropped as an independent explanatory variable of skipjack catches over time.

An alternative form used for the production function replaces the time trend variable with a "dummy" variable, Y:

$$C/T = f_4\ (L/T,\ K/T,\ Y), \tag{10}$$

and in Cobb-Douglas form:

$$C/T = A(L/T)^{\alpha}\ (K/T)^{\beta}\ e^{(\delta_1 Y_1 + \delta_2 Y_2 + \ldots + \delta_p Y_p)}, \tag{11}$$

where Y takes on the value of unity for a particular year's observations and zero otherwise and δ is the additional parameter to be estimated, and where there are $(p + 1)$ years. This form was used in an attempt to estimate annual fluctuations in the catch due to non-economic phenomena. It is known, for example, that the availability of the skipjack tuna resource (stock abundance) to the local fishing industry in a particular year is influenced by oceanographic and environmental factors, e.g., water temperature and salinity (Seckel, 1972). An attempt is made to estimate these effects in the production function through the use of the standard dummy variable technique (Rao and Miller, 1971; Suits, 1957). In log transformation, the expression is:

$$\ln C/T = \ln A + \alpha \ln L/T + \beta \ln K/T + \delta_1 Y_1 + \delta_2 Y_2 + \ldots + \delta_p Y_p \tag{12}$$

and the least squares regression estimates of the coefficients are as follows:

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[7] The *Anela*, a vessel of modern design and equipment and substantially greater fishing capacity, began operations in mid-1972 and was not included in the sample.

$$\ln C/T = 6.393 + \underset{(2.299)}{0.451} \ln L/T + \underset{(4.427)}{0.235} \ln K/T - \underset{(1.389)}{0.167} Y_1 - \underset{(0.639)}{0.077} Y_2$$

$$- \underset{(3.333)}{0.423} Y_3 - \underset{(1.609)}{0.191} Y_4 + \underset{(2.988)}{0.375} Y_5 + \underset{(0.461)}{0.058} Y_6; \qquad (13)$$

$$R^2 = .616; \; F = 12.613.$$

This form represents a substantial improvement over equation (5) in that included in equation (13), as partial determinants of catch per trip, are estimates of natural fluctuations in skipjack availability to the Hawaiian fishery each year. The two of significance are the exceptionally poor year of 1969 (Y_3) and the exceptionally good year of 1971 (Y_5). Moreover, the production elasticity of capital, once these factors are taken into account, increases to 52 percent that of labor, suggesting that the coefficients were extremely biased in the case of equation (5).

It is also known that there are differences in the productive capability between vessels which were not entirely reflected by the input measures. These include vessel reconstruction, new engine installation, fishing equipment, and other characteristics which were not taken into account in the capital input measure due to lack of information. Also, there are differences in the quality of the fishing units themselves which cannot be quantified, e.g., entrepreneurial ability and fishing strategy (Uchida, 1970). In an attempt to estimate these vessel differences, a dummy variable, V, was included in the production function:

$$C/T = f_5 \; (L/T, \; K/T, \; Y, \; V), \qquad (14)$$

and in Cobb-Douglas form:

$$C/T = A(L/T)^{\alpha} \; (K/T)^{\beta} \; e^{[(\delta_1 Y_1 + \delta_2 Y_2 + \ldots + \delta_p Y_p) + (\lambda_1 V_1 + \lambda_2 V_2 + \ldots + \lambda_s V_s)]} \qquad (15)$$

where V takes on the value of unity for a particular vessel's observations and zero otherwise and λ is the additional parameter to be estimated, and where there are (s + 1) vessels. In this final form of the production function, log transformation is expressed as:

$$\ln C/T = \ln A + \alpha \ln L/T + \beta \; K/T + \delta_1 Y_1 + \delta_2 Y_2 + \ldots + \delta_p Y_p$$

$$+ \lambda_1 V_1 + \lambda_2 V_2 + \ldots + \lambda_s V_s, \qquad (16)$$

and the least squares regression coefficients are as follows:

$$\begin{aligned} \ln C/T = 6.288 &+ \underset{(2.070)}{0.421} \ln L/T + \underset{(1.215)}{0.219} \ln K/T - \underset{(1.608)}{0.153} Y_1 - \underset{(0.878)}{0.090} Y_2 \\ &- \underset{(3.220)}{0.340} Y_3 - \underset{(1.186)}{0.156} Y_4 + \underset{(2.718)}{0.428} Y_5 + \underset{(0.810)}{0.116} Y_6 + \underset{(0.449)}{0.052} V_1 \\ &+ \underset{(1.548)}{0.346} V_2 + \underset{(3.751)}{0.425} V_3 + \underset{(1.936)}{0.275} V_4 + \underset{(1.633)}{0.247} V_5 + \underset{(2.664)}{0.383} V_6 \\ &+ \underset{(0.328)}{0.074} V_7 + \underset{(1.889)}{0.210} V_8 + \underset{(2.176)}{0.537} V_9 + \underset{(0.173)}{0.063} V_{10} + \underset{(2.572)}{0.422} V_{11} \\ &+ \underset{(1.683)}{0.209} V_{12} - \underset{(1.032)}{0.188} V_{13}; \qquad (17) \end{aligned}$$

$$R^2 = .820; \; F = 10.855.$$

Although this form of the production equation improves the explanation of the variation in catch per trip, as evidenced by the higher value of R^2, the coefficient of the measure of capital input is insignificant. This is due to the incorporation of vessel dummies into the equation which now encompasses most, if not all, of the differences in vessel characteristics. In view of this finding, the capital input variable was dropped and the production relation was estimated using the labor input variable and the respective year and vessel dummies. Thus:

$$C/T = f_6 \; (L/T, Y, V). \qquad (18)$$

In Cobb-Douglas form, the expression is:

$$C/T = A(L/T)^{\alpha} \, e^{[(\delta_1 Y_1 + \delta_2 Y_2 + \ldots + \delta_p Y_p) + (\lambda_1 V_1 + \lambda_2 V_2 + \ldots + \lambda_s V_s)]} \qquad (19)$$

and in log transformation:

$$\begin{aligned} \ln C/T = \ln A + \alpha \ln L/T &+ \delta_1 Y_1 + \delta_2 Y_2 + \ldots + \delta_p Y_p \\ &+ \lambda_1 V_1 + \lambda_2 V_2 + \ldots + \lambda_s V_s, \qquad (20) \end{aligned}$$

where V is now the proxy for capital input. The results are as follows:

$$\begin{aligned}\ln C/T = 7.170 &+ \underset{(2.740)}{0.516} \ln L/T - \underset{(1.650)}{0.157}\, Y_1 - \underset{(1.500)}{0.141}\, Y_2 - \underset{(3.715)}{0.378}\, Y_3 - \underset{(2.784)}{0.266}\, Y_4 \\ &+ \underset{(2.781)}{0.281}\, Y_5 - \underset{(0.063)}{0.006}\, Y_6 + \underset{(0.308)}{0.035}\, V_1 + \underset{(1.585)}{0.355}\, V_2 + \underset{(4.060)}{0.452}\, V_3 \\ &+ \underset{(1.502)}{0.162}\, V_4 + \underset{(2.996)}{0.360}\, V_5 + \underset{(3.593)}{0.463}\, V_6 - \underset{(1.560)}{0.167}\, V_7 + \underset{(1.884)}{0.211}\, V_8 \\ &+ \underset{(2.061)}{0.290}\, V_9 - \underset{(1.278)}{0.288}\, V_{10} + \underset{(5.038)}{0.567}\, V_{11} + \underset{(2.696)}{0.287}\, V_{12} \\ &- \underset{(0.229)}{0.029}\, V_{13};\end{aligned} \tag{21}$$

$$R^2 = .815;\ F = 11.219.$$

This form of the estimating equation is comparable with the preceding equation in terms of explaining the variation in catches per trip between vessels and clearly indicates that it is not necessary to include a specific measure of capital input, or that the measure dropped did not improve the fit significantly.

Method II

An alternative for analyzing production relationships in the Hawaiian skipjack tuna fishery is to use fishing trips (days fished) as a proxy for a composite measure of fishing effort in explaining variations in catches. Simply:

$$C = g_1\ (T), \tag{22}$$

where, as before, C is skipjack catch and T is the number of fishing trips. In this case, the Cobb-Douglas form of the production function is non-applicable and a simple linear form is used. Further, since labor input (size of crews) is now omitted as a specific variable in the production function, the number of observations in the sample increases from 72 to 110. The estimating form of the equation is simply:

$$C = bT, \tag{23}$$

where b is the parameter to be estimated. Using this form, the estimated results are as follows:

$$C = 17.2529 + \underset{(8.5557)}{4.6522}\, T;\ R^2 = .406;\ F = 73.199. \tag{24}$$

It is not unexpected that the number of fishing trips made, or fishing days, is the strongest factor in explaining variations in catches among vessels and would serve as a good proxy for effort expended in this fishery. However, as shown by the value of R^2, this still accounts for approximately 41 percent of the variation in catches.

By specifying catch as a function of the number of fishing trips and annual abundance of the skipjack stocks (as well as other annual effects), a dummy variable, Y, is added for the year effect. Thus:

$$C = g_2\ (T,\ Y). \tag{25}$$

The estimating equation then becomes:

$$C = bT + c_1Y_1 + c_2Y_2 + \ldots + c_pY_p, \tag{26}$$

and the regression estimates are as follows:

$$\begin{aligned} C = 13.6265 &+ \underset{(9.1330)}{4.4005\ T} - \underset{(0.7796)}{54.8194\ Y_1} - \underset{(0.5688)}{41.3734\ Y_2} - \underset{(2.1649)}{159.2357\ Y_3} \\ &- \underset{(1.3440)}{99.3372\ Y_4} + \underset{(3.8803)}{293.9392\ Y_5} + \underset{(1.4571)}{109.3534\ Y_6}; \end{aligned} \tag{27}$$

$$R^2 = .592;\ F = 20.888.$$

As indicated by the higher R^2, the estimates of equation (27) improve on those of equation (24) by measuring the effect of fishing trips on catches of the fleet while neutralizing the effect of fluctuations in the annual abundance of skipjack stocks. Thus, an additional fishing trip could be expected to return approximately two metric tons of skipjack over the time period under consideration without any exogenous disturbances due to changes in the fishing environment. In this respect, the coefficient of fishing trips represents the real marginal physical product of fishing effort as a composite of capital and labor in this particular fishery.

A dummy variable, V, was added to the functional form in order to sift out, or abstract from, vessel differences in explaining catches as a function of fishing trips. Thus:

$$C = g_3\ (T,\ Y,\ V), \tag{28}$$

and:

$$C = bT + c_1Y_1 + c_2Y_2 + \ldots + c_pY_p + d_1V_1 + d_2V_2 + \ldots + d_sV_s. \tag{29}$$

The results of the estimation using this functional form are as follows:

$$\begin{aligned} C = 201.9216 &+ \underset{(4.4065)}{2.5546\ T} - \underset{(1.9612)}{92.3518\ Y_1} - \underset{(1.2568)}{61.3843\ Y_2} - \underset{(4.1695)}{209.9120\ Y_3} \\ &- \underset{(2.5188)}{125.5260\ Y_4} + \underset{(5.3679)}{274.3259\ Y_5} + \underset{(0.5824)}{30.8054\ Y_6} - \underset{(1.2582)}{158.4976\ V_1} \\ &- \underset{(0.5999)}{44.0798\ V_2} + \underset{(0.0638)}{5.0869\ V_3} + \underset{(1.0219)}{77.4317\ V_4} + \underset{(5.4798)}{454.0696\ V_5} \\ &- \underset{(0.2442)}{20.1682\ V_6} + \underset{(0.1849)}{13.8648\ V_7} + \underset{(2.8364)}{213.4356\ V_8} + \underset{(2.0798)}{154.6809\ V_9} \\ &- \underset{(1.2863)}{94.9696\ V_{10}} + \underset{(1.2118)}{91.8184\ V_{11}} + \underset{(0.2064)}{21.4697\ V_{12}} - \underset{(1.1885)}{91.4526\ V_{13}} \\ &- \underset{(1.3191)}{150.6390\ V_{14}} + \underset{(6.9995)}{516.0645\ V_{15}} + \underset{(2.1001)}{154.2922\ V_{16}} \\ &- \underset{(0.8521)}{70.1582\ V_{17}}; \end{aligned} \tag{30}$$

$$R^2 = .851;\ F = 20.032.$$

It is clear that these results improve even further on those of the preceding equation in explaining the production relationships involved in the Hawaiian skipjack tuna fishery. The production equation in this form as indicated by R^2 can explain 85 percent of the variation in catches. A comparison of the actual catches of the vessels in the sample fleet and the estimated catches simulated by the production-function model is presented in Table 7. The differences are relatively small, amounting to around 1 percent in most cases, with the largest difference amounting to only 5 percent.

TABLE 7. ACTUAL AND ESTIMATED CATCHES OF SAMPLE FLEET* IN HAWAIIAN SKIPJACK TUNA FISHERY: 1966-72

Year	Actual Catch (x 1,000 lb.)	Estimated Catch (x 1,000 lb.)
1966	9,448	9,336
1967	8,174	8,284
1968	9,422	9,268
1969	6,041	5,979
1970	7,380	7,753
1971	13,361	13,226
1972	9,969	9,774

*Includes only the skipjack vessels in the sample

Source of actual catch data obtained from the official records of the Division of Fish and Game, Department of Land and Natural Resources, State of Hawaii. Estimated catch data obtained from use of regression equation (30)

Not only can this functional relationship be used to estimate catches of the entire sample fleet, but, with the information provided by this method, each vessel can be ranked according to its overall fishing performance taking into account not only the size of the vessel but other quantitative and qualitative factors affecting vessel catches. This is shown in Table 8, where vessels have been ranked in descending order according to a constructed "index of fishing effectiveness." It shows, for example, the relative fishing capability of each vessel while holding fishing trips and fish stock abundance constant. Indicating the wide dispersion of fishing effectiveness is the fact that the index of the top-ranking vessel is over 2.5 times that of the bottom-ranking vessel. To test whether these differences are due primarily to differences in size of vessel, a rank correlation between these rankings and the respective rankings of these vessels as reflected by their gross tonnages was performed. The result was a rank correlation coefficient, $r_s = .27$, which shows little, if any, correlation between the two rank orderings. This finding tends to verify the hypothesis that the differences in the coefficients of the vessel dummy variables include not only differences in size but, more significantly, entrepreneurial ability and strategy of fishing in Hawaiian waters.

TABLE 8. HAWAIIAN SKIPJACK TUNA VESSELS RANKED BY "INDEX OF FISHING EFFECTIVENESS" AND EXPECTED CATCH

Vessel	Index of Fishing Effectiveness	Expected Catch*		
		1966	1969	1971
A	198	1,042	833	1,317
B	186	980	771	1,255
C	140	740	530	1,014
D	129	681	471	955
E	129	681	471	955
F	117	618	408	893
G	115	604	394	878
H	104	548	338	822
I	103	540	330	815
J	101	531	322	806
K	100	526	316	801
L	96	506	296	781
M	92	482	272	757
N	87	456	246	731
O	83	435	225	709
P	82	431	221	706
Q	71	376	166	650
R	70	368	158	642

*In thousand pounds for each vessel making 127 trips in each year

Note: Estimated catch data obtained from regression equation (30)

Table 8 shows the expected catches of each vessel making 127 fishing trips (the average number of trips for the sample) for each of three years: an average year (1966), a relatively poor year (1969), and a relatively good year (1971). To test whether these rankings correspond to vessel rankings according to actual catches made by these vessels in each year, a rank correlation was again performed resulting in the following rank correlation coefficients for the three respective years: $r_s = .784$; $r_s = .822$; $r_s = .816$. These results are all significant at the 5 percent level and indicate that rankings by expected catches closely correspond to the actual catches in each of the three years. In fact, there would be an even closer correspondence, approaching a value of unity, if all vessels had actually made 127 fishing trips in each of the three years. Instead, some vessels made more and others made less, thus affecting their relative rankings according to catches. Another significance of these results is that they tend to modify results of previous studies which measured effectiveness (or performance) of vessels in the Hawaiian skipjack fishing fleet either by size of vessel and/or area fished (Uchida, 1970) or simply by magnitude of a vessel's annual catch (Ahsan et al., 1972).

Relative Contribution of Labor and Capital in the Productive Process

From the estimating equations, an attempt can be made to determine the relative contribution of labor and capital to the productive process in the Hawaiian skipjack tuna fishery. This requires measuring the marginal productivity of labor and capital, or the incremental output attributed to incremental inputs of each, respectively. Since the final estimating equations (21) and (30) under Method I and Method II, respectively, abstract from the capital input directly, it is only possible to measure the marginal product of labor directly from the coefficient of the labor variable. However, by knowing the relative renumerative shares of labor and capital in the catch of each vessel in the Hawaiian skipjack tuna fishery and first comparing the marginal product of labor with its relative share of the total product, it is possible to infer, by exhausting the product, the relative contribution of capital to the productive process. The results are shown in Table 9.

Under Method I, equation (21), the marginal product of labor is computed by taking the partial derivative of C/T with respect to L/T. Under Method II the marginal product of labor is obtained directly from the coefficient of T in equation (30). It is assumed that after accounting for the effects on catches from changes in stock abundance and vessel productivities through the use of dummy variables, the residual represents the marginal product of labor. The fact that the result is not significantly different from the result as computed under Method I suggests that the coefficient of T in equation (30) does reflect the product of labor. Thus, if the marginal product of T (trips) is given by the coefficient of T in equation (24), then subtracting the marginal product of labor results in the marginal product of capital, as shown alongside Method II in Table 9.

TABLE 9. MARGINAL PRODUCTS AND RELATIVE SHARES OF LABOR AND CAPITAL IN THE HAWAIIAN SKIPJACK TUNA FISHERY

	Marginal Product of Labor (MPL)	Marginal Product of Capital (MPC)
Method I	2.646*	---
Method II	2.555†	2.098§
Relative Shares of Labor and Capital#	2.791	1.861

*Computed by using the formula: marginal product of labor = $\alpha(\overline{C}/\overline{L})$, where α is the coefficient of labor in repression equation (21), $\overline{C}$ is the average annual catch of skipjack per vessel, and $\overline{L}$ is the average number of man-days per vessel. The result is multiplied by nine, the average number of men aboard per vessel-trip, to obtain the marginal product of labor per trip.

†See regression equation (30).

§Computed by subtracting the marginal product of labor (2.555) in equation (30) from the marginal product of trips or effort (4.652) in equation (24).

#Computed by taking 60 percent and 40 percent, respectively of the marginal product of trips (4.652) in equation (24).

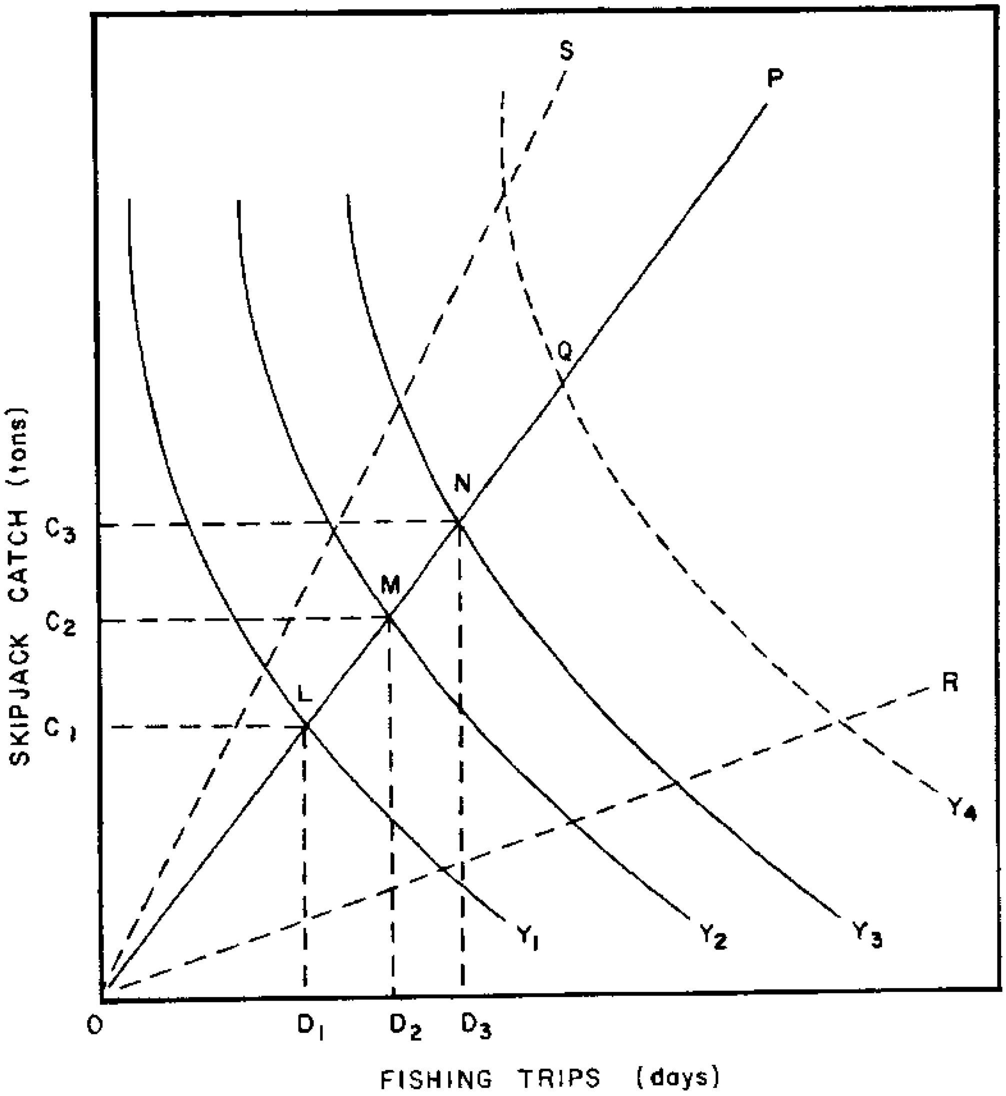
Note: See regression equations (21), (24), and (30).
The information provided in this table was derived from the estimating equation.

A comparison can now be made of the marginal productivities of labor and capital with their respective shares of the total product (catch) as given by the conventional 60:40 split in the Hawaiian skipjack fishery (i.e., 60 percent of the catch goes to labor while capital receives 40 percent). The results are in Table 9. By applying the standard t-test, it is found that the marginal productivities of labor and capital, as computed under Method II, are not significantly different from their respective shares of product as reflected by the conventional 60:40 split of the catch. Thus it can be said that the relative contributions of labor and capital in the productive process conform fairly closely to the respective shares of renumeration in the total product.

ECONOMIC ANALYSIS AND CONCLUSIONS

Options to the Course of Development

The findings and results of the preceding chapters can be summarized in a diagram such as Figure 10. The skipjack tuna catch is shown on the vertical axis. On the horizontal axis, fishing trips (days) as a proxy



Note: Information obtained directly from the official records of the Division of Fish and Game, Department of Land and Natural Resources, State of Hawaii

Figure 10. Catch and effort relationships in the Hawaiian skipjack tuna fishery

for fishing effort is shown. The ray, OP, emanating from the origin expresses the relationship between catch and fishing effort, as given by the production-function equation. The curves, Y_1, Y_2, and Y_3, express different levels of skipjack abundance in the fishery. These will shift to the right for higher levels of abundance and shift to the left for lower levels of abundance. The shape of the curves can be likened to the contours on a map, expressing higher or lower elevations. Thus, moving from left to right, higher catch levels can be attainable at a given level of fishing intensity if skipjack abundance is greater.

At any skipjack population level, say Y_2, given the production function OP, the industry will make OD_2 fishing trips and catch OC_2 tons of skipjack, as indicated by the intersection of Y_2 and OP at M. If in the following year the skipjack stock available to the fishery increases to say Y_3, the industry will adjust to this new situation by increasing the number of trips to OD_3 and catch OC_3 tons of skipjack, as indicated by the intersection of Y_3 and OP at N. However, if the skipjack stock available to the fishery decreases to say Y_1, the industry will adjust by making fewer trips, OD_1, and catching fewer tons, OC_1, as indicated by the intersection of Y_1 and OP at L. Thus, the catch levels of the industry will move along the ray OP, given by the industry production function, by reacting to exogenous changes in the level of skipjack abundance to the industry. In actuality, points L and N, and their respective levels of catch and fishing trips, appear to reflect the situations in 1969 and 1971. In both of these years (Table 1), substantial changes were seen in the catch levels and in the number of fishing trips from the previous year as the level of stock abundance showed significant changes [regression equation (27)].

This analysis supports the view that the instability of the Hawaiian skipjack tuna industry is due to random fluctuations of annual skipjack abundance. Although the number of vessels and fishermen has declined over the years, catch levels have fluctuated within a certain range, e.g., from C_1 to C_3. The industry has shown no further tendencies towards expansion ever since the unique pole-and-line fishing technology was adapted to exploit the available stocks of skipjack in the vicinity of the Hawaiian Islands. Thus, the industry has been moving along the production ray OP. It is unlikely, with the current level of technology, that the industry can reach catch levels much beyond C_3. Nor is it likely that the industry will eventually vanish, as some fear, from the decline in the size of the fleet. Given the random fluctuations in annual stock abundance, it is just as likely that some years will show rising catch levels and fishing trips and other years will show falling catch levels and fishing trips. There appears to be almost unmistakable evidence to this effect in examining the trends of selected indicators in this fishery.

The growth of the industry and catch levels prior to World War II resulted largely from the introduction of a steadily improving technology over the crude outrigger canoe technique of the original Hawaiian fishery (see ray OR in Figure 10). As techniques steadily improved, the production function shifted upwards toward ray OP, giving higher catch rates along a given level of stock abundance. Thus, in order for catch levels to rise, the industry must either continually adopt new fishing techniques, thus giving higher catch levels for any given level of stock abundance, or continue expanding outward along a given production path by increasing the number of fishing trips (days). This is the dilemma facing the Hawaiian skipjack tuna fishing industry. What, then, is a feasible solution to the current stagnation of the industry and the attainment of higher catch levels?

One approach is to shift the production function to ray OS. This would require the adoption of a radically new technique of fishing in Hawaiian waters, i.e., purse seining. Such an innovation would improve on the existing pole-and-line technique by catching greater amounts of fish from any given stock. Thus, the catch rate would be higher at any given level of fishing effort. This is apparently what happened in the eastern Pacific tropical tuna fishery after the conversion from the pole-and-line technique to the purse seining method. But, for reasons already mentioned, adoption of a purse seine technology is not feasible for Hawaiian waters. Thus, interest in this approach to further development of the industry has waned.

Another approach would be to move along the expansion ray OP using the same production technology as at present, i.e., the pole-and-line method. This would entail the ability to expand out to new, higher levels of stock abundance, e.g., Y_4, requiring higher levels of fishing intensity than at present. Such a prospect would be possible only if longer trips to farther offshore waters could be made. However, this would require a more durable baitfish than is presently available and acceptable to the local fishermen. It also would require larger vessels with greater holding capacities and the installation of refrigeration equipment on board. The industry, in this case, could sustain the marginal catch rates by moving along the expansion ray OP to fish stock level Y_4 at Q.

With the attempt to introduce a wholly new fishing technology aborted, the attention of the industry and the supportive governmental research and development facilities have turned to concentrating on utilizing the pole-and-line technology to fish higher stock levels of skipjack tuna. Recent interest in improving the baitfish specie to be more durable and the attempt to transport new bait species to Hawaii are moving in this direction.

Catch Requirements for a Viable Skipjack Tuna Fishery

Previous economic studies of the Hawaiian skipjack tuna industry focused primary attention either on the conditions necessary to attract new investment capital into the industry or on the inability of the industry to attract local manpower to work as crews on the pole-and-line vessels (Shang, 1969; Ahsan et al., 1972). These constraints limit any potential expansion of the industry along ray OP, since the necessary conditions for further development require new investment in larger vessels, gear, refrigeration equipment, and crews trained in pole-and-line operations. However, even if these conditions were somehow met, they are not sufficient because of the additional requirement of a suitable baitfish supply. This is an additional constraint to the development of the industry and must be included in any analysis of the requirements necessary for industry expansion to offshore waters.

The necessary and sufficient conditions for a viable Hawaiian skipjack tuna fishery can be determined through the following model:

$$Y_g - V = Y_n, \qquad (31)$$

where Y_g and Y_n are gross and net proceeds from skipjack fishing, respectively, and V represents annual operating expenses. Normally, the net proceeds are divided between the vessel owner and crew according to agreed-on shares, e.g., c = percentage going to crew, and b = percentage going to vessel owner. Thus:

$$Y_n = b(Y_n) + c(Y_n), \qquad (32)$$

Rearranging:

$$b(Y_n) = Y_n(1 - c). \qquad (33)$$

Since the vessel owner charges the annual capital expenses, F, against his share before computing his net profit, this is expressed as:

$$b(Y_n) - F = rK. \qquad (34)$$

Net profit from fishing operations is then equal to some rate of return, r, on the capital invested, K. If it can be assumed that r* is the minimum rate of return necessary to attract and hold capital in the skipjack industry, then a given capital, K, with annual capital expenses, F, and a fixed share of the net proceeds, b, must give a <u>minimum</u> Y_n*, which is called the equilibrium Y_n. The rate, r*, is the <u>opportunity cost</u> of capital invested in the fishery, which is the minimum that must be earned in order to attract and retain capital in the industry. That is, from equation (34):

$$Y_n{}^* = \frac{r^*K + F.}{b} \qquad (35)$$

Similarly:

$$Y_n{}^* = \frac{w^*L,}{c} \qquad (36)$$

where w* is the <u>opportunity wage</u>, or earnings, of labor and L is the number of fishermen employed (crew).

Thus, it follows that:

$$Y_n{}^* = \frac{r^*K + F}{b} = \frac{w^*L,}{c} \qquad (37)$$

which means that, to attract and retain both vessels and crew into the skipjack tuna fishery, earnings in the industry must match earnings elsewhere in the economy for an equivalent amount of capital and labor time used.

From equation (31), the equilibrium Y_g can be derived if there is knowledge of the percentage, q, that operating expenses are to gross proceeds, i.e., $V = q(Y_g)$. Thus:

$$Y_g{}^* - q(Y_g{}^*) = Y_n{}^* \qquad (38)$$

and

$$Y_g^* = \frac{Y_n^*}{(1 - q)}. \tag{39}$$

Alternatively, assume that operating costs and gross proceeds from skipjack fishing are constant functions of the number of fishing days, D, e.g.,

$$V = vD \tag{40}$$

$$Yg = aD \tag{41}$$

Solving for V, gives:

$$V = (v/a)Y_g, \tag{42}$$

so that

$$Y_g^* - (v/a)Y_g^* = Y_n^* \tag{43}$$

and

$$Y_g^* = \frac{Y_n^*}{(1 - v/a)} \tag{44}$$

Y_g^* represents the minimum gross proceeds, or equilibrium Y_g, necessary to attract labor and capital into the industry. As can be seen, Y_g^*, given Y_n^*, is crucially dependent upon the relationship between operating costs, v, and catch value per trip, a. Operating costs, or direct expenses, include such items as fuel and oil, ice, and fish handling and transportation. The catch value per trip depends upon both the quantity of skipjack caught and the price per ton. As expected, from equation (44), higher operating costs would require a vessel to have larger gross proceeds from skipjack fishing in order for it to be an attractive alternative to other investments and occupations. A higher price, on the other hand, or larger catches per fishing day, would attract capital and labor into this industry.

From equation (41) can be derived the minimum number of days, D*, a skipjack vessel must operate during the season in order for fishing to be an attractive venture, i.e.,

$$D^* = \frac{Y_g^*}{a}. \tag{45}$$

Since a pole-and-line operation requires the use of live bait, the size of the fleet is constrained by the minimum fishing days necessary and the availability of a live bait supply at a reasonable cost. The number of fishing days per vessel, therefore, is dependent upon the size of the bait resource in an integrated operation and/or the opportunity cost of obtaining live bait. This is because the higher the cost of bait, the higher the required Y_g^* and therefore the higher the required D*. Through equation (45), a higher D* limits the size of the fleet, or the number of vessels capable of earning Y_g^*.

Fundamentally, this explains the reasons behind the transformation of the Hawaiian skipjack tuna fishing fleet. As the opportunity costs of fishing steadily rose with the development of the Hawaiian economy, the minimum required gross proceeds, Y_g*, to sustain a skipjack fishing operation increased. Since neither the average price per ton of skipjack nor the catch per trip showed any apparent upward trend during the 1950's and early 1960's (Figures 2 and 5), the average number of trips (fishing days) per vessel rose significantly (Figure 6). The average number of trips per vessel increased from 69 before 1965 to 127 since 1965 (Table 1). This meant that the bait catch per vessel had to increase and indeed increased at the same rate as the increase in trips per vessel (Figure 9). But, since neither the total skipjack catch nor the total bait catch rose significantly, the adjustment must have come through a reduction in the number of vessels in the fleet. This meant that each vessel used its plant, equipment, and labor complement more intensively in order to earn the minimum required gross proceeds to stay in operation. The industry, relying on the traditional stocks of skipjack, simply cannot support more than 14 or 15 vessels unless expansion to exploit the farther offshore stocks is made.

From the foregoing analysis, it is clear that the major constraints to Hawaiian skipjack tuna fisheries development lie in the skipjack resource potential relative to the opportunity costs of capital and labor and also the costs of obtaining baitfish. Even if the costs of capital and labor are relatively low, if the costs of obtaining bait are excessively high, the required catch proceeds must also be high, thus limiting the viability of the industry.

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