NOAA Technical Report NMFS Circular 408

Collection of Tuna Baitfish Papers

Richard S. Shomura (Editor)

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U.S. DEPARTMENT OF COMMERCE
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National Marine Fisheries Service

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369. Field guide to the anglefishes (Pomacanthidae) in the western Atlantic. By Henry A. Feddern. November 1972, iii + 10 p., 17 figs. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

370. Collecting and processing data on fish eggs and larvae in the California Current region. By David Kramer, Mary J. Kalin, Elizabeth G. Stevens, James R. Thrailkill, and James R. Zweifel. November 1972, iv + 38 p., 38 figs., 2 tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

371. Ocean fishery management: Discussion and research. By Adam A. Sokoloski (editor). (17 papers, 24 authors.) April 1973, vi + 173 p., 38 figs., 32 tables, 7 app. tables.

372. Fishery publications, calendar year 1971: Lists and indexes. By Thomas A. Manar. October 1972, iv + 24 p., 1 fcg. For sale by the Superintendent of Documents, U.F. Government Printing Office, Washington, D.C. 20402.

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377. Fishery publications, calendar year 1970: Lists and indexes. By Mary Ellen Engett and Lee C. Thorson. December 1972, iv + 34 p., 1 fig. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

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384. Marine flora and fauna of the northeastern United States. Higher plants of the marine fringe. By Edwin T. Moul. September 1973, iii + 60 p., 109 figs. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

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386. Marine flora and fauna of the northeastern United States. Pycnogonida. By Lawrence R. McCloskey. September 1973, iii + 12 p., 1 fig. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

387. Marine flora and fauna of the northeastern United States. Crustacea: Stomatopoda. By Raymond B. Manning. February 1974, iii + 6 p., 10 figs. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

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Juanita M. Kreps, Secretary

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Richard A. Frank, Administrator

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CONTENTS

A Summary of the Tuna Baitfish Workshop

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An invitational workshop on tuna baitfish problems, cosponsored by the National Marine Fisheries Service and the University of Hawaii Sea Grant College, was held at the Honolulu Laboratory, Southwest Fisheries Center, on 4-6 June 1974. The central issues addressed by the workshop dealt with the problem of securing adequate supplies of bait to support the development or expansion of skipjack tuna, *Katsuwonus pelamis*, fishing in the central and western tropical Pacific.

The 38 participants (see Appendix A for list of participants) from the mainland United States, Hawaii, Japan, and islands of the western Pacific reviewed and discussed a number of background papers prepared for the workshop. These background documents make up the bulk of the papers provided in this volume.

The workshop was organized around three sessions which focused attention on 1) natural stocks of baitfish, 2) culture of suitable baitfish species, and 3) transporting and holding bait and substitute baits. These sessions were preceded by a general review of baitfish problems and a discussion on the criteria for a good baitfish species. The workshop concluded with a general summary session. The following brief review of the workshop should provide the reader with a framework for relating the individual papers of this volume.

TUNA FISHING AND THE BAITFISH PROBLEM

Presently the only two economically viable methods of catching tuna in commercial quantities in tropical waters are purse seining and pole-and-line fishing with live bait. The expansion of tuna fishing in the central and western tropical Pacific is currently limited by certain technical problems associated with both methods of fishing. Purse seine trials conducted thus far in the central and western tropical Pacific using conventional seines have resulted in a success rate much lower than that enjoyed in the eastern tropical Pacific tuna fishery. It is generally believed that the clear waters and deep thermoclines of the central and western Pacific make it possible for tuna, especially skipjack tuna, to avoid capture by conventional purse seines. Thus, new net designs or new fishing techniques will have to be developed before purse seining can become a widespread, economically successful method of fishing in these waters.

The major problem associated with development or expansion of existing pole-and-line tuna fisheries in the central and western tropical Pacific is the lack of adequate supplies of baitfish. In the most severe cases suitable baitfish species are lacking altogether. In many areas of the Pacific, e.g. American Samoa, the stocks of naturally occurring baitfish species are inadequate to support even a small domestic tuna fishery. In other areas, baitfish may occur only in small quantities, limiting catches of tuna to a point far below the probable level of optimum sustainable yield.

In Hawaii and the Western Carolines, the supply of baitfish has been sufficient for the operation of only small fleets of tuna vessels. The Hawaiian fishery is conducted by 12 to 15 boats, generally less than 90 ft in length, which annually land about 4,500 t of skipjack tuna. Based on skipjack tuna surveys and an analysis of the fishery conducted several years ago by the National Marine Fisheries Service, it is believed that the catch of the Hawaiian fishery could be increased in direct proportion to an increase in fishing effort. However, because successful purse seine fishing in these waters seems technologically unfeasible at this time, the increase in tuna fishing effort can only be achieved by an increase in pole-and-line fishing effort. While the problems faced by the Hawaiian tuna fishery are complex, a basic constraint has been the limited supply of suitable baitfish. A similar situation exists in the Western Carolines.

In developing their southern fishery for skipjack tuna, the Japanese have overcome the lack of locally available baitfish by transporting baitfish from the Japanese home ports. Despite the problems of transporting an anchovy species, *Engraulis japonicus*, which is native to colder waters of the higher latitudes into tropical waters, the Japanese southern fishery has expanded to a present annual catch exceeding 100,000 t/yr.

CRITERIA OF GOOD BAITFISH SPECIES

The workshop started with a discussion of the characteristics that are considered important in a good baitfish for tuna fishing. A consensus resulting from the discussion was that while some species could be categorized as "good" baitfish, none of the species examined to date could be considered a "perfect" baitfish. For example, some species may be good at initially attracting the tunas, but may not be too effective in holding the fish at the boat.

In discussing size of baitfish, it was noted that the visual acuity of skipjack tuna and the clear waters of the

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tropics make it unnecessary for the maximum size of the baitfish to exceed 8 cm. Under most circumstances in tropical waters a baitfish 8-cm long can be detected at 50 m, the usual distance of a fish school from the fishing vessel when chumming is initiated.

A summary of the relative merits of several baitfish species currently used in the Pacific is given in Table 1. The use of a species in an area is generally related to its availability. The effectiveness of the various baitfish species (catch of tuna per unit of baitfish) has not been determined because, while some data are available, there are still too many unknown variables to allow comparisons. In Hawaii, the skipjack tuna catch per pound of baitfish, nehu—*Stolephorus purpureus,* would rank very high due to judicious use of this scarce commodity. In the eastern Pacific where the availability of baitfish is generally not a critical problem, the skipjack tuna catch per pound of northern anchovy, *Engraulis mordax*, or anchoveta, *Cetengraulis mysticetus,* would be considerably lower than the catch rate for Hawaii because of the liberal use of baitfish by the eastern Pacific fishermen.

NATURAL STOCKS

The objectives of the Natural Stocks Session were 1) to evaluate the principal natural baitfish resources of the Pacific with respect to their capacity for supporting local skipjack tuna fisheries and as sources of baitfish for distant-water transport systems, and 2) to recommend specific actions for improving the understanding, development, and management of natural baitfish resources.

Resource Evaluation

Based on available baitfish resource information in the Pacific, areas were described as having 1) known large stocks of baitfish species, 2) limited supplies of baitfish and capable of supporting only localized fisheries, and 3) very little baitfish. In the third category were also areas where information on baitfish is altogether lacking.

In the first group are areas in the Pacific where stocks of anchovies of various species (*Engraulis* spp.) are sufficiently large to support large tuna pole-and-line fisheries. In the eastern Pacific the anchovy and anchoveta found from southern California to Peru have formed the basis for the successful tuna fishery in that region. The annual landings of skipjack tuna in the eastern Pacific fishery ranged from 15,690 to 61,235 t during the period from 1950 to 1960 (before the purse seiners dominated the fishery). In the western Pacific the stocks of *Engraulis japonicus* from coastal waters of Japan currently support Japan's coastal skipjack tuna fishery as well as the recently successful distant southern water tuna fishing operation. The annual Japanese catch of skipjack tuna ranged from 70,428 to 212,985 t from 1960 to 1970. The baitfish stocks in other areas of the western Pacific including Korea, Taiwan, the Philippines, and Australia were believed to be adequate to support any currently existing or projected local skipjack tuna fishery.

A number of the island areas of the central and western Pacific fall into the second category. The principal baitfish species available in these areas belong to the genus *Stolephorus*. Skipjack tuna fisheries in Hawaii, Palau, Papua New Guinea, and the Solomons are examples of localized fisheries.

In Hawaii, the principal baitfish species is the nehu, *Stolephorus purpureus*. The skipjack tuna fishery there is relatively small with total annual landings of less than 5,000 t. The availability of nehu is inadequate for any substantial expansion of the skipjack tuna fishery in Hawaii; thus, increases in the baitfish supply must come from other sources, e.g., cultured species or transport of baitfish from other areas.

The anchovy, *S. heterolobus*, supports a modest skipjack tuna fishery in Palau; the average annual catch was around 4,650 t from 1966 to 1971. A recent study of the baitfish resource indicates that the current harvest of *S. heterolobus* may be approaching the maximum sustainable yield of the stock. Further expansion of the fishery is possible primarily through improved bait handling and usage.

In 1971 the catch of skipjack tuna in the Papua New Guinea fishery amounted to 16,864 t. There appears to be sufficient reason to believe that the *Stolephorus* resources of the area are large enough to support and expand the tuna fishery with current fishing practices. In

Table 1.—Characteristics of various bait species used in the Pacific.

Category	Dussumieridae	*Stolephorus* sp.	Anchovy	Caesiodidae	Apogonidae	Atherinidae	Clupeidae
Survival	Weak	Weak	Medium	Strong	Strong	Strong	Medium
Abundance							
Eastern Pacific	?	Low	High	None	None	High	High
Central Pacific	Low	Moderate	Low	None	Low	Low	Low
Western Pacific	High	High	High	Low	Low	Low	High
Behavior	Good	Good	Good	Good	Good	Poor	Fair
Size (cm)[1]	5	4-6	8-14	4-8	4-5	4-8	8-14
Body form	Elongate	Elongate	Elongate	Elongate	Deep bodied	Elongate	Elongate
Color	Shiny	Shiny	Shiny	Dull	Shiny	Shiny	Shiny
Color pattern	Silvery	Silvery	Silvery	Nonsilvery	Nonsilvery	Silvery	Silvery

[1]Size used as bait.

addition, more effective use of the baitfish resources can be achieved with improved handling and carrying techniques.

In the British Solomons, the stocks of *Stolephorus* presently support a skipjack tuna harvest of 6,000 t. Prospects for expansion are unknown.

The third category includes all other areas where baitfish stocks are known to be very small (e.g., American Samoa), or areas where the available information is too scanty to permit an accurate assessment for skipjack tuna development. Included in this category is Fiji, where a skipjack tuna fishery is in the early stages of development.

Recommendations

In summarizing the discussion on natural stocks of baitfishes, the Session participants developed a set of recommendations for the National Marine Fisheries Service and other organizations interested in baitfish research. The recommendations included:

1. Develop better bait handling and holding techniques to permit fullest utilization of natural baitfish stocks for tuna fishing.
2. Clarify the taxonomic status and nomenclature of the stolephorids and establish a reference collection of specimens.
3. Encourage the exchange of information on research and natural baitfish stocks including unpublished data and trip reports.
4. Adopt the recommendations of the South Pacific Commission's Expert Committee on Tropical Skipjack regarding the collection of standardized baitfish catch statistics, including a measure of nominal baiting effort.

CULTURED BAITFISH SPECIES

From a review of the workshop documents and a discussion based on individual participants' expertise, it was apparent that there is no single baitfish species to solve the problems of all the areas of the Pacific. Nor is there a simple solution to the use of cultured baitfish. Problems faced in culturing baitfish differ markedly from place to place, especially as to the availability of land and fresh water necessary for developing the culture facilities.

In discussing pond culture of baitfishes, a set of general requirements for potential culture species was developed. These included: 1) high reproductive potential, 2) ability to spawn readily in ponds, 3) ability to obtain food low in the food chain, 4) readily handleable and transportable, 5) euryhaline, and 6) lacking spines. Although hardiness is an important factor in the baitfish used in tuna fishing, experience in freshwater baitfish culture work suggests that this characteristic can be developed through proper selective breeding.

Table 2 summarizes the principal characteristics of species that have either been cultured or show culture potential. Highlights of the discussion of these species follow.

Threadfin Shad

This is a euryhaline species which is probably a suitable candidate for polyculture. Threadfin shad, *Dorosoma petenense*, are reported to spawn several times per year, subsist on material low on the food chain, and be fairly economical to raise. Being a euryhaline species, threadfin shad is ideally suited for areas where fresh water is abundant. Unfortunately, for many areas of the Pacific where natural stocks of baitfish are lacking, e.g., most of the tropical islands, fresh water is also a scarce commodity. It was noted that in Hawaii where threadfin shad have been introduced into an agricultural water impoundment system the standing crop of bait-sized threadfin shad during the 1969-70 season was estimated to be 45,454-68,181 kg (100,000-150,000 lb). The reservoir has a surface area of 122 ha at high water and contains approximately 1.14×10^{10} liters of water. The estimated standing crop is equal to approximately 17% to 25% of the baitfish caught in the Hawaiian fishery in 1971.

To date only limited field trials have been conducted using threadfin shad as baitfish for skipjack tuna fishing. Definitive results describing the fishing power of threadfin shad relative to the natural baitfish used in Hawaii are still lacking.

Tilapia

The most extensive field trials using tilapia, *Tilapia mossambica*, as baitfish for tuna fishing have taken place in Hawaii. The results to date have been inconclusive. While the evidence suggests that tilapia may be a suitable substitute baitfish species, in Hawaii it has been generally rejected as such by commercial fishermen. This nonacceptance by fishermen has been attributed to the general conservative nature of fishermen.

Tilapia has the attribute of hardiness and ease in culture. It is conceivable that improvement in fishing success could be achieved by changes in fishing technique.

Mollies

Although cost figures for the culture of various baitfish species are not readily available, the mass-rearing of mollies appears to be the most attractive in terms of economics. An estimate of $2.60/bucket (investigators used 2.7 kg (6 lb)/bucket) was provided as the cost for mollies under a 30,000-bucket annual production system. Favorable characteristics of the mollies include being euryhaline, having the ability to withstand extreme crowding conditions in the baitwells, and having the ability to withstand low oxygen levels. To date the effectiveness of mollies in skipjack tuna fishing has not been demonstrated. While evidence exists that mollies have been used in the past by commercial fishermen in Hawaii

Table 2.—Principal factors of tuna baitfish culture.

Item	Threadfin shad	Tilapia	Mollies	Golden shiner	*Apogon*
Fecundity	14,000-16,000 eggs per female per year. Multiple spawnings	200-800 eggs per female per year (six times per year). 700-1,000 fry survival per female per year	1,600 per female per year	Unknown	Unknown
Hardiness	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory
Density tolerance	1,000 lb per acre per year (estimated possible)	Present: 8,000-13,000 lb per acre per year. Estimated: 25,000 lb per acre per year	18,000 lb per acre per year	800-1,600 lb per acre per year (one or two crops)	Unknown
Appearance re traditional bait	Same	Different	Different	Same	Different
Behavior:					
Culture	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Unknown
Used at sea	Satisfactory, but more tests needed	Satisfactory	Inconclusive	Inconclusive	Satisfactory
Ease of culture:					
Intensive	Not established	Good	Good	Not established	Unknown
Extensive	Good	Good	Good	Good	Unknown
Economics	$14 per bucket and 3,660 buckets per acre	$19.58 per bucket with profit; $1.06-1.65 reduced	$2.69 per bucket or $0.45 per pound (@ 30,000 buckets)	$4.00 per pound (air-shipped to Hawaii)	Unknown
Polyculture	Unknown	Unknown	Unknown	Unknown	Unknown
State of the art re mass culture	Not much known	Known	Known	Known	Unknown
Field experiments to date	Inconclusive	Inconclusive	Inconclusive	Inconclusive	Satisfactory
What needs to be done?	1. Project costs, etc. Wahiawa Reservoir 2. Field test	1. Project proposal 2. Field test	1. Hawaii project proposal 2. Hawaii test 3. American Samoa	1. Project costs, etc. 2. Hawaii test	1. Life history research (fecundity)

to catch skipjack tuna, evidence is still lacking that the fishing power of mollies is comparable to that of natural baitfish species, e.g., nehu, in the Hawaiian Islands.

Golden Shiner

Although golden shiner, *Notemigonus crysoleucas*, is strictly a freshwater species and cannot live in seawater, some views were expressed that freshwater species should not be discounted in the search for a suitable baitfish for skipjack tuna fishing. The underlying assumption is that circulation systems can be developed to economically carry freshwater species in baitwells for varying periods of time. The advantages of golden shiner are that the mass culture of this species is well known, they have some of the physical attributes of a good baitfish species, e.g., light coloration, and this species is relatively hardy and withstands mass transport.

To date the golden shiner has not been field tested adequately. The short single test conducted in the Hawaiian Islands was inconclusive.

Apogon

In discussing the suitability of culturing apogons as a baitfish species, the general consensus was that not enough was known about this group to form any definite conclusions.

Since apogons have not been cultured and reared in laboratories to date, the general consensus was that the lack of biological information precludes even a rough estimate of the economics of large-scale culturing systems for these species.

Recommendations

The Session participants recommended the following:

1. Critically analyze future field tests to provide conclusive information on the effectiveness of different baitfish species.
2. Determine the fishing power of the various baitfish species under consideration, using existing data with particular reference to nehu and other *Stolephorus* species as models.
3. Conduct additional field tests with species that have previously shown promise as successful baitfish species, e.g., threadfin shad and golden shiner.
4. Reevaluate the economics of bait production at intervals, using updated cost figures.
5. Recognizing the lack of a "perfect" baitfish species,

continue the search for suitable candidates for cultured baitfish species.

6. Defer work on culture of *Apogon* until studies on critical parameters of this baitfish have been completed, e.g., estimates of fecundity and growth rates.

7. Conduct baitfish extension activities concurrently with the testing of the species in order to overcome problems in fishermen's acceptance of new baitfish species.

TRANSPORTING, HOLDING, AND SUBSTITUTE BAITS

In areas where the supply of natural baitfish stock is lacking or is in very short supply, the several alternatives available to solving the problems include:

1) culturing selected species of baitfish;
2) developing an artificial (substitute) bait; and
3) moving large quantities of baitfish from areas of abundance to areas of scarcity.

Participants of this Session reviewed activities on artificial bait and the transport of baitfish.

A very brief review was made during the Session of previous attempts to attract and hold skipjack tuna schools close to the fishing vessels by using nonliving material. It was noted that some work had been done in Hawaii on the use of dead baitfish, animal extracts, shiny metals, and calcium carbide. While some extracts appeared to create a feeding response by skipjack tuna, none of these responses was of sufficient strength or duration to be promising for commercial fishing application. There has been no work conducted in this field in recent years.

The expansion of the Japanese skipjack tuna fishery to southern waters of the central and western Pacific has been possible because the vessels are able to carry a full load of baitfish from Japan to the fishing grounds. Reports indicate that "aged" anchovy, *Engraulis japonicus*, are carried successfully for 4 wk or more without much mortality.

The attempt by the Honolulu Laboratory (National Marine Fisheries Service) to develop a method of transporting large quantities of northern anchovy from California to Hawaii on commercial freighters was discussed at length. Although the northern anchovy can be carried on baitfishing vessels, it was noted that the commercial roll-on/roll-off freighters represented a possible cost-effective method of transporting baitfish on a continuing basis. The experiment is still in progress and its success could not be predicted at the time.

Special emphasis was placed on the fact that the hardiness of baitfish could be increased substantially by holding the baitfish in pens prior to transporting them. Hardiness appeared to be a key factor in transportation over long distances. If a method of successfully transporting baitfish from one area to another can be developed, the opportunities for an expanded fishery become obvious. The availability of an increased supply of hardy baitfish would mean extending the range of a fishery, providing opportunities for an expansion of fleet size, and increasing the efficiency of tuna fishing by eliminating a major nonfishing activity, i.e., catching of bait.

SUMMARY SESSION

At the Summary Session each chairman reviewed briefly the major findings of his group. The participants then held a general discussion on priorities of future research. Table 3 provides a summary of this discussion.

Table 3.—Three action priorities/alternatives.

	1	2	3
Hawaii	Anchovy transport (Sea Grant, NMFS)	Improve bait handling and utilization (nehu)	Shiners and shad
American Samoa	Mollies (Government of American Samoa)	Economic evaluation of bait transport	—
Trust Territory	*Apogon*	—	—
Other areas	Develop use of natural stocks (availability and accessibility)	Culture suitable species	—

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A Review on the Use of Live Baitfishes to Capture Skipjack Tuna, *Katsuwonus pelamis*, in the Tropical Pacific Ocean With Emphasis on Their Behavior, Survival, and Availability[1]

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ABSTRACT

The use of live baitfishes in the Pacific Ocean skipjack tuna fishery is reviewed primarily to provide essential information for future baitfish investigations and as a useful reference for fishery development. Emphasis is placed upon various baitfish characteristics such as size, coloration, body form, behavior, schooling, survival in captivity, and their suitability for capturing skipjack tuna, *Katsuwonus pelamis*, by pole-and-line methods. In addition, data on their capture and handling methods are given. Thirty-one baitfish families are included in the text and pertinent information on each family is summarized in two tables. A total of approximately 160 baitfish species are discussed in the text and their area of geographical use recorded in a table and map of the Pacific Ocean. Recommendations for future research related to the use of baitfishes and an extensive bibliography are included.

INTRODUCTION

The dependence of the commercial pole-and-line fishery for skipjack tuna, *Katsuwonus pelamis*, on live baitfishes throughout the warm Pacific Ocean is a leading factor controlling the expansion of this fishery (Rothschild and Uchida 1968). Skipjack tuna represent an extensive fishery resource in the oceanic regions of the Pacific currently underharvested due primarily to insufficient supplies of live baitfishes. Extensive investigations have been done on the distribution and biology of skipjack tuna but less is known of the baitfishes on which this fishery depends. Literature on the development of this fishery in the central and western Pacific has been reviewed by Hester and Otsu (1973).

Many of the reports on baitfishes are mostly from brief observations or findings that were of a cursory nature with some related project being the primary interest. The purpose of this report is to bring together existing information on baitfishes that will hopefully provide essential background data for future investigations and serve as a useful aid for the development of island fisheries.

Biological data on baitfishes related to capture, confinement, handling, and use in pole-and-line fishing for skipjack tuna is, with several exceptions, inadequate and fragmentary. More detailed investigations have been conducted on important bait species, especially anchovies such as the nehu, *Stolephorus purpureus*; anchoveta, *Cetengraulis mysticetus*; Japanese anchovy, *Engraulis japonicus*; and the northern anchovy, *E. mordax*. Additional studies have been completed or are in progress on other species that include tilapia, *Tilapia mossambica*; Japanese sardine, *Sardinops melanosticta*; threadfin shad, *Dorosoma petenense*; milkfish, *Chanos chanos*; and two topminnows, *Poecilia vittata* and *P. mexicana*.

Baitfish surveys have been conducted in central and western Pacific areas to identify existing species and to determine their potential value to the fishery. The areas under recent study include New Caledonia, New Zealand, Fiji, Marshall Islands, Samoa, Palau, New Guinea, Bismarck Sea, Ryukyu Islands, and Hawaii.

METHODS

Although useful studies on many species will no doubt provide important biological and technical data, this information has been excluded unless directly applicable to pole-and-line fishing. Also excluded are numerous fishes listed as observed or captured during a baitfish survey but not representing a bait resource. Many species listed by Nakamura (n.d.), Kikawa (1971), Grandperrin and Fourmanoir (1972), Kearney et al. (1972), and by Lewis et al. (1974) are of scientific interest but offer little practical value as live bait for tuna fishing. No doubt many reef fishes throughout the Pacific have been used successfully as bait without being recorded in literature. For example, species such as *Apogon brachygrammus* (Apogonidae), *Saurida gracilis* (Synodontidae), and *Asterropteryx semipunctatus* (Eleotridae) were observed in baitwells of Hawaiian tuna boats, having been taken incidentally during seining and night lighting for nehu. Such occurrences are not sufficient to establish them as baitfishes in the true sense of the word. They are captured by chance when fishermen

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are in pursuit of other bait species and are used as chum accordingly.

All small fishes that are associated with coral reefs can be used as bait, but they are sparsely scattered and it is difficult to take them in large quantities (Anonymous 1937a). There is no special selection in the Minicoy Island fishery, Laccadive Archipelago, where all small reef fishes are captured and used as chum (Jones 1958). Kikawa (1971) noted that it is important to use as many species as possible to establish a more stable bait fishery.

Data included in the discussion of each family and recorded in Tables 1 and 2 are not meant to imply that additional information is not extant. Only those references that were accessible or were considered pertinent are included. It is reasonable to assume that some useful species have been inadvertently omitted.

Larval fishes and eels were used as chum for skipjack tuna by the Japanese (Imamura 1949). The general use of vernacular names in this and a similar study (Anonymous 1937a) leaves some degree of doubt as to the correct identification of many species. In cases where specific identifications could not be determined, they were omitted. In the English synopsis, Far Seas Fisheries Research Laboratory (1969:170), juvenile squirrelfishes (Holocentridae) were reported as being captured by night lighting in the Bismarck Sea area but they were considered too small for use as chum. Suda (1972) noted the use of mini-samna, *Cololabis saira*?, as live bait for tuna—a species commonly used as longline bait. The sand lance (Ammodytidae) was supposedly used in Japan to some extent as a live baitfish (U.S. National Marine Fisheries Service, 1972). A report (Anonymous 1937a) noted that filefish were caught at Saipan along with other reef fishes as live bait for tuna.

Kearney et al. (1972) briefly noted that flyingfishes (Exocoetidae) may be of possible importance as bait for tuna in Papua New Guinea. No additional comments were made but seven species were noted in the appendix (p. 134).

In the text which follows, the families are treated alphabetically. Under each family listed in Tables 1 and 2 the baitfishes are arranged alphabetically by genus and species. Only current names have been used and no taxonomic changes or new distributional records included.

The various descriptive categories in Table 1 were selected in an effort to be explicit and to include only those that would contribute to a better understanding of baitfish biology and behavior as applied to pole-and-line fishing. The sequence does not indicate relative importance.

Body Length

Two size groups are included, 1) 2.5-7.5 cm and 2) 7.5-15.2 cm total length. Since the use of live baitfishes over 15.2 cm (6 in) in length is rare, a larger size range was excluded. Many species reach a size greater than 15.2 cm and in these cases it is the juveniles that are used as live bait. Some reports noted that the young, juveniles, or small sizes were used without giving specific information. In most cases the species in question was placed in one of the two size groups. The data included in Table 1 for each species are referable to that specific size range indicated under column A.

Body Form

Body shapes represented by baitfishes successfully employed as bait suggest that this particular characteristic is not critical. The greatest number of bait species occurs in group number 1, which includes elongate forms ranging from larval eels (Imamura 1949) to some species of *Sardinella* that have a moderately deep body, almost approaching a perchlike form. The second group, the oblong or perchlike body form, appears second in frequency while the deep-bodied forms appear last. Body form invariably changes with growth even within a particular size group. The body shape most frequently encountered when used as bait is indicated in column B. Since most have compressed bodies that may differ slightly, it was considered impractical to separate individuals on this characteristic. Species notably compressed such as some of the Clupeidae and Carangidae are indicated by a number 4.

Body Coloration

A silvery color and elongate body have most often been considered important baitfish requirements since the greatest number of good baitfishes have these characteristics. Some generalizations can be made relative to coloration, but specific data are lacking concerning the attractability and holding capabilities of one color or color pattern over another. The increased visibility of one baitfish over another may effectively attract more skipjack tuna to the fishing vessel. Successful fishing has been accomplished with fishes displaying a wide range of colors and color patterns. No attempt is made to evaluate species on this single characteristic due to the lack of data. The five groups listed in column C note coloration for a species when it was used as live bait. The five groups are: 1) silvery, 2) light, dusky, 3) medium dark to dark, 4) dark and light, and 5) bright colors.

Baitfish Behavior

Information within this category is meager due to the difficulties of obtaining accurate observations at sea by trained observers. Although four selections are available, the lack of entries is quite noticeable. It appears that movement by a live fish of a proper size is required for successful skipjack tuna fishing. The movement of a baitfish in relation to the vessel, its swimming motion, body movements, and reaction in the presence of a predator are important to the effectiveness of a bait species. The terms, 1) response to predator and 2) no response to predator, were included to emphasize that baitfish behavior in the presence of feeding skipjack tuna influences its effectiveness when chummed at sea. For

Table 1.—Compilation of biological data on live baitfishes used commercially, experimentally, or reported to represent a bait resource for capturing skipjack tuna, *Katsuwonus pelamis*, in the Pacific. (For explanation of categories A through G see pages 9-14.)

A.	Body length	1 = 2.5-7.5 cm, 2 = 7.5-15.2 cm
B.	Body form	1 = elongate, 2 = oblong (perchlike), 3 = deep bodied, 4 = notably compressed
C.	Body coloration	1 = silvery (bright), 2 = light, dusky, 3 = medium dark to dark, 4 = dark and light, 5 = bright colors
D.	Baitfish behavior	1 = response to predator, 2 = no response to predator, 3 = schooling or "balling" around vessel, 4 = disperses, dives, sounds, or leaves vessel
E.	Schooling behavior	1 = schools at or near surface, 2 = schools at or near bottom, 3 = aggregates on or adjacent to reefs, 4 = disperses or solitary
F.	Survival in captivity	1 = good, 2 = fair, 3 = poor
G.	Baitfish evaluation	1 = excellent (high attraction rate), 2 = good (effective, suitable, successful, etc.), 3 = poor (low attraction rate)

	A	B	C	D	E	F	G
ALBULIDAE (bonefish)							
Albula vulpes	1	1	1	—	1	2	1
APOGONIDAE (cardinalfishes)							
Apogon notatus	—	2	2	—	2	1	—
A. truncatus	—	2	3,4	—	—	—	—
Apogon sp.	1	2	—	—	3	—	—
Archamia bleekeri	1	2	—	—	—	1	2
A. fucata	—	2	2	—	3	—	—
A. lineolatus	—	2	2	—	—	1	—
Cheilodipterus sp.	—	2	—	—	—	—	—
Rhabdamia cypselurus	1	2	2	—	3	1	1
R. gracilis	1	2	2	—	—	—	2
ATHERINIDAE (silverside)							
Allanetta bleekeri	—	1	1	—	—	—	—
A.forskali	—	1	1	—	1	1	3
A. ovalaua	1	1	1	—	1	1	2
A. valenciennei	—	1	1	—	1	3	3
A. woodwardi	1	1	1	—	1	—	3
Atherinops sp.	—	1	1	—	—	—	—
Hypoatherina tsurugae	—	1	1	—	—	—	—
Pranesus duodecimalis	—	1	1	—	—	1	2
P. insularum	1, 2	1	1	1, 3	1	1	1
P. pinguis	1, 2	1	1	—	1	1	—
ARRIPIDAE							
Arripis georgianus	—	2	1, 5	—	—	—	2
BERYCIDAE							
Beryx decadactylus	—	3	1	—	—	—	—
CARANGIDAE (jacks)							
Atule djebada	—	2	2	—	—	—	—
Carangoides malabaricus	—	3	1	—	1	—	—
Caranx sp. (several)	1, 2	2	2	—	4	1	2
Caranx mate	1	2	2	—	4	1	2
Chloroscombrus sp.	—	2, 4	1	—	—	—	—
Decapterus sp. (several)	1	2	2	—	1	—	2
Decapterus macrosoma	—	2	1	—	—	—	—
D. muroaji	—	2	1	—	—	—	—
D. pinnulatus	2?	1	1	—	1	—	—
D. russelli	—	2	1	—	—	—	—
Megalaspis cordyla	—	1	1	—	—	—	—
Scomberoides lysan	1, 2	2, 4	1	1, 4	4	2	2
S. tol	1, 2	2, 4	1	1, 4	—	—	—
S. toloo	1, 2	2, 4	1	—	—	—	—
Selar crumenophthalmus	—	2	2	—	1	1	1
Selaroides leptolepis	—	2	2	—	1	—	—
Trachurus sp. (several)	—	2	2	—	—	—	—
Trachurus declivis	—	2	1	3	1	—	2
T. japonicus	—	2	1	—	—	—	2?
Usacaranx georgianus	—	2,4	1	—	—	—	—
CHANIDAE (milkfish)							
Chanos chanos	1	2	1, 2?	1	1	1	2
CICHLIDAE (cichlids)							
Tilapia macrocephala	—	2	2, 4	—	4	—	—
T. mossambica	1	2	2, 4	2, 4	4	1	1, 2
CLUPEIDAE (herrings, sardines)							
Clupea bassensis	—	1	1	—	1	3	—
Dorosoma petenense	1	3, 4	1	1,3,4	1	2	2
Harengula thrissina	—	3	1	—	1	—	—
Herklotsichthys ovalis	1, 2?	2	1	—	1	—	—
H. punctatus	1, 2	2	1	—	1	1	2
H. schrammi	1	2	1	—	—	—	—
Ilisha furthi	—	2	1	—	1	3	3
Konosirus punctatus	—	3	1	—	—	—	—
Lile stolifera	—	2	1	—	—	—	—
Neopisthopterus tropicus	—	2, 4	1	—	—	—	—
Opisthonema berlangai	—	2, 4	1	—	—	—	—
O. bulleri	—	2, 4	1	—	—	—	—
O. libertate	1, 2	2, 4	1	—	1	2	2
O. medirastre	—	2, 4	1	—	—	—	—
Opisthopterus dovi	—	2, 4	1	—	—	—	—
O. equatoralis	—	2, 4	1	—	—	—	—
Pellona ditchela	2	2	1	—	—	—	2
Sardinella clupeoides	—	2	1	—	—	—	—
S. fimbriata	—	2	1	—	—	—	—
S.·immaculata	—	2	1	—	1	—	—
S. jussieu	—	2	1	—	—	2	—
S. leiogaster	2	1	1	—	1	3	1
S. marquesensis	1, 2	2	1	3	1	1	2
S. melanura	2	2	1	—	1	—	—
S. perforata	—	2, 4	1	—	—	—	—
S. sindensis	—	2	1	—	—	—	—
S. sirm	2	1	1	—	1	1	2
S. stolefora	—	2	1	—	—	—	2
S. zunasi	—	2	1	—	—	—	—
Sardinops melanosticta	2	1	1	—	1	3	1
S. neopilchardus	1, 2	1	1	—	1	1	2
S. sagax caeruleus	1, 2	1	1	1	1	2, 3	1
CYPRINIDAE (minnows, carps)							
Carassius auratus	—	2	2, 3	4	—	1	3
Hypophthalmichthys molitrix	—	2	2	4	—	1	3
Notemigonus crysoleucas	—	2	2	4	—	3	2
DINOLESTIDAE							
Dinolestes lewini	—	2	1	—	—	—	—
DUSSUMIERIIDAE (round herrings)							
Dussumieria acuta	2	1	1	—	—	3	2
Etrumeus teres	1, 2	1	1	—	1	3	2
Spratelloides delicatulus	1, 2	1	1	3	1	2, 3	1, 2
S. gracilis	—	1	1	—	1	2, 3	1, 2
S. japonicus	—	1	1	—	1	—	—
ENGRAULIDAE (anchovies)							
Anchoa arenicola	—	1	1	—	—	—	—
A. compressa	—	1	1	—	1	1?	2
A. curta	—	1	1	—	1	—	—
A. exigua	—	1	1	—	1	—	—
A. ischana	—	1	1	—	1	—	—
A. lucida	—	1	1	—	1	—	—
A. naso	—	1	1	—	1	—	—
A. panamensis	—	1	1	—	1	—	—
A. spinifer	—	1	1	—	1	—	—
A. starksi	—	1	1	—	1	—	—
Anchovia macrolepidota	—	1	1	—	1	3	—
A. rastralis	—	1	1	—	1	3	—

Table 1.—Continued.

	A	B	C	D	E	F	G
Cetengraulis mysticetus	1, 2	1, 2	1	—	1	1	1
Engraulis australis	1, 2	1	1	—	1	2, 3	1, 2
E. japonicus	2	1	1	—	1	3	1
E. mordax	2	1	1	—	1, 2	1	1
E. ringens	1, 2	1	1	—	1	—	—
Lycengraulis poeyi	—	1	1	—	4	—	—
Scutengraulis mystax	—	1	1	—	—	1	1
Stolephorus sp.	1	1	1	1,3,4	1	3	1
Stolephorus bataviensis	—	1	1	—	1, 2	—	1
S. buccaneeri	1	1	1	—	1, 2	1, 3	1
S. commersoni	1	1	1	—	—	3	—
S. devisi	1	1	1	—	1	3	1
S. heterolobus	1	1	1	—	1	1, 3	1
S. indicus	—	1	1	—	1	3	1, 2
S. purpureus	1	1	1	1,3,4	1	3	1
S. zollingeri	—	1	1	—	—	—	—
Thrissina baelama	—	1	1	4	—	1, 2	2
Thryssa setirostris	—	1	1	—	—	1	—
GOBIIDAE (gobies)							
Glossogobius giurus	—	1	3	—	—	1	—
KUHLIIDAE (flagtails)							
Kuhlia sandvicensis	1	2	1	3	1, 2	1	1
LABROCOGLOSSIDAE							
Labrocoglossa argentiventris	—	2	2, 5	—	—	—	—
LEIOGNATHIDAE							
Gazza minuta	—	3	1, 5	—	1	—	3
LUTJANIDAE (snappers)							
Caesio coerulaureus	2?	2	5	—	—	1	1
C. chrysozonus	2	2	5	—	2	1	1
C. diagramma	—	2	5	—	—	—	—
C. tile	—	2	2, 5	—	—	—	—
C. xanthonotus	—	2	5	—	—	—	—
Gymnocaesio argentius	1	2	4	—	2	1	1
G. gymnopterus	—	2	5	—	—	—	—
Lutianus vaigensis	—	2	2	—	3, 4	—	—
Pterocaesio pisang	—	2	5	—	—	—	2
MUGILIDAE (mullets)							
Crenimugil crenilabis	1, 2	2	1	—	1	—	—
Mugil sp. (several)	1, 2	2	1	—	1	1	—
Mugil cephalus	—	2	1	—	1	2	—
M. longimanus	1, 2	2	1	1, 3	1	2	2
M. trichilus	1, 2	2	1	—	1	—	—
M. vaigiensis	1, 2	2	1	—	1	—	2
Neomyxus chaptallii	2	2	1	—	1	—	2
MULLIDAE (goatfishes, surmullets)							
Mulloidichthys sp.	1	2	1	3, 4	1	2	—
Mulloidichthys auriflamma	1?	2	1	—	1	—	2
M. samoensis	—	2	1	4	1	—	2
Parupeneus sp.	—	2	—	—	—	—	—
Parupeneus pleurostigma	—	2	2	—	1	2	—
Upeneus sp.	—	2	—	—	—	—	—
Upeneus tragula	1	2	3, 4	—	—	—	—
PEMPHERIDAE							
Parapriacanthus beryciformis	—	3	2	—	—	—	—
PLECOGLOSSIDAE							
Plecoglossus altivelis	—	1	2	—	—	—	—
POECILIIDAE (topminnows)							
Gambusia sp.	1	2	3	—	2, 4	1	—
Gambusia affinis	1	2	3	—	2, 4	1	—
Poecilia sp.	1	2	2,3,4	4	1, 2	1	3
Poecilia latipinna	1, 2	2	2	4	1, 2	1	—
P. mexicana	1	2	2	—	—	1	—
P. sphenops	1	2	2	—	1, 2	—	3
P. vittata	1	2	2	2,3,4	1, 2	1	2, 3
POLYNEMIDAE (threadfins)							
Polydactylus sp.	—	2	2	—	1	—	2
Polydactylus sexfilis	1, 2?	2	2	—	1, 4	—	2
POMACENTRIDAE (damselfishes)							
Abudefduf anabatoides	—	2	3, 5	—	2, 4	—	—
A. coelestinus	1	3	4	—	3	—	3
A. dicki	—	3	3	—	3	—	—
Chromis caeruleus	1?	3	3	—	3	1?	—
C. ternatensis	—	3	3	—	3	—	—
Dascyllus trimaculatus	—	3	3	—	3	—	—
Pomacentrus pavo	1	3	3	—	3, 4	—	2
PRIACANTHIDAE (bigeyes)							
Priacanthus sp.	—	3	2	—	3	1	—
PRISTIPOMATIDAE (salemas)							
Xenistius californiensis	—	2	2, 4	—	3	—	—
Xenocys jessiae	—	2	2, 4	—	3	—	—
SCOMBRIDAE (tunas, mackerels)							
Rastrelliger kanagurta	1, 2	2	2, 3	—	1	—	—
Scomber japonicus	—	2	2, 3	—	1	—	2
SPHYRAENIDAE (barracudas)							
Sphyraena obtusata	1, 2?	1	2	—	1	—	3
TETRAGONURIDAE							
Tetragonurus atlanticus	1	1	3	3	1	1	2

example, the nehu, an excellent baitfish, was observed to dive but to return to the surface and exhibit marked dodging when pursued by feeding tuna (Iversen 1971). The two selections, 3) schooling or "balling" around the vessel and 4) disperses, dives, sounds, or leaves vessel, are terms used by various authors to describe baitfish behavior at sea.

Schooling Behavior

The four selections under this category are descriptive terms from various reports that relate to a particular bait species at time of capture. The entry in column E refers to that size group noted under column A. For more detailed information on a family or a specific baitfish consult the text since these groups are general in coverage.

Survival in Captivity

Terms describing survival were used in various reports of baitfishes in enclosures or during captivity aboard ship. Environmental conditions, capture and handling methods, live-bait well design, etc. all vary at time of capture and invariably influence survival of baitfishes. Frequently poor survival is due to overcrowding, rough handling, and substandard holding facilities. Juvenile anchovies and sardines are extremely delicate and regardless of treatment do not survive well in captivity. Lewis et al. (1974) reported that loading of night-captured baitfishes during daytime significantly reduced mortalities. An improved understanding and application of the basic requirements of baitfishes in captivity will improve survival in most cases.

Table 2.—Geographical location of the use of live baitfishes commercially and experimentally or representing a bait resource for capturing skipjack tuna, *Katsuwonus pelamis*, in the Pacific. (For explanation of geographical areas see page 14 and Figure 1.)

1. Eastern Pacific (includes Revillagigedos, Clipperton, Cocos, and Galapagos Islands)
2. Marquesas, Tuamoto Archipelago, Society, and Austral Islands
3. Line Islands
4. Hawaiian Islands (includes Johnson and Midway Island)
5. Phoenix, Tokelau, Samoan, Ellice, Fiji, and Tonga Islands
6. Marshall and Gilbert Islands
7. Mariana and Caroline Islands (includes Saipan, Guam, Palau, Yap, Truk, and Ponape)
8. New Guinea, New Caledonia, Admiralty, Solomon, New Hebrides, Santa Cruz, and Loyalty Islands.
9. Australia (Queensland, New South Wales, Victoria), Tasmania, and New Zealand
10. Philippine Islands, Celebes, Borneo, East Malaysia, and South China Sea
11. Japan, Ryukyu, Bonin, Volcano, Daito Islands, Taiwan, and North and South Korea
12. "South Seas"—A general term used by Cleaver and Shimada (1950) designating the area encompassed by the Japanese southern skipjack fishery.
13. Non-Pacific Ocean localities (not shown on map)

	1	2	3	4	5	6	7	8	9	10	11	12	13
ALBULIDAE (bonefish)													
Albula vulpes				X									
APOGONIDAE (cardinalfishes)													
Apogon notatus											X		
A. truncatus											X		
Apogon sp.							X	X					
Archamia bleekeri												X	
A. fucata											X		
A. lineolatus								X					
Cheilodipterus sp.												X	
Rhabdamia cypselurus							X	X					
R. gracilis					X								
ATHERINIDAE (silverside)													
Allanetta bleekeri											X		
A. forskali								X					
A. ovalaua					X		X						
A. valenciennei							X	X					
A. woodwardi							X				X		
Atherinops sp.	X												
Hypoatherina tsurugae											X		
Pranesus duodecimalis										X			
P. insularum				X									
P. pinguis					X	X	X	X					
ARRIPIDAE													
Arripis georgianus									X				
BERYCIDAE													
Beryx decadactylus											X		
CARANGIDAE (jacks)													
Atule djebada											X		
Carangoides malabaricus												X	
Caranx sp. (several)				X	X							X	
Caranx mate				X									
Chloroscombrus sp.	X												
Decapterus sp. (several)	X				X	X	X	X			X	X	
Decapterus macrosoma											X		
D. muroaji											X		
D. pinnulatus				X				X					
D. russelli							X					X	
Megalaspis cordyla										X			
Scomberoides lysan				X									
S. tol					X					X			
S. toloo										X			
Selar crumenophthalmus				X	X	X	X			X	X	X	
Selaroides leptolepis												X	
Trachurus sp. (several)	X				X	X					X		
Trachurus declivis									X				
T. japonicus												X	
Usacaranx georgianus									X				
CHANIDAE (milkfish)													
Chanos chanos			X	X						X			X
CICHLIDAE (cichlids)													
Tilapia macrocephala				X									
T. mossambica				X	X							X	

	1	2	3	4	5	6	7	8	9	10	11	12	13
CLUPEIDAE (herrings, sardines)													
Clupea bassensis									X				
Dorosoma petenense				X									
Harengula thrissina	X												
Herklotsichthys ovalis					X	X	X	X			X		
H. punctatus					X	X	X	X				X	
H. schrammi							X					X	
Ilisha furthi	X												
Konosirus punctatus											X		
Lile stolifera	X												
Neopisthopterus tropicus	X												
Opisthonema berlangai	X												
O. bulleri	X												
O. libertate	X												
O. medirastre	X												
Opisthopterus dovi	X												
O. equatoralis	X												
Pellona ditchela								X					
Sardinella clupeoides											X		
S. fimbriata										X			
S. immaculata											X		
S. jussieu								X					
S. leiogaster							X			X		X	
S. marquesensis		X		X									
S. melanura					X		X			X			X
S. perforata										X			
S. sindensis											X		
S. sirm					X			X					
S. stolefora	X												
S. zunasi											X		
Sardinops melanosticta											X		
S. neopilchardus									X				
S. sagax caeruleus	X												
CYPRINIDAE (minnows, carps)													
Carassius auratus											X		
Hypophthalmichthys molitrix											X		
Notemigonus crysoleucas				X									
DINOLESTIDAE													
Dinolestes lewini									X				
DUSSUMIERIIDAE (round herrings)													
Dussumieria acuta					X					X			
Etrumeus teres	X			X									
Spratelloides delicatulus			X	X	X		X	X			X	X	X
S. gracilis					X		X	X			X	X	
S. japonicus											X		X
ENGRAULIDAE (anchovies)													
Anchoa arenicola	X												
A. compressa	X			X									
A. curta	X												
A. exigua	X												
A. ischana	X												
A. lucida	X												
A. naso	X												

Table 2.—Continued.

	1	2	3	4	5	6	7	8	9	10	11	12	13
A. panamensis	X												
A. spinifer	X												
A. sparksi	X												
Anchovia macrolepidota	X												
A. rastralis	X												
Cetengraulis mysticetus	X	X											
Engraulis australis									X				
E. japonicus											X		
E. mordax	X												
E. ringens	X												
Lycengraulis poeyi	X												
Scutengraulis mystax										X			
Stolephorus sp.					X		X	X					
Stolephorus bataviensis								X					
S. buccaneeri				X	X			X					
S. commersoni					X		X						
S. devisi								X				X	
S. heterolobus					X		X				X	X	
S. indicus					X		X	X		X	X		
S. purpureus				X									
S. zollingeri											X		
Thrissina baelama					X			X					
Thryssa setirostris								X					
GOBIIDAE (gobies)													
Glossogobius giurus					X								
KUHLIIDAE (flagtails)													
Kuhlia sandvicensis				X	X								
LABROCOGLOSSIDAE													
Labrocoglossa argentiventris												X	
LEIOGNATHIDAE													
Gazza minuta												X	
LUTJANIDAE (snappers)													
Caesio coerulaureus								X			X		X
C. chrysozonus								X			X	X	X
C. diagramma											X		
C. tile											X		X
C. xanthonotus											X		
Gymnocaesio argenteus							X						
G. gymnopterus								X					
Lutianus vaigensis					X						X		
Pterocaesio pisang								X					
MUGILIDAE (mullets)													
Crenimugil crenilabis			X		X								X
Mugil sp. (several)				X	X								
Mugil cephalus				X									
M. logimanus			X	X	X								
M. trichilus			X										
M. vaigiensis			X		X								
Neomyxus chaptalii				X									
MULLIDAE (goatfishes, surmullets)													
Mulloidichthys sp.				X									
Mulloidichthys auriflamma				X	X								X
M. samoensis				X		X	X						
Parupeneus sp.											X		
Parupeneus pleurostigma				X									
Upeneus sp.												X	
Upeneus tragula												X	
PEMPHERIDAE													
Parapriacanthus beryciformis											X		
PLECOGLOSSIDAE													
Plecoglossus altivelis				X									
POECILIIDAE (topminnows)													
Gambusia sp.				X									
Gambusia affinis					X								
Poecilia sp.				X									
Poecilia latipinna				X									
P. mexicana					X								
P. sphenops				X									
P. vittata				X									
POLYNEMIDAE (threadfins)													
Polydactylus sp.	X												
Polydactylus sexfilis				X									
POMACENTRIDAE (damselfishes)													
Abudefduf anabatoides											X		
A. coelestinus							X						
A. dicki											X		
Chromis caeruleus											X		X
C. ternatensis											X		X
Dascyllus trimaculatus												X	
Pomacentrus pavo							X						
PRIACANTHIDAE (bigeyes)													
Priacanthus sp.							X						
PRISTIPOMATIDAE (salemas)													
Xenistius californiensis	X												
Xenocys jessiae	X												
SCOMBRIDAE (tunas, mackerels)													
Rastrelliger kanagurta					X			X		X		X	
Scomber japonicus	X								X		X		
SPHYRAENIDAE (barracudas)													
Sphyraena obtusata										X		X	X
TETRAGONURIDAE													
Tetragonurus atlanticus							X						

Baitfish Evaluation

Information on the success of various species for attracting and holding skipjack tuna was taken from reports and is not my evaluation. The three selections in this category are general terms since many reports were of a very general nature. For more specific information than is given in Table 1, see the appropriate text section and citation.

A baitfish may be more successful on one occasion than on another. Suehiro (1938) reported that offshore skipjack tuna schools responded better to pole-and-line fishing than schools close to shore and that morning was the best time for fishing. Also, spring was a better time than autumn. The method in which the vessel approaches the school, type of natural food items in their stomachs, and the length of time since last feeding all affect skipjack tuna response to fishing. It was noted by Uda and Tsukushi (1934), Aikawa (1937), and Sasaki (1939) that there is a seasonal difference in the response of skipjack tuna. Also, oceanographic conditions, density of the skipjack tuna school, and relation of the school to birds, floating logs, sharks, or whales may affect their response to live bait. Strasburg and Yuen (1960) described a "feeding frenzy" in which tuna indiscriminately fed on any small object in the water. Strasburg (1961) observed that diving schools were difficult to attract with live bait. Even after fishing had begun, it was often interrupted by the school periodically diving. Yuen (1962, 1969), Kearney et al. (1972), and Lewis et al. (1974) reported a difference in the response of skipjack to live bait that was apparently associated with the vessels' water spray system.

A description of the different types of tuna schools and associated terminology is given by Scott (1969) and Lewis et al. (1974) and a review of field observations on tuna behavior by Nakamura (1969). Studies on the nehu indicate that approximately 50% of the skipjack tuna schools chummed in Hawaiian waters do not respond to chumming. The time of day, weather conditions, experience of the fishermen, and type of skipjack tuna school may influence the effectiveness of nehu. Yuen (1959) indicated that biting response was not affected by weather conditions or time of day. Factors related to biting response while fishing with nehu were the distance from land, skipjack tuna stomach contents, and whether skipjack tuna were feeding on fast-swimming or slow-swimming fishes.

The geographical areas outlined in Figure 1 are primarily for convenience in locating areas discussed in the text and recorded in Table 2. The numerical sequence in Table 2 is arbitrary and does not indicate political affiliations or importance as baiting areas. Although some faunal entities may be suggested in Figure 1, it is not intentional, but simply an aid for locating unfamiliar and remote places within an area as extensive as the Pacific Ocean. Since many Pacific bait species are wide ranging forms that have also been used in other areas, pertinent information on these outside the Pacific area has been included in the text. Many species not used in the Pacific Ocean for skipjack tuna but noted as being used elsewhere are not included (e.g., Labridae). For additional information on these see: Anderson et al. (1953), Rawlings (1953), Siebenaler (1953), Jones (1958, 1964a), Bane (1961), Raju (1964), and Thomas (1964).

BAITFISH FAMILIES

Albulidae

The bonefish, *Albula vulpes*, is not extensively used as a baitfish but juveniles were considered an excellent bait for pole-and-line fishing by June and Reintjes (1953). Young *A. vulpes*, 5.0 to 7.5 cm in length, are slender, elongate, and silvery. They school along sandy shores and on reef flats and are captured in seines during the day or by night lighting. Jones (1964a) noted this species is used in the Indian Ocean and small individuals are suitable baitfishes. They are usually captured in small numbers while seining for other species.

Apogonidae

Cardinalfishes are small, nocturnal, reef-dwelling fishes. They are widely distributed throughout the warm and temperate seas of the world and are noted to aggregate near coral reefs and coral heads. Their coloration is quite variable, many species displaying exotic colors and color patterns while some are drab in appearance. Because of their nocturnal habits and close proximity to coral reefs, catching sufficient quantities for fishing requires specialized techniques. These fishes are effective bait and are reported to be slow in movement (Anonymous 1937a). They were extensively used as live bait especially in the Ryukyu Islands (Cleaver and Shimada

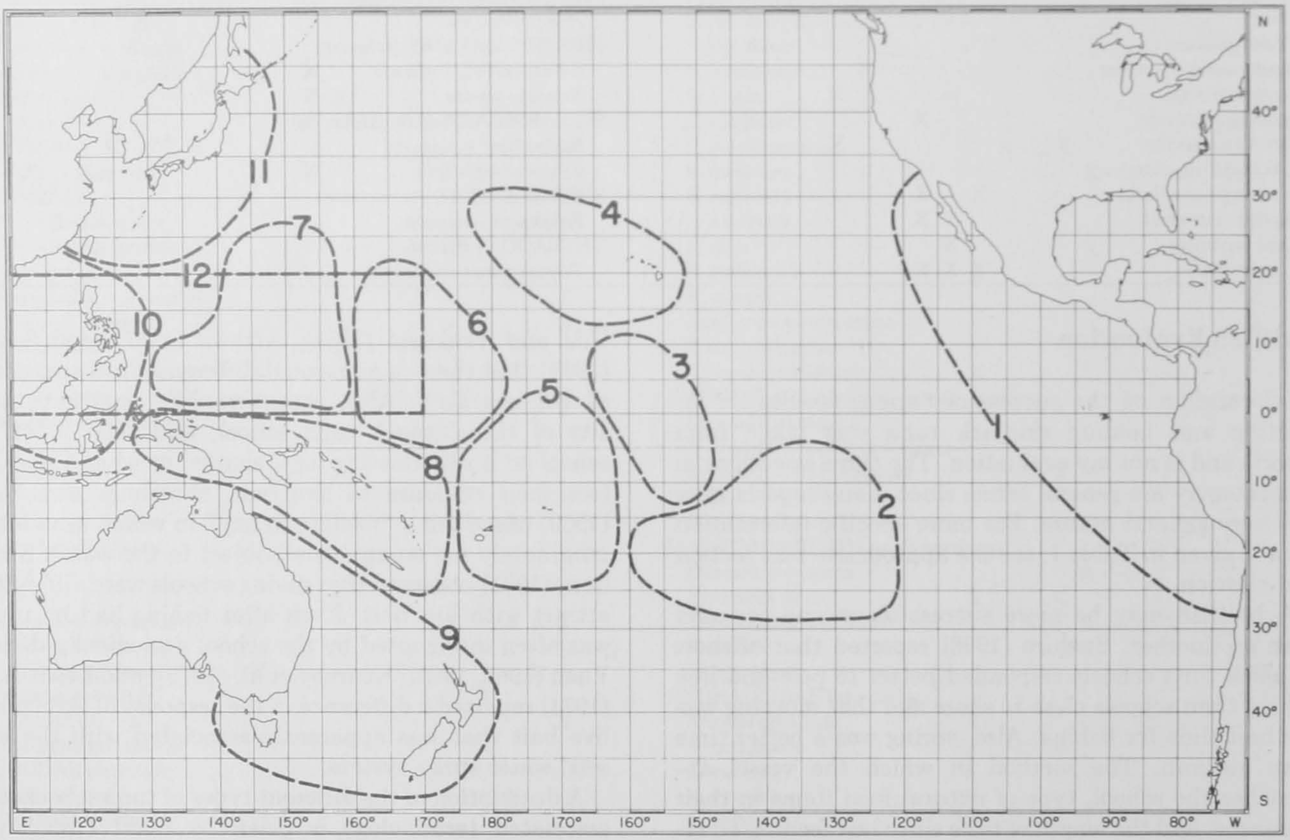

Figure 1.—Geographical location of the use of live baitfishes in the Pacific Ocean (see Table 2).

1950; Isa 1972), Palau (Anonymous 1937a; Wilson 1963), and Truk (Wilson 1963, 1971), while Jones (1964a) and Raju (1964) recorded their use in the Indian Ocean.

They are hardy and can be kept in confinement with reasonable care (Marukawa 1939; Jones 1964a; Wilson 1971). In Palau, cardinalfishes are excellent bait; they survive well aboard ship and are easily captured (Anonymous 1937a). They were noted to be present all year, especially between January and May, but their abundance fluctuates. Some preference for cardinalfishes by skipjack tuna was indicated in an unpublished report by Wilson,[3] primarily from information obtained through Palauan fishermen. They said it was a better baitfish than *Spratelloides delicatulus* because it came to the vessel faster, remained longer, and had a lower mortality in the baitwells; but it is the least abundant of the live-bait species in Palau. Wilson (see footnote 3) noted that an average staghorn coral head yielded about five to six 4-gal buckets of live bait in 1 h. Two mo were required before the same coral head could be fished again and 4 to 5 mo before the population returned to normal.

In Truk, the akaesa, *Rhobdamia cypselurus*, is an excellent baitfish and second only to the takabe, *Gymnocaesio argenteus* (Wilson 1971). They form aggregations under coral heads and are captured with special nets at night. Details of this method and the drive-in net method of capture are given by Marukawa (1939), Shapiro (1949), Wilson (1971), Isa (1972), and Hester (1974).

Kearney et al. (1972), recorded three species captured by using night-lighting methods in New Guinea. They were: *R. cypselurus*, *R. gracilis*, and *Archamia lineolata*. Lewis et al. (1974) noted that *R. cypselurus* was a satisfactory and easily handled species, but not abundant. Jones and Kumaran (1964) noted that it is occasionally captured in appreciable numbers.

Rhabdamia gracilis, 4.1 to 5.9 cm, is used in Fiji as a baitfish but it is not important (Lee 1973).

Archamia bleekeri was reported to be hardy in confinement and effective as baitfish for skipjack tuna in the "south seas" (Marukawa 1939). Two additional species of *Archamia* of some importance are *A. lineolata* and *A. fucata*. The former was reported by Jones (1964a) to be the most important apogonid in the Laccadive fishery, but it exhibits rapid fluctuations in abundance. The latter species and *A. notatus* are important baitfishes in the Ryukyu Islands fishery (Isa 1972). The quantity of apogonids taken from three major localities in this fishery in 1966 and 1967 were 71.7 and 111.1 t, respectively. They were captured in a manner similar to that described by Wilson (1971) for the Truk fishery and occasionally by inserting tree leaves in the crevices and chasing the fish into a net. Cleaver and Shimada (1950) listed *Amia truncata* as used in Japan and the Ryukyu Islands fisheries without comment. This species is apparently as synonym of *Apogonichthys poecilopterus* (Herre 1953).

Most cardinalfishes are reported to be abundant near reefs, especially around coral heads (Uchida 1970). Hida (1971) observed cardinalfishes around coral heads and scattered along the shallow reef in Micronesia, but it was impractical to capture them in sufficient quantity for a tuna clipper.

From the information available on cardinalfishes and their use as bait for skipjack tuna, it appears that most species are seasonal but can be used if found in quantity and in localities where they can be captured.

Atherinidae

Silverside are found throughout the warm Pacific and are generally considered hardy live baitfishes easily kept in captivity for extended periods. The various species are slender, silvery, and with moderately large scales that are firmly attached. They are found inshore along sheltered and semisheltered beaches, reef flats, in or near mangroves, or over sandy and mud bottoms. Capture methods include both beach seining and night lighting. The iao, *Pranesus insularum*, is the second most important baitfish in the Hawaiian fishery (Eckles 1949; Smith and Shaefer 1949; June 1951a; Ikehara 1953; June and Reintjes 1953). Although it is a good, hardy baitfish, seasonal fluctuations in abundance make it an unreliable source of bait (June and Reintjes 1953). Uchida and Sumida (1973) reported that when *P. insularum* is thrown as chum at sea it balls up and remains close to the vessel. Yuen (1961,[4] 1969) noted silverside elicited less response from skipjack tuna than either *Caranx* sp. or nehu. It is hardier and generally larger than the nehu and subject to fewer injuries (Welsh 1950), but Hawaiian fishermen still prefer the nehu as live bait for skipjack tuna.

Uchida and Sumida (1973) reported fair to good quantities of *Pranesus pinguis*, 6.5 to 8.9 cm, at Majuro in the Marshall Islands. This species is a satisfactory baitfish and exhibits low mortality after handling. In Fiji, *P. pinguis* is hardy, vigorous, and withstands crowding with proper care (Lee 1973). This species and the sardine, *Herklotsichthys punctatus*, made up 81% of the 1972 baitfish catch in Fiji. Smith and Schaefer (1949) observed silverside (probably *P. pinguis*) along beaches and cliffs at Palau and it was the only species caught in quantity. Little information is available on the use of *P. duodecimalis* in the Philippine fishery (Domantay 1940a, 1940b) and in the Laccadive fishery, Indian Ocean (Jones 1964a). Jones (1964a) noted that it is hardy, occurs in shoals, and that this species and *Allanetta forskali* are the most dominant of four silverside.

Of the five species of *Allanetta* used for fishing skipjack tuna, only limited information on their use is

[3]Wilson, P. T. Undated. The bait resources of the Palau Islands. Mimeogr., 21 p. Hawaiian Tuna Packers, Ltd., Honolulu, HI 96809.

[4]Yuen, H. S. H. 1961. Experiments on the feeding behavior of skipjack at sea. Report presented at Pacific Tuna Biology Conference, Lake Arrowhead, Calif., August 1961, 6 p. U.S. Bur. Commer. Fish. Biol. Lab., Honolulu, HI 96812.

available. According to Wilson (see footnote 3) the teber, *A. woodwardi*, with an average length of 4.96 cm, is quite hardy. In Palau it is not necessarily a good baitfish since skipjack tuna seemed to prefer other species. Hooks baited with teber were less effective than hooks baited with mekebud, *H. punctatus*. It is present all year in brackish water and seawater habitats; it is not attracted to night lights. Wilson (1971) noted that it is a poor baitfish at Truk and not found in commercial quantities. It is not important in the Ryukyu Islands fishery (Isa 1972), although it is used to some extent. *Allanetta forskali* is used less than other forms of *Allanetta*. Jones (1964a) noted that in the Laccadives it occurs in schools and is hardy. Kearney et al. (1972) reported that silverside were second in abundance to anchovies with *A. forskali* and *A. valenciennei* being the most common in Papua New Guinea. They were attracted to lights and easy to handle, but they were not very successful in attracting skipjack tuna. Marukawa (1939) noted that *A. valenciennei* was seldom used, however, they were considered a good, but delicate, baitfish in Palau (Anonymous 1937a). June and Reintjes (1953), Wilson (1971), and Lee (1973), reported *A. ovalaua* is relatively hardy and can be easily carried on vessels. It is rarely captured in large numbers in the Phoenix Islands (June and Reintjes 1953). In Truk, Wilson (1971) noted that it is used only when other bait species are not available. Lee (1973) listed *A. ovalaua* (4.7 to 8.0 cm) as one of the important bait species in Fiji. *Allanetta bleekeri* is listed by Cleaver and Shimada (1950) as having been used as live bait in the Japanese and the Ryukyu Islands fisheries along with *Hypoatherina tsurugae*.

Silverside reported as *Atherina* sp. from Pacific localities can be more correctly listed as *Pranesus* or *Allanetta* since the former genus is restricted to European species (Schultz 1948). The only eastern Pacific silverside reportedly used as live bait is *Atherinops* sp. (Alverson and Shimada 1957).

Arripidae

The young of one species of this family, *Arripis georgianus*, was noted by Sampson (1962) as being successfully used for live bait in Australia. It is an elongate, compressed fish with large scales and reported to reach an average length of 22.8 to 25.3 cm. The juveniles have a series of golden bars that disappear with age.

Berycidae

Considering the fact that members of this genus are known to be deep-sea fishes, the record of *Beryx decadactylus* being used in Japan and the Ryukyu Islands as live bait for skipjack tuna (Cleaver and Shimada 1950) appears questionable.

Carangidae

None of the carangids listed appear capable of supplying the annual quantities of baitfishes required by a pole-and-line fishery. They are predominantly silver, some species having dark bars, and the body is compressed and quite variable in shape. Only the juveniles are used and they are most often captured with night lights and lift nets or with drive-in nets inshore over a sandy bottom. Occasionally limited numbers are captured in bait seines during the day along with other species. They are available on a seasonal basis, hardy, and effective in attracting skipjack tuna.

Sea tests using *Trachurus declivis* as a live baitfish were conducted in Australia (Flett 1944). They were captured with a "hood net" alongside the wharf at Eden, New South Wales. When "liberated" they immediately sought shelter under the vessel. Blackburn and Rayner (1951) tested *T. declivis* and *Sardinops neopilchardus* off New South Wales and reported good catches. Roughley (1966) described tests with young *T. declivis* that were captured in a lampara net at night. *Trachurus japonicus* was used as a live baitfish in the "south seas" (Marukawa 1939; Cleaver and Shimada 1950). Before the anchovy, *Stolephorus heterolobus*, was known to be abundant, *T. japonicus* was one of the principal baits for skipjack tuna (Marukawa 1939). They are captured at night using "fishing lights" and lift nets. An important carangid in the Saipan fishery is *Selaroides leptolepis* and it appears to hold about the same level of importance as *T. japonicus* (Marukawa 1939; Cleaver and Shimada 1950).

Alverson and Shimada (1957) listed *Trachurus* sp. as a miscellaneous baitfish infrequently used in the eastern Pacific fishery.

The genus *Decapterus* has been reported by various authors in several areas including the eastern Pacific, but little information appears to be available on its use. Imamura (1949) listed *D. muroaji* as being used in Japan, but made no additional comment. Isa (1972) listed *D. macrosoma* and *Selar crumenophthalmus* as being used as bait in the Ryukyu Islands fishery, with the latter the more important of the two. The quantity of both species used in this fishery from three major localities in 1966 and 1967 was 41.4 to 17.7 t, respectively. Cleaver and Shimada (1950) noted *D. russelli* was used by the Japanese fishery in the "south seas" and its use has been reported in Ponage (Anonymous 1937a, 1937b).

Decapterus sp. is a baitfish, reported by Ikebe and Matsumoto (1938), that is used in Saipan and usually captured during the day in dip nets with other bait species. These fish are found outside the reef where they sometimes school around vessels at anchor. Their season is irregular from June to September; they are not present every year. At Ponape the young of *Decapterus* were noted as being abundant in shallow areas where they are taken with drive-in nets (Anonymous 1937b). Lewis et al. (1974) considered *Decapterus* sp. as having the most potential among the carangids in the Papua New Guinea area, but this species and *Selar* sp. were not sufficiently abundant to critically evaluate. *Decapterus* sp. and *Selar* sp. appear in the lagoons of the Gilbert and

Ellice Islands at certain times, but night lighting did not attract sufficient quantities (UNDP/FAO 1969). A report by Welsh (1950) noted that young opelu, *D. pinnulatus*, and young akule, *S. crumenophthalmus*, were occasionally used in the Hawaiian fishery. These two plus two species of topminnows, *Poecilia sphenops* and *P. latipinna*, and the piha, *Spratelloides delicatulus*, made up about 1% of the total live-bait catch in Hawaii during 1947.

Juvenile *Caranx* evidently are not used as bait to any great extent, although occasional use was noted by Cleaver and Shimada (1950) and by Lee (1973). In Fiji, *Caranx* sp., 6.3 to 8.5 cm in length, are taken in small quantities while night lighting. Tests were conducted at sea in Hawaii by Yuen (see footnote 4; 1969) with *Caranx* sp.,[5] *Kuhlia sandvicensis* (Kuhliidae), and *Pranesus insularum* (Atherinidae). The attack rate by skipjack tuna was greater with the vessel's water spray on during chumming with *Caranx* sp. and *K. sandvicensis* than when turned off. Yuen (see footnote 4) also noted that when *Caranx* sp. was tested in alternate periods with *P. insularum*, *Caranx* sp. elicited a greater response. Hida (1971) reported jacks, mostly *Caranx* sp., common in Micronesia in the shallows close to shore or occasionally along the lagoon dropoff, but they were not found in large concentrations.

The most widely used carangid baitfish is the bigeye scad, *Selar crumenophthalmus*. The young appear inshore in large schools seasonally where they are captured in surround nets, set nets, or by using night lights. In Saipan the season is from June to September and they are considered suitable bait for medium and large skipjack tuna (Ikebe and Matsumoto 1938). Uchida and Sumida (1973) observed juveniles along the beaches in American Samoa but not in large quantities. In Fiji they are captured by night-lighting methods and considered hardy (Lee 1973). They are also used in the Philippine fishery (Domantay 1940a), in the "south seas" (Marukawa 1939; Imamura 1949; Cleaver and Shimada 1950), and in the Ryukyu Islands (Isa 1972).

Three species of leatherbacks (genus *Scomberoides*) have been used as live baitfish for skipjack tuna. They include *S. tol* reported by Lee (1973) in Fiji; *S. lysan* reported by June and Reintjes (1953) in Hawaii; and *S. toloo* used in the Philippine fishery (Domantay 1940a, 1940b). According to Smith-Vaniz and Staiger (1973), *S. toloo* may be a synonym of *S. tala*. In Hawaii, the lae, *S. lysan*, is taken incidentally when seining for nehu. Large numbers of juvenile lae are frequently taken during the spring and summer. Hawaiian fishermen dislike the lae because of painful stings received from the sharp dorsal and anal spines, and they are considered a nuisance. In addition they prey upon nehu in the baitwells and are responsible for high mortalities when present in numbers (Halstead et al. 1972).

Marukawa (1939) reported that *Carangoides malabaricus* is an important baitfish in Saipan, and Cleaver and Shimada (1950) noted its use in the "south seas." Additional carangids used as live baitfish include *Magalapsis cordyla* in the Philippines (Domantay 1940a, 1940b), *Atule djebada* in Japan and the Ryukyu Islands (Cleaver and Shimada 1950), and *Chloroscombrus* sp. in the eastern Pacific (Alverson and Shimada 1957). Small carangids called gatsun (probably *Atule djebada* or *Selar crumenophthalmus*) were a principal baitfish at one time in Saipan (Marukawa 1939). Wherever small carangids are captured in sufficient quantity they can be employed successfully as a live baitfish for tuna. Their ability to attract skipjack tuna and to survive confinement in baitwells is relatively good.

Chanidae

Only small juvenile milkfish are of a suitable size for live-bait fishing. When obtainable, they are effective and quite hardy. The young are silvery, with elongate, compressed bodies. They form schools along beaches and reefs in shallow water where they are captured by seine.

Yuen and King (1953) reported catching yellowfin tuna, *Thunnus albacares*, in the Line Islands with live bait that consisted of mullet (species unknown) and juvenile milkfish, *Chanos chanos*. Warfel (1950) reported young milkfish as a suitable baitfish in the Philippines. Since milkfish are in demand as a food fish, the price is usually excessive for economical use as live bait. Tests at sea demonstrated they were easy to handle, schooled well in the bait tanks, and were attractive to tuna. The satisfactory size was noted as being around 35 to 44 milkfish per kilogram.

Juvenile milkfish may be of value in the future as a live baitfish if techniques for producing them economically and in quantity throughout the year are developed. There is a possibility of culturing milkfish in Fiji (UNDP/FAO 1969) and Sri Lanka (Samarakoon 1972) as a source of live baitfish.

Cichlidae

Several species of *Tilapia* have been introduced to Hawaii as an aid in controlling aquatic vegetation, as food fish, and as a possible source of live baitfish (Brock 1960). They are a hardy perchlike fish, with a deep, compressed body; the adult females are usually grey with dark vertical bands and the males black above. The young have several dark fin markings but generally resemble the adult female.

In Hawaii they are found in freshwater impoundments, stream mouths, and in bays and harbors in seawater. *Tilapia mossambica* has received considerable attention as a possible baitfish for skipjack tuna, including studies of its culture potential (Brock and Takata 1955; King and Wilson 1957; Hida et al. 1962; Uchida and King 1962).

Extensive tests were conducted at sea with juvenile *T. mossambica* (Brock and Takata 1955; King and Wilson 1957; Hida et al. 1962; Shomura 1964; Yuen 1969). These tests demonstrated that tilapia is an effective baitfish

[5]Yuen (see footnote 4, p. 1) listed this species as *Caranx mate*.

but it is evidently not as good as the traditional nehu. Individuals larger than 2.5 cm tend to "sound" when chummed, while the small individuals stayed near the surface and swam along with the slowly moving vessel. King and Wilson (1957) and Hida et al. (1962) noted that tilapia were slow swimmers requiring a reduced vessel speed. They performed well on "wild" schools and were especially good for large skipjack tuna. When used as bait on skipjack tuna, tilapia elicit a hard-biting quality that is considered a very favorable reaction (King and Wilson 1957). No noticeable differences in the behavior of nehu and tilapia were reported when they were chummed alternately on the same school. During sea tests scuba divers followed tilapia and threadfin shad, *Dorosoma petenense*, to a depth of 23 m before discontinuing the pursuit (Iversen 1971). This diving behavior by tilapia over 5 to 6 cm in length may not be detrimental to the taking of hard-biting skipjack tuna schools (King and Wilson 1957).

Shomura (1964) suggested designing an artificial lure specifically for use with tilapia since the standard nehu lure used in Hawaii may not be completely suitable. Sea tests conducted in 1958 and 1959 (Anonymous 1960) demonstrated successful use of juvenile tilapia in Hawaiian waters. In 1958 and 1959 the average catches per pound of tilapia live bait were 46 and 92 pounds, respectively, of skipjack tuna. For the same years the average catch rates using nehu were 50 and 57 pounds, respectively.

The importance of *Tilapia mossambica* as a live baitfish in the Laccadive fishery, Indian Ocean, was reported by Jones (1964b). It was introduced into ponds on Minicoy Island as a supplementary baitfish to be used when natural baitfish supplies were scarce.

Culture of *T. mossambica* as a live baitfish was considered worthwhile in American Samoa by Villaluz (1972) and in Fiji (UNDP/FAO 1969).

Clupeidae

Clupeids are used throughout the Indo-Pacific as live baitfishes for skipjack tuna. Of the 30 or more species reportedly used, all apparently have a high attraction rate for skipjack tuna. They resemble each other closely and separation of the various species is usually difficult. They are schooling fishes, silvery in color, with a compressed, elongate to moderately deep body usually lacking prominent markings. Juveniles less than 7.5 cm in length are undoubtedly used, but sizes from 7.5 to 15 cm are in demand.

They are reasonably hardy if handled with care and survival rates range from good to poor. It is difficult to assign a relative "hardiness" rating to most species due to the number of variables associated with their capture, handling, and subsequent confinement. Although many factors related to their confinement aboard ship influence survival, baitwell mortalities also reflect the degree of injury and scale loss received during capture and loading.

Baitfish size may also affect survival, as indicated by Anderson et al. (1953). They noted that small thread herring, *Opisthonema libertate*, are hardier than large individuals. Ikebe and Matsumoto (1938) stated that a baitfish should be selected first for its desirability and secondly for its hardiness, and that the best baitfishes are fat sardines 6 to 9 cm in length. It was observed that lean baitfishes are more subject to injury and stress than fat baitfishes. Cleaver and Shimada (1950), in reference to *Sardinops melanosticta* and the Japanese anchovy, *Engraulis japonicus*, stated that small fish are more resistant to the effects of confinement although they are more liable to injury from handling. They concluded that the most desirable baitfish size is from 7.5 to 12.5 cm and that small fish are as attractive to skipjack tuna as larger fish and a greater number can be carried in the baitwells.

Species such as *Clupea bassensis* and *Sardinops neopilchardus* from southern Australia represent future baitfish resources in that area (Flett 1944). Sampson (1962) noted that *S. neopilchardus* is the next most difficult baitfish species to keep with *Engraulis australis* (Engraulidae) being the most difficult. An interesting note by Roughley (1966:213) briefly mentioned successfully substituting small brass cylinders in place of live pilchards, *S. neopilchardus*, when fishing tuna in Australia.

Baitfish surveys conducted in 1970 and 1972 provide considerable detail of the Japanese method of bōuke net fishing for pilchard, *S. neopilchardus*, and anchovy, *E. australis*, in New Zealand (Webb 1972a). Webb noted that the best temperature for bōuke netting pilchard was 15°-19°C and that pilchard were too lively or did not surface at higher temperatures. If predators were present, the baitfish were scary; if too deep, the baitfishes would not be attracted to the light. In addition, the weather had to be favorable with a light breeze of 0 to 10 kn and a calm water surface. The baitfish survived from 3 to 8 days in the baitwells. Although there were quantities of pilchard in the area, bōuke net fishing was considered unsuccessful. In Tasmania, difficulties were experienced when night lighting pilchard because predators disrupted the concentrations of baitfishes (Anonymous 1951).

Webb (1972b) described in detail a bait fishing survey in the Marlborough sounds, New Zealand, using purse seining gear. Webb noted that altering engine or propeller speed when setting the seine caused the baitfishes to scatter. The best method of seining at night was to leave the lights turned off until just prior to setting the net. Baitfishes were observed to concentrate near the light soon after it was turned on and then to gradually disperse.

Bait was kept in holding pens for 5 days or more before being loaded aboard the fishing vessel to allow time for the baitfishes to acclimate and the weaker individuals to die off. Apparent panic or stress behavior by the baitfishes was due to overcrowding, presence of predators, confining nature of the purse seine, or to sudden flashes of light. Also, among newly caught baitfishes, this behavior was caused by vessel vibration, vessel motion, lighting, and variable sea temperatures. Mortalities in the holding pens ranged from 3.5 to 17%, averaging 10.6%. During the survey the best bait catches were made at night, with 85% of the bait being captured during hours of darkness.

Webb (1972b) also observed that following each storm, baitfishes were absent from shallow waters and were located by an echo sounder at depths below 27 m. They returned to shallower water following 24 to 36 h of calm weather. Additional observations were reported on the effects of precipitation, moon phase, presence of predators, and light intensity on capture. Schools of bait accumulated near the bait-filled pens, indicating that schools of captive bait attracted nearby concentrations. Webb (1972b) suggested that this attraction was caused by school noise from the captive baitfishes. Lewis et al. (1974) also used echo finders to locate, identify, and follow baitfish movements during night-lighting operations in New Guinea.

Kearney et al. (1972) listed three clupeids, *Pellona ditchela*, *Sardinella jussieu*, and *S. sirm*, as potentially useful baitfishes in New Guinea. The former species was noted by Lewis et al. (1974) to be an attractive baitfish in spite of its larger size.

Observations on baitfish resources were made in the western Pacific by Smith and Schaefer (1949). They reported the flat herring, *Sardinella* sp., in the Marshall Islands, at Truk, and at Palau, and noted that occasionally they were difficult to capture. At Palau the herring were wild and would dart under and around the bait seine or, when once surrounded by the net, they would jump over the corkline. Similar difficulties associated with capture were also noted by Peterson (1956) with *Harengula* sp. and with the thread herring, *Opisthonema libertate*, in Costa Rica. Wilson (1971) observed that the sardine, *Herklotsichthys punctatus*,[6] was easily taken by day bait nets in Truk while Lee (1973) noted that *H. punctatus* and the anchovy, *Thrissina baelama*, were "skittish" when captured by night lift net. Kearney et al. (1972) observed that *H. punctatus* (reported as *H. ovalis*) was the most abundant and widely distributed clupeid in New Guinea waters and the only species of *Herklotsichthys* so far recorded there. According to Lewis et al. (1974) it occurs regularly and in quantity. Observations indicate it schools near the surface, shows erratic vertical movements, and appears to be a good baitfish.

Two species of the subfamily Dorosomatinae come within the scope of this report; the threadfin shad, *Dorosoma petenense*, used experimentally in Hawaii, and *Konosirus punctatus*, a commercial species used in the Ryukyu Islands. Although little information is available on *K. punctatus*, Isa (1972) reported that 1.0 and 6.8 t were captured in 1966 and 1967, respectively, from several localities in the Ryukyu Islands.

Tests at sea have demonstrated that threadfin shad is an effective live baitfish for skipjack tuna. Preliminary tests reported by King et al.[7] demonstrated the effectiveness of shad when compared with nehu. The average size was 72 mm fork length, and the baitwell mortality during the test period was insignificant. Observers noted that they swam along with the vessel and skipjack tuna seemed to strike the shad more vigorously than the nehu, but the catch rate dropped off when shad were in use. A hypothetical explanation for this reduced catch rate was termed "instantaneous conditioning," in which the skipjack tuna would not respond as well to the nehu lure when shad was used. Strasburg (1959) observed a similar reduction in catch rate and attributed this to a "too-conspicuous" or a "too-active" baitfish.

On an exploratory cruise to the eastern Pacific shad were used quite successfully (Hida 1970a). They held up well during the 5-wk cruise and demonstrated their effectiveness as skipjack tuna bait. A subsequent report (Hida 1970b) noted high mortalities of shad while en route to Samoa from Hawaii, probably the result of rough seas during the 10-day trip.

A series of tests were conducted in Hawaiian waters (Iversen 1971), and shad were judged to have the ability to produce catches similar to the nehu. Iversen noted that shad were as effective as nehu in their ability to lure skipjack tuna to the vessel, to concentrate tuna at the fishing station, and to catch tuna. Underwater observations showed shad had a swimming behavior similar to the nehu, with some differences. The diving angle was usually 45° to 65°, not as steep as the nehu, and they did not swim as fast or dodge as vigorously. They are more visible underwater because of a deeper silvery body than the nehu. Both species were observed to dive but to return to the surface when pursued by skipjack tuna and to swim alongside the vessel. When followed by scuba divers, shad were recorded to dive to 23 m, at which depth the divers discontinued the pursuit (Iversen 1971). Supplies of threadfin shad were seined from a freshwater reservoir near Honolulu. They were then transported on trucks to Kewalo Basin for acclimation to seawater before being placed into baitwells.

Sea trials were conducted in Hawaii using threadfin shad or nehu simultaneously with a purse seine ([Hawaii.] Division of Fish and Game and Bumble Bee Seafoods [1970?]). Chumming directly from the purse seiner was unsuccessful as were experiments with drifting bait dispensers and chumming from a skiff. But working in cooperation with a commercial fishing vessel demonstrated that skipjack tuna can be captured using shad in a bait-purse seine operation. The shad were noted to swim away from the vessel or sound, and skipjack tuna did not take them as well as nehu, but successful fishing was reported when skipjack tuna schools were first attracted with nehu before chumming with

[6]I follow Whitehead (1964:273-284) in using *Herklotsichthys* as the generic name for all Indo-Pacific species of the family Clupeidae that were formerly placed in the genus *Harengula*. *Harengula thrissina* (Jordan and Gilbert) is an eastern Pacific form.

[7]King, J. E., D. W. Strasburg, H. S. H. Yuen, and P. T. Wilson. 1958. Introduction of threadfin shad to Hawaii and initial tests on its use as skipjack bait. Unpubl. rep., 8 p. Pacific Oceanic Fishery Investigations, U.S. Fish Wildl. Serv., Honolulu, HI 96812.

shad. They were considered a suitable supplementary baitfish with a high rate of survival. A practical test with shad was conducted aboard the MV *Marlin* (R. T. B. Iversen, National Marine Fisheries Service, Honolulu, pers. commun.) but the overall catch rate was considerably less than that of other vessels fishing simultaneously and using nehu.

Techniques developed for capturing and handling threadfin shad are described by Iversen and Puffinburger (1977). Details concerning their introduction to Hawaii are given by Hida and Thomson (1962), and Shang and Iversen (1971) reported on the economics and culture feasibility.

The genus *Sardinella* (see Chan 1965) is represented by a dozen or more species used as live baitfish for skipjack tuna in the Pacific. The Marquesan sardine, *S. marquesensis*, is moderately abundant in the Marquesas area (Royce 1954; Anonymous 1957; Wilson and Rinkel 1957) and is thought to be effective as a live baitfish; however, Wilson and Austin (1959) believed the supply unreliable. Successful fishing was reported following a survey in the Marquesas and Tuamotus by the National Marine Fisheries Service research vessel *Charles H. Gilbert* (Anonymous 1957). Wilson and Austin (1957, 1959) reported Marquesan sardines form small schools, return to the vessel when chummed, and are quite suitable for skipjack tuna. They were captured in bays over a shallow sandy bottom and were attracted to lights. More sardines were attracted by a diffused light than by an intense light from a single bulb. They withstand crowding once acclimated to shipboard conditions and survive for extended periods.

The introduction of this species to Oahu, Hawaii, as a supplementary live baitfish was reported by Murphy (1960). Although it has successfully spawned in Hawaii and spread to the islands of Hawaii, Kauai, and Maui, it is not taken in any significant quantities by tuna fishermen (Hida and Morris 1963; Randall and Kanayama 1972).

The species of *Sardinella* that appear to be the most important as live bait include *S. leiogaster* (Anonymous 1937a; Marukawa 1939; Domantay 1940a, 1940b) and *S. melanura* (Domantay 1940a, 1940b; Wilson 1971; Hida 1973). Both species are satisfactory baitfishes and individuals 7.5 to 15.0 cm in length are the most desirable size for skipjack tuna. *Sardinella leiogaster* is considered to be hardy and a preferred species in the Philippines (Domantay 1940a, 1940b) while Marukawa (1939) considered this species fragile in the "south seas."

Little information is available on the remaining species of *Sardinella* as applied to pole-and-line fishing. Isa (1972) listed *S. sindensis* as commonly used in the Ryukyu Islands fishery and Lee (1973) noted that *S. sirm* is important in Fiji, while *S. stolefera* is occasionally used in the eastern Pacific (Schaefer 1963). Domantay (1940a, 1940b) noted *S. perforata* is used but not preferred in the Philippine fishery.

Wilson (see footnote 3; 1971), Hida (1973), Lee (1973), and Uchida and Sumida (1973) noted that *Herklotsichthys punctatus* has potential as a live baitfish in the Marshall Islands, Truk, Palau, and Fiji. Hida (1971) observed large schools ranging in size from hundreds of buckets to over 25 tons at Jaluit and Majuro Atolls, Marshall Islands. They school along the shore and are readily captured in seines during the day. Inamura (1949) noted that they concentrate in the shade of trees nearshore. They were not used in Palau by the Japanese and Okinawans since they grew too large for use on the smaller skipjack tuna of that area (Wilson see footnote 3). They are reasonably abundant in quiet, sheltered waters but move into deep waters at night and are occasionally known to completely disappear from some areas. Following World War II, Palauan fishermen preferred this species because it was not necessary to fish for them at night. It is attracted to lights and is considered to be a good baitfish, relatively hardy, easily transported, and lasting for several days under crowded conditions. Eighty-one percent of the baitfish catch in Fiji during 1972 was this species and *Pranesus pinguis* (Lee 1973).

Herklotsichthys ovalis is used as a baitfish in the Ryukyu Islands fishery (Isa 1972). This species plus *Sardinella clupeoides* and *S. sindensis* made up 7.8 and 4.8 t of clupeids captured from three major localities in 1966 and 1967, respectively. Ikebe and Matsumoto (1938) once observed a few *H. ovalis* about 12 cm long at Saipan. Large schools were later collected using night-lighting methods. Ikebe and Matsumoto (1938) noted that no baitfishes were available in Saipan from September to November except *H. ovalis* and an unidentified carangid. During these months both species were too large for skipjack tuna bait, but they would be useful as longline bait.

Following a baitfish survey in the Bismarck Sea by the Far Seas Fisheries Research Laboratory (1969), clupeids were noted to be one of the five dominant families with *H. ovalis* being the most common. Baitfishes were captured with an "above-water" or an "underwater" light that was dimmed shortly before the net haul was made. The lights were later switched to red lights which were more effective in concentrating the baitfish near the surface. The use of red lights during bōuke net fishing was also noted by Webb (1972a). Fishes considered suitable as to size, silvery color, and schooling habit were anchovies, round herrings, silversides, and herrings.

Ikebe and Matsumoto (1938) briefly noted that a few aoesa, probably *H. schrammi*, 2.0 to 2.2 cm were captured in Tanapag Harbor, Saipan. This fish was also taken at Woleai and Lamotrek Islands in the Carolines using a stick-held dip net (Matsumoto 1937). Herrings reportedly used in the eastern Pacific fishery include *Ilisha*, *Lile*, *Neopisthopterus*, *Opisthopterus*, and *Opisthonema*. They were usually caught incidentally or when more desirable bait species were scarce (Inter-American Tropical Tuna Commission 1952; Alverson and Shimada 1957). Anderson et al. (1953) noted that the flat-iron herring, *Ilisha furthi*, did not survive well in captivity and was not commonly used.

One of the most important baitfishes in the Japanese fishery is the sardine, *Sardinops melanosticta*. It is used along with the Japanese anchovy, *Engraulis japonicus*, but reported to be less hardy (Suehiro 1936; Imamura 1949). Imamura (1949) reported that of the two species the former was more resistant to injury. In Japan a separate bait fishery sells live bait to the tuna vessels. When requiring a supply of live baitfish, a tuna vessel, by prior arrangement, purchases the bait needed before heading for the fishing grounds. Also, bait supply vessels carry quantities to the tuna boats on the fishing grounds (Cleaver and Shimada 1950). The advantages of this system include little loss of fishing time and a better quality of "aged" live bait. The techniques employed in the eastern Pacific fishery are described by Alverson and Shimada (1957), and in the Hawaiian fishery by June (1951b).

The Pacific sardine, *Sardinops sagax caeruleus*, has been used extensively as a live baitfish from California to the Galapagos Islands. In southern California and Baja California, it is captured with surround nets during summer and fall. Alverson and Shimada (1957) noted they were successfully transported aboard ship as far south as the Galapagos Islands. This species was reported as being superior to anchovetas from the standpoint of attracting and chumming tuna but not as hardy (Anderson et al. 1953). In the Galapagos Islands they are captured from September through February and used throughout the islands and off the west coast of South America. It is a good baitfish and available during the fishing season in large numbers (Alverson and Shimada 1957). Capture is with surround nets or lampara nets, and in rocky areas it is necessary to have divers working underwater to "walk" the heavy leadline over the bottom. Methods of capture and handling were described by Godsil (1938).

Cyprinidae

None of the minnows and carps listed in Table 1 have been used on a commercial basis as live baitfish for skipjack tuna. They have either been experimented with or they have received only cursory attention.

The silver carp or rengo, *Hypophthalmichthys molitrix*, has received some attention in Japan as a possible live baitfish (Anonymous 1972; Otsu 1973[8]). Although the first reports were optimistic, later tests were disappointing. When only silver carp was used, skipjack tuna did not respond, and when silver carp was used with anchovies, the response was poor. It dives when chummed, and attempts to alter this behavior with salt water or chemicals before chumming were unsuccessful. It was found to be effective only when used as live bait on hooks (Otsu see footnote 8).

[8]Otsu, T. 1973. Trip report: Trip to Japan, February 3-22, 1973. Unpubl. rep., 20 p. Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

Another freshwater species tested in Japan was the common goldfish, *Carassius auratus* (Otsu see footnote 8). Tests at sea indicated it was sluggish in movement and not as effective as anchovies. It was deemed unsatisfactory and further tests were halted.

The golden shiner, *Notemigonus crysoleucas*, widely popular as a freshwater baitfish for recreational fishing in North America, was recently tested in Hawaii on skipjack tuna. Kato (1973)[9] reported their physical appearance was suitable and sluggish individuals demonstrated behavioral patterns expected of a good baitfish. By placing them in 6‰ brackish water their activity decreased producing a sluggish behavior that may make them more desirable to skipjack tuna.

Dinolestidae

According to a single report by Sampson (1962), the long-tailed pike, *Dinolestes lewini*, was successfully used in Australia as a live baitfish for tuna. Apparently juveniles were used, but no additional information appears available. It is silvery with an elongate body and is reported to reach 50.8 cm in length.

Dussumieriidae

Round herrings are slender, elongate, silvery fishes, with deciduous scales that are easily lost during handling. They are delicate and must be handled with considerable care. Although weak, *Spratelloides delicatulus* and *S. gracilis* are important as live bait in areas where they occur in reasonable quantity. They are usually captured using night lights but they are also taken with bait seines and with drive-in nets, often incidentally with other species.

The makiawa, *Etrumeus teres*, and the piha, *S. delicatulus*, are considered by Hawaiian fishermen to be excellent baitfishes but fragile (June 1951a; Ikehara 1953; June and Reintjes 1953). They do not occur in sufficient numbers to be of importance as a baitfish in Hawaii but successful captures are occasionally made (Anonymous 1950a; Welsh 1950). *Spratelloides delicatulus* is the most widely used round herring in the Indo-Pacific. It is an excellent baitfish but does not survive well in captivity (Anonymous 1950b; Ikehara 1953; June and Reintjes 1953; Wilson 1971; Lee 1973), and it is seasonal with the greatest abundance occurring in the summer months (Welsh 1950; June 1951a; Wilson 1963). Summer and fall are usually the seasons for piha in Hawaii, where it is captured in the open seas off the southern coasts of most of the islands. Hida (1971) noted that it was abundant in lagoons of large atolls in Micronesia and aggregated under night lights. It is one of the important bait species found in Palau (Wilson see footnote 3). Its length ranges from 4.5 to 6.0 cm and it forms small, scattered schools in Malakal Harbor or in shallow inshore

[9]Kato, K. 1973. Baitfish project (interim report). Pacific Aquaculture Corp., Kihei, HI 96753. Unpubl. rep., 6 p. Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

areas. It schools inshore and in adjacent deep water during the day and occasionally is observed far from land. It avoids muddy or dirty water and is captured by night lighting except during periods of full moon.

Prior to World War II when the Japanese fishery was established at Truk, it was an important baitfish especially from March to May when the more desirable takabe, *Gymnocaesio argenteus*, was scarce (Wilson 1971). Matsumoto (1937) reported that *S. delicatulus* is the most important baitfish at Saipan where it is found all year but is scarce in November and December. In January it was considered worthless as live bait and catching it was prohibited. At the peak of the season, one haul of the bait net captured enough for a day's fishing. It is not found in sufficient quantities in Saipan from September to February and is not good as a live baitfish during the spawning season in January (Wilson 1963). Jones (1960, 1964a) reported that it is seasonally available and is captured with night lights whenever possible for use as live bait in the Laccadive Archipelago.

Its behavior is typical of round herrings. It is a fast swimming, schooling fish attracted to lights, and when used as chum, it schools near the vessel. At times it schools so close that it is necessary to move the vessel forward to expose the bait to the tuna (Ikehara 1953). It is attractive to predators and has good catching qualities (Manar 1969).

Both *S. delicatulus* and *S. gracilis* are considered as possible baitfish resources in New Guinea by Kearney et al. (1972). Lewis et al. (1974) reported that both species are the most attractive baitfishes for skipjack tuna in waters of Papua New Guinea. Reduced mortalities were experienced by daylight loading of night-captured bait, but shipboard mortalities when crowding for chumming still are a problem.

In the Saipan and Tinian fisheries, *S. delicatulus* is a preferred bait species (Cleaver and Shimada 1950). A good baitfish size is 3.8 cm while sizes over 15 cm in length do not attract skipjack tuna as well. This species was reported abundant in Western Samoa (Van Pel 1960); no additional information is available.

Wilson (1971) noted that *S. gracilis* is a good live baitfish but not as hardy as *S. delicatulus* and not extensively used at Palau, while Lee (1973) noted that it is important in the Fiji fishery, but survival is poor.

Isa (1972) reported *S. japonicus* is an important baitfish in the Ryukyu Islands fishery. The quantity of round herrings, consisting of *S. japonicus*, *S. delicatulus*, and *S. atrofasciatus*, from three major localities in the Ryukyu Islands for 1966 and 1967 was 54.7 and 45.0 metric tons, respectively. Jones (1960, 1964a) noted *S. japonicus* is used in the Laccadive fishery and that it occurs in small schools but is not as abundant as *S. delicatulus*. Both species are seasonally available and have been observed on occasion in large quantities, but after December they are scarce (Thomas 1964).

Dussumieria acuta is used in the Philippine fishery (Domantay 1940a, 1940b) and in Fiji (Lee 1973). In Fiji it is used in lesser quantities than other available baitfishes because it is extremely fragile and does not survive for more than 6 h, but it occasionally produces good catches. The main drawbacks with this species are poor survival and seasonality of abundance.

A single species of round herring listed as *Etrumeus* sp. (probably *Etrumeus teres* according to Whitehead 1963) was used in the eastern Pacific fishery (Alverson and Shimada 1957). Additional observations on round herrings were made in the Tuamotus (Royce 1954), in the Tuamotus and Marquesas Islands (Anonymous 1955), and in Guam and Palau (Smith and Schaefer 1949).

Engraulidae

Throughout the Pacific Ocean, anchovies rank first in terms of quantity used, value, and general desirability as baitfishes. Their ability to attract and hold skipjack tuna, wide distribution, and occurrence in schools nearshore throughout the year contribute to their demand.

The majority of species are 12.5 cm or less in length with a silvery, elongate, compressed body, and with deciduous scales that are easily dislodged during handling. They range from quite delicate, as examplified by the nehu (Struhsaker et al. 1975), to quite hardy, as reported by Alverson and Shimada (1957) and Bayliff and Klima (1962), for the anchoveta, *Cetengraulis mysticetus*.

Although many baitfishes are employed by the Japanese the two most important are *Engraulis japonicus* and *Sardinops melanosticta*. Of the two, the Japanese anchovy is the better baitfish since it can be kept more successfully than the sardine (Suehiro 1936) and is more resistant to oxygen deficiency (Cleaver and Shimada 1950). The most desirable size is 7.5 to 12.5 cm since small sizes are more resistant to death from confinement. Small baitfishes are as attractive to tuna as larger baitfishes and a greater number can be carried per unit of space. High mortality usually follows capture, handling, and confinement in holding enclosures and aboard ship (Anonymous 1971). They are usually held for 10 days to allow them time to "age," thus leaving the stronger individuals for tuna bait. Mortalities are highest in baitwells of the fishing vessel en route to the fishing grounds. A complete description of this fishery is given by Cleaver and Shimada (1950).

Baitfish surveys were conducted in Korea and Taiwan by the Japanese (Federation of Japan Tuna Fisheries Cooperative Associations and Japan Tuna Fisheries Federation 1972) to determine the resources of *E. japonicus* and the feasibility of transporting them to Japan to supplement their baitfish supplies. Observations indicate that they can be successfully captured in lift nets, a method superior to the lampara net method. Anchovies transported to Japan from Chungmu Harbor, Korea, had low mortalities when held in enclosures for 4 wk before loading them aboard the transporting vessel. Anchovies captured in Taiwan are of considerable value to the Japanese southern fishery since there is no need to transport them first to Japan.

The live bait and reduction fishery for the northern anchovy, *Engraulis mordax*, in California has developed into an important fishery in recent years (Messersmith et al. 1969; Wood and Strachan 1970; Spratt 1973). In addition to being used for tuna bait, the anchovy is of considerable value as live bait for recreational fishing. Quantities are captured by bait fishermen and then sold to sports fishermen, an operation resembling the Japanese bait fishery. Anderson et al. (1953) noted *E. mordax* is not as hardy as the anchoveta.

Engraulis mordax is taken in the same areas and used in the same manner as the Pacific sardine. Capture localities include southern California, Baja California, and the Gulf of California from June to November, and it is used almost exclusively on adjacent fishing grounds (Alverson and Shimada 1957). Methods of capture include purse seines and lampara nets described by Godsil (1938), Young (1949), and Wood and Strachan (1970).

Additional anchovies of the genus *Engraulis* include *E. ringens* used in the eastern Pacific fishery (Alverson and Shimada 1957), and *E. australis* reported by Flett (1944) from southeast Australia.

During exploratory fishing in Australia, *E. australis*, 7.5 to 8.8 cm, were captured with a submerged light and a "hoop net," and with a lampara net from different localities. They survived well and were freely taken by skipjack tuna but the catch rate was low. The majority of skipjack tuna were taken on hooks baited with live anchovies. On occasion they were observed to bite well perhaps due to rough seas that helped obscure the vessel and the fishing lines. The occurrence of *E. australis* in New South Wales fluctuates, although populations in Port Phillip Bay, Victoria, occur regularly during the skipjack tuna season. Sampson (1962) reported that individual *E. australis* are extremely prone to panic when captured and it is necessary to remain in port to allow the bait time to adapt to confinement. He notes that even after 2 days they may die faster than other species but were excellent bait for tuna. Additional information on capture, equipment, handling, and biology of *E. australis* is given by Webb (1972a, 1972b).

The most important baitfish in the eastern Pacific fishery for skipjack and yellowfin tunas is the anchoveta, *Cetengraulis mysticetus*. It is preferred because it is hardy, withstands crowding, and is tolerant to a wide range of water temperature. It survives for periods up to several months in captivity with low mortality (Anderson et al. 1953; Alverson and Shimada 1957). Its importance is emphasized by the fact that 40 to 60% of all the tuna landed in the eastern Pacific live-bait fishery each year were captured using this species for bait (Peterson 1956). A brief report by Mead (1949) on the capture of anchovetas at Macapule, Mexico, noted that bait was plentiful and easily located. Following a 3-day baiting period, 3,600 scoops of anchovetas were placed in the baitwells. They began milling immediately and mortalities were not excessive. Anchovetas have been successfully transported to the Marquesas and Tuamotus (Angot 1959).

The population of anchovetas in the Gulf of Nicoya, Costa Rica, declined in 1947 and subsequent transplanting of mature anchovetas from Panama to the Gulf of Nicoya was successful and the population was reported increasing. The biology of the anchoveta has been studied by Howard (1954), Howard and Landa (1958), Barrett and Howard (1961), Peterson (1961), Bayliff and Klima (1962), Klima et al. (1962), and Bayliff (1963a, 1963b, 1964, 1965, 1966, 1967).

Anchovies of the genus *Anchoa* are infrequently used as live bait for tuna in the eastern Pacific (Alverson and Shimada 1957; Schaefer 1962). They are less desirable than the anchoveta since they are not as hardy in captivity. The various species, usually under 12.5 cm in length, are difficult to identify and generally considered to be good baitfishes. *Anchoa compressa* was introduced to Hawaii in 1932 (Brock 1960) but this was unsuccessful. Additional anchovies used in the eastern Pacific include *Anchovia rastralis* and *A. macrolepidota*, but like the various species of *Anchoa* the quantities used are negligible and they do not live well in captivity.

Of the different species of anchovies listed, the nehu and the anchoveta have been studied more thoroughly than all the others combined. Anchovies of the genus *Stolephorus* occur throughout most of the tropical Pacific. The nehu, *S. purpureus*, is the primary bait species in Hawaii. It is captured in sheltered bays and harbors and tends to occupy habitats where fresh water enters the sea (Welsh 1950). A synopsis of the biological data on the nehu was compiled by Nakamura (1970). In 1947, 95% of the total baitfish catch in Hawaii was nehu. It is endemic to Hawaii,[10] seasonally abundant, and considered delicate with mortalities following capture up to 25% per day.

Capture methods include day bait seining or with a night net. Causes of nehu mortalities were investigated by Brock and Takata (1955), Pritchard (1955), [U.S.] Bureau of Commercial Fisheries (1969), and Struhsaker et al. (1975). Recommendations on improved handling methods and live baitwell design were studied by Welsh (1950), Brock and Takata (1955), [U.S.] Bureau of Commercial Fisheries (1969), Baldwin et al. (1972), and Baldwin (1970, 1973a, 1973b). Details concerning the Hawaiian methods of capture, handling, and gear are described by June (1951a, 1951b) and by Yamashita (1958). Operational aspects of the Hawaiian fishery were investigated by Brock and Uchida (1968).

Nehu behavior, when used as chum at sea, was observed by King and Wilson (1957), Strasburg (1959), Strasburg and Yuen (1960), Shomura (1964), and Iversen (1971). Strasburg (1959) and Strasburg and Yuen (1960) noted that when using dead nehu the skipjack tuna decreased their swimming speed, reduced the number of surface dashes, and fell astern of the vessel. When too many live nehu accumulated during chumming, small schools of skipjack tuna were noted to fall astern of the

[10]It is doubtful that records of *Stolephorus purpureus* from Saipan and Truk (Smith 1947) and from Guam (Van Pel 1956; Rothschild and Uchida 1968) are valid.

vessel. They reported that when insufficient numbers of nehu were chummed, skipjack tuna were observed to scatter perhaps due to an "insufficient feeding stimulus." When the water spray was off, the skipjack tuna reduced their swimming speed, swam deeper, and made fewer surface dashes.

Tests with monofilament gill nets were conducted in Hawaii (Shomura 1963) while chumming with live nehu. The results indicated this method was not as effective as the pole-and-line technique. Underwater observations made on nehu and shad (Iversen 1971) noted both species tend to dive but nehu appeared to dive faster and exhibit marked dodging. Both returned to the surface when pursued by skipjack tuna and were observed to flee to the side of the vessel and swim along with it. Iversen (1971) noted that their swimming behavior was similar and both were observed to dive to a considerable depth. Yuen (1969) found skipjack tuna responded better to live than dead nehu in catch rate, rate of attack by tuna, and in the numbers of tuna attracted to the vessel. The catch rate also increased when the vessel's water spray was in operation and nehu were more effective than juvenile tilapia.

The roundhead, *Stolephorus buccaneeri*, is occasionally observed in schools offshore but is of little importance to the Hawaiian fishery. It is occasionally mixed with *S. purpureus* (Matsui 1963). It is a pelagic species and, according to Whitehead (1965), it has a wide distribution that was recently substantiated by Hida (1973). Kearney et al. (1972) reported that this species may prove to be important in New Guinea waters. They and Ronquillo[11] believed *S. buccaneeri* was frequently misidentified as *S. zollingeri* by others. Lee (1973) noted that *S. buccaneeri*, 4.7 to 8.5 cm in length, is an important and abundant live bait in Fiji. It is captured at night with other bait species, considered delicate, but will survive up to 2 days in captivity. The behavior and taxonomy of *Stolephorus* anchovies were studied by Lewis et al. (1974). They reported *S. buccaneeri* was an excellent baitfish with good handling qualities and tuna attractability but unfortunately its occurrence is unpredictable.

Stolephorus heterolobus was noted by Marukawa (1939) to be an excellent and hardy baitfish. It occurs along the shore in shallow water near mangroves and where fresh water enters the sea. Lee (1973) considered *S. heterolobus* delicate, requiring extreme care in handling. Although it is reported to be abundant at Yap, Caroline Islands, Ikebe and Matsumoto (1937) noted that it was difficult to capture by night lighting on moonlit nights. It is similar to the Hawaiian anchovy and appears to be seasonal in abundance (Anonymous 1937b; Smith and Schaefer 1949; Cleaver and Shimada 1950). Hida (1971) observed *S. heterolobus* at Ponape mostly in areas too deep for their shallow day seine; however, it was attracted to night-lights. Smith (1947) reported schools of baitfish (probably *Stolephorus*) were attracted by lights and after a large school had assembled it was led to the bait net by moving the light.

Stolephorus indicus is used as a live baitfish at Ponape and Fiji (Lee 1973) and in the Philippine fishery (Domantay 1940a, 1940b), but like other members of this genus it is delicate. Lewis et al. (1974) reported *S. indicus* and *S. bataviensis* were not common during a survey in New Guinea and mortalities were high. They attain a larger size than other species of *Stolephorus* and are difficult to handle.

The remaining species of *Stolephorus* are not as important although *S. devisi* may represent a baitfish resource in the Solomon Islands; however, further testing is needed (Far Seas Fisheries Research Laboratory 1969). Kearney et al. (1972) noted *S. devisi* was the most abundant bait species captured under a night light in Papua New Guinea. It was an excellent baitfish but delicate and difficult to transport. They also noted that *S. bataviensis* was occasionally abundant and may represent a bait resource.

Lee (1973) reported that *S. commersoni* is fragile and does not live longer than 6 h in captivity, but gives good results on skipjack tuna in Fiji.

Read (1971) described the capture and use of *Stolephorus pseudoheterolobus* as a live baitfish in Palau. Ronquillo (see footnote 11) considered *S. pseudoheterolobus* to be a junior synonym of *S. heterolobus*. Isa (1972) noted that this species and *S. zollingeri* are used in the Ryukyu Islands fishery. The latter species is possibly *S. buccaneeri* as suggested by Kearney et al. (1972). Lewis et al. (1974) noted *S. heterolobus* and *S. devisi* are quite similar in their response to dimming the night-light when enclosed within the holding pen alongside the vessel. Both species are considered very good baitfishes, but *S. heterolobus* may be more attractive to tuna due to its metallic blue and silver color. These and other captive engraulids were reluctant to enter red or pink buckets that were later discarded in favor of blue buckets. A similar color preference by the nehu was observed by Struhsaker et al. (1975).

Of moderate importance in New Guinea and Fiji is *Thrissina baelama* (Lee 1973; Lewis et al. 1974). It is attracted to lights and is hardy, but it looses its scales easily and must be handled with care. This species and *Herklotsichthys punctatus* are "skittish" when captured with night-lights and a lift net. Lewis et al. (1974) noted *Thrissina setirostris* and *T. baelama* could be "dry scooped" into buckets with low mortalities, but *T. baelama* would leap out of the container when startled. The latter species was reported to swim rapidly away from the vessel when chummed, but, because it is hardy, further use of this species was suggested.

Gobiidae

Although there are no records of the white goby, *Glos-*

[11]Ronquillo, I. A. Undated. An illustrated key to the genus *Stolephorus*, 2 p. [and] A review of the genus *Stolephorus*, with a key to species, 31 p. Manuscript on file at Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

sogobius giurus, being used as bait for skipjack tuna, Villaluz (1972) considered its potential culture as a baitfish worthwhile for American Samoa. The reasons for this selection are that *G. giurus* can survive under extreme environmental conditions and reproduces rapidly. It reaches a maximum length of about 30 cm, it is found naturally in fresh and salt water, but it is known to be cannibalistic.

Kuhliidae

A family of moderately common fishes found throughout the Indo-Pacific area. They are perchlike in appearance with an oblong, compressed body, silver color, and large eyes. Their size is usually under 30 cm. They are found in fresh, brackish, and saltwater habitats and are captured by seines during the day in shallow water nearshore. Since they are usually scattered or in small schools often over rough bottom and are not attracted to lights, capturing sufficient numbers requires too much effort to consider them as important bait species (Tester and Takata 1953).

The aholehole, *Kuhlia sandvicensis*, has been used as live bait for skipjack tuna in the Pacific. Jones (1964a) reported an additional species , *K. taeniurus*, that is used in the Laccadive Archipelago, Indian Ocean. It is hardy and found in fairly large numbers nearshore.

The young of *K. sandvicensis* make good live bait because they school when chummed and are readily taken by skipjack tuna (Ikehara 1953). However, their sharp dorsal and anal spines entangle in the nets and prick the chummer's hands. They were considered a satisfactory baitfish by June and Reintjes (1953) and Brock and Takata (1955), and will withstand long-distance transport if handled properly.

Sea tests conducted by Yuen (see footnote 4; 1969) with *K. sandvicensis* along with other species demonstrated that higher catch rates were made when the vessels' water spray was in use and this was independent of the attack rate by skipjack tuna. It was observed that they tend to dive when thrown as chum.

Tester and Takata (1953) concluded that because of its slow growth rate, late maturity, spawning difficulties, and problems related to egg retention and larvae; pond cultivation was not feasible.

Labrocoglossidae

Labracoglossa argentiventris, called takabe in Japan, is moderately elongate with a maximum size of 20 cm and common to central and southern Japan. Cleaver and Shimada (1950) briefly noted that this species was used as a baitfish in the Japanese fishery.

Leiognathidae

A single species of this family, *Gazza minuta*, has been used as a live bait for tuna (Marukawa 1939; Cleaver and Shimada 1950). It is a deep-bodied, compressed fish, reaching a maximum length of 14 cm and found in schools in coastal waters. It is silvery with a pattern of orange and grey-blue lines on the upper sides. The Japanese capture it during the day with drive-in nets and at night with lights and a lift net. According to Marukawa (1939), it is not especially good as a live baitfish since skipjack tuna do not take to them readily; however, it is used in localities where bait is scarce.

Kearney et al. (1972) listed the family Leiognathidae as having possible importance as a bait resource in Papua New Guinea.

Lutjanidae

Snappers are widespread throughout tropical and subtropical areas. Their body is typically fusiform-compressed and many species are brightly marked with blue and yellow. They are seasonal with the juveniles appearing in schools near reefs. Large schools of juvenile bananafishes (subfamily Caesioidinae) were reported outside the reef in Palau (Anonymous 1937a). It was thought that the occurrence of skipjack tuna schools nearshore was due to the abundance of this bait. They are an excellent baitfish, available in Palau from February to June. It is primarily the juveniles that are used for pole-and-line fishing (Marukawa 1939; Anonymous 1937a; Jones 1964a; Wilson 1971; Isa 1972; Kearney et al. 1972).

They are hardy and live well in captivity. Juveniles of such species as *Caesio chrysozonus*, 7.5 to 10.1 cm in length, are considered to be excellent baitfishes. Marukawa (1939) noted that juveniles, 7 to 10 cm in length, are used in the "south seas." They form large schools during the day and live in crevices and caves of shallow reefs. They are captured in lift nets at night and during the day with drive-in nets. Methods of capture are described by Shapiro (1949), Jones and Kumaran (1959), Wilson (1971), Isa (1972), and Hester (1974). They are extremely important in areas where anchovies are not available. Ikebe and Matsumoto (1938) mentioned that *C. chrysozonus* is most suitable for skipjack tuna bait, but that in Saipan it is seasonal and is not available every year. The season lasts only for several days, although enough can be obtained in one haul for several days of fishing. When available it is collected and held in hastily constructed ponds. Isa (1972) noted this species and *C. tile* were second only to the cardinalfishes in quantity in three major baiting localities of the Ryukyu Islands for the years 1966 and 1967.

Juveniles of *C. chrysozonus* and *C. coerulaureus* are valuable in the Laccadive fishery and occur in fairly large quantities throughout the skipjack season (Jones 1958, 1964a). Jones (1964a) noted that they are hardy, survive well, and are very effective. *Caesio coerulaureus* was the most important while *C. erythrogaster* was present only in small numbers. Jones and Silas (1963) noted that at Minicoy Island, *C. tile* is very effective but availability limits its usage.

Little information on the use of *C. coerulaureus*, *C. xanthonotus*, and *C. diagramma* in Japan, Okinawa, and the Ryukyu Islands is available. These species are simply listed as being used as bait (Shapiro 1949; Cleaver and Shimada 1950).

The results of a baitfish survey in Papua New Guinea were reported by Kikawa (1971). Several methods of collecting were used including drive-in nets and night lighting with scoop nets and stick-held lift nets. The dominant species taken by the drive-in net method were *C. coerulaureus*, *C. pisang*, and *C. chrysozonus*.

The best baitfish in Truk is the takabe, *Gymnocaesio argenteus* (Wilson 1971). It is hardy and can be confined under crowded conditions with good survival. It is captured on the reefs during the day by divers using a drive-in net. It appears in the lagoon around May or June when quite small and is not abundant from January through April. The larger adults called akamoro are evidently not good for tuna. Jones and Kumaran (1964) noted the use of *G. argenteus* at Minicoy Island, Laccadive Archipelago.

Two species considered by Kearney et al. (1972) to have good baitfish potential in Papua New Guinea are *Gymnocaesio gymnopterus* and *Pterocaesio pisang*. They are apparently good bait species in all respects and relatively abundant and hardy. Lewis et al. (1974) noted that preliminary estimates of abundance by Kearney et al. (1972) may have been premature since they were based only on two collections. The former is the most important bait species captured by the drive-in net method in the Bismarck Sea (Kearney 1973).

Hida (1971) observed these fishes during a baitfish survey in Micronesia over coral outcroppings close to the lagoon drop-off. Some schools were equivalent to about 10 buckets (36.4 kg).

Two species of the genus *Lutjanus* have been used to capture skipjack tuna. Cleaver and Shimada (1950) noted *L. vaigensis* was used in the Japanese and Ryukyu Islands but they make no comment on its capture or quantities used. It has been reportedly captured by seining along with other baitfishes in shallow water at Canton Island (Anonymous 1950b). Jones (1964b) reported *L. kasmira* is occasionally used in the Laccadive fishery in the Indian Ocean.

Snappers, especially bananafishes, appear to hold good potential as live baitfishes for skipjack tuna since they are hardy and quite effective as bait. Their main drawbacks according to the available literature are that they are seasonal in abundance and it is primarily the juveniles that are effective as live bait.

Mugilidae

Mullets are found throughout the warm oceans of the world; they occur in both fresh and salt water and are important food fishes. The juveniles occur seasonally and are considered to be a favorable live baitfish. They occur in schools in lagoons, along the shore in shallow water, and on reef flats where they are captured with bait seines usually along with other species. The juveniles have a silvery, oblong body without prominent markings and with large scales that are firmly attached.

At least four species of *Mugil* have been used for skipjack tuna (June 1951a; Ikehara 1953; June and Reintjes 1953). The grey mullet, *M. cephalus*, is relatively hardy and can withstand long distance transport, but, because of the greater availability of nehu, it is of little importance as a baitfish in Hawaii (Ikehara 1953). June and Reintjes (1953) reported that it is a fair baitfish, abundant at Midway Island. They also note that *M. longimanus* and *M. vaigiensis* are fair baitfishes occurring in considerable quantities in the Phoenix and Line Islands. At Palmyra Island, *M. trichilus* was observed in schools with *Crenimugil crenilabis* and *M. vaigiensis* up to a hundred scoops in quantity (June 1951a). Whether sufficient supplies are there to support a fishery is not known. Both *M. vaigiensis* and *C. crenilabis*, 2.5 to 30.4 cm in length, were most common at Canton Island. Ikehara (1953) noted that *M. vaigiensis* and *M. longimanus* are the most common mullets in the Line and Phoenix Islands and could be used whenever available. A baitfish survey there by the NMFS research vessel *Hugh M. Smith* resulted in the capture of 1,135 buckets of live bait including several species of mullets.

Tests at sea were conducted by Yuen (see footnote 4; 1969) with *M. longimanus*. He found with this species the catch rate was better without the water spray in use. Skipjack tuna responded equally to juvenile tilapia and *M. longimanus* when the two were used alternately on the same school.

Crenimugil crenilabis is a fair baitfish, but it is not as common in the Line and Phoenix Islands as other species of mullets (June and Reintjes 1953). It is a primary species at Palmyra Island along with *M. vaigiensis* and *M. trichilus*, with schools varying in size from a few to a hundred or more scoops (June 1951a).

The false mullet, *Neomyxus chaptalii*, was reported by June and Reintjes (1953) to be a fair live baitfish. In Hawaii, it is most abundant in the northwest Hawaiian Islands and is usually caught while seining for other species. Ikehara (1953) noted that this species and *M. cephalus* were the most common mullets in Hawaii and that they were not used as live bait due to their value as food.

Jones (1964a) reported the use of small *C. crenilabis* in fairly large numbers in the Laccadive fishery, Indian Ocean. Another useful mullet in this fishery, but not as abundant in the baitfish catches, is *Valamugil seheli*.

Several mullets (species unknown) were used to capture yellowfin and skipjack tunas during exploratory fishing in the Line Islands (Anonymous 1951; Yuen and King 1953) but bait was scarce. Two species of mullets were the only baitfishes available in accessible areas of the lagoon and outer beach at Palmyra; however, quantities of mullet and goatfish were observed at Christmas Island and along the beaches at Palmyra (Smith and Schaefer 1949). Difficulties were encountered in transporting bait in the bait receiver because of the shallow inshore water. *Mugil* spp. were also captured at Midway and Canton Islands and reportedly survived well (Anonymous 1950a, b), but they were scarce at Hull Island. During exploratory fishing for tuna in the Line Islands, Ikehara (1953) observed that small mullet reacted favorably when chummed except when weak or injured individuals were used.

According to the above reports young mullet represent a limited baitfish resource for tuna in the tropical Pacific. They are moderately effective and considered to be relatively hardy with reasonable care. Their main disadvantages are that the juveniles occur seasonally and they are a food fish of considerable importance.

Mullidae

Several species of goatfishes have been used to capture skipjack tuna in the tropical Pacific, but they usually occur in limited quantities. They are found close to shore in lagoons, bays, and on the reef flats or along sandy beaches. Occasionally they form small to moderately large aggregations and are usually captured in bait seines during the day, frequently with other species. Most adults are brightly colored with an elongate compressed body, large scales, and with two unbranched barbels on the lower jaw. They are generally found all year. In Saipan they are most abundant from June through August (Ikebe and Matsumoto 1938) and are captured both day and night in beach seines. They are evidently used only when more desirable baitfishes are unavailable.

June (1951a) reported goatfishes are abundant at Palmyra and Canton Islands in June, July, and August but only enough for limited fishing. They were also observed at Christmas Island by Smith and Schaefer (1949) and by Yuen and King (1953); the latter reported they were 20 to 25 cm in length and too large for skipjack tuna.

Small *Mulloidichthys*, called oama in Hawaii, are used whenever available and at times occur in fair quantities in the northwest Hawaiian Islands and in the Line and Phoenix Islands (Ikehara 1953). The two species listed by June and Reintjes (1953) were *M. samoensis* and *M. auriflamma*. Reports on their behavior when used as chum were conflicting—some observers noted that they school at the surface around the vessel and others reported that they sound (Ikehara 1953). Their usefulness as a live baitfish is limited although they are relatively hardy.

Young *M. samoensis* are not used to any great extent but occur in the baitfish catches occasionally and are considered to be suitable (June and Reintjes 1953). Hida (1971) reported that juvenile goatfishes, mostly *M. samoensis*, were common in Micronesia but not in suitable concentrations.

Tests at sea were conducted by Yuen (see footnote 4; 1969) with *M. samoensis* and with *Mulloidichthys* sp. to determine their value as live baitfishes. It was observed that when young goatfishes were used the catch rate was higher when the vessel's water spray was in operation and seemed to be independent of the rate of attack, but since the tests were brief the results are questionable. They were also noted to dive when chummed.

June and Reintjes (1953) listed *M. auriflamma* as a suitable baitfish in Hawaii while its use in the Laccadive fishery, Indian Ocean, was reported by Jones (1964a).

Information on the remaining species of goatfishes used for skipjack tuna is fragmentary. Cleaver and Shimada (1950) listed four genera that were used in Japan and the Ryukyu Islands and in the "south seas": *Mullus*, *Pseudupeneus*, *Upeneus*, and *Upenoides*. The latter genus should more correctly be *Upeneoides*, a synonym of *Upeneus*, while *Pseudupeneus* refers to *Parupeneus* (see Lachner 1960).

Marukawa (1939) reported juvenile *Upeneus tragula* were captured in drive-in nets during the day and used when preferred species were scarce. A single record of *Parupeneus pleurostigma* being used as live bait was noted in Anonymous (1950b).

Although no additional goatfishes have been reported for the Indo-Pacific area, Jones (1964a) listed three *Parupeneus* that were occasionally used in the Laccadive fishery, Indian Ocean: *P. macronema*, *P. bifasciatus*, and *P. barberinus*. Juveniles of *P. macronema* were noted to be an esteemed baitfish but they do not occur in large numbers.

Young goatfishes are suitable as baitfishes and used when more desirable species are not available. According to the preceding reports they are comparatively unimportant to the fishery, but they are occasionally captured with other bait species. In Hawaii, their primary value is as a food fish.

Pempheridae

Two species of this family have been used as live bait for skipjack tuna. They are small, compressed, deep-bodied fishes with large eyes and relatively large scales. They are occasionally found in shoals. *Parapriacanthus beryciformis* is of some importance in the Ryukyu Islands fishery (Isa 1972) but no information was given on its use or capture. Its color was described as translucent pinkish. Raju (1964) reported that *Pempheris vanicolensis* was used as a live baitfish to capture skipjack tuna during a study in the Indian Ocean. Considering the nature of the bait fishery in the Laccadive Archipelago, all reef fishes are used as live bait without any apparent selection other than size. Species such as the above were frequently in the baitfish catches but probably not in significant quantities.

Plecoglossidae

The ayu, *Plecoglossus altivelis*, found in Japan, is an anadromous fish that has been viewed with interest as a possible baitfish. Specimens of *P. altivelis* were imported to Hawaii from Japan for experimental purposes as live bait for skipjack tuna.[12] No information on experiments with this species appears available. The baitfish poten-

[12]Report, Aku Committee Meeting, November 7, 1968. Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

tial of *P. altivelis* is diminished by its being anadromous and an important food fish.

Poeciliidae

Topminnows, called mosquitofishes or tabai in Hawaii, have been used as a supplementary live baitfish since the early 1930's during periods when nehu were scarce. Although reported to be less effective than nehu, various species were in demand and extensively used as bait for skipjack tuna (Bell and Higgins 1939). They were first introduced to Hawaii from the U.S. mainland in 1905 for mosquito control and have since spread throughout the islands. They are small, viviparous fishes, variable in color, and capable of reproducing in a variety of freshwater and seawater environments (Baldwin 1974). An undetermined species originally from tropical Mexico was introduced to Saipan and Palau as a possible live baitfish but evidently it was not tested on skipjack tuna (Ikebe 1939).

A brief test was conducted at sea in 1972 with two buckets of topminnows, *Poecilia vittata*, cultured at the Hawaii Institute of Marine Biology. The test to determine their effectiveness on skipjack tuna was inconclusive because of the limited supply. No skipjack tuna were captured but tuna were observed to feed on the topminnows, about 60% of which slowly spiralled downward while the remainder swam near or just below the surface with some forming aggregations near the vessel (Baldwin 1974).[13] During this test, one of the researchers[14] observed from an underwater observation port that many exhibited a whirling behavior upon hitting the water. Some continued to a depth of 6 to 8 ft before returning to normal swimming. These, and the remaining individuals, dispersed in all directions, some forming small or tightly packed aggregations with many swimming towards the vessel. The silvery-white belly was visible at a considerable distance in the clear water, especially among those individuals exhibiting the whirling behavior. King et al. (see footnote 7), after testing threadfin shad with mosquitofish (species unknown), observed that the latter were completely ignored by the feeding skipjack tuna that were avidly taking shad.

Tests were conducted with 11 buckets of Mexican mollies, *Poecilia mexicana*, from February to April 1974 in American Samoa aboard the research vessel *Alofaga* (S. N. Swerdloff, Office of Marine Resources, Pago Pago, American Samoa, pers. commun.). These preliminary tests indicated that cultured topminnows are suitable as baitfish for skipjack tuna and that shipboard mortalities are insignificant. These tests also demonstrated that for maximum effectiveness traditional pole-and-line techniques will require some modifications. These include methods of school approach, vessel speed during chumming, quantity of baitfish used, manner of chumming, and lure design and lure use during fishing. Cultured *P. mexicana* gave an equivalent catch rate when compared with mixed natural bait that consisted of *Sardinella*, *Caranx*, and *Selar*. Culture of *P. mexicana* is described briefly by Swerdloff (1973) and that of *P. vittata* by Baldwin (1972,[15] 1973c, 1974) and Herrick and Baldwin (1975).

June and Reintjes (1953) reported that *P. latipinna*, the sailfin molly, was the most important of the topminnows used in Hawaii, and that *P. sphenops* and *P. vittata* were occasionally captured along with the former species. They noted that *P. latipinna* was especially important at times when other bait species were scarce. Brock and Takata (1955) noted *P. latipinna* and *P. vittata* were seldom used for bait in Hawaii and together accounted for only 0.05% of the baitfish catch from 1948 to 1953. Welsh (1950) reported that two mosquitofishes, *P. latipinna* and *P. sphenops*, were used when nehu and iao were scarce. He noted that they occurred extensively in brackish water throughout Hawaii, especially in shallow marshy areas in fish ponds. When chumming, a special method of pinching the head of individual fish was used to alter their behavior in order to attract the skipjack tuna schools to the vessel.

The response of skipjack tuna to nehu and to the topminnow, *P. vittata*, when chummed alternately on the same school was compared by Yuen (see footnote 4). The nehu and topminnow combination, when chummed on skipjack tuna, was observed to receive the same response as tilapia, *Tilapia mossambica*, and mullet, *Mugil longimanus*, and tilapia and mountain bass, *Kuhlia sandvicensis*, combinations. Ikehara (1953) reported that topminnows (genus *Poecilia*) were used in Hawaii during periods when nehu and iao were in short supply. They were noted to occur in streams and estuaries of the main Hawaiian Islands. They were not an ideal tuna bait, however, because they sounded when thrown as chum. Bell and Higgins (1939) noted that *Gambusia* sp. was employed as a live baitfish and that there was a possibility of raising them in Hawaii.

Polynemidae

Threadfins are widely distributed in the tropics and juveniles of several species are occasionally used as chum for skipjack tuna. They are greyish above with silvery sides and with an oblong, compressed body. Many are found close to shore, along beaches, in bays and harbors, and in shallow water over sandy bottom. Their value as a baitfish is limited since it is difficult to capture enough for pole-and-line fishing. They are usually taken incidentally while seining or night lighting for other species.

Juveniles of *Polydactylus sexfilis*, called moi-lii in

[13]This species was previously reported by Baldwin (see footnote 15, 1973c, 1974) as *Poecilia sphenops*.

[14]Dollar, S. 1972. Field observations of molly behavior aboard the RV CHARLES H. GILBERT, September 1972. Unpubl. rep., 2 p. Hawaii Institute of Marine Biology, Univ. Hawaii, Honolulu, HI 96822.

[15]Baldwin, W. J. 1972. A preliminary study on the feasibility of pond rearing sharpnose mollies (*Poecilia sphenops*) as a live baitfish for the skipjack tuna fishery, American Samoa. Hawaii Inst. Mar. Biol., Univ. Hawaii, Contract Rep. C-248-73, 11 p.

Hawaii, are captured while seining for nehu but small numbers are occasionally taken while night lighting. The young do not closely resemble the adults in color, and those smaller than 10.0 cm in length have several pronounced dark bars on their bodies. Jones (1964a) briefly noted that small *P. sexfilis* are suitable as live bait in the Laccadive fishery, Indian Ocean, but are not abundant.

Polydactylus sp. was listed by Alverson and Shimada (1957) and IATTC (1952) as a baitfish occasionally used in the eastern Pacific fishery. It is captured from Baja California, Mexico, to the Gulf of Guayaquil, Ecuador. Both eastern Pacific species, *P. approximans* and *P. opercularis*, were no doubt included in the bait catches.

Pomacentridae

The damselfishes appear unlikely as live baitfishes for skipjack tuna, but reports covering a wide geographic range substantially document their use. They are a secondary baitfish and are used when more desirable species are scarce. Since they are closely associated with coral reefs, special techniques such as the drive-in net method have been developed for their capture. Most are small and brightly colored, with a flattened, deep to oblong body, and they are usually seen darting in and around coral heads with some species occurring in aggregations.

Wilson (1971) reported that *Pomacentrus pavo* was used by the Japanese at Truk and Saipan when other baitfishes were not available. It was difficult to capture and one method employed, that of breaking off coral heads to catch them, was obviously very destructive. It would take 20 men 1 day to catch a bucket of bait, and three or four buckets were required for fishing. This species was described as an adequate bait but was used sparingly due to the effort required to capture it. In Saipan, *Abudefduf coelestrinus* (listed as *A. sexfasciatus*) was used, but only as a last resort (Ikebe and Matsumoto 1938). Small individuals, 1.7 to 2.0 cm in length, are found inside the reef and are evidently present all year. Large individuals are not suitable live bait.

The most important damselfish in the Ryukyu Islands fishery is *Chromis ternatensis* (Isa 1972). That author also listed *C. caeruleus* and *Abudefduf dicki* and stated that these three species combined made up 4.1 to 6.1 t of live bait in 1966 and 1967, respectively. Damselfishes played a minor role as tuna bait in the Ryukyu Islands fishery in 1966 and 1967, as these figures indicate.

Jones (1964a) reported *C. ternatensis* and *C. caeruleus* were used to some extent in the Laccadive fishery, Indian Ocean. While he noted that *C. ternatensis* occurs commonly in baitfish catches, *C. caeruleus* is second in importance among the pomacentrids, the first being *Lepidozygus tapeinosoma*. Jones and Silas (1963) regarded *L. tapeinosoma* as the most suitable of all the baitfishes at Minicoy Island. *Chromis caeruleus* is used mainly at the beginning of the tuna season and may occur in fairly large numbers (Jones 1964a). Thomas (1964) noted that *C. caeruleus* formed 2.1% of the total baitfish catch during 1960 and 1961 in the Minicoy Island fishery.

Dascyllus trimaculatus was used in the "south seas" by the Japanese and *Abudefduf anabatoides* in Japan and the Ryukyu Islands fishery (Cleaver and Shimada 1950). No further comments were made regarding either species. A report by the Far Seas Fisheries Research Laboratory (1969) listed the three families Pomacentridae, Abudefdufidae, and Chromidae as being worthy of consideration as a possible live bait resource in the Bismarck Sea area. [I follow Norman (1966) in placing these all in the Pomacentridae.] Kearney et al. (1972) noted the family Pomacentridae has potential as a baitfish resource in Papua New Guinea and that it is rarely encountered in a night bait fishery. Little additional information on the use of damselfishes in the Indo-Pacific fisheries appears available. They no doubt occur in baitfish catches throughout the area but most frequently in small numbers.

Damselfishes hold some importance in the Laccadive fishery (Jones 1958, 1964a; Jones and Kumaran 1959; Raju 1964; Thomas 1964). These authors listed *Abudefduf anabatoides, A. biocellatus, Chromis caeruleus, C. dimidiatus, C. ternatensis, Dascyllus aruanus, Lepidozygus tapeinosoma, Pomacentrus* sp., and *P. tripunctatus* as live bait. They are not of major importance except for *L. tapeinosoma* and *C. caeruleus*. Jones (1964a) noted that the former is the most important tuna bait used at Minicoy Island and that it occurs in large schools although it is occasionally scarce. It is suitable due to its high rate of survival and it is active and very effective on tuna (Thomas 1964). Its peak abundance in January coincides with the peak tuna catch. In the Minicoy Island fishery, *L. tapeinosoma* has the best survival rate and when chummed it swims towards the vessel and takes shelter in the shadow of the boat.

Priacanthidae

Juveniles of *Priacanthus* sp., called bigeyes or aweoweo in Hawaii, are briefly noted by Cleaver and Shimada (1950) as having been used as skipjack tuna bait at Ponape and Truk. It is doubtful that they were taken in quantity especially when other more accessible bait species were available.

Pristipomatidae

Several species of this family, commonly called salemas, have been used in the eastern Pacific as live bait for tuna. They are usually 25 cm or less in length and are known to be hardy. They generally have several longitudinal dark stripes on the body, large eyes, and small scales. The California salema, *Xenistius californiensis*, is noted by Roedel (1953) and Alverson and Shimada (1957) as occasionally taken in Baja California, Mexico, but it was evidently not important to the fishery.

Anderson et al. (1953) noted that two species of salemas have been used in the Galapagos Islands and they were noted to be hardy. Alverson and Shimada (1957) reported that *Xenocys jessiae*, restricted to the

Galapagos Islands, was the only nonclupeoid fish of importance as tuna bait in the eastern Pacific fishery. The second salema noted by Anderson et al. (1953) was probably *Xenichthys agassizi*, also restricted to the Galapagos Islands. It is favored as hook bait since it is quite hardy but the sharp dorsal spines are a nuisance. Capture is usually by seine in shallow water during the day near rocky shores and in sheltered rocky coves.

Scombridae

Reports of the use of juvenile scombrids to capture skipjack tuna are primarily from the western tropical and subtropical Pacific; however, Alverson and Shimada (1957) noted that *Scomber* sp. was used in the eastern Pacific fishery as a miscellaneous baitfish.

Cleaver and Shimada (1950) noted without further comment that *Scomber japonicus* was used in the Japanese and the Ryukyu Islands fisheries. Sampson (1962) reported that this species was also used successfully in Australia as bait for tuna. In reference to baitfishes in general, he noted that 15 cm is the most useful size and that probably any small local fish would be suitable. Imamura (1949) reported small mackerel and small skipjack tuna were used in the Miyasaki area of Japan, but whether or not the latter is in fact *Katsuwonus pelamis* is not known.

The most common scombroid used as bait for skipjack tuna is *Rastrelliger kanagurta*, commonly known as striped mackerel or saba in Japan. Marukawa (1939) noted that juvenile *R. kanagurta*, 12 to 13 cm in length, were used as live bait in the "south seas." They were usually captured along with other bait species in lift nets, but were not abundant. A report by the Far Seas Fisheries Research Laboratory (1969) noted that the juveniles were observed in the Bismarck Sea several times in great numbers and that they were attracted to lights.

According to Lee (1973), *R. kanagurta* is used in Fiji but it is a baitfish taken in lesser quantities. Cleaver and Shimada (1950) noted that it was used by the Japanese in the "south seas" fishery, and Hida (1970b, 1973) reported its capture in Pago Pago Harbor, American Samoa. Details on its effectiveness were not given because of the limited amount used. They died several hours after capture probably from overcrowding that resulted in oxygen deficiency.

Domantay (1940a, 1940b) briefly noted the use of juvenile *R. kanagurta* in the Philippines, with a description of baiting and fishing methods.

Sphyraenidae

An unlikely species used as a live baitfish for skipjack tuna is the barracuda, *Sphyraena obtusata*. The juveniles were captured with night lights and a lift net but they were not captured in great numbers (Marukawa 1939). They were not especially suited for skipjack tuna but were used when other species were scarce. Cleaver and Shimada (1950) noted its use by the Japanese in the "south seas" and Domantay (1940a, 1940b) reported its use in the Philippine fishery.

A report by the Far Seas Fisheries Research Laboratory (1969:170) noted that juveniles were sometimes used for tuna but were not in abundance.

Tetragonuridae

The successful use of the squaretail, *Tetragonurus atlanticus*, by the Japanese to capture skipjack tuna was recently reported by Otsu (1975). Large quantities of this species were captured on the "high seas" near the eastern Caroline Islands by night lighting. They were 4 to 7 cm long and reported to be a satisfactory baitfish that swims slowly at the surface when chummed. They are dark in color, slender, elongate, and reported to be easily maintained in baitwells for 16 days.

REMARKS

It is apparent that further studies on live baitfishes are warranted, especially research related to improved capture and handling methods, natural stocks, baitfish behavior, and tuna attractability, baitfish culture, and the use of live baitfishes in combination with other fishing methods. The wide variety of fishes successfully employed as bait for skipjack tuna in the Pacific indicates that a critical examination of traditional pole-and-line fishing techniques would be worthwhile. One specific method may be highly effective using a particular species of baitfish but less effective using another species. It is reasonable to believe that certain modifications to the standard handling methods, shipboard live-bait holding facilities, vessel approach to schools, chumming techniques, lure use, and lure designs may significantly improve the use of many bait species for capturing skipjack tuna.

The single most important key to expanding existing skipjack tuna fisheries and developing new fisheries in Pacific island areas now known to be "bait poor" lies in the availability of suitable baitfishes throughout the year. The information included in this report on baitfishes and their use provides a basis for recognizing the various factors that seem to be important qualities in a good bait species. Without question, the anchovies (Engraulidae) provide the greatest source of desirable baitfishes in the eastern and western Pacific and to some extent in the central Pacific. They have a behavior that is highly attractive to skipjack tuna, are generally less than 15 cm in length, silvery, and elongate, and they form aggregations nearshore where they can be obtained by day and night capture methods. However, their survival in baitwells, depending upon the species involved, may be from excellent to poor. In areas where there appears to be an abundance of baitfishes (Papua New Guinea, Japan, eastern Pacific) the main factors restricting growth of the fisheries through geographical expansion are technological rather than restricted natural bait resources. Here the major baitfish requirements are behavior (attractability to tuna) and survival. The longer the distance baitfishes must be carried aboard ship, the greater the emphasis upon survival. In areas where baitfishes are unavailable on a commercial fishery level, then the order of relative importance is obviously availability, survival, and behavior, with such characteristics as size, body coloration, and body shape being of less importance. For example, in American Samoa baitfish catches usually produced limited quantities of mixed species including anchovies, herrings, carangids, mullets, etc., all relatively good baitfishes that are useful on a small fishery level but offer little potential for commercial pole-and-line fishery growth. Live baitfishes must either be reared locally or imported from areas of abundance. Fishery development may also occur through improved purse seining technology, the application of electronics, chemical attractants, manufactured bait substitutes, etc., but fishery development in Pacific island areas through these means appears unrealistic at least for the present. Until alternate means are available through research and development that can be applied to the skipjack tuna fishery, live baitfishes must be made available economically in quantity throughout the year from high density culture techniques or by shipment of baitfishes from areas of abundance.

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The Pacific Tuna Pole-and-Line and Live-Bait Fisheries

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ABSTRACT

The pole-and-line and live-bait fisheries of the eastern, central, and western Pacific Ocean are reviewed, including landing trends of tunas and catch and effort statistics on the fisheries for the tuna baitfishes. It was estimated that landings of tuna by the live-bait, pole-and-line fisheries contributed about 35% of the total Pacific landings of tunas in 1970. Also included were gross comparisons of the relative effectiveness of the live bait used in the various fisheries and discussions of the factors that may affect the relative effectiveness. The mean catch of tuna in metric tons per metric ton of bait was estimated at 7.5 in the eastern Pacific, 9.8 in the Japanese fishery, and 23.1 in the Hawaiian pole-and-line fishery. Thus, in terms of the catch per unit of bait, the Hawaiian fishery was 3.1 times more efficient than the eastern Pacific fishery and 2.3 times more efficient than the Japanese pole-and-line fishery.

The Japanese anchovy, *Engraulis japonicus*, is the most important bait species used in the Japanese pole-and-line fishery. In the eastern Pacific fishery the more important bait species are the anchoveta, *Cetengraulis mysticetus*; northern anchovy, *E. mordax*; California sardine, *Sardinops caerulea*; Galapagos sardine, *S. sagax*; and southern anchovy, *E. ringens*. The Hawaiian skipjack tuna fishermen primarily use nehu, *Stolephorus purpureus*.

INTRODUCTION

The total landings of skipjack tuna, *Katsuwonus pelamis*; yellowfin tuna, *Thunnus albacares*; albacore, *T. alalunga*; and bigeye tuna, *T. obesus*, in the Pacific Ocean by all methods of fishing amounted to an estimated 702,600 t in 1970 (FAO 1971). It is estimated that of these total landings, 243,800 t were made by the pole-and-line fishing method using live bait. The landings by the pole-and-line fisheries represent about 35% of the total landings by all methods of fishing.

Purse seine fishing for tropical tunas in the eastern Pacific was not very successful during the years prior to 1957. During the period from 1931 to 1956 the fishery for yellowfin tuna and skipjack tuna was dominated by bait boats, and purse seiners produced less than 15% of the yellowfin tuna and about 13% of the skipjack tuna catch (Broadhead 1962). However, beginning in 1957, the development of several technological innovations helped to reverse the trend, so that by 1960, the purse seine fleet had displaced the bait boats as the major producer of tunas in the eastern Pacific Ocean (Alverson 1963).

Because of the success of purse seining as practiced in the eastern Pacific, attempts were recently made to utilize this method on skipjack tuna in the central Pacific ([Hawaii.] Division of Fish and Game and Bumble Bee Seafoods [1970?]). The experiments were partially successful. In the western Pacific the Japanese have also been trying this method (Watakabe 1970) but, like the Hawaiian experiments, they have not been an unqualified success (Hester and Otsu 1973). Thus, in spite of its highly successful use in the eastern Pacific, the purse seine method with all of its technological advancements still requires more improvement for successful use in the central and western Pacific. Consequently, pole-and-line fishing with live bait is still the dominant method of fishing for tunas at the surface in the central and western Pacific.

Although the fishery in the eastern Pacific is now dominated by purse seiners, pole-and-line fishing with live bait is still practiced. In 1972 there were 52 bait boats of U.S. registry operating in the eastern Pacific (IATTC 1973). In the western Pacific, the Japanese have a highly viable pole-and-line fishery for skipjack tuna and albacore. And in the central Pacific a small but important pole-and-line fishery for skipjack tuna exists in Hawaii.

The purpose of this report is to present descriptions of the pole-and-line and live-bait fisheries in the eastern, central, and western Pacific, to review the historical catch and effort statistics on the fisheries for tuna baitfishes, and to compare the relative effectiveness of the live bait used in the three representative fisheries mentioned above. We will also discuss the factors that may contribute to the relative effectiveness of bait in terms of the volume of tuna produced. The material for this paper was taken almost entirely from published papers and reports.

EASTERN PACIFIC FISHERY

As noted earlier, the eastern Pacific tropical tuna fishery at present is essentially a purse seine fishery but,

[1]Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

prior to 1957, was predominantly a live-bait fishery. In 1948, of 118,752 t of skipjack tuna and yellowfin tuna landed by the eastern Pacific fleet, about 84% was caught by bait boats. By 1960, the proportion had dropped to about 40% as the "purse-seine revolution" launched a mass conversion of bait boats to seiners. In recent years, only about 10% of the tunas has been landed by bait boats.

The geographical extent of the eastern Pacific pole-and-line fishery for yellowfin and skipjack tunas, as given by Shimada and Schaefer (1956) is shown in Figure 1. This figure shows the extent of the fishery in 1954, and includes purse seiner operations. During the period prior to 1957, when the bait boats dominated the fishery, they ranged over a large area in the eastern Pacific, from Cedros Island, Mexico (lat. 28°N), to northern Peru (about lat. 10°S). Except for the offshore islands and banks, most of the tuna catches were made within a few hundred miles of the coastline (Alverson 1959). By 1963, as noted in the Annual Report of the Inter-American Tropical Tuna Commission (IATTC 1964), many of the larger bait boats had been converted to purse seiners and the remaining bait boat fleet was composed of vessels of less than 170 tons capacity which generally operated north of the Gulf of Tehuantepec (ca. lat. 15°N).

Alverson (1959) discussed the seasonal nature of the eastern Pacific fishery for yellowfin and skipjack tunas during the period from 1952 to 1955. During this 4-yr period the catches of yellowfin tuna and particularly skipjack tuna were poorest in the first quarter (January-March). The catches of both species improved in the second quarter and continued good in the third. Alverson believed that the fourth quarter would have been the best of the year had it not been for some economic factors, including strikes and slow unloading of vessels. It should be pointed out that the seasonal nature of the fishery as described above is an oversimplification. The geographical extent of the fishery is large and there are variations in abundance in various localities in any one season.

Beginning in 1966, because of the use of increasingly efficient purse seine vessels, management procedures were implemented on the yellowfin tuna. These procedures were in the form of restricted fishing periods. In recent years the season of unrestricted fishing has grown increasingly short and in 1972 was only about 4 mo

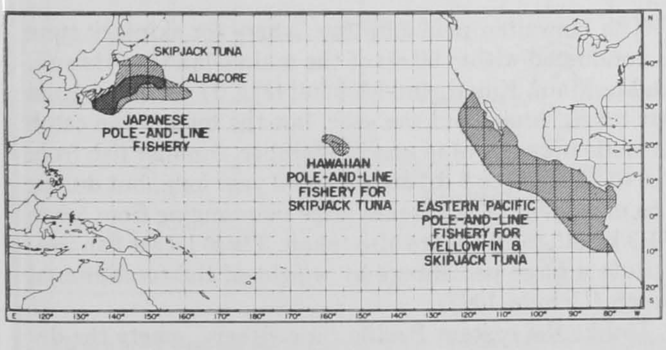

Figure 1.—Geographical location of the eastern Pacific, Hawaiian, and Japanese pole-and-line fisheries for tunas.

(IATTC 1972). The skipjack tuna stocks in the eastern Pacific are still not under management.

Bait Species Utilized

Nearly all the species of fish used as live bait in fishing for tunas in the eastern Pacific belong to the herring and anchovy families (Alverson and Shimada 1957). These fishes are usually small and school in shallow waters nearshore. In 1946-58, the anchoveta, *Cetengraulis mysticetus*, composed from 29.6 to 59.5% of the bait taken by the bait boats, but in 1959, it represented only 21.8% of the bait taken (Table 1). In 1960-69, the percentage of the catch consisting of anchoveta varied between 10.0 and 34.9% and averaged slightly more than one-fifth of the bait catch.

Among the qualities that made anchoveta highly desirable as a baitfish were its wide distribution, wide range of temperature tolerance, and ability to survive for long periods in the baitwells (Alverson and Shimada 1957).

A species that has become important only since the 1960's is the northern anchovy, *Engraulis mordax*. Table 1 shows that in 1946-60, less than 19% of the catch consisted of this species. In 1961-69, however, the northern anchovy gradually replaced the anchoveta as the predominant bait species (Fig. 2). While the 1961 catch of anchoveta composed 32.5% of the total bait catch, the northern anchovy and California sardine, *Sardinops caerulea*, represented 27.5% and 16.3% of the total bait catch, respectively, both relatively higher than in 1960 (IATTC 1962). By 1963, the northern anchovy had become the predominant species in the catch. The change from anchoveta to northern anchovy as the predominant bait species reflected the shift in the composition of the tuna fleet from one consisting predominantly of bait boats to one of purse seiners. As noted earlier, after the mass conversion from bait boats to seiners, the majority of the remaining bait boats were small vessels of under 150-ton capacity that usually fished north of the Gulf of Tehuantepec where northern anchovies were more common.

Baiting Areas

Alverson and Shimada (1957) listed the anchoveta, the California sardine, the Galapagos sardine, *Sardinops sagax*, the northern anchovy, and the southern anchovy, *Engraulis ringens*, as the most important baitfishes in the eastern Pacific. The principal baiting areas for these five major species are given in Table 2 and their locations are shown in Figure 3.

Catch and Baiting Effort

Alverson and Shimada (1957) noted that the fishery for baitfish, a subordinate but integral part of the eastern Pacific tuna fishery, is not predisposed to the easy collection of reliable catch records. The only source of information is the detailed accounts of baiting kept by fisher-

Table 1.—Estimated amounts, in thousands of scoops and percentages of kinds, of baitfishes taken from 1946 to 1969 by bait boats (excludes bait caught by vessels fishing out of Latin American ports and that by a few small vessels fishing out of California).

	Anchoveta, *Cetengraulis mysticetus*		California sardine, *Sardinops caerulea*		Galapagos sardine, *Sardinops sagax*		Northern anchovy, *Engraulis mordax*		Southern anchovy, *Engraulis ringens*		California sardine and northern anchovy mixed		Herring, *Opisthonema, Harengula*		Salima, *Xenocys jessiae*		Miscellaneous and unidentified		Total catch
Year	Scoops	%	Scoops	%	Scoops	%	Scoops	%	Scoops	%	Scoops	%	Scoops	%	Scoops	%	Scoops	%	Scoops
1946	398	29.6	389	28.9	28	2.1	132	9.8	—	—	203	15.1	23	1.7	126	9.4	45	3.3	1,344
1947	836	39.5	405	19.1	97	4.6	141	6.7	—	—	250	11.8	62	2.9	259	12.2	66	3.1	2,116
1948	964	32.3	416	13.9	753	25.2	147	4.9	—	—	349	11.7	42	1.4	217	7.3	95	3.2	2,983
1949	1,079	39.3	514	18.7	570	20.7	138	5.0	—	—	217	7.9	40	1.5	117	4.3	73	2.6	2,748
1950	1,700	47.6	318	8.9	959	26.9	239	6.7	—	—	187	5.2	45	1.3	32	0.9	90	2.5	3,570
1951	1,708	63.5	366	13.6	130	4.8	143	5.3	—	—	13	0.5	137	5.1	118	4.4	76	2.8	2,691
1952	2,542	59.5	286	6.7	596	14.0	577	13.5	—	—	53	1.2	124	2.9	51	1.2	40	0.9	4,269
1953	1,618	37.2	413	9.5	1,145	26.3	814	18.7	36	0.8	168	3.9	88	2.0	31	0.7	36	0.8	4,349
1954	1,820	46.3	203	5.2	590	15.0	604	15.4	553	14.1	65	1.7	49	1.2	23	0.6	20	0.5	3,927
1955	1,321	51.0	541	20.9	247	9.6	159	6.2	214	8.3	9	0.4	49	1.9	21	0.8	25	0.9	2,586
1956	1,667	45.6	362	9.9	152	4.2	594	16.2	355	9.7	38	1.0	368	10.1	27	0.7	95	2.6	3,658
1957	2,070	55.8	290	7.8	38	1.0	547	14.8	410	11.1	30	0.8	193	5.2	17	0.5	112	3.0	3,707
1958	1,515	34.0	601	13.5	141	3.2	736	16.5	1,169	26.3	57	1.3	102	2.3	16	0.4	110	2.5	4,447
1959	649	21.8	290	9.7	110	3.7	190	6.4	1,484	49.8	30	1.0	75	2.5	24	0.8	128	4.3	2,980
1960	416	34.9	110	9.2	82	6.9	212	17.8	214	17.9	6	0.5	64	5.4	15	1.2	74	6.2	1,193
1961	211	32.5	106	16.3	8	1.2	179	27.5	88	13.5	2	0.3	26	4.0	14	2.2	16	2.5	650
1962	123	29.6	89	21.4	34	8.2	110	26.5	25	6.0	2	0.5	16	3.9	7	1.7	8	1.9	414
1963	56	23.2	19	8.0	29	12.1	101	41.8	—	—	8	3.3	22	9.2	1	0.4	5	2.2	241
1964	37	16.5	54	24.1	74	33.0	41	18.3	—	—	1	0.4	8	3.6	4	1.8	5	2.2	224
1965	34	11.0	41	13.3	33	10.7	147	47.7	—	—	2	0.7	34	11.0	10	3.3	7	2.3	308
1966	49	17.3	68	23.9	22	7.7	106	37.3	—	—	3	1.1	24	8.4	9	3.2	3	1.1	284
1967	61	25.6	56	23.5	14	5.9	94	39.5	—	—	—	—	8	3.4	4	1.7	1	0.4	238
1968	37	13.7	54	19.9	18	6.6	148	54.6	—	—	1	0.4	10	3.7	2	0.7	1	0.4	271
1969	25	10.0	40	16.1	10	4.0	153	61.5	—	—	1	0.4	16	6.4	0	0.0	4	1.6	249

men in their logbooks. Based on data collected from about 85% of the bait boats based in California ports, scientists at the IATTC have been able to estimate the amounts and kinds of baitfish taken by all California bait boats operating in the eastern Pacific.

Table 3 gives the annual catches of all species of baitfish caught by bait boats in 1946-69. The annual catches, measured in scoops holding 4 kg (8 lb) of bait (Shimada and Schaefer 1956), varied from 224,000 scoops in 1964 to 4,447,000 scoops in 1958. At the height of the bait boat era, annual catches of 3.5-4.0 million scoops were not uncommon. From 1946 to 1959, when the bait boats dominated the fishery, the annual catches averaged 3,241,000 scoops. In 1960-69, the average annual catch reached only 407,000 scoopes, about one-eighth of the pre-1960 catches.

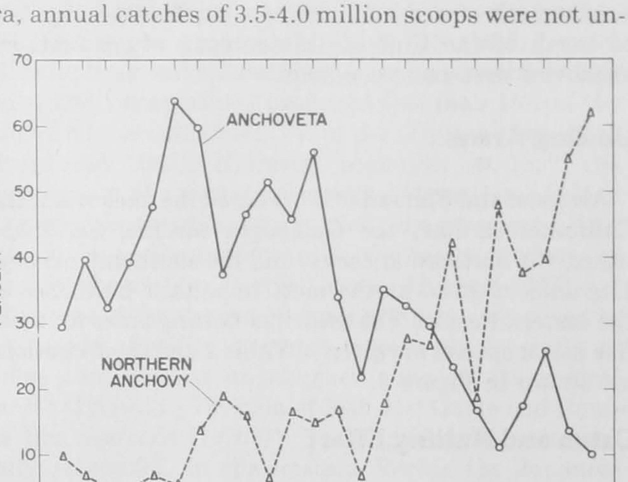

Figure 2.—Percentage of anchoveta and northern anchovy in the baitfish catches of bait boats in the eastern Pacific tuna fishery, 1946-69.

Data on baiting effort are not usually published in the annual reports of the IATTC. For 1939-51, Peterson (1956) gave the recorded and estimated catches and baiting effort for anchovetas, herring, and other miscellaneous species in the Gulf of Nicoya (Table 4). Alverson and Shimada (1957) also published catch and baiting effort data giving the catch per standard day's baiting, estimated total catch, and calculated baiting intensity for anchovetas in several of the major baiting grounds. Their data are reproduced in Table 5.

HAWAIIAN FISHERY

The Hawaiian pole-and-line fishery for skipjack tuna is conducted within 90 mi of the main islands of Hawaii, Oahu, Maui, Kauai, and Molokai (Fig. 1). Skipjack tuna are taken throughout the year, but the bulk of the catch is made between May and September. Smaller fish from 1.8 to 2.3 kg (4 to 5 lb) are taken all year long, but during the months of peak catches large fish ranging from 5.9 to 11.3 kg (13 to 25 lb) are also taken. These larger fish constitute a large percentage by weight of the total annual catch (Uchida 1967).

Unlike the eastern Pacific tuna fishery, where the demand for live bait has declined since 1960, catches of live bait are becoming increasingly important in other areas

Table 2.—Major baiting localities for five of the most important bait species used by eastern Pacific bait boats (compiled from Alverson and Shimada 1957).

Species	Major baiting grounds	Season
Anchoveta *Cetengraulis mysticetus*	Ranges from central Baja California to northern Peru. Important baiting grounds are Almejas Bay in Baja California, Guaymas and Ahome Point in the Gulf of California, and Gulf of Fonseca and Gulf of Panama in Central America.	Caught in appreciable numbers at one season or another throughout the year.
California sardine *Sardinops caerulea*	Ranges from San Diego, Calif., along outer coast of Baja California and along western side of Gulf of California as far north as Santa Catalina Island. Important grounds are at Cedros Island, Santa Maria Bay, and Magdalena Bay in Baja California and San Jose Island in Gulf of California.	July to November.
Galapagos sardine *Sardinops sagax*	Galapagos Islands.	September through February.
Northern anchovy *Engraulis mordax*	From San Diego, Calif., to Cape Falso at southernmost extremity of Baja California. Important grounds are at Turtle Bay, Santa Maria Bay, and Magdalena Bay; San Quentin Bay and Abreojos Point in some years.	June through November.
Southern anchovy *Engraulis ringens*	Cape Blanco, Peru to about lat. 10°S.	September through January.

of the Pacific. The Hawaiian fishery for skipjack tuna is small compared with those in the eastern and western Pacific, but it is the only commercial pole-and-line fishery in the midst of what is believed to be a vast resource of skipjack tuna extending throughout the tropical and subtropical central Pacific.

Bait Species Utilized

In Hawaii, a small, fragile anchovy locally called nehu, *Stolephorus purpureus*, is captured day and night and constitutes roughly 95% of the baitfish used for skipjack

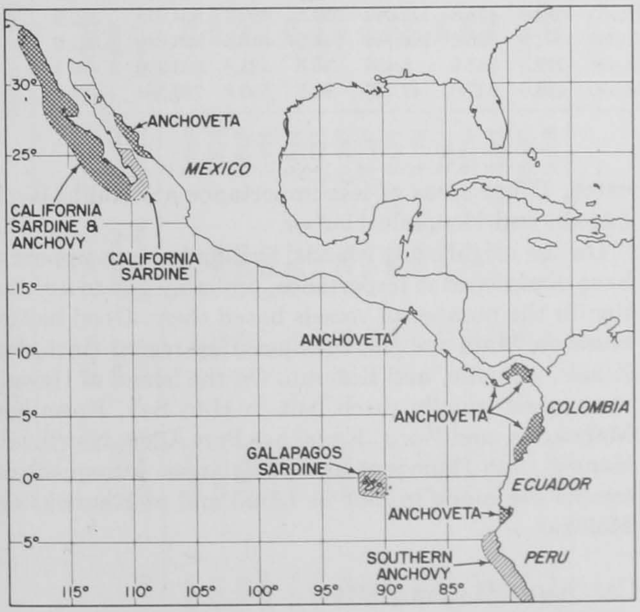

Figure 3.—Principal baiting areas of the California live-bait fishery for yellowfin and skipjack tunas (from Alverson and Shimada, 1957).

Table 3.—Annual catches of live bait in the eastern Pacific (all species), Hawaiian (nehu), and Japanese (anchovy) fisheries for bait.

Year	Eastern Pacific[1] (scoops)	Hawaii[2] (buckets)	Japan[3] (metric tons)
1946	1,344,000	25,860	—
1947	2,116,000	30,750	—
1948	2,983,000	42,036	—
1949	2,747,000	39,558	—
1950	3,570,000	39,638	—
1951	2,691,000	40,491	—
1952	4,269,000	29,807	—
1953	4,349,000	37,682	—
1954	3,927,000	43,737	—
1955	2,586,000	49,712	—
1956	3,653,000	40,864	—
1957	3,707,000	30,638	18,468
1958	4,447,000	33,303	18,109
1959	2,980,000	37,637	16,304
1960	1,193,000	22,849	15,916
1961	650,000	37,092	15,604
1962	414,000	34,256	15,526
1963	241,000	32,670	16,067
1964	224,000	30,606	14,915
1965	308,000	36,352	27,568
1966	284,000	31,603	22,262
1967	238,000	31,832	18,320
1968	271,000	35,535	20,771
1969	249,000	30,096	21,606
1970	—	33,596	21,264
1971	—	42,098	20,848
1972	—	38,970	—

[1]Data for 1946-69 are from IATTC (1956, 1962, 1968, 1970).

[2]Data for 1946-53 are from Yamashita (1958); data for 1954-72 are unpublished data courtesy of the Hawaii Division of Fish and Game. (Data for 1960-72 have been adjusted after correcting errors in catch reports.)

[3]Data from [Japan.] Ministry of Agriculture and Forestry, Statistics and Survey Division (1958-62, 1964-73).

Table 4.—Recorded and estimated catches in scoops and number of days of fishing for anchovetas, *Cetengraulis mysticetus*, and other baitfishes taken by California-based tuna clippers from the Gulf of Nicoya from 1939 to 1951. On the left side of the table are the recorded or actual catches and actual number of days of fishing obtained from logbooks made available to the commission by a segment of the fleet. Estimates for the entire fleet are shown to the right. Also shown is the average catch of anchovetas per day of fishing (from Peterson 1956).

	Recorded catch and days fishing					Estimated catch and days fishing					
Year	Anchoveta	Herring	Miscellaneous	Total	No. days fishing	Anchoveta	Herring	Miscellaneous	Total	No. days fishing	Catch of anchovetas per day of fishing
1939	23,902	—	—	23,902	49.0	220,756	—	—	220,756	486.0	454
1940	1,958	—	—	1,958	12.0	25,310	—	—	25,310	152.5	166
1941	11,704	—	—	11,704	58.0	89,590	—	—	89,590	449.5	199
1942	2,438	—	—	2,438	9.5	19,249	—	—	19,249	74.5	258
1943	7,600	—	—	7,600	16.0	54,688	—	—	54,688	116.0	471
1944	2,917	—	—	2,917	18.5	23,539	—	—	23,539	143.0	165
1945	6,148	357	—	6,505	47.0	29,282	2,156	—	31,438	232.5	126
1946	35,408	58	667	36,133	115.0	90,190	554	5,848	96,592	323.5	279
1947	23,420	4,647	1,821	29,888	233.5	57,536	14,978	4,984	77,498	628.0	92
1948	3,473	7,920	5,272	16,665	82.5	7,123	15,090	10,432	32,645	163.5	44
1949	683	53	—	736	11.0	1,157	89	—	1,246	19.5	59
1950	—	4,181	1,547	5,728	26.0	—	6,615	2,449	9,064	51.5	0
1951	—	—	—	—	2.0	—	—	—	—	2.0	0

Table 5.—Catch per standard day's baiting, estimated total catch, and calculated fishing intensity for anchovetas in Almejas Bay, Guaymas, Ahome Point, Gulf of Fonseca, and Gulf of Panama, 1946-54 (Alverson and Shimada 1957).

	Almejas Bay			Guaymas			Ahome Point			Gulf of Fonseca			Gulf of Panama		
Year	Catch per standard day's baiting scoops/class 4 day	Estimated total catch in scoops	Calculated fishing intensity, in class 4 days	Catch per standard day's baiting scoops/class 4 day	Estimated total catch in scoops	Calculated fishing intensity, in class 4 days	Catch per standard day's baiting scoops/class 4 day	Estimated total catch in scoops	Calculated fishing intensity, in class 4 days	Catch per standard day's baiting scoops/class 4 day	Estimated total catch in scoops	Calculated fishing intensity, in class 4 days	Catch per standard day's baiting scoops/class 4 day	Estimated total catch in scoops	Calculated fishing intensity, in class 4 days
1946	283.4	28,847	102.0	520.0	184,192	354.0	404.8	47,705	110.5	334.7	39,896	119.0	300.0	5,999	20.0
1947	289.4	100,594	347.5	424.9	325,503	766.0	313.8	149,186	475.5	220.6	36,020	163.5	355.6	143,445	403.5
1948	410.8	218,728	532.5	—	0	0	502.0	331,539	660.5	29.9	972	32.5	456.7	395,563	886.0
1949	291.4	236,293	811.0	76.4	949	12.5	751.6	278,166	370.0	118.1	3,336	28.0	679.1	513,973	757.0
1950	583.6	498,558	854.3	819.9	481,470	587.0	676.8	81,830	121.0	355.0	18,669	52.5	355.7	183,378	515.5
1951	526.1	246,077	467.5	618.6	433,088	700.0	711.5	419,033	589.0	478.8	172,062	359.5	597.7	204,479	352.0
1952	451.5	374,115	828.5	627.8	584,706	931.5	360.6	72,460	201.0	526.2	286,148	544.0	616.8	925,689	1,501.0
1953	599.4	347,016	578.9	748.9	355,580	475.0	753.3	165,491	219.5	148.9	5,435	36.5	421.5	623,290	1,478.5
1954	613.8	101,754	166.0	829.0	439,903	530.5	892.1	114,133	128.0	527.0	47,793	90.5	530.8	760,564	1,433.0

tuna fishing. Nehu is preferred above all others by the skipjack tuna fishermen because it possesses most of the qualities of a good baitfish. But nehu is also extremely fragile and during seining and transferring from seines to baitwells, many fish are injured and die of their injuries. Annually, an average of about 22% of the nehu die before they can be used in tuna fishing.

Other small fish are also used for bait. Almost all the remainder of the bait catch in Hawaii is composed of silverside or iao, *Pranesus insularum*, and small round herring or piha, *Spratelloides delicatulus*.

Baiting Areas

Nearly 79% of the live bait captured in the Hawaiian Islands comes from the island of Oahu. Two of the major baiting grounds are Kaneohe Bay and Pearl Harbor, which together contribute about 71% of the State's bait catch. Other areas of less importance are Kalihi-Keehi Lagoon and Honolulu Harbor.

On the neighboring islands, baiting grounds appear to have diminished in importance, probably due to a reduction in the number of vessels based there. Good baiting areas on Maui are the Maalaea Bay region (including Kihei), Lahaina, and Kahului. On the island of Hawaii, the vessels usually catch bait in Hilo Bay, Kawaihae, Mahukona, and Kona. Kauai has Port Allen, Nawiliwili, Hanalei, and Hanapepe as baiting areas. Infrequent attempts are made to bait at Lanai and at Kaunakakai, Molokai.

Catch and Baiting Effort

In Hawaii, bait catches are reported to the State on the same form as that used for reporting skipjack tuna catches. The form has undergone several revisions over

Table 6.—Catch, effort, and catch per effort in the fishery for nehu in Hawaii, 1960-72.

Year	Nehu - day			Nehu - night			Nehu - day and night			Other species - day and night			Totals		
	Catch (buckets)	Effort days (no.)	Catch per day (buckets)	Catch (buckets)	Effort nights (no.)	Catch per night (buckets)	Catch (buckets)	Effort days and nights (no.)	Catch per effort (buckets)	Catch (buckets)	Effort days and nights (no.)	Catch per effort (buckets)	Annual catch (buckets)	Effort days and nights (no.)	Catch per effort (buckets)
1960	15,735	1,001	15.7	3,069	408	7.5	2,489	297	8.4	1,556	145	10.7	22,849	1,851	12.3
1961	25,309	940	26.9	7,804	639	12.2	2,150	130	16.5	1,829	102	17.9	37,092	1,811	20.5
1962	23,544	823	28.6	7,819	623	12.6	1,585	126	12.6	1,308	83	15.8	34,256	1,655	20.7
1963	21,832	817	26.7	7,731	851	9.1	1,414	95	14.9	1,693	124	13.6	32,670	1,887	17.3
1964	18,454	774	23.8	9,618	1,003	9.6	1,547	82	18.9	987	63	15.7	30,606	1,922	15.9
1965	19,972	839	23.8	14,251	1,424	10.0	1,142	50	22.8	987	52	19.0	36,352	2,365	15.4
1966	20,696	781	26.5	10,242	1,011	10.1	480	20	24.0	185	19	9.7	31,603	1,831	17.2
1967	22,432	740	30.3	9,201	914	10.1	—	—	—	199	12	16.6	31,832	1,666	19.1
1968	30,148	1,055	28.6	4,911	544	9.0	96	4	24.0	380	17	22.4	35,535	1,620	21.9
1969	25,650	870	29.5	4,164	374	11.1	65	2	32.5	217	25	8.7	30,096	1,271	23.7
1970	30,332	1,017	29.8	2,654	288	9.2	112	3	37.3	498	24	20.8	33,596	1,332	25.2
1971	38,786	1,334	29.1	2,776	288	9.6	30	1	30.0	506	38	13.3	42,098	1,661	25.3
1972	36,503	1,171	31.2	2,187	206	10.6	30	1	30.0	250	15	16.7	38,970	1,393	28.0
Total	329,393	12,162		86,427	8,573		11,140	811		10,595	719		437,555	22,265	
Mean	25,338	936	27.1	6,648	659	10.1	928	68	13.7	815	55	14.8	33,658	1,713	19.6

the years, but in all the various versions used, the fishermen have reported date of catch, locality, amount of bait caught, and amount used. More recently, the forms have also included spaces for recording zero-catches, the amount of bait that died, and the amount of bait left over after fishing. Unlike commercial fish catches that are published and distributed monthly by the Hawaii Division of Fish and Game, bait catches are not published.

The annual catches of live bait in the Hawaiian Islands are given in Table 3 (see also Uchida 1977). In 1946-72, the bait catches ranged from a low of 22,849 buckets in 1960 to 49,712 buckets in 1955 and averaged 35,528 buckets. Yamashita (1958) estimated that a bucket holds about 3.2 kg (7 lb) of nehu.

Data on catch, baiting effort, and catch per effort of nehu taken in 1960-72 are given for day and night baiting in Table 6. Also included in the table are nehu catches for which the bait reports gave no time of capture, and catches of other species. Data on effort have not been corrected for variations in bait catches due to differences in efficiency among the different-sized fishing vessels.

Of particular interest were the opposite trends of day and night catches of nehu. Table 7 gives the baiting effort expended during the day and at night and their percentages of the total effort in 1960-72. A distinct pattern was obvious. Whereas 71% of the baiting effort in 1960 was expended in day operations, only 37% was expended during the day in 1965. A change in the ratio of day to night baiting in 1966, however, carried day effort back to the 1960 level and by 1972, 85% of the baiting effort expended was during the day. The change in emphasis in day and night baiting in 1960-72 is reflected in the catches of day and night bait shown in Figure 4.

JAPANESE POLE-AND-LINE FISHERY

In Figure 1 can be seen the geographical extent of the Japanese pole-and-line fishery for skipjack tuna and albacore. The figure for skipjack tuna was taken from

Table 7.—The amounts, percentages, and means of day and night effort expended in the bait fishery for nehu in Hawaii, 1960-72.

Year	Baiting effort				
	Day	Percent	Night	Percent	Day and night total effort
1960	1,001	71	408	29	1,409
1961	940	60	639	40	1,579
1962	823	57	623	43	1,446
1963	817	49	851	51	1,668
1964	774	44	1,003	56	1,777
1965	839	37	1,424	63	2,263
1966	781	44	1,011	56	1,792
1967	740	45	914	55	1,654
1968	1,055	66	544	34	1,599
1969	870	70	374	30	1,244
1970	1,017	78	288	22	1,305
1971	1,334	82	288	18	1,622
1972	1,171	85	206	15	1,377
Total	12,162		8,573		20,735
Mean	936		659		1,595
Percent		59		41	

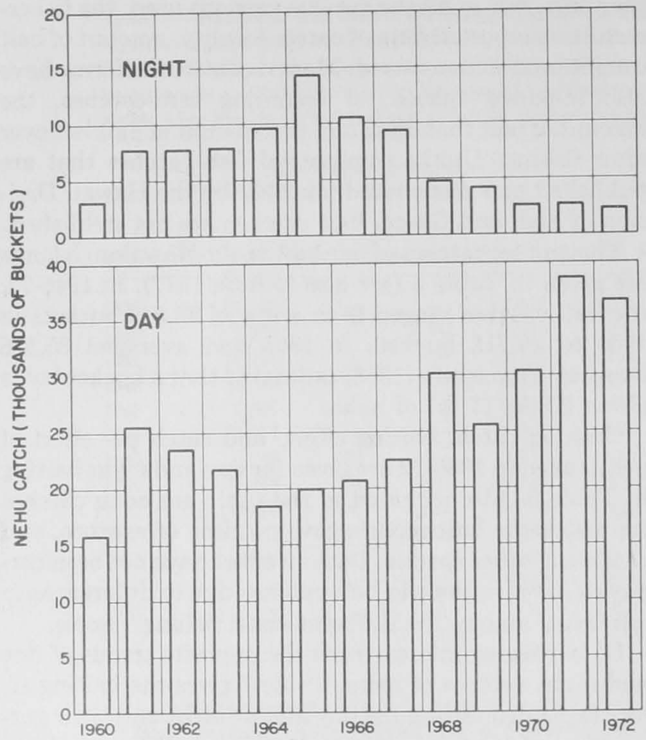

Figure 4.—Annual catches in the day and night fishery for nehu in Hawaii, 1960-72.

Rothschild and Uchida (1968) and that of albacore from Otsu and Uchida (1963). The albacore fishery extends over a thousand miles offshore whereas the skipjack tuna fishery tends to be more coastal.

Generally, over 75% of the annual catch of skipjack tuna is made from May through September. However, variations to this general rule occur in the sector of the fishery north of about lat. 35°N. Here the fishery may begin as early as April or as late as July and may end as early as August or as late as October. The seasonal development of the albacore fishery is somewhat similar to that of the skipjack tuna. Small catches of albacore are usually made in March or April and between the latter part of April and the end of May the first large catches are made. The season peaks in June and by the end of July the season is virtually over. Fishing for skipjack tuna and albacore are interrelated in that most of the pole-and-line fleet seek out skipjack tuna except during the brief period when the albacore are most abundant (Van Campen 1960).

Japanese vessels harvest about two-thirds of the world's skipjack tuna catch, which annually reaches about 300,000 t (Kawasaki 1972). The bulk of the catch is made by the traditional method using pole-and-line and live bait, although since 1964 the Japanese fishing industry has been actively engaged in experimental fishing with purse seines to capture skipjack tuna (Watakabe 1970; Yabe 1972).

Despite the fact that the skipjack tuna fishery has a long history and is well established among Japanese commercial fishing enterprises, pressure has been mounting in recent years to expand and develop this fishery even further. In 1970, realizing that the deep-swimming larger tunas were already being fished at or near the maximum level by the far ranging longline fleet, the Japanese Fisheries Agency turned its attention to further development of the skipjack tuna resource in southern waters (Suisan Shūhō 1973). Automatic fishing poles installed on pole-and-line fishing vessels proved successful and will probably help in significantly reducing future manpower needs (Suzuki Tekkojo Kabushiki Kaisha 1970). But skipjack tuna fishing has not developed as rapidly as expected. Two of the most pressing needs at present are to develop methods of transporting live bait to distant fishing grounds and to capture live bait in areas outside foreign territorial waters (Suda 1972).

Bait Species Utilized

About 97% of the live bait used in Japan today is an anchovy, *Engraulis japonicus*, known as katakuchi iwashi in Japanese (Katsuo-Maguro Nenkan 1971). Imamura (1949) listed various other species that have been used as bait in the past. Among them were maiwashi or sardines, *Sardinops melanosticta*; muroaji or scad, *Decapturus muroaji*; and the juveniles of masaba or mackerel, *Scomber japonicus*. Cleaver and Shimada (1950) published an extensive list of fishes that were used as live bait in the pre-World War II fisheries in Japan, the Ryukyu Islands, and the South Seas (Table 8).

Katakuchi iwashi was not always the predominant bait species in Japan. Imamura (1949) listed maiwashi as the predominant species in the immediate post-World War II period. Maiwashi, he stated, was more resistant to injury and excitement, whereas katakuchi iwashi was resistant to oxygen deficiency.

Baiting Areas

There are more than 60 baiting areas for anchovy in Japan (Katsuo-Maguro Nenkan 1971). These areas are given in Table 9. During a visit to Japan in 1974, one of the coauthors (T. Otsu) made firsthand observations on the bait fisheries in Shizuoka Prefecture (Ajiro, Usami), Oita Prefecture (Tsukumi), and Nagasaki Prefecture (Segawa). The areas are representative of the Kanto and Kyushu baiting areas (central and southwestern Japan, respectively). Following are some of the observations made during that visit.

There is considerable demand for live bait in Shizuoka Prefecture, which is the leading skipjack tuna fishing prefecture in Japan. Because the prefectural baiting areas periodically experience shortages, several bait-transport vessels are now in operation carrying fish purchased from Kyushu baiting areas to Shizuoka Prefecture. Most of the anchovy in Shizuoka Prefecture are taken by one-boat or two-boat purse seines. In addition to the seiners, a baiting unit includes a fish-finder vessel, a small scouting vessel, and a tugboat to tow the bait receivers to and from the fishing grounds.

Table 8.—Some baitfishes used by the Japanese skipjack tuna fishery (from Cleaver and Shimada 1950).

Scientific name	Common names
Japan and Ryukyu Islands	
Amia notata	kurohoshi-tenjikudai, ufumi
A. truncata	ufumi
Atherina bleekeri	tōgoro-iwashi
A. tsurugae	aoharara, gin-isō-iwashi
Beryx decadactylus	gasagasa, nanyō-kinmedai
Caesio coerulaureus	saneera, shimamuro-gurukun
C. digramma	gurukun
Caranx djeddeba	gatsun
Engraulis japonicus	katakuchi-iwashi, segurō-iwashi, tarekuchi-iwashi
Harengula zunasi	sappa
Lutjanus vaigiensis	mochinogwa, okifuefuki
Pomacentrus anabatoids	hichigwa, hikigwa
Pseudupeneus sp.	himeji
Sardinella mizun	mizun
Sardinia immaculata	hoshinashi-iwashi, shiira
S. melanosticta	ma-iwashi
Scomber japonicus	ōsabanoko, saba
South Seas	
Amia sp.	akadoro
Apogon sp.	akadoro
Archamia bleekeri	atohiki-tenjikudai
Atherina sp.	kokera, tobi-iwashi, tōgoro-iwashi
Atherina valenciennesii	nanyō-tōgoro-iwashi
Caesio chrysozonus	akamuro, gurukun, saneera, umeiro
Caranx leptolepis	aji
C. malibalicus	shima-aji
Caranx sp.	aji, gatsun
Chilodipterus sp.	akadoro
Dascyllus trimaculatus	montsuki
Decapterus russelli	akamuro
Decapterus sp.	muro, shima-muro
Gazza equulasformis	hiiragi
Harengula molluciensis	ma-iwashi, nanyō-ma-iwashi
Labracoglossa argentiventris	takabe
Mullus sp.	ojisan
Sardinella leiogaster	mangurōbu-iwashi
Scomber kanagurta	saba
Sphyraena obtusata	kamasu
Spratelloides delicatulus	ao-iwashi, baka, nanyō-kibinago, shiira
Trachurops crumenophthalma	me-aji
Trachurus japonicus	ma-aji
Upeneus sp.	ojisan
Upeneus tragula	yomehimeji
Upenoides sp.	ojisan
Stolephorus heterolobus	nanyō-katakuchi-iwashi, tarekuchi
S. japonicus	bakasako, kibiko-iwashi, sururu

The bait fishery at Tsukumi in Oita Prefecture is one of the important baiting areas in Kyushu. It is operated strictly for vessels from outside prefectures since Oita Prefecture does not have a skipjack tuna fishery of its own. Vessels from Shizuoka, Kochi, and Miyazaki Prefectures, among others, come here to purchase bait. The baiting fleet in Tsukumi consists of two 7-ton catcher boats (seiners), a one-boat seiner, a 2-ton lightboat, a transport, and a tugboat.

Bait from the bait fishery in an area in Segawa Bay, Nagasaki Prefecture, is reported to be of excellent quality. It is known as "Sasebo bait" and is taken in Omura Bay, an enclosed bay located between Nagasaki City and Sasebo City. Vessels from various prefectures come here to make purchases. Fishing is largely by purse seining but about a third of the catch is made by beach seining, a method which reportedly produces superior bait.

Table 9.—Baiting areas for anchovy in Japan (Katsuo-Maguro Nenkan 1971).

Prefecture	Baiting areas
Iwate	Miyako, Yamada, Tanohama, Oozuchi, Ofunato, Hirota, Ohno, Takada
Miyagi	Kesennuma, Shizukawa, Takenoura, Onagawa, Sameura, Makinohama, Momoura, Koamigura
Chiba	Tateyama, Tomiura, Katsuyama, Hoda, Kisarazu
Kanagawa	Koajiro, Shimoura, Sajima, Hayama
Shizuoka	Ajiro, Usami, Tago, Mito, Heda, Enoura
Mie	Goza, Hamajima, Shukutaso, Kamimae, Shiroura, Sugari, Mikiura, Nagashima
Wakayama	Kushimoto, Tanabe
Kochi	Asakawa, Shukumo
Ehime	Uwajima
Oita	Tsukumi, Saeki
Miyazaki	Takashima
Saga	Imari
Nagasaki	Sasebo, Imafuku, Hatashita, Takashima, Higashihama, Omodaka, Tawaragaura, Nakura
Kumamoto	Ushibuka, Miyaura, Yokoura
Kagoshima	Ooneshime, Furue, Umigata, Sakurajima, Yamakawa, Oura

Catch and Baiting Effort

Data on the amount of anchovy caught and sold as live bait may be found in the Annual Report of Catch Statistics on Fishing and Aquiculture ([Japan.] Ministry of Agriculture and Forestry, 1958-62, 1964-73). There are, however, no statistical data on the amount of effort expended in catching bait.

Japanese pole-and-line vessels usually purchase bait from bait fishermen. It has been estimated that roughly 10% of the anchovy catch in Japan is actually marketed for use as live bait (Katsuo-Maguro Nenkan 1971). Data on total catch of anchovy and the amount of anchovy sold as live bait in three principal regions of Japan show that in 1968, out of a total catch of 225,348 t of anchovy, 24,027 t or 10.7% was sold as live bait.

In 1957-71, the catch of anchovy as live bait varied from 14,915 t in 1964 to 27,568 t in 1965 (Table 3). The average amount of anchovy sold as live bait annually was 19,103 t.

Although the amount of anchovy sold as live bait is reported in metric tons, the actual unit of measurement that the bait fishermen use in selling bait is the bucket. As in Hawaii, the amount of bait per bucket is quite variable. For example, the bucket in the Kanto (central Japan) baiting areas holds an average of 3.4 kg of baitfish whereas that in the Sanriku (north of Ibaragi Prefecture including the Tohoku area) and the Shikoku-Kyushu areas averages 6-7 kg or more of baitfish. In order to compare bait production from the eastern and western

Pacific, we converted the eastern Pacific catches to metric tons, using 3.6 kg of bait per scoop. The average annual eastern Pacific catch of live bait during the period when bait boats dominated the fishery (1946-59) was 11,760 t, roughly two-thirds of the Japanese bait production.

LANDINGS OF TUNA

The estimated landings of yellowfin and skipjack tunas by bait boats in the eastern Pacific are shown in Figure 5. These estimates were obtained by using the data on the percentage of the total landings made by bait boats as given in the annual reports of the IATTC and the California landings data provided by Frey (1971). The most striking feature of Figure 5 is the sudden drop in the landings of both species starting in 1959. This sudden decline was caused, of course, by the conversion of a large number of the bait boats to purse seiners. It can be seen that, during the period from 1950 to 1958, the bait boats landed between about 37,000 and 68,000 t of yellowfin tuna and 33,000 and 62,000 t of skipjack tuna. In more recent years the bait boat landings have stabilized at a low level with only small fluctuations.

The landings of tuna in the Japanese pole-and-line fishery from 1958 to 1971 are shown in Figure 6. The category "others" in this figure includes yellowfin, bigeye, and bluefin, *Thunnus thynnus*, tunas; and frigate mackerels, *Auxis*. The Japanese pole-and-line fishery appears to be stabilized in that there are no apparent upward or downward trends in the landings. Skipjack tuna landings fluctuated from 70,428 to 212,985 t during this period. The landings of albacore varied between a low of 8,729 and a high of 52,957 t. The landings of other tunas ranged from 9,081 to 28,342 t.

The Hawaiian pole-and-line fishery also did not show any positive or negative trends (Fig. 7). The landings ranged from a low of 2,679 to a high of 7,329 t during the period from 1950 to 1972.

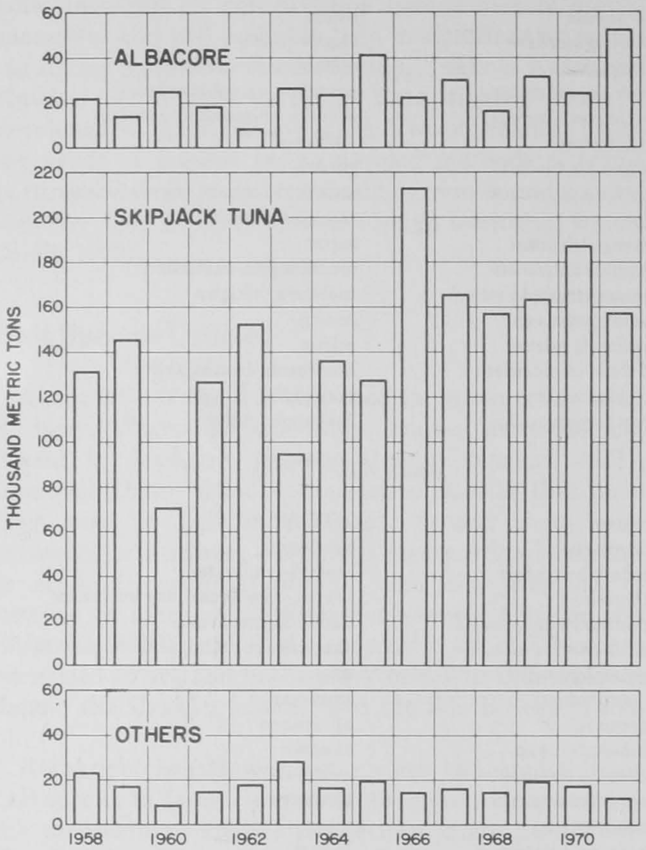

Figure 6.—Landings of tuna in the Japanese pole-and-line fishery.

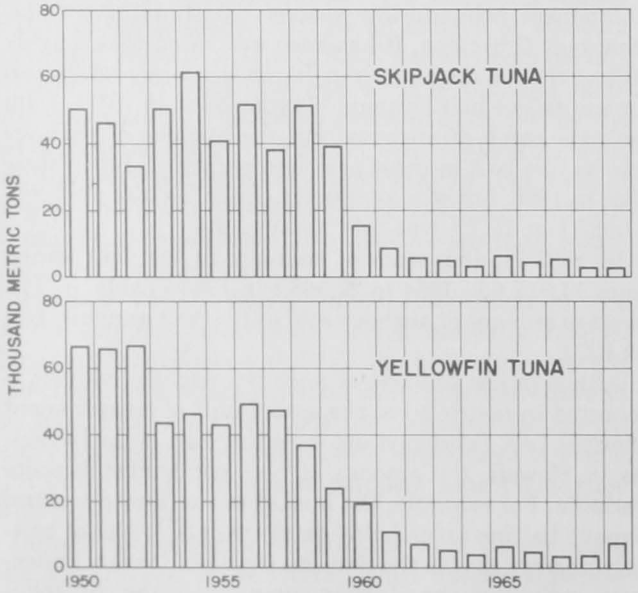

Figure 5.—Estimated landings of yellowfin and skipjack tunas by California-based bait boats in the eastern Pacific fishery.

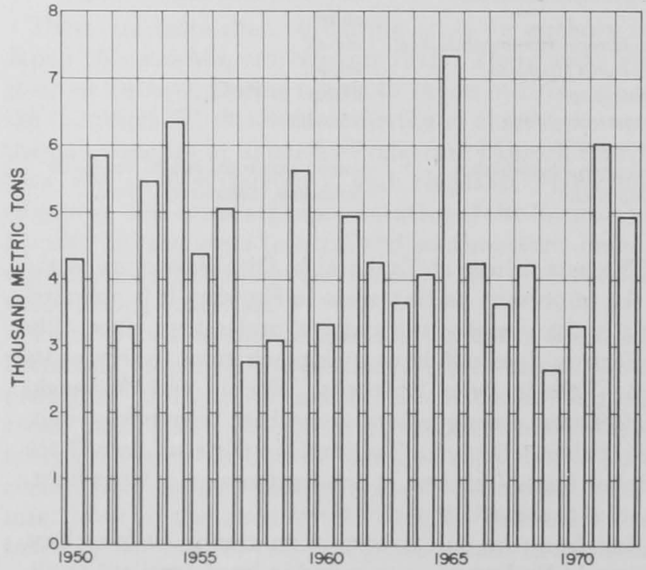

Figure 7.—Landings of skipjack tuna in the Hawaiian pole-and-line fishery.

RELATION OF LANDINGS TO FLEET SIZE

It is interesting to determine, roughly, how the total landings are related to number of boats and to catch per boat, especially in the eastern Pacific where a large number of bait boats were converted to purse seiners. The combined total catch of yellowfin and skipjack tunas, the number of bait boats, and the catch per boat in the eastern Pacific are shown in Figure 8. As noted earlier the conversion of bait boats to purse seiners caused a decline in the number of bait boats in the eastern Pacific tuna fleet. This resulted directly in a decline in the total landings of tuna by the bait boats and also a decline in the mean catch per boat, probably related to the resultant size composition of the bait boat fleet after the mass conversion. It has been shown in the eastern Pacific fishery for tunas that the success of fishing is related to vessel size, the larger vessels being the more efficient (Shimada and Schaefer 1956). Recent data in the annual reports of the IATTC on the size composition of the bait boat fleet show very few boats larger than 182 t (200 short tons) capacity after 1959 (Table 10). Therefore it appears that the eastern Pacific bait boat fleet has been reduced not only in number but also in efficiency.

Similar data on the total catch of tuna, number of boats, and the catch per boat from 1958 to 1971 in the Japanese pole-and-line fishery are shown in Figure 9. The total catch includes all the tunas taken by pole and line and the boats include only those larger than 20 t. Live-bait boats smaller than 20 t number in the thousands but these vessels primarily catch frigate mackerel and contribute only a small amount to the skipjack tuna and albacore landings (Van Campen 1960).

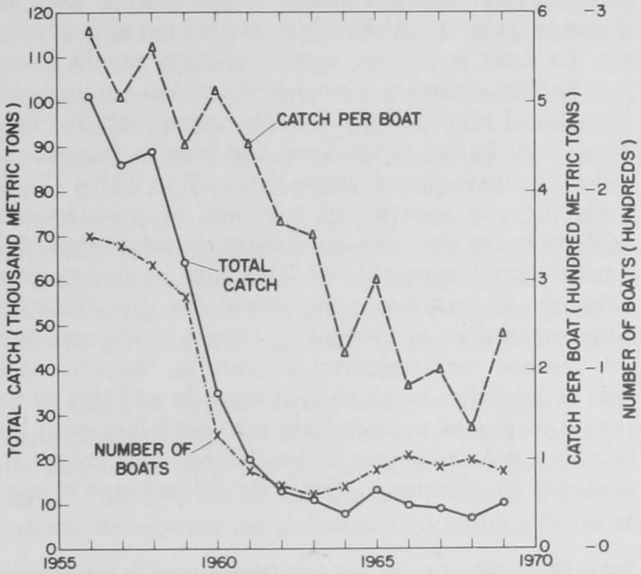

Figure 8.—Total catch of yellowfin and skipjack tunas, number of bait boats, and catch per boat in the eastern Pacific pole-and-line fishery.

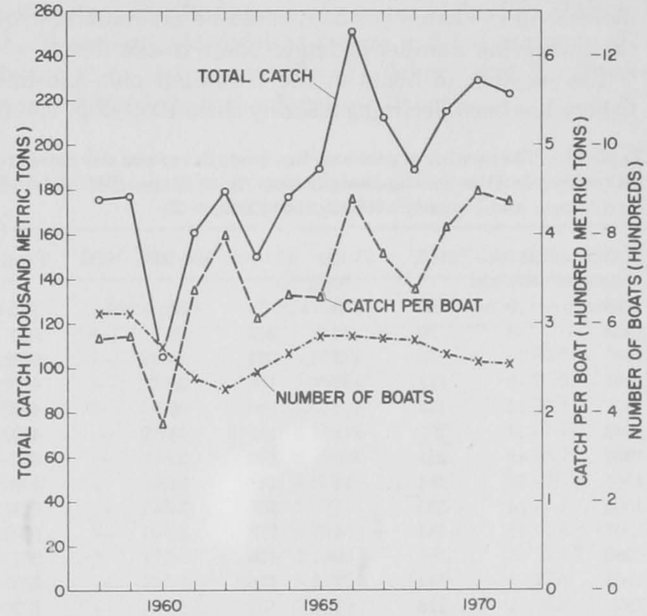

Figure 9.—Total catch of tunas, number of boats, and catch per boat in the Japanese pole-and-line fishery. (Original data from [Japan.] Ministry of Agriculture and Forestry. Statistics and Survey Division, 1960-1973.)

Table 10.—The number of bait boats based in U.S. ports (including Puerto Rico) in the pole-and-line fishery in the eastern Pacific (from IATTC 1961, 1966, 1971).

	Capacity in metric tons and short tons (in parentheses)						
Year	<46.4 (51)	46.4-90.9 (51-100)	91.8-181.8 (101-200)	182.7-272.7 (201-300)	273.6-363.6 (301-400)	364.5 (≥ 401)	Total
1956	12	11	43	66	32	11	175
1957	11	11	43	60	35	10	170
1958	12	8	35	56	36	11	158
1959	13	8	31	46	33	10	141
1960	10	7	21	11	17	3	69
1961	11	4	17	1	11	0	44
1962	13	4	12	1	6	0	36
1963	13	4	11	2	0	0	30
1964	16	5	11	2	1	0	35
1965	21	7	12	3	1	0	44
1966	25	9	11	5	2	0	52
1967	21	9	10	4	2	0	46
1968	23	11	10	4	2	0	50
1969	17	12	9	4	1	0	43

Because catches of boats smaller than 20 t, but not number of boats, were included in the computations, the catches per boat as shown in Figure 9 are probably higher than the actual catches. However, this should not mask any trends that may be present.

The number of boats in the Japanese pole-and-line fishery has fluctuated between 451 and 623 from 1958 to 1971. Although, as it was pointed out earlier, there was no trend apparent in the landings of the various tuna species, it appears that the total tuna landings are increasing. The catch per boat also appears to be on a slight upward trend. There has been a change in the size composition of the Japanese pole-and-line fleet in that since 1967 the number of vessels in the 200- to 500-t class has been increasing (Table 11). If size is also related to efficiency in the Japanese pole-and-line fishery, then the increase in the catch per boat could be accounted for by the increasing number of larger boats in the fleet.

The number of boats in the Hawaiian pole-and-line fishery has been declining steadily since 1950 (Fig. 10). It is interesting that in spite of this the landings have not declined correspondingly. The catch per boat showed large annual fluctuations, but appeared to be at a higher level after 1963 than before. Except for the addition of one new vessel in December 1971, the composition of the Hawaiian fleet has remained unchanged for many years. Thus, although the new addition to the Hawaiian fleet is a larger vessel with a greater fish-carrying capacity and range than the average Hawaiian boat, this fact alone cannot account for the apparent increase in efficiency. Among other things, a change in fishing techniques has been suggested as a factor in the improved efficiency of Hawaiian pole-and-line vessels (Uchida 1967).

Table 11.—The number of pole-and-line boats in various size categories (metric tons) in the Japanese fishery (from [Japan.] Ministry of Agriculture and Forestry 1959-62, 1964-73).

Year	20-30	30-50	50-100	100-200	200-500	>500	Total
1958	19	68	239	273	24	—	623
1959	18	80	234	262	26	—	620
1960	11	98	179	229	28	—	545
1961	19	122	132	178	26	—	477
1962	13	173	111	126	28	—	451
1963	33	207	111	112	29	—	492
1964	40	251	103	106	32	—	532
1965	14	284	91	148	35	—	572
1966	14	285	71	167	34	—	571
1967	12	284	54	173	41	—	564
1968	5	271	60	170	54	1	561
1969	4	244	71	156	53	—	528
1970	2	218	91	140	61	—	512
1971	2	163	133	129	83	—	510

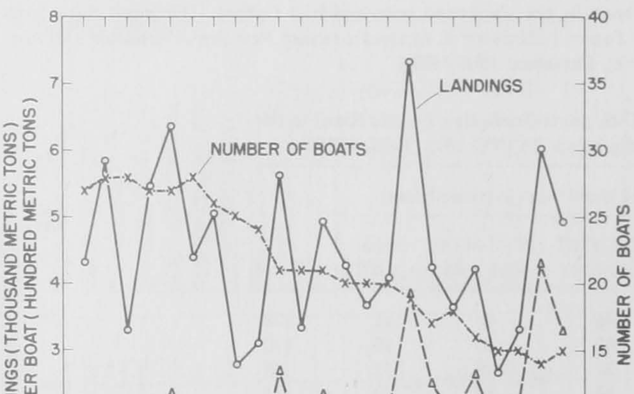

Figure 10.—Landings of skipjack tuna, number of boats, and catch per boat in the Hawaiian pole-and-line fishery. (Original data from Hawaii Division of Fish and Game.)

BAIT AND TUNA CATCHES

The catch of tuna and the amount of bait used in the Japanese pole-and-line fishery from 1957 to 1971 are shown in Table 12. Although skipjack tuna and albacore are the most important species of tuna caught in the pole-and-line fishery, as noted earlier appreciable amounts of other species are also taken with live bait. These include frigate mackerel and bluefin, bigeye, and yellowfin tunas (listed under "others" in Table 12). In analyzing the relative effectiveness of the Japanese anchovy in the pole-and-line fishery the total catch of all species should be considered. This must be done because although the statistics published by the Japanese Government lists all the species caught by the pole-and-line method, no breakdown is given on the amount of bait expended to catch each species. In addition to the tunas, species of mackerel are actively fished with live bait and pole and line. These catches will not be included in the discussion, but it should be borne in mind

Table 12.—Catch of tunas and bait (metric tons) in the Japanese pole-and-line fishery (from [Japan.] Ministry of Agriculture and Forestry, Statistics and Survey Division 1958-62, 1964-73.)

Year	Skipjack tuna	Albacore	Others[1]	Total	Japanese anchovy[2]	Tuna catch per unit of bait
1957	92,156	49,500	20,675	162,331	18,468	8.8
1958	131,441	22,190	22,778	176,409	18,109	9.7
1959	145,447	14,252	17,058	176,757	16,304	10.8
1960	70,428	25,156	9,081	104,665	15,916	6.6
1961	127,011	18,636	14,914	160,561	15,604	10.3
1962	152,387	8,729	18,111	179,227	18,526	9.7
1963	94,757	26,420	28,342	149,519	16,067	9.3
1964	136,081	23,858	16,827	176,766	14,915	11.8
1965	127,436	41,491	19,821	188,748	27,568	6.8
1966	212,985	22,830	14,718	250,533	22,262	11.2
1967	165,492	30,481	16,431	212,404	18,320	11.6
1968	157,340	16,597	15,021	188,958	20,771	9.1
1969	163,455	31,912	19,641	215,008	21,606	10.0
1970	187,438	24,263	17,391	229,092	21,264	10.8
1971	157,380	52,957	12,327	222,664	20,848	10.7
Total				2,793,642	286,548	
n				15	15	
Mean				186,243	19,103	9.7

[1]Includes *Auxis*, bluefin, bigeye, and yellowfin tunas.
[2]*Engraulis japonicus*.

that an undetermined amount of bait and effort is expended towards the catch of these nontuna species.

The total landings of tuna from 1957 to 1971 in the Japanese pole-and-line fishery ranged from 104,665 to 250,533 t with an expenditure of 14,915 to 22,262 t of bait. The tuna catch per unit of bait (CPUB) ranged from 6.6 to 11.8 t per metric ton of bait. The mean values for the 14-yr period were 186,243 t for the total annual catch of tuna, 19,103 t for the annual catch of anchovy, and 9.7 t of tuna per metric ton of bait for the mean annual CPUB.

Table 13 gives the estimated landings of skipjack and yellowfin tunas and the amount of bait caught from 1950 to 1969 by bait boats based in California ports. The bait data were given in terms of "scoops" in the IATTC annual reports, and these were converted to metric tons.

The total bait boat landings of skipjack and yellowfin tunas ranged from 6,811 to 117,369 t and averaged 54,602 t. The total bait catch ranged from 813 to 16,138 t and averaged 7,304 t. The CPUB of yellowfin and skipjack tunas ranged from 5.5 to 12.2 t per metric ton of bait and averaged 7.5 t per metric ton of bait.

As noted earlier, several different species of fish are used as bait in the eastern Pacific bait boat fishery. However, there is nothing in the literature on a comparison of the relative effectiveness of the various species of bait used in this fishery. Although figures are available on the catch of baitfishes by species (Table 1), no figures are available on the catch of tunas by the use of the various species of bait. Thus the CPUB figures given in Table 13 are based on the total catch of all species of bait.

The catch of skipjack tuna and the amount of bait caught from 1950 to 1972 in Hawaii are given in Table 14. The bait catch statistics provided by the Hawaii Division of Fish and Game, which are given in terms of buckets, were converted to metric tons using a factor of 5.4 kg (12 lb) per bucket. In the past, the bucket was assumed to be equivalent to about 3.2 kg (7 lb) of fish (Yamashita 1958). However, more recent data indicate that this figure is an underestimate (T. S. Hida, Southwest Fisheries Center, Honolulu, HI 96812, pers. commun.).

The skipjack tuna catch ranged from 2,679 to 7,324 t from 1950 to 1972. The catch of bait ranged from 124 to 270 t and the skipjack tuna CPUB ranged from 16.3 to 37.0 t per metric ton of bait. The mean values were 4,478 t of skipjack tuna, 194 t of bait, and 17.2 t of skipjack tuna per metric ton of bait.

The relative effectiveness of the bait used in these fisheries in terms of CPUB is summarized in Table 15. It can be seen that the mean annual CPUB for the Hawaiian fishery at 23.1 was higher than the Japanese and eastern Pacific fisheries. In terms of the CPUB then, the Hawaiian pole-and-line fishery is 3.1 times more efficient than the eastern Pacific fishery and 2.3 times more efficient than the Japanese fishery.

Table 13.—Estimated landings (metric tons) of yellowfin and skipjack tunas by bait boats based in California ports.

	Landings				
Year	Yellowfin tuna	Skipjack tuna	Total	Catch bait	Tuna catch per unit of bait
1950	66,655	50,714	117,369	12,956	9.0
1951	66,000	46,626	112,626	9,766	11.5
1952	67,018	33,435	100,453	15,492	6.5
1953	43,797	50,374	94,171	15,782	6.0
1954	46,524	61,235	107,759	14,251	7.6
1955	43,157	41,041	84,198	9,384	9.0
1956	49,363	51,940	101,303	13,257	7.6
1957	47,524	38,403	85,927	13,453	6.4
1958	37,173	51,511	88,684	16,138	5.5
1959	24,332	39,215	63,547	10,814	5.9
1960	19,664	15,690	35,354	4,329	8.2
1961	10,965	8,900	19,865	2,359	8.4
1962	7,257	5,972	13,229	1,502	8.8
1963	5,468	5,215	10,683	874	12.2
1964	3,988	3,656	7,644	813	9.4
1965	6,604	6,649	13,253	1,118	11.8
1966	4,812	4,728	9,540	1,031	9.2
1967	3,692	5,587	9,279	864	10.7
1968	3,748	3,063	6,811	983	6.9
1969	7,409	2,936	10,345	904	11.4

Table 14.—Catch of nehu and skipjack tuna (metric tons) in the Hawaiian pole-and-line fishery.[1]

Year	Nehu catch	Skipjack tuna catch	Skipjack tuna catch in metric tons per metric ton of nehu
1950	216	4,312	20.0
1951	220	5,863	26.6
1952	162	3,308	20.4
1953	205	5,470	27.1
1954	238	6,360	26.7
1955	270	4,397	16.3
1956	222	5,050	22.7
1957	167	2,781	16.6
1958	181	3,100	17.1
1959	205	5,631	27.5
1960	124	3,338	26.0
1961	202	4,942	24.3
1962	186	4,271	22.7
1963	178	3,674	20.6
1964	166	4,093	23.5
1965	198	7,329	37.0
1966	172	4,257	24.8
1967	173	3,647	21.0
1968	193	4,228	21.9
1969	164	2,679	16.3
1970	183	3,314	18.2
1971	229	6,023	26.3
1972	212	4,930	23.1

[1]Original data courtesy Hawaii Division of Fish and Game.

Table 15.—The relative effectiveness of live bait used in the eastern Pacific, Japanese, and Hawaiian pole-and-line fisheries.

Area and period	Mean annual catch of tuna (metric tons)	Mean annual catch of bait (metric tons)	Mean annual catch of tuna per unit of bait (metric tons)
Eastern Pacific (1950-69)	54,602	7,304	7.5
Japan (1957-71)	186,243	19,103	9.7
Hawaii (1950-72)	4,478	194	23.1

FACTORS AFFECTING CPUB

The CPUB in terms of the weight of tuna caught in a pole-and-line fishery can be affected by many variables including the size and species of fish caught, the number of men fishing, the number of fish in a unit weight of bait, and, less directly, the apparent abundance of the fish caught.

The size of the fish would affect the CPUB in that, assuming that fish up to a certain maximum size, i.e., one-pole size fish, are caught at the same rate, the catch in weight would be greater if the fish caught were larger. If the fish are so large as to require a two-pole rig, then the effective fishing power would be reduced because it would require two men to bring in one fish. However, it may happen that the fish are large enough to balance out or even exceed the difference caused by the loss of fishing power in using a two-pole rig. In the eastern Pacific fishery, one pole is used on fish up to 13.6 kg (30 lb). For fish from 13.6 to 27.2 kg (30 to 60 lb) two-pole rigs are used. With fish larger than 27.2 kg, a three-pole rig is used (Godsil 1938). In the Japanese pole-and-line fishery albacore fishing is done with two-pole rigs and one-pole rigs are used on skipjack tuna (Van Campen 1960).

Another important variable affecting the CPUB is the number of fish in a unit weight of bait. Obviously, the size of the fish will affect the number in a unit weight of bait: the larger the fish, the fewer per unit. Presumably, the greater the number of fish per unit weight of bait, the greater would be the "fishing power." The length-frequency distribution of the baitfishes used in the three fisheries is shown in Figure 11. For the eastern Pacific fishery, the length distribution of two of the more important baitfishes, the anchoveta and the northern anchovy, is shown. If it is assumed that these size distributions are representative of the bait in the three fisheries, it can be seen that the bait used in the Hawaiian fishery is generally the smallest and that used in the eastern Pacific the largest. The Japanese anchovy is intermediate in size between the Hawaiian and the eastern Pacific baitfishes. It can be deduced, then, that the fishing power of a unit weight of bait in the Hawaiian fishery is greater than that in the eastern Pacific and Japanese pole-and-line fisheries.

Finally, the apparent abundance of the tunas in any one year may have an influence on the mean annual

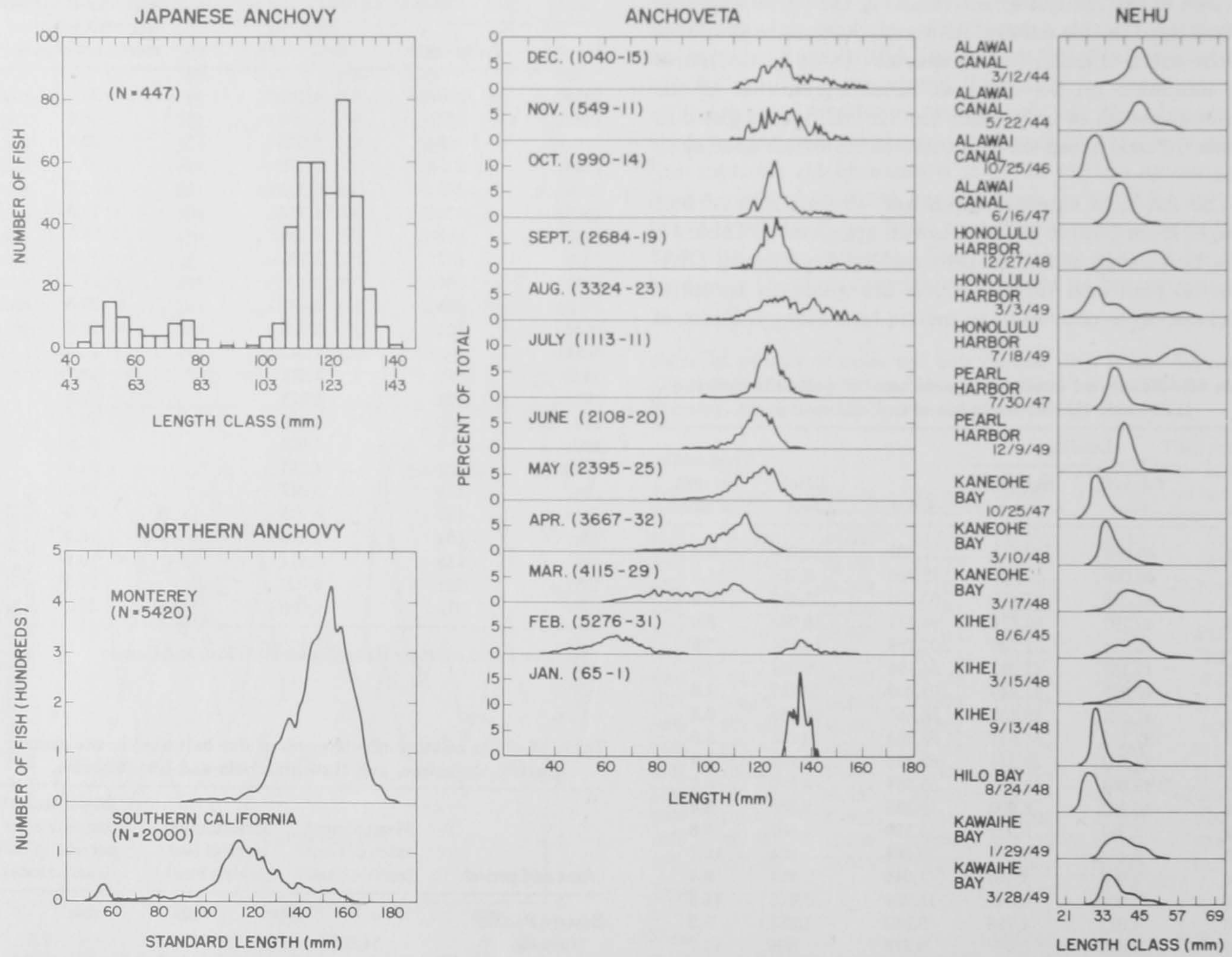

Figure 11.—Length-frequency distribution of Japanese anchovy, anchoveta, northern anchovy, and nehu. (From Clark and Phillips 1952; Tester and Hiatt 1952; Mie Prefectural Fisheries Experiment Station 1953; Howard and Landa 1958.)

CPUB: if the apparent abundance is higher, it may be expected that the mean annual CPUB will be greater. Figure 12 shows the relation between the mean annual CPUB and the mean annual apparent abundance for skipjack tuna in the Hawaiian fishery, and Figure 13 shows the mean annual CPUB and the mean annual apparent abundance of yellowfin and skipjack tunas in the eastern Pacific fishery. For the eastern Pacific figure, the apparent abundance is expressed in terms of the mean catch of yellowfin and skipjack tunas per day's fishing. The data for 1950-58 are based only on bait boat operations and the data for 1959-69 are means based on bait boat and purse seiner operations. The basic data were taken from the annual reports of the IATTC.

For the Hawaiian pole-and-line fishery figure, apparent abundance is simply represented by the total annual catch. Uchida (1967) found that the apparent abundance of skipjack tuna expressed as the catch per standard effective trip was correlated with the total catch of skipjack tuna from 1952 to 1962. He stated, therefore, that the total catch may be used as an index of apparent abundance during 1952-62. Although he cautioned against the use of the total catch as an index of apparent abundance for other years, we assumed that it was reliable for other years also.

It can be seen that CPUB was positively related to the apparent abundance of tuna in the eastern Pacific and the Hawaiian fisheries. In years when the apparent abundance was high the CPUB was also high. The coefficient of correlation was computed for the data for both fisheries. The results (eastern Pacific fishery, $r = 0.556$; df = 19; $P<0.01$; Hawaiian fishery, $r = 0.839$; df = 22; $P<0.01$) indicated that the mean annual CPUB was highly correlated with the apparent abundance of tuna.

Higgins (1966) examined the size distribution of the various tunas caught in the Pacific and noted fundamental differences in the sizes caught in the different areas. For example, he noted that larger skipjack tuna are caught around the Hawaiian Islands than in the eastern Pacific or near Japan. Obviously, it would be expected that differences in size would exist among the different species of tuna. The albacore caught by pole and line in the Japanese fishery are larger than the skipjack tuna caught by the same method. The yellowfin tuna taken by pole and line in the eastern Pacific are larger than the skipjack tuna. Thus CPUB is not only influenced by differences in sizes within the same species among the different fisheries, but also by the species of fish taken.

The number of men fishing per unit of bait expended also affects the CPUB. In the eastern Pacific fishery the size of the crew on a bait boat ranged from 12 to 20 men (Godsil 1938). The average number of crewmen on a Japanese pole-and-line boat ranged from 29 on 20- to 50-ton boats to 54 on 100- to 200-ton boats (Van Campen 1960). In the Hawaiian pole-and-line fishery from 1950 to 1960, Uchida (1967) indicated that, depending on the size of the vessel, an average of 6.7 to 10.4 fishermen fished on each trip. However, the relation between the number of men fishing and the amount of bait expended is not very clear. Generally, it is likely that more men fishing would require a greater use of bait. In the Japanese pole-and-line fishery bait is chummed at the stern, amidships, and forward (Van Campen 1960). In the eastern Pacific fishery, the smaller boats have one chummer and the larger ones usually have two (Godsil 1938). The Hawaiian pole-and-line boats usually have only one chummer.

SUMMARY

This report reviews the pole-and-line and live-bait fisheries of the eastern, central, and western Pacific Ocean including historical catch and effort statistics on

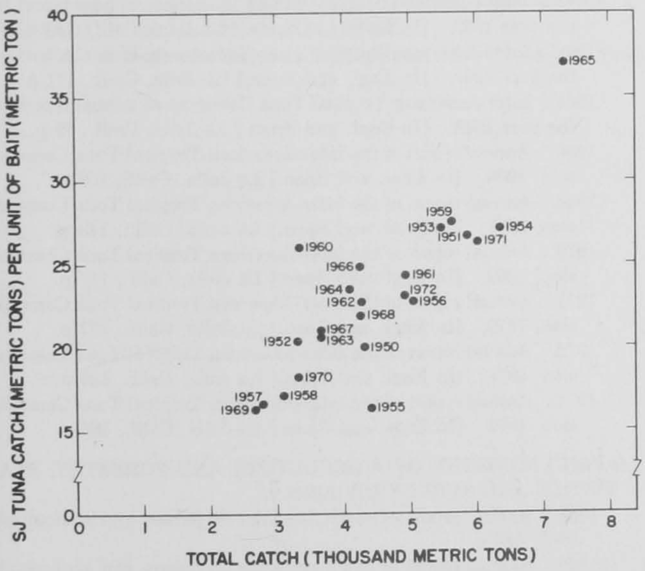

Figure 12.—Relation between total catch of skipjack tuna and catch per unit of bait in the Hawaiian pole-and-line fishery, 1950-72.

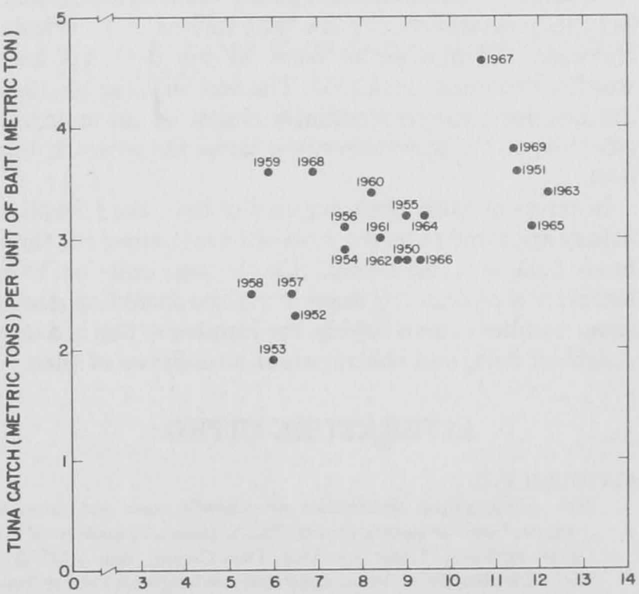

Figure 13.—Relation between the mean apparent abundance (catch per day's fishing) of yellowfin tuna and skipjack tuna and the catch per unit of bait in the eastern Pacific, 1951-69.

the fisheries for tuna baitfishes. Included in the report are comparisons on the relative effectiveness of the live bait used in the fisheries and a discussion of the factors that may contribute to the relative effectiveness.

Although the eastern Pacific fishery for yellowfin and skipjack tunas is now dominated by the purse seiners, bait boats are still active in that fishery. In Japan, the pole-and-line technique of catching albacore and skipjack tuna is still one of the important methods of fishing for tuna. And in Hawaii, the pole-and-line fishery for skipjack tuna is the most important fishery in the State.

In the Japanese pole-and-line fishery, the Japanese anchovy, *Engraulis japonicus*, is the most important bait species used. The more important bait species utilized in the eastern Pacific fishery are anchoveta, *Cetengraulis mysticetus*, northern anchovy, *E. mordax*, California sardine, *Sardinops caerulea*, Galapagos sardine, *S. sagax*, and southern anchovy, *E. ringens*. The Hawaiian skipjack tuna fishermen primarily use an anchovy called nehu, *Stolephorus purpureus*.

In the eastern Pacific it was seen that landings of yellowfin and skipjack tunas by the bait boats dropped suddenly starting in 1959 owing largely to the reduced number of bait boats in the fleet following the conversion of many of them to purse seiners. It was also seen that there was a downward trend in the catch per boat, which was attributed to a reduction in efficiency of the remaining bait boat fleet.

Landings of tuna by species in Japan did not show any important trends, although the total catch of all tuna species combined appeared to be increasing. The catch per boat also appeared to be on a slight upward trend. A change in the composition of the fleet by the addition of larger vessels may have contributed to the increasing catch per boat.

Landings of skipjack tuna in the Hawaiian pole-and-line fishery did not show any significant trends. However, the number of boats in the fleet has been steadily declining since 1950. The fact that the landings did not decline correspondingly suggested an improved efficiency in the operation of the Hawaiian pole-and-line fleet.

In terms of tuna catch per unit of bait, the Hawaiian fishery appeared to be the most efficient among the three tuna fisheries considered. Catch per unit of bait, however, is affected by many variables including size of tuna, number of men fishing, the number of fish in a unit weight of bait, and the apparent abundance of tuna.

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Desired Characteristics of a Bait for Skipjack Tuna, *Katsuwonus pelamis*

HEENY S. H. YUEN[1]

ABSTRACT

Skipjack tuna, *Katsuwonus pelamis*, fishing in the central Pacific Ocean is largely dependent upon a limited supply of live baitfish, the nehu, *Stolephorus purpureus*. Experiments by the Honolulu Laboratory in a search for effective live-bait substitutes or supplements have resulted in the collection of much information on behavioral characteristics of the experimental baits. Characteristics of an effective skipjack tuna bait are: a tendency to flee towards the surface, elusiveness, a high light reflectance, a length of 2 to 6 cm, and the durability to survive in a baitwell.

INTRODUCTION

The only successful method of catching skipjack tuna, *Katsuwonus pelamis*, on a commercial scale in the clear waters of the central Pacific Ocean has been the pole-and-line method in which the skipjack tuna are attracted to the fishing boat with live bait. The major fishery for this species in the central Pacific Ocean is located in the Hawaiian Islands where the supply of nehu, *Stolephorus purpureus*, the principal bait species, is an important factor limiting the catch of skipjack tuna (June 1951). Since 1951 the Honolulu Laboratory of the National Marine Fisheries Service (then known as the Pacific Oceanic Fishery Investigations) has invested research effort in developing an artificial bait or finding a substitute species to augment the nehu.

As part of this effort studies were made of the perceptual abilities of skipjack tuna, their responses to various stimuli, their feeding responses at sea, and their responses to various species of live bait. For this paper on desired bait characteristics, I have tried to gather the relevant information from these studies.

SOURCE OF DATA

Beginning in 1957 (Strasburg and Yuen 1960), various underwater viewing facilities installed on the *Charles H. Gilbert*, a research ship of the Honolulu Laboratory, provided many opportunities to observe bait behavior and feeding responses of skipjack tuna under experimental conditions at sea. Many of the experiments were designed to compare the effectiveness of two different species as bait. In most cases nehu was one of the two species and was used as a control. With the exception of tilapia, *Tilapia mossambica*, which could be purchased, selection of experimental species was opportunistic; trials were made with whatever species could be obtained.

Because skipjack tuna at sea respond to live bait with a wide range of variability (Yuen 1959), experiments require much replication for reliable conclusions. Many of the experiments were not replicated sufficiently or not replicated at all because the desired bait was not sufficiently available, and, therefore, was not included in an earlier publication (Yuen 1969). The experiments, however, provided the opportunity to collect many observations on the behavioral characteristics of the experimental baits and the reaction of skipjack tuna to them. This collection of field notes is the major source of information on the desired characteristics of bait.

A total of 14 species (Table 1) was involved in the experiments. The species provided a wide range of characteristics in physical attributes as well as in behavior (also see Baldwin 1977). Some fish were shiny, others were dull; some were deep-bodied, others slender; some were fast, others slow; swimming motions were different.

CHARACTERISTICS

In the fishing operation for skipjack tuna the use of live bait serves two purposes. When the ship intercepts the

Table 1.—Species used in baitfish experiments in Hawaii.

Common Name	Scientific Name
Aholehole	*Kuhlia sandvicensis*
Iao	*Pranesus insularum*
Lae	*Scomberoides lysan*
Marquesan sardine	*Sardinella marquesensis*
Moi	*Polydactylus sexfilis*
Mullet	*Mugil longimanus*
Nehu	*Stolephorus purpureus*
Northern anchovy	*Engraulis mordax*
Oama	*Mulloidichthys* sp. (mix of several species)
Omaka	*Caranx mate*
Tabai	*Limia vittata*
Thread herring	*Opisthonema medirastre*
Threadfin shad	*Dorosoma petenense*
Tilapia	*Tilapia mossambica*

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school, bait is used to attract the skipjack tuna to the boat. Once the school is at the boat, the bait is used to hold the fish there so that they may be fished. A desirable characteristic for one function may not be a desirable characteristic for the other. For example, the most attractive bait should lure the skipjack tuna to the boat. On the other hand, if the bait is so attractive that the skipjack tuna always takes it in preference to the hook, it is not a desirable bait. In discussing the desired characteristics I shall consider both roles that the bait must play.

Behavior

Perhaps the most important characteristic to consider in examining the effectiveness of a bait is its behavior. The baits that were most effective in attracting the school to the boat were those that hastened back to the boat only after they were under attack by the skipjack tuna. Nehu, Marquesan sardine, *Sardinella marquesensis*, and mullet, *Mugil longimanus*, belong to this group. Most nehu gathered into a school before swimming away, almost always heading down. Mullet and Marquesan sardine swam away singly or in groups in no preferred direction. When attacked they all returned to the ship by following the wake.

Once the skipjack tuna are at the ship the most desirable bait behavior is initial diving and then fleeing towards the surface. With species that flee by diving only, results have been mixed. Catches have been good when the feeding frenzy of the skipjack tuna was great and each piece of bait was consumed as soon as it hit the surface. When the skipjack tuna were feeding lethargically or when the bait was especially elusive, diving bait took the skipjack tuna below the range of the hooks.

Some baits moved quickly to within a few centimeters of the hull of the boat for protection. These lost much of their effectiveness, because skipjack tuna did not seem to come closer to the ship than approximately a meter. Quickly moving the ship ahead to expose the bait was sometimes successful, but usually it was impossible to stop the ship before the skipjack tuna were beyond reach of the poles.

Iao, *Pranesus insularum*, did not move close to the ship but stayed exclusively at the surface. In general this behavior was effective in keeping the skipjack tuna within striking distance of the hooks. However, a common behavior of skipjack tuna is to move away from the boat and dive. In this circumstance, a bait that dives may attract the tuna back to the boat, whereas a bait that stays at the surface will not.

I have noticed that a bait that has a quick, short darting movement will excite skipjack tuna much more than a bait which swims in a slow steady manner. On occasion a slow steady bait has been completely ignored by the skipjack tuna. Excited skipjack tuna are more apt to take a hook than those that are not. An excited fish will snap at a hook unhesitatingly but an unexcited one may come up to a hook and veer away. A very quick and elusive bait can whip the school into a frenzy. It seems that excitement builds up with every unrewarded attack. If, however, the bait is very elusive and flees by diving, which is true with thread herring, *Opisthonema medirastre*, it can quickly draw the skipjack tuna down below the range of the hooks.

Size

Vision is the primary sense used by skipjack tuna during feeding. Therefore, large bait size would be expected to be desirable because the bait would then be detected at a greater distance. The largest size bait I have found in the stomach of a 60-cm skipjack tuna is 20 cm. A rough estimate of the maximum bait size for 70-cm skipjack tuna is 23 cm.

Water clarity and a high reflectance of the bait are important in the visibility range of the bait. Let us assume that water clarity limits the visible range to 50 m in extremely clear water. What size would the bait have to be to be seen? The visual acuity of skipjack tuna is about 0.18 (Nakamura 1968). The bait would have to be 8 cm long to be detected at 50 m. Under most circumstances 50 m is an unusual range so that 8 cm is as large as a bait needs to be.

If the bait behavior is such that it swims towards the ship when attacked, it can extend the effective range of the ship much more than a large bait can.

Another consideration in size of bait is the bait carrying capacity of boats. The number of fish to be caught with a load of bait depends on the number of pieces of bait. To the extent that the carrying capacity is fixed, one can carry a lot more pieces of small bait than large bait; therefore, a smaller bait is better.

Another argument against large bait is that large bait will satiate the skipjack tuna faster.

Survival

An obviously important characteristic for a bait is that it should be able to survive in a baitwell. The duration it needs to survive depends upon how far the fishing grounds are.

Flavor

Although aqueous extracts of skipjack tuna, shrimp, and squid have evoked positive and often violent responses from captive tuna, the use of these extracts at sea on "wild" skipjack tuna schools did not heighten their responses during feeding (Tester et al. 1954). From this I conclude that the taste or flavor of the bait is not important.

DISCUSSION AND SUMMARY

Yuen (1969), in discussing the effectiveness of water sprays in increasing the catch rate, felt that each skipjack tuna caught represented an error in discrimination by the skipjack tuna: a hook was mistaken for a live bait. Any strategem a pole-and-line fisherman uses to cause more mistakes by the skipjack tuna will increase his catch. He can make it more difficult for the skipjack tuna to discriminate between bait and hook by designing his hooks to look more like the bait or use sprays to distort vision. He can also cause the fish to be less discriminatory by exciting them with the use of a more elusive bait.

The most important characteristics of an effective bait are its behavioral characteristics. The bait should flee toward the boat when the predator is encountered. It should be elusive with fast, darting movements. It should be durable enough to survive in a baitwell. It should have a high light reflectance. It should be 2 to 6 cm long. The flavor of the bait is not important.

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Estimates of the Amount of Nehu, *Stolephorus purpureus*, Per Bucket of Bait in the Hawaiian Fishery for Skipjack Tuna, *Katsuwonus pelamis*

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ABSTRACT

A sample survey in the Hawaiian pole-and-line fishery for skipjack tuna, *Katsuwonus pelamis*, showed that the average bucket of nehu, *Stolephorus purpureus*, the principal baitfish used in the fishery, weighs 6.4 kg (14.2 lb). This is greater than prior estimates for buckets of nehu (3.2 or 3.6 kg, 7 or 8 lb). It is not known whether the difference is due primarily to changes in bait handling practices or to inaccuracies in the early sampling and estimation procedures.

INTRODUCTION

Throughout the Pacific in the pole-and-line fisheries for skipjack tuna, *Katsuwonus pelamis*, the amount of bait taken aboard and subsequently used in fishing is customarily measured in units of "scoops" or "buckets." However, because bait handling practices differ among fisheries, and even among vessels in the same fishery, the average weight of bait per bucket or scoop varies widely. In the eastern Pacific a scoop of northern anchovy, *Engraulis mordax*, averages 3.6 kg (8 lb), while in Japan the average bucket of *E. japonica* varies from 3.4 kg (7.5 lb) to 7 kg (15.4 lb), depending on the area where observations are taken (Yoshida et al. 1977). Palauan skipjack tuna fishermen convey the local anchovy, *Stolephorus heterolobus*, in relatively small buckets with a high proportion of water, so an average bucket of bait in that fishery contains only 2 kg (4.4 lb) of fish (Muller 1977). In the Hawaiian pole-and-line fishery, the figure used historically for buckets of nehu, *S. purpureus*, is 3.2 or 3.6 kg (7 or 8 lb).

While many analyses within a particular fishery can be based on the amount of bait caught in terms of scoops or buckets, comparisons between fisheries require that the bait statistics be reduced to common units. Even within fisheries it is often necessary to know the actual weight of bait used. For example, this is critical in the evaluation of bait substitution schemes (Wetherall 1977).

We present results of a sampling program conducted in 1974-75 in the Hawaiian pole-and-line fishery with the objective of estimating the average weight of a bucket of nehu.

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PROCEDURE

Observers sampled buckets of bait aboard cooperating skipjack tuna vessels during normal baiting operations. Buckets were sampled randomly. The baiting crews did not know which buckets were to be sampled until the baitfish were in the buckets and ready to be placed into the baitwells. Thus no bias was introduced by fishermen when loading the buckets. Two buckets were to be sampled from each of two sets on the designated baiting trips. Sampled baitfish were poured into a dip net and allowed to drain before being weighed with a spring scale to the nearest 0.1 kg (0.25 lb). Each sample was taken to the laboratory where the number of fish in a 0.5-kg (1-lb) sample was counted. Standard lengths of 50 specimens from each sampled bucket were measured. The stainless steel buckets on each vessel were measured and their volumes were calculated.

RESULTS

Although the response of vessel captains was good, scarcity of baitfish, rough seas, and drydocking of some vessels hampered the sampling, so only 13 samples were collected from five vessels. Results are given in Table 1.

The weight of nehu in the sampled buckets ranged from 3.2 to 10.4 kg (7.0 to 23.0 lb), averaging 6.4 kg (14.2 lb). The number of nehu per pound varied from 504 to 956 (averaging 725) and the estimated number of nehu per bucket ranged from 5,670 to 20,769 (averaging 10,414). The volume of the buckets used by the five vessels varied from 23.1 to 25.4 liters, averaging 23.5 liters (6.1 to 6.7 gal, averaging 6.2 gal).

Nehu are customarily bucketed directly from the bunt of the bait seine into baitwells, but since the mid-1960's a few vessels such as the *Anela*, the *Buccaneer*, and the *Lehua* have used a different procedure—nehu are dip

Table 1.—The results of sampling buckets of nehu from five Hawaiian skipjack tuna fishing vessels.

Vessel	Date sampled	Bucket size (liters)	Set no.	Sample no.	Weight of nehu per bucket (kg)	Number of nehu per kilogram	Estimated number of nehu per bucket	Size range (standard length, centimeters)
Anela	2/21/74	23.1	1	1	5.21	1,235	6,434	3.1-5.3, mostly
			1	2	7.02	1,217	8,543	between 4.0 and 4.6
			2	1	5.10	1,147	5,850	
			2	2	5.10	1,111	5,666	
Kilohana	5/30/74	23.1	2	1	3.17	2,108	6,682	3.1-4.6, mostly
			2	2	4.76	2,000	9,520	between 3.3 and 4.0
			2	3	7.13	2,022	14,417	
Lehua	2/14/74	23.8	1	1	6.00	1,312	7,872	3.1-4.9, mostly
			1	2	7.36	1,435	10,562	between 3.9 and 4.3
Buccaneer	5/ 1/75	23.1	1	1	8.38	1,451	12,159	3.0-5.4, mostly
			1	2	6.57	1,865	12,253	between 3.0 and 4.7
Marlin	5/ 6/75	25.4	1	1	7.70	1,885	14,514	2.7-5.3, mostly
			1	2	10.42	1,991	20,746	between 3.2 and 4.6

netted from the bunt of the seine into buckets and then loaded into the baitwells. Our feeling is that the latter procedure results in less variability in the weight of nehu per bucket.

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The Fishery for Nehu, *Stolephorus purpureus*, a Live Bait Used for Skipjack Tuna, *Katsuwonus pelamis*, Fishing in Hawaii

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ABSTRACT

With increasing interest in the baitfish resources and their capacity to support local skipjack tuna, *Katsuwonus pelamis*, fisheries, we need to evaluate their distribution and relative abundance. This paper describes the trends in production of nehu, *Stolephorus purpureus*, an anchovy used as live bait in the fishery for skipjack tuna in Hawaiian waters.

Kaneohe Bay and Pearl Harbor, two of the most important baiting sites in the Hawaiian Islands, produce 71% of the bait. Another important site on Oahu, particularly for night baiting, is Kalihi-Keehi Lagoon.

Day baiting produced 79% whereas night baiting produced 21% of the State's nehu catch. Catches and baiting effort showed a downward trend in the day fishery and an upward trend in the night fishery in 1961-65. In 1966-72, however, catches and baiting effort increased steadily in the day fishery whereas they declined in the night fishery.

INTRODUCTION

The Hawaiian pole-and-line fishery for skipjack tuna, *Katsuwonus pelamis*, is dependent on a steady supply of live bait. Essentially, two separate fisheries are involved. The first is for live bait which is caught with nets in shallow waters of bays and harbors. The second is for skipjack tuna and other tunas which are caught in offshore waters with pole and line after the fish are attracted to the boat with live bait. Thus, live bait is essential in the Hawaiian skipjack tuna fishery, and fishermen spend a good part of their time catching it. This report presents and analyzes the bait catch statistics associated with the Hawaiian skipjack tuna fishery for the years 1960 to 1972. It supplements a previous report on the Hawaiian skipjack tuna fishery by Yamashita (1958).

SPECIES UTILIZED

Basically, almost any small fish in sufficient numbers can be used as live bait, but their effectiveness varies from species to species. By far, Hawaiian skipjack tuna fishermen prefer the nehu, *Stolephorus purpureus*, a small (40-60 mm), fragile anchovy that schools over sand and mud bottoms in harbors and bays throughout the Hawaiian Islands. It apparently possesses most of the qualities of a good baitfish. Captured both day and night, nehu constitutes roughly 97% of the bait caught in Hawaiian waters. Most of the remainder is made up of silverside or iao, *Pranesus pinguis*, and small round herring or piha, *Spratelloides delicatulus*.

BAITING LOCALITIES

Within the Hawaiian Islands there are several baiting grounds; they are listed below, by islands.

Island	*Baiting grounds*
Oahu	Kaneohe Bay
	Pearl Harbor
	Kalihi-Keehi Lagoon
	Honolulu Harbor
	Ala Wai Canal
	Kewalo Basin
	Waialua Bay including Haleiwa
Maui	Maalaea Bay region including Kihei
	Lahaina
	Kahului including NASKA (formerly Naval Air Station, Kahului)
Hawaii	Hilo Harbor
	Kawaihae
	Mahukona
	Kailua-Kona
Kauai	Port Allen
	Hanalei
	Nawiliwili
	Hanapepe
Molokai	Kaunakakai
Lanai	—

Oahu has the most important bait resource. Roughly 79% of the State's bait production comes from Oahu's baiting grounds (Fig. 1). Two of them, Kaneohe Bay on the windward side and Pearl Harbor on the leeward side of Oahu, are the major sources of bait, providing about

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Figure 1.—Baiting areas on Oahu.

71% of the State's production. A third site of some importance, particularly for night baiting, is Kalihi-Keehi Lagoon. Generally, Oahu-based vessels do their "baiting" (catching of bait) on Oahu although they may also bait at Kauai, Maui, Molokai, and Lanai. Maui-based vessels usually bait on Maui, Oahu, Molokai, and Lanai, but rarely venture to Kauai. Hawaii-based vessels are generally restricted to grounds off their island. They capture a large proportion of their live bait at night as Hilo Harbor is fringed by a predominantly rocky shoreline that is not suitable for day seining.

METHODS OF CAPTURE

Bait is caught by two methods in the Hawaiian Islands. Day baiting usually starts at dawn and ends when enough bait for a day's fishing has been caught. If day baiting is unproductive, night baiting is attempted and, if little or no night bait is caught, day baiting is resumed the next morning.

Day Baiting

Day baiting may last for 1.5 to 7 h but usually lasts about 3 h (Uchida and Sumida 1971). The fishermen use an outboard-powered skiff loaded with a surround net measuring roughly 156 m (80 fathoms) long and 7 m (4 fathoms) deep (June 1951). They scout the shallow waters of bays and harbors. When a school of baitfish is located, the net is set from the skiff as the skiff encircles the school. The net is then partially "dried up" to form a bag to hold the school. To keep mortalities to a minimum, the fishermen "swim" the net-enclosed baitfish to the vessel. Once alongside the vessel, the fishermen, using 23-liter capacity (about 6 gal) stainless steel buckets, brail the fish from the net into the baitwells. Each scoop of the bucket contains both water and baitfish to minimize injury to the baitfish. The amount of baitfish in a bucket varies considerably. Yamashita (1958) estimated the amount of nehu in a bucket to be about 3.2 kg (7 lb), but recent estimates (Hida and Wetherall 1977) indicate that the actual weight of the baitfish in a bucket may be about 22-24 kg (10-11 lb). Usually, several sets are required to obtain enough bait to justify tuna fishing. Uchida and Sumida (1971) estimated from data collected in June-August 1967 that the average is about three sets although as many as nine sets in a single day may not be uncommon.

Night Baiting

For night baiting, lift nets which measure about 27-46 m (15-25 fathoms) long and 22 m (12 fathoms) deep are used (June 1951). Night baiting does not involve active scouting for schools of baitfish. Rather, a submerged light is used to take advantage of the fact that nehu are attracted to light. After dark, the vessel is anchored or moored and a light is suspended several feet below the water surface from a 6-m (20-ft) pole which is lashed to the vessel's portside. Just before daybreak, a rheostat dims the light causing the baitfish to concentrate. The net is set around the tightly schooled baitfish from a skiff and the captured bait is transferred to the baitwells. Uchida and Sumida (1971) found that night-baiting operations from setting the light to drying up the net, usually lasted 8 h. Usually one set is made per night.

CATCH, EFFORT, AND CATCH PER EFFORT

The bait reports, turned in by the fishermen to the Hawaii Division of Fish and Game, were summarized by baiting locality and by time of baiting (day or night). Reports which showed nehu catches but gave no indication of day or night baiting, and those which indicated the capture of baitfish other than nehu, were included only in statewide summaries. In the following sections, I discuss bait production in the day and night fisheries.

STATEWIDE PRODUCTION

Statewide catch statistics of baitfish, combined for all species, baiting grounds, and times of capture, are plotted in Figure 2. With the exception of 1960, when the baitfish catch amounted to 22,849 buckets, catches in 1961-72 have never fallen below 30,000 buckets annually and in some years they have been well over 35,000 buckets. The peak in bait production occurred in 1971 when 42,098 buckets were caught.

Baiting effort tended to drift upward in 1960-65 and downward in 1966-72. Actually the uncorrected effort presented in Figure 2 includes both day and night effort and does not take into account the curtailment of night-baiting operations after 1965 concurrent with increases in day-baiting operations. As I will discuss in later sections, 1 day of baiting will usually produce a catch which is much greater than that obtained by night baiting. The

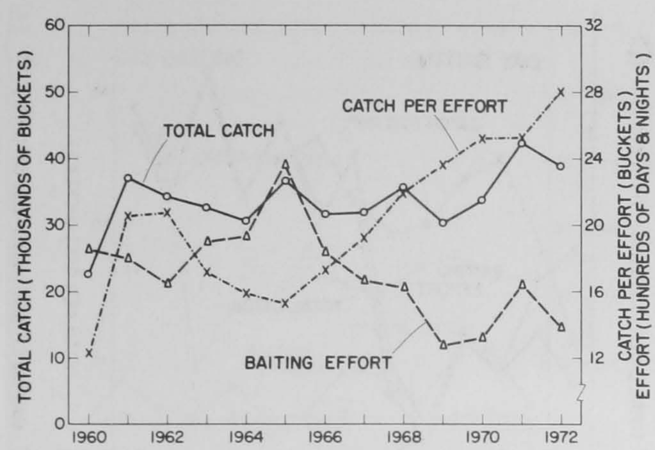


Figure 2.—Catch, baiting effort, and catch per effort in the fishery for live bait in Hawaii, 1960-72.

progressive increase in catch per effort in 1965-72, therefore, results from an increase in day baiting and a decrease in night baiting.

DAY-BAIT PRODUCTION

The statewide production of day bait averaged 25,338 buckets in 1960-72. In 1960, production reached 15,735 buckets with 1,001 days of baiting effort. Figure 3A shows that although production rose in 1961, day effort started on a downward trend that also carried production to lower levels. An upturn in production occurred in 1965, but day effort did not begin its upward climb until 1968, when it reached 1,055 days. The result was that production climbed to 30,148 buckets. Poor tuna fishing in 1969 dropped baiting intensity to 870 days and production to 25,650 buckets. In 1970, an upward trend started that was to carry day effort well over 1,000 days and production to exceptionally high levels, particularly in 1971 when 1,334 days of baiting produced 38,786 buckets.

In terms of apparent abundance, as measured by catch per day baited (C/D), only 15.7 buckets/day were taken in 1960 (Fig. 3A). The C/D rose sharply thereafter to 28.6 buckets in 1962, then declined to 23.8 buckets in 1964-65. In 1966-67, however, an upswing occurred and in recent years, catches have been nearly 30 buckets/day. The peak in the index was reached in 1972 when 31.2 buckets of bait were caught per day's baiting. The overall average for the 13-yr period was 27.1 buckets/day of baiting.

Among the State's baiting grounds, Pearl Harbor was the most productive for day-baiting operations. In general, both bait production and baiting intensity at Pearl Harbor show an upward trend (Fig. 3B). Production averaged 10,127 buckets annually and accounted for 40% of the statewide average catches. Annual catches ranged from a low of 3,517 buckets in 1960 to a high in 1971 of 18,992 buckets.

Day effort expended at Pearl Harbor paralleled the annual catches. It ranged from a low of 244 days in 1962 to a high of 687 days in 1971. The average over 13 yr was 396 days or roughly 42% of the average annual day-baiting effort statewide.

The abundance index for Pearl Harbor showed very little variation and no distinct trend over the years (Fig. 3B). Abundance was lowest in 1960 when only 13.5 buckets/day were caught. The indices in 1961-72 fluctuated within a fairly narrow range between 23.4 and 28.1 buckets. The average C/D in 13 yr was 25.6 buckets.

Kaneohe Bay, the second major ground for day bait, produced an average annual catch of 8,783 buckets of nehu. This catch represented about 35% of the day bait caught annually in the State. The annual catches tended to decline in 1960-64 (Fig. 3C). But the upward trend which started in 1965 carried production to well over 10,000 buckets in 1966-72. Production, at a low of 2,116 buckets in 1964, increased over sevenfold to a peak of 15,709 buckets in 1970.

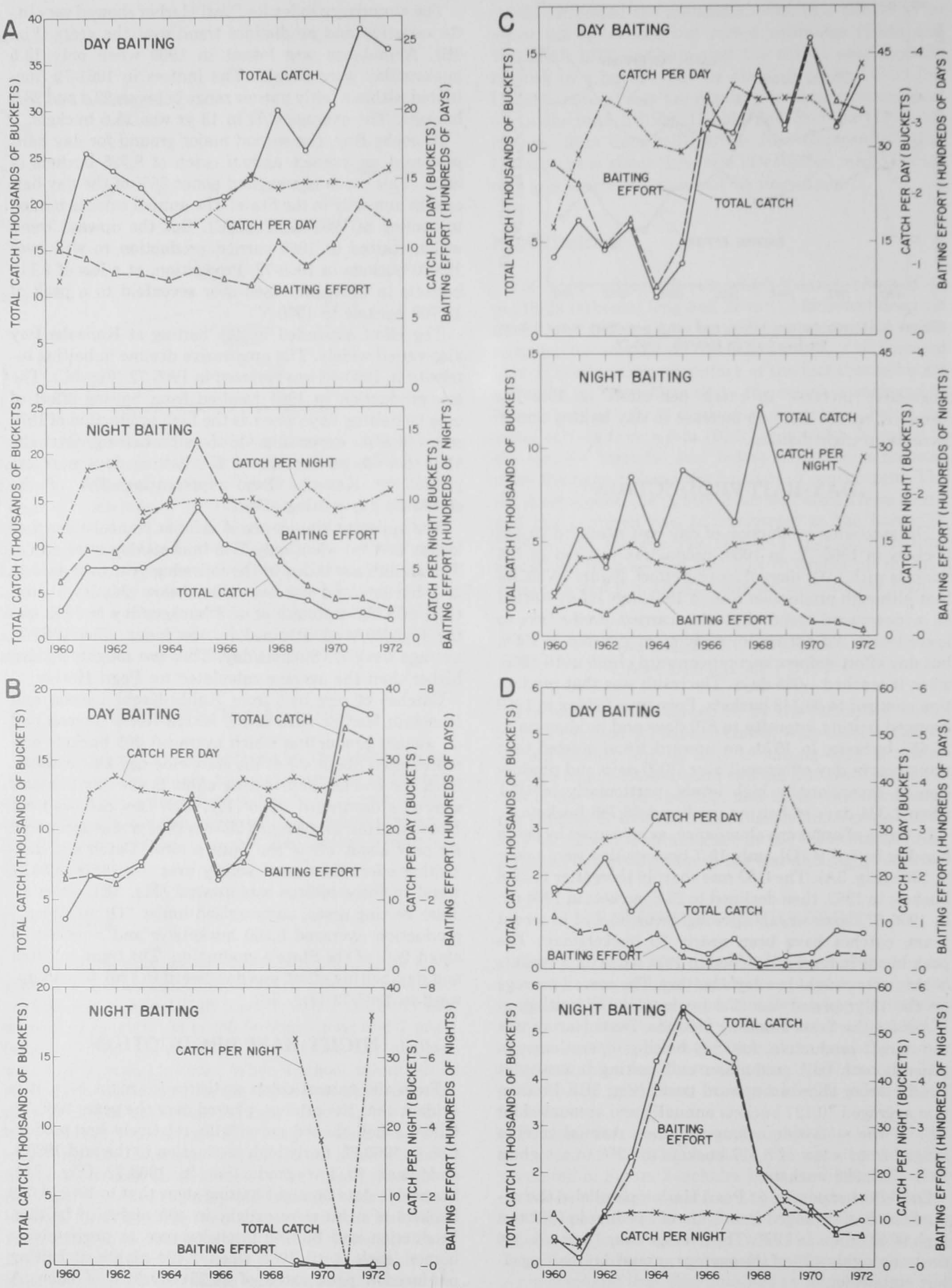
The effort expended in day baiting at Kaneohe Bay also varied widely. The progressive decline in baiting intensity in 1960-64 was reversed in 1965-72 (Fig. 3C). The low production in 1964 resulted from baiting effort of only 69 baiting days whereas the high production of 1970 resulted from expending 418 days on baiting. Over the 13-yr period, an average of 253 baiting days were expended at Kaneohe Bay, representing 27% of the statewide day-baiting effort.

The apparent abundance of nehu at Kaneohe Bay was lowest in 1960 when only 17.3 buckets/day were taken. The abundance index in the following year increased to 28.7 buckets and has not fallen below this level since (Fig. 3C). An estimate of 43.3 buckets/day in 1972 was the highest level attained by the index. The 1960-72 average was 34.7 buckets/day. This was roughly a third higher than the average calculated for Pearl Harbor.

Catches of day bait from Kalihi-Keehi Lagoon and Honolulu Harbor were small. Kalihi-Keehi Lagoon had an annual production which averaged 968 buckets and represented about 4% of the statewide day-bait catches. Both the catches and baiting effort in the day fisheries showed a downward trend (Fig. 3D). Day catches from Honolulu Harbor averaged 259 buckets/yr and accounted for only about 1% of the State's total. Catch and day-baiting effort fluctuated widely over the years but the trend in these indices was upward (Fig. 3E). From all other baiting areas, summarized under "Other Areas," production averaged 5,200 buckets/yr and represented about 20% of the State's production. The trend in catch and day-baiting effort was downward in 1961-67 and upward in 1968-72 (Fig. 3F).

NIGHT-BAIT PRODUCTION

From the annual catch statistics for night bait, it is evident that the catches, plotted over the years 1960-72, follow a bell-shaped curve with relatively low production in 1960-63, fairly high production in the mid-1960's, and back to low production in 1968-72 (Fig. 3A). Statewide data on night baiting show that in 1960, 3,069 buckets of nehu were caught in 408 nights of baiting. Production and baiting intensity rose to progressively higher levels until 1965 when 1,424 nights of baiting produced a peak catch of 14,251 buckets of nehu. A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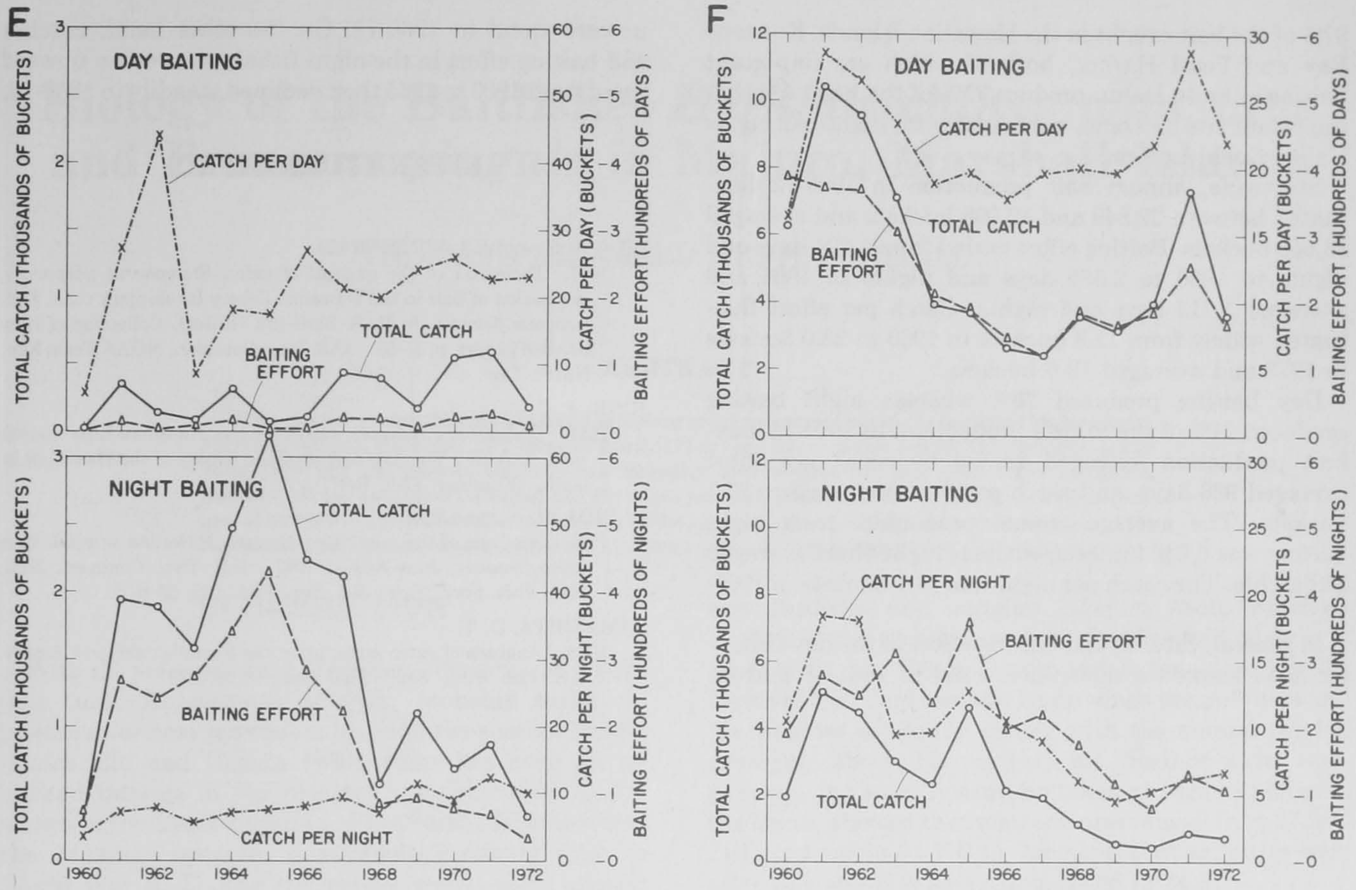

Figure 3.—Catch, baiting effort, and catch per effort in the day and night fisheries for nehu, in Hawaii, 1960-72. A. Total catch in Hawaii, 1960-72. B. Pearl Harbor. C. Kaneohe Bay. D. Kalihi-Keehi Lagoon. E. Honolulu Harbor. F. Other areas in Hawaii.

downward trend in night baiting started the following year and by 1972, only 2,187 buckets were produced in 206 nights of baiting. The average annual production and baiting intensity were 6,648 buckets and 659 nights, respectively.

Among the grounds contributing to night-bait production, Kalihi-Keehi Lagoon was by far the most important. In 1960-65, production rose sharply from a low of 188 buckets in 46 nights of baiting in 1961 to a high of 5,570 buckets in 547 nights in 1965 (Fig. 3D). A decline, starting in 1966, resulting from a change in emphasis to less night baiting and more day baiting, carried production progressively lower in subsequent years. The average annual production, representing about 35% of the statewide night catches, was 2,347 buckets. An average of 220 nights expended at Kalihi-Keehi Lagoon annually accounted for about 33% of the statewide night effort.

Estimates of nehu abundance at Kalihi-Keehi Lagoon were low in 1960-61, falling below six buckets per night in both years (Fig. 3D). Catch per night calculated for 1962-72 was 10 buckets or more and reached a peak of 15.0 buckets in 1972. The average for the 13-yr period was 10.7 buckets.

Second in importance in night-bait production was Honolulu Harbor. The night-bait catch from here was lowest in 1960 when 259 buckets were caught in 72 nights of baiting. An increase in night-baiting intensity in subsequent years was reflected in progressively higher catches. In 1965 the production reached 3,175 buckets, a 12-fold increase (Fig. 3E). A steady decline in night-baiting intensity carried production progressively lower and by 1972, 30 nights devoted to night baiting produced only 303 buckets. The average annual catch was 1,464 buckets representing 22% of the statewide night production. Night effort at Honolulu Harbor amounted to 190 nights or 29% of the statewide night effort.

The abundance of nehu caught per night averaged 7.7 buckets in 1960-72. Whereas the abundance index was 9.5 buckets or less in 1960-68, it was higher in 1969 and in 1971-72. The peak of 12.4 buckets was attained in 1971 (Fig. 3E).

Among the remaining areas, several were relatively good for night baiting. Kaneohe Bay produced an average annual catch of 575 buckets or roughly 9% of the statewide night catches. Grounds at Hawaii and Kauai, included in the statistics for "Other Areas," were also moderately good for night baiting.

SUMMARY

The purpose of this report was to examine the trends in the production of nehu, *Stolephorus purpureus*, a live bait used for skipjack tuna fishing in Hawaiian waters. Briefly, the results showed that nehu constitutes roughly

97% of the bait caught in the Hawaiian Islands. Kaneohe Bay and Pearl Harbor, both of which are important baiting sites on Oahu, produce 71% of the bait. Another important site on Oahu, particularly for night baiting, is Kalihi-Keehi Lagoon.

Statewide, annual bait production in 1960-72 fluctuated between 22,849 and 42,098 buckets and averaged 33,658 buckets. Baiting effort varied from 1,271 days and nights in 1960 to 2,365 days and nights in 1965 and averaged 1,713 days and nights. Catch per effort fluctuated widely from 12.3 buckets in 1960 to 28.0 buckets in 1972 and averaged 19.6 buckets.

Day baiting produced 79% whereas night baiting produced 21% of the State's production. In 1960-72, day-bait production averaged 25,338 buckets, day effort averaged 936 days, and catch per day amounted to 27.1 buckets. The average annual production from night baiting was 6,648 buckets, whereas night effort averaged 659 nights. The catch per night was 10.1 buckets in 1960-72.

In general, catches and baiting effort in the day fishery for nehu showed a downward trend in 1961-65 and an upward trend in 1966-72. On the other hand, catches and baiting effort in the night fishery showed an upward trend from 1960 to 1965 then declined steadily in 1966-72.

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ABSTRACT

The results of a baitfish scouting and sampling program carried out in the lagoon of Majuro Atoll, Marshall Islands, from May 1972 through April 1973 are presented in this report. The distribution and abundance, age and growth, maturity and fecundity, and stomach contents of the major baitfishes, *Herklotsichthys punctatus* (sardine) and *Pranesus pinguis* (silverside), are discussed. Adequate samples of baitfish could not be collected because of the apparent absence of suitable concentrations of the two major bait species, whose abundance fluctuated widely during the period of the observations.

INTRODUCTION

With the yellowfin tuna, *Thunnus albacares*, and skipjack tuna, *Katsuwonus pelamis*, probably being exploited at or near maximum levels in the eastern Pacific (Rothschild and Uchida 1968), there has been an increased interest in the skipjack tuna resources in the waters of the Trust Territory of the Pacific Islands where the Japanese operated a substantial fishery prior to World War II. During the prewar years, the Japanese vessels operated from bases in Palau, Truk, Yap, Saipan, Ponape, and Jaluit utilizing the available local baitfishes. There is very little information on the baitfish resources in the Trust Territory and since live-bait fishing for skipjack tuna is dependent upon the supply of baitfish, the National Marine Fisheries Service's RV *Townsend Cromwell* was dispatched to the area to assess this resource.

This project was undertaken as a result of findings made on three cruises of the *Townsend Cromwell* in 1971 and 1972. Of all island groups of the Trust Territory surveyed, the best baitfish concentrations observed during the cruises were in the Marshall Islands. A school of sardine, *Herklotsichthys punctatus*, seen in Jaluit Atoll on cruise 53 of the *Cromwell* (June-July 1971) was estimated to exceed 2.5 t and other schools of sardine and silverside, *Pranesus pinguis*, plus a few other bait species estimated at "several thousand" buckets (3.5 kg equals a bucket) were also seen (Hida 1971). Since the sardine and silverside were found to be in quantities suitable for conducting live-bait fishing for skipjack tuna, it was thought desirable to learn about the distribution, abundance, and biology of these species for management purposes.

Although the best concentrations of baitfishes were seen at Jaluit Atoll, Majuro Atoll was chosen as the site to carry out our baitfish observational program because it is serviced by a commercial airline and has the necessary facilities and supplies. Majuro Atoll, which is located in the southern part of the Marshall Islands, is roughly 32 km (20 mi) long and 6 km (4 mi) wide. Northeasterly and easterly trade winds prevail there and the weather is usually cloudy with the annual rainfall averaging about 356 cm (140 in). Surface water temperature and salinity samples taken at various places in the lagoon showed that temperatures ranged from 27.8°C in December to 32.8°C in June and that salinities were relatively stable ranging from 33.88 to 34.32‰.

OBSERVATIONAL PROGRAM

The sampling and observational methods used in this program were not ideal, but under the circumstances, the most feasible. Quarterly field trips were made by two or three observers from the Honolulu Laboratory for about 10 days per trip. The field trips were made in May, August-September, and November-December of 1972 and April of 1973. In addition, a resident Micronesian was employed to scout for and to sample baitfish on a weekly basis. In this way, the program was carried out continuously from May 1972 through April 1973. Observations were made each month except for July, when the Micronesian observer was ill, and October, because of adverse weather conditions.

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Scouting for baitfish was conducted in the lagoon close to the shoreline of Majuro (Fig. 1), usually from a 4-m skiff powered with a 20-hp outboard motor. Conditions for scouting were usually good during low tide except that maneuvering of the boat was difficult because of numerous exposed coral heads. The scouting runs, which covered most of the northeastern half of the lagoon as shown in Figure 1, were made daily during the quarterly visits. However, rough and murky waters or the necessity for carrying out other types of sampling did alter this routine. Occasionally, scouting was conducted from shore with an automobile. In this case, stops were made

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97% of the bait caught in the Hawaiian Islands. Kaneohe Bay and Pearl Harbor, both of which are important baiting sites on Oahu, produce 71% of the bait. Another important site on Oahu, particularly for night baiting, is Kalihi-Keehi Lagoon.

Statewide, annual bait production in 1960-72 fluctuated between 22,849 and 42,098 buckets and averaged 33,658 buckets. Baiting effort varied from 1,271 days and nights in 1960 to 2,365 days and nights in 1965 and averaged 1,713 days and nights. Catch per effort fluctuated widely from 12.3 buckets in 1960 to 28.0 buckets in 1972 and averaged 19.6 buckets.

Day baiting produced 79% whereas night baiting produced 21% of the State's production. In 1960-72, day-bait production averaged 25,338 buckets, day effort averaged 936 days, and catch per day amounted to 27.1 buckets. The average annual production from night baiting was 6,648 buckets, whereas night effort averaged 659 nights. The catch per night was 10.1 buckets in 1960-72.

In general, catches and baiting effort in the day fishery for nehu showed a downward trend in 1961-65 and an upward trend in 1966-72. On the other hand, catches and baiting effort in the night fishery showed an upward trend from 1960 to 1965 then declined steadily in 1966-72.

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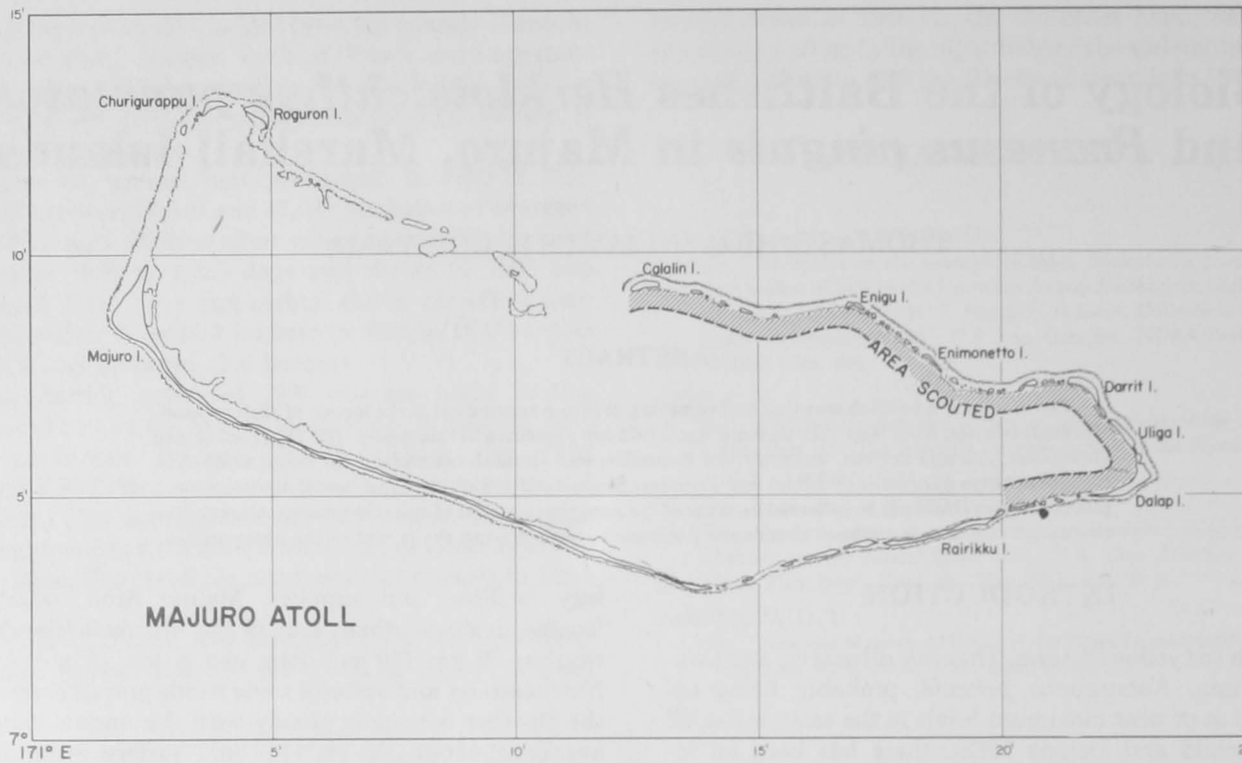

Figure 1.—Majuro Atoll, Marshall Islands.

frequently and whenever it was possible to gain access to a beach. About half a mile of shoreline was scouted on foot on these stops. The Micronesian observer did his scouting during weekends.

SAMPLING METHODS

Cast Net

Monofilament cast nets of 1.27 and 1.9 cm stretch mesh size were used to collect sardine and silverside during the scouting runs. Samples were collected whenever possible. The baitfish sampled were limited mostly to the larger sizes due to gear selectivity, especially in the case of the silverside. However, since there were usually only two observers, and because of the reefs and coral heads in the area, it was not possible to use a beach seine. The cast net was believed to be the most practical sampling gear under the circumstances. The collected samples were preserved in 10% Formalin[2] or 75% isopropynol and returned to the laboratory for examination.

Night-Light

During the quarterly visits, night-light stations were conducted by the field team with the skiff whenever the schedule allowed; a few were conducted by the Micronesian observer. Either a double mantle gas lantern or a 50-W bulb powered by a 12-V gasoline generator was used as the light source. Invertebrates and fishes that were attracted to the light were dip netted.

Handline

Small handlines were used to capture bigeye scad, *Selar crumenophthalmus*, which were usually attracted to the night-light together with other predators. The bigeye scad were sampled to see if they were feeding on baitfish. Their stomachs were collected and preserved in 10% Formalin for study at the laboratory.

Zooplankton Net

Fine meshed plankton nets, 20.3 and 45 cm in diameter, were towed by the skiff to sample zooplankton in the lagoon. Most of the samples were collected by the field team during the quarterly visits but a few were collected by the Micronesian observer. Tows were taken at the surface and at 5- or 10-m depths for durations of 15 to 20 min. Tows were made in the late afternoon, midmorning, or early evening hours. The occurrence of large numbers of large jellyfish at the surface at night precluded night tows. The samples were preserved in 10% Formalin and returned to the laboratory for study.

Trolling

Trolling was conducted during the quarterly visits by using a small spinner with a lure and a trolling rod and reel. Trolling was usually carried out routinely while heading out for the scouting grounds, but at times it was

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

done directly into an actively feeding school of fish or around feeding bird flocks.

DISTRIBUTION AND ABUNDANCE

On cruise 53 of the *Townsend Cromwell*, June-July 1971, an estimated 2,500 buckets of silverside and 1,000 buckets of sardine were observed in Majuro lagoon. On *Cromwell* cruise 55, in November 1971, an estimated 800 buckets of sardine and 700 buckets of silverside were seen. In April 1972, on *Cromwell* cruise 57, it was estimated that there were about 1,000 buckets of sardine and silverside (mostly sardine) in Majuro. Most of the baitfish were seen in scattered schools in fairly shallow (2 m or less) waters along the eastern shoreline of the main island and along the many small islets on the northeastern part of the atoll. In May of 1972, on the first quarterly survey, about 100 buckets of sardine and 80 buckets of silverside were seen in scattered schools on the scouting runs. The largest school was estimated to consist of about 100 buckets of sardine and silverside. The baitfishes were often seen in quiet waters over fairly good seining grounds with sandy bottom and at times in areas with reefs and coral heads. Up until September 1972, a few small schools totaling about 50 buckets were seen on the scouting runs. The month of October was stormy and no observations could be made. From November 1972 through May 1973, there were no visible signs of baitfish concentrations in Majuro. Only a few small schools of fewer than five buckets of sardine and scattered small schools of silverside were seen. This study showed that the abundance of sardine and silverside in Majuro lagoon had apparently declined considerably since our first observations. Whether this apparent decline in abundance is an annual occurrence or whether this was an abnormal year is not now clear.

It is conceivable that the baitfish had moved out of the lagoon to other areas or into deeper or murkier waters of the lagoon where they could not be detected on our scouting runs.

Also, in May 1972, there was a Japanese fishing vessel conducting experimental live-bait, pole-and-line fishing in the Marshalls. They reportedly baited in the Marshalls, but where they caught the baitfish and how much they caught is not known. One of the ship's representatives said that an average of 200 buckets of sardine and, at times, as much as 500 buckets was taken in a single haul of a night net. If these amounts were taken out of Majuro lagoon with any frequency, it is possible that this would have affected the baitfish population during the period of our observation.

Our Micronesian observer also informed us that there was an unusual abundance of small kawakawa, *Euthynnus affinis*, in the lagoon in July of 1972. It was unfortunate that we were unable to find out on what these fish were feeding. Whether the occurrence of kawakawa in large numbers in the lagoon played a part in the "disappearance" of baitfish is again left to speculation.

As of November 1973, the Micronesian observer reported that the baitfish had not returned to Majuro. However, more recently, in April 1974, the baitfish apparently had returned to Majuro lagoon as well as to Jaluit Atoll (Robert M. Oka, former Honolulu Laboratory leading fisherman, pers. commun.).

AGE AND GROWTH ESTIMATES OF *HERKLOTSICHTHYS PUNCTATUS* AND *PRANESUS PINGUIS*

Because of inadequacies in sample size and in the size range (mostly 6.0 to 11.0 cm SL (standard length)) of baitfish specimens collected, growth estimates based on size-frequency mode progressions were not possible. Pannella (1971) provided indirect evidence of the presence of daily growth increments in fish otoliths. Struhsaker and Uchiyama (1976) have provided direct evidence that these increments are present in otoliths of the Hawaiian nehu, *Stolephorus purpureus*. Similar appearing structures are apparent in otoliths from *H. punctatus* and *P. pinguis* and for this study it was assumed that they are daily growth lamellae.

The largest *H. punctatus*, 10.92 cm SL, appeared to be 265 days old while *H. punctatus*, 8.62 and 8.69 cm SL, were estimated to be 189 days old. Specimens between 8.6 and 10.5 cm SL fell linearly (Fig. 2). The presence of the 10.92 cm SL specimen is an indication that growth decreases after 10.5 cm SL. The average growth in length was 0.35 mm/day for the specimens examined. *Pranesus pinguis*, 3.2 cm SL, was 112 days old. The largest specimen, 6.7 cm SL, was 265 days old. Other specimens fell linearly between these points (Fig. 2). The average growth in length was 0.227 mm/day. Interestingly, both species appeared to reach sexual maturity at the same age, between 6 and 7 mo.

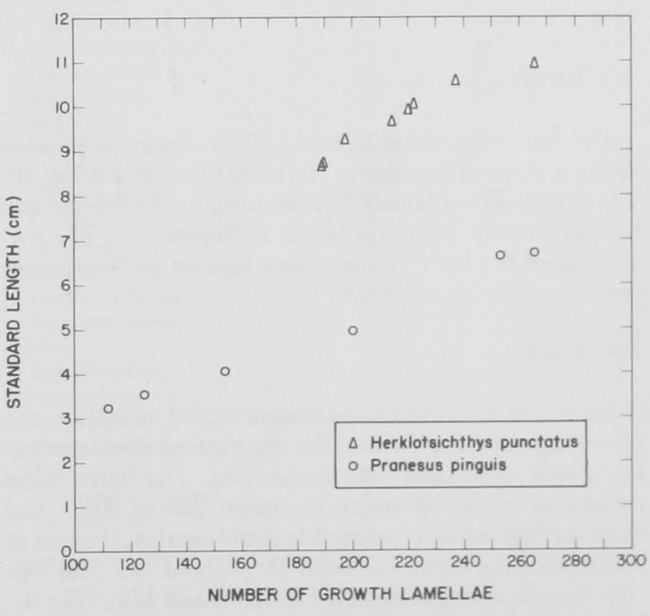

Figure 2.—The number of daily growth lamellae of *Herklotsichthys punctatus* and *Pranesus pinguis* otoliths plotted against standard length (cm).

MATURITY AND FECUNDITY

Material and Method

Specimens were pooled into groups by month of capture and then measured (SL) and the sex determined for sex ratio information. The ova diameters of the most advanced mode were measured and classified by appearance for maturity studies. Classification by appearance was believed to be more reliable than diameter measurements as shrinkage occurred during preservation in Formalin. The descriptions of the developmental stages of baitfish are the same as those used by Uchiyama and Shomura (1974) for swordfish (*Xiphias*) ova.

1. Primordial: ova diameters are less than 0.1 mm, transparent and ovoid.
2. Early developing: ova develop a chorion membrane, opaque yolk material deposits within the ovum, and ova are larger than primordial ova but less than 0.3 mm in diameter.
3. Developing: ova are completely opaque and spherical, chorion is stretched and not visible, and ova diameters range between 0.3 and 0.7 mm.
4. Advanced developing: ova have a fertilization membrane, a translucent margin around the yolk, and diameters range between 0.6 and 0.9 mm.
5. Early ripe: ova range between 0.7 and 1.0 mm in diameter, yolk material becomes translucent, and oil globules begin to form.
6. Ripe ova: ova are transparent, range in diameter from 0.9 to 1.1 mm, and oil globules are present.

For the fecundity study, the largest ovary of the month was examined. An attempt was made to keep the length of the fish constant. All ova in the most advanced mode were counted.

Sex Ratio

The sex ratios of sardine and silverside are presented as percentage of females in the monthly sample (Fig. 3). The percentage of female *H. punctatus* in the sample was highest in May-June and lowest in September. The percentage of female *P. pinguis* was highest in September and lowest in November.

Maturity

Since the number of specimens varied monthly, the percentage composition of the six ovarian developmental stages was used for comparison. *Herklotsichthys punctatus* appeared ready to spawn during April and May, as ripe ova were present in some ovaries. Ovaries at the developing stage occurred throughout the year but ripe ovaries were present only in April and May (Fig. 4). There were few *H. punctatus* under 7.3 cm SL in the samples and their ovaries were all immature. Ripe ovaries occurred in specimens over 9.0 cm SL.

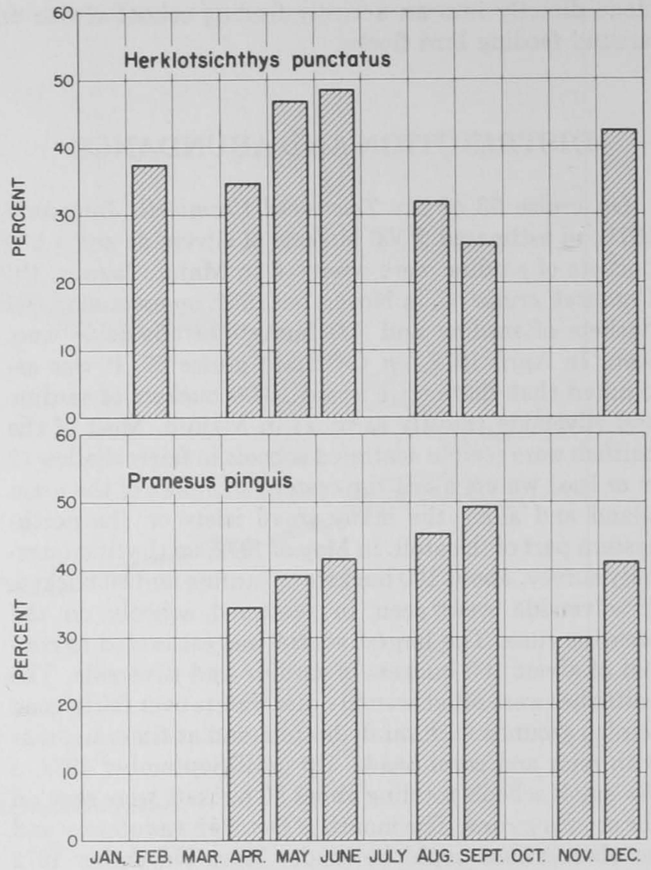

Figure 3.—Female component of monthly samples of Majuro baitfishes.

Ripe ovaries of *P. pinguis* occurred throughout the year. Spawning appeared to peak in August when over 80% of the ovaries contained ripe or early ripe ova (Fig. 3). The smallest silverside with a ripe ovary measured 5.5 cm SL.

Fecundity

Fecundity data are presented in Tables 1 and 2. The fecundity of *H. punctatus* ranged from 3,035 for a 9.3-cm specimen to 6,294 for a 9.8-cm specimen. There appeared to be a slight increase in fecundity from May through September. The fecundity of *P. pinguis* ranged from 272 for a 7.1-cm specimen to 852 for a 7.5-cm specimen.

STOMACH CONTENTS

Stomach contents of bigeye scad, sardine, and silverside were examined to see if they were feeding on juvenile baitfishes.

Bigeye scad were caught handlining from the skiff while carrying out night-light stations during August, September, November, and December 1972. Fifty-eight stomach samples were collected and examined. Among the principal food items were shrimps, isopods, ostracods, and fishes, especially of the family Bregmacerotidae (Table 3).

Table 1.—Fecundity of *Herklotsichthys punctatus* collected in Majuro.

Month (1972)	Standard length (cm)	Left ovary	Right ovary	Loose ova	Total	Maturity	Size range of ova (mm)
Feb.	10.2	2,610	1,381	151	4,142	Advanced developing	0.69-0.78
Apr.	9.3	1,840	1,171	24	3,035	Early ripe	0.86-0.94
May	9.8	3,294	1,790	33	5,117	Early ripe	0.90-0.98
June	9.8	4,508	1,663	23	6,194	Advanced developing	0.69-0.78
June	10.0	3,352	1,506	381	5,239	Early ripe	0.73-0.94
Sept.	10.6	2,322	2,821	10	5,153	Advanced developing	0.57-0.65
Dec.	10.6	3,243	1,161	0	4,404	Advanced developing	0.65-0.78

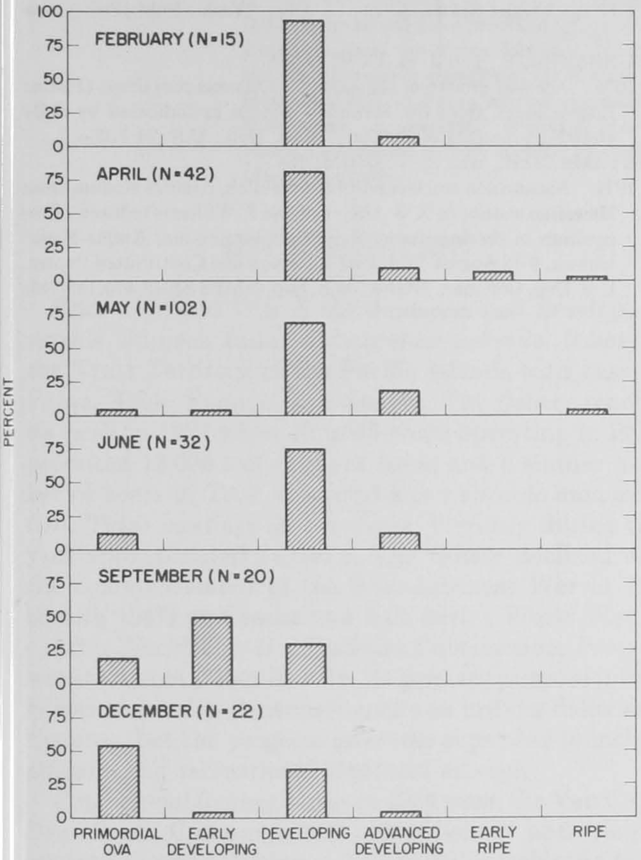

Figure 4.—Percentage of most advanced ovarian stages of *Herklotsichthys punctatus* by month (1972).

About 50 sardine stomachs were examined. It was found that they fed on shrimps, lucifers, and copepods, especially, *Labidocera acutum* and *Undinula vulgaris* (Table 3).

About 100 silverside stomachs examined showed that their stomachs were essentially empty. This apparent habit of not feeding during the day was mentioned by Hobson and Chess (1973).

Examination of stomach contents showed that larval and juvenile sardine were not eaten by these predators at the time of our collections. It was hoped that larval and juvenile sardine could be obtained from stomach contents since our sampling methods were unable to capture them. Bigeye scad did feed on juvenile silverside but these could be sampled under the night-light. We were unable to catch enough silverside or sardine under the night-light to compare their feeding habits with fish caught during the day.

Table 2.—Fecundity of *Pranesus pinguis* collected in Majuro.

Month-year	Standard length (cm)	Fecundity	Size range of ripe ova (mm)
Apr. 1972	7.1	272	0.98-1.14
May 1973	7.3	504	0.98-1.14
Aug. 1972	7.4	504	0.82-0.94
Sept. 1972	7.1	624	0.78-0.98
Nov. 1972	7.5	852	0.82-1.10
Dec. 1972	7.0	558	0.82-1.14

Table 3.—Stomach contents of the bigeye scad, sardine, and silverside sampled in Majuro (x = present; xx = common).

Organisms	Bigeye scad	Sardine	Silverside
Polychaeta	x	—	—
Cephalocordata	x	—	—
Crustacea:			
Amphipoda	x	x	—
Decapoda:			
Crab megalopa	x	x	—
Shrimp	xx	xx	x
Lucifer	—	xx	—
Unidentified	x	—	—
Copepoda:			
Labidocera acutum	x	xx	—
Undinula vulgaris	—	xx	—
Unidentified	x	—	x
Euphausiacea	x	—	—
Mysidacea:			
Anchialina grossa	x	x	x
Siriella vulgaris	—	—	x
Unidentified	xx	—	—
Isopoda	xx	—	x
Ostracoda	xx	x	—
Mollusca:			
Gastropod larvae	x	x	—
Pelecypod larvae	—	x	—
Fishes:			
Acanthuridae	x	—	—
Atherinidae	x	—	—
Balistidae	x	—	—
Bregmacerotidae	xx	—	—
Fistulariidae	x	—	—
Leptocephalus larvae	x	—	—
Syngnathidae	x	—	—
Unidentified	xx	—	x

CONCLUSION

The inability to collect adequate samples during our field trips, largely due to the apparent absence of baitfish concentrations, left much to be desired in this study. However, we did find that the apparent abundance of *H. punctatus* and *P. pinguis* can fluctuate widely in Majuro. We also found that the two species reached maturity in about 6 to 7 mo at a size of 9 cm SL for *H. punctatus* and 5.5 cm SL for *P. pinguis*. From the presence of ripe ova in the ovaries, it seems that *H. punctatus* spawns in spring and *P. pinguis* throughout the year with a peak in August.

ACKNOWLEDGMENTS

We thank the observers that participated on the field trips to Majuro; Joe de Brum, our Micronesian observer; the staff of the District Administrator's Office for helping us with this study; and Denis C. K. Pang for doing the fecundity counts.

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Observations of Tuna Bait Species and Their Habitats in the Palau Islands

PETER T. WILSON[1]

ABSTRACT

The establishment of a live-bait skipjack tuna, *Katsuwonus pelamis*, fishery and several years of field observations have provided information on baitfishes and their habitats that were previously unavailable from the Palau Islands. The baitfish habitats in Palau include areas around limestone islands, mangrove shorelines, coral atolls, and barrier coral reefs. The principal fishes used as skipjack tuna bait in Palau are an engraulid, *Stolephorus heterolobus*; a dussumieriid, *Spratelloides delicatulus*; an atherinid, *Pranesus pinguis*; and a clupeid, *Herklotsichthys punctatus*. Species of lesser importance as bait include *Stolephorus buccaneeri*, *Dussumieria acuta*, and several unidentified apogonids.

INTRODUCTION

Prior to World War II the Japanese had developed a sizable skipjack tuna, *Katsuwonus pelamis*, fishery in the Trust Territory of the Pacific Islands with bases at Palau, Truk, Ponape, and Saipan. The fishery reached its peak in 1937 when 40 to 45 boats operating in Palau produced 13,600 t of skipjack tuna, and a similar number of boats in Truk produced a comparable amount of fish. Total landings in the Trust Territory during that year approximated 34,000 t. The fishery declined with the commencement of the Sino-Japanese War in 1938 (Smith 1947) and came to a halt during World War II.

After World War II a Fisheries Development Program was started in Palau in 1958. Its primary purpose initially was to develop the subsistence and inshore fisheries of the area, but the program later was expanded to include offshore and recreational resources as well.

Commercial fishing began in 1964 when the Van Camp Sea Food Company was established and fishing operations using Okinawan live-bait skipjack tuna boats with Okinawan and Micronesian crews were initated. Within 5 yr the fishery, using eight or nine boats, reached a total annual production of over 5,500 t of skipjack tuna.

Because tropical bait species are often less hardy, smaller, and less abundant than those in more temperate waters, the fishery was forced to operate as a "day fishery," where vessels made trips lasting only 1 day. Fishing thus was limited to an area within a hundred miles of home port.

Not much is known of the live-bait resources of the Trust Territory, for the Japanese published little on the subject and even less has been written under United States auspices. The establishment of a live-bait skipjack tuna fishery in Palau, coupled with several years of field observations, has made it possible to gather information on the various species of baitfish found in Palau. I have identified these fish and described where they can be found. I have also examined the nature of the biotope in which they live.

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DESCRIPTION OF BAIT GROUNDS

The Palau Islands are comprised of numerous islands of which Babelthuap is the largest. The total land area of Palau is about 487 km^2, while the nearly enclosed lagoon, in which most of the islands are located, contains about 1,238 km^2. The main islands of Babelthuap, Koror, Malakal, Arakabesan, Urukthapel, Eil Malk, and Peleliu (Fig. 1) are all surrounded by a single coral reef about 113 km long. The reef fringes the eastern shores but on the western side it extends to almost 18 km from shore.

Palau's inshore area can be divided into the following baitfish habitats: 1) central limestone islands, 2) mangrove shoreline of Babelthuap, 3) coral atolls, and 4) barrier coral reef (Fig. 1).

Central Limestone Islands

The most important baiting area is found around the numerous limestone islands in the lagoon south of the west entrance to Malakal Harbor and west of Urukthapel. Some of the islands are less than one-half ha in size, but several are 800 ha or more and nearly all of them are more than 60 m high, affording considerable shelter from the prevailing winds. Most of the islands are bordered by deep water and seldom offer problems of navigation.

Foliage is heavy on all the limestone islands and varies from shrubbery and ferns to large trees (Fig. 2). Competition for sun and space sometimes causes trees to grow as much as 20 ft horizontally over the water.

There appears to be considerable runoff from the islands, carrying with it rotting vegetation, waste products from birds, and phosphate leached from the limestone.

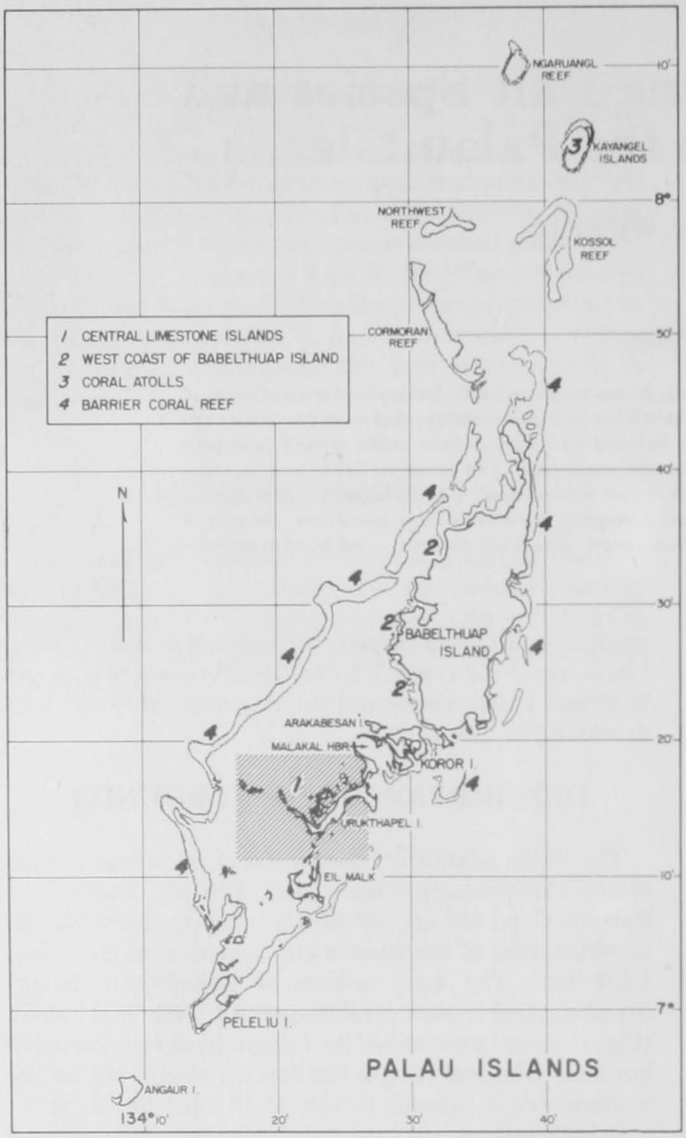

Figure 1.—Palau Islands (numerals indicate the various types of baiting grounds).

Figure 2.—Aerial view of the bait ground in Koror. The many limestone islands found in this area offer sheltered night baiting even in very poor weather.

The effect of the runoff is questionable, but in all probability it plays an important part in enriching the water in this area, enabling it to support a heavy population of plankton. This hypothesis was partially confirmed by a study carried out in Palau between 1935 and 1937 by Motoda (1969) in which he concluded that primary productivity of the phytoplankton population is higher in the lagoon than in the open sea.

The underwater profile of most of the limestone islands is similar, sloping abruptly into deep water. Sand and extensive coral growths form shallow areas between some of the more closely grouped islands.

Plankton hauls from various stations in this habitat all showed large populations of various kinds of zooplankters. No particular type predominated, and inshore and open ocean copepods occurred in equal abundance.

Mangrove Shoreline of Babelthuap

The west coast of Babelthuap is lined with heavy growths of mangrove. The shoreline adjacent to the mangroves has a mud bottom with some rocky areas. The water is turbid and lateral underwater visibility is usually not more than 3 m. At high tide the water is approximately 2 m deep at the outer edge of the mangrove, and at low tide this area is either exposed or in very shallow water. There is little eel grass here, although it becomes more abundant in the deeper water about 90 m from the edge of the mangrove.

Plankton hauls from three stations adjacent to the mangroves produced exceptionally large amounts of *Acartia*, a calanoid copepod which serves as food for plankton feeders. A haul in a nearby area, however, consisted primarily of algal debris with practically no zooplankton. Another haul at yet a different location showed a heavy population of chaetognaths and a limited amount of crustaceans. With the presence of a large population of predacious zooplankton and the low pH characteristic of mangrove environments (Motoda 1940), it is possible that larval fish find it difficult to survive. This may account for the sparseness of fish in this environment.

Coral Atolls

The Kayangel Islands are the only atolls in the Palau group, and lie north of Kossol Reef. A reef surrounds the islands and the lagoon is quite shallow in most areas, varying in depth from 1.8 to 9.1 m. The water of the lagoon is usually clear and calm, and the bottom is characterized by large sandy areas with scattered coral heads and staghorn coral (*Acropora*).

Barrier Coral Reefs

The barrier reef on the western or outer rim of the lagoon is a typical fringing reef. The actual breaker area is relatively small, while the reef flat or shoal area inside the reef is quite large, occasionally extending inshore a kilometer or more.

Plankton samples collected from just inside the breaker zone were practically devoid of zooplankton while algal debris was common. Since wave action makes this zone turbulent, such results are not unexpected.

DESCRIPTION, DISTRIBUTION, AND ABUNDANCE OF BAITFISH

There are four principal species of fish found in Palau that are recognized as good live bait for fishing skipjack tuna in tropical waters. The most commonly used and most desirable is an anchovy, *Stolephorus heterolobus*. Others include a round herring, *Spratelloides delicatulus*; a silverside, *Pranesus pinguis*; and a sardine, *Herklotsichthys punctatus*. These and several less important species found in Palau are discussed here.

Engraulidae

Scientific name:	*Stolephorus heterolobus* (Rüppell)
Palauan name:	Tilai
Japanese-Okinawan name:	Nanyo katakuchi iwashi or tarekuchi iwashi
English name:	Anchovy

This nearly transparent anchovy is the best and most commonly used bait species in Palau (Fig. 3). It is quite closely related to the Hawaiian nehu, *S. purpureus*, which is the best and most abundant bait species in Hawaii. In Palau there is no record of *S. heterolobus* being taken while day baiting. It is readily attracted to a light and is taken at night in this manner. It is reportedly abundant in water 30 to 40 m deep (Marukawa 1939), but I have never seen it during daylight. In Hawaii, *S. purpureus* is often seen in bays but frequent observations of similar areas in Palau have failed to disclose the presence of *S. heterolobus*.

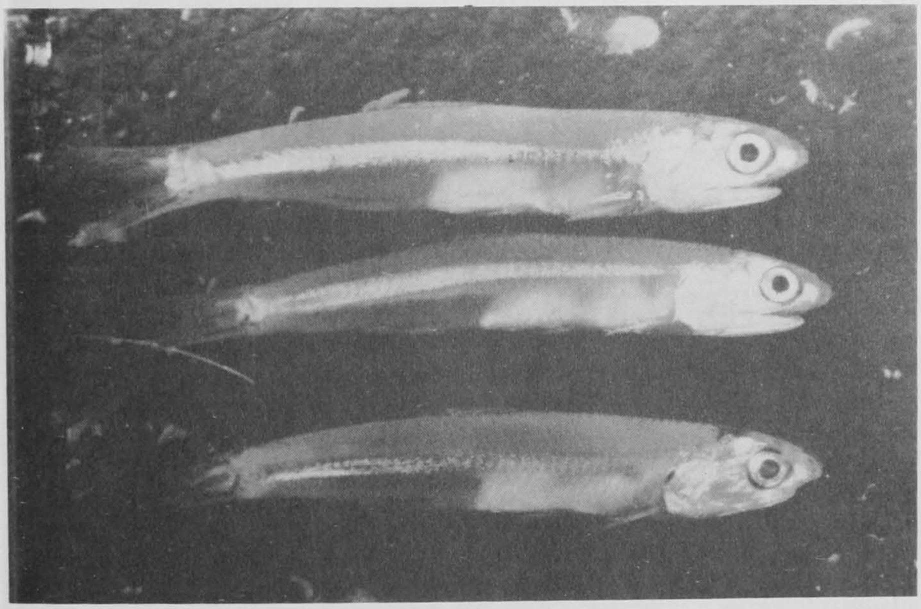

Figure 3.—The anchovy, *Stolephorus heterolobus*. This is the most commonly used bait species in Palau.

It must be handled very carefully during night baiting operations, but stays alive reasonably well after capture. The live-bait method of skipjack tuna fishing requires the bait to live at least 1 day aboard the fishing vessel. This is normally accomplished with no problem and on occasion it has lived 3 days in baitwells with overflow pump systems.

Scientific name:	*Stolephorus buccaneeri* (Strasburg)
Palauan name:	none
Hawaiian name:	Nehu
Japanese name:	unknown
English name:	Anchovy

This species is mentioned here not for its importance as a baitfish, but for its scientific interest. The Palauans have no name for it and it was never recorded as being present or used for bait during the Japanese period. Until recently this species was known only from Hawaii, but more recent collections have also shown it to be present in the Red Sea.

The manner in which this fish was collected is unique. Two Palauans working in the Marine Resources Development Program were trolling between Angaur and Peleliu when they noticed a tight ball of baitlike fish being fed upon by a school of *Euthynnus affinis*. They approached this dense ball in their outboard skiff and, while alongside, simply reached down with a hat and scooped up a sample. It has not been observed since.

Dussumieriidae

Scientific name:	*Spratelloides delicatulus* (Bennett)
Palauan name:	Kuaol
Hawaiian name:	Piha
Japanese-Okinawan name:	Aoesa, shira, minami-kibinago
English name:	Round herring

Kuaol is one of the most abundant bait species found in Palau waters. Scattered schools are regularly seen all through the inner reef area, but seldom are these schools very large. Kuaol can easily be found during the day in such areas as Malakal Harbor, on the shoal sand and coral flats near bodies of moving water, and in the shallow water inside fringing reefs. It can be taken with a day net, but is seldom caught in commercial quantities at night.

Reports from Palauan fishermen indicate that kuaol is occasionally encountered some distance from the islands. Fishermen catching skipjack tuna 11 km off Kayangel reported that although they had been using mekebud, *H. Punctatus*, for bait, hooked tuna regurgitated large amounts of kuaol. Conversely, observations made in the mangrove area, in muddy bays, on banks, and in rivers have failed to show any evidence of kuaol, and it appears that thie species prefers clear water of the type found around the limestone islands and fringing reefs.

Scientific name:	*Dussumieria acuta* (Valenciennes)
Palauan name:	Adins
Hawaiian name:	none
Japanese-Okinawan name:	Urume iwashi
English name:	Round herring

This species is closely related to the Clupeidae and is distinguishable by its lack of abdominal scutes.

I suspect that there are considerable numbers of this species present in the mangrove area around the island of Babelthuap as it is easily recognized by island fishermen; however, only one specimen has been collected in Palau to date by the Marine Resources Division. Additional specimens have been sought unsuccessfully. Local fishermen were able to agree on a name, which indicates that it, or a related species, probably is common in Palau.

Atherinidae

Scientific name:	*Pranesus pinguis* (Lacépède)
Palauan name:	Teber
Hawaiian name:	Iao
Japanese name:	Togoro-iwashi
English name:	Silverside

Of the major bait species in Palau, this is probably the most hardy (Fig. 4). Observations have revealed no favored habitat for this species, and it appears to have the widest range of occurrence of all the baitfish in Palau. It is found in either brackish water or seawater and, unlike mekebud or kuaol, frequents the mangrove area, the fringing reef, and the limestone island habitats.

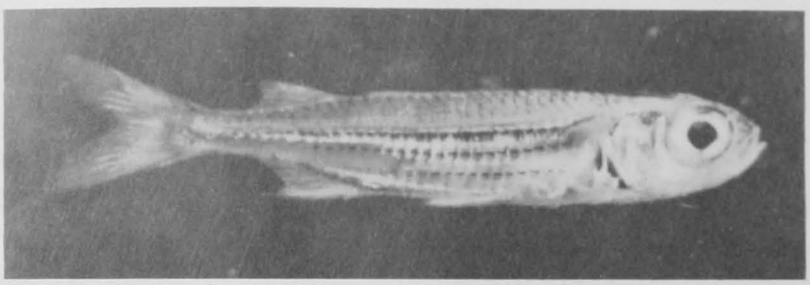

Figure 4.—The atherinid, *Pranesus pinguis*. This is probably the strongest of the major bait species in Palau.

Reports differ as to the extent this species was used as bait prior to the war. Local fishermen familiar with the Okinawan fishing methods recall that it was a relatively common bait species, but Marukawa (1939) says it was almost never used for bait because skipjack tuna do not take it readily. The Fisheries Research Station's progress report states "togoro-iwashi are taken well by the fish and are very suitable for use as bait" (Shimada and Van Campen 1951).

Palauan fishermen feel that the behavior of this atherinid does not make it suitable as chum for skipjack tuna fishing. In limited trials in Palau, hooks baited with the mangrove sardine or mekebud produced more skipjack tuna than did those baited with teber.

Catching teber in commercial quantities at night has proved difficult, as this species is not attracted to light in adequate numbers. Seining with a Hawaiian day net in sandy coves and along the beaches, however, is an efficient method of catching teber in suitable quantities. Care must be taken to shut off all avenues of escape, as this species will readily swim under, over, or through any opening in the net.

Clupeidae

Scientific name:	*Herklotsichthys punctatus* (Rüppell)
Palauan name:	Mekebud
Hawaiian name:	none
Japanese-Okinawan name:	Mangurobu iwashi
English name:	Mangrove sardine

This sardine is common in Palau and can be found along the mangrove coastline of Babelthuap. It lies quietly in dense schools along sandy beaches in the limestone island area. It has never been reported around waves or currents of any strength.

I have not observed these fish in deep water during the day, but they may move there at night to feed since the schools of mekebud disappear from their daytime habitat in the evening. In addition, stomach samples taken during the day were always empty, indicating night feeding habits. Palauan fishermen have reported that this species is found only as far north as northern Babelthuap, and that the maximum size increases from south to north.

During the prewar skipjack tuna fishery, fishermen did not utilize mekebud for bait as it is weak and does not live long when confined (Marukawa 1939). Marukawa stated that this fish is attracted to night-light and is taken with lift nets; however, night baiting operations since the war have not attracted large concentrations of this species and it is doubtful that it can be taken by this method in commercial quantities.

Mekebud was used as live bait by a group of Palauan fishermen shortly after the war. They caught mekebud with a day net and fished off a former Okinawan skipjack tuna boat. The fishermen who were engaged in the actual fishing operations stated that the skipjack tuna took this fish readily and that they felt it was an adequate baitfish.

This species is a popular food fish of the Palauans. It is commonly taken with throw nets and illegally with explosives. It is also an important forage fish and schools of carangids and small tuna may be seen feeding on it. Schools of mekebud are often mixed with teber.

Apogonidae

Scientific name:	(Palauan species not identified; a Truk species is *Rhabdamia cypselurus*)
Palauan name:	Sebus
Hawaiian name:	unknown
Japanese-Okinawan name:	Akadoro or akaesa
English name:	Cardinalfish

There are about 15 members of this family presently in the Palau Islands. Some of the species have been used for bait in the past by Okinawan skipjack tuna fishermen. They are a hardy fish but difficult to catch and are not as abundant as other baitfish. They do not travel in large schools and are not found free-swimming in the lagoon or in other areas. Instead, the species used for bait live around coral heads, forming a dense layer a few inches away from the coral. They remain almost motionless and, when alarmed, seek shelter among its branches.

The best grounds for these fish are on the inside of the outer fringing reefs, where the coral heads are usually found on flat sandy stretches. According to local fishermen, an average coral head yields four or five 15-liter buckets of bait. When the Okinawan fishermen wanted to catch this type of bait, they went to the outer reef in the early morning, since sebus is not attracted to a light and cannot be caught at night. There was usually a sufficient amount of this bait available, as sebus was seldom fished except when the moon was full and it was difficult to night bait for the local species of anchovy.

Fishermen who formerly worked in the Okinawan skipjack tuna fishery indicate that the skipjack tuna took sebus as readily as tilai. Some of them say it was actually a better bait as it came to the boat faster and remained there longer. An advantage of sebus over kuaol was that it lived longer in the baitwells of the fishing boats.

Of all the bait species found in these waters, however, sebus appears to be the most difficult to catch. For this reason, it is seldom used in today's Palau skipjack tuna fishery.

OTHER BAITFISH OF MINOR IMPORTANCE

Marukawa (1939) reported that *Caesio chrysozoma*, a lutjanid, was used for bait by prewar Okinawan fishermen. They called it "akamuro" or "umeiro," and "saneera" or "gurukon." Adults of this species are too large for bait; only juveniles measuring 7 to 10 cm are used. Schools have been observed in the general reef area in concentrations that appeared large enough to be used for bait. Marukawa stated that this species was usually caught during the day in shallow water with drive-in nets. He also stated, "they are strong when confined and make excellent bait for skipjack. This species is extremely important as baitfish at Saipan and in other localities where the South Sea anchovy is not available in quantity."

Local fishermen have also reported several other small fish used for bait when they were available and when the usual bait was difficult to catch. Marukawa identified at least some of these as *Selar crumenophthalmus* called "me-aji," and several other carangids of the genus *Caranx*, called "gatsun" by the Okinawans, and stated that they were attracted to night-light and taken while night baiting. They were reportedly of more importance in areas such as Saipan, where bait stocks were poor, than in Palau and Truk where bait was more abundant.

Goatfishes (Mullidae) have also been reported as bait, but were used only when the preferred bait species were not available.

CONCLUSION

With commercial skipjack tuna fishing operations now underway again in the Trust Territory, we can look forward to learning more about the bait and tuna resources of the area. As knowledge of these stocks accumulates, more effective development and management programs should be initiated to take maximum advantage of skipjack tuna, Micronesia's greatest known marine resource.

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Ponape Live-Bait Observations

PETER T. WILSON[1]

ABSTRACT

Information on naturally occurring stocks of baitfish in Ponape lagoon is necessary to the development of any offshore skipjack tuna, *Katsuwonus pelamis*, fishery in the area. A live-bait survey of the lagoon was carried out during the period July-October 1971. Seven species of baitfish residing there have potential as live bait for skipjack tuna fishing. These were the dussumieriids, *Spratelloides delicatulus* and *S. gracilis*; the lutjanids, *Pterocaesio pisang, P. tile*, and *Caesio coerulaureus*; and the apogons, *Apogon lateralis* and *A. leptacanthus*.

INTRODUCTION

In April of 1971 the Ponape District of the Trust Territory of the Pacific Islands convened its first Ponape Marine Resources Conference. This conference recommended that the Marine Resources Division carry out a live-bait survey of the Ponape District as soon as possible. This recommendation was prompted by fishermen of Ponape who were anxious to proceed with the development of their offshore skipjack tuna, *Katsuwonus pelamis*, fishery, but recognized a lack of basic information relating to the naturally occurring stocks of baitfish. The Director of Resources and Development, acting on this recommendation, made additional funds available to the Marine Resources Division to carry out the survey.

PROCEDURE

Sinkichi Nakachi, an Okinawan crew member with 43 yr of experience in commercial skipjack tuna fishing in the Pacific, was selected as primary surveyor of the prewar bait grounds of Ponape. His assistant was fisherman Kioske Monop.

These two men were recruited for a 4-mo period (July-October 1971). They were provided an open 5.1-m (17-ft) Mokil-type, lap-strake boat, which resembles an old whaleboat. It was powered by a 25-hp outboard motor. Other necessary support gear, such as an Okinawan live-bait net, was also made available. Assistance in using this net was provided by the Ponape Starfish Control Team, which consisted of six divers experienced with scuba gear. Normal daytime activities consisted of traveling through the lagoon to the bait grounds frequented by Okinawan bait fishermen during the prewar years. The abundance and type of bait in each of these areas was determined by swimming and diving to depths of 18.3 m (60 ft), using Okinawan-type goggles for underwater observation.

Night-light stations were run at various times using a small Honda[2] generator and a 500-W underwater light. Bait samples were collected with scoop nets and the samples were preserved in Formalin and sent to Gerald Allen, formerly at the Bishop Museum in Honolulu, for identification.

During the survey period most of the inshore lagoon area of Ponape was covered by the survey team. Night bait observations were also made in the principal deepwater harbors.

OBJECTIVES

The objectives of the Ponape live-bait survey were: 1) to identify the live-bait species of Ponape lagoon; 2) to determine the relative abundance and distribution of the live-bait species in Ponape lagoon; 3) to survey the night and day bait resources of Ponape lagoon; and 4) to evaluate the prewar baiting methods practiced in Ponape lagoon.

AREA DESCRIPTION

Ponape

Ponape is located at lat. 6°53′N, long. 158°14′E. The island is of volcanic origin and is about 22.5 km (14 mi) from north to south and 25.7 km (16 mi) from east to west. At its highest point, it is 791.0 m (2,595 ft) above sea level. Its population as of June 1970, was 14,520. It is 482.7 km (300 mi) from Kusaie, 732.1 km (455 mi) from Kapingamarangi, and 402.2 km (250 mi) from Nukuoro. Ponape is surrounded by about 25 small islands of both coral and volcanic origin. A barrier reef with numerous small passages surrounds the entire lagoon, which is 178.2 km^2 (68.8 mi^2) in size. Ponape itself covers 334.1 km^2 (129 mi^2) (see Fig. 1). Ant and Pakin are nearby atolls which were not included in the bait survey.

[1]Marine Resources Division, Trust Territory of the Pacific Islands, Saipan, Marianas 96950; present address: Department of Primary Industry, Port Moresby, Papua New Guinea.

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

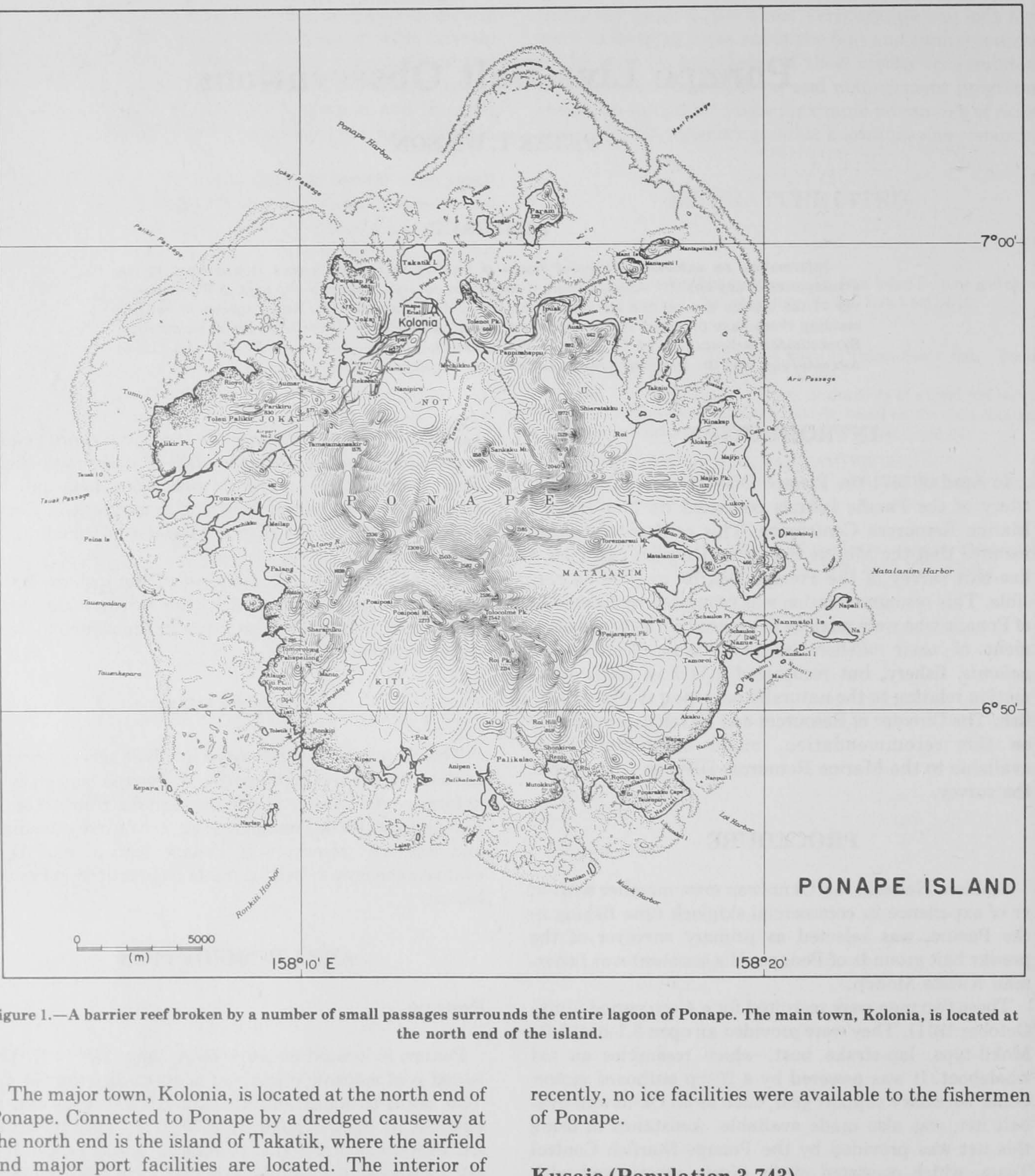

Figure 1.—A barrier reef broken by a number of small passages surrounds the entire lagoon of Ponape. The main town, Kolonia, is located at the north end of the island.

The major town, Kolonia, is located at the north end of Ponape. Connected to Ponape by a dredged causeway at the north end is the island of Takatik, where the airfield and major port facilities are located. The interior of Ponape consists of a series of sharply eroded peaks and deep valleys. The peaks are located near the center of the island and the principal flat areas are found along the coast and up some of the river valleys.

Unlike many islanders, the residents of Ponape live in widely scattered homes. There is not the normal concentration of homes in villages such as on Babelthuap at Palau or on Moen at Truk.

A fisheries cooperative is located in Kolonia and all of the fish landed here is provided by islanders and comes from the inshore and nearby offshore waters. Until recently, no ice facilities were available to the fishermen of Ponape.

Kusaie (Population 3,743)

Kusaie is located at lat. 5°20'N, long. 163°E. It is the easternmost of the Caroline Islands in the Ponape District. The island is 13.7 km (8.5 mi) long by 16.1 km (10 mi) wide and has an area of approximately 108.8 km^2 (42 mi^2) (see Fig. 2). Kusaie is made up of two volcanic peaks which rise as high as 629.1 m (2,064 ft). Both of these mountains are surrounded by an alluvial coastal plain of varying width. This coastline has a dense cover of mangrove behind which are coconut, mango, and breadfruit

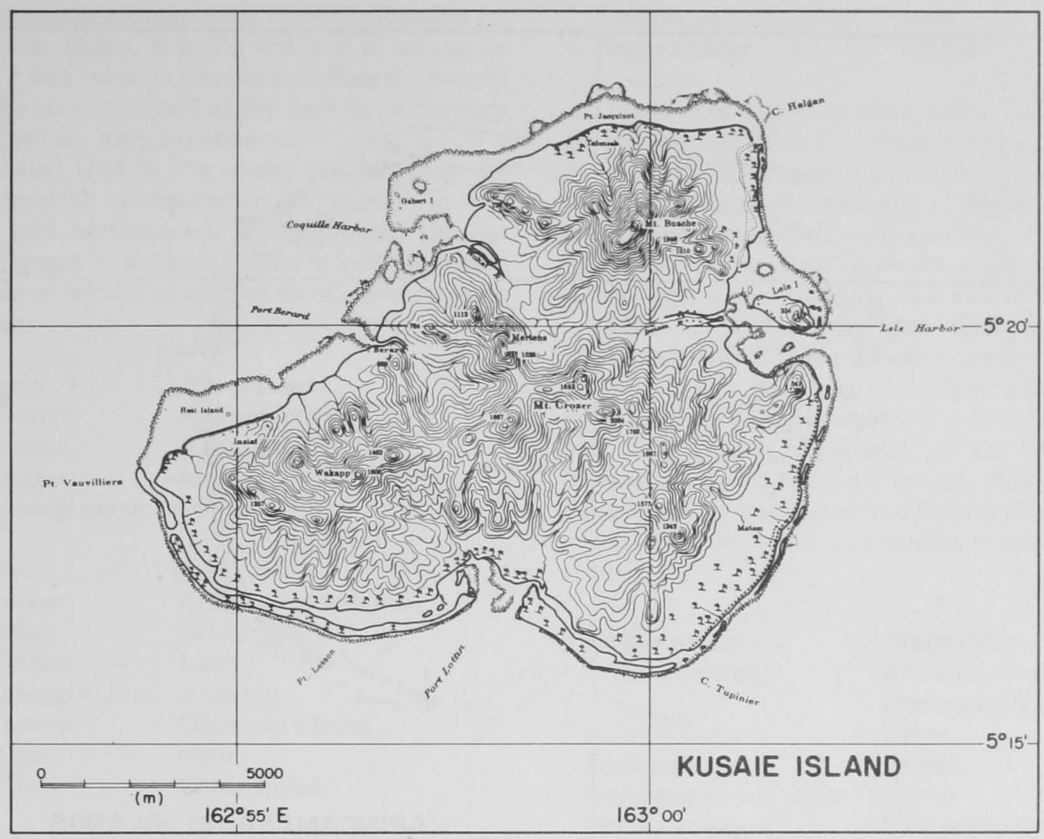

Figure 2.—Kusaie is the easternmost of the Caroline Islands in the Ponape District. It is about one-third the size of Ponape Island, and like the larger island, is of volcanic origin.

trees. At the mouths of the rivers, nipa palms can also be found.

The inshore lagoon waters of Kusaie are limited and consequently provide only enough fish for subsistence purposes. However, the offshore waters are reportedly rich with pelagic fish such as the skipjack tuna.

Kapingamarangi (Population 423)

Kapingamarangi is a small atoll located in the southern portion of the Ponape District at lat. 1°05'N, long. 154°45'E (see Fig. 3). It is inhabited by Polynesians rather than Micronesians, and while the reefs and lagoons have good stocks of reef fish, there is no record of any baiting there during the prewar fishery. Cursory surveys by starfish control teams and the National Marine Fisheries Service's RV *Townsend Cromwell* have not revealed large concentrations of bait species such as *Stolephorus* or *Spratelloides*. However, it is possible that concentrations of *Caesio* or *Apogon* exist in enough abundance to support one or more live-bait boats on a seasonal basis. The 732.1 km (455 mi) distance from Kapingamarangi to Ponape, and the lack of adequate refrigeration facilities would, however, seem to preclude the use of Kapingamarangi for commercial fishing operations.

SURVEY RESULTS

About the time the live-bait survey of Ponape started, a mother ship operation with three Okinawan skipjack tuna catcher vessels was also begun in Ponape. Nakachi was able to work with this group of fishermen part of the time and he reported on the baiting techniques being used in this operation.

According to Nakachi, the prewar boats and the ones now fishing in Ponape normally took "shira," *Spratelloides delicatulus* and *S. gracilis*. These species are common in Palau and Truk, but are not used extensively there as live bait.

In Ponage, *Spratelloides*—called "shira" by the Okinawans and "unam" by the Ponapeans—is taken with two skiffs and a drive-in net. "Takabe" (small) or "akamuro" (large), the Okinawan names for the genus *Caesio*, and the apogonid "akaesa" were not used during this period. They were abundant throughout the lagoon, but the Okinawans were not equipped to catch them.

The lack of a commercial abundance of *Stolephorus* was also noted during this bait survey. Despite night-light trials on the survey skiff and the Okinawan vessels fishing in Ponape at the time, very few anchovy were taken. Concentrations of *Stolephorus heterolobus* in the Palau bait grounds vary throughout the year. It is possible that the survey was conducted during a period of time or in areas in which *Stolephorus* was not available. However, Nakachi stated that during the prewar years it was never used for bait.

In the course of the survey, seven species were found to have bait potential. The most important species follow:

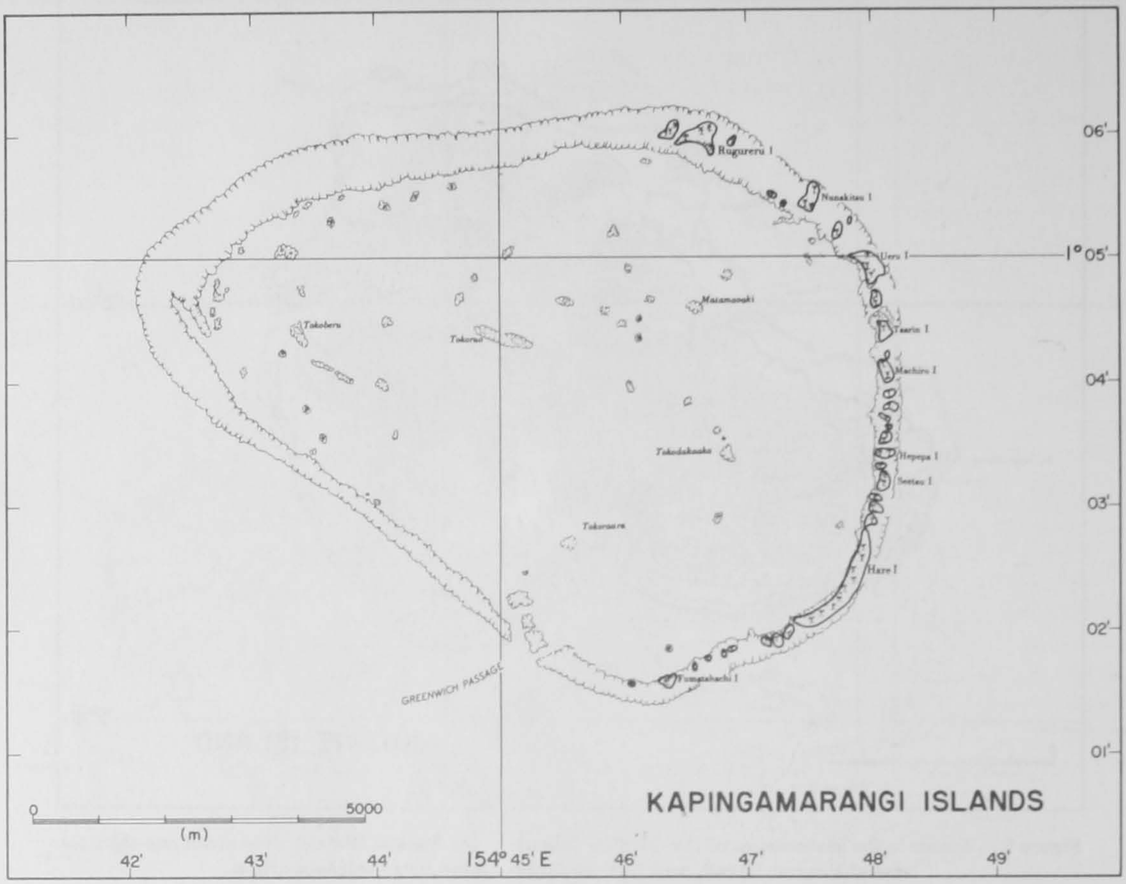

Figure 3.—Kapingamarangi Islands make up a small atoll in the southern part of the Ponape District.

Family name:	Dussumieriidae
Scientific name:	*Spratelloides delicatulus* (Bennett)
	Spratelloides gracilis
Palauan name:	Kuaol
Ponapean name:	Unam
Kapingamarangi name:	Dawen
Okinawan name:	Shira
Trukese name:	Nienika
Japanese name:	Aoesa, Minami-kibinago
English name:	Round herring
Hawaiian name:	Piha

Spratelloides is very common in Ponape and, during the time of the survey, was the species most frequently taken by the three Okinawan boats fishing from the mother ship. It is considered to be a good bait, but it is weak and will no longer than a day or two in the baitwells. *Spratelloides* occurs in the northeast portion of the Ponape lagoon. During high tide, it gathers on top of coral heads with takabe or akamuro underneath, but during low tide *Spratelloides* moves into deeper water away from the coral and nearby sandy areas and channels.

Spratelloides delicatulus and *S. gracilis* are found in lagoons throughout the Trust Territory. They are very similar but can be distinguished from one another by the brighter lateral lines of *S. gracilis*.

Family name:	Lutjanidae
Scientific name:	*Pterocaesio pisang*
	Pterocaesio tile
	Caesio coerulaureus
Ponapean name:	Ikonid
Kapingamarangi name:	Duri
Okinawan name:	Takabe (young)
	Akamuro (mature)
Trukese name:	Tinika or tinipu
English name:	Snapper

Wilson (1971) stated that takabe is an excellent baitfish. However, it is seasonal and reportedly enters the lagoon around May or June when very small. It concentrates in dense schools in midwater areas between the surface and the coral heads and seeks shelter around the coral when startled. Excellent divers with a special type of net are required to catch it.

This fish is one of the hardiest of all the baitfish found in Micronesia. It was commonly used during the prewar years in Truk and can be carried for long distances at sea under much more crowded conditions than is possible with the Palauan baitfish *Stolephorus heterolobus* or the Ponapean baitfish *Spratelloides delicatulus*.

Okinawan live-bait boats use this fish extensively for live-bait skipjack tuna fishing, carrying it on occasion into Trust Territory waters from Okinawa. During 1971 an Okinawan skipjack tuna vessel was apprehended for illegal entry into Palau. It had a full load of takabe on board which it had taken in Okinawa. During the several weeks that the boat remained at the dock in Palau, very low bait mortalities were experienced.

Nakachi stated that in the course of his survey, he found the greatest concentration of takabe in the northeastern and northwestern lagoon sectors. He also stated that it would be a simple matter to harvest sizable concentrations of takabe to support an offshore skipjack tuna operation.

Family name:	Apogonidae
Scientific name:	*Apogon lateralis*
Ponapean name:	Kendip
Okinawan name:	Ishida
Kapingamarangi name:	Pikute

Family name:	Apogonidae
Scientific name:	*Apogon leptacanthus*
Palauan name:	Sebus ibad
Ponapean name:	Lisap
Kapingamarangi name:	Kupepot
Okinawan name:	Ohome or akaesa
Trukese name:	Sipu
English name:	Cardinalfish

The Okinawans use the general term "akaesa" for fish of this group, and have long recognized it as being an excellent baitfish. Wilson (1971) reported that Okinawans consider it second only to the takabe. It is very hardy and lives for long periods of time in the baitwells. This group of fish forms dense clouds around coral heads and does not come out into the open water during the day. In the evening, it leaves the coral heads to forage on plankton and returns just before daylight. Akaesa lives in the same general environment as does takabe, the difference being that takabe prefers the midwater area above coral heads, while akaesa concentrates in dense schools very close to the coral.

Akaesa is not attracted to light and cannot be taken commercially at night by the use of the night-light method. Although it is common in the Ponape lagoon, it was not used as a baitfish by the Okinawans during the survey period. However, it was used during prewar years when *Spratelloides* and takabe were not available. Akaesa is taken in the early morning by placing nets over the coral heads prior to the return of the fish. When the fish return shortly after daylight, the divers lift the net and the bait that has gathered over the net to the surface. This method of baiting is hard on the divers and on the gear and is avoided when other species can be taken.

Family name:	Clupeidae
Scientific name:	*Herklotsichthys punctatus*
Palauan name:	Mekebud
Ponapean name:	Saip
Kapingamarangi name:	Saip
Okinawan name:	Iwashi
Trukese name:	Senif
English name:	Sardine

This species served satisfactorily as a temporary bait during postwar fishing operations in Palau, but there is no record of its being used extensively at bait in Ponape, where it occurs most commonly in schools along the mangrove coastlines and off sandy beaches. It usually schools with *Allanetta ovalaua* or *Pranesus pinguis*.

This fish is an excellent food fish and is eaten raw, cooked, or pickled by the local people. Many Micronesians feel that while this species occurs in large schools, it can be easily overfished; hence, there is a reluctance by many islanders to allow its use as a live-bait fish. During the period of the Ponape survey, *Spratelloides* was common enough that the Okinawan fishermen had no need to look further for other baitfish, and as a consequence this sardine was not used extensively.

Family name:	Atherinidae
Scientific name:	*Allanetta ovalaua* *Pranesus pinguis*
Palauan name:	Teber
Ponapean name:	Apatik
Kapingamarangi name:	Sowou
Okinawan name:	Pora or yajanguwa
Trukese name:	Nou
English name:	Silverside

This atherinid occurs in the same environments as the mangrove sardine, *Herklotsichthys punctatus*. It is strong and can live for a considerable period of time in the live wells of the tuna boats, but it is not considered to be a particularly good baitfish. It is used for bait when better species are not available. Wilson (1971) reported that *Allanetta avalaua* does not school with sardines in deep water. However, they do school together in the shoal water areas off mangroves and beaches during the day.

This species was not used as a baitfish by the Okinawan boats that were fishing in Ponape during the survey period; however, it was used occasionally during the prewar years when other bait species were difficult to take.

BAITING AND FISHING IN PONAPE

Two skiffs are used in setting the Ponape drive-in net for catching *Spratelloides*. This net has two wings, which measure approximately 18.3 m (60 ft) in length. They lead into a bag that is about 7.3 m (24 ft) across and about 3.7 m (12 ft) deep. The mesh on the wings is larger than that on the bag, which is the standard minnow netting and measures approximately 0.6 cm (¼ in).

As the bait is normally caught in the shoal areas around coral heads, the Okinawans prefer a smaller type of skipjack tuna vessel for maneuvering between coral heads inside the lagoon. The boats that were used in the postwar fishery were approximately 50 tons, which, in the opinion of some Okinawan fishermen, is too large. They argue that the boats should be in the 20- to 30-ton range as this would give them more maneuverability. In addition, the fishermen stressed the need for faster boats in order to expedite travel to and from the fishing grounds.

During the survey period, the Okinawans started their baiting operations around 0500. In an hour or two after several sets of the nets, they had enough bait for a day's fishing and proceeded to fish in the general area between Ant Atoll and Ponape. Most of the fishing was apparently done on the west side of Ponape, but the vessels fished the east side as well. Apparently very little fishing is done to the south of Ponape because of the distance from the northern pass. The boats usually returned to Ponape between 1800 and 2000, offloaded their catch, and tied up for the night, departing again early in the morning for the baiting grounds.

PREWAR SKIPJACK TUNA FISHERY OF PONAPE

During the prewar years, the Japanese had several fishing companies in operation on Ponape. Reportedly, Nanyo Boeki Kaisha had 2 skipjack tuna boats, Nanko Suisan Kaisha had 4, and miscellaneous private companies had 6—for a total of 12 live-bait skipjack tuna vessels in Ponape prior to the war.

At the conclusion of each day's fishing, these skipjack tuna boats would return to port. The catch was offloaded and work was started immediately to process it into katsuobushi, which was later exported to Japan. Nanko Suisan and Nanyo Boeki Kaisha were the two principal manufacturers of katsuobushi during the prewar years.

Fishing in Ponape was reportedly fairly good in January, but poor in February and March. It improved in April and May and was best in June, July, and August. In September, fishing usually declined and remained poor through October. It improved and continued good during November and December, tapering off in January. The average size of skipjack tuna taken was about the same as the Palau and Truk fish, running around 4.5 kg (10 lb).

THE FUTURE SKIPJACK TUNA FISHERY OF PONAPE

The demand for skipjack tuna on the world market is continuing to grow at a rapid pace. The Japanese and American tuna industries have expressed a great deal of interest in establishing bases in the Trust Territory in order to tap the skipjack tuna stocks occurring in this area.

However, the local leaders of Ponape have indicated that they want to develop the tuna fisheries of Ponape with their own resources. They are reluctant to accept foreign investment capital which they feel will take over their greatest natural resource—the skipjack tuna.

Efforts are underway to develop this potential using west coast dories and trolling gear. Seven vessels are now fishing with varying degrees of success. However, basic support facilities such as a dock, ice, and freezing and cold storage facilities are lacking, and local capital to provide them has yet to be located.

LITERATURE CITED

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Japanese Skipjack Tuna, *Katsuwonus pelamis*, Baitfish Surveys in the Western and Southwestern Pacific Ocean

SHOJI KIKAWA[1]

ABSTRACT

Several Japanese agencies have conducted skipjack tuna, *Katsuwonus pelamis*, baitfish surveys in coastal areas of tropical islands and oceanic regions of the western and southwestern Pacific Ocean with a view to developing pole-and-line skipjack tuna fisheries. The areas surveyed included Papua New Guinea, equatorial oceanic waters, and some of the major South Pacific islands. Fishes from 42 families, mostly juveniles and larvae, were collected by stick-held lift net and drive-in net trials throughout the Papua New Guinea area from 1968 to 1970. Principal bait species attracted to light included those of the Engraulidae, Dussumieriidae, Clupeidae, and Atherinidae. Generally, lagoons and coastal areas with distinct fringing reefs provided better baiting grounds than areas just outside the reef. Relative abundance of baitfish attracted to light was presented by area types throughout the region. Positive and negative species relationships for major species as they occurred in the night-light collections were shown. Night-light surveys made on 11 fishing trips in the western equatorial Pacific indicated the difficulty of obtaining commercial quantities of baitfish in oceanic waters, although members of several families, especially Myctophidae and Holocentridae, were relatively common around the night-light. Principal species that occurred in the night-light collections made in coastal regions of the islands of New Hebrides, New Caledonia, Tonga, and Wallis from 1971 to 1974 were nearly identical with those collected in Papua New Guinea. In these areas, however, fishes of the Clupeidae were more abundant than the Engraulidae. No engraulids occurred in Tonga.

INTRODUCTION

Since 1968, several agencies in Japan have conducted skipjack tuna, *Katsuwonus pelamis*, baitfish surveys in coastal areas of tropical islands and oceanic regions of the western and southwestern Pacific Ocean. The areas surveyed included Papua New Guinea, equatorial oceanic waters, and some of the major South Pacific islands. This paper presents general results obtained on these surveys.

PAPUA NEW GUINEA

The annual Papua New Guinea skipjack tuna landings have fluctuated greatly since the start of joint venture (with Japanese companies) fisheries in 1971. Undoubtedly some of this fluctuation is due to the availability of baitfish. Live bait has sometimes been in short supply as a result of unusual environmental conditions in coastal waters. In general, however, the Papua New Guinea skipjack tuna fisheries have been blessed with a supply of baitfish sufficient to keep the existing fleet of skipjack tuna vessels in active operation. Papua New Guinea fisheries are now based in Kavieng, Rabaul, Madang, and Kimbe on the coasts of major islands bordering the Bismarck Sea.

Prior to the inception of the joint venture commercial fisheries in Papua New Guinea, the Japan Fisheries Agency sent research vessels to the area several times to study the feasibility of developing skipjack tuna fisheries. Three cruises were made by the *Shunyo Maru*, a research vessel attached to the Far Seas Fisheries Research Laboratory (Far Seas Fisheries Research Laboratory 1969, 1970); two survey cruises were made by the *Fuji Maru*; and one survey cruise was made by the *Suruga Maru*, the research vessels of the Shizuoka Prefectural Fisheries Experimental Station (Shizuoka Prefectural Fisheries Experimental Station 1970). These survey cruises were conducted between 1968 and 1970. The results of the surveys by the *Shunyo Maru* are summarized below.

First Survey (October-December 1968)

The *Shunyo Maru* made its first cruise to the Bismarck Sea in October-December 1968. Areas surveyed included New Ireland, New Britain, and part of mainland New Guinea and associated smaller islands. Baitfish surveys revealed that anchovies (Engraulidae), round herring and sprats (Dussumieriidae), herrings and sardines (Clupeidae), flyingfishes (Exocoetidae), and hardyheads (Atherinidae) were particularly abundant in stick-held lift net (bōuke ami) collections made at night). Among these, the first three groups were considered to be the most important skipjack tuna baitfish. In addition to the above, many other species of fish were collected at night-light stations but most were in the larval or juvenile stages, and were too small to be used as baitfish (Table 1).

[1]Far Seas Fisheries Research Laboratory, Shimizu, Japan.

Table 1.—Numbers of stations having fishes of two size categories, as divided by 40 mm in total length (TL), the probable lower size limit for tuna baitfish. (From Far Seas Fisheries Research Laboratory 1969).

Family	Numbers of stations having fish smaller than 40 mm TL	Numbers of stations having fish larger than 40 mm TL
Dorosomidae	0	1
Engraulidae	10	8
Dussumieriidae	8	8
Clupeidae	7	8
Myctophidae	3	1
Paralepididae	0	1
Synodontidae	4	2
Anguilliformes	0	4
Exocoetidae	1	3
Fistulariidae	0	3
Syngnathidae	0	2
Bregmacerotidae	2	1
Bothidae	4	0
Holocentridae	5	1
Atherinidae	8	8
Polynemidae	1	0
Sphyraenidae	2	4
Scombridae	5	4
Carangidae	9	3
Mullidae	10	2
Priacanthidae	2	0
Apogonidae	6	0
Serranidae	7	0
Lutjanidae	7	0
Caesiodidae	5	0
Lethrinidae	6	0
Pomadasyidae	4	0
Theraponidae	7	0
Blenniidae	5	0
Eleotridae	2	0
Chaetodontidae	6	0
Pomacanthidae	1	0
Abudefdufidae	6	0
Chromidae	6	0
Labridae	2	0
Acanthuridae	3	0
Siganidae	6	0
Balistidae	3	0
Canthigasteridae	3	1
Tetraodontidae	5	0
Scorpaenidae	2	0
Cirrhitidae	1	0

In the Bismarck Sea, commercial skipjack tuna fishing vessels have operated successfully chiefly due to the abundance of the anchovy, *Stolephorus devisi*, and sprats, *Spratelloides japonicus* and *S. delicatulus*, found there.

Second Survey (October-December 1969)

Area of Survey.

1. Southern New Ireland, Buka, and Bougainville (nine stations).
2. East coast of New Ireland (three stations).
3. Off-lying islands east of New Ireland and Nuguria Islands (eight stations).

Method of Collection.—A small, stick-held lift net (8 m × 10 m) was used in combination with fish-luring lamps at night. Three lamp systems were used: one on the port side of the vessel has five 500-W white bulbs; the second on the starboard side, has two 500-W white bulbs and one 500-W red bulb (both systems were suspended about 2.5 m above sea level from long poles), and the third is an underwater lamp used in combination with these two.

Baitfishes Collected.—Most of the large variety of fishes taken in the stick-held lift net were in the larval and juvenile stages. Of these, members of Clupeidae, Dussumieriidae, Engraulidae, and Atherinidae were the dominant components both in volume and number. Their occurrences were as follows:

1. Dussumieriidae
   a. *Spratelloides japonicus* and *S. delicatulus* occurred at all of the stations except at the southern coast of Bougainville.
   b. *Dussumieria hasselti* was taken at three widely separated stations, thus indicating a wide range in its distribution.
2. Clupeidae
   a. *Amblygaster clupeoides* and *Sardinella jussieu* occurred at all of the stations except that in Nuguria.
   b. *Amblygaster sirm, S. melanura, Herklotsichthys ovalis*, and *Pellona ditchela* occurred in limited areas (southern New Ireland coast facing St. George's Channel, Buka, and Bougainville).
3. Engraulidae
   a. *Stolephorus devisi*,[2] *S. buccaneeri*, and *Thrissina baelama* occurred in limited areas similar to group b of Clupeidae described above.
4. Atherinidae
   a. *Pranesus pinguis* occurred rather widely but was not found in Nuguria.
   b. *Allanetta forskali* was collected at five widely separated stations, indicating a wide distribution.
   c. *Allanetta valenciennei* and *Hypoatherina barnesi* occurred along the coast of New Ireland and the associated eastern off-lying islands.
   d. *Pranesus duodecimalis, P. eendrachtensis*, and *Stenatherina temmincki* were taken sporadically and in small numbers.

In addition to the above, fishes of the following groups were noted in fairly large numbers in collections made with the stick-held lift net and with scoop nets: Myctophidae, Holocentridae, Mugilidae, Scombridae, Sphyraenidae, Carangidae, Mullidae, Apogonidae, Blenniidae, Pomacentridae, Acanthuridae, and Siganidae. Only the larvae or juveniles were caught as the adults did not aggregate in schools under the lights. Especially abundant were the juveniles of Pomacentridae, Apogoni-

[2]Kearney et al. (1972) recognized Papua New Guinea *Stolephorus devisi* as the *S. devisi* complex consisting of two different morphs. I considered this point in Figure 1 and Table 3 in showing *S. devisi*.

dae, and Siganidae, all smaller than about 10 mm in length.

Third Survey (May-July 1970)

Area of Survey.

1. Barrier reef area near Cape Lambert, New Britain (seven stations).
2. Nuguria Islands (six stations).
3. Trobriand Islands, near Tagula Island, and southeastern coast of Papua New Guinea (four stations).

Method of Collection.

1. Stick-held lift net. The net was similar to the one used on the second survey. The fish-luring lamp systems on this survey cruise consisted of the following:

   a. Two 1 kW white bulbs and one 500-W white bulb on port side.
   b. Two 1 kW white bulbs and one 500-W red bulb on starboard side.
   c. One 2 kW white bulb (underwater lamp).

2. Drive-in net (oikomi ami). The drive-in net is the traditional bait catching method used by Okinawan fishermen. During the developmental stages of the joint venture operations in Papua New Guinea, the Kavieng-based fishermen used this method a great deal. It is particularly suited to capturing baitfish that live close to the reef bottom. Swimmers drive the fish from reef crevices into the nets. Not only is this a labor intensive method, it is generally not possible to catch as many fish as with a stick-held lift net. The drive-in net is thus no longer used in the commercial operations in Papua New Guinea. On the survey cruise, the drive-in net was an experimental sampling gear of simple design, a square net with wooden floats on one edge and lead weights along the opposite edge.

Baitfishes Collected.

1. Stick-held lift net and scoop net collections. Fishes of the families Dussumieriidae, Engraulidae, and Atherinidae made up the greater part of the collections, and occurred throughout the areas surveyed. The occurrence of major groups of baitfishes in the three main areas was as follows:

   a. Cape Lambert area. *Stolephorus devisi* and *Spratelloides delicatulus* were dominant in this lagoon area. *Thrissina baelama* also occurred in numbers but was locally distributed. *Spratelloides japonicus* was not taken in this area.
   b. Nuguria Islands. *Spratelloides japonicus, S. delicatulus, Allanetta forskali*, and *A. valenciennei* were represented in the catches made with the stick-held lift net. Sprats (especially *S. japonicus*) were particularly abundant. Most were juveniles ranging in length from 25 to 40 mm. Neither engraulids nor clupeoids occurred in this area.
   c. Southeastern Papua New Guinea. No stick-held lift net trials were made in the southeastern districts of Papua New Guinea since very few fish were attracted to the lights. It appeared that adverse sea conditions associated with the strong southeast trades, as well as the moonlight, were responsible for the poor bait fishing condition. While at Port Moresby, some lift net trials were conducted in Fairfax Harbor with resulting good catches of anchovy, *Stolephorus devisi*, and a small number of the clupeoid, *Sardinella jussieu*. *Stolephorus devisi, S. buccaneeri, Spratelloides delicatulus, S. jussieu*, and some members of the family Atherinidae were among the fish collected with scoop nets in this area.

2. Drive-in net collection. The net used was constructed specially for operation by a few men, and was thus considerably smaller than commercially used nets. The personnel handling the net, with the exception of one expert, had no experience with it. This contributed to the rather poor record in locating suitable areas for its use.

   Trials were conducted in areas where there were scattered coral heads on a flat sandy bottom, usually 5 to 10 m deep.

   a. Cape Lambert area. *Caesio pisang* was found to be dominant. Other species included *C. coerulaureus, C. diagramma, C. crysozonus*, and *C. xanthonotus*.
   b. Cape Boli, Kiriwina Island, Trobriand Islands. At a location 0.8 mi west-southwest of Cape Boli on Kiriwina Island, about 1 kg of *C. coerulaureus* and juvenile apogonids were taken. Most of the baitfish in the area were small and escaped through the mesh of the net resulting in a catch of only about 1,000 fish.
   c. Sariba Island. The survey was centered around Possession Bay in waters 1 to 10 m in depth. The area abounded in several species of coral; dead coral were numerous in certain locations. The principal baitfish species seen were representatives of the family Serranidae. Juvenile apogons were also seen but they were not numerous. No attempts were made to capture the fish since observations did not seem to warrant using the nets.
   d. Nuguria Islands. The reef zones on the western side of Tekanie Island and between Tekanie Island and Renau Island were surveyed. *Caesio chrysozonus* and pomacentrids, *Chromis caeruleus* and *C. ternatensis*, were numerous. Reefs were everywhere and these locations were not considered suitable for effective operation of the drive-in net. Furthermore, the fish appeared to be scattered throughout the various reefs and were not concentrated anywhere. A total of about 20 kg of fish were taken.

General Pattern of Baitfish Distribution

Indented and fringed by submerged banks, much of the Papua New Guinea coastline embraces numerous small bays and lagoons. The coastal areas are commonly dotted with scattered islets or coral heads that can create dangerous passages with swiftly flowing currents. Night-light stations were conducted in various types of environment along this coastline (Table 2). A large variety of fishes inhabited the area and sometimes occurred in close relationship with each other. The relationship between species in a particular area was determined by constructing 2 × 2 chi-square contingency tables for given pairs of species as shown below,

		Species A		
		+	−	
Species B	+	*a*	*b*	*a* + *b*
	−	*c*	*d*	*c* + *d*
		a + *c*	*b* + *d*	*n*

where block "*a*" is the number of stations having both species A and B, block "*b*" is the number of stations having species B alone, block "*c*" is the number of stations having species A alone, and block "*d*" is the number of stations having neither A nor B species. Because of the small sample sizes, the chi-square formula used was:

$$\chi^2 = \frac{(|ad - bc| - \frac{n}{2})^2}{(a + b)\ (c + d)\ (a + c)\ (b + d)}$$

(Kershaw 1964). The results are shown in Figure 1.

Baitfishes of four principal families were encountered everywhere (Table 3) but, generally, lagoons or coastal areas with distinct fringing reefs provided better baiting grounds for anchovies, sardines, and sprats than areas just outside the reef (Table 4).

Changes in Availability of Baitfish

During 1972 (through October) commercial fishing vessels at all bases in Papua New Guinea suffered from a shortage of baitfish. The reason for this is not clear although fishermen attributed it to unusually low water temperatures. They believed that the inflow of an extraordinarily large volume of cooler water into the Bismarck Sea caused changes in baitfish habitat. Compared with data given in the World Atlas of Sea Surface Temperature (U.S. Navy Hydrographic Office 1944), the prevailing temperatures in 1972 around Madang and Kimbe were somewhat lower. According to records kept by the joint venture companies, temperatures during 1972 were 1°-3°C lower than the 1970-71 period. However, they were close to those of the average year in terms both of values and seasonal variation as given in the World Atlas for coastal regions of the Bismarck Sea. Low temperatures in the Bismarck Sea persisted until October 1972 (U.S. Navy Hydrographic Office 1944; [Japan.] Fisheries Agency 1973). Baitfishing improved after this period.

EQUATORIAL OCEANIC WATERS

The occurrence of baitfish in the offshore pelagic waters is of great interest to Japanese southern water skipjack tuna fishermen. From November 1970 to April 1971, tests were carried out by the Hamajima Fisheries Experimental Station of Mie Prefecture (1971) to see if they could locate concentrations of baitfish in pelagic areas. These surveys involved five large commercial pole-and-line fishing vessels. Night-light collections were made on a total of 11 fishing trips. The survey area extended from the Equator to lat. 10°N, and from long. 130° to 160°E.

Method of Collection

Underwater lamps of 1 kW or 2 kW white bulbs were employed to attract fish while drifting at night. Scoop nets were used to capture fish attracted to the lights. All fish specimens collected were preserved in formalin[3] for subsequent examination ashore.

Baitfishes Collected

The night-light surveys resulted in the collection of a very small number of fish families in the scoop net collections: Myctophidae, Holocentridae, Exocoetidae, Oxyporhamphidae, Carangidae, Mullidae, Sphyraenidae, Stromateidae, and Gempylidae. Of these, the first two families were relatively common around the night-light. These surveys indicated the difficulty inherent in obtaining commercial quantities of baitfish in oceanic waters, although this conclusion should await further investigation.

SOUTH PACIFIC ISLANDS

Extensive baitfish surveys have been conducted at some of the South Pacific islands by the Japan Marine Fisheries Resource Research Center (1972, 1973). These surveys, conducted by chartered commercial vessels, included tests on maintaining locally caught baitfish in net enclosures. The Center conducted three surveys as follows: October 1971-March 1972, August-December 1972, and October 1973-January 1974. The areas surveyed included coastal regions of the islands of Nauru, New Hebrides, New Caledonia, Tonga, and Wallis. The results are summarized below.

Methods of Collection

1. Two-boat purse seine.
2. Stick-held lift net.
3. Beach seine.

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

Table 2.—Areas of night-light surveys and the relative abundance of baitfishes attracted to lights (*Shanyo Maru* cruises, 1968-70).

Region	Area	Area type: Lagoon area with distinct submerged reef	Passages or shore zones with fringing reef	Bays with fringing reef	Outside reef, 100-1,000 m in depth	Offshore waters, deeper than 1,000 m	Density of baitfishes attracted to lights[1]
Northern Bismarck Sea	Wuvulu Island				+		1
	Ninigo Island		+				2
	Hermit Island	+					3
	Manus Island		+				1
	Off Manus Island					+	1
	Rambutyo Island				+		1
	Doppel Reef				+		1
Southeastern Bismarck Sea	Djaul Island				+		2
	Moewe Passage		+				4
	New Hanover			+			3
	New Hanover				+		3
	Ataliklikun Bay			+			3
	Hixon Bay			+			3
	Massava Bay (Cape Lambert)	+					2
	Tongalomo Island (Cape Lambert)	+					4
	Cape Pomas (Cape Lambert)	+					2
	Gararr Bay (Cape Lambert)	+					3
	Uasvit River mouth (Cape Lambert)	+					2
	Watasellibuka Bay (Cape Lambert)	+					2
	Wulai Island	+					4
	Garowe Island	+					2
	Umboi Island			+			3
	Lamassa Island			+			3
North coast of mainland New Guinea	Finsch Harbor			+			2
	Natter Bay			+			3
	Holnicote Bay			+			3
	Off Holnicote Bay					+	2
	Langemak Bay			+			3
	Off Madang					+	1
	Astrolabe Bay			+			3
	Sek Harbor		+				3
	Hansa Bay			+			3
	Broken Water Bay			+			2
	West Harbor			+			4
Buka Island and Bougainville Island	Queen Carola Harbor		+				3
	Matchin Bay		+				3
	Empress Augusta Bay			+			3
	Moliko River mouth		+				3
	Tonolei Harbor			+			4
	Toimanapu Bay			+			3
	Kobuan Bay		+				4
	Numanuma Harbor			+			3
East coast of New Ireland Island	Elizabeth Bay			+			3
	Putumbu Bay			+			2
	Kapeu Bay			+			2
Eastern off-lying islands	Kilinailau Island					+	1
	Green Island			+			4
	Feni Island			+			4
	Tanga Island			+			3
	Lihir Island			+			2
	Tabar Island			+			2
Nuguria Islands	Nuguria Islands	+					4-5
Southeast coast of mainland New Guinea	Trobriand Islands			+			2
	Near Tagula Island	+					2
	Sariva Island			+			2
	Modewa Bay			+			2

[1]Numerals show density of baitfish arbitrarily assigned as follows: 1—no baitfish in evidence; 2—very few fish; 3—small schools of baitfish; 4—large and dense schools of fish; 5—very large and massive concentration.

General Pattern of Baitfish Distribution

Indented and fringed by submerged banks, much of the Papua New Guinea coastline embraces numerous small bays and lagoons. The coastal areas are commonly dotted with scattered islets or coral heads that can create dangerous passages with swiftly flowing currents. Night-light stations were conducted in various types of environment along this coastline (Table 2). A large variety of fishes inhabited the area and sometimes occurred in close relationship with each other. The relationship between species in a particular area was determined by constructing 2 × 2 chi-square contingency tables for given pairs of species as shown below,

		Species A +	Species A −	
Species B	+	*a*	*b*	*a* + *b*
	−	*c*	*d*	*c* + *d*
		a + *c*	*b* + *d*	*n*

where block "*a*" is the number of stations having both species A and B, block "*b*" is the number of stations having species B alone, block "*c*" is the number of stations having species A alone, and block "*d*" is the number of stations having neither A nor B species. Because of the small sample sizes, the chi-square formula used was:

$$\chi^2 = \frac{(|ad - bc| - \frac{n}{2})^2}{(a + b)\ (c + d)\ (a + c)\ (b + d)}$$

(Kershaw 1964). The results are shown in Figure 1.

Baitfishes of four principal families were encountered everywhere (Table 3) but, generally, lagoons or coastal areas with distinct fringing reefs provided better baiting grounds for anchovies, sardines, and sprats than areas just outside the reef (Table 4).

Changes in Availability of Baitfish

During 1972 (through October) commercial fishing vessels at all bases in Papua New Guinea suffered from a shortage of baitfish. The reason for this is not clear although fishermen attributed it to unusually low water temperatures. They believed that the inflow of an extraordinarily large volume of cooler water into the Bismarck Sea caused changes in baitfish habitat. Compared with data given in the World Atlas of Sea Surface Temperature (U.S. Navy Hydrographic Office 1944), the prevailing temperatures in 1972 around Madang and Kimbe were somewhat lower. According to records kept by the joint venture companies, temperatures during 1972 were 1°-3°C lower than the 1970-71 period. However, they were close to those of the average year in terms both of values and seasonal variation as given in the World Atlas for coastal regions of the Bismarck Sea. Low temperatures in the Bismarck Sea persisted until October 1972 (U.S. Navy Hydrographic Office 1944; [Japan.] Fisheries Agency 1973). Baitfishing improved after this period.

EQUATORIAL OCEANIC WATERS

The occurrence of baitfish in the offshore pelagic waters is of great interest to Japanese southern water skipjack tuna fishermen. From November 1970 to April 1971, tests were carried out by the Hamajima Fisheries Experimental Station of Mie Prefecture (1971) to see if they could locate concentrations of baitfish in pelagic areas. These surveys involved five large commercial pole-and-line fishing vessels. Night-light collections were made on a total of 11 fishing trips. The survey area extended from the Equator to lat. 10°N, and from long. 130° to 160°E.

Method of Collection

Underwater lamps of 1 kW or 2 kW white bulbs were employed to attract fish while drifting at night. Scoop nets were used to capture fish attracted to the lights. All fish specimens collected were preserved in formalin[3] for subsequent examination ashore.

Baitfishes Collected

The night-light surveys resulted in the collection of a very small number of fish families in the scoop net collections: Myctophidae, Holocentridae, Exocoetidae, Oxyporhamphidae, Carangidae, Mullidae, Sphyraenidae, Stromateidae, and Gempylidae. Of these, the first two families were relatively common around the night-light. These surveys indicated the difficulty inherent in obtaining commercial quantities of baitfish in oceanic waters, although this conclusion should await further investigation.

SOUTH PACIFIC ISLANDS

Extensive baitfish surveys have been conducted at some of the South Pacific islands by the Japan Marine Fisheries Resource Research Center (1972, 1973). These surveys, conducted by chartered commercial vessels, included tests on maintaining locally caught baitfish in net enclosures. The Center conducted three surveys as follows: October 1971-March 1972, August-December 1972, and October 1973-January 1974. The areas surveyed included coastal regions of the islands of Nauru, New Hebrides, New Caledonia, Tonga, and Wallis. The results are summarized below.

Methods of Collection

1. Two-boat purse seine.
2. Stick-held lift net.
3. Beach seine.

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

Table 2.—Areas of night-light surveys and the relative abundance of baitfishes attracted to lights (*Shunyo Maru* cruises, 1968-70).

Region	Area	Area type: Lagoon area with distinct submerged reef	Passages or shore zones with fringing reef	Bays with fringing reef	Outside reef, 100-1,000 m in depth	Offshore waters, deeper than 1,000 m	Density of baitfishes attracted to lights[1]
Northern Bismarck Sea	Wuvulu Island				+		1
	Ninigo Island		+				2
	Hermit Island	+					3
	Manus Island		+				1
	Off Manus Island					+	1
	Rambutyo Island				+		1
	Doppel Reef				+		1
Southeastern Bismarck Sea	Djaul Island				+		2
	Moewe Passage		+				4
	New Hanover			+			3
	New Hanover				+		3
	Ataliklikun Bay			+			3
	Hixon Bay			+			3
	Massava Bay (Cape Lambert)	+					2
	Tongalomo Island (Cape Lambert)	+					4
	Cape Pomas (Cape Lambert)	+					2
	Garerr Bay (Cape Lambert)	+					3
	Usavit River mouth (Cape Lambert)	+					2
	Watassellibuka Bay (Cape Lambert)	+					2
	Wulai Island	+					4
	Garowe Island	+					2
	Umboi Island			+			3
	Lamassa Island			+			3
North coast of mainland New Guinea	Finsch Harbor			+			3
	Natter Bay			+			3
	Holnicote Bay			+			3
	Off Holnicote Bay					+	2
	Langemak Bay			+			3
	Off Madang					+	1
	Astrolabe Bay			+			3
	Sek Harbor		+				3
	Hansa Bay			+			3
	Broken Water Bay			+			2
	West Harbor			+			4
Buka Island and Bougainville Island	Queen Carola Harbor		+				3
	Matchin Bay		+				3
	Empress Augusta Bay			+			3
	Moliko River mouth		+				3
	Tonolei Harbor			+			4
	Toimanapu Bay			+			3
	Kobuan Bay		+				4
	Numanuma Harbor			+			3
East coast of New Ireland Island	Elizabeth Bay			+			3
	Putumbu Bay			+			2
	Kapsu Bay			+			2
Eastern offlying islands	Kilinairau Island					+	1
	Green Island			+			4
	Feni Island			+			4
	Tanga Island			+			3
	Lihir Island			+			2
	Tabar Island			+			2
Nuguria Islands	Nuguria Islands	+					4-5
Southeast coast of mainland New Guinea	Trobriand Islands			+			2
	Near Tagula Island	+					2
	Sariva Island			+			2
	Modeiwa Bay			+			2

[1]Numerals show density of baitfish arbitrarily assigned as follows: 1—no baitfish in evidence; 2—very few fish; 3—small schools of baitfish; 4—large and dense schools of fish; 5—very large and massive concentration.

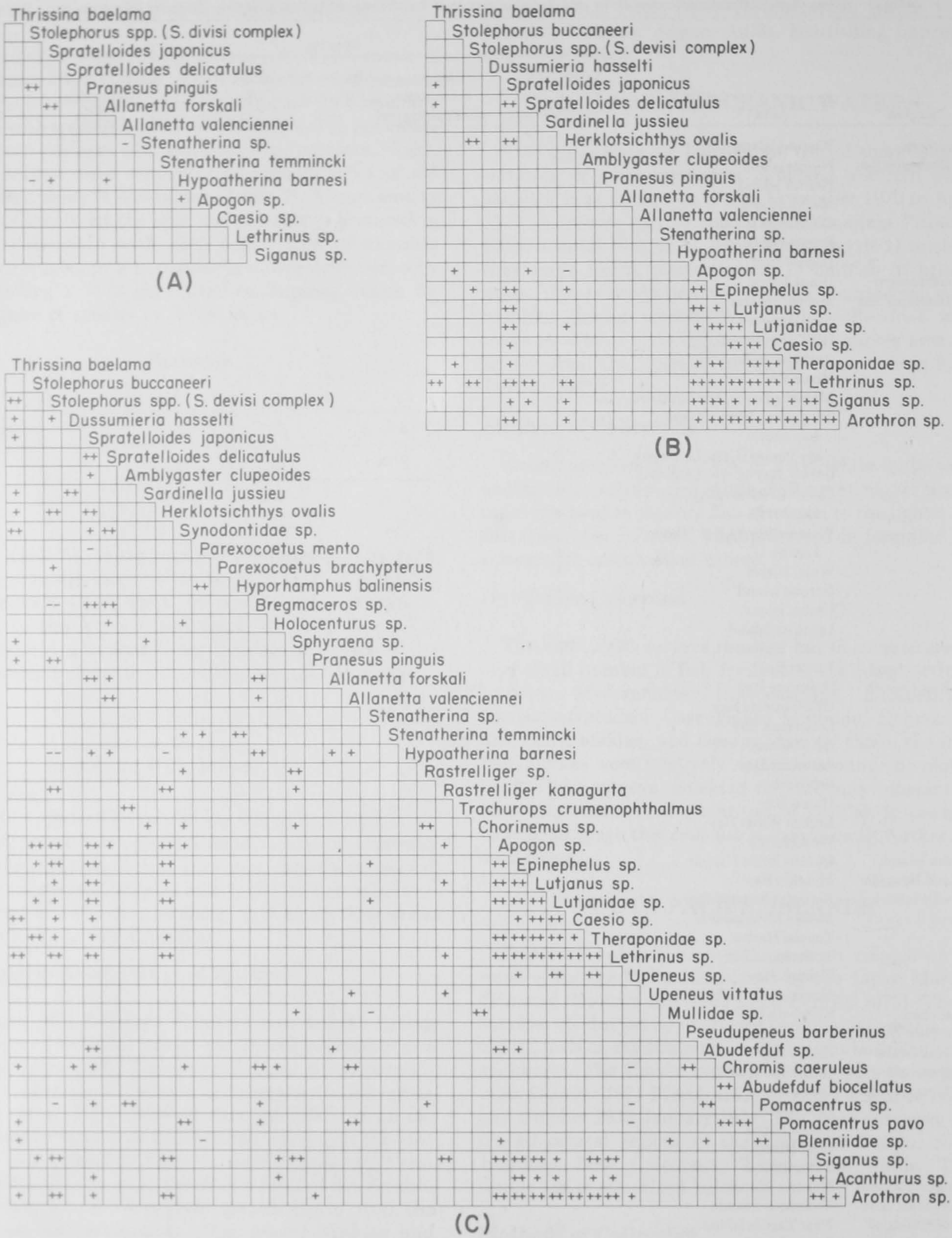

Figure 1.—Species relationships as determined by chi-square matrices showing positive and negative species relationships for three different areas. A. Lagoon areas with distinct submerged reef (for 14 species which occurred 3 or more times out of a total of 15 stick-held lift net trials). B. Passages, shore zones, and bays with fringing reef (for 23 species wich occurred 3 or more times out of a total of 35 stick-held lift net trials). C. Throughout the Papua New Guinea area (for 46 species which occurred 7 or more times out of the cumulative total of 57 stick-held lift net trials). + = $0.05 \geq P > 0.01$, ++ = $P \leq 0.01$.

Table 3.—Regional occurrence of fishes of four principal families (night-lighting on the *Shunyo Maru* cruises, 1968-70). Numerals 1-3 denote degree of abundance of fish (1—few, 2—moderate, 3—abundant) in stick-held lift net and dip net collections.

Species	Area[1]							
	a	b	c	d	e	f	g	h
Sardinella jussieu				3	2	1		1
S. perforata			2					
S. melanura		1		1				
S. sirm				1				
Amblygaster clupeoides		2		2	2	1		
Herklotsichthys ovalis	1	1	3	2				
Pellona ditchela			2	2				
Dussumieria hasselti	1	1	1	2		2		1
Spratelloides japonicus	1	1	1	1	1	2	3	
S. delicatulus	1	2	2	3	2	2	2	1
Stolephorus devisi complex	1	3	3	3		1		2
S. indicus				1				
S. buccaneeri		2	1	1				1
S. bataviensis			1					1
Thrissina baelama	1	3	1	1	1			
Allanetta forskali	2	2	1	1	1		3	1
A. valenciennei		2	2			2	3	1
Hypoatherina barnesi					2	3	2	1
Stenatherina temmincki		2		1	1			
Pranesus pinguis	2	1	1	3	3	1		1
P. duodecimalis				1				
P. eendrachtensis				2			1	

[1]a = northern Bismarck Sea; b = southeastern Bismarck Sea; c = north coast of mainland New Guinea; d = Buka Island and Bougainville Island; e = east coast of New Ireland Island; f = eastern off-lying islands of New Ireland Island; g = Nuguria Islands; h = southeast coast of mainland New Guinea.

The two-boat purse seine and lift net were employed at night in combination with fish-luring lamps.

Baitfishes Collected

Nauru Island.—Only small numbers of squids, halfbeaks, and flyingfishes were attracted to the light. The nearshore submerged banks provide this island with a limited shallow coastal zone. Distribution of baitfish in this zone was not determined.

New Hebrides Islands.—The following groups were collected: Engraulidae, Dussumieriidae, Clupeidae, Atherinidae, Carangidae, Scombridae, and Siganidae. Of these, *Sardinella perforata* was dominant. *Sardinella melanura, Herklotsichthys ovalis,* and *Stolephorus devisi* were taken in small quantities. Baitfish for tuna fishing were considered relatively scarce throughout the areas surveyed.

New Caledonia Islands.—The following were collected: Engraulidae, Dussumieriidae, Clupeidae, Atherinidae, Leiognathidae, Caesiodidae, Carangidae, Scombridae, and Siganidae. *Herklotsichthys ovalis* was the dominant species in the catch, followed by *Sardinella perforata.*

Table 4.—Relative abundance of baitfishes in Papua New Guinea by type of area. Numerals denote numbers of stations having the various densities of baitfish attracted to night-light (cumulative results from all cruises of the *Shunyo Maru*, 1968-70).

Area type	Density of baitfishes attracted to lights[1]				
	1	2	3	4	5
Lagoon areas with distinct submerged reef		6	2	7	2
Passages or shore zones with fringing reef	1	1	4	2	
Bays with fringing reef	1	8	16	4	
Outside reef, 100-1,000 m in depth	3	1	1		
Offshore waters, deeper than 1,000 m	3	1			

[1]1—no baitfish in evidence; 2—very few fish; 3—small schools of baitfish; 4—large and dense schools of fish; 5—very large and massive concentration.

Tonga Island.—Fishes collected included members of Dussumieriidae, Clupeidae, Atherinidae, and Mugilidae. The dominant species belonged to Atherinidae. *Herklotsichthys ovalis* was relatively common. No engraulids occurred here.

As indicated above, the most important tuna baitfishes available in this part of the Pacific appear to be the herrings, *Sardinella perforata* and *Herklotsichthys ovalis*. This is in contrast to the Bismarck Sea region where the most important species are anchovies and sprats, represented by *Stolephorus devisi, Spratelloides japonicus*, and *S. delicatulus*, followed by herring. Taking into consideration the very large variety of possible baitfishes and their relatively small biomass, typical of the tropics, baitfishing in the South Pacific islands will eventually depend upon use of a large variety of fish and not on the abundance of any particular bait species.

ACKNOWLEDGMENTS

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Distribution and Abundance of Baitfish Resources In Papua New Guinea Waters

A. D. LEWIS[1]

ABSTRACT

Examination of a large number of representative samples from lift net hauls showed two species of *Stolephorus, S. devisi* and *S. heterolobus*, to be the major component of the baitfish resource. Habitat preferences of the more important species are considered, and basic features of the commercial bait fishery drawn. Stocks are considered to be underexploited at present, particularly in the numerous smaller baiting areas. It is felt, however, that attempts to improve handling and increase bait survival, thus more fully utilizing present catches, should precede expansion into new areas.

INTRODUCTION

Dependence of the Papua New Guinea fishery for skipjack tuna, *Katsuwonus pelamis* (Linnaeus), on local bait resources is complete. To date, little trouble has been experienced in obtaining adequate bait supplies, and in the space of 4 yr, the annual tuna catch has grown to 28,000 metric tons (1973). Baiting activities of the joint-venture companies have been confined to a few areas only, and it has not been clear how the resource was distributed over the wider area of Papua New Guinea. Some understanding had, however, been gained of the species composition of the stocks (Far Seas Fisheries Research Laboratory 1969; Kearney et al. 1972).

In response to the need for an appraisal of the bait fishery, this paper examines, on the basis of data currently available, the importance of particular species to the fishery, their distribution, geographically and by habitat, and fluctuations in catches during 1972-73. Courses of future development for the bait fishery are discussed in the light of these findings.

SOURCES OF DATA

Apart from a brief period of dependence on drive-in nets in the early stages of the fishery, the use of stick-held lift nets (bōuke ami) and night lights for bait collection has been, and continues to be, universal. Limited trials with a lampara net in night-baiting operations were not successful for several reasons, and resort has not been made to daylight operations involving purse or beach seines. As a result, the basis of this assessment is a large collection of representative samples from lift net hauls during the years 1971-73. These samples have been obtained from several sources.

1. Research cruises of the 20-m RV *Tagula*, commissioned in mid-1971 to investigate stocks of surface-schooling tunas and baitfish in Papua New Guinea waters, have provided the bulk of information on species distribution, as well as valuable data on species abundance. At each bait station, emphasis was placed on correct identification of all species taken, accurate assessment of numerical representation by species in the haul (see Kearney et al. 1972 for discussion of why numbers were preferred to biomass), weight of the haul, and collection of basic environmental data.
2. Smaller vessels, deployed by the Kanudi Fisheries Research Station, have systematically sampled sites in the Port Moresby area in an investigation of the biology of one species, *Stolephorus devisi*.
3. Detailed catch statistics, in which daily bait catches per boat (buckets) and some environmental data are listed, are obtained routinely from the joint-venture companies. For an 18-mo period the companies were also required to supply, at fortnightly intervals, a random scoop of bait (approximately 200 g) from a haul in the baiting area currently being fished.

In all, data are available for 81 anchorages, with sampling intensity varying widely. From 1 site, over 50 samples were collected, whereas 36 sites have provided 1 sample only, and 13 sites 2 samples. For each locality, a dominant species or species combination has been recognized on the basis of available samples. Whilst there are obvious dangers in assigned dominance where available data are limited, there is a general constancy in species composition at localities, and it is not expected that collection of additional data would substantially change the interpretation presented.

RESULTS

Distribution of the Resource

Figure 1 shows the location of all sites investigated. Those areas where at least one haul has yielded over 40 kg (normally more) of usable live bait or, alternatively,

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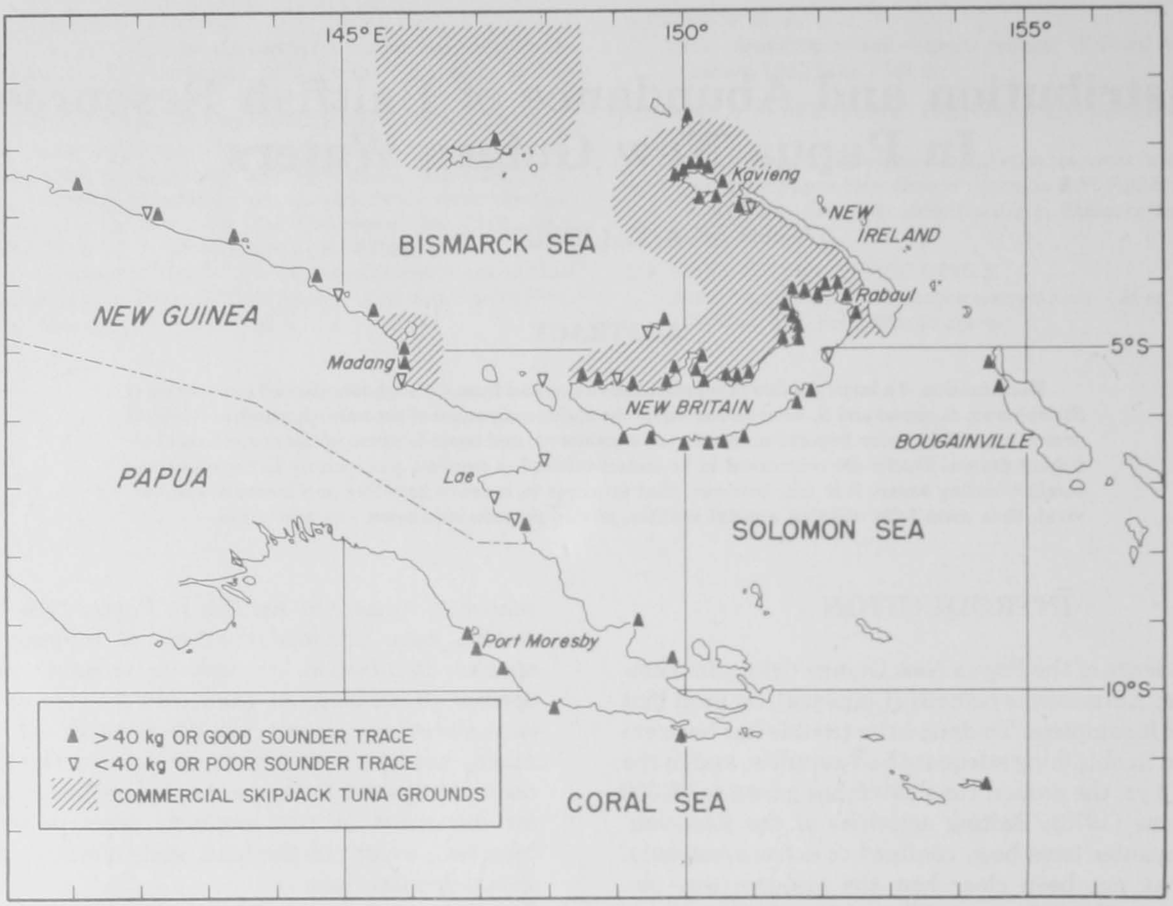

Figure 1.—Location of baitfish sites investigated in Papua New Guinea waters.

where echo sounder indications have been favorable, are indicated by a solid symbol. Approximate limits of the main skipjack tuna fishing areas are shown by stippled areas.

Although the survey of baitfish resources was intended to give as wide a coverage of the coastline as possible, many gaps between sites are evident, and this is attributable to several factors. Long stretches of coastline are steep-to and virtually devoid of all-weather anchorages (e.g., most of the New Ireland coast; the coastline between Lae and Madang). Other gaps are attributable to the lower priority accorded surveying areas distant from the present skipjack tuna fishery, which is centered on the Bismarck Sea. Bougainville Island and much of the Papuan coast are examples of such areas.

Very few sites (9 of 81) appeared to offer little or no potential, and promising bait areas were the rule rather than the exception, allowing that sites were selected rather than chosen at random. The spread of favorable baiting areas is wide (Fig. 1) and almost any point in Papua New Guinea waters is within daily cruising range of at least one of these areas, with others yet to be investigated.

Relative Species Abundance

Over 300 species have been taken by lift netting, although fewer than a third of these have been captured more than a few times, and only about 50 species were regularly taken. Fewer than 20 species feature in patterns of numerical dominance.

The number of sites dominated by each species or species combination is listed in Table 1. Although 81 sites were surveyed, hauls were not made at 9 of these because of discouraging echo sounder indications nor at 7 others for a variety of reasons, even though indications were good. Hence 65 sites are represented in the table.

The prime importance of the anchovies, Engraulidae, and in particular the stolephorids, is clearly demonstrated. Two similar species, *Stolephorus devisi* and *S. heterolobus*, grouped because their separate identities were not distinguished in some early hauls, compose the nucleus of the bait resource. Together, they figure in the dominance pattern at over two-thirds of the 65 sites. Only two other members of the family are of real importance: *S. buccaneeri*, roundhead anchovy, proved abundant on occasions and provided the largest single catch yet taken by the RV *Tagula*; and *Thrissina baelama*, little priest, was the only nonstolephorid anchovy of the many occurring in these waters to dominate hauls.

The sprats, Dussumieriidae, ranked next in abundance, with two species—*Spratelloides gracilis*, silver sprat, and *S. delicatulus*, blue sprat—of some importance. *Herklotsichthys punctatus* (Clupeidae), the goldspot herring, and *Gymnocaesio gymnopterus* (Lut-

Table 1.—Observed patterns of numerical dominance of baitfish species in Papua New Guinea waters. (Bracketed figures following family names are the number of sites at which that family figures in the dominance pattern.)

	No. of sites
Engraulidae [53]	
Stolephorus devisi / S. heterolobus	34
Stolephorus buccaneeri	4
Stolephorus devisi and *S. bataviensis*	2
Several *Stolephorus* spp.	2
Stolephorus devisi and *Spratelloides gracilis*	2
Stolephorus devisi and *Herklotsichthys punctatus*	2
Stolephorus devisi and *Sphyraenella flavicauda*	1
Total containing stolephorids	47
Thrissina baelama	4
Thrissina baelama and *Spratelloides delicatulus*	2
Dussumieriidae [8]	
Spratelloides gracilis	2
Spratelloides delicatulus	1
Spratelloides gracilis and *Gymnocaesio gymnopterus*	1
Clupeidae [5]	
Herklotsichthys punctatus	2
Other Species	
Gymnocaesio gymnopterus	1
Rastrelliger kanagurta	1
Rastrelliger kanagurta and *Sardinella* spp.	1
Hypoatherina barnesi	1
Small hauls with several species codominant	2
No. of sites represented	65

janidae), red bait, made minor contributions to the dominance listings.

There are, however, numerous other species which, although they rarely dominate sampling sites and only occasionally dominate individual hauls, nevertheless make regular and useful contributions to catches and should not be dismissed as unimportant. Their presence helps to dampen fluctuations in catch which inevitably occur in fisheries dependent on the presence or absence of shoaling pelagic species. These include the following:

Stolephorus bataviensis, S. indicus
Rastrelliger kanagurta
Dussumieria acuta
Selar boops, S. crumenophthalmus
Selaroides leptolepis
Sardinella spp.
Pellona ditchela
Rhabdamia cypselurus
Various atherinids
Pterocaesio pisang and *Dipterygonotus leucogrammicus*
Gazza minuta and *Secutor* spp.
Sphyraenella spp.

Distribution of the Major Species

The major species *Stolephorus devisi, S. heterolobus, S. buccaneeri, Spratelloides delicatulus, S. gracilis, Herklotsichthys punctatus*, and *Thrissina baelama* were found to be widely distributed throughout Papua New Guinea waters, although *S. gracilis* and *Stolephorus buccaneeri* were taken from fewer sites than the others.

Of more interest than their geographical distribution is the type of habitat regularly occupied by these species and the nature of any observed differences. A species' habitat preference is governed by a complex series of factors and only for a few species has it been possible to gain some understanding of factors involved. Most available information pertains to the most abundant group, the stolephorids, where significant though not clear-cut differences in habitat have been observed.

The close similarity between *Stolephorus devisi* and *S. heterolobus* extends beyond morphology, as their habitat is very similar. Proximity to stream discharge and extensive areas of shallow water are typical components of this habitat. Both tend to be absent from steep-sided, deep harbors lacking the above traits. Waters of markedly low salinity are avoided; although as very few stations have been located in waters below 30°/₀₀ salinity, it is difficult to fix a lower limit to this. It is interesting that whilst the requirements of both species appear to include contiguity to areas of reduced salinity and increased turbidity, the effect of these factors exceeding a certain level is adverse. *Stolephorus devisi* was taken at more sites than *S. heterolobus* and was more likely to be taken in waters of reduced salinity. Conversely, areas where *S. heterolobus* was found in the absence of its congener tended to have higher salinity and clear water. Hardenberg (1934) noted that his *S. pseudoheterolobus* (= *heterolobus*) is less common in Indonesia than his *S. heterolobus* (similar to *S. devisi*) and is caught "further in sea."

The habitat of *S. buccaneeri* is decidedly more oceanic than that of the previous species. Hida (1973) has recorded the species up to 700 miles distant from the nearest land. It was the only stolephorid found in pelagic fish stomachs examined by him over wide areas of the Pacific and has been the most common stolephorid in stomachs of pelagic fish examined in Papua New Guinea waters (unpublished data). *Stolephorus buccaneeri* does enter deepwater harbors, although its occurrence is more irregular than that of *S. devisi* and *S. heterolobus*, and catches of the species tend to be either rather large (up to 500 kg) or quite small. All specimens of *S. zollingeri* (= *buccaneeri*) examined by Hardenberg (1934) similarly came from steeply shelving coastlines.

Thrissina baelama proved to be a common species throughout, but dominated hauls only in habitats from which *S. devisi* and *S. heterolobus* were virtually absent. These were typically deep-sided harbors or small anchorages on outlying islands.

The absence of anchovy species typically associated with estuarine conditions, e.g., *Stolephorus tri, Thryssa* spp., and *Scutengraulis* spp., reflects avoidance of turbid waters during baiting operations.

Analysis of all environmental and biological data collected at each station in an attempt to understand habitat preference has not been attempted. Table 2, however, seems to implicate salinity as one of the many factors determining distribution. All reliable salinity

Table 2.—Salinities associated with baitfish species occurrences in hauls.

Species	Surface salinity range (°/₀₀)	Mean (°/₀₀)	No. of observations
Stolephorus devisi without *S. heterolobus*	22.4-36.5	34.0	14
Stolephorus devisi and *S. heterolobus*	28.2-36.8	34.5	50
Stolephorus heterolobus without *S. devisi*	35.4-36.5	35.7	9
Stolephorus buccaneeri	34.6-35.9	35.5	14
Thrissina baelama	28.2-36.5	34.5	39

data (surface only) have been used and, although inconclusive, support subjective observations on habitat preference. Note particularly the restriction of *Stolephorus buccaneeri* to waters of high salinity and the presence of *S. devisi* in low salinity water.

Tham (1953) recorded a range of salinities associated with *S. heterolobus* of 26-32°/₀₀, higher salinities apparently being uncommon in the area studied, and found a close relationship between precipitation, salinity, phosphate content, phytoplankton and zooplankton abundance, and stolephorid abundance.

Less is known of the habitat preferences of other species. Both blue and silver sprats appear to favor situations with clear saline water, particularly near reefs. *Spratelloides gracilis* was previously of considerable importance to the drive-in fishery at Kavieng. *Herklotsichthys punctatus* resembles *Thrissina baelama* in that it occurs in a wide range of habitats but dominates hauls only in situations that appear to represent a marginal habitat for *Stolephorus devisi* and *S. heterolobus*.

As more information becomes available, the predictive value of distributional data should increase, a decided advantage if some species prove more attractive as bait, or easier to handle than others (Smith 1977).

THE COMMERCIAL FISHERY

Areas available to joint-venture fleets have been subject to restrictions from the outset. On commencing operations, companies were asked to submit a list of anchorages sought for baiting purposes. Access to these was granted or denied after claims to traditional fishing rights by indigenous fishermen had been examined. Certain of these areas have since proved to be among the best available in Papua New Guinea and have been fished continuously since operations began in 1970 (one company) and 1971 (two companies). Figure 2 shows the locations of these major areas (large circles), other areas used with some regularity (smaller circles), and areas used occasionally (dots).

Analysis of 77 bait samples supplied by the companies and assumed to be representative of the catch at that time, reveals that, as expected, *S. devisi/S. heterolobus* dominate catches at each of the major sites (Table 3).

Apart from differences in composition of the catch in the major areas, there are also differences in magnitude of the catch and reliability of supply, with the Madang-Sek fishery being the least stable. In addition to exploiting the only large harbor along hundreds of miles of steeply shelving coastline, the Madang-Sek fishery is heavily dependent on *S. devisi/S. heterolobus* catches alone. With considerable runoff from many streams emptying into the area, catches of these two species are often adversely affected. In recent times, greater use has thus been made of an alternative site in West New Britain. By contrast, the Cape Lambert and Ysabel Pass fisheries rely to some extent on other species, particularly in the latter area where *Spratelloides gracilis* rivals the anchovies in importance. This broader base of supply confers a greater degree of stability on the bait fishery as does the proximity of other baiting areas, compared to Madang-Sek.

Figure 3 graphs the average bait catch per day (buckets) on a monthly basis for the years 1972-73. Figures for companies C and D, which alternated between several areas, are included for interest only. The figures are not always a true index of bait abundance, as increased effort often accompanies increased availability of skipjack tuna (Kearney 1977), but they give some idea of the continuity of supply and the absence of wild fluctuations, particularly at Cape Lambert and Ysabel Pass. This has been a major factor in the rapid expansion of the fishery.

The monthly means mask daily variation in bait catch that is important to individual vessels. The main influence here is lunar (Kearney 1977). Against this background of lunar influence are less predictable sources of variation, which include influxes of turbid water, unfavorable weather, and predator influence on bait catchability.

Table 3.—Patterns of species dominance in company bait samples.

Species	Area: Cape Lambert	Ysabel Pass	Madang-Sek	Other areas	Total
Stolephorus devisi / S. heterolobus	14	11	8	10	43
Stolephorus buccaneeri	3	—	—	1	4
Spratelloides gracilis	—	5	—	1	6
Stolephorus devisi and *Spratelloides gracilis*	—	8	—	—	8
Stolephorus devisi and others	2	—	—	2	4
Others	4	2	4	2	12
Total	23	26	12	16	77

DISCUSSION

Previous opinions as to the importance of stolephorids (Far Seas Fisheries Research Laboratory 1969; Kearney et al. 1972) have been confirmed by the results of this more comprehensive work, and parallels can be readily found in other fisheries. *Stolephorus heterolobus* is the mainstay of the Palau bait fishery (Uchida 1970; Wilson 1972), and *S. purpureus* accounts for 93% of the bait

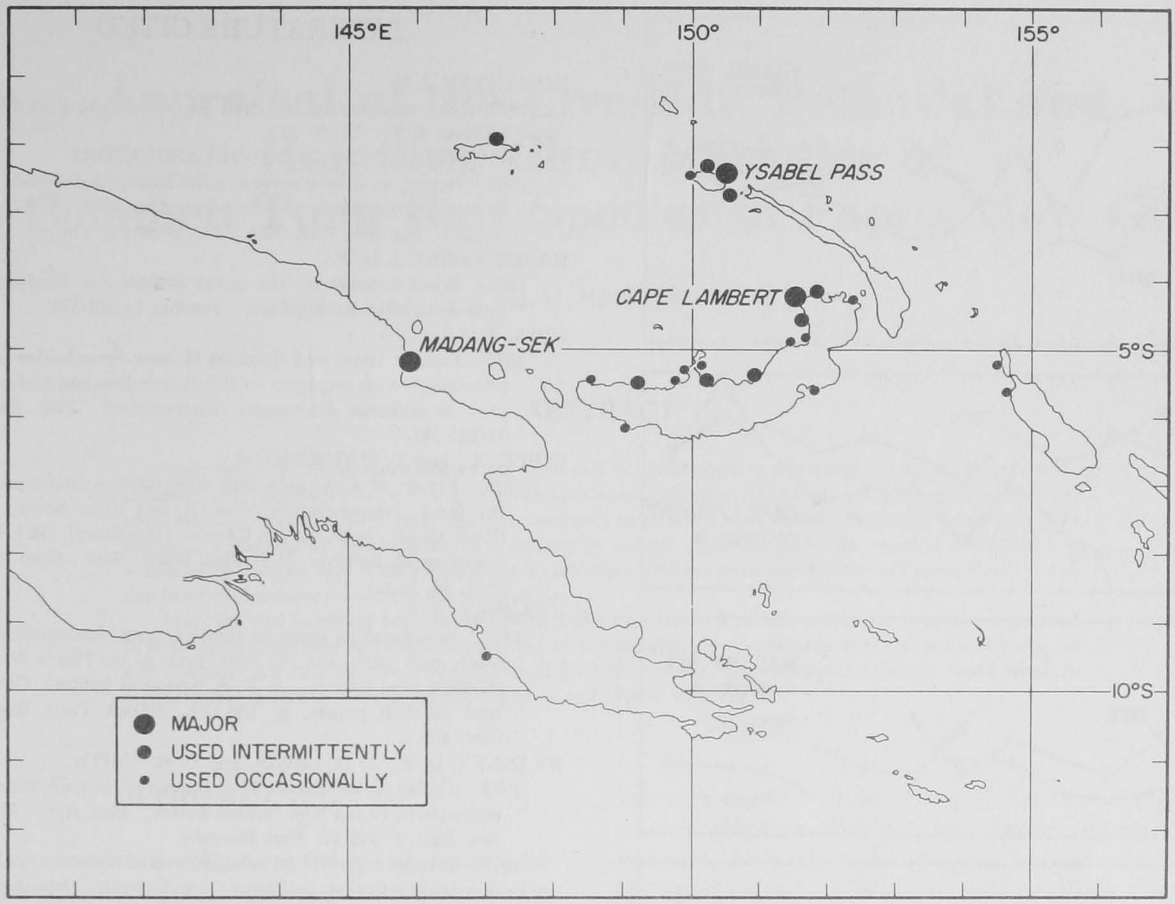

Figure 2.—Baiting areas used by the joint venture fleets in Papua New Guinea waters.

catch in Hawaii (Uchida and Sumida 1971). The Japanese and eastern Pacific live-bait fisheries rely principally on the anchovies, *Engraulis japonicus* and *Cetengraulis mysticetus*, respectively.

Within the genus, the predominance of *Stolephorus devisi* and *S. heterolobus* finds equivalents in the Philippine anchovy fishery where the contribution of *S. heterolobus*-like anchovies to monthly samples of the catch ranged between 42% and 96% (Tiews et al. 1970), and in the fishery of Singapore and the east coast of West Malaysia, where *S. heterolobus*-like anchovies make up about 90% of the catch (Tham 1974).

Little is known of *S. buccaneeri* and *Thrissina baelama* catches elsewhere. Both contribute to the Fijian bait fishery (Lee 1973), and Tiews et al. (1970) reported that *S. buccaneeri* made up between 1% and 22% of the Philippine anchovy catch samples during the years 1957-58.

Other species of some importance to the Papua New Guinea fishery, or closely related forms, are variously important in other fisheries or areas: *Spratelloides delicatulus* in the prewar Saipan fishery (Ikebe and Matsumoto 1938), Palau (Wilson 1972); *Herklotsichthys punctatus* in the Fiji beach seine catch (Lee 1973), the Marshall Islands (Uchida and Sumida 1973), Palau (Wilson 1972); *Sardinella* spp. in Zamboanga and Davao (Domantay 1940); *Pranesus pinguis* in the Fiji beach seine catch (Lee 1973), Palau (Wilson 1972); and *Gymnocaesio argenteus* in the Truk drive-in fishery (Wilson 1971).

Although the present study examined only one aspect of the resource, viz. species attracted to lights and vulnerable to capture by dip net, results show the bait fishery in Papua New Guinea to be well served by it in terms of both abundance and stability of supply, and there has been no need to resort to other types of baiting operation. These also may have considerable potential. Catches of *Herklotsichthys punctatus* and *Selar* spp. exceeding 500 kg have been taken not infrequently in beach seine hauls. The use of drive-in nets has already been mentioned, and many areas appear eminently suited to this method, which has the disadvantage of being rather labor-intensive.

The fleets, with their mother ship type of operation, require at present relatively extensive baiting areas that can accommodate and consistently provide good catches for up to 15 vessels. Areas currently in use continue to provide catches of an acceptable level, free from marked fluctuations. Further, the RV *Tagula* has surveyed many smaller anchorages in which a long-range vessel, equipped with its own refrigeration facilities and thus freed from the need to unload daily, could consistently obtain adequate supplies of bait and add to the flexibility of its operations. Good concentrations of skipjack and yellowfin tunas are known to occur at times in areas not

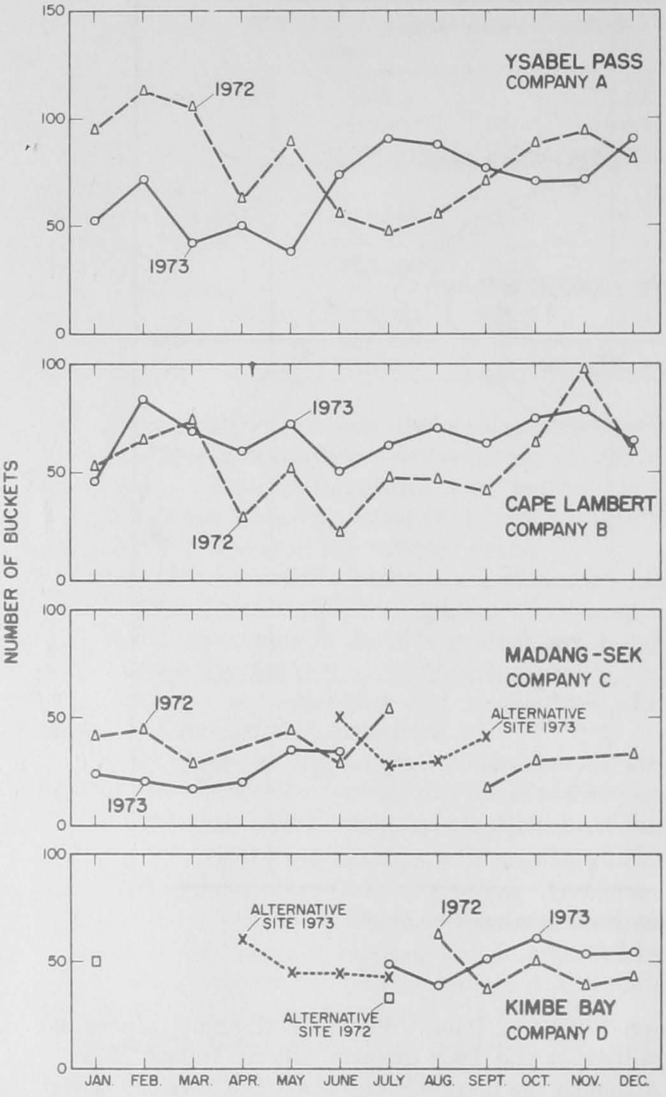

Figure 3.—Average daily bait catch by month for the major areas in Papua New Guinea waters.

presently fished (Kearney et al. 1973 and unpublished data), but lack of nearby fleet anchorages has impeded their utilization. Smaller anchorages are numerous on adjacent coasts, however, and could be used as bases for long-range vessels operating in these areas.

As stocks of schooling pelagic species appear to be more susceptible to drastic and sometimes permanent reductions in abundance than do other fish stocks, any large scale expansion of the present bait fishery would be viewed with concern until the population dynamics of the stocks have been adequately studied. Because of difficulties associated with the delicate nature of many bait species, heavy losses during handling, and short survival time in bait tanks, even present catches are not fully utilized by the fishery. Hence, efforts to improve this situation, which could also help to free vessels from their present rather rigid day-to-day mode of operations, would seem to be preferable to expansion into new baiting areas. A companion paper examines possible avenues of improvement, with some encouraging results.

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Appraisal of the Live-Bait Potential and Handling Characteristics of the Common Tuna Bait Species in Papua New Guinea

B. R. SMITH[1]

ABSTRACT

The desirable characteristics of an "attractive" bait species for skipjack tuna, *Katsuwonus pelamis*, are considered to be 1) highly reflective lateral surface, 2) surface swimming with rapid erratic motion, 3) size of 60-80 mm, and 4) a tendency to return to the vessel after being broadcast. The value of a particular bait species to a fishery is further determined by its relative abundance or availability and the ease with which it can be handled. The common bait species of Papua New Guinea are briefly discussed using the above criteria.

More careful handling techniques and in particular daylight loading of the bait catch were found to substantially reduce initial bait mortality, with dramatic improvement in survival rates of juveniles and the more delicate species. Adoption of these techniques by the commercial fishery could result in considerable benefits both to industry and to individual fishermen.

INTRODUCTION

Until successful development of purse seine techniques suitable for tropical waters, pole-and-line fishing with live bait will continue to be the principal method of harvesting skipjack tuna, *Katsuwonus pelamis*, in the central and west Pacific. Effectiveness of this method has been limited in some areas by the delicate nature of the bait species available or poor supplies of bait. In Papua New Guinea, where the skipjack tuna fishery has undergone rapid expansion since 1970, the baitfish resource is considerable and not yet fully exploited (Lewis 1977). Heavy bait losses during capture and handling, and the limited survival time in the bait tanks, have, however, proved a serious problem. High bait mortality rates represent a considerable waste of a valuable resource and limit the skipjack tuna catch well short of its true potential by effectively reducing the fishing power of individual catcher boats.

This paper assesses the importance of the major bait species in terms of their "attractiveness" as live bait for skipjack tuna. Underlying causes of bait mortality are examined and techniques developed to alleviate this problem are outlined. Implications of improved bait survival to the commercial fishery are discussed.

METHODS AND SOURCES OF MATERIAL

This report is largely based on experimental baiting and fishing operations conducted during cruises of the 60-ft RV *Tagula*, from her commissioning as a tuna research vessel in June 1971 until December 1973. On all cruises, skipjack tuna tagging took priority over baitfish research. As a result, little quantification or experimental analysis of bait behavior and handling characteristics was possible, and the majority of the observations presented are subjective and qualitative in nature. Bait rearing and holding experiments under laboratory conditions were conducted at Kanudi Research Station.

A full description of all methods and procedures involved in experimental baiting and fishing operations is presented elsewhere (Kearney et al. 1972). Where it is thought necessary to highlight different methods or techniques, they are described in the text.

OBSERVATIONS ON BAIT SPECIES

Definitions of a Good Bait Species

The basic requirement of a good bait species is the ability to attract and concentrate skipjack tuna at the stern of the fishing vessel and to produce good catch rates. If, in addition, the attractive species is robust and occurs in abundance, its practical value as a live-bait species is greatly enhanced (Iversen 1971). These desirable attributes are discussed in more detail below.

Species Attractiveness.—The catch rate during pole-and-line fishing operations is directly related to the intensity of the feeding activity, or "feeding frenzy" elicited by the bait species. The relative ability to induce and maintain this feeding activity is termed "species attractiveness."

The varying response of skipjack tuna schools to different bait species has been previously studied (Yuen 1959, 1969; Strasburg 1961; Shomura 1964; Iversen 1971),

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but the factors contributing to species attractiveness are less well known. Experience gained during the present field studies suggests that the following characteristics are important in a good bait species:

1. Silver coloration or highly reflective surface—this presumably offers a stronger visual stimulus.
2. Surface swimming with rapid erratic movements.
3. Size—optimum bait size for the skipjack tuna encountered in Papua New Guinea waters (usual range 50-60 cm) is thought to be 60-80 mm. The silver-headed feather "squid" or lure used by the fishermen is jiggled up and down in the water to imitate the swimming action of live bait. Its effectiveness depends on how closely it resembles the physical and behavioral characteristics of the bait species being used (Yuen 1969). Larger bait species (>120 mm) usually produce a lower catch rate, possibly because of the disparity between size of the bait and the "squid."
4. Tendency to return to the vessel after being broadcast.

This list, which is by no means complete, supports the conclusions of earlier work (Yuen 1959; FAO 1969:77) and serves as a convenient guide when comparing the relative attractiveness of different species.

Bait hardiness.—This is the relative ability to survive capture and transport to the fishing ground. Tropical bait species, in general, are smaller and less robust than their counterparts in more temperate areas, but with improved techniques, handling and keeping qualities of even delicate species can be improved dramatically. Sources of bait mortality and techniques developed to alleviate this problem are discussed under bait handling.

Abundance and availability to the fishery.—The potential value to the fishery of a desirable bait species is limited by its abundance and geographical distribution in relation to the major fishing grounds. Lewis (1977), in his analysis of Papua New Guinea baitfish resources, defined the major baitfish species in terms of their relative abundance and overall contribution to the fishery. The more important species belong to the families Engraulidae (*Stolephorus heterolobus, S. devisi, S. buccaneeri*, and *Thrissina baelama*), Dussumieriidae (*Spratelloides gracilis* and *S. delicatulus*), Clupeidae (*Herklotsichthys punctatus*), and Caesiodidae (*Gymnocaesio gymnopterus*). The bulk of the observations cited in this report pertain to these species.

Live-Bait Potential of the Major Species

The live-bait characteristics of the major baitfish families and species are briefly summarized and, where possible, supplemented with information from other areas. Species of minor importance are mentioned where of interest.

Family Engraulidae (anchovies)

This diverse group dominates skipjack tuna live-bait fisheries throughout the Pacific, with two stolephorids, *Stolephorus devisi* and *S. heterolobus*, unrivalled in importance in Papua New Guinea. Both species are excellent baitfish and are highly regarded by the fishermen. They are very active swimmers with a tendency to return to the stern of the vessel when broadcast, forming dense aggregations between the stern and the spray zone. *Stolephorus heterolobus*, with its blue coloration and more prominent lateral band, appears to be the more attractive of the two. Both species survived well in the bait tanks and have been maintained in concrete aquaria for periods up to 3 wk. Postlarvae and subadults (<40 mm) are extremely weak and can only be handled under ideal conditions. *Stolephorus heterolobus* is the dominant species taken in the night fishery in Palau and is highly prized as a bait species (Uchida 1970; Wilson 1977). Of some importance in Fiji, it is considered very delicate with survival time in the bait tanks limited to 2 days (Lee 1973).

Stolephorus buccaneeri exhibited handling and keeping qualities superior to any other stolephorid, and on one occasion was maintained with ease for a week before it was necessary to empty the bait tanks. From limited observations it appears to be slightly more attractive as chum than *S. heterolobus*, which it resembles in body coloration. The importance of this species to live-bait fisheries in other areas is small (Matsui 1963; Wilson 1977), but it makes a sizable contribution to commercial anchovy catches in Taiwan, southern Japan (Ronquillo n.d.),[2] and the Philippines (Tiews et al. 1970).

Of the remaining stolephorids (*S. indicus, S. commersoni*, and *S. bataviensis*), only the last is of any significance in the bait catch. These species, the largest of the anchovies, are readily eaten by skipjack tuna, but have proved difficult to handle without prohibitive mortality rates. Lee (1973) reported good results when using *S. indicus* and *S. commersoni* as baitfish, but experienced similar handling problems.

Of the anchovies, only *Thrissina baelama* could be called robust. Carrying capacity of the bait tanks was considerably increased with this species, which can be maintained with ease for lengthy periods. Its potential will be fully realized when utilized by extended or long-range pole boats where bait hardiness is of prime importance. Its value as a bait species is of some doubt, however, because of the tendency to swim rapidly away from the boat. Attempts to counteract this by squeezing the head before broadcasting were only moderately successful.

In Fiji, *T. baelama* constitutes up to 19% of the day seine catch and is classed as a moderately hardy species, with a limited survival time in bait tanks (Lee 1973).

[2]Ronquillo, I. A. Undated. An illustrated key to the genus *Stolephorus*, 2 p. [and] A review of the genus *Stolephorus*, with a key to species, 31 p. Manuscripts on file at Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

This possibly reflects the difference between day and night baiting techniques.

Family Dussumieriidae (sprats, round herrings)

Sprats rank second to anchovies in terms of overall abundance and contribution to the fishery. *Spratelloides gracilis* and *S. delicatulus*, with their brilliant coloration and rapid darting swimming action, are very attractive and proved to be excellent bait. *Spratelloides gracilis* is considered by many Okinawan fishermen to be superior to anchovies as chum. These species were previously considered to be very delicate (Kearney et al. 1972) but they can now be loaded with negligible initial mortality. Heavy losses in the bait tank following crowding for chumming purposes is still a problem, particularly with *S. gracilis*. As with the anchovies, juveniles are weaker than adults and appear less effective as chum. Both species figure prominently in baitfish catches taken at night in Fiji (Lee 1973) and in day bait catches in the Truk Islands (Wilson 1971). In both areas they are regarded as good bait whose desirability is greatly reduced by poor survival characteristics.

Dussumieria acuta, a desirable bait species in most respects, has proved impossible to handle without severe losses.

Family Clupeidae (sardines, herrings)

The widely distributed sardine *Herklotsichthys punctatus* has been the only clupeid to contribute significantly to bait catches. It seemed of moderate attractiveness to skipjack tuna, but a tendency to swim away from the vessel detracted from its overall effectiveness as chum. A very robust species, it handled well and survived for lengthy periods in the bait tanks. It has been held in aquaria on two occasions for 16 and 20 days, respectively. In the daytime, it forms dense schools in shallow inshore waters and is particularly vulnerable to purse or beach seines. It is less susceptible to night baiting techniques and catches do not necessarily reflect true abundance. Not unexpectedly, its importance in other areas varies with the degree of dependence on day baiting techniques. A major component of Fijian day seine catches, it is only of limited importance in night-light catches (Lee 1973). Similar experience is reported in Palau (Wilson 1977) and the Truk Islands (Wilson 1971).

Pellona ditchela proved an exception to the general rule that large fish are less effective as skipjack tuna live bait than smaller individuals. This typically large species (>100 mm) with its silver body and violent evasive swimming action, elicited a strong feeding response in skipjack tuna, with resultant improved catch rates. It is robust and easily handled, but unfortunately is rarely captured in any quantity.

Other sardines, *Sardinella* spp., appear to be fair bait species, having characteristics similar to *H. punctatus*, but were never taken in sufficient numbers to fully evaluate. *Sardinella sirm*, a major bait species in Fiji (Lee 1973), is of little importance in Papua New Guinea, although juveniles are reported by fishermen to be excellent live bait.

Family Caesiodidae (fusiliers)

Gymnocaesio gymnopterus and *Pterocaesio pisang* dominated catches in the Okinawan drive-in net fishing in New Ireland during 1970 and early 1971, but rarely occur in commercial quantities in night-light bait catches. Juveniles of both species are very robust, survive well in bait tanks, and are considered very good bait species by the fishermen. *Gymnocaesio argenteus*, regarded as the best bait species in Truk, has been held in bait tanks for up to 4 days (Wilson 1971).

Family Apogonidae (cardinalfish)

One species, *Rhabdamia cypselurus*, was widely distributed but rarely contributed significantly to the catch. Handling characteristics of this species were excelllent and it appeared quite satisfactory as chum. *Rhabdamia cypselurus* is highly prized as a bait species in the Truk Islands, primarily for its handling and keeping qualities (Wilson 1971).

Family Atherinidae (hardy heads, silversides)

Hardy heads are attracted to lights in limited numbers only and are of little importance where night baiting predominates, e.g., Palau and Papua New Guinea. Sluggish swimmers with a tendency to remain inactive when broadcast, hardy heads lack the ability to induce frenzied feeding activity in skipjack tuna schools. However, they are eaten readily when mixed with a more attractive chum species. All are very robust and easily carried for long periods in bait tanks. The slender-bodied species, *Allanetta ovalaua* and particularly *Hypoatherina barnesi* with its prominent lateral band, are more desirable baitfish than the deeper-bodied *Pranesus pinguis*. Similarly, in the Truk Islands *A. ovalaua* is preferred to *A. woodwardi*, a thick-bodied species with a wide head (Wilson 1971).

Pranesus pinguis forms large schools in inshore waters during the daytime, often in association with the sardine *Herklotsichthys punctatus*. In Truk (Wilson 1971) and Fiji (Lee 1973), *P. pinguis* is regularly taken in day bait catches, but opinions on its value as a live-bait species vary. In general, hardy heads are prized more for their excellent handling and keeping qualities than as attractive baitfish, and are used to supplement bait catches when more desirable bait species are unavailable.

Family Mullidae (goatfish)

Large schools of the pelagic blue juvenile stage common to many species of goatfish (*Upeneus* spp., *Mulloidichthys* spp.) were occasionally observed in deeper offshore waters. Although it rarely occurred in bait catches it was the dominant fish species recognized in skipjack tuna stomachs.

BAIT CAPTURE AND HANDLING

The method of bait capture on RV *Tagula*, using a stick-held lift net and light attraction, was similar to that employed in the commercial fishery with minor modifications. Instead of a single lamp suspended from a skiff, two bait attraction units were used and alternated to transfer the attracted bait mass to the opposite side of the vessel during net setting and back again into the center of the netting area prior to the haul. The size of the net (14 m × 14 m) was smaller than that used by commercial boats (20 m × 20 m). Use of a small echo sounder with the transducer (narrow beam), mounted alongside one bait attraction lamp, enabled a precise monitoring of the response of attracted bait species to changes in light intensity, presence of predators, and other factors during baiting operations.

Most species exhibit a distinctive behavior pattern when under the influence of a bait attraction light, and it was possible to recognize characteristic sounder traces for certain species or species combinations as Figure 1 illustrates. Behavioral observations on the more important bait species are summarized in Table 1. Recognition of the major components of the bait mass before hauling of the net enabled capture and handling techniques to be geared to the requirements of the bait species concerned.

Sources of Bait Mortality

Heavy bait mortalities are commonplace in the Papua New Guinea fishery, and daily losses of up to 50% have been reported, particularly in catches dominated by small anchovies (<40 mm). In Hawaii, Brock and Uchida (1968) reported daily mortalities averaging 25% for *Stolephorus purpureus*, the mainstay of the fishery. Most of the research aimed at a reduction of initial handling mortality and improved bait survival time has been directed at this species (Pritchard 1953; Brock and Takata 1955; Baldwin 1969; [U.S.] Bureau of Commercial Fisheries 1969). Practical applications of this research are summarized by Baldwin et al. (1972).

Table 1.—Observations on bait behavior in relation to bait attraction lamp.

Species	Echo sounder trace	Average depth of bait mass	Response to dimming of light	General observations
Stolephorus devisi	A fine grained trace (see Figure 1A) indicative of a relatively immobile bait mass.	Closer to surface than other stolephorids.	Very good. Will encircle dimmed bait lamp endlessly.	Under a surface lamp, schools will boil to surface, "flick" at surface and sound again at irregular intervals—thought to be feeding activity. Will school on surface under surface lamp, on occasion.
Stolephorus heterolobus	Similar to above; when both species present often get a layering effect the trace—not known if of specific nature.	Deeper than *S. devisi*.	As above.	Do not "flick" under surface lamp.
Stolephorus buccaneeri	Very distinctive zig-zag trace (see Figure 1B) indicative of a dense bait mass rising and falling in vertical profile.	Very deep.	Will rise precipitously.	Do not surface.
Thrissina baelama	No trace recognized.	Close to surface.	Difficult to control with light—bait mass very mobile.	Do not surface.
Herklotsichthys punctatus	Irregular trace—fluctuating in density and depth (see Figure 1C).	Close to surface.	Poor.	
Spratelloides delicatulus	Do not show on sounder.	At surface.	Good.	Small discrete schools which circle light continuously. Will gather under surface light in preference to underwater lamp.
Spratelloides gracilis	Fine grained trace with regular striations—the effect of schools continuously circling the light (see Figure 1D).	Near but not at surface.	Very good.	Dense schools circle in vicinity of light in a rapid erratic manner. Will congregate around underwater lamp in preference to surface lamp (cf. *S. delicatulus*).
Pranesus pinguis *Allanetta ovalaua*	Not visible on sounder.	At surface.	Fair.	All species form loose aggregations at surface which lazily circle light.

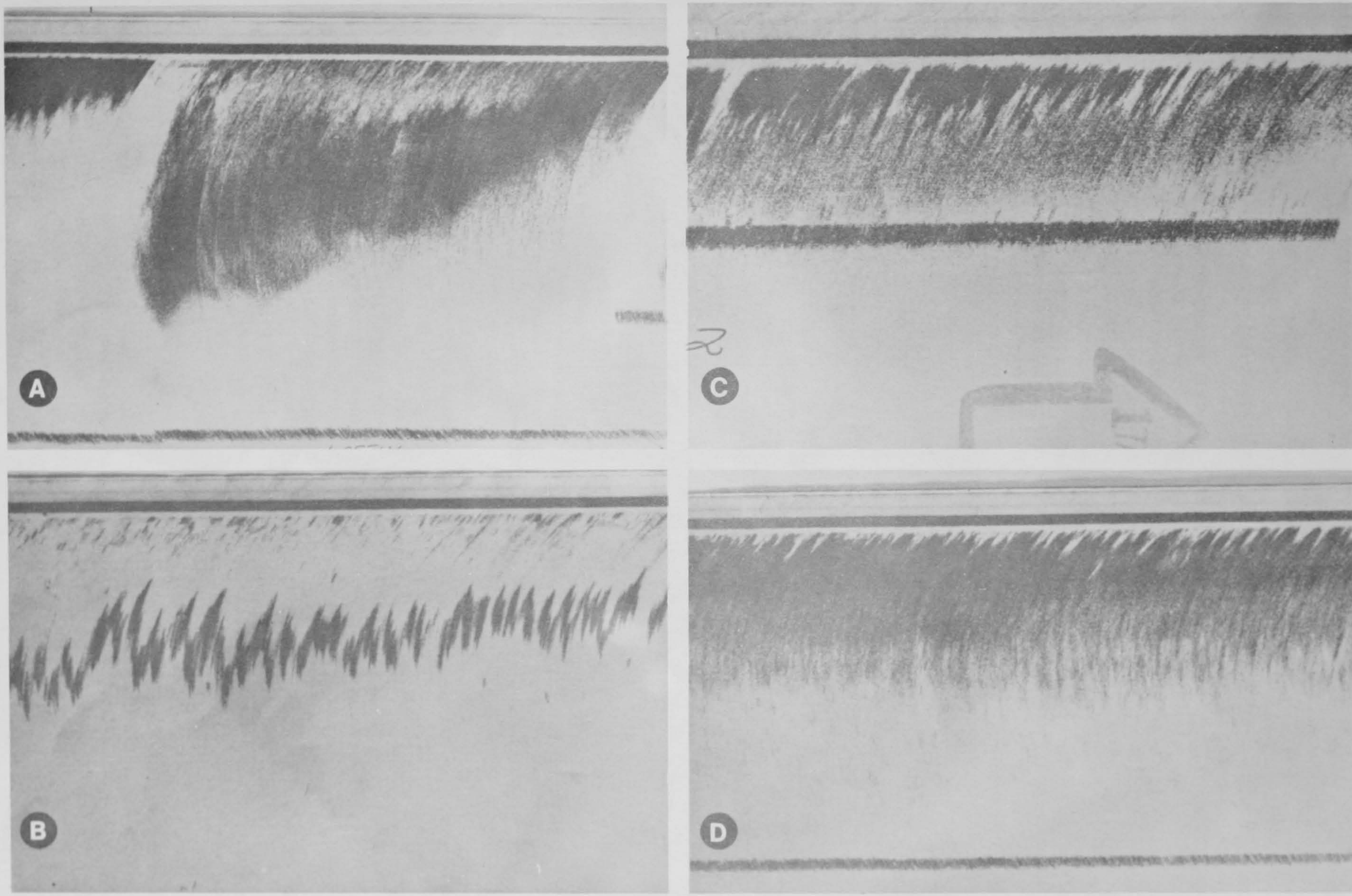

Figure 1.—Echo sounder traces of four species of baitfishes. A. Juvenile *Stolephorus devisi*—fine grained trace showing response to dimming. B. *Stolephorus buccaneeri*—characteristic zig-zag trace. C. *Herklotsichthys punctatus*—trace dense in upper layers with anchovy (*Stelephorus* spp.) below. D. *Spratelloides gracilis*—trace of bait fish concentrated in upper layers showing characteristic straitions.

The varying and unpredictable mortality of bait catches experienced during *Tagula* cruises in 1971 and early 1972 stimulated research into methods of reducing bait losses to an acceptable level. Bait mortality is attributable to many varied and complex factors, most of which proved insensitive to subjective analysis. The two main causes of death appear to be injury caused by net abrasion or contact with other individuals, with resultant scale and mucus loss; and secondly, a stress or shock reaction induced by the trauma of capture and handling. Shock rather than physical injury is implicated as the major killer. Baitfish, which are conditioned to confinement in a net or bait tank, can sustain considerable damage and scale loss without visible distress. Similar injuries if incurred during initial capture and loading invariably prove fatal. This increased resistance to injury or "hardening" following a period of minimum stress greatly reduces bait mortality during subsequent handling.

Bait Handling

The following bait handling techniques were developed and adopted with encouraging results.

In night bait loading operations, unavoidable fluctuations and abrupt changes in light intensity unsettled the baitfish and often caused precipitate flight and panic with subsequent high mortality rates. In the tank, initial bait behavior was characterized by a rapid disoriented swimming action which effectively reduced the carrying capacity of the bait tank. In an attempt to overcome these problems, daylight loading of the catch was tried. Following completion of the haul, the lift net was secured alongside the vessel and used as a bait keeper. The bait mass was left to slowly circle an underwater light, dimmed to a low intensity (60-80V), until first light. By daybreak, the catch was usually cruising up and down within the confines of the net and proved easy to crowd and load into bait tanks, where the bait quickly settled into dense slowly circling balls. Daylight loading more than any other factor contributed to the dramatic improvement in bait handling.

Crowding and bait transfer were carried out quietly and smoothly to minimize the effect of handling. Overcrowding of the catch in the bait net was avoided as this results in disruption of the orderly swimming pattern and the onset of "panic" swimming into corners and folds in the net. Bait was transferred to the bait tanks in 4-gal plastic buckets, which were filled with water, and the bait guided rather than scooped into each container. Pink or red buckets could not be used because of the marked reluctance of anchovies and other species to enter them, whereas they entered blue buckets readily, diving immediately to the bottom. Figure 2 depicts crowding and guiding of the bait into buckets during loading operations. In the bait tanks, each bucket, containing an average 0.75 kg of bait, was partly submerged and gently upended. Mortality during handling of the more delicate bait species, particularly juvenile anchovies (<40 mm) and the silver sprat, *Spratelloides gracilis*, was reduced markedly and has approached zero on many occasions.

The tendency of *Thrissina baelama* to leap when startled made normal loading procedures impossible. The fish were dry scooped into buckets containing a minimum amount of water for transfer to the bait tanks. This operation could be conducted with almost negligible mortality.

Daylight loading allows the bait to settle down and recover from the trauma of capture and confinement before being subjected to a new stress situation (i.e., crowding and loading). No longer orientating to a point source of light, the bait form more compact, slower swimming schools, and are much easier to control. The increased amount of time to load bait with a fishing vessel using these techniques is more than compensated by the dramatic improvement in bait survival rate.

Provided the bait has been handled carefully, the survival rate in the bait tanks will depend on the species carried, the quantity of bait loaded, the shape, color and general dimensions of the tank, and, most important of all, the volume and flow pattern of water circulated. The color of the internal surface of the bait tank was found to influence bait behavior. In dark blue or green bait tanks, the bait formed dense slowly circling schools, whereas, in a white tank, they displayed a reduced tendency to school and higher swimming speeds. These differences were less marked when bait was loaded during daylight. Light green or blue green are preferred colors for Hawaiian bait tanks (Baldwin et al. 1972).

Rearing and Holding Experiments

Development of techniques for holding and rearing baitfish for lengthy periods of time is a logical extension of previous research on bait mortality and improved handling techniques. The results of three preliminary experiments conducted at Kanudi Research Station have proved encouraging.

Small numbers of *S. devisi* and *S. heterolobus* have been held in concrete aquaria supplied with running seawater. Initial mortalities (i.e., within the first 24-h period) varied between 5% and 68% and reflected the method of capture (bōuke ami or lift net) and the previous history of the fish. Day seining, tried on several occasions, proved unsatisfactory for collecting live anchovy. Hawaiian scientists found similar differences between seined and trap-caught nehu ([U.S.] Bureau of Commercial Fisheries 1969). Maximum survival time varied from 16 to 29 days. Further experiments using bait pens are planned.

DISCUSSION

Lack of reliable supplies of bait has never posed a serious problem to the expanding Papua New Guinea skipjack tuna industry. Initial difficulties were largely the result of inexperience and lack of local knowledge as to the whereabouts of suitable baiting grounds. The continuity of bait supplies with the virtual absence of any marked fluctuations has been a major factor in the rapid

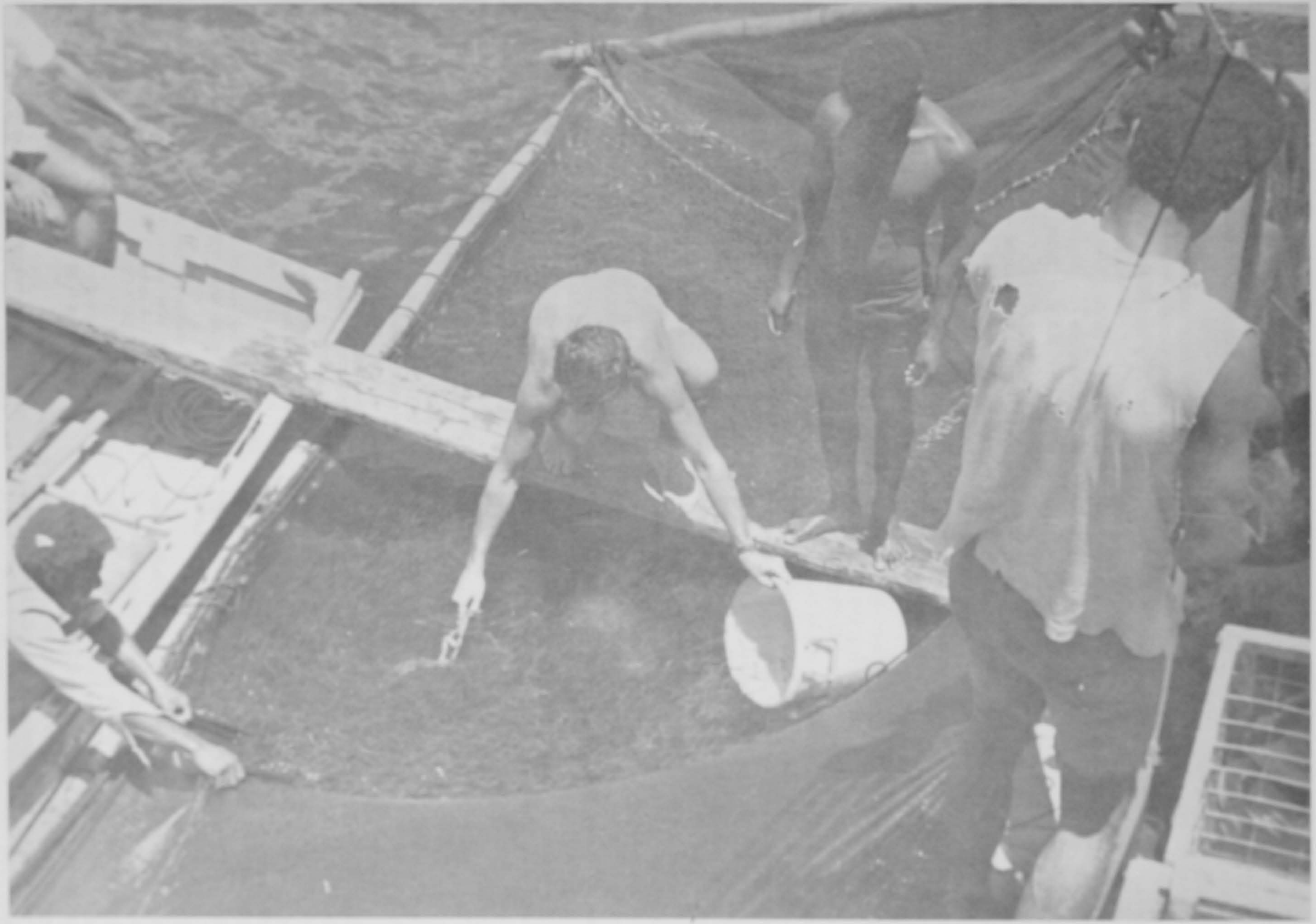

Figure 2.—Crowding and guiding baitfishes into buckets on board the RV *Tagula*, Papua New Guinea.

development of the fishery (Lewis 1977). The only serious bait-imposed limitation on the fishery is that associated with the delicate nature of many of the major bait species. Daily mortality rates as high as 50% are not uncommon. Bait handling techniques used in the commercial fishery were designed for more robust temperate forms such as the Japanese anchovy, *Engraulis japonicus*, and the sardine, *Sardinella melanosticta*. They have proved completely unsuitable for the weaker tropical bait species. Also, bait-keeping qualities of baitwells on board the smaller skipjack tuna catcher boats fishing in Papua New Guinea are considered poor. Water surges through a series of inlet and outlet pipes in the bottom of the tank and is sometimes supplemented by a deck hose inserted into the tank. This produces an uneven and often disruptive water flow pattern which has a deleterious effect on the bait. The continuous removal of dead bait from the bottom of the tank is a good feature of the design.

Adoption of the techniques outlined earlier would result in a substantial reduction in bait loss during capture and transport to the fishing grounds. Benefits to the fishery and to individual fishermen would be immediate and of considerable magnitude. The bait supply to the fishery would be greatly enhanced without any increase in fishing pressure on the bait stocks, and the "effective" bait capacity of each fishing vessel would be increased with a corresponding increment in the potential skipjack tuna catch. The increase in time required to load bait using these techniques is of little importance when compared with the possible rewards.

Daylight loading of bait, on the other hand, would decrease the time spent on the actual fishing grounds by up to 2 h. This would detract from its value to the smaller catcher boats, which operate from mother ships on a daily basis, particularly when bait supplies were abundant. It would be of maximum benefit to the extended-range pole boats.

The incidence of high mortalities in the bait tanks has tied the few extended-range pole boats operating in Papua New Guinea to nightly baiting operations, thus preventing them from capitalizing on their bait-carrying capacity and general mobility. Improved handling and daylight loading would enable large quantities of bait to be loaded and held in the bait tanks for longer periods of time without crippling losses, thus making extended-range operations feasible. There are numerous small anchorages scattered along the coast of Papua New Guinea from which extended-range pole boats can effectively fish the seasonal concentrations of skipjack and yellowfin tunas in areas unsuited to fleet operations (Lewis 1977).

Improvement in bait survival rates and limited success of bait-holding experiments raised the possibility of holding bait in pens to reduce the effect of day-to-day fluctuations in the bait supply. Kearney (1977) suggests that bait captured in moon phases other than full moon might be more profitably utilized if kept until full moon to supplement the expected low catches during this period, when the skipjack tuna catch per bucket of bait is higher than for other periods. Stolephorids such as *S. devisi* and *S. heterolobus* can be held in aquaria for 14 to 16 days before cumulative mortality reaches 50%. It is felt that this success can be duplicated under field conditions.

Any future expansion of the skipjack tuna fishery in Papua New Guinea must be accompanied by improved bait-handling techniques and more efficient utilization of present bait catches. Establishment of separate bait-catching and holding facilities on an area or fleet basis would maximize the skipjack tuna catch per bucket of bait by effecting a more equitable distribution of available bait supplies among the individual catcher boats. Further advantages would accrue if the bait was hardened for a period of 24 h before sale to the catcher boats.

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Relationships Amongst Skipjack Tuna, *Katsuwonus pelamis*, Catch, Bait Catch, and the Lunar Cycle in Papua New Guinea Skipjack Tuna Fishery

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ABSTRACT

This study is based upon analyses of 13,000 daily catch returns of skipjack tuna, *Katsuwonus pelamis*, submitted by the live bait and pole fishing boats in Papua New Guinea. A strong correlation exists between lunar phase and bait catch, with full moon periods producing considerably lower average daily catches (51.4 buckets for full moon periods compared with 64.1 buckets for new moon; $P = 0.007$). More skipjack tuna fishing days were lost due to the failure to catch bait during full moon periods (11.8%) than during periods of new moon (6.8%). Average daily skipjack tuna catches show little variation from one moon phase to another (2,878 kg per day for new moon and 2,690 kg per day for full moon; $P = 0.592$). A curvilinear relationship of the type $f(x) = a(1 - e^{-bx})$ exists between skipjack tuna catch and bait catch such that unusually large bait catches are not as beneficial per unit as smaller ones. Possible benefits of keeping a fraction of large bait catches for use on another day are discussed.

INTRODUCTION

In any tuna pole-and-line fishery, catches will be dependent on the availability of suitable baitfish. The Papua New Guinea skipjack tuna, *Katsuwonus pelamis*, fishery is no exception.

Commercial skipjack tuna fishing in Papua New Guinea is based on joint-venture operations (Kearney 1973) which only commenced operating in 1970, and, therefore, any generalizations about the fishery are based on limited data. However, importance of the bait fishery necessitated that some attempt be made to evaluate the influence of varying bait catches on the resultant skipjack tuna catches and to give a preliminary prediction of the possible benefits from a more equitable distribution of the bait available.

Preliminary examination of the results of the first years of the fishery indicated that the high degree of fluctuation in bait catch from day to day was greatly influencing daily variations in skipjack tuna catch. It was anticipated that moon phase would influence bait catch and might also in some way influence "catchability" of skipjack tuna. It was also anticipated that there would be a decrease in the catch per bucket of bait as the quantity of bait held increased.

DATA COLLECTION AND PREPARATION

The problems associated with the limited accumulated data were exaggerated by the occurrence in one year (1972) of unusually poor skipjack tuna catches. It is not possible to accurately evaluate the influence of the data for this year on the observations to date nor is it possible to predict if similar low catches are likely to occur with any regularity. However, as in excess of 13,000 records of bait and skipjack tuna catch had been accumulated it was anticipated that analyses of variations in the yield of skipjack tuna per unit of bait would be meaningful if based largely on a comparison of 1972 and one other year's data, in this case 1973.

Under the terms of the fisheries agreements between the Papua New Guinea Administration and the joint-venture fishing companies, all companies are required to furnish catch and effort statistics as requested. Details of the amount of bait and the number and weight of each tuna species captured are among the statistics required on a daily basis for each boat. The present investigation is based entirely on an analysis of data supplied by the joint-venture fishing companies.

Since May 1971 night-baiting techniques have been exclusively used and all baitfishing has been done by skipjack tuna catcher boats with no large, specifically bait-catching vessels being employed. The companies fishing for skipjack tuna in Papua New Guinea originally claimed that because of the fragility of the bait available, it was not possible to keep live bait from one day to the next. Hence, all figures used in this study refer to the quantity of bait captured on that one day and no provision has been made for carryover of bait to the next day.

Four companies (designated companies A-D) have commenced fishing since 1970 but two of them (companies A and B) accounted for 80.6% of the total skipjack tuna catch to the end of 1973. Data from company A were found to be extremely accurate and reliable and hence were considered in greatest detail in this report.

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Even though company B fished in only one area and supplied daily bait and skipjack tuna figures for each boat, a detailed analysis of these results revealed that the company tended to combine all the catcher boat figures for each day and supply the Papua New Guinea Administration with approximations of each boat's daily catch, rather than absolute values. For this reason the data were not deemed sufficiently reliable to be considered in any detail, but when considered in toto they still showed the same variation with season and moon phase.

Companies C and D caught bait and skipjack tuna in many different localities within Papua New Guinea's waters, and for this reason it was difficult to ascertain if variations in the catches of skipjack tuna, bait, or skipjack tuna per unit of bait were due to different fishing areas, season, or lunar cycle. Combined data from these two companies have been included in Tables 1, 6, 8, and 9 merely to show that even with the variations caused by these variables the influence of moon phase could not be masked.

Although it is probable that the average contents of a bucket of bait varies considerably between vessels and companies, the results from company A, which are the basis of most analyses, have been checked by independent observers and are considered relatively constant. An average bucket contains between 1.5 and 2.0 kg of bait.

Juvenile yellowfin tuna, *Thunnus albacares*, normally account for between 1% and 5% of the total Papua New Guinea tuna catch, but for the purpose of this study a division of the catch by species was not warranted and whenever skipjack tuna catch is referred to it can be considered to include some small percentage of yellowfin tuna.

As in other fisheries, standardization of effort has proved difficult. A fishing day has been considered to be any day on which a catcher boat had sufficient bait to warrant fishing and did in fact proceed to the skipjack tuna fishing grounds. No differentiation has been made between whole days or parts of days. A day lost due to no bait was a day on which the crew of the vessel actually attempted to catch bait but was unsuccessful and therefore did not go fishing. In Tables 2-5 the number of days fished per month is obtained by combining the number of days fished by each boat for that month.

For the purpose of this study no differentiation has been made between species of baitfishes, but it can be assumed that the greater part of the baitfish used was of the genus *Stolephorus* (Kearney et al. 1972; Lewis 1977; Smith 1977).

Each day has been classified as belonging to one of the four moon phases, namely new moon (N), first quarter (F), full moon (M), and last quarter (L). The classification has been based upon calendars given in The Nautical Almanac (1969, 1970, 1971). Each month has been divided by labeling 3 days on either side of the day on which the moon phase occurs with the same moon phase. When the time between moon phases is 7 days, the extra day is allotted to the preceding phase, and when 8 days separate two moon phases, each phase is assigned 1 extra day.

The significance of observed differences in average catch rates (buckets of bait per day, skipjack tuna catch per day, skipjack tuna catch per bucket of bait) between various moon phases, different years, and other classifications was determined in the customary manner using F-tests. A computer program (NG-4) was employed. This program is a modification of an anlysis of variance routine, AVAR 23, described by Veldman (1967). In the tables which follow, means for the various categories are accompanied by the value of P. This is the

Table 1.—Average daily bait and skipjack tuna catches for each moon phase in 1972 and 1973.

		New moon			First quarter		
Year	Company	Average bait per day	Average catch per day	Catch per bait bucket	Average bait per day	Average catch per day	Catch per bait bucket
		Buckets	*kg*		*Buckets*	*kg*	
1972	A	85.0	3,560.3	*41.9*	81.0	2,726.5	33.6
1972	B	57.8	3,097.3	*53.6*	59.2	3,282.9	55.5
1972	A,B,C,D	69.4	2,585.6	*37.3*	74.3	2,438.3	32.8
1973	A	75.3	5,162.5	*68.6*	78.5	5,180.3	66.0
1973	B	70.3	4,123.4	*58.7*	70.0	3,874.1	55.3
1973	A,B,C,D	64.15	3,854.6	*60.1*	64.2	3,737.7	58.2
		Full moon			**Last quarter**		
Year	*Company*	Average bait per day	Average catch per day	*Catch per bait bucket*	Average bait per day	Average catch per day	Catch per bait bucket
		Buckets	*kg*		*Buckets*	*kg*	
1972	A	64.2	2,414.3	*37.6*	72.5	2,818.7	38.9
1972	B	57.2	3,370.5	*58.9*	57.6	3,320.7	57.7
1972	A,B,C,D	48.8	2,488.2	*51.0*	66.6	2,596.4	39.0
1973	A	55.6	5,270.0	*94.9*	73.7	5,255.2	71.3
1973	B	58.3	3,284.5	*56.3*	60.5	3,770.9	62.3
1973	A,B,C,D	49.2	3,366.0	*68.4*	57.8	3,718.6	64.3

Table 2.—Number of days fished and number of days lost due to no bait and average daily bait and skipjack tuna catches for each moon phase for company A in 1972.

	New Moon				First quarter			
Mo	Number days fished	Number days lost due to no bait	Average bait per day	*Average weight skipjack tuna per day*	Number days fished	Number days lost due to no bait	Average bait per day	Average weight skipjack tuna per day
			Buckets				*Buckets*	
Jan.	2	0	127.5	174.5	5	2	128.0	745.2
Feb.	16	5	96.3	2,113.0	28	0	120.4	1,573.0
Mar.	21	2	93.1	2,429.6	31	2	104.2	1,701.8
Apr.	47	0	94.0	4,264.7	43	5	29.8	2,518.0
May	60	1	93.4	4,665.2	73	4	110.7	2,751.4
June	52	11	64.4	2,331.3	74	11	54.0	1,817.9
July	41	9	61.9	2,231.0	59	5	51.9	3,008.1
Aug.	43	5	65.7	2,580.6	36	5	58.9	2,503.1
Sept.	39	0	75.2	1,282.7	30	1	95.6	1,292.2
Oct.	45	3	94.1	2,539.9	41	1	97.0	3,916.7
Nov.	48	0	115.1	8,135.9	36	0	119.4	5,356.2
Dec.	23	0	80.7	4,862.5	20	1	82.1	4,693.7
Total	437	36			476	37		
Probability of no bait	8.24%			7.77%				

	Full moon				Last quarter			
Mo	Number days fished	Number days lost due to no bait	Average bait per day	*Average weight skipjack tuna per day*	Number days fished	Number days lost due to no bait	Average bait per day	Average weight skipjack tuna per day
			Buckets				*Buckets*	
Jan.	5	1	110.0	183.8	25	11	82.6	361.7
Feb.	12	2	95.8	1,605.2	15	3	129.3	870.7
Mar.	21	5	105.2	2,604.5	29	2	116.4	3,300.1
Apr.	43	4	52.2	3,792.8	23	8	77.8	2,260.8
May	71	9	87.5	1,946.8	63	0	57.9	1,709.8
June	56	13	30.7	2,156.8	75	3	73.0	2,650.3
July	41	6	38.6	2,616.2	70	14	43.1	2,680.5
Aug.	39	1	52.0	1,611.4	45	4	55.2	3,124.0
Sept.	29	4	61.9	1,543.3	38	0	62.2	1,771.8
Oct.	35	1	71.9	4,171.1	54	0	92.1	4,292.6
Nov.	41	1	73.2	3,461.0	45	1	77.0	5,696.5
Dec.	18	2	76.2	4,222.4	17	0	91.9	2,728.2
Total	411	49			499	46		
Probability of no bait	11.92%			9.22%				

probability, under the null hypothesis, that an F ratio as large or larger than the one observed in the particular comparison would have arisen by chance.

ANNUAL VARIATIONS IN NUMBER OF DAYS LOST DUE TO FAILURE TO CATCH BAIT

Since January 1972 there has been a progressive decrease in the number of fishing days lost due to the failure to catch bait (Tables 2-5). The number of days lost in 1973 by companies A and B combined was 235 compared with 616 in 1972, despite an increase from 3,611 to 5,187 in the total number od days fished. While it would be anticipated that loss of fishing days would be closely related to variations in general abundance of baitfish, this does not appear to have been the case. The average daily catch of bait for companies A and B was 66.98 buckets in 1972 and 66.95 buckets in 1973. This suggests that the decrease was due to improvement in the ability of the fishermen to catch bait at times when conditions for baitfishing were unsuitable; it is possible that by 1973 both companies had been in operation for

Table 3.—Number of days fished and number of days lost due to no bait and average daily bait and skipjack tuna catches for each moon phase for company B in 1972.

Mo	New Moon				First quarter			
	Number days fished	Number days lost due to no bait	Average bait per day	Average weight skipjack tuna per day	Number days fished	Number days lost due to no bait	Average bait per day	Average weight skipjack tuna per day
			Buckets				*Buckets*	
Jan.	59	11	53.2	2,388.5	42	11	47.1	1,390.5
Feb.	40	9	59.8	1,880.2	52	8	71.2	4,224.2
Mar.	63	5	72.1	2,736.3	74	2	75.1	5,460.8
Apr.	19	28	13.7	1,840.3	5	34	30.0	279.2
May	58	2	57.8	5,119.5	55	8	50.8	2,696.6
June	21	3	16.9	702.6	30	15	17.7	1,208.3
July	35	9	43.1	1,881.9	25	4	42.0	1,760.3
Aug.	28	3	45.4	1,704.8	26	0	48.8	2,352.6
Sept.	22	6	43.2	1,395.2	4	0	55.0	280.3
Oct.	24	1	41.9	1,622.2	32	2	67.5	5,657.2
Nov.	46	1	100.0	5,708.0	30	0	101.3	4,274.3
Dec.	73	4	66.3	4,527.4	56	13	54.5	2,344.0
Total	488	82			431	97		
Probability of no bait	16.80%			22.51%				

Mo	Full moon				Last quarter			
	Number days fished	Number days lost due to no bait	Average bait per day	Average weight skipjack tuna per day	Number days fished	Number days lost due to no bait	Average bait per day	Average weight skipjack tuna per day
			Buckets				*Buckets*	
Jan.	27	17	61.1	1,509.3	23	11	48.3	2,428.0
Feb.	43	14	70.2	4,898.2	43	26	54.9	2,160.4
Mar.	57	15	70.5	3,523.8	63	14	74.0	2,676.0
Apr.	39	20	32.5	1,947.7	52	4	27.8	3,675.9
May	21	33	37.1	2,466.6	44	15	45.9	2,213.3
June	34	6	25.1	1,868.9	17	32	21.2	552.8
July	15	5	42.0	1,861.1	43	15	48.8	2,385.6
Aug.	23	1	40.0	2,617.8	23	5	47.6	2,673.6
Sept.	10	3	36.0	39.0	19	6	47.4	2,208.6
Oct.	33	1	62.7	3,059.4	31	0	83.2	6,237.8
Nov.	35	1	101.1	6,745.5	61	1	94.7	5,426.7
Dec.	47	2	60.9	4,790.8	66	22	53.2	3,925.9
Total	384	118			485	151		
Probability of no bait	30.73%			31.13%				

sufficient time for the fishermen to have gained significantly better understanding of the behavior of the baitfish on their respective grounds; it is also possible that as 1973 was a far more productive year for skipjack tuna than 1972 (28,269 metric tons compared with 13,124 metric tons), the fishermen exerted greater effort on baitfishing when good skipjack tuna catches were more certain. This latter possibility is supported by the marked decrease in the number of days lost in the latter half of 1973 when skipjack tuna fishing was particularly productive.

Since fishing commenced there has been a tendency for bait catches to be higher in those months in which skipjack tuna catches have been greatest. This tendency adds support to the theory that baitfishing effort is in some ways dependent upon skipjack tuna "catchability."

Irrespective of the reason for the decrease in the number of days when bait was not available, it should be noted that from July to December 1973 only 94 days of fishing were lost by the two companies considered here and 3,002 days were actually fished. This represents a loss in fishing time of only 3.1% or less than 1 day/boat per month.

Table 4.—Number of days fished and number of days lost due to no bait and average daily bait and skipjack tuna catches for each moon phase for company A in 1973.

Mo	New Moon				First quarter			
	Number days fished	Number days lost due to no bait	Average bait per day	Average weight skipjack tuna per day	Number days fished	Number days lost due to no bait	Average bait per day	Average weight skipjack tuna per day
			Buckets				*Buckets*	
Jan.	7	1	47.9	1,681.7	6	0	54.3	609.3
Feb.	6	0	76.7	182.5	2	0	50.0	117.5
Mar.	19	1	62.5	2,695.9	23	0	58.1	2,268.5
Apr.	45	2	54.4	2,099.4	41	0	52.0	912.4
May	53	4	40.4	5,496.2	54	0	49.0	5,825.1
June	26	1	52.3	4,374.8	48	0	80.6	5,003.5
July	55	0	97.3	6,396.9	47	0	101.1	8,676.3
Aug.	56	0	84.2	5,633.6	55	0	101.8	5,515.8
Sept.	46	0	87.0	7,308.0	52	0	71.8	6,199.2
Oct.	55	0	75.4	4,166.9	58	0	94.8	5,772.5
Nov.	55	0	84.5	7,075.1	51	0	81.0	4,422.1
Dec.	25	0	117.0	5,056.4	30	0	84.0	5,904.5
Total	448	9			467	0		
Probability of no bait	2.01%				0%			

Mo	Full moon				Last quarter			
	Number days fished	Number days lost due to no bait	Average bait per day	Average weight skipjack tuna per day	Number days fished	Number days lost due to no bait	Average bait per day	Average weight skipjack tuna per day
			Buckets				*Buckets*	
Jan.	8	0	66.3	1,610.5	3	0	31.7	1,039.7
Feb.	0	0	—	—	0	0	—	—
Mar.	22	6	27.4	1,666.5	26	1	31.8	1,278.1
Apr.	49	4	43.9	1,032.2	45	2	55.2	1,922.0
May	47	7	19.7	2,070.5	41	0	45.2	2,725.0
June	55	0	52.6	3,312.9	67	1	94.85	11,137.3
July	53	0	82.3	12,750.8	49	0	87.9	6,555.3
Aug.	48	0	83.9	5,532.6	49	0	88.6	2,247.5
Sept.	38	1	59.1	7,426.5	37	0	91.3	7,769.4
Oct.	46	1	46.7	5,378.7	44	0	63.1	3,907.5
Nov.	42	0	65.3	7,307.3	46	0	54.4	5,499.9
Dec.	26	0	57.0	5,070.1	34	0	104.9	5,678.3
Total	434	19			441	4		
Probability of no bait	4.38%				0.91%			

VARIATION ACCORDING TO MOON PHASE IN NUMBER OF DAYS LOST DUE TO FAILURE TO CATCH BAIT

In Tables 2-5 the numbers of days lost by moon phase are given and an estimate of the percentage probability of losing a fishing day during any one period is presented. From these tables and the points previously mentioned, it seems that season, abundance of skipjack tuna, and variables other than the abundance or "catchability" of bait may influence chances of an unsuccessful baiting operation occurring. However, it is obvious from the figures given that there is generally a far greater likelihood of losing a fishing day due to lack of bait during periods of full moon than at any other stage of the lunar cycle. Combining the figures for companies A and B in 1972 and 1973 (Tables 2-5), the possibilities of losing a day due to lack of bait in each of the moon phases are new moon 7.3%, first quarter 7.8%, full moon 13.4%, last quarter 10.5%. Full moon periods are therefore comparatively unfavorable for night baitfishing.

Table 5.—Number of days fished and number of days lost due to no bait and average daily bait and skipjack tuna catches for each moon phase for company B in 1973.

Mo	New Moon				First quarter			
	Number days fished	Number days lost due to no bait	Average bait per day	Average weight skipjack tuna per day	Number days fished	Number days lost due to no bait	Average bait per day	Average weight skipjack tuna per day
			Buckets				*Buckets*	
Jan.	56	5	52.1	1,611.5	49	5	40.1	1,425.5
Feb.	31	7	74.2	396.0	43	8	63.7	1,766.9
Mar.	43	5	77.4	2,051.9	31	5	92.9	3,232.7
Apr.	72	4	56.3	1,665.2	55	5	61.2	576.4
May	98	0	88.0	4,921.1	92	4	75.5	5,566.0
June	51	1	63.4	3,307.6	79	2	58.1	2,636.0
July	106	2	60.6	4,352.1	95	5	75.2	2,783.3
Aug.	111	1	80.8	6,261.7	121	3	66.4	6,181.1
Sept.	109	3	63.6	4,925.2	105	2	83.0	5,442.4
Oct.	52	5	85.1	1,943.7	97	3	79.2	4,149.8
Nov.	62	2	75.2	5,670.8	44	0	73.4	4,248.5
Dec.	71	1	65.9	6,391.2	60	0	60.4	3,281.3
Total	862	36			871	42		
Probability of no bait	4.18%				4.82%			

Mo	Full moon				Last quarter			
	Number days fished	Number days lost due to no bait	Average bait per day	Average weight skipjack tuna per day	Number days fished	Number days lost due to no bait	Average bait per day	Average weight skipjack tuna per day
			Buckets				*Buckets*	
Jan.	65	8	42.3	1,131.3	53	1	50.5	838.7
Feb.	45	7	67.4	2,099.8	31	2	101.1	2,526.4
Mar.	47	1	80.3	2,532.4	65	8	52.3	1,153.9
Apr.	58	13	53.4	929.8	62	0	67.1	4,075.1
May	90	6	64.9	4,673.5	85	2	61.0	3,354.5
June	83	10	46.7	1,160.0	108	2	49.8	3,511.6
July	96	11	62.8	3,209.3	86	4	52.3	3,224.5
Aug.	81	3	69.4	5,843.3	95	2	68.3	5,065.8
Sept.	86	11	49.8	3,917.3	89	3	54.0	5,355.7
Oct.	67	8	67.1	1,719.0	56	14	73.4	1,053.6
Nov.	53	3	49.2	5,089.1	56	0	50.7	5,090.3
Dec.	36	5	33.8	2,066.3	71	1	72.4	7,915.5
Total	807	86			857	39		
Probability of no bait	10.66%				4.55%			

INFLUENCE OF MOON PHASE ON DAILY AVERAGE CATCH OF BAIT

The figures given for bait catch per day for each moon phase in Table 1 have been arranged in order of magnitude in Table 6.

From Table 6 it can be seen that bait catches are lowest during periods of full moon (M) while the last quarter catches (L) are consistently lower than for new (N) and first quarter (F) phases. If the total averages are considered (Table 1), catches in the first quarter are slightly higher than for new moon. Analysis of variance of the monthly means of daily bait catches for all four moon

Table 6.—Ranking of average bait catch per day in each of the four moon phases. (N = new moon; F = first quarter; L = last quarter; M = full moon.)

Company	1972	1973
A	N > F > L > M	F > N > L > M
B	F > N > L > M	N > F > L > M

phases for 1971, 1972, and 1973 showed that even though the differences are consistent they are hardly significant (P = 0.06). This lack of significance is largely due to the gradual decrease in average bait catch from new moon and first quarter through to full moon (Table 1). When results for first and last quarters are removed and the average bait catch per day for new moon is compared with similar data for full moon, the difference is very significant. The mean bait catch per day for new moon from January 1971 to June 1973 for all companies (see Table 8) was 64.1 buckets while the figure for full moon was 51.3 (P = 0.0070). When the ranking of the average bait catches for each moon phase (Table 6) is tested by nonparametric methods, the difference between the moon phases is once again proved significant (P = 0.0016).

Differences between baitfishing success in the various moon phases may be greater than indicated above when the bait catch is related to the fishing effort involved. In times when bait is difficult to catch (regardless of moon phase), crews of many catcher boats will haul their nets more than once a night. Therefore during such periods the catch per haul is considerably lower than would be envisaged from an examination of the catch returns. As previously mentioned, abundance of skipjack tuna at the time also influences the baitfishing effort.

That bait catches should be lower during full moon was anticipated and is almost certainly explained by the reduced effectiveness of bright lights in attracting bait during periods when natural light is greatest. The comparative success of baitfishing during first quarter is probably due to this phase being ideally suited to early morning (just before daybreak) hauling of the bait net. Most skipjack tuna fishermen in Papua New Guinea prefer to set their bait lights in the early evening and haul the net just before dawn, allowing the crew to rest while the bait gathers. During the first quarter the moon sets early in the night, ideal for this preferred operation.

INFLUENCE OF THE AMOUNT OF BAIT HELD ON TUNA CATCH AND CATCH PER BUCKET

Regression analyses of moon phase, wind velocity, sea conditions, water temperature, and bait catch on the skipjack tuna catches revealed that the quantity of bait was by far the best predictor. This was an anticipated result and was also in agreement with opinions of the fishing masters of each of the joint-venture companies. In an attempt to quantify the relationship between bait and skipjack tuna catch, the following analyses were carried out: Every fishing day by each boat of company A from January to 30 June 1973 was classified into one of four categories dependent upon the amount of bait taken, viz ≤24, 25-49, 50-99, and ≥100 buckets. For each of these categories the amount of bait, the catch of skipjack tuna, and the skipjack tuna catch per bucket of bait were subjected to analyses of variance using the program NG-4. Table 7 gives the means for all effects and P values for differences between the different bait categories.

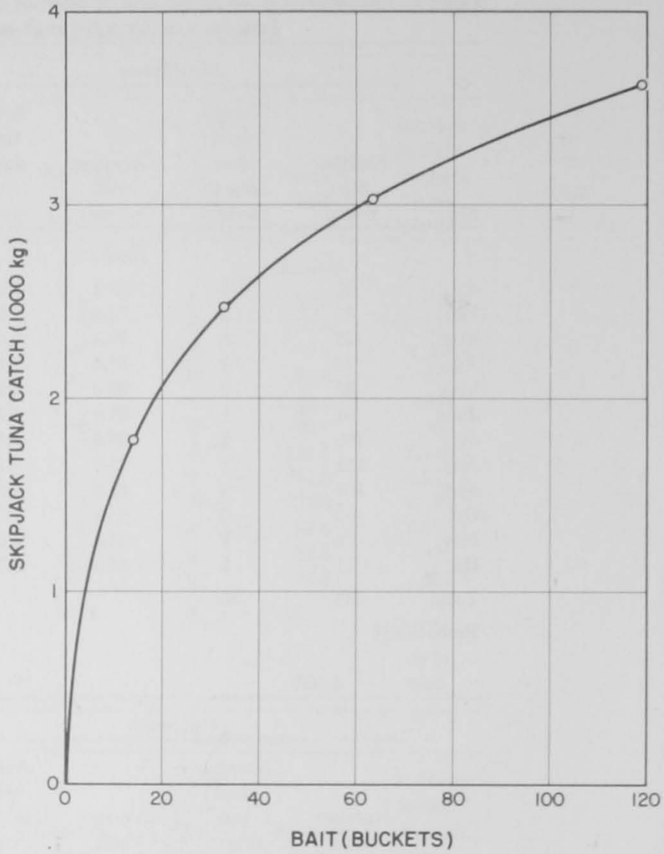

Figure 1.—Variation in skipjack tuna catch with increasing bait catches for company A, January to June 1973 (curve fitted by eye).

Disregarding differences between the moon phases, a plot of skipjack tuna catch against bait catch for company A 1973 data to 30 June produces an exponential curve (Figure 1) of the general form $f(x = a(1 - e^{-bx})$. While the position of this curve would be expected to move according to the abundance of skipjack tuna, its general shape should remain relatively constant.

Estimation of the relative value of a bucket of bait from Figure 1 is not difficult when reliable and unlimited supplies of bait are available. For example, a fisherman buying bait and paying a fixed price per bucket can determine what he considers to be the optimum number of buckets. This number will be governed by the relationship between bait and catch as in Figure 1, by the cost of bait and current price of skipjack tuna, and

Table 7.—Mean skipjack tuna catches per day and skipjack tuna catches per bucket of bait for varying bait catches by company A.

Bait quantity	Mean bait per day	Mean skipjack tuna catch per day	Skipjack tuna catch per bucket
Buckets	*Buckets*	*kg*	*kg*
≤ 24	14.1385	1,786.6	133.8
25-49	32.8300	2,471.1	74.0
50-99	63.1669	3,030.5	50.0
≥100	118.7946	3,618.7	30.8
P	0.0000	0.0136	0.0000

by the abundance of skipjack tuna at the time. Secondly, when the bait facility is run by a company or cooperative of more than one boat, the prospect of sharing large bait catches has obvious merit. For example, subject to an analysis of daily running costs it would appear more economical to have two boats fishing with 70 buckets than one with 140. Cost and benefit analyses of these two examples are comparatively simple.

When skipjack tuna catcher boats are also catching their own bait, as in Papua New Guinea, the problem of valuing a bucket of bait is considerably complicated. In Papua New Guinea nightly baiting operations have been necessitated by the delicate nature of the most common bait species. Any determination of the benefits of keeping bait from one day to another must take into account the probable survival rates that can be anticipated. Obviously these will vary greatly with the bait species. While many species are extremely delicate, it is now considered that improved handling techniques can greatly increase the survival percentages of most (Smith 1977). It is not the aim here to consider the possible percentage survival attainable with each species, nor to consider the relative merits of keeping various species but merely to consider what percentage survival of an "average" baitfish is required to make bait keeping economically attractive.

Using Figure 1 it is interesting to examine the influence of incremental changes to bait catch on the resulting skipjack tuna catches. As average daily bait catches are normally of the order of 70 buckets, an example based on this figure has been taken. Seventy buckets of bait should produce 3,150 kg of skipjack tuna on an average fishing day. If an additional 50 buckets of bait were available on that same day, the anticipated skipjack tuna catch would be increased by only 480 to 3,630 kg. The steeper slope of the curve for lower bait catches indicates that this additional 50 buckets could well realize more skipjack tuna if they were kept for a day on which no bait or only small quantities of bait were taken. A drop in bait from 70 to 41 buckets results in a decrease in predicted catch of 480 kg; conversely only 29 buckets of bait are required to increase the skipjack tuna catch by the same amount that requires 50 buckets when greater quantities of bait are held. Commencing with 20 buckets only, an additional 13 buckets are required to increase the catch by 480 kg. Therefore, if 120 buckets of bait are taken and it is all used on one day, the expected skipjack tuna catch will be 3,630 kg; if 70 buckets are used on that day (giving 3,150 kg of skipjack tuna) and the remainder held in a bait pen, a 58% survival is required until a day when only 41 buckets of bait are taken and the same total catch would be realized. Only a 26% survival rate is required if on the second day 20 buckets are taken. These figures are all based on the assumption that the increased effort involved in keeping the bait does not result in any additional cost or decrease in efficiency.

In the period of time from which the results in Figure 1 and Table 7 were taken, company A had 688 fishing days, 53.9% of which resulted in 40 buckets of bait or less, 25.7% with 20 buckets or less, and 15.8% with more than 70 buckets. Therefore, it is probable that bait will not have to be held for long periods before a day of low bait catch is encountered. As already shown, the likelihood of a low bait catch is greatly influenced by moon phase and if a large bait haul is made just prior to full moon its potential value if kept is even greater. This is even more marked when the prospect of missing a day's fishing due to no bait (13.4% at full moon and 7.3% at new moon) is considered. Obviously at such times a very low survival rate can be tolerated without decreasing the utility of the original bait held.

Data from a greater range of average daily skipjack tuna catches are required before the real value of a bucket of bait can be predicted, but it should be possible to devise tables giving predictions of probable value, enabling estimations of the merit in keeping bait for times of low supply.

INFLUENCE OF MOON PHASE ON SKIPJACK TUNA AND TUNA CATCH PER BUCKET OF BAIT

No significant difference in the average skipjack tuna catch per day could be found among the four moon phases. The most noticeable characteristic of the catches in the four moon phases was the extremely slight variation even though the bait catches were significantly different. This difference in bait catch but consistency in daily skipjack tuna catch suggested that the average catch per bucket of bait should vary from one moon phase to another. In order to test this hypothesis the results from all companies for January 1971 to June (inclusive) 1973 were analyzed. It was anticipated that any differences would be most marked between new moon and full moon periods and hence the analysis was restricted to these two. The results are given in Table 8.

Table 8.—Average daily catch of bait and skipjack tuna for all companies from January 1971 to June 1973.

	New moon	Full moon	P
Skipjack tuna catch per day (kg)	2,878.2	2,689.5	0.5919
Bait catch per day (buckets)	64.10	51.41	0.0070
Skipjack tuna catch per bucket	48.34	59.19	0.3038

Although the differences in the catch per bucket between the moon phases are substantial, from the figures in Table 8 they do not appear to be significant. It was found that the seasonal variation in the catch per bucket (as evident from Tables 2-5) was so great that a true test of the significance of the influence of moon phase could not be made using these raw data. Conversion was, therefore, made to eliminate the dominating influence of annual and seasonal fluctuations. Each new moon period was compared with the full moon in the same calendar month and the results expressed as a percentage of the combined monthly totals (Table 9).

Table 9.—Average percentage differences in daily catches for new moon and full moon from January 1971 to June 1973.

	New moon	Full moon	
	New moon + full moon	New moon + full moon	P
Skipjack tuna catch per day (kg)	50.24%	49.76%	0.8711
Bait catch per day (buckets)	55.99%	44.01%	0.0000
Skipjack tuna catch per bucket	44.36%	55.64%	0.0003

From the figures in Table 9 it is established that the moon phase does definitely influence the skipjack tuna catch per bucket of bait.

It has already been shown that the total skipjack tuna catch and catch per bucket of bait are dependent upon the absolute quantity of bait held (Fig. 1). It is, therefore, probable that much of the elevation in catch per bucket of bait for the full moon period is due to the comparatively low bait catches taken during this period. However the consistency in the average skipjack tuna catch per day in both moon phases, even though the bait catches vary (Table 1), demonstrates that there is a real difference between the "catchabilities" of skipjack tuna during the two phases, independent of the amount of bait held. Comparison of the expected catches from Figure 1, with the actual catches in Table 8, realized from 64.1 buckets for new moon and 51.4 buckets for full moon, indicates that while this difference in "catchability" may be real it is not great.

CONCLUSIONS

In this study the dependence of baitfish catch on the phase of the moon has been demonstrated. Although the differences between new and full moons are quite significant they are even more marked when the increase in the baitfishing effort when bait is less abundant is considered. If the periods coded for each moon phase are restricted to 1 day on either side of the day on which the phase occurs, these differences are even more marked.

Consistency in the skipjack tuna catch per day from one moon phase to the other indicates that skipjack tuna "catchability" varies to some extent independently of actual abundance of skipjack tuna. This suggests that bait captured in moon phase periods other than full moon (particularly first quarter) might well be more profitably utilized if kept until full moon when bait catches can be expected to be low and the skipjack tuna catch per bucket of bait higher than for other periods.

Uncertainty about the contents of an average bucket of bait makes it impossible to accurately value the bait catch in terms of return of skipjack tuna. During 1972 and 1973 the total quantity of bait taken in Papua New Guinea was 784,598 buckets for a total skipjack tuna and tuna catch of 41,393,000 kg. This gives an average return of 52.8 kg of skipjack tuna per bucket and probably on the order of 30 kg per kilogram of bait. An exact determination of the latter figure requires considerable additional information, but it would appear that the skipjack tuna return per kilogram of bait in Papua New Guinea compares facorably with that from Japan (T. Otsu, Southwest Fisheries Center, Honolulu, pers. commun.).

The possible advantages resulting from the regulated use of bait catch as opposed to total usage on the day of capture have already been briefly discussed. However it is most interesting to consider the possibility of predicting what percentage of the bait should be used or kept.

The catch resulting from using some of the bait on the day it is caught (day 1) and keeping the remainder for use on another day (day 2) can be expressed as

$$Q = Q_1 + Q_2 = f(x_1 - a) + f(pa + x_2)$$

where Q = predicted total skipjack tuna catch from the 2 days
Q_1 = predicted skipjack tuna catch on day 1
Q_2 = predicted skipjack tuna catch on day 2
x_1 = bait catch on day 1
x_2 = bait catch on day 2
a = the amount of the first day's bait (x_1) which is kept for use on day 2
p = the fraction of the kept bait that survives from day 1 to day 2

A curve of the type shown in Figure 1 can be represented by the general expression

$$f(x) = a(1 - e^{-bx})$$

or in this case

$$Q = a(1 - e^{-b(x_1 - a)}) + a(1 - e^{-b(x_2 + pa)}).$$

To find the value of a which will maximize Q,

$$\frac{dQ}{da} = abpe^{-bx_2}\, e^{-bpa} - abe^{-bx_1}\, e^{ba} = 0$$

$$=> \ln p - bx_2 - bpa = -bx_1 + ba$$

$$\text{or } a^* = \frac{\ln p + b(x_1 - x_2)}{b\,(1 + p)}$$

when a^* = optimum value of a.

So, for example, when $p = 1, a^* = \frac{x_1 - x_2}{2}$

Estimated values of a^* will be greatly influenced by the general abundance of bait and skipjack tuna and the probability of a zero or low bait catch occurring shortly after day 1. However, when sufficient additional data have been accumulated to give accurate estimations of b it will be possible to draw up tables for estimating a^* under different fishing conditions.

Additional data are likewise required to confirm the stability of the bait fishery on each of Papua New Guinea's major fishing grounds as the 2 years' data which have been accumulated are inadequate to allow accurate assessments of the resource potential. Despite the lack of data due to the short period the industry has been functioning, it is felt that the known bait resources are adequate to support some expansion of the skipjack tuna fishery. It is also anticipated that improved bait handling and improved management of the bait catch will increase the skipjack tuna catch without necessitating an increase in the bait catch.

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Catch Statistics and Abundance of Nehu, *Stolephorus purpureus*, in Kaneohe Bay

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ABSTRACT

Catch and nominal effort statistics from the Kaneohe Bay day-baiting fishery for nehu, *Stolephorus purpureus*, were used to explore hypotheses concerning two sources of variation in baiting success: 1) nehu stock abundance, and 2) abiotic environmental variables. Baiting success was found to be positively correlated with streamflow in a major tributary to Kaneohe Bay, but was unrelated to nominal baiting effort. However, the assumptions underpinning the analyses cannot be accepted with confidence, because the available nominal effort data do not provide a good measure of effective baiting effort. A definitive understanding of nehu stock dynamics will require changes in data collection practices of the Hawaii Division of Fish and Game. In particular, detailed information on catch per set of the bait seine and on size composition of the nehu stock and catch are needed.

INTRODUCTION

The high cost of acquiring bait from the natural stocks of nehu, *Stolephorus purpureus*, has been a major obstacle to the full development of Hawaii's fishery for skipjack tuna, *Katsuwonus pelamis*. Accordingly, it has stimulated government research programs spanning a quarter of a century, seeking to develop cheaper and more reliable substitutes.

Successful creation of alternative bait supplies requires a two-pronged research effort: 1) technical development of new bait sources at unit costs permitting substitution, and 2) practical demonstration of the effectiveness of new baits and building of confidence in their use among skipjack tuna fishermen. Current status reports on research related to several alternative bait substitution schemes are presented elsewhere in this publication. Until effective substitutes are developed, skipjack tuna fishermen will continue to favor the traditional baiting practices and abundance of nehu will be of central concern to the fishing industry.

One concern is apt to be that baiting success or nehu abundance is affected by fishing pressure. The question of overfishing of Oahu nehu stocks was posed early by Hiatt and Tester (1950),[2] but the data available to them did not permit a conclusive study. Even now, details of nehu population dynamics are largely unknown, and the customary approach to nehu stock assessment has been to study an index of abundance, such as catch per unit of fishing effort. This was done by Bachman (1963), who examined the relationship between average catch per day of baiting and the number of days of baiting for several nehu fisheries, using data covering the period from 1948 through 1960. He found no evidence that fishing had diminished the stocks.

In this paper I will summarize the results of some analyses similar to Bachman's which I conducted recently. I will first show that the available unit of nominal fishing effort is probably not a good measure of effective effort, i.e., not proportional to the fishing mortality it generates. In particular, fluctuations in effective fishing effort over a wide range are severely dampened in construction of the catch per nominal effort statistics.

With the shortcomings of the available data clearly in mind, I will explore two analyses using catch statistics from the day fishery of Kaneohe Bay, one of the key baiting grounds of the Hawaii skipjack tuna fleet. The first analysis assumes that the catch of nehu per day of baiting effort is proportional to nehu abundance, and the second assumes that abundance of nehu is relatively constant and that variations in the catch per day reflect changes in catchability or availability of nehu. Results of both analyses should be viewed circumspectly.

CONSTRUCTING AN INDEX OF ABUNDANCE

For the Kaneohe Bay baiting operations, records of nehu catch (in buckets) for each trip to the baiting grounds are available. During a baiting session a boat may make as many as 10 sets of its seine before sufficient nehu are captured to support a trip for skipjack tuna. When nehu are abundant one set may be enough.

If we assume that availability of nehu and effectiveness of the fishing operation (catchability) are constant, a good measure of abundance might be the average catch per set. Unfortunately the number of sets is not recorded. The best one can do is to calculate a provisional index of abundance as the average catch of nehu per "day" of fishing, i.e., per trip to the baiting grounds.

[1]Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

[2]Hiatt, R., and A. Tester. 1950. The supply of nehu. Univ. Hawaii, Mar. Lab. News Circ. 6, 3 p. [Processed.]

Separate records are available for each boat in the fleet. Four vessels, about one-third of the fleet, had fairly continuous records from 1966 to 1972. Data for the analyses were taken from these four boats. One of the vessels was selected as a standard boat, and the fishing power of each vessel relative to the standard was estimated. The average standardized catch of nehu per day of baiting (CPU) was then computed on a monthly basis, giving an 84-mo sequence.

The Hawaii Division of Fish and Game records for Kaneohe Bay also give the catch of nehu taken in the night-light operations and by users other than skipjack tuna fishermen. Thus, estimates of the total monthly nehu harvest for the Bay are available. These figures were divided by the standard index of nehu abundance to give estimates of total fishing effort, measured in standard boat days (Tables 1, 2; Fig. 1).

A major difficulty in using CPU as a measure of abundance is that skipjack tuna boats generally stay on the baiting grounds until a certain quantity of nehu is captured. This amount is determined largely by the capacity of the vessel's baitwells. A demonstration of this is given in Figure 2, for the four selected vessels, where relative fishing power or catch per day is plotted against average baitwell capacity. This shows clearly that the average catch per day is not a particularly good index of abundance, even if the number of sets per day does not vary.

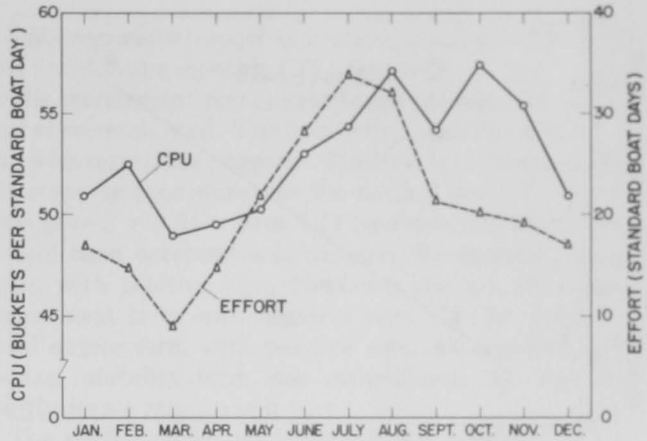

Figure 1.—Monthly average of CPU and effort, computed over 7-yr period (1966-72), for Kaneohe Bay nehu.

During periods when nehu are abundant, the boats will easily fill their baitwells in a trip to the Bay, and the index of abundance will be truncated. Figure 3 shows the relationship between the index of abundance and abun-

Table 1.—Average catch rate of Kaneohe Bay nehu, in buckets per standard boat day, 1966-72.

	Year							
Month	1966	1967	1968	1969	1970	1971	1972	Mean
Jan.	48.57	57.60	56.37	39.96	56.42	50.10	47.39	50.92
Feb.	50.73	65.67	53.94	42.78	47.96	53.27	52.61	52.42
Mar.	55.23	49.97	37.53	51.16	46.66	51.16	50.65	48.91
Apr.	50.82	43.41	54.16	44.91	52.10	53.03	48.01	49.49
May	52.55	45.18	55.65	58.02	47.57	42.88	50.03	50.27
June	48.55	54.90	56.84	51.45	51.64	49.48	58.34	53.03
July	52.88	58.64	56.56	65.11	59.91	34.78	52.57	54.35
Aug.	57.48	57.65	53.81	58.66	61.23	50.95	59.83	57.09
Sept.	56.55	62.14	35.27	62.83	54.79	51.79	55.84	54.17
Oct.	59.03	60.41	49.84	64.42	54.18	55.92	58.04	57.40
Nov.	57.75	59.16	57.20	58.09	47.72	49.38	58.64	55.42
Dec.	62.33	50.75	33.05	57.75	47.42	50.00	55.25	50.94
Mean	54.37	55.46	50.02	54.60	52.30	49.40	53.93	52.87

Table 2.—Average baiting effort in standard boat days, Kaneohe Bay, 1966-72.

	Year							
Month	1966	1967	1968	1969	1970	1971	1972	Mean
Jan.	9.88	12.08	29.23	24.88	9.59	22.93	9.83	16.92
Feb.	12.77	6.59	17.02	6.68	22.89	23.28	11.20	14.35
Mar.	15.15	11.23	11.94	2.15	14.36	0.59	7.26	8.95
Apr.	16.23	10.94	13.44	7.99	18.77	14.29	18.64	14.33
May	24.05	14.59	22.14	15.03	16.38	37.78	22.90	21.84
June	21.01	22.35	28.74	26.70	32.69	39.59	25.50	28.08
July	36.63	26.75	37.99	22.27	37.19	52.72	23.93	33.92
Aug.	21.68	27.79	45.88	27.29	36.81	25.04	39.88	32.05
Sept.	12.25	14.63	18.32	19.38	36.45	14.67	32.86	21.22
Oct.	19.91	9.73	19.28	24.28	30.34	9.67	27.62	20.12
Nov.	19.72	21.37	26.94	19.73	29.52	2.37	14.70	19.19
Dec.	15.58	26.56	24.05	15.31	17.29	1.68	18.52	17.00
Mean	18.74	17.05	24.58	17.64	25.19	20.38	21.07	20.66

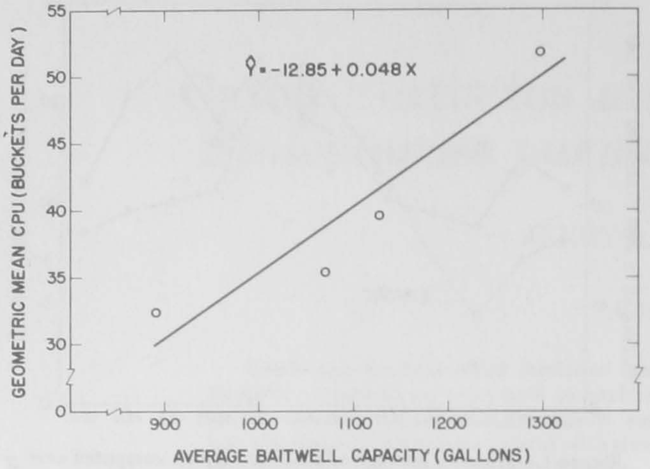

Figure 2.—Relationship between average nehu CPU and baitwell capacity for selected skipjack tuna vessels, Kaneohe Bay.

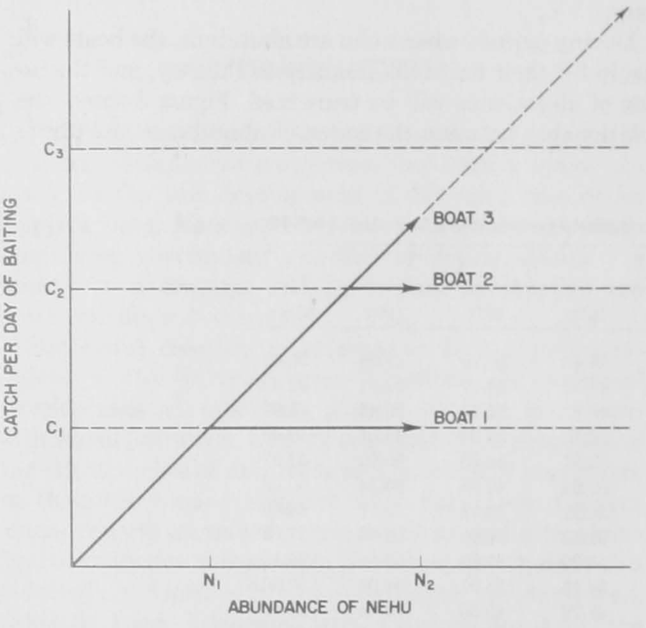

Figure 3.—Catch per day of baiting as a function of nehu abundance for hypothetical vessels with different baitwell capacities (C_1, C_2, C_3).

dance, where there are three vessels with varying baitwell capacities. In this hypothetical situation the catch per day of all three boats is a good measure of abundance as long as abundance does not exceed N_1. If the abundance increases to N_2, only the boat with the largest baitwell capacity, C_3, will still provide a comparable measure of abundance. All this assumes that the number of sets per day is constant. This is patently unrealistic as long as abundance varies.

Thus it is clear that the average catch per day has at least two serious weaknesses when used as an index of abundance: 1) the number of sets per day varies, there tending to be more sets made when nehu are relatively scarce, and 2) baitwell capacity obviously determines an upper limit to catch per day, and, since the objective is to get a full load of bait if possible, baitwell capacity tends to establish a lower bound to catch per day as well The net result is that the CPU will "underestimate" abundance when nehu are plentiful and "overestimate" it when the fish are scarce.

SOME ANALYSES

It should be recognized at the outset that any analysis of nehu abundance using the CPU rests on a set of assumptions almost certainly violated. In the following exploratory treatments of the data, I put on the blinders and assume that changes in CPU reflect similar changes in abundance of nehu with reasonable fidelity. Catchability and availability are assumed to be constant.

The empirical relationship between CPU and standardized effort was used to indicate the response of the nehu resource to fishing pressure. Since the average age of nehu in the exploited stock is believed to be only a few months, the data were first averaged by quarters of the year, producing a series of 28 points assumed to represent equilibrium conditions. If the assumptions are correct, the relationship (Fig. 4) clearly indicates no significant effect of fishing effort on average nehu abundance, over the effort levels observed. This result, not surprisingly, is the same as Bachman's.

In the analysis just discussed the only factor explicitly set out as a determinant of stock abundance was fishing effort. Effort was regarded as the input to a "black box" production process with CPU (abundance) as output. An alternative approach is to do a regression analysis in which the other factors of production, such as natural mortality and recruitment are also modeled explicitly. We may begin as before by assuming that

$$U_i = q D_i$$

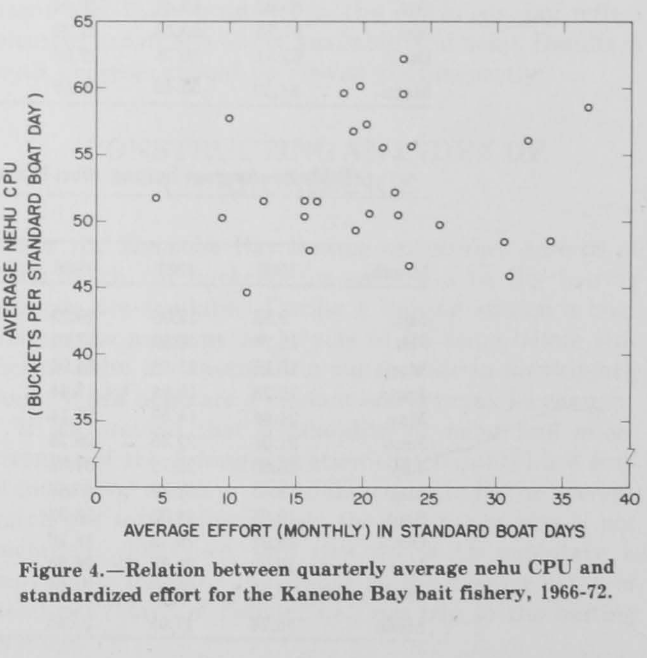

Figure 4.—Relation between quarterly average nehu CPU and standardized effort for the Kaneohe Bay bait fishery, 1966-72.

where U_i = CPU during period (month) i
D_i = average abundance of exploited stock during period i (number of nehu)
q = constant catchability coefficient.

As a first approximation,

$$U_i = U_{i-1} \exp\left\{-\left(M + \frac{f_{i-1} + f_i}{2} q\right)\right\} + q R_i$$
$$= U_{i-1} S \exp\left\{-q\left(\frac{f_{i-1} + f_i}{2}\right)\right\} + q R_i$$

where M = instantaneous natural mortality rate (monthly)
S = monthly survival rate in absence of fishing mortality
f_i = standard units of fishing effort during period i
R_i = average number of newly recruited fish in exploited stock during period i.

The recruitment process may be modeled by a simple Ricker-type function, e.g.,

$$R_i = a D_{i-\delta} \exp\left\{-b D_{i-\delta}\right\}$$

where for nehu we set δ equal to 2 mo. This may be linearized by expanding the exponential in a Taylor series to obtain

$$R_i = a D_{i-2} - \frac{ab}{2} D_{i-2}^2 + \ldots.$$

Alternatively, R_i may be represented by a more general polynomial in D_{i-2} without a constant term,

$$R_i = \gamma_1 D_{i-2} + \gamma_2 D_{i-2}^2 + \gamma_3 D_{i-2}^3 + \ldots.$$

Further, since fishing mortality is assumed to be insignificant, we let

$$\exp\left\{-q\left(\frac{f_{i-1} + f_i}{2}\right)\right\} \approx 1 - q\left(\frac{f_{i-1} + f_i}{2}\right).$$

Finally, combining these assumptions we have a linear regression model, in the usual notation,

$$Y_i = \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \ldots$$

where $Y_i = U_i$, $\beta_1 = S$
$X_{1i} = U_{i-1}$, $\beta_2 = -qS$
$X_{2i} = U_{i-1}\left(\frac{f_{i-1} + f_i}{2}\right)$, $\beta_3 = \gamma_1$
$X_{3i} = U_{i-2}$, $\beta_4 = \gamma_2$
$X_{4i} = U_{i-2}^2$, .
.
.
.

This regression model is a nonequilibrium form and was fitted to the monthly CPU data with $i = 3, 4, \ldots, 84$. In the recruitment component terms through the fourth degree were allowed. The concoction was fitted using a stepwise regression program. The first term accepted by the stepwise procedure was the natural mortality term. This gave $\hat{S} = 0.34$ or $\hat{M} = 1.07$ on a monthly basis. The second term accepted was the first degree recruitment term, with positive sign. Next was the second degree recruitment term with negative sign. Finally came the third degree term with positive sign. As expected, the fishing mortality term was insignificant. So was the fourth degree recruitment term.

The regression model accounted for only 20% of the variation in CPU. Still, the estimates of the coefficients have the proper signs and the estimate of M is consistent with our best guess of the life-span of nehu, judged tentatively to be about 6 mo. Bayliff (1967) studied the relationship between maximum age (Tmax) and instantaneous total mortality rate (Z) for six species of engraulids. On an annual basis his result was $Z = 6.384/T$max. Using this relation for nehu we set Tmax $= 0.5$ and obtain $\hat{Z} = 12.768$. Assuming that fishing mortality is negligible ($M \approx Z$) *we have* $M = 1.06$ on a monthly basis, compared with $M = 1.07$ from the regression analysis. The astounding correspondence between these estimates must be judged with due regard for the battery of assumptions made in each case. At best we might infer that the CPU data trace the general trend of nehu abundance, but even this conclusion is tenuous.

The preceding analysis was based on the assumption that CPU is proportional to nehu abundance, with catchability and availability constant. An alternative point of departure is to regard abundance as being relatively constant and to assume that variations in CPU are due to fluctuations in catchability or availability. A simple statement of these conditions is

$$U_i = q\, DA_i$$

where the new symbols are

A_i = overall availability during the ith time period
$= \prod_j A_{ij}$
A = availability due to factor j during period i $(0 \leq A_{ij} \leq 1)$.

Assuming a single availability process is causing variation in CPU, we factor this out (say the kth one) and take logs to obtain

$$\ln U_i = \theta + \ln A_{ik}$$

where $\theta = \ln(q D \prod_{j \neq k} A_{ij}) =$ constant.

In the bait fishery of Kaneohe Bay one factor suspected of influencing catchability or availability (it makes no difference in the analysis which process is involved) is turbidity of the water near the mouths of streams where nehu congregate. Fishermen often do not attempt to catch nehu during periods of heavy rainfall, when turbidity increases due to the boost in runoff.

An index of runoff into Kaneohe Bay is the average discharge of a major tributary such as Kamooalii Stream, which flows (via Kaneohe Stream) into the southern sector of the Bay near the city of Kaneohe. Appropriate discharge data, in cubic feet per second, are available in reports of the U.S. Geological Survey (1966-72).

Denoting the availability factor by A_i, we may write

$$A_i = \exp\left\{-\beta[d_i - d_0]\right\}$$

where d_i = Kamooalii Stream discharge in period i (cfs)

d_0 = minimum discharge level such that as $d_i \rightarrow d_0, A_i \rightarrow 1$.

Combining this with the previous equation we obtain

$$\ln U_i = \theta' - \beta d_i$$

where $\theta' = \theta + \beta d_0$.

This linear regression model was fitted to log CPU and monthly average discharge data for each year, 1966 through 1972. Logs to base 10 were used. Only two of the regressions were significant, at the 1% level. The other five were not significant. However, six of the seven correlation coefficients were negative, as expected, with values ranging from −0.16 to −0.86. The model was also fitted to all 84 data points, yielding a highly significant regression and a correlation of −0.36.

Finally, the availability model was fitted to the log of the geometric mean of CPU, and the average discharge, with the means computed over the 7 yr (Fig. 5). The regression is highly significant with a correlation coefficient of −0.71. If the assumptions of this analysis are

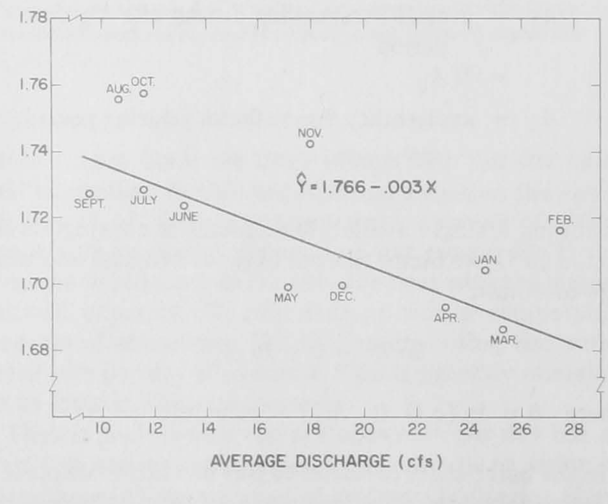

Figure 5.—Regression of log CPU on the average discharge of Kamooalii Stream at Kaneohe. Monthly data averaged over 1966-72.

correct, we may take this as evidence that availability, catchability or both are reduced during periods of high rainfall (January through April) and enhanced when streamflows drop (June through October).

THE NEED FOR BETTER DATA

The last analysis above suggests that variations in catch per unit of baiting effort may be due largely to changes in availability or catchability arising from exogenous abiotic variables such as runoff, turbidity, etc. If this is so, we can have little confidence that catch and effort statistics, taken alone, will provide useful measures of nehu abundance, particularly when short-term changes are of interest. This applies equally to measures based on catch per set and those based on catch per day. Still, the results of the exploratory analyses presented here are based on assumptions not easily accepted. While the first analysis indicated no long-term effect of baiting effort on nehu abundance, it is quite possible that there are important short-term effects of baiting effort which are erased from the CPU index in the smoothing processes discussed earlier.

A more definitive analysis of nehu stock dynamics and the relative importance of baiting effort and environmental variables in the regulation of baiting success requires a much stronger data base than is now available. At the minimum, reporting requirements for statistics on nominal baiting effort should be extended to include information on the number of sets made each day by each vessel. In addition, catches of nehu should be sampled systematically and frequently to determine size and age composition, so that more detailed modeling can be done. The responsibility for data collection in the nehu fisheries rests jointly with the Hawaii Division of Fish and Game and with members of the aku fishing industry.

ACKNOWLEDGMENTS

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Some Aspects of the Population Biology of *Stolephorus heterolobus* from Palau[1]

ROBERT G. MULLER[2]

ABSTRACT

Over 90% of the bait used for skipjack tuna, *Katsuwonus pelamis*, fishing in Palau is *Stolephorus heterolobus*. Length frequencies of bait collected from the commercial fleet from December 1971 to July 1973 were used to estimate growth and total mortality. The von Bertalanffy growth equation for *S. heterolobus* was: $L_t = 91[1 - \exp(-0.0058\ (t + 3.4))]$ where L_t was the standard length in millimeters and t was age in days. The average total mortality for the 19-mo period was 0.61/mo and the average fishing mortality for the same period was 0.28/mo. "Simple" production models gave monthly maximum sustainable yield estimates of about 6,700 buckets of bait with an effort of under 170 boat nights/mo. The dynamic pool model gave a maximum yield at a fishing mortality of 0.67/mo, but the present fishing mortality, only 0.28/mo, yields 90% of the maximum. Based on the results of this study, the bait fishery in Palau is operating near its optimal level.

INTRODUCTION

Uchida (1970) has discussed the fishery for skipjack tuna, *Katsuwonus pelamis*, which is Palau's largest industry and nongovernmental employer. Briefly, the Japanese fished there from 1924 to World War II. Their largest catch, 13,774 tons, was taken in 1937. With the completion of a freezer plant in Palau in 1964, the fishery resumed. A typical 24-h period consists of the boats night-lighting their bait supply, departing for the fishing grounds in the early morning, and returning to port in the evening to unload the tuna catch, resupply, and return to the baiting area.

This pole-and-line fishery requires a ready supply of bait, but like the Hawaiian skipjack tuna fishery, bait is sometimes limiting. Presently, the skipjack tuna fleet is restricted to 12 boats by the Trust Territory Government, but there is a desire to increase the fishing fleet. In addition, outside nations, such as Japan, would like to be able to buy bait in Palau. This demand and a poor year in 1971 prompted this study of the population biology of the primary Palauan baitfish, *Stolephorus heterolobus* Rüppell (Engraulidae).

This paper concerns the determination of growth and mortality estimates of *S. heterolobus*, their use in the dynamic pool model (Beverton and Holt 1957), and the analysis of bait catch statistics in "simple" production models (Schaefer 1954; Fox 1970) for a first level assessment of the bait resource.

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MATERIALS AND METHODS

Bait samples from commercial catches were obtained twice weekly from December 1971 to mid-July 1973. In addition, for an historical perspective, the National Marine Fisheries Service (NMFS) in Honolulu made available monthly length-frequency data from June 1965 to May 1968 on *S. heterolobus* from Palau.

For the recent data, hereafter designated as UH, the standard length (SL) frequencies from the bait samples, tallied in 2-mm increments (Gulland 1966), were pooled monthly. Howard and Landa (1958) noted that for fish which school by size, a more representative sampling of the fish's size distribution comes from sampling a few fish from many schools instead of the reverse. *Stolephorus heterolobus* schools by size and all samples in a month were summed by size after down-weighting the larger samples. The pooling procedure down-weighted all samples containing over 100 fish to 100 fish and used raw counts for samples with less than 100 fish. A functional regression (Ricker 1973) was calculated to convert the NMFS data from fork length to standard length.

Probability plots (Harding 1949; Cassie 1954) yielded the number of modes in the length frequencies, their means, and their standard deviations for each month. In addition to the probability plots, pooled length frequencies were analyzed using NORMSEP, an FAO Fisheries Stock Assessment Program (Abramson 1971; LeGuen and Sakagawa 1973). Although NORMSEP gives a higher probability for the chi-square test than the graphical method, it has the disadvantage of requiring the number of modes and their cut-off points as input. In this analysis, probability plots supplied the required information on the number of modes and their cut-off points for use in NORMSEP.

Once the modes were identified for each month, the modes were linked by successive months in a fashion believed to approximate the growth of the anchovy. These links, i.e., the initial length, final length, and elapsed time, were the input for a program by Fabens' (1965) which calculated the von Bertalanffy growth parameters: K, the intrinsic growth rate, and L_∞, the asymptotic length. The growth equation was tied to a time scale by using the size of *S. heterolobus* at hatching, 1.8 mm.

Estimates of total mortality were obtained from raised length frequencies (Gulland 1969), i.e., the number of fish per boat night in each size category. The raising factor, r, was

$$r = W\,2{,}000/w \qquad (1)$$

where W is the number of buckets per boat night from the night being sampled and w is weight of the bait sample. The 2,000 is a bucket to gram conversion factor. This factor is inexact because the actual mass of fish in a bucket is quite variable. Also, this factor is lower than the Hawaiian value of 3,600 g/bucket because in Palau a smaller bucket with more water is used to reduce crowding effects during the transfer process.

An age-length key was constructed by assuming that fish 16 days to 45 days old were 1 mo; fish 46 days to 75 days old were 2 mo; and so on. Lengths corresponding to these ages were calculated from the von Bertalanffy equation and the raised length frequencies were regrouped into age frequencies.

Catch statistics from the first day of fishing in August 1964 were obtained from Van Camp Sea Food Company in Koror, Palau, and from Marine Resources Division of the Trust Territory of the Pacific Islands. These data included daily bait catch, skipjack tuna catch, yellowfin tuna catch, weather, crew composition, and track of each vessel. Since July 1970, the number of buckets of bait and the location of each lift have been recorded.

RESULTS

Growth

The von Bertalanffy growth equation for *S. heterolobus* in Palau was

$$L_t = 91[1 - \exp(-0.0058(t + 3.4))] \qquad (2)$$

where L_t is the standard length of a fish in millimeters at time t in days. By different linkings of the modes, K values from 0.0048 to 0.0068/day were obtained together with L_∞ values of 85 to 95 mm.

The earlier NMFS frequency data were compiled with fewer fish, some months having only 300 fish, and consequently following successive modes was difficult. Estimates of L_∞ and K for these data were 85 mm and 0.0059/day, respectively.

Tham (1966) obtained a similar equation for *S. pseudoheterolobus* in the Singapore Straits,

$$L_t = 89[1 - \exp(-0.0057(t + 16))]. \qquad (3)$$

Stolephorus pseudoheterolobus is a synonym for *S. heterolobus* (Whitehead 1965). There was close agreement for the growth rate and the asymptotic size. Also, only 6 fish out of over 40,000 examined in Palau exceeded 90 mm SL.

The main difference between Equations (2) and (3) is in the scaling terms, the time at which the length would be zero, t_0, −3.4 and −16 days. Tham (1966, 1967) initially obtained a t_0 value of −4 days using a hatching length of 2 mm but he rejected this value citing Gulland's (1964) observation that estimates of t_0 from each age for which the mean size is known will not be equally good. But Gulland was referring to estimates derived from older fish where small differences in length result in large differences in t_0 (Gulland 1969). Fabens (1965:278) also pointed out the difficulties in estimating t_0 from larger animals and recommended using the size at birth or hatching. Therefore, I think that Equation (2) with a t_0 value of −3.4 days yields a reasonable average description of the growth of *S. heterolobus* in Palau.

Mortality

The total number of fish at each age, determined with the von Bertalanffy equation (2), is shown in Figure 1 for both sets of length frequencies. The earlier-NMFS data were mostly linear implying that for all ages after recruitment, the fish were equally vulnerable to the fishing gear. The UH data showed a slight concavity in the curve for older fish. Concavity in the catch curve indicates either increased vulnerability or immigration of older

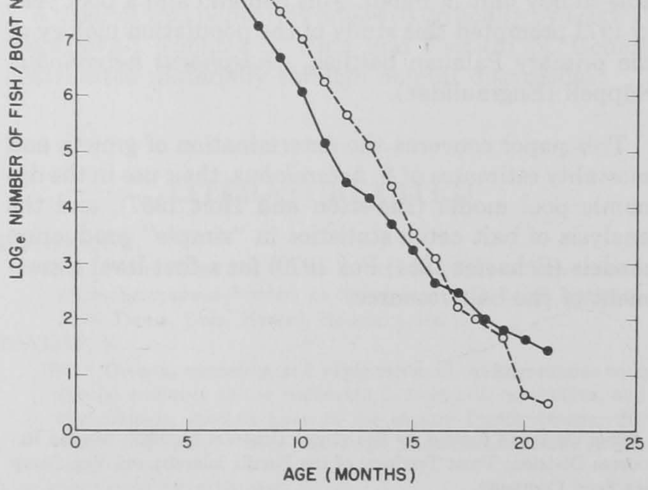

Figure 1.—Catch curves for *Stolephorus heterolobus* from two time periods in the Palauan bait fishery.

fish into the baiting area. These two possibilities cannot be distinguished with the data. However, the number of fish involved is less than a half of 1% and, therefore, they contribute little to the bait catch.

Total mortality estimates, Z, were determined from the aged frequencies by

$$Z = -\ln(\bar{X}/(1 + \bar{X})) \quad (4)$$

where $\bar{X}$ is the mean coded age in the aged frequencies (Chapman and Robson 1960; by

$$Z \approx -\ln(\sum_{t=4}^{21} N_t / \sum_{t=3}^{21} N_t) \quad (5)$$

where N_t is the number of fish at age t (Beverton 1963); and by a semilog regression of log number of fish at age t on age t (Ricker 1958). Table 1 lists the estimates of total mortality.

Since the data were smoothed by combining all 34 mo of the NMFS data and all 19 mo of the UH data, the precision of these estimates is less than that indicated in Table 1. The first two methods tended to emphasize the younger, more abundant age categories whereas the semilog technique weighted all the ages equally and by comparison emphasized the older fish. Also, in the second half of Table 1, the UH data were recalculated using $K = 0.0048$/day and $K = 0.0068$/day and the average total mortality of the three methods was found to vary directly with K. Therefore, the average total mortality of the 19 mo of recent data, $Z = 0.61$/mo, was used in the remaining analyses.

Mean longevity of *S. heterolobus* was determined by defining longevity as that age when only one out of a thousand recruits remains. With the age of recruitment at 3 mo, the longevity of *S. heterolobus* is 14 mo. The length corresponding to 14 mo is 83 mm SL, and 53 fish out of the 40,000 exceeded 84 mm. Tham (1970) estimated the age of an 83-mm fish at 15 mo but added that few fish over 80 mm were observed in the Singapore Straits.

Table 1.—Total mortalities, Z, of *Stolephorus heterolobus* in the Palauan bait fishery estimated by methods 1 - Chapman and Robson 1960, 2 - Ricker 1958, and 3 - Beverton 1963.

KD^{-1}	Year		Z month^{-1}	SD	Method
0.0058	1965-68		0.41	0.0002	1
			0.55	0.060	2
			0.34	—	3
		Mean	0.43		
	1971-73		0.65	0.0004	1
			0.52	0.087	2
			0.66	—	3
		Mean	0.61		
0.0048	1971-73		0.52	0.0003	1
			0.46	0.057	2
			0.53	—	3
		Mean	0.50		
0.0068	1971-73		0.69	0.0003	1
			0.67	0.073	2
			0.78	—	3
		Mean	0.71		

Partitioning the Total Mortality

Tagging methods for estimating fishing mortality were not feasible as the fishing does not examine individual fish; the bait are transferred collectively from net to baitwell and then from baitwell to chum. Furthermore, since the fish is short-lived and since the fishery uses several million fish per year, it would be unlikely that a significant portion of the bait population could be tagged. Estimates of fishing mortality on the baitfish were obtained indirectly.

The partitioning method used was based upon the same reasoning as the swept area method (Beverton and Holt 1956; Paloheimo and Dickie 1964; Hirayama 1972), i.e., a fishing operation, in this case one lift of the blanket net, affects a measurable segment of the population. The sampled volume was the quantity of water illuminated by an underwater light. The probability of catching a fish is the probability that a fish will be in the lighted water times the probability of a fish in the lighted water being caught. I have assumed that all fish in the lighted water are caught. The net is 13 m on a side and after the light is dimmed prior to hauling, the bait forms a ball approximately 7 m in diameter and most of the fish are caught. With this assumtion, the probability of catching a fish simplifies to the ratio of the lighted volume of water to the volume of the available habitat, in this case the lagoon. Details of the actual calculations are given in the Appendix.

The catchability coefficient was 0.0012/lift and the monthly values of fishing mortality, F, varied from 0.13/mo in December 1971 and 1972 to 0.56/mo in May 1973. The average value of F for the 19 mo, weighted by the number of lifts in each month, was 0.28/mo. Table 2 contains the monthly catch statistics and the fishing mortality.

Natural mortality for the population is the unexplained mortality difference between the average total mortality, $Z = 0.61$/mo, and the average fishing mortality, $F = 0.28$/mo, during the 19 mo. A natural mortality coefficient of 0.33/mo or 4.0/yr is high but consistent for a fish with a short life-span (Beverton and Holt 1959). The longevity of *S. heterolobus* in the absence of fishing, $Z = M = 0.33$/mo, would be 24 mo. This value would decrease with time as other, presently potential, predators increase.

Bait Fishery

This section of the paper is concerned with analysis of the bait catch statistics. Table 3 is an annual summary of the bait catch, effort, and catch per effort. The bait catch is tallied in buckets and each bucket contains approximately 2 kg of bait. The boat night was the only index of effort until July 1970 when the actual number of lifts and the sector of the baiting area began to be record-

Table 2.—Monthly catch statistics for *Stolephorus heterolobus* in Palau.

Month	Catch (buckets)	Lifts	Catch/lift buckets/lift	F month^{-1}
1971				
December	3,078	106	27.7	0.13
1972				
January	4,576	106	43.2	0.13
February	5,381	144	37.4	0.17
March	5,332	201	26.5	0.24
April	7,376	265	27.8	0.32
May	10,473	333	31.3	0.40
June	7,867	243	32.4	0.29
July	8,684	251	34.6	0.30
August	8,901	359	25.1	0.43
September	6,353	375	16.9	0.45
October	5,380	185	29.1	0.22
November	5,041	156	32.3	0.19
December	5,166	111	46.5	0.13
1973				
January	5,532	184	30.1	0.22
February	4,538	174	26.1	0.21
March	3,357	149	22.5	0.18
April	4,653	220	21.2	0.26
May	3,673	465	7.9	0.56
June	6,620	373	17.7	0.45

Table 3.—Annual total catch, effort, and catch per effort statistics for the Palauan bait fishery.

Year	Catch (buckets)	Boat nights	Catch/boat night
1964	10,888	270	40.3
1965	53,358	1,073	49.7
1966	62,780	1,406	44.7
1967	73,620	1,616	45.6
1968	82,082	1,784	46.0
1969	111,103	1,590	69.9
1970	96,462	1,565	61.6
1971	48,674	2,860	17.0
1972	80,630	1,755	45.9

ed. The bait fishery quickly developed until an average of 70,000 buckets of bait were caught annually with an average effort of 1,600 boat nights/yr.

Effort varied about threefold during a year depending, to an extent, upon availability of tuna. When tuna were present and the crews were hopeful of obtaining good catches, the number of boats that failed to make bait decreased. Similarly, bad weather did not prevent fishing if tuna schools were nearby. But on an annual basis, total effort has varied little except during 1971 when mother ships and their catcher boats were brought into Palau doubling the fleet. The catch statistics show the results of this increased effort (Table 3).

The decline in catch per effort during 1971 suggests that perhaps there is an optimum fishing intensity beyond which the catch drops sharply. Table 4 shows the maximum sustainable yields and their respective efforts for the "simple" production models: the logistic model (Schaefer 1954) and the exponential model (Fox 1970). Data for these models were given in Table 3. Since the fitting methods involved effort as a common term, tests of significance were not strictly valid, but Fox's asymmetrical model gave a slightly better fit than the Schaefer model ($r^2 = 0.60$ as compared to $r^2 = 0.51$). Both methods gave an annual maximum bait catch of approximately 80,000 buckets with an effort of under 2,000 boat nights or, on a monthly basis, 6,700 buckets at under 170 boat nights/mo.

The dynamic pool model (Beverton and Holt 1957) is based on estimates of growth and mortality instead of combining all of the biological parameters into a single coefficient of increase like the "simple" models. A basic assumption is constant recruitment. In Palau, recruitment is not constant so the more meaningful statistic is yield per recruit. For *S. heterolobus* in Palau, recruitment is at an age of 3 mo or an average length of 39 mm.

Figure 2 shows the yield per recruit for different combinations of natural mortality and growth rate. For the estimated natural mortality of M = 0.33/mo, the three curves are somewhat similar in shape but with the location of their maxima shifted depending upon the growth rate. Higher yields are obtained with less fishing at faster growth rates. The maximum yield at a high natural mortality, M = 0.61/mo, is attained with unrealistically high levels of fishing. With the estimated values of M and K, 0.33/mo and 0.0058 day^{-1}, the maximum yield per recruit, 0.83 g/fish, occurs at a fishing mortality of 0.67/mo, but the present average fishing mortality of 0.28/mo gives a yield within 10% of the maximum.

Recruitment is not going to be considered here except to say that the "normal" pattern for *S. heterolobus* is for recruits to enter the fishery during every month but with definite increases in the late spring and in the fall. Tiews et al. (1970) reported a similar pattern for *Stolephorus* eggs in Manila Bay and Sitthichockpan (1972) found a similar situation in the Gulf of Thailand. In Palau, recruitment apparently was more dependent on environmental factors than upon the number of eggs spawned (unpubl. data).

Table 4.—Annual maximum sustainable yield estimations in the Palauan bait fishery as determined by the logistic and exponential models.

Model	Maximum sustainable yield Buckets		E max Boat nights	
	Annually	Monthly	Annually	Monthly
Logistic	82,500	6,880	1,960	163
Exponential	77,000	6,420	1,470	123

DISCUSSION

Gulland (1971) noted that significant changes in a fishery can occur quickly and that sometimes it is necessary to make rapid assessments on scant data. It must be remembered that most of the findings in this paper are based upon length frequencies, plankton tows, and catch statistics, all of which are subject to error in their measurement. The fishery models employed in this exercise are based upon many assumptions, few of which are rigidly met by fish populations, especially tropical fish populations. But if we assume that perhaps the es-

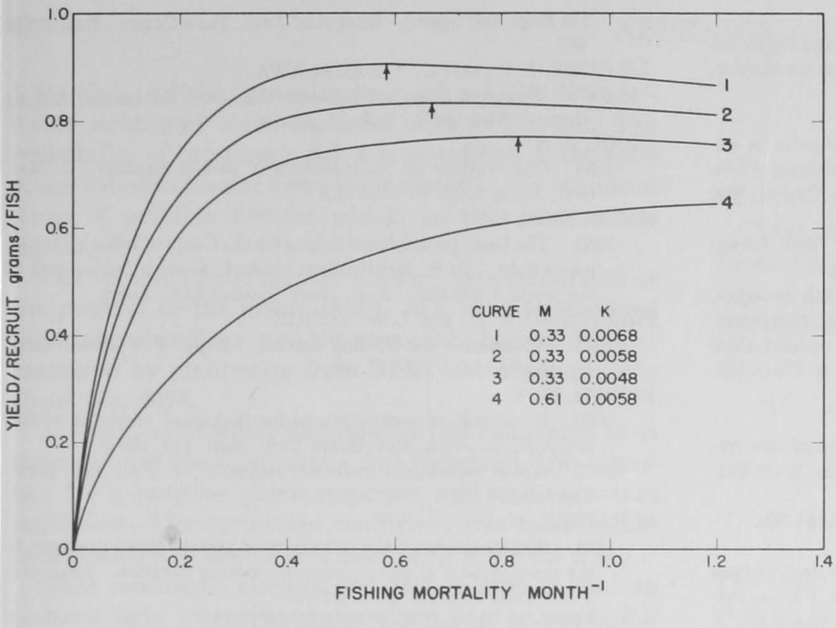

Figure 2.—Yield per recruit curves for *Stolephorus heterolobus* calculated with two values of natural mortality and three growth rates. The positions of the maximum yields are indicated by arrows.

timates reflect average values for the population, at least a first level assessment can be obtained.

The yield models predicted increased catches with increased effort at low fishing levels. However, the increment in catch decreases with increasing effort such that eventually a maximum catch, C_{max}, is reached. Any increase in effort beyond that level of effort associated with the maximum catch, E_{max}, will decrease the total catch. The bait catch data in Table 2 show this same correspondence. The catch kept pace with effort until August 1972. By September, fishing mortality was up to 0.45/mo, and the bait catch was down from the previous months' catches. During the spring of 1973, bait catches again failed to keep pace with effort. The simple production models were data limited with only 1971 at a high fishing intensity, but the monthly data show the same conclusion that with increasing effort catches will not continue to rise.

More important than the actual catches is the catch per effort at different fishing intensities. This statistic has its maximum at one unit of effort and declines thereafter. Therefore, any decision on desirable fishing intensities will necessitate a compromise between increased total catches and decreased catch per effort for effort levels below E_{max}. Actual delimiting of the optimum yield requires additional information of such as the management goals of the fishery and the economics of the fishery. Based on the production models, the bait fishery in Palau is near its optimum. The average fishing intensity for the 19-mo period was 148 boat nights, which is close to the E_{max} of the "simple" production models (Table 4). The dynamic pool model (Fig. 2) gives an E_{max} 139% higher than present levels and yielding a catch of only 10% higher. Catch per effort at E_{max} is only 46% of the present value. The dynamic pool model predicts the yield per recruit, and so the actual catches are subject to the vagaries of recruitment.

This analysis has been based on material from the main baiting area almost exclusively. There are other small bays and river mouths where *S. heteolobus* occur in Palau, and there are other suitable baitfish species. But over 90% of the bait used in Palau is *S. heterolobus* and over 95% of the baiting occurs in the main baiting area.

If the present fishery is near its optimum, what is the future of the bait fishery? Any expansion of the bait fishery will have to come through conservation and through effective utilization of the bait resource. A possible means of increasing the fleet size without affecting the bait supply would be the implementation of multiday trips. By baiting every other day instead of daily, the fleet size can be doubled. The multiday trip should be desirable from the industry standpoint because lost time due to transportation and baiting would be reduced while fishing time would be increased. In the fall of 1972, one of the boats in Palau made a few 3-day trips with the bait surviving satisfactorily after the initial postcapture die-off. These trips were discontinued, though, because of a scarcity of tuna at that time.

ACKNOWLEDGMENTS

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APPENDIX

Baitfish in Palau are attracted with a 1,000-W underwater light and then captured with a lift net. The probability of catching a fish was simplified to the ratio of the volume of water being illuminated to the volume of water of suitable habitat which, in this case, is the lagoon.

The volume of the lagoon, 9.2 km , was calculated as the product of the mean depth, 30.5 m as determined from echo soundings, and the area of the lagoon, 300 km^2 measured by planimeter from U.S. Navy Hydrographic Chart No. 6073.

The volume of water illuminated was calculated from the output of the light source, the threshold light intensity for a positive photo response, and the extinction coefficient. The extinction coefficient was initially obtained with a K-meter and later with a Secchi disk.

Since moonlight affected the bait catches, I used an ambient light intensity of moonlight at 2 m, 6×10^{-4} $\mu W\ cm^{-2}$ (interpolated from Clarke [1971]), as the initial threshold light intensity. Light is attenuated in water by dilution which follows the inverse square law and by absorption which is measured by the extinction coefficient (Nicol 1958). Combining these two processes yields an Equation (1) for the light intensity at any distance that is similar to Nikonorov's (1959) equation for the night lighting of the Caspian kilka, *Clupeonella* sp.

$$I_R = I_0 (\exp - (K\ R))/4\pi R^2$$

where I_R is the intensity at a distance R, I_0 is the output intensity of the light source, K is the extinction coefficient, and the 4π is necessary because the light source can be considered a point source. Solving Equation (1) interatively for R gives a capture radius of 74 m for a 1,000-W light and $K = 0.106$/m.

During this study, bait catches from nights near the full moon significantly averaged 40% less bait than those catches during nights without a moon ($t = 4.4$, df = 352). This decline was attributed to the higher ambient light levels reducing the effectiveness of the night light. Thus, a new capture radius of 88 m was calculated and the resulting threshold for a positive photo response was 9.1×10^{-5} $\mu W\ cm^{-2}$.

The total volume of water illuminated during a baiting operation, V, is the amount of water illuminated at any one instant, V', plus the tidal flow through the lighted cross section, V''. The basic equation for calculating either of these quantities is

$$R^2 = X^2 + Z^2 \qquad (2)$$

where X is the horizontal distance in meters, Z is the depth in meters, and R is the capture radius of 88 m.

The amount of water illuminated at any one instant, V', is obtained by intergrating Equation (2) with respect to depth with the light or center at a depth of 2 m.

$$V' = \pi \int_{-2.0}^{28.5} (R^2 - Z^2)\, dz = 7.2 \times 10^4\ km^3. \qquad (3)$$

Tidal currents in the baiting area averaged 0.5 km/h based upon timing floating objects and a drogue. The typical period between lifts is 4 h and so the tidal flow through the lighted cross section, V'', is

$$V'' = (4.0\ h\ 0.5\ km/h)(2) \int_{-2.0}^{28.5} (R^2 - Z^2)^{1/2}\, dz \sim 1.0 \times 10^{-2}\ km^3. \qquad (4)$$

The total amount of water being sampled during the average lift is

$$V = V' + V'' \sim 1.1 \times 10^{-2}\ km^3. \qquad (5)$$

The probability of capturing a fish in the net is

$$P \sim 1.1 \times 10^{-2}\ km^3/9.2\ km^3 \sim 1.2 \times 10^{-3}/lift. \qquad (6)$$

If P is the probability of being caught, then $1 - P$ is the probability of surviving one lift of the net. The survival, S, for a month is

$$S = (1 - P)^E. \qquad (7)$$

Where E is the number of lifts during that month and the instantaneous fishing mortality rate, F, is

$$F = -\ln(S). \qquad (8)$$

Combining Equations (7) and (8) gives

$$F = -E \ln(1 - P) \qquad (9)$$

and for $-1 < P < 1$, $\ln(1 - P)$ can be expanded by a Taylor series

$$\ln(1 - P) = -P + \frac{P^2}{2} - \frac{P^3}{3} + \frac{P^4}{4} - \ldots \qquad (10)$$

but for small values of P, such as 1.2×10^{-3}/lift, the higher terms are negligible. Therefore, $\ln(1 - P) = -P$ and substituting into Equation (9) gives

$$F = P\ E. \qquad (11)$$

Since the instantaneous fishing mortality is a linear function of effort or the number of lifts, P is equivalent to the catchability coefficient, q (k_2 in Schaefer's 1954 derivation). Following Schaefer and Beverton (1963), the monthly catch and number of lifts from July 1970, when the number of lifts began to be recorded, to July 1973 were used to develop three simultaneous equations which yielded an average catchability coefficient of 8.4×10^{-4}/lift. The agreement of the estimates is good but the precision of q is unknown (Hennemuth 1961; Schaefer and Beverton 1963).

The average fishing mortality for the 19 mo of December 1971 to June 1973, weighted by the number of lifts in each month, was 0.28/mo.

Capture, Transportation, and Pumping of Threadfin Shad, *Dorosoma petenense*

ROBERT T. B. IVERSEN[1] and JAY O. PUFFINBURGER[2]

ABSTRACT

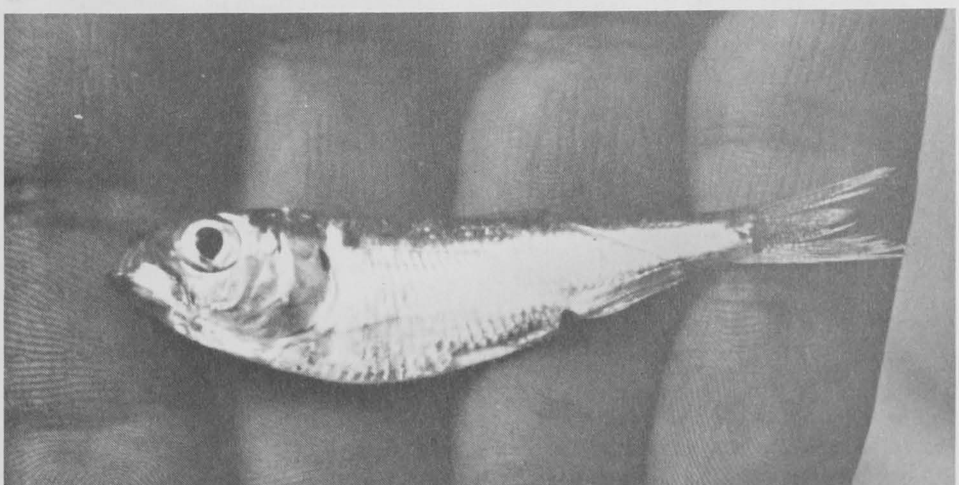
Methods of capturing, transporting, and acclimating threadfin shad, *Dorosoma petenense*, for use as live bait in skipjack tuna, *Katsuwonus pelamis*, fishing are described. The shad were captured in a 122-ha (302-acre) reservoir on Oahu Island, Hawaii, using a seine net either 146 or 110 m long and 7 m deep which was deployed from a skiff 6 m in length. Captured shad slowly swam to the shoreline while enclosed in a pocket of netting alongside the skiff. After being bucketed into 2,347-liter (620-gal) portable tanks, the shad were trucked 37 km to holding facilities at the Honolulu waterfront where they were acclimated to 100% seawater over a 72-h period. Up to 22,500 (40 to 70 mm long) shad in individual portable tanks have been trucked the 37 km distance with mortalities that on occasion have been less than 1%. Five experiments were conducted to determine the feasibility of pumping the shad with a vacuum pump and a centrifugal pump. Shad pumped were from 19 to 95 mm long in groups ranging from 1,210 to 1,633 individuals. Mortalities ranged from less than 0.1% 264 h after pumping to 9.7% 25 h after pumping. Use of the centrifugal pump is recommended.

INTRODUCTION

Development of an alternate live bait for Hawaii's pole-and-line fishery for skipjack tuna, *Katsuwonus pelamis*, by the Honolulu Laboratory, Southwest Fisheries Center, National Marine Fisheries Service, has since 1967 been based in part on the use of threadfin shad, *Dorosoma petenense* (Fig. 1).

In the process of capturing shad from a Hawaii reservoir, acclimating them to seawater, and conducting fishing trials, a considerable amount of experience has been acquired on handling and transportation of shad on a mass scale. The purpose of this report is to describe the techniques we have found successful in handling threadfin shad and also to present the results of several experiments which evaluated two different fish pumps for transferring shad.

Figure 1.—Threadfin shad, *Dorosoma petenense*.



SOURCE OF SHAD

Threadfin shad were first introduced into freshwater impoundments and streams in Hawaii in 1958, and by 1960 had become established in several reservoirs (Hida and Thomson 1962). Attributes of threadfin shad which

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led to their investigation as a new baitfish are: tolerance to both freshwater and seawater, hardiness, silvery color, size, and swimming behavior. In recent years shad in Wahiawa Reservoir, Oahu, have become sufficiently abundant to make large-scale capture and fishing tests possible.

Wahiawa Reservoir is located in central Oahu, 37 km from the Honolulu waterfront, where they were trucked prior to experimental use. The reservoir has a surface area of 122 ha (302 acres) at high water, a maximum depth of 26 m, and contains approximately 1.14×10^{10} liters (3 billion gal) of water. The annual range in surface temperature is approximately 21°-30°C, and the annual fluctuation in water level can be as much as 12 m. Banks of the reservoir are as steep as 45° in many places; this allows the use of relatively deep seines close to shore where the shad often aggregate. The magnitude of the shad population in Wahiawa Reservoir is unknown but probably contains 14,000-17,000 buckets of shad during the summer (William Devick, Hawaii Division of Fish and Game, pers. commun.). During 32 days of baiting in the reservoir between 18 February 1970 and 16 August 1971, we captured 2,076 buckets of shad, an average of 65 buckets/day. More could have been captured, for the amount removed was limited by the carrying capacity of our portable tanks and the holding facilities at docksite. The unit of bait measure in the Hawaiian skipjack tuna fishery is the "bucket," so-called because the fishermen use stainless steel buckets to transfer the bait. A bucket of bait-sized (40-70 mm) shad weighs approximately 3 kg, ±1.5 kg, and contains about 1,500 shad, depending on size.

BAIT SEINE AND SKIFF

The principal seines used measured either 146 or 110 m long by 7 m deep. Side measurement of the square mesh was 6.4 mm. The longer net was set from a skiff 6 m in length, while the shorter net could be set from a 4.8-m skiff. The larger skiff contained a live well that could be used to transport a few buckets of shad to the truck when distance to the capture site was greater than about 0.5 km. A minimum of seven men were needed to set and haul either net, including two scuba divers.

PORTABLE TRANSPORT TANKS

Elliptical fiber glass tanks (Fig. 2) with a capacity of 2,347 liters (620 gal) were used to transport the shad. Each tank is 2.4 m long, 1.8 m wide, and 60 cm deep. An elliptical opening 46 cm wide, 76 cm long, with a raised 30 cm coaming, is located in the center of the lid. The lid is secured to the tank with wing nuts and bolts and can be removed. A detailed description of the tank, base, and lifting A-frame is given by Nakamura (1966). These tanks were originally designed for the transfer of tuna and other pelagic fishes to shoreside tanks. A 7.5-cm-diameter drain pipe is located in the bottom of the tank. We later added a plastic cloth tube 30 cm in diameter by 1.1 m long to the other end of the tank. This allowed rapid transfer of the shad with less crowding in the tank as the water level dropped. The entire tank could be drained in 60 s through this tube. When not in use, the tube was rolled up and held tightly against the outside wall of the tank by a hinged aluminum cover (Fig. 3).

OXYGENATION SYSTEM

The oxygenation system consisted of a 6.8-m^3 cylinder of 100% oxygen, pressure regulator, a 10-gang valve, and hoses leading to two oxygenation stones in each tank (Fig. 4). The oxygenation stones were modified from grinding wheels (#800 grit) 15 cm in diameter. The upper and lower surfaces of the grinding wheels were coated with fiber glass resin and the oxygen bubbles escaped from the outer edges of the stones. Such oxygenation devices release bubbles about 0.25 mm in diameter and are much more efficient than round aquarium stones which release much larger bubbles. For a description of this type of an oxygenation device, see Baldwin 1970.

DOCKSITE HOLDING TANKS

Circular, plastic-lined swimming pools, 7 m in diameter and 1.2 m deep, containing 34,822 liters (9,200

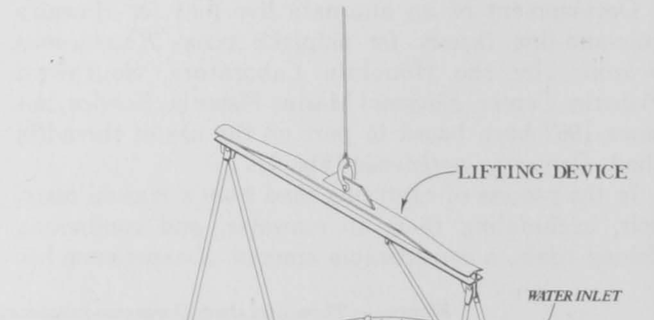

Figure 2.—A diagram of the portable transport tank, base, and lifting device. From Nakamura (1966).

Figure 3.—(a) Plastic cloth tube attached to portable transport tank for rapid unloading of baitfish. (b) Hinged aluminum cover holding rolled up tube against outside of tank (arrow).

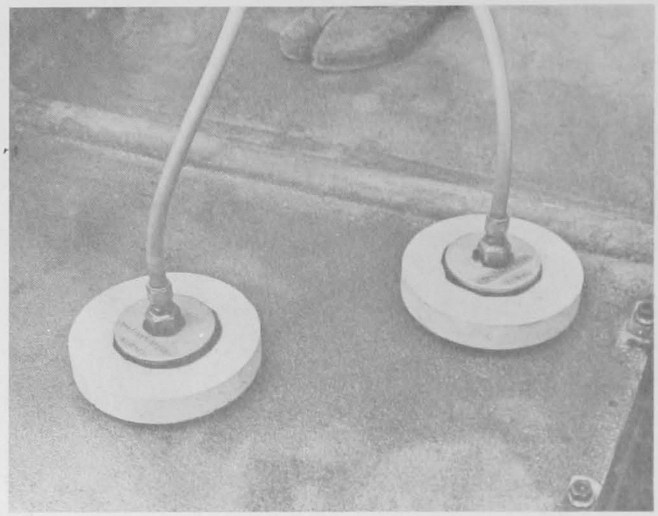

Figure 4.—Oxygenation stones used during transportation of shad. They are modified from 15-cm-diameter grinding wheels.

gal) of water, were used to hold the shad during acclimation to seawater (Magnuson 1965).

FISH PUMPS

Two pumps were tested. One, the Morton[3] batch pump developed by the Oregon State Game Commission (Morton 1963), utilized a vacuum principle to move the shad. The other was a standard centrifugal pump used extensively in the food processing industry.

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

Morton Batch Pump

This device (Fig. 5) is operated on a vacuum principle with a 76.2-mm (3-in) Homelite 1,135 liters/min (300 gal/min) water pump. A 5.2-m snorkel tube, 12.7 cm in diameter, is attached to the top of a fiber glass vacuum tank holding approximately 946 liters (250 gal) of water. The other end of the snorkel tube is submerged in the holding tank. The system is pumped full of water and all air purged from the system by a valve on the top of the vacuum tank. The water flow is then reversed instantaneously by closing two three-way valves. As the water is drawn from the vacuum tank through the bottom, the fish are gently drawn into the tank via the snorkel tube in the holding tank. After the fish enter the vacuum tank, the vacuum is broken by the air-purge valve and the water flow reversed. The end of the snorkel tube is then raised to the receiving tank and the water flow increased. A round brass screen crowder in the bottom of the vacuum tank is slowly raised to the top of the tank, gently forcing the fish into the snorkel tube for delivery to the receiving tank. The screen crowder is then lowered to the bottom of the vacuum tank before the next "batch" of fish enters the tank.

Centrifugal Pump

This system (Fig. 6) consisted of a Pacific Pumping Company 10.2 cm (4 in) BM type standard frame mounted food pump, and a Reliance 3 hp variable speed

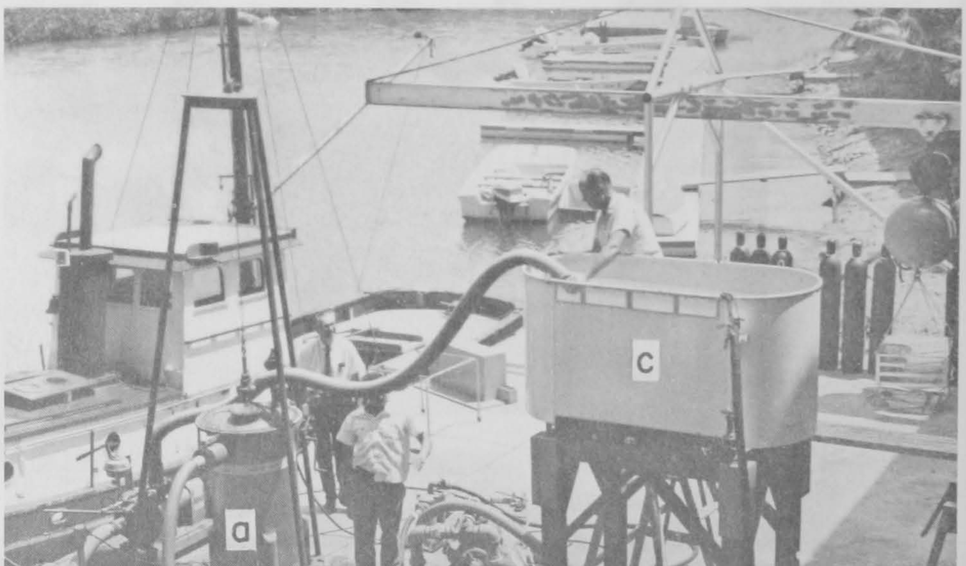

Figure 5.—Morton batch pump system.
(a) Fiber glass vacuum tank.
(b) Pump and motor.
(c) Elevated receiving tank.
(Hawaii Institute of Marine Biology photo.)

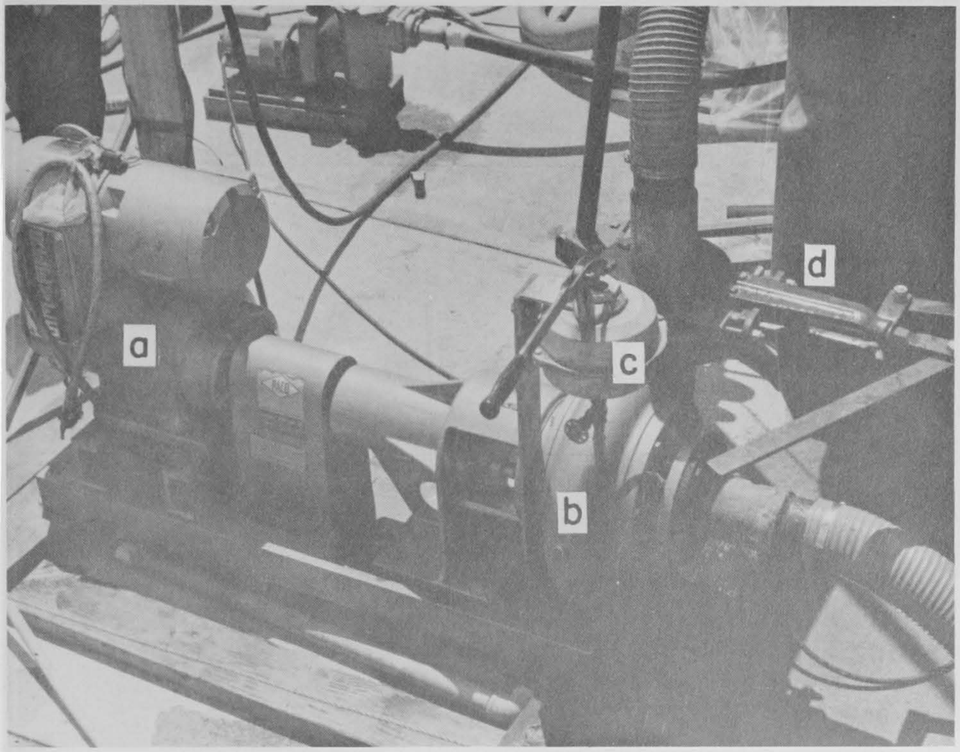

Figure 6.—Centrifugal pump.
(a) Motor. (c) Printing unit.
(b) Pump. (d) Fabri valve.
(Hawaii Institute of Marine Biology photo.)

drive electric motor (600-1,200 rpm). Other components were a 10.2-cm (4-in) Fabri valve and a 12.7-mm (½-in) hand-operated diaphragm priming unit. Smooth bore plastic hose, 10.2-cm diamter, was used on the suction and discharge sides of the pump. This pump has a hollow impeller and the fish pass through the impeller as they move through the pump.

CAPTURE AND HANDLING

Seining

Upon locating a school of shad, the seine was set in a large circle around the school. Some sets were "blind" sets, i.e., sets made with no surface signs of shad. After completion of a set, the ends of the float line were draped over the bow and stern of the skiff, and the ends of the lead line were brought together amidships. One swimmer was positioned at the water's surface next to the skiff to keep the two lead lines close together, and as far as possible, in a vertical position. Two other swimmers using scuba gear were positioned 4.6 to 6.1 m (15-20 ft) below the surface swimmer in order to keep the lead lines together and prevent an opening under the boat through which the shad might escape. In case of snags on bottom debris, one scuba diver could patrol the lead line until the obstruction was cleared. The scuba divers also assisted in pulling the net while underwater.

One end of the net was then hauled until the entire lead line was aboard, and a small pocket of netting was formed alongside the skiff. Bamboo poles and oars were used to keep the pocket from collapsing, and the shad in the pocket were slowly brought to the shoreline with the outboard motor at slow speed (Fig. 7). As much as 128 buckets of shad per set have been captured and delivered to the shoreline in this manner. Times en route after the shad were in the pocket have been as much as 30 min. Upon reaching the shoreline, the floaters of the net were placed over the edge of a floating dock which had one arm extending from each end in order to keep the skiff about 1 m (Fig. 8) from the dock. This prevented the pocket in the net from collapsing. The net was then gradually gathered up and the concentrated shad were bucketed (Fig. 9) to the portable transport tanks on the trailer (Fig. 10). Other species were often captured with the shad, especially *Tilapia* sp., and catches of 25 to 50 kg of tilapia per set were not uncommon. Some tilapia escaped by jumping over the float line (Fig. 7) while others were removed by using a large mesh (5-7 cm) dip net to separate them from the shad. The distance over which the shad were carried in the buckets was not less than about 10 m and occasionally was as much as 40 m.

Transportation[4]

Ten to fifteen buckets of shad were usually placed in each portable tank for the 37-km trip to the docksite, but on two occasions 21 to 27 buckets per tank were carried with mortalities of only 1% or 2%. We carried five por-

[4] This report does not cover experiments in transporting shad during 1975 utilizing a 18,925-liter (5,000-gal) tanker-trailer. A total of 1,241 buckets of shad were captured during 25 days of baiting from 23 June to 18 September 1975. Mortalities during the transport phase were low, less than 10%, but became heavy during the acclimation phase, probably due to excessive handling as the fish were removed from the tanker-trailer.

Figure 7.—Delivering threadfin shad to shore via net. Note the tilapia (arrow) escaping by jumping over the oar and float line.

Figure 8.—Floating dock used in removing shad from the bait seine.

table tanks on a 12.2-m-long (40-ft) flatbed trailer (Fig. 10). Water in the tanks was a mixture of 75% freshwater and 25% seawater, and was not recirculated. Seawater was added to make the transport water more closely isotonic with the shad's internal environment, thus lessening osmotic stress caused by loss of scales during capture and bucketing. Tranquilizing chemicals were not added to the water.

An oxygen level of at least 10 ppm was maintained in the portable tanks, and levels that occasionally reached as high as 17 ppm for a short time did not have any adverse effect on the shad. Oxygen levels were checked about every 30 min with a portable electronic oxygen meter. Under these conditions it was not unusual to find less than 100 dead shad out of 15 buckets (ca. 22,500 individuals) in a portable tank upon arrival at docksite.

Figure 9.—Bucketing shad from the bait seine. Note adequate supply of water in the bucket.

Figure 10.—Portable tanks and trailer used for transporting shad.

On a few occasions we had no mortalities. If the oxygen level went as low as 3 ppm, even momentarily, mortalities as high as 50% sometimes resulted. High oxygen levels are apparently required to offset an oxygen deficit incurred during capture and bucketing.

Upon arrival at docksite, the shad were transferred to the large holding tanks either by immersing the portable tank, minus the lid, and then overturning it (Fig. 11) or through the plastic cloth tube (Fig. 12). Immersing the portable tank resulted in fewer mortalities.

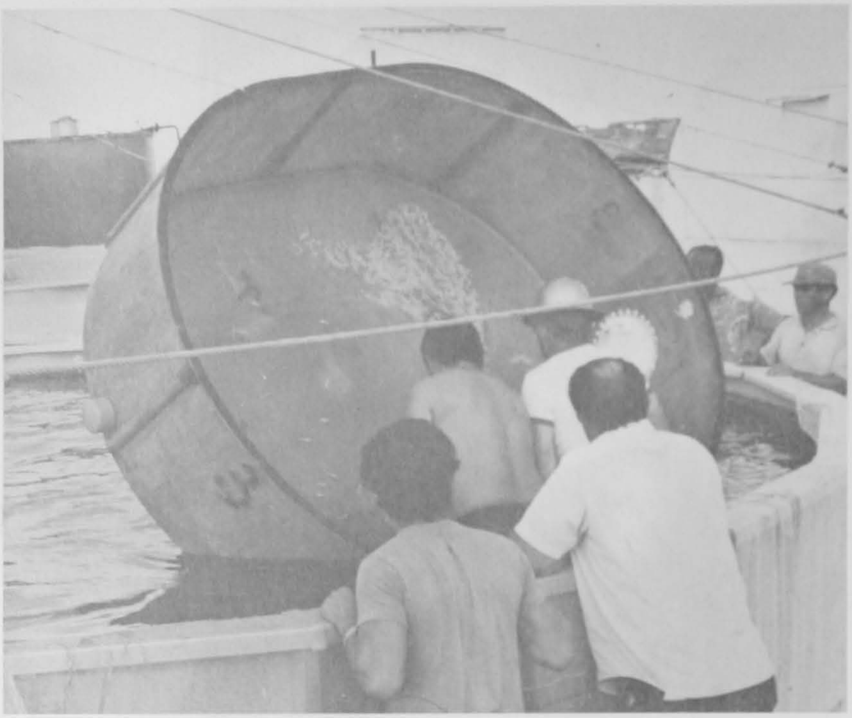

Figure 11.—Overturning a portable transport tank to transfer threadfin shad to the 34,822-liter (9,200-gal) holding tank for acclimation to seawater.

Figure 12.—Plastic cloth tube extending from portable transport tank. The tube is used to flume shad from the portable tank into a larger shad holding tank. The portable tank is partially immersed in the large holding tank.

Acclimating Shad to Seawater

We have found it possible to acclimate shad from freshwater to seawater in 8 h, using shad held in captivity for 2 mo. However, we ordinarily took from 36 to 72 h, preferably 72 h, to acclimate them if the acclimation period occurred just after capture. For a 72-h acclimation period the shad were held in 75% freshwater and 25% seawater for the first 24 h; 50% freshwater and 50% seawater for the next 24 h; 25% freshwater and 75% seawater for the next 24 h. Following this time the freshwater was turned off over a period of several hours. Through trial and error, we have found it impractical to acclimate more than about 50 buckets of shad in a 7-m diameter tank with 34,822 liters (9,200 gal) of water. The flow of water into such a tank should not be less than 284 liters (75 gal)/min, and preferably 378 liters (100 gal)/min. Once the shad are in large holding tanks, the oxygen level should not be less than 5 to 6 ppm. We did not recirculate the water supplying the large holding tanks. When possible, shad were held for several days in 100% seawater prior to placing them aboard vessels for fishing. The best sign of shad in good enough condition to withstand the rigors of a second transfer to a fishing vessel's baitwell is a tank of actively feeding fish. We used a mixture of 50% fish meal and 50% trout chow to feed the shad.

Transfer of Shad to Vessels

Shad were transferred to the fishing vessel either by bucketing or by the portable tank used to transport the shad from the reservoir. A small crowder was used to concentrate the shad for bucketing or for herding into the submerged portable tanks. Bait was drained from the portable tank into the vessel's baitwells by two methods. One method employed a smooth bore plastic hose 10 cm in diameter placed over the 7.5-cm drain pipe. The tank was then lifted by crane, and the bait flowed through the hose into the baitwell. One man was deployed on top of the tank with a seawater hose to flush out the last of the shad and to provide enough weight to tilt the tank slightly. Using this technique, for example, 113 buckets of shad were transferred by hose into three baitwells of the RV *Charles H. Gilbert* during cruise 116 with a mortality of only 2% the following day.

The other draining method employed the large diameter plastic cloth tube and long stainless steel chutes (Fig. 3) to place bait aboard the purse seiner *Jeanne Lynn*. Mortalities aboard the *Jeanne Lynn* averaged 10% for six transfers. Until 1971, over a wide variety of transfer conditions to different vessels, the average mortality of 1,033 buckets of shad the following day was 16%. In some cases, it was necessary to bucket the shad under adverse conditions, or to place shad aboard that had not been completely "rested" following acclimation to seawater. Assuming optimum conditions for transfer, we believe mortalities of 10% or less can be consistently achieved. This is suggested by the fact that placing 204 buckets of shad aboard the fishing vessel *Marlin* during July and August 1971 for commercial fishing trials resulted in a mortality of only 7%. Once shad have adjusted to the baitwell environment, long distance transportation at sea is feasible. The 113 buckets aboard the *Gilbert* during cruise 116 were carried for 14 days to an area 4,300 km southeast of Hawaii for use as live bait in skipjack tuna fishing. Mortalities of these shad en route were negligible.

We placed up to 36 buckets of shad aboard the *Gilbert* in a baitwell containing 10,704 liters (2,828 gal) of water, for a maximum ratio of one bucket of shad per 295 liters (78 gal) of water. Water flow through the baitwell was 378 liters (100 gal)/min. This is less than the ratio of one bucket of shad per 696 liters (184 gal) of water for 50 buckets of shad in 34,822 liters (9,200 gal) of water in the holding tank. When 36 buckets of shad were placed in the baitwell, the mortality was 7% for the first 24 h. On a few occasions when shad were placed aboard commercial skipjack tuna vessels, the maximum crowding ratio was one bucket per 322 liters (85 gal) of water.

PUMPING EXPERIMENTS

During the summer of 1970, the purse seiner *Jeanne Lynn* was chartered by Bumble Bee Seafoods, in a joint venture with the State of Hawaii, to conduct experimental purse seining for skipjack tuna in Hawaiian waters ([Hawaii.] Division of Fish and Game and Bumble Bee Seafoods [1970]. In anticipation of the need to use live bait in conjunction with purse seining, several experiments were conducted during August 1969, to test the feasibility of pumping shad from a portable transport tank to a 1,260-liter (333-gal) receiving tank elevated 3 m above the portable transport tank. The tests simulated pumping bait from the *Jeanne Lynn*'s baitwell to a bait skiff on the deck above.

Following capture, the threadfin shad used in the experiment were acclimated to seawater in the portable transfer tanks instead of the large holding tanks. Water flow through the portable transport tanks was 19 liters (5 gal)/min. An oxygen level greater than 5.0 ppm was maintained by bubbling compressed air through three airstones. Water flow through the elevated receiving tank was 8 liters (2 gal)/min and oxygen was provided in the same manner as the portable transport tanks. The shad were acclimated to seawater over a 48-h period. The shad used for the tests ranged from 13 to 95 mm total length. Mortalities were computed by weight as well as by number.

About 3 to 5 buckets of shad remained in the tanks upon completion of acclimation, but only one to two buckets were pumped during any one experiment. Water temperature in the portable tanks and elevated receiving tank was 24° to 26°C.

After pumping, the dead bait were removed every hour or several hours for the first 4 to 8 h, counted, and weighed. The remainder were left unattended overnight. The following day the dead fish were removed, counted, and weighed. The tank was then drained and the remaining fish were counted and weighed. A screen on the drainpipe prevented the loss of shad between measurement intervals.

Mortalities in the hours following pumping for the five tests are given in Table 1. Mortalities for shad pumped with the centrifugal pump ranged from less than 0.1% by number and weight after 11 days to a high of 5.0% by weight and 9.7% after 25 h. Mortalities of the shad pumped through the batch pump were intermediate. The low mortalities observed during centrifugal pump tests 2 and 3 are apparently due to larger average size of the shad used for these tests. However, the mortalities observed with the smaller shad are still much less than those occurring during the first 24 h with the nehu, *Stolephorus purpureus*, used as skipjack tuna bait by Hawaiian fishermen. The average mortality of nehu for the first day after capture is about 25% (Brock and Uchida 1968).

No significant difference is apparent in mortalities between the two pumps. However, since the batch pump is more difficult to operate, and pumping times are twice as long, the centrifugal pump is recommended for pumping threadfin shad. Care should be taken, however, that all internal surfaces of the pump and impeller are smooth and free of holes. Two preliminary tests when the centrifugal pump had a hole in the impeller resulted in mortalities of 75% to 90% within 5 min after pumping. After the impeller was repaired, rust removed, and the inside of the pump painted, the results cited above were obtained.

ACKNOWLEDGMENTS

We thank Wayne J. Baldwin, Randolph K. C. Chang, Roger E. Green, and Eugene L. Nakamura for reading

Table 1.—Mortalities of threadfin shad after pumping.

Test No.	Date 1969	Total length Range (mm)	Total length Mean (mm)	Quantity pumped (no.)	Quantity pumped (g)	Pumping time (min)	Mortalities Elapsed time (h)	Mortalities Cumulative percent (g)	Mortalities Cumulative percent (no.)
Morton batch pump									
1	8/13	19-51	38	1,348	2,035.2	10	1	0.5	0.7
							2	1.0	1.4
							4	1.9	2.4
							5	2.9	3.7
							7	3.6	4.8
							23	4.6	6.2
2	8/14	51-64	—	1,210	2,960.4	11	1	1.6	1.3
							5	1.9	1.8
							22	2.1	2.0
Centrifugal pump									
1	8/22	13-38	—	1,257	1,699.1	3	1	1.2	2.6
							2	2.3	4.2
							3	2.9	6.0
							5	3.6	7.2
							25	5.0	9.7
2	8/28	19-95	64	1,633	2,629.1	4	1	0.0	0.0
							2	0.0	0.0
							4	0.0	0.0
							8	0.0	0.0
							23	0.1	<0.1
3	8/29	19-95	64	1,511	2,908.1	5	1	0.0	0.0
							2	0.0	0.0
							4	0.0	0.0
							8	0.0	0.0
							24	0.0	0.0
							264	<0.1	<0.1

the manuscript and for technical advice. We also thank the many crewmen, technicians, and biologists of the Honolulu Laboratory, NMFS, for their efforts in catching and transporting the shad. The pumps were provided through the courtesy of Bumble Bee Seafoods and the Oregon State Game Commission.

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A Commercial Tilapia, *Tilapia mossambica*, Hatchery for Hawaiian Skipjack Tuna, *Katsuwonus pelamis*, Fishery—Cost Analysis and Problematical Study

BRUCE L. CRUMLEY[1]

ABSTRACT

The Hawaiian skipjack tuna fisherman spends a good part of his time catching nehu, *Stolephorus purpureus*, for bait instead of fishing. This paper considers pond-raised tilapia, *Tilapia mossambica*, as a possible alternative bait, and sets forth information about a commercial tilapia production plant. If the fishermen purchased tilapia and fished full time, their bait would cost less than it does now, since the current break-even cost to the fisherman of a bucket of nehu is determined to be $30.12, while the highest cost estimate for pond-reared tilapia is $17.56.

The catch rates for tuna when using nehu and tilapia as bait were studied, and found to be comparable. Tilapia still need extensive trials as a bait species, however, and tilapia data need further scrutiny.

Tilapia characteristics, both favorable and unfavorable, are discussed and should offer some insight into the problems and advantages of raising tilapia. The possibility of sharing the tilapia tanks with a compatible, marketable species, and thereby helping to defray expenses, are also discussed.

Fish diseases contracted during three different baitfish rearing studies are reviewed, along with their treatments.

INTRODUCTION

This paper sets forth information about a commercial tilapia, *Tilapia mossambica*, production plant, as far as what must be known and considered prior to the actual investment of cash. I investigated this subject as though this tilapia plant were being directed primarily to furnish tilapia for the local Hawaiian skipjack tuna, *Katsuwonus pelamis*, industry, although at the end of this paper I discuss possible alternative markets for tilapia and alternate uses of the production plant.

I began by studying the economic feasibility of such a production plant. Obviously, the figures used here will not apply in the future because of expected changes in price factors, but they provide a basis from which any interested individual or firm can derive information needed in considering such a commercial enterprise. I also discuss differences between the currently used baitfish, nehu, *Stolephorus purpureus*, and tilapia, and examine their relative efficiencies as skipjack tuna live bait.

I discuss the type of tank construction which has been used in the past and pointed out ways to facilitate such a plant's operation.

BACKGROUND

The Hawaiian skipjack tuna fishery is a live-bait fishery with an average annual ex-vessel value in excess of $2 million. Annual landings average over 4 million kg (9 million lb), but fluctuate between 2 and 7 million kg (5 and 16 million lb). This fluctuation is primarily due to:

1) availability of bait,
2) fragility of the bait, and
3) abundance and availability of the skipjack tuna.[2]

A possible solution to the problem of obtaining an adequate and dependable supply of baitfish would be for the fishermen to purchase bait, and to replace the time spent fishing for it ("baiting time") with time devoted entirely to fishing for aku ("fishing time"). This additional fishing time could increase the annual catch by as much as 66% and provide an increase in ex-vessel value of the catch by $1.9 million. This increase could occur with the existing fleet. Any growth of the fleet would result in an accompanying increase in ex-vessel value, since the skipjack tuna is underutilized (see footnote 2).

The problem then, is to estimate the indirect cost that the fisherman is incurring and the amount of skipjack tuna he is not catching because of the time he is spending baiting. This will give the estimated maximum cost per bucket that the fisherman should be willing to pay for bait. Obviously, this assumes that he will buy bait offered at a price that is less than the cost he is incurring by catching the bait himself. Past experience has shown this not to be the case. In the future, however, increasing

[1]Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

[2]U.S. National Marine Fisheries Service. 1973. The tuna baitfish problem of Hawaii—an assessment and development of an action program. Unpubl. rep. prepared by Staff, Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812, 33 p.

pressure may be exerted upon the fisherman to use his time more efficiently, abandoning the less efficient "traditional" ways that have hindered expansion of the commercial aku industry. This pressure could come from:

1) changing fleet composition, with more modern vessels in the *Anela*[3] class being added, permitting longer trips and travel to better fishing grounds during the off-season (October-April) and, at the same time, increasing the demand for live bait; and
2) increased world demand for high protein foods arising from a rapidly increasing population.

It is to the advantage of this study that the *Anela* has worked with different types of baitfish. This could serve to encourage other fishermen to use species other than the nehu.

One additional point is that the crew size could be reduced without the need for added crew members to bait (see footnote 2).

I have employed the approach used by Shang and Iversen (1971) to determine the indirect cost of baitfish to the fishermen, relying heavily upon Hida et al. (1962) for their statistics. Previously unpublished data gathered by the State Fish and Game Division at the Honolulu Bait Station (HBS) were used in a present-day cost estimate for a commercial tilapia production facility.

AN ESTIMATE OF THE VALUE OF NEHU

A good cost estimate at today's market prices is of prime importance in considering a commercial tilapia production plant. The cost estimate obtained in this paper is derived from prices effective as of 1 January 1974.

To determine the cost of nehu, the same problems present themselves here as they did to Shang and Iversen (1971), those of a vertically integrated system for fishing. Since no market exists for bait, the cost of nehu has been determined indirectly.

I have described an operation similar to that set forth in Shang and Iversen (1971) with 1973 prices for fuel, ice, and total catch. Because final figures are not yet available for the total days fished and days baited, certain assumptions must be made. Using Shang and Iversen's table 2, but with the new prices substituted:

Cost of Fishing and Baiting Per Trip

	Fishing	Baiting
Hours of operation[a]	14	3-h day baiting 5-h traveling
Fuel consumption (gal/h)	12.5	5 gal/h during baiting 12.5 gal/h during traveling
Price of fuel per gallon	$ 0.215	$ 0.215
Price of ice	$17.50	—
Total cost[b]	$55.12[c]	$16.66[d]

a. Fishing: 10-h scouting-fishing and 4-h traveling time (both ways). Baiting: 5-h traveling—about 2 h to Pearl Harbor, 8 h to Kaneohe Bay (both ways).
b. Baiting trip uses less time than fishing trip and allows for more leisure time. The value of leisure time of fishermen is not incorporated in the calculation.
c. (14 × 12.5 × $0.215) + $17.50 = $55.12.
d. (3 × 5 × $0.215) + (5 × 12.5 × $0.215) = $16.66.

This shows that a fishing trip costs $38.46 more than a baiting trip. This must be taken into account when one is talking of increasing fishing time and reducing baiting time.

Referring to Table 1 we can see that the total skipjack tuna catch (in metric tons) did not vary much between 1972 and 1973. Ths actual day-baiting effort and actual days fished were assumed to remain relatively constant for these 2 yr, since the 1973 data for these two areas were not yet available. Shown are the effects of reductions in baiting effort by the amounts of 25%, 50%, 75%, and 100%.

Table 2 shows the number of buckets of nehu caught during day and night baiting. Since the number of buckets of bait caught in 1971 and 1972 did not fluctuate appreciably, an average for these 2 yr was used to estimate the number of buckets of bait caught in 1973.

38,786 buckets
36,713 buckets
75,499 buckets

$$\frac{75{,}499 \text{ buckets}}{2} = 37{,}748 \text{ buckets of bait}$$

Using Shang and Iversen's (1971) formulas:

$$C_0 = \left(\frac{D_b}{D_f}\right)V - (D_b \cdot C_d) \text{ and}$$

$$B_t = B_0 + B_a$$

$$\text{where } B_a = \frac{Q_a}{Q_b} = Q_a \cdot \left(\frac{B_0}{Q_t}\right)$$

and taking the values from Tables 1 and 2, the net opportunity costs (C_0) and the total amount of bait required (B^t) (in buckets) were obtained. Dividing C_0 by B_t gives the break-even price of nehu.

$$C_0 = \$1{,}974{,}673{,}698$$

$$B_t = 65{,}671 \text{ buckets.}$$

The break-even price is $30.12 per bucket of bait. (See p. 145, for calculations.)

[3]The *Anela*, a 26.6-m steel vessel, joined the Hawaiian skipjack tuna fishing fleet in December 1971. Unlike the remainder of the skipjack tuna fleet (about 12 vessels), which consists of boats 17.8 to 24.5 m long with a bait-carrying capacity of only about 35 buckets, the *Anela* is capable of carrying 130 buckets. The *Anela* also has greater fish-carrying capacity and greater range, and represents a new look in the Hawaiian skipjack tuna fishery.

Table 1.—The actual and projected catch and value of skipjack tuna derived by reducing day-baiting effort by 25%, 50%, 75%, and 100%, 1965-72.

Year	Actual day-baiting effort	Actual days fished	Skipjack catch	Value	Catch per day fished	Price per ton	Reduction in day baiting	Reduction in day-baiting effort	Projected days fished	Projected skipjack catch	Projected value	Increase in catch	Increase in value
	No. of days	*No. of days*	*Metric ton*	*Dollar*	*Metric ton*	*Dollar*	*Percent*	*No. of days*	*No. of days*	*Metric ton*	*Dollar*	*Percent*	*Dollar*
1965	838	2,400	7,328.96	2,013,861	3.05	274.78	25	210	2,610	7,960.50	2,187,386	9	175,525
1966	781	2,086	4,256.82	1,403,623	2.04	329.74	25	195	2,281	4,653.24	1,534,359	9	130,736
1967	736	2,010	3,646.80	1,263,116	1.81	346.36	25	184	2,194	3,971.14	1,375,444	9	112,328
1968	1,055	2,177	4,227.41	1,539,617	1.94	364.20	25	264	2,441	4,735.54	1,724,684	12	185,067
1969	864	1,743	2,704.94	1,245,204	1.55	460.34	25	216	1,959	3,036.45	1,397,799	12	152,595
1970	1,017	1,894	3,334.46	1,496,919	1.76	448.92	25	254	2,148	3,780.48	1,697,133	13	200,214
1971	1,334	2,013	6,051.39	2,752,710	3.01	454.89	25	334	2,347	7,064.47	3,213,557	17	460,847
1972	1,187	1,882	4,952.12	2,949,372	2.63	595.58	25	297	2,179	5,730.77	3,413,132	16	463,760
1973	1,187	1,882	4,877.00	3,203,246	2.59	656.84	25	297	2,179	5,643.61	3,706,949	16	503,540
1965	838	2,400	7,328.96	2,013,861	3.05	274.78	50	419	2,819	8,597.95	2,362,545	17	348,684
1966	781	2,086	4,256.82	1,403,623	2.04	329.74	50	390	2,476	5,051.04	1,665,530	19	261,907
1967	736	2,010	3,646.80	1,263,116	1.81	346.36	50	368	2,378	4,304.18	1,490,796	18	227,680
1968	1,055	2,177	4,227.41	1,539,617	1.94	364.20	50	528	2,705	5,247.70	1,911,212	24	371,595
1969	864	1,743	2,704.94	1,245,204	1.55	460.34	50	432	2,175	3,371.25	1,551,921	25	306,717
1970	1,017	1,894	3,334.46	1,496,919	1.76	448.92	50	508	2,402	4,227.52	1,897,818	27	400,899
1971	1,334	2,013	6,051.39	2,752,710	3.01	454.89	50	667	2,680	8,066.80	3,669,507	33	916,797
1972	1,187	1,882	4,952.12	2,949,372	2.63	595.58	50	594	2,476	6,511.88	3,878,345	31	928,973
1973	1,187	1,882	4,877.00	3,203,246	2.59	656.84	50	594	2,476	6,412.84	4,212,209	32	1,008,801
1965	838	2,400	7,328.96	2,013,861	3.05	274.78	75	628	3,028	9,235.40	2,537,703	26	523,842
1966	781	2,086	4,256.82	1,403,623	2.04	329.74	75	586	2,672	5,450.88	1,797,373	28	393,750
1967	736	2,010	3,646.80	1,263,116	1.81	346.36	75	552	2,562	4,637.22	1,688,876	27	425,760
1968	1,055	2,177	4,227.41	1,539,617	1.94	364.20	75	791	2,967	5,755.98	2,096,328	36	556,711
1969	864	1,743	2,704.94	1,245,204	1.55	460.34	75	648	2,391	3,706.05	1.706,043	37	460,839
1970	1,017	1,894	3,334.46	1,496,919	1.76	448.92	75	763	2,657	4,676.32	2,099,294	40	602,375
1971	1,334	2,013	6,051.39	2,752,710	3.01	454.89	75	1,000	3,013	9,069.13	4,125,456	50	1,372,746
1972	1,187	1,882	4,952.12	2,949,372	2.63	595.58	75	890	2,772	7,290.36	4,341,993	47	1,392,621
1973	1,187	1,882	4,877.00	3,203,246	2.59	656.84	75	890	2,772	7,179.48	4,715,770	47	1,512,361
1965	838	2,400	7,328.96	2,013,861	3.05	274.78	100	838	3,238	9,875.90	2,713,700	35	699,839
1966	781	2,086	4,256.82	1,403,623	2.04	329.74	100	781	2,867	5,848.68	1,928,544	37	524,921
1967	736	2,010	3,646.80	1,263,116	1.81	346.36	100	736	2,746	4,970.26	1,721,499	36	458,383
1968	1,055	2,177	4,227.41	1,539,617	1.94	364.20	100	1,055	3,232	6,270.08	2,283,563	48	743,946
1969	864	1,743	2,704.94	1,245,204	1.55	460.34	100	864	2,607	4,040.85	1,860,165	49	614,961
1970	1,017	1,894	3,334.46	1,496,919	1.76	448.92	100	1,017	2,911	5,123.36	2,299,979	54	803,060
1971	1,334	2,013	6,051.39	2,752,710	3.01	454.89	100	1,334	3,347	10,074.47	4,582,776	66	1,830,066
1972	1,187	1,882	4,952.12	2,949,372	2.63	595.58	100	1,187	3,069	8,071.47	4,807,206	63	1,857,834
1973	1,187	1,882	4,877.00	3,203,246	2.59	656.84	100	1,187	3,069	7,948.71	5,221,031	64	2,041,268

Table 2.—Catch, baiting effort, and catch per effort in the fishery for nehu in Hawaiian waters, 1965-72. Percentages of the catch and the effort expended, by day and night baiting operations, are given in parentheses. (Note: The total catch from both day- and night-baiting operations for each year is not the same as that shown in Table 1 because some catch reports failed to designate when the catches were made.) (U.S. NMFS, 1973, see text footnote 2.)

Year	Catch		Baiting effort		Catch per effort	
	Day	Night	Day	Night	Day	Night
	Buckets	*Buckets*			*Buckets*	*Buckets*
1965	19,972 (58)	14,251 (42)	838 (37)	1,424 (63)	23.8	10.0
1966	20,696 (67)	10,242 (33)	781 (44)	1,011 (56)	26.5	10.1
1967	22,336 (71)	9,187 (29)	736 (45)	913 (55)	30.4	10.1
1968	30,148 (86)	4,911 (14)	1,055 (66)	544 (34)	28.6	9.0
1969	25,535 (86)	4,164 (14)	864 (70)	374 (30)	29.6	11.1
1970	30,332 (92)	2,724 (8)	1,017 (78)	290 (22)	29.8	9.4
1971	38,786 (93)	2,776 (7)	1,334 (82)	288 (18)	29.1	9.6
1972	36,713 (94)	2,187 (6)	1,187 (85)	206 (15)	30.9	10.6

Average for 1971 and 1972 = 37,748 + 2,482 = 40,230 buckets = B

$$Q_b = \frac{(4{,}877 \text{ tons of tuna caught 1973})\ (2{,}204.6 \text{ lb/t})}{40{,}230 \text{ buckets}}$$

$$= \frac{10{,}751{,}129 \text{ lb}}{40{,}230} = 267 \text{ lb of tuna/bucket of bait.}$$

This is the price that the fisherman indirectly pays per bucket of baitfish caught. If a baitfish could be offered at a price less than this, the fisherman should, in principle, be willing to buy it since it would be more economical to do so than to catch his own.

COST ESTIMATE FOR CONSTRUCTION OF A COMMERCIAL TILAPIA PRODUCTION PLANT

HBS was run by the State Division of Fish and Game. Construction was finished in March 1962 and rearing of tilapia commenced immediately thereafter. Termination of this pilot project occurred in July 1965 because of the lack of demand by the commercial fisherman in spite of a plentiful supply of skipjack tuna that year.

The total construction costs (1962 prices) for the 10 brood tank, 44 fry-holding tank facility, and a small residence are shown below.

CONSTRUCTION

A.	Contract work items		$119,070.00
B.	Design engineering		
	1. Field survey	—	
	2. Subsurface inspection	—	
	3. Office engineering	$8,248.08	
	4. Consultant services	350.00	
	5. Blueprinting	263.17	
	6. Miscellaneous	132.70	
	Subtotal		8,993.95
C.	Construction engineering		
	1. Field survey	—	
	2. Material	113.44	
	3. Office engineering	—	
	4. Inspection	1,607.09	
	5. Miscellaneous	5.98	
	Subtotal		1,726.51
Total construction costs			$129,790.46

(Source: State Division of Fish and Game.)

As noted in the above figures, there were several areas which were completed at no cost to HBS, but which would have to be taken into account in the construction of such a plant by a private firm or individual. Consequently, a rounded figure of $130,000 is probably somewhat low.

HBS found after some time that this plant should have had an additional 16 fry tanks to handle the fry properly. This would have made a total of 10 brood tanks and 60 fry tanks. Assuming no difference between the cost of a brood and a fry tank, this would have increased construction costs by 23%. Since the $130,000 figure includes the residence, I used section A as the construction cost of the tanks, rounding this figure to $120,000.

$$\frac{(10 + 44) \text{ tanks}}{(10 + 60) \text{ tanks}} = 0.77 \text{ or } 77\% \text{ of the ideal facility actually constructed}$$

$$(\$120{,}000)/\ 77\% = \$155{,}844 \text{ would have been the cost of the ideal facility.}$$

Consequently, the construction cost for the complete 10 brood and 60 fry tank facility would have been approximately $166,000.

The increase in construction costs between 1962 and January 1974 was 64.4%.

$$(164.4\%)\ (\$166{,}000) = \$272.904.$$

The figure, therefore, for such a facility built as of 1 January 1974, would be approximately $273,000.

A commercial tilapia production plant requires about 2 acres of land. At $3.00/sq ft, this would cost $261,360, and land cost plus construction cost would total $534,360 (Tables 3, 4).

Table 3.—Total annual expense incurred raising tilapia on chicken feed; cost per bucket of bait-sized tilapia.

Total production and operating expenses (chicken feed)	$46,585.00	
Total construction and land costs (@ $3.00/sq ft) (2 acres)		$534,360.00
Total + 10% interest on construction and land costs (payable in 12 yr)	49,047.00	588,566.00
Annual total	$95,632.00	
Total fry production in pounds	51,082	
Cost per pound of bait (no profit)	1.87	
Cost per bucket (@ 7 lb/bucket)	13.09	
Cost per bucket (@ 10% profit)	14.40	
Cost per bucket (@ 20% profit)	15.71	

Table 4.—Total annual expense incurred raising tilapia on trout feed; cost per bucket of bait-sized tilapia.

Total production and operating expenses (trout feed)	$57,585.00	
Total construction and land costs (@ $3.00/sq ft) (2 acres)		$534,360.00
Total + 10% interest on construction and land costs (payable in 12 yr)	49,047.00	588,566.00
Annual total	$106,632.00	
Total fry production in pounds	51,082	
Cost per pound of bait (no profit)	2.09	
Cost per bucket (@ 7 lb/bucket)	14.63	
Cost per bucket (@ 10% profit)	16.09	
Cost per bucket (@ 20% profit)	17.56	

OPERATING EXPENSES

Utility Costs

Electricity.—HBS paid an average of $375 per month for power. This would cover only 77% of the electricity costs of a 70-tank facility.

$$(\$375)/77\% = \$487.01.$$

The cost per kilowatt hour in 1962 was $0.03125.

$$\frac{\$487.01}{\$0.03125} \simeq 15{,}600 \text{ kwh/month.}$$

The cost per kilowatt hour for 1 January 1974 was $0.03351.

$$(\$0.03351)\ (15{,}600 \text{ kwh}) \simeq \$523.00.$$

Water.—The maximum rate of water usage at HBS was 40 gal/min (Table 5). Again (40 gal/min)/77% = 51.94 gal/min for the ideal case. This volume of water requires a code 06 m, with a monthly base charge at January 1974 rates of $7.50 (Board of Water Supply, Water Service Rate Schedule, effective 23 December 1970).

The average number of gallons of freshwater used per month would be 1,112,879 gal (Table 5) with the 23% increase included or 2,225,758 gal bimonthly. Bimonthly rates apply with a code 06 m.

Table 5.—Quantity of water used during one year of raising tilapia at Honolulu Bait Station.

Month	Gallons of fresh water
January	84,000
February	21,000
March	105,000
April	735,000
May	1,344,000
June	1,743,000
July	1,491,000
August	812,000
September	1,407,000
October	1,218,000
November	987,000
December	336,000
Total	10,283,000

$$\frac{10{,}283{,}000}{(12)\ (77\%)} = 1{,}112{,}879 \text{ gal/mo}$$

Using the maximum amount of water used in June, we can calculate the number of gallons per day and hour and minute:

$$\frac{1{,}743 \text{ gal/mo}}{30 \text{ days}} = 58{,}100 \text{ gal/day}$$

$$\frac{58{,}100 \text{ gal/day}}{24 \text{ h/day}} = 2{,}400 \text{ gal/h}$$

$$\frac{2{,}400 \text{ gal/h}}{60 \text{ min/h}} = 40 \text{ gal/min.}$$

First 100,000 gal @ $0.37/1,000 gal	=	$ 37.00
Next 700,000 gal @ $0.30/1,000 gal	=	210.00
Next 2,000,000 gal @ $0.22/1,000 gal for 1,425,758 gal	≃	314.00
Total bimonthly water costs		$560.00

Sewer charges.—Although there are no sewer charges at this time, I feel that they should be included since they will probably have to be taken into consideration for any future plant operation. Proposed charges are substantial: $0.40/1,000 gal of freshwater used. For 1,112,879 gal/mo (Table 6), the cost would be approximately $445/mo.

Table 6.—Monthly and annual total operating expenses of tilapia rearing facility.

Operating expenses	Monthly	Annual
Utility costs:		
Electricity	$ 523.00	$ 6,276.00
Water	287.50	3,450.00
Sewer charges	445.00	5,340.00
Labor	2,125.00	25,500.00
Maintenance	68.25	819.00
Miscellaneous	100.00	1,200.00
Total	$3,548.75	$42,585.00

Labor

A facility such as this would require at least three persons for maintenance and operation. They would have the responsibilities of cleaning the tanks, handling the paper work, feeding the tilapia, and supervising the loading of the bait aboard fishing vessels. The annual wages of two employees with a GS-2 level and a supervisor with a GS-7 level would give a fairly accurate salary assessment. Current salaries run:

2 GS-2 @ $6,800	=	$13,600 annually
1 GS-7	=	11,900 annually
Total		$25,500 annually

Maintenance and Repair

Cost of maintenance and repair should run approximately 6% of the total construction cost of $273,000. Prorated over a 20-yr period, this equals $819/yr.

Miscellaneous Expenses

Approximately $1,200 a year should cover such items as office supplies and equipment. See Table 6 for total operating expenses.

PRODUCTION AND PRODUCTION COSTS

Brackish water breeding at HBS resulted in a threefold increase over that of the freshwater control. HBS estimates (the numbers were not as carefully controlled as the Hida et al. project) agreed closely with the Hida et al. (1962) report. The production at Paia, Maui, was 1,033 bait-size fish per female per year (Hida et al. 1962). Production with brackish water would have been 3 × 1,033 = 3,099 fry. With 3,000 females, the estimated annual production at HBS would have been 3,000 × 3,099 = 9,297,000 bait-size fish. With 182 bait-size fish equal to 1 lb (Brock and Takata 1955), the production for such a facility would be:

$$\frac{9{,}297{,}000}{182} = 51{,}082 \text{ lb of baitfish per year}$$

and

$$\frac{51{,}082 \text{ lb}}{7 \text{ lb/bucket}} = 7{,}297 \text{ buckets/yr.}$$

Feed requirements would run about 50,000 lb/yr. Chicken feed is currently about $0.08/lb and trout feed is approximately $0.30/lb. This gives:

Chicken feed = $4,000 annually or $334/mo
Trout feed = $15,000 annually or $1,250/mo.

The above data are given in Tables 3 and 4 and show the cost per bucket at 10% and 20% profits with these two types of feed. Since three persons could also operate a 20/120 plant, the cost per bucket should remain the same even after doubling this 70-tank facility. The price may even decrease. Depending upon the finances of the individual or firm, then, the size of the tilapia plant could theoretically be expanded to fill the entire fleet's live-bait needs, though I presently regard tilapia as only a supplemental baitfish.

Using the figures from Table 2 to obtain the number of buckets of bait caught, and my calculations of tilapia production, it is seen that this 10/60 commercial plant would provide 19% of the total day baitfish requirement for the present skipjack tuna fleet. If this plant were increased in size and production to, say, 25% of the total bait needs of the fleet, the projected value of its production can be seen in Table 1.

Effectiveness of Tilapia as Baitfish

I have so far assumed that tilapia would be as acceptable to the skipjack tuna fisherman as the currently used live bait, nehu. There are several points overlooked by such an assumption. First, the number of pounds of skipjack tuna caught per pound of bait used might differ between tilapia and nehu. Secondly, tilapia exhibit different swimming characteristics from nehu. Thirdly, the hooks currently used are shiny and somewhat similar in appearance to nehu; tilapia are darker in coloration and present a greater contrast to the hooks than do nehu.

The total mortality of nehu in the baitwells of the Hawaiian skipjack tuna fleet has been calculated by Yoshida et al. (1977) and found to average 21.7% from 1960 through 1972. For the period from 1954 through 1972 (Table 7), I obtained a mean value of 50.25 lb of tuna caught per pound of nehu used (see Calculations, p. 145). Nehu may be more efficient than this during the peak fishing season (May-September) and less so during the other months.

For comparison, I took information from all the literature which mentioned use of tilapia as skipjack tuna bait (Table 8). I converted the number of skipjack tuna taken with tilapia into pounds, using 18 lb as the average weight for tuna caught between May and September (King and Wilson 1957). From Shomura's (1964)

Table 7.—Annual catches of skipjack tuna and live bait from 1954 through 1972.

Year	Metric tons of skipjack	Buckets of nehu
1954	6,360.13	43,737
1955	4,397.43	49,712
1956	5,049.58	40,864
1957	2,780.66	30,638
1958	3,100.15	33,303
1959	5,630.65	37,637
1960	3,338.46	22,849
1961	4,941.66	37,092
1962	4,270.81	34,256
1963	3,673.86	32,670
1964	4,093.10	30,606
1965	7,328.96	36,352
1966	4,256.82	31,603
1967	3,646.80	31,832
1968	4,227.41	35,535
1969	2,704.94	30,096
1970	3,334.46	33,596
1971	6,051.39	42,098
1972	4,952.12	38,970
Total	84,139.39	675,446

Date	Vessel	No. schools chummed w/tilapia	Scheme employed	No. buckets nehu	No. skip-jack[1]	Pounds skipjack caught	No. skipjack per bucket nehu	Pounds skipjack per pound nehu	No. buckets tilapia	No. skipjack per bucket tilapia	Pounds skipjack per pound tilapia
6/15/54	*Makua*	1	Attract with nehu, then chum with tilapia and nehu alternately.[2]	—	11 (small)	—	—	—	5	—	2.5 (assume 2 lb)
8/ 4/54	*Darling Dot*	2	Attract with nehu, then chum with nehu and tilapia.[2]	20	[3]313	8,184	—	—	2	—	104
9/21/54	*Buccaneer*	1	Attract with nehu, then chum with nehu initially then with tilapia alone.[2]	30	—	3,860	—	—	2	—	—
6/21/56	*Orion*	3	One school of three chummed first with tilapia. Nehu and tilapia may have been used in some.[4]	30	911/59	—	30.2	—	5	11.8	30.4
6/26/56	*Orion*	3	All three schools chummed first with tilapia.[4]	30	627/275	—	31.4	—	12	22.9	[5]59
7/11/56	*C. H. Gilbert*	6	Five schools chummed first with tilapia, others with nehu.[4]	—	56/—	—	3.5	—	—	—	—
7/12/56	*C. H. Gilbert*	2	Both schools chummed with tilapia only.[4]	2	—	—	—	—	2	—	—
7/26/56	*Marlin*	2	One school chummed first with tilapia, others with nehu.[4]	14	86/31	—	6.1	—	4	7.8	[5]20
7/27/56	*Marlin*	1	Chummed first with nehu, then tilapia.[4]	10	72/93	—	7.2	—	5	18.6	[5]48
8/10/56	*Buccaneer*	4	All four schools chummed first with tilapia, two others chummed first with nehu.[4]	5	12/1	—	2.4	—	4	0.1	—
9/22/56	*Buccaneer*	2	Both schools chummed only with tilapia.[4]	—	—	—	—	—	2	—	—
7/22/58	*Amberjack*	—	Tilapia and nehu used at discretion of fishermen. Estimate of buckets used derived from pounds used.[6]	17	—	4,110	26.6	30.7	5	14.0	16.2
8/25/58	*Olympic*	—	Same as above	14	—	9,000	21.7	68.8	6.5	15.4	48.6
8/30/58	*Olympic*	—	Same as above	—	—	4,500	—	—	6	21.0	53
9/ 4/58	*Olympic*	—	Same as above	6.4	—	9,000	22.4	44.4	4.6	40	79.2
7/ 8/59	*Tradewind*	—	Same as above	5	—	6,708	11.6	198.0	< 1	2.1	4.8
7/10/59	*Tradewind*	—	Same as above	26	—	9,100	21.7	35	2.6	2.1	5.0
7/10/59	*Sooty Tern*	—	Same as above	39.5	—	18,030	30	65	1.7	1.4	2.5
7/30/59	*Sailfish*	—	Same as above	12.8	—	5,600	31.7	56.7	2.6	10.5	27.5
7/31/59	*Sailfish*	—	Same as above	20.6	—	6,943	1.7	40.9	11.6	7.0	13.0
8/10/59	*Buccaneer*	—	Same as above	9	—	4,429	9.8	37.0	2	42.7	156.2
8/11/59	*Buccaneer*	—	Same as above	34	—	10,114	131.3	32.5	3	44.0	105.3
8/12/59	*Buccaneer*	—	Same as above	3	—	5,120	17.5	39.8	9	29.4	67.0
8/27/59	*Sailfish*	—	Same as above	13	—	15,000	—	55.5	15.4	—	92.5
9/ 5/59	*Sailfish*	—	Same as above	—	—	5,600	—	—	13	21.7	62.2
9/ 7/59	*Olympic*	—	Same as above	—	—	9,500	—	—	13	16.1	50.0
1952-62	*C. H. Gilbert*	6	Nehu and tilapia altered every 2 min.[7]	—	—	—	—	—	—	—	—
5/62-8/62	*Broadbill*	73	Used as live bait for pole-and-line fishing in connection with monofilament gill netting. Tests not designed to test tilapia as skipjack bait.[8]	—	—	—	—	—	—	—	57

[1]Number of skipjack tuna caught with nehu/number of skipjack tuna caught with tilapia.
[2]Source of data—Brock and Takata 1955.
[3]At approximately 19 lb per tuna.
[4]Source of data—King and Wilson 1957.
[5]Assume 18 lb per skipjack tuna due to time of year.
[6]Source of data—Hida et al. 1962.
[7]Source of data—Yuen 1969.
[8]Source of data—Shomura 1964.

data, I obtained a value of 57 lb of tuna per pound of bait. The average for the five papers consulted was 53 lb of skipjack tuna caught per pound of tilapia used. This agrees with Hida et al. (1962) at least in part because the large quantity of data that they contributed caused this final figure to be skewed in their direction.

I feel that this 53-lb figure may not be real, because, as can be seen in Table 8, the ratio between the amount of nehu used and the amount of tilapia used in these trials was quite high, and it appears that most, if not all, of the trials did not provide a nonbiased test for tilapia. The tilapia were probably used as if they were nehu, with little regard for tilapia's own special characteristics and associated problems, which also probably biases the data; but, observing the trial dates, it can be seen that they were conducted during the "fishing season," which could be the reason for a high efficiency figure. Evaluation of these different factors is difficult and will not be attempted here. However, it appears that the efficiency of tilapia, as measured by available data, is quite comparable to the efficiency of nehu in catching skipjack tuna.

As mentioned earlier, there are several problems with tilapia. They are slower swimmers than nehu, and with present fishing methods, the tilapia are "left behind," causing the tuna to fall behind also, and out of range of the pole and line. Tilapia reportedly have a tendency to sound, which also draws the tuna out of range of the pole and line.

The color contrast between nehu and tilapia makes the tilapia a less desirable supplemental baitfish, because the shiny hooks presently used more closely approach the coloration of nehu than that of tilapia. Thus the tuna might be able to differentiate more easily between the hooks and tilapia, making it less effective under the present fishing method.

Another drawback mentioned previously is the sharp dorsal spines that tilapia have, which are apt to injure the chummer's hands. For the size of a baitfish (3.8-6.4 cm), however, the spines should be too poorly developed to present a problem.

Problems and Advantages of Tilapia Culture

One major problem in culturing tilapia is the need for controlled growth. There is a need to cultivate the correct bait-sized fish, and predict when they will reach such a size. In addition, cannibalism occurs in this species, calling for a continuing separating procedure.

On the other hand, there are numerous advantages to using tilapia. They are very hardy and relatively easy to cultivate. They can be raised in fresh, brackish, or salt water, with proper acclimatization. Properly acclimatized, the mortality is negligible, say 5% at most, when held in a baitwell for extended periods. In addition, the fisherman probably will not have to "rest" the bait as he currently does.

Tilapia are edible, and fish that have grown beyond bait size could be sold for human consumption. A public information program would probably have to be carried out, however, before tilapia is readily accepted as food fish.

"Ogo," *Gracilaria coronopifolia*, an algae which is sold locally, could possibly be grown in conjunction with tilapia (E. L. Nakamura, Southeast Region, National Marine Fisheries Service, NOAA, Panama City, Fla., pers. commun.). Since it appears that tilapia do not actively feed upon this algae, it could be harvested, providing additional income and thus helping to defray the operating expenses of a tilapia production plant. There may be other species that could share the tilapia tanks and help defray operating costs while not harming, or being harmed by, the tilapia.

Enclosing the tanks and regulating the temperature could aid in maintaining a constant production throughout the year, and would provide protection from predators and poachers.

Fish Diseases, Cures, and Prevention

Knowledge of fish diseases or parasitic infestations is very important because they can kill a large quantity of fish in a matter of hours or a few days. Hatchery operators must constantly check the fish tanks and fish to ensure early detection and must institute treatment promptly.

Hida et al. (1962) described their problems. Their tanks remained almost disease free in 1958; a minor outbreak of the protozoan *Trichodina* occurred which was controlled by treatment with 0.5 ppm copper sulfate or 3 ppm potassium permanganate solution. They also encountered acute catarrhal enteritis, and because there was no known cure, they simply increased the flow of freshwater. They gave a prophylactic treatment of 3 ppm potassium permanganate or 0.5 ppm copper sulfate before adding new fry in 1959. They attributed their low infection rate, in part, to having an independent water supply for each tank instead of using recirculated water.

Uchida and King (1962) encountered infestations by the ectoparasite, *Trichodina*, and reported that potassium permanganate (3 ppm) was easiest to use and as effective as other methods. They used the same solution to control the protozoan *Chilodon*. Acute catarrhal enteritis, now called infectious pancreatic necrosis, is a viral infection which has characteristics similar to those caused by the protozoan *Octomitus salmonis*. The symptoms are whirling or corkscrewing accompanied by rapid ventilating, and subsequent sinking to the bottom and cessation of feeding. A "pin head" appearance results from this last symptom. Uchida and King found that by treating the feed with PMA (pyridylmercuric acetate) both of these latter diseases were eventually controlled. They also periodically added potassium permanganate as a prophylactic treatment. Their conclusion was that the single most important factor favoring diseases was overcrowding.

The HBS also encountered fish diseases. They had problems with a "whirling" disease and corrected this by changing the diet from pelleted dry feed to algae. Their prebait-size fish suffered from "pin head" a condition that was corrected by using filamentous algae collected from the ocean, alfalfa pellets, and cooked taro peels. This ailment was believed to have been caused by insufficient algae production in the tanks. They experienced heavy mortality among bait- and prebait-size fish caused by an unidentified disease. They treated this with a 12-h 0.8 ppm copper sulfate solution once every fourth day and increased the rate of water turnover from once every 2.5 days to once every 5 h.

FEATURES OF TANK CONSTRUCTION

The construction of the brood and fry tanks is very important in facilitating the overall operation of a tilapia plant. The cannibalistic characteristics of tilapia make it necessary to separate fry from the brood stock and different size fry from one another.

The HBS constructed a lip around the rim of the brood tanks that provided an area of refuge for the fry (Fig. 1). Periodically, this trough was emptied into fry tanks that had been "aged" with heavy growths of algae upon which the fry fed. There needs to be sufficient difference between the level of the trough and that of the fry tank to create a good head of water for flushing the fry easily and quickly from one location to another. There should also be a cascade arrangement between fry tanks for further separation after the fry begin to grow. Frames with different mesh sizes might also be used to separate the fry.

The bottom of the tanks should slope so as to drain properly and facilitate cleaning. Hose connections should be handy, and might even be saltwater outlets to reduce freshwater consumption.

Plumbing should be arranged so that water can be filtered and recirculated if desired, and proper lighting should be considered for night work and transferring the bait to the baitwells of the vessels.

A good pier with easy access both from land and sea should be available. Work saving devices might include a trough system to deliver bait to the baitwells, a movable crane, preferably motorized, for moving heavy objects, and an automatic feeder. The resulting ease of maintenance and operation would reduce personnel needs, helping to keep costs down.

CONCLUSIONS

In this paper I have analyzed the current break-even cost to the skipjack tuna fisherman of his bait, using an indirect method. I concluded that this cost, to the fisherman, is $30.12 per bucket of bait.

I analyzed the pilot tilapia production plant that was funded and run by the State Division of Fish and Game. From their raw data I drew a current cost estimate for a similar plant that could be theoretically increased to any size to handle either a portion or all of the bait needs of the current skipjack tuna fleet. Using the highest cost estimates, 10% interest on construction costs, land costing $3.00/sq ft payable over a 12-yr period, and using trout feed, I still obtained a cost per bucket of tilapia of $17.56. This includes a 20% profit for the producer.

Therefore I submit that if fishermen no longer catch bait, but purchase it instead and spend full time fishing, their bait will cost them less.

I also looked at the catch rates for tuna when using nehu and tilapia as bait, and found them to be comparable. Tilapia still need extensive trials as a bait species, however, and tilapia data need further scrutiny.

Tilapia characteristics, both favorable and unfavorable, were discussed and should offer some insight into the problems and advantages of raising tilapia. I also mentioned the possibility of sharing the tilapia tanks with a compatible, marketable species, and thereby helping to defray expenses.

Fish diseases contracted during three different baitfish rearing studies were reviewed, along with their treatments.

CALCULATIONS

$$C_0 = \frac{D_b}{D_f} V - (D_b \cdot C_d)$$

$$= \frac{1187}{1882} (\$3{,}203{,}246) - (1{,}187 \text{ days}) (\$38.46)$$

$$= \$1{,}974{,}674 \text{ net opportunity cost}$$

$$B_a = \frac{Q_a}{Q_b} = Q_a \frac{B_0}{Q_t}$$

= 3,072 tons (40,230 buckets/yr) / (4,877 tons caught for 1973)

= 25,341 buckets (additional amount of bait required to catch additional skipjack tuna)

$$B_t = (B_0 + B_a)$$

= (40,230 buckets) + (25,341 buckets)

= 65,571 buckets.

Break-even (maximum) price for nehu:

C_0/B_t = 1,974,674/65,571 = $30.12.

Determination of the number of pounds of tuna caught per pound of nehu used.

Total number of metric tons of skipjack tuna caught from 1954 through 1972 (from Table 7):

(84,139.39 t of tuna) (2,204.6 lb/t)

= 185,493,699 lb of tuna caught.

Total number of buckets of nehu caught, 1954-72: (673,446 buckets of nehu caught) (21.7% mortality)

= 146,137.782 buckets of nehu died

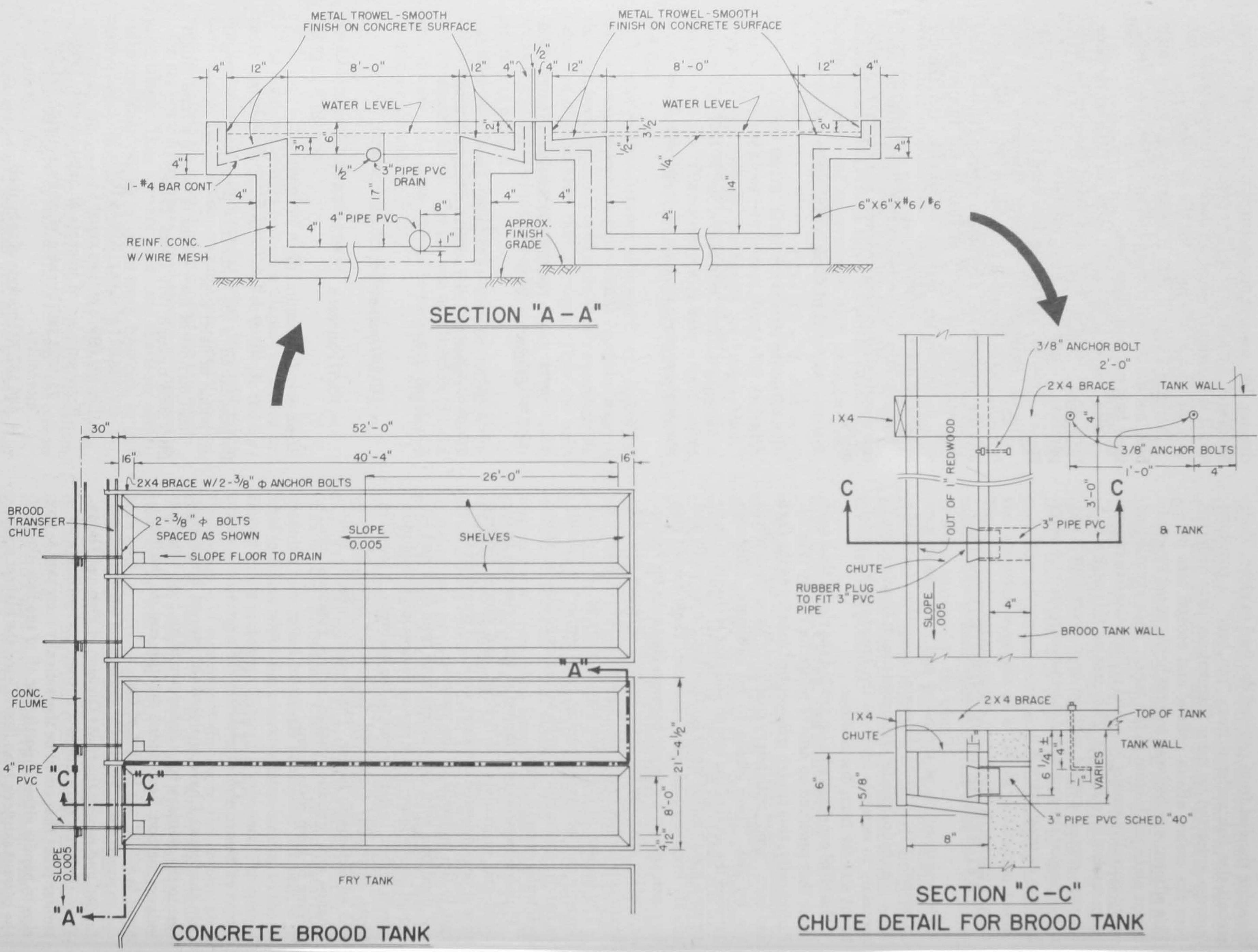
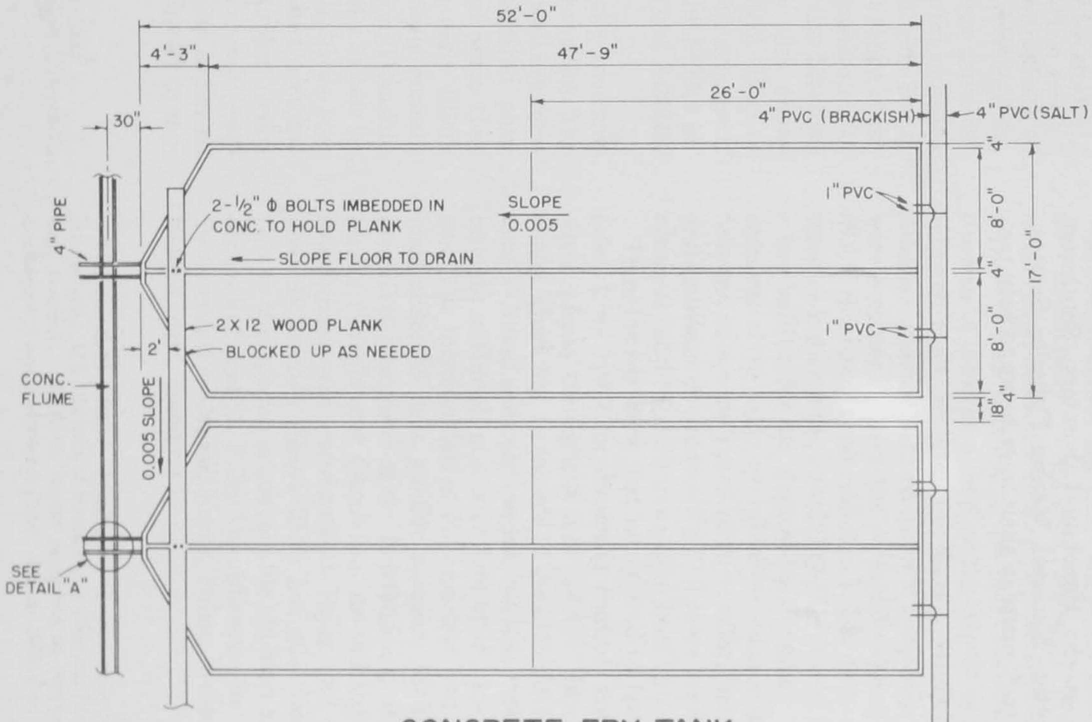
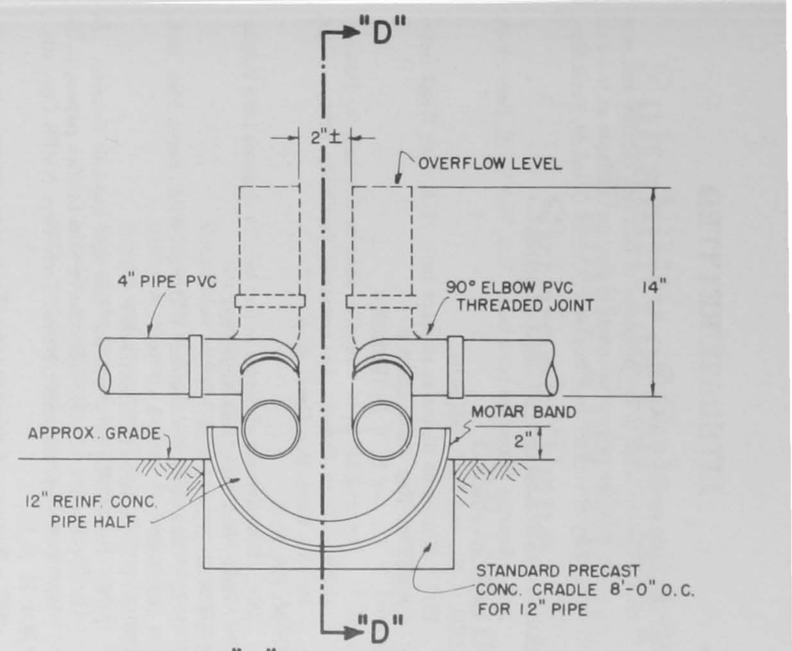

METAL TROWEL-SMOOTH FINISH ON CONCRETE SURFACE
WATER LEVEL
1-#4 BAR CONT.
3" PIPE PVC DRAIN
4" PIPE PVC
REINF. CONC. W/WIRE MESH
APPROX. FINISH GRADE
6"X6"X#6/#6
SECTION "A-A"
52'-0"
40'-4"
26'-0"
2X4 BRACE W/2-3/8" ф ANCHOR BOLTS
BROOD TRANSFER CHUTE
2-3/8" ф BOLTS SPACED AS SHOWN
SLOPE 0.005
SHELVES
SLOPE FLOOR TO DRAIN
CONC. FLUME
4" PIPE PVC
21'-4 1/2"
FRY TANK
CONCRETE BROOD TANK
3/8" ANCHOR BOLT
2X4 BRACE
TANK WALL
1X4
3/8" ANCHOR BOLTS
OUT OF 1" REDWOOD
3" PIPE PVC
℄ TANK
CHUTE
RUBBER PLUG TO FIT 3" PVC PIPE
BROOD TANK WALL
TOP OF TANK
VARIES
3" PIPE PVC SCHED. "40"
SECTION "C-C"
CHUTE DETAIL FOR BROOD TANK

Figure 1.—Copies of blueprints from which the Honolulu Bait Station constructed brood and fry tanks for the rearing of young tilapia.

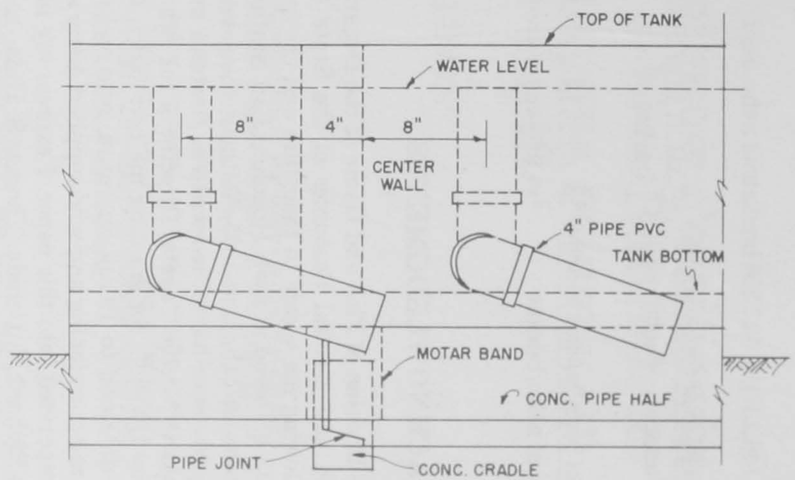
A. Overall plan for the concrete brood tank.
B. Detailed end view of two concrete brood tanks.
C. Chute detail of brood tank.
D. Detail of concrete drain flume.
E. Concrete tank for rearing tilapia fry.



CONCRETE FRY TANK



DETAIL "A"



SECTION "D-D"

(673,446) − (146,137) = 527,308 buckets of nehu used

$$\frac{185{,}493{,}699 \text{ lb of tuna caught}}{527{,}308 \text{ buckets of nehu used}} = 351.77 \text{ lb of tuna/bucket of nehu}$$

$$\frac{351.77 \text{ lb of tuna/bucket of nehu}}{7 \text{ lb. of nehu/bucket}} = 50.25 \text{ lb of tuna/lb of nehu used}$$

ACKNOWLEDGMENTS

I thank the Division of Fish and Game of the Department of Land and Natural Resources of the State of Hawaii for allowing me access to their files and the use of the raw data gathered at their Honolulu Bait Station during the years 1962 through 1965. Without their data this paper could never have been written. I extend my personal thanks to Michio Takata, Director of the State Fish and Game Division, for granting me permission to publish their data and to Takuji Fujimura, who had to bear with all my questioning and who supplied many of the ideas incorporated into this paper. I express my indebtedness to Richard N. Uchida, Thomas S. Hida, and Tamio Otsu at the Honolulu Laboratory, Southwest Fisheries Center, National Marine Fisheries Service, NOAA, who took many of their busy hours to help me.

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Suitability of Cultured Topminnow *Poecilia vittata*, Family Poeciliidae, as a Live Baitfish for Skipjack Tuna, *Katsuwonus pelamis*, in the Tropical Pacific[1]

WAYNE J. BALDWIN[2]

ABSTRACT

An account is given of the use of the topminnow *Poecilia vittata* and other species of the family Poeciliidae as live baitfishes for skipjack tuna, *Katsuwonus pelamis*, in Hawaii. The other species are: sailfin molly, *P. latipinna*; sharpnose molly, *P. sphenops*; Mexican molly, *P. mexicana* (new distribution record); guppy, *P. reticulata*; mosquitofish, *Gambusia affinis*; swordtail, *Xiphophorus helleri*; and platyfish, *X. maculatus*. Optimum biological and technical factors that can be applied toward the intensive culture of *P. vittata* are briefly discussed; included are water temperature, salinity, water exchange rate, dissolved oxygen, pH, lighting requirements, population density, sex ratio, and food and feeding. Recommendations for facility design are also noted.

INTRODUCTION

Recent studies conducted at the Hawaii Institute of Marine Biology (HIMB) with the topminnow *Poecilia vittata* (Fig. 1) indicate that this species has considerable potential as a cultured, live baitfish for skipjack tuna, *Katsuwonus pelamis*. This species is very hardy and can be reared successfully under a wide range of environmental conditions. Currently under investigation in American Samoa is a similar topminnow, the Mexican molly, *P. mexicana*. The Mexican molly also shows promise as a cultured baitfish (S. N. Swerdloff, Office of Marine Resources, Pago Pago, American Samoa, pers. commun.). This study was supported by the NOAA office of Sea Grant under Grant Nos. GH-93 and 2-35243, and the University of Hawaii.

Fishes of the family Poeciliidae are generally known as topminnows, mosquitofishes, livebearers, or mollies. The several species of Poeciliidae present in Hawaii are combined under the vernacular name tabai. Hawaiian pole-and-line fishermen are familiar with tabai since they were used a live bait as far back as the early 1930's (Baldwin 1974). Large quantities of tabai were periodically captured from the shallow mud flats in Honolulu Harbor near Sand Island and used successfully as bait for skipjack tuna, especially when nehu, *Stolephorus purpureus*, was in short supply. Reports indicate that tabai were less effective than the traditional nehu, but nevertheless they were successfully employed for many years until the supply diminished from the effects of harbor development and it became increasingly difficult to capture sufficient quantities for fishing.

Although actual sea trials with *P. vittata* in Hawaii were inconclusive (Yuen 1961[3]; Baldwin 1974), sufficient information was accumulated from these tests and from reports of their past use as live bait to indicate the effectiveness of tabai as a baitfish for attracting and holding skipjack tuna. In addition, tests conducted at sea in American Samoa with cultured *P. mexicana* during 1974 were encouraging as to the potential value of this species (S. N. Swerdloff pers. commun.). The following characteristics indicate the suitability of cultured *P. vittata* as a live baitfish for the tropical Pacific area: 1) easy and economical to rear by intensive culture methods; 2) tolerant to a wide range of freshwater, brackish-water, and saltwater environments; 3) disease resistant; 4) omnivorous; and 5) viviparous (live bearing).

Topminnows were first introduced to Hawaii in 1905 (Van Dine 1907) for mosquito control, and they have since spread throughout most of the Hawaiian Island chain. There are no records of the introduction of *P. vittata*, a Cuban endemic species, but it is likely that it was brought to Hawaii at a later date by tropical fish hobbyists. The introduction of *P. mexicana* into Samoa may have occurred in a similar manner. Many species of poeciliids now have wide distributions, especially the genera *Poecilia* and *Gambusia*. An unknown species of topminnows was introduced to Palau and Saipan as a possible baitfish (Ikebe 1939) but additional information on this species is unavailable. At least one form now occurs in Palau (J. P. McVey, Micronesian Mariculture Demonstration Center, Koror, Palau, Western Caroline Islands, pers. commun.).

[1]Hawaii Institute of Marine Biology Contribution No. 534.

[2]Hawaii Institute of Marine Biology, University of Hawaii, Honolulu, HI 96822.

[3]Yuen, H. S. H. 1961. Experiments on the feeding behavior of skipjack at sea. U.S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hi 96812. Report presented at Pacific Tuna Biology Conference, Lake Arrowhead, Calif., August 1961, 6 p.

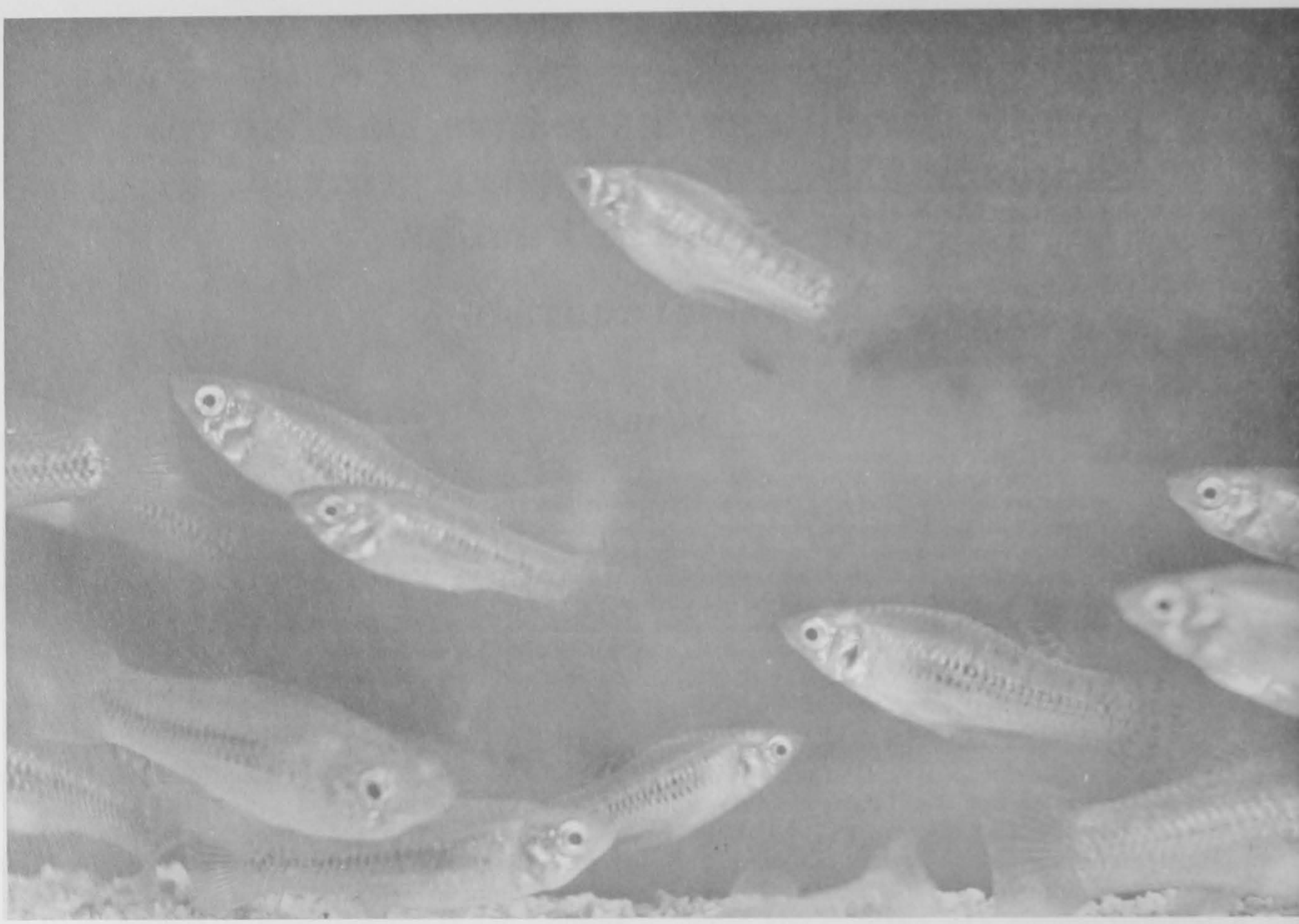

Figure 1.—Aquarium photograph of adult topminnow *Poecilia vittata*. Males have spotted dorsal and caudal fins, and ventral gonopodium. The largest female (lower left) is approximately 60-mm total length.

According to Welsh (1950) and June and Reintjes (1953), the topminows most frequently used as live baitfishes in Hawaii were the sailfin molly, *P. latipinna*, and sharpnose molly, *P. sphenops*, followed by the topminnow *P. vittata*, and mosquitofish, *G. affinis*. The guppy, *P. reticulata*, was probably included in the baitfish catches in some localities. Recent collections in Kaneohe Bay, Oahu, Hawaii, indicate that the two most frequently encountered species taken from saltwater and brackish-water habitats were *P. vittata* and *P. latipinna*. One adult female *P. mexicana* was collected near the mouth of Kaneohe Stream in 1975. It is not known when this species was first introduced to Hawaii or if it was used along with the above species as a baitfish.[4] Additional species that may have been included in the baitfish catches were the swordtail, *Xiphophorus helleri*, and platyfish, *X. maculatus*. Both were reported to occur in streams and stream mouths (Brock 1960; Walsh 1967); however, this cannot be confirmed since baitfish capture records were not kept by the Hawaiian pole-and-line fishery in the 1930's.

[4]New geographical record for Hawaii. Species identification by William L. Fink, Division of Fishes, National Museum of Natural History, Washington, D.C.

PROCEDURES

The primary aims of this study were to identify those biological and technical factors that could be applied on a practical level toward development of a commercial topminnow culture system in the tropical Pacific area. The plan was to design a simple culture system that did not require sophisticated equipment and could be operated primarily by semiskilled and unskilled personnel. The manpower consideration is extremely important for many of the Pacific islands concerned since skilled and experienced personnel are seldom available.

The experimental stock of topminnows at HIMB was collected by seine from a mangrove habitat in the southeast sector of Kaneohe Bay in 1970. The topminnows were transported to HIMB, located on Coconut Island in Kaneohe Bay, in a plywood bait receiver and placed in a saltwater pond measuring approximately 15 × 12 × 1 m deep (48 × 35 × 3 ft deep). Seasonal variations in water quality and the physical environment of the ponds on Coconut Island were investigated by Tseu (1953). Water exchange was first provided by tidal action through two screened gates but aeration and forced water exchange were later added because of an increase in pond population to 150,000 topminnows (Fig. 2). The quantity of topminnows placed into the pond was determined by a volumetric method to be 18,000 individuals of three species of poeciliids: *P. vittata* (75%), *P. latipinna* (20%), and *G. affinis* (5%). Within 1 yr the pond population was predominantly *P. vittata* while the latter two species made up an estimated 1% of the total population.

All experiments were conducted with this population in a number of plastic 26.5-liter (7-gal) aquaria, four irregular shaped concrete tanks of 2,500 to 4,542 liters (660-1,200 gal) maximum capacity, and one 1,800-liter (475-gal) experimental brood tank. The experiments were preliminary in nature and were not replicated unless it was necessary to clarify some of the results. Experimental controls for the most part were not in effect during many of the experiments.

RESULTS

Water Temperature

A water temperature of 28°-30°C is recommmended for optimal growth, survival, and production of young. However, depending upon the effects of other environmental and biological factors such as salinity, dissolved oxygen, population density, and feeding, successful results were obtained in temperatures from 23° to 34°C. The upper lethal temperature was not investigated but observations indicate it may be as high as 36°C or higher. A diurnal temperature range of 8°C was recorded in the experimental brood tank during the summer months and no adverse effects to the brood stock or the newly released young were observed. In tropical localities, where wide ranges in temperature are common, control of water temperature by addition of shade is advisable.

Water Salinity

Poecilia vittata were successfully reared in a salinity range from freshwater to full strength seawater (35°/₀₀ . However, maximum survival, growth, and production of young were obtained in salinities from 3.5°/₀₀ to 17°/₀₀ (10% to 50% seawater) (Fig. 3). Both adults and young can be repeatedly transferred from freshwater to seawater, or the reverse, without prior acclimation provided the difference in temperature of the freshwater and seawater is not great.

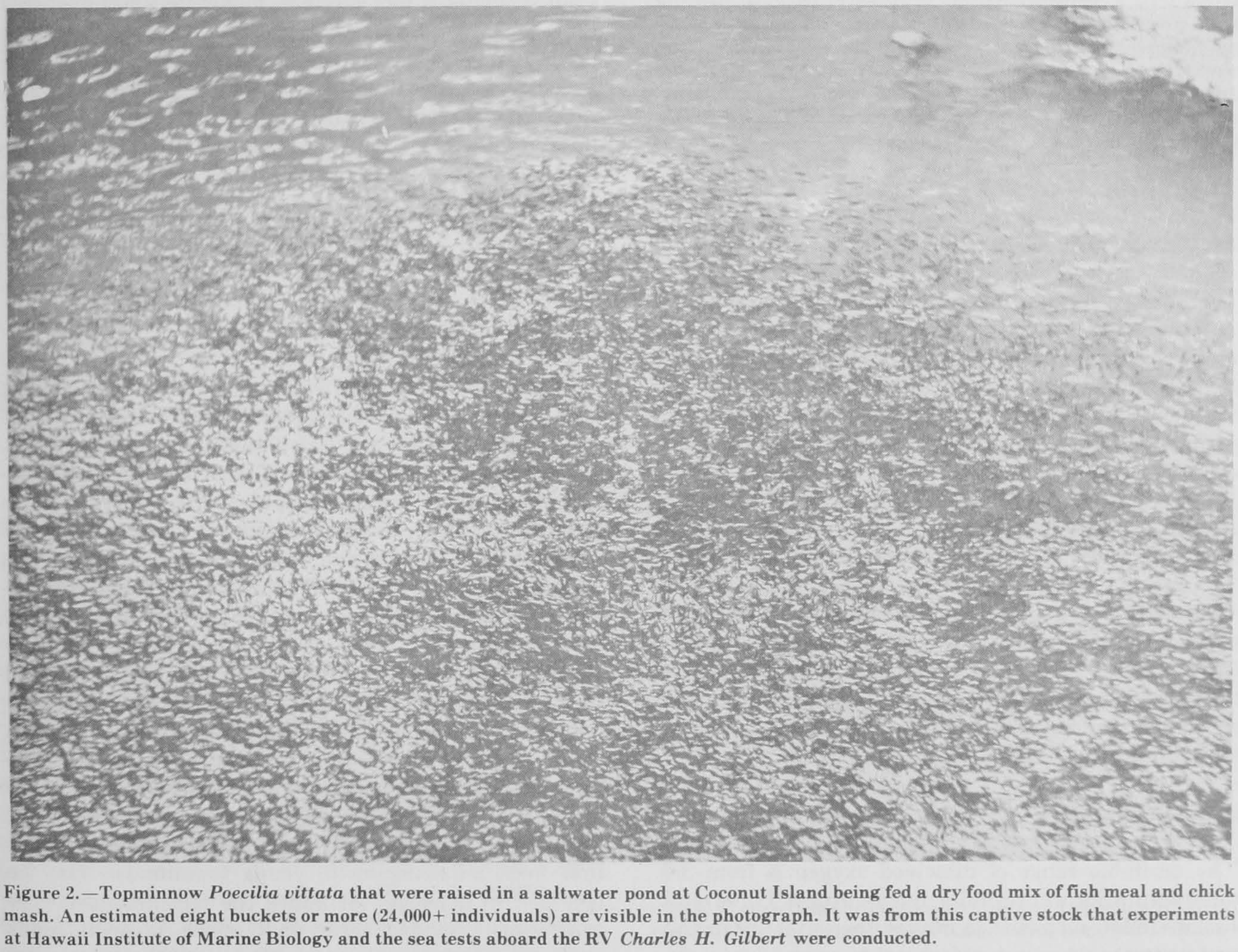

Figure 2.—Topminnow *Poecilia vittata* that were raised in a saltwater pond at Coconut Island being fed a dry food mix of fish meal and chick mash. An estimated eight buckets or more (24,000+ individuals) are visible in the photograph. It was from this captive stock that experiments at Hawaii Institute of Marine Biology and the sea tests aboard the RV *Charles H. Gilbert* were conducted.

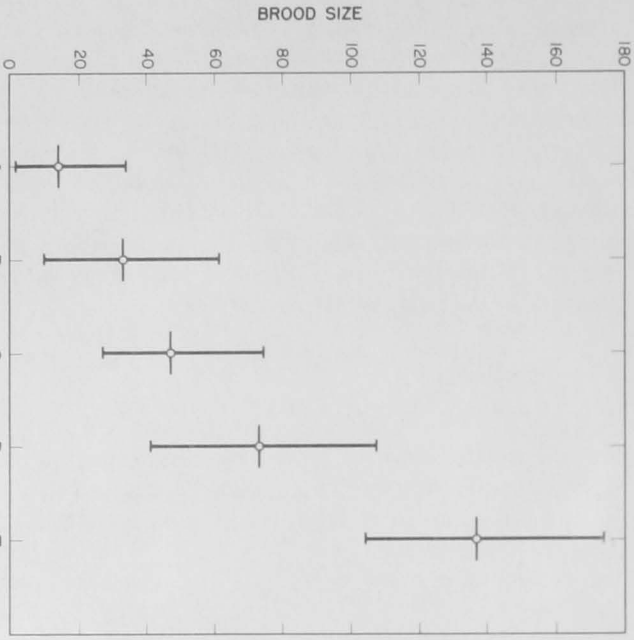

Figure 3.—Brood counts taken from five samples of 20 adult female *Poecilia vittata* from different environments. The horizontal line = mean brood size, vertical line = brood size range. A, Wild stock collected from a mangrove habitat in Kaneohe Bay. B, Random sample removed from the saltwater pond on Coconut Island. C, Sample from the experimental brood tank following a 101-day test in freshwater. D, Select sample of large females removed from the saltwater pond, Coconut Island. E, Sample removed from the experimental brood tank following a 103-day test in brackish water (mean salinity 17.5‰).

Water Exchange Rate

Topminnows are very tolerant of a wide range of water quality conditions, but a moderate rate of water exchange coupled with good aeration consistently provided the best results when other environmental factors were under control. Brood ponds with a density of four to six adults per 3.8 liters (1 gal) of standing water and an exchange every 24-48 h is recommended. Tests at HIMB demonstrated that successful rearing can be attained in situations with good aeration and an exchange of water every 7 days provided the population density is not over one to one and one-half adults per 3.8 liters (1 gal). The recommended exchange every 24-48 h is a "yardstick" measurement intended to provide a reasonable safety factor against loss of brood stock. High mortalities have resulted from the combined effects of equipment failure, high water temperatures, and low tide followed by low dissolved oxygen levels.

Dissolved Oxygen

The desirable range of dissolved oxygen is from 3.0 ppm to saturation at prevailing temperatures. On several occasions following power shortages, the water pump and air compressor were not in operation overnight in the saltwater pond and the topminnows were observed to aggregate at the surface and appear to "gulp" air. On two such occasions the dissolved oxygen measured 0.9 and 1.1 ppm. The estimated mortality on both occasions was 10%. Other marine fishes previously observed in the pond with the topminnows were found dead or dying. These included the moray eel, *Gymnothorax undulatus*; striped mullet, *Mugil cephalus*; cardinalfish, *Apogon brachygrammus*; and the surgeonfish, *Acanthurus sandvicensis*. The above occurrences indicate that lethal dissolved oxygen levels are near 0.9 to 1.1 ppm or slightly higher.

Hydrogen Ion Concentration (pH)

The recommended pH range is 7.8 to 8.3. A range of 7.6 to 9.3 was, however, recorded during some of the closed system experiments using the 26.5-liter (7-gal) aquaria.

Lighting Requirements

Sunlight appears essential for maximum production of young. The most encouraging results were obtained in shallow ponds and tanks exposed to full or partial sunlight for at least part of the day. The combination of shallow ponds, direct sunlight, moderate water exchange rate, good aeration, some natural food available, no predators, and an organized hatchery routine consistently provided the best results for growth, reproduction, and survival. Artificial lighting during hours of darkness does not appear necessary unless for security reasons. When dense concentrations of topminnows are confined in containers or baitwells, some lighting may be necessary especially for the first day or so following capture and handling.

Density of Topminnows

Several density requirements must be considered. Experiments in a series of aquaria and a prototype brood tank indicated that the brood stock density should not exceed six adults per 3.8 liters (1 gal). The maximum optimum density of the adult population in the brood tanks requires further investigation and will depend largely on some basic biological and environmental factors. With improvements in the facility design and routine operations, it is very likely that the six adults per gallon can be increased.

In rearing ponds where young topminnows are raised to a baitfish size, 1.5-2.25 in (3.8-5.7 cm), a density of 15 or less young per gallon (3.8 liters) is recommended. In an open system where optimum conditions are present, density of young may possibly be increased. However, there is evidence (Fig. 4) that growth may be retarded if the young are overcrowded for extended periods. During the first week following birth, young topminnows may be confined in densities far above the recommended concentration provided additional space is soon made available. Although it was recognized that there are growth inhabiting factors related to population density,

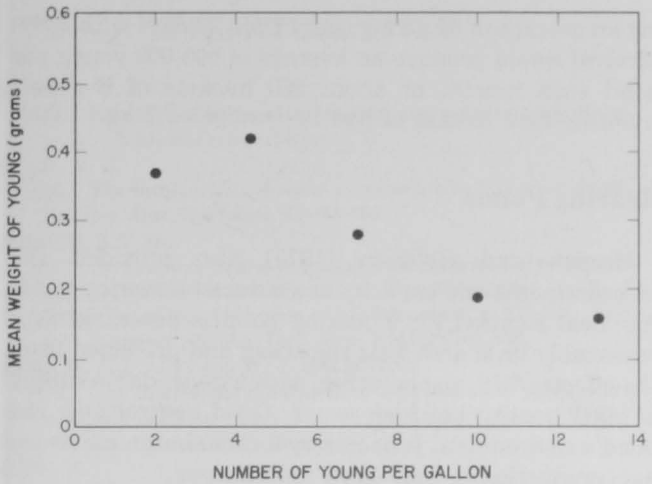

Figure 4.—Effect of density on mean weight of juvenile topminnows confined in a series of 32-liter aquaria for 77 days (brackish water, 18‰; temperature range, 29.7°-31.0°C; no water exchange except during periodic cleaning; 100% survival).

especially in closed aquaria, they were not investigated beyond this point.

Optimum densities of bait-sized topminnows confined in live baitwells need to be determined more precisely through experiments at sea under actual fishing conditions. Tests at HIMB and the single test aboard the National Marine Fisheries Service RV *Charles H. Gilbert* in 1972 demonstrated that topminnows can be confined successfully in live baitwells under very crowded conditions with insignificant mortalities. A maximum density test conducted at HIMB in a 100-gal (378.5-liter) bait tank for 10 days with adult topminnows (mean weight 1.31 g) indicated densities up to 81 adults per gallon (106.1 g per 3.8 liters) can be successfully maintained with mortalities not exceeding 1.0%. This density is equivalent to 23.4 lb (10.6 kg) of topminnows in 100 gal of seawater, a concentration far above the standard nehu densities usually maintained by Hawaiian skipjack tuna vessels. During this test, the water exchange rate was 7.5 liters (2 gpm) and aeration was provided.

Brood Stock

Sex ratio of adult topminnows and size of females influenced production of young. A sex ratio of 1 female:1 male gave the largest brood sizes. Sex ratios of 7 females:3 males, and 9 females:1 male gave lower brood sizes (fertilized eggs to fully developed embryos) with all other factors being equal. Brood size increased with increased size of females (Fig. 5). Adult topminnows collected from a mangrove habitat in Kaneohe Bay and from the saltwater pond at Coconut Island usually had a greater number of females. It is believed that this was due mainly to a sampling error caused by behavior and size differences between males and females. Additional experimentation must be conducted to clearly identify those factors related to sex ratio that influence the production of young. At this point, it is reasonably clear that increasing the ratio of females to males will not necessarily increase overall production to the desired level.

Food and Feeding

Topminnows are omnivorous and will thrive on a large variety of natural and prepared foods. During the entire test period, a dry food mixture of 50% fish meal (54%-58% crude protein) and 50% chick mash (20% crude protein) was used almost exclusively since both items were readily available. The quantity fed was 3% of the fish's body weight per day. Although dietary needs were not investigated, captive topminnows consumed all food items offered: soybean meal, meat meal, copra meal, prepared tropical fish foods, Oregon moist pellets, Purina Trout Chow[5], daphnia, mosquito larvae, detritus, live and frozen brine shrimp, fresh fish muscle, pig manure, chicken manure, crackers, bread, dried and crushed leaves of the plant *Leucaena* sp., and fine sediment and algae covering chunks of dead coral. Newly released young topminnows will consume the same food as the adults but the food should be sifted through a fine mesh screen to a flourlike texture.

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

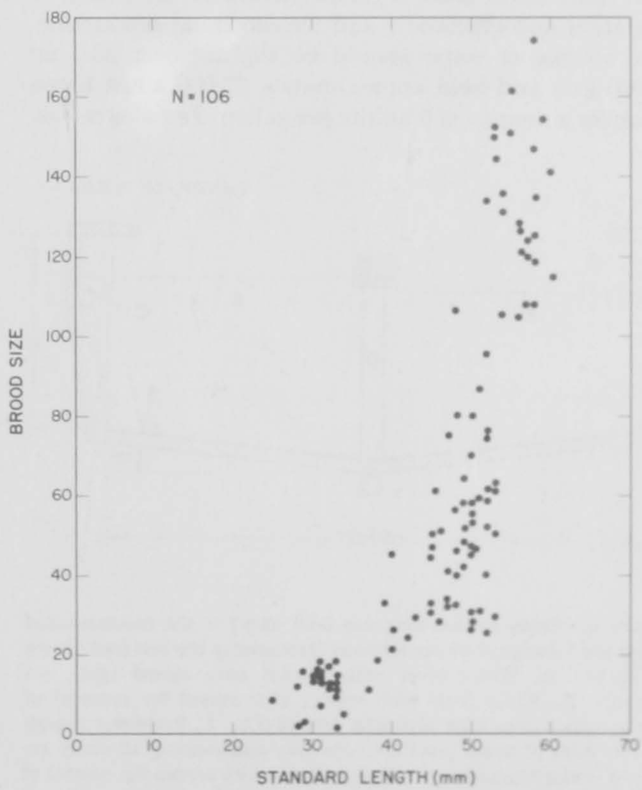

Figure 5.—Relationship of standard length of pregnant adult female *Poecilia vittata* and size of brood. Largest brood observed to date was a 72-mm standard length female that contained 281 developing embryos (not indicated in figure).

RECOMMENDED FACILITY DESIGN

Brood Pond

Newly released young congregate at the surface near the water's edge or near clumps of floating vegetation for several days following birth. Herrick and Baldwin (1975) have taken advantage of this behavior in a system for removing the newborn topminnows from an experimental brood tank on a daily basis. They provided a screened trough at the water's edge accessible only to the infant baitfish, and flushed them easily from the trough at any time after lowering the water level of the tank below the trough's edge.

Due to the high degree of success of their simple design, recommendations can be made toward the basic design of a larger and more advanced brood pond that can be incorporated into a commercial topminnow hatchery system. This unit (Fig. 6) should be constructed of concrete similar in design to the smaller brood tank of Herrick and Baldwin (1975). It should measure 15 × 4.5 m (50 × 15 ft) and have a mean depth of 45 cm (18 in). It should have an improved perimeter trough, trough shade cover, aeration, suitable water supply, automatic feeders, and a backup system for emergencies. The entire length of the bottom of the pond should slope towards the center at a 15° angle similar to a shallow "V." This would tend to accumulate solid waste at the center for periodic removal by pump or siphon. This basic brood pond is recommended for simplicity of operation and efficiency, and for continual production. The volume of water should be slightly over 30.3 m^3 (8,000 gal) and hold approximately 32,000 adult brood stock for a density of 4 adults per gallon. Females releasing an average of 50 young every 28 to 30 days with 100% survival would produce an average of 800,000 young per pond each month, or about 260 buckets of live bait monthly (one bucket of live bait weighs 2.7 kg (6 lb)).

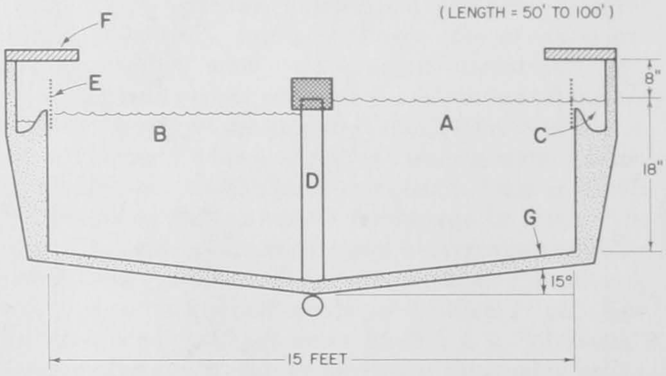

Figure 6.—Cross section diagram (end view) of the recommended brood pond design showing features discussed in the test (not drawn to scale). A, Water level with trough gate closed (gate not shown). B, Water level with trough gate raised for removal of young topminnows from perimeter trough (C). C, Perimeter trough around edge of brood pond for collection and removal of newly released young topminnows. D, Standpipe with screen for control of water level in pond. E, 0.7-mm (¼-in) mesh screen on edge of perimeter trough. Screen prevents adults from entering trough but allows free passage of young. F, Hinged or removable shade cover over entire perimeter trough. G, Bottom of brood pond angled at 15° towards the center to facilitate the removal of wastes and unwanted materials by siphon or pump.

Rearing Ponds

Herrick and Baldwin (1975) also provided the measurements and capacity of a successful rearing pond. An ideal location for a rearing pond is described as a reasonably level area near the ocean and protected from the effects of adverse weather, with a dependable supply of good quality brackish water. Good control over the pond's environment is necessary for maximum efficiency and production of bait-sized topminnows.

COMMENTS

Intensive culture of a suitable live baitfish for skipjack tuna appears to offer a reasonable solution in areas known to have little or no natural stocks of baitfish. With few exceptions, a limited supply of baitfishes is the primary factor restricting the development and expansion of skipjack tuna fisheries throughout the tropical Pacific islands.

Although definitive sea trials have not been completed to determine the effectiveness of topminnows as live bait for skipjack tuna, preliminary experiments indicate their potential use to be promising and economically feasible (Herrick 1977). The tests conducted in American Samoa with cultured Mexican mollies demonstrated that for maximum effectiveness some changes must be made to traditional pole-and-line fishing techniques, including modifications to lure design and lure use during fishing, chumming techniques, vessel approach to schools, water spray system, live baitwell configuration, and handling of baitfishes. Since shipboard mortalities of cultured topminnows should normally be insignificant, their utility as baitfishes for new or expanding fisheries throughout the Pacific island areas appears quite feasible.

ACKNOWLEDGMENTS

I thank Samuel F. Herrick, Jr. and Steve J. Dollar for their valuable contributions to this study. Thanks also go to the University of Hawaii Marine Option Program and to Ray Tulafono, Earl Yamaguchi, and Howard Deese for their generous assistance with technical and biological problems. The cooperation of National Marine Fisheries Service personnel is gratefully acknowledged, especially Frank J. Hester, Randolph K. C. Chang, and the crew of the RV *Charles H. Gilbert* for making it possible to complete preliminary sea tests. Special thanks go to the Edwin W. Pauley Estate for the use of pond facilities on Coconut Island. I also thank the National Marine Fisheries Service, Honolulu Laboratory, and the University of Hawaii Sea Grant Program for making it possible to attend the Baitfish Workshop while I was on leave to American Samoa in 1974.

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Some Economic and Technological Aspects Related to Commercial Production of the Topminnow *Poecilia vittata*

SAMUEL F. HERRICK, JR.[1]

ABSTRACT

The skipjack tuna, *Katsuwonus pelamis*, fishery in Hawaii is in need of a reliable alternate source of live bait. In a recent effort to provide such a baitfish, research supported by the University of Hawaii Sea Grant Program has been conducted at the Hawaii Institute of Marine Biology with the topminnow *Poecilia vittata*. Economic and technological aspects of intensive culture were considered: Total costs associated with a 3,000 and a 30,000 bucket per year production enterprise were estimated and the resulting cost per bucket for each level calculated as $12.93 per bucket and $3.69 per bucket, respectively. The economic feasibility of a topminnow enterprise will hinge upon their relative effectiveness as bait, and future research should focus there.

INTRODUCTION

In a recent effort to provide an alternative source of baitfish in Hawaii, research supported by the University of Hawaii Sea Grant Program has been conducted at the Hawaii Institute of Marine Biology (HIMB) with the topminnow *Poecilia vittata*. Preliminary investigation reveals this species to have potential as a substitute baitfish in the Hawaiian skipjack tuna, *Katsuwonus pelamis*, fishery. Topminnows are hardy, easily handled, and adapt readily to a variety of environmental conditions. In addition, the rearing of topminnows at HIMB using intensive culture methods has been reasonable successful (Baldwin 1972,[2] 1974, 1977), indicating the possibility of mass producing this species in order to satisfy local baitfish needs. It is this potential with regard to some of the technological and economic aspects that will be considered herein.

MASS PRODUCTION OF TOPMINNOWS

Basic site requirements (Baldwin, see footnote 2) for mass production of topminnows include a sufficient amount of flat land with a supply of warm brackish water, located preferably near the ocean, with access to an uninterrupted power supply and a source of labor. The site should be able to accommodate 1) one or more brood ponds; 2) one or more rearing ponds; 3) one or more wells; and 4) water storage tanks, drains, open sluices, and spillways. It should have some protection against both natural and man-made contingencies. Perhaps the most important consideration in site location is the availability of a water supply that is adequate in both quantity and quality. The exact salinity for optimal topminnow production is yet unknown. However, initial experimental results have shown that topminnows thrive best in continuously circulating brackish water.

A detailed description of topminnow brood ponds and rearing ponds may be found in Herrick and Baldwin (1975). The brood pond described there is capable of producing 3,000 buckets[3] of bait-sized topminnows annually. As young are produced, they are periodically flushed from the shallow screened trough around the inside perimeter of the brood pond and transported via container or sluiceway to the rearing ponds. Here they are allowed to mature to baitfish size, at which time they can be pumped or seined from the rearing ponds into transport tanks and delivered to the skipjack tuna fleet. Additional production activities include feeding the fish on a regular schedule, water testing, and system maintenance.

From the preliminary investigations, the basic requirements for commercial production of topminnows at various levels of annual output are estimated and presented in Table 1.

ESTIMATED ANNUAL COSTS FOR A 3,000 AND 30,000 BUCKET PER YEAR TOPMINNOW PRODUCTION ENTERPRISE

Initial Capital Investment

Initial capital investment represents expenditures for the construction of ponds, wells, and water storage tanks,

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[2]Baldwin, W. J. 1972. A preliminary study of the feasibility of pond rearing sharpnose mollies (*Poecilia sphenops*) as a live baitfish for the skipjack tuna fishery, American Samoa. Hawaii Inst. Mar. Biol., Univ. Hawaii, Contract Rep. C-248-73, 11 p.

[3]One bucket of topminnows is equivalent to about 2.7 kg (6 lb) of 3,000 individuals at 3 mo of age.

Table 1.—Production schedule of the topminnow *Poecilia vittata* by numbers of buckets per year including basic requirements for a commercial enterprise.

	Production level in thousands of buckets per year[1]										
	3	6	12	18	24	30	36	42	48	54	60
Brood ponds[2]											
Number of brood ponds	1	2	4	6	8	10	12	14	16	18	20
Total water volume in thousands of gallons[3]	8	16	32	48	64	80	96	112	128	144	160
Volume of compressed air in cubic feet per minute	0.6	1.2	2.4	3.6	4.8	6.0	7.2	8.4	9.6	10.8	12.0
Pounds of dry food mixture required per day	21	42	84	126	168	210	252	294	336	378	420
Thousands of adult topminnows (1:1 sex ratio)	32	64	128	192	256	320	384	448	512	576	640
Thousands of breeding female topminnows	16	32	64	96	128	160	192	224	256	288	320
Rearing ponds[4]											
Number of rearing ponds	1	2	4	6	8	10	12	14	16	18	20
Total water volume in thousands of gallons	81	163	326	489	652	815	978	1,140	1,303	1,466	1,629
Volume of compressed air in cubic feet per minute	4.8	9.6	19.2	28.8	38.4	48.0	57.6	67.4	77.0	86.6	96.4
Pounds of dry food mixture required per day	8.5	17	34	51	68	85	102	119	136	153	170

[1]One bucket of topminnows is equivalent to about 2.7 kg (6 lb) of 3,000 individuals at 3 mo of age.
[2]Pond size 16.5 m × 5 m × 0.5 m (50 ft × 15 ft × 18 in) deep.
[3]This volume is equivalent to the flow rate per day required for one complete exchange as recommended.
[4]Pond size used in these calculations is equivalent to about 500 m² (⅛ acre) with a mean depth of 0.75 m (24 in) or 1,000 m² (¼ acre) with a mean depth of 0.3 m (13 in).

Table 2.—Estimated initial capital costs of ponds (rearing and brood) and related facilities for selected topminnow enterprises.

Annual output	Construction cost of ponds	Wells	Water storage tanks	Experimental work, and storage sheds
Buckets		*Dollars*		
3,000	9,675	3,600 (2 wells—10" dia., 25' deep)	4,263 (2 tanks—25,000 gal each)	2,930
30,000	71,247	3,600 (2 wells—10" dia., 25' deep)	14,263 (2 tanks—53,000 gal each)	4,392

and the experimental work and storage shed (Table 2). Pond construction costs (brood and rearing) will depend upon the geographic and topographic considerations mentioned earlier. In this discussion the estimated outlay for pond construction includes design, excavation, and concrete lining.

The number of wells required is based upon the brackish-water requirement noted above. Here it is assumed that separate sources of fresh and salt water will have to be combined in order to obtain salinity conducive to optimum production. Thus both the 3,000 and 30,000 bucket/yr enterprises will require two wells (one salt-brackish water and one freshwater) each.

In the preliminary design, well water is pumped to fiber glass storage tanks and then mixed and gravity metered to the pond system. Thus these reservoirs will allow for desired control over water salinity and exchange rate. Furthermore the storage tanks will serve as a safeguard in the event of a pump failure.

Equipment costs include the cost of pumps, plumbing, air compressor, vehicle, portable fish pump and transfer hoses, water analysis kit, refrigeration and food preparation equipment, and generator (the generator is for emergency back-up purposes only).

Capacity of the pumps is based upon the water exchange rates for the 3,000 and 30,000 bucket/yr topminnow enterprises (see Table 1). Similarly, the capacity of the air compressor is based on the aeration requirements of the respective enterprises. Where the physical life of equipment is less than the operational time span of the topminnow enterprise, new equipment will have to be purchased to replace old ones. Estimates of the cost of equipment for the two levels of production are presented in Table 3.

In this analysis, items of capital and equipment are depreciated over a 20-yr period,[4] or its physical life, whichever is less. The straight line method of deprecia-

[4]Some capital items and equipment may have a physical life in excess of 20 yr. However, in view of the uncertainties related to changes in fishing technology, 20 yr is chosen as the economic, or useful, life of capital and equipment when employed in topminnow production.

Table 3.—Estimated equipment costs for selected topminnow enterprises.

Annual output	Pumps	Plumbing (3' PVC)	Air compressor	Vehicle	Portable fish pump and transfer hoses	Water analysis kit	Refrigeration and food preparation	Generator
Buckets	*Dollars*							
3,000	600 (2 pumps—30 gpm, 5 hp each)	1,000	900 (6 cfm. 2 hp)	5,000 (½-ton utility truck)	3,775	250	3,360	2,400
30,000	3,000 (2 pumps—325 gpm, 20 hp each)	2,000	2,800 (55 cfm, 15 hp)	10,000 (1-ton utility truck)	3,775	250	4,000	2,400

tion is employed[5] and annual depreciation schedules for the 3,000 and 30,000 bucket/yr topminnow enterprises are shown in Tables 4 and 5, respectively. The individual depreciation values are then summed and this amount, rather than the full cost of capital and equipment, is charged against the quantity of topminnows produced during the year.

[5]The annual depreciation using the straight line method is obtained by dividing the acquisition cost of the item by its useful life in years. For simplicity, salvage values are assumed to be zero.

Table 4.—Depreciation schedule for a 3,000 bucket per year topminnow enterprise.

Item	Estimated cost	Useful life in years	Annual depreciation
	Dollars		*Dollars*
Ponds	9,675	20	484
Wells	3,600	20	180
Water storage tanks	4,263	20	213
Experimental, work, and storage shed	2,930	15	195
Pumps	600	2	300
Plumbing	1,000	20	50
Air compressor	900	20	45
Vehicle	5,000	5	1,000
Portable fish pump and transfer hoses	3,775	10	378
Water analysis kit	250	5	50
Refrigeration and food preparation	3,360	15	224
Generator	2,400	20	120
Total	37,753		3,239

Table 5.—Depreciation schedule for a 30,000 bucket/yr topminnow enterprise.

Item	Estimated cost	Useful life in years	Annual depreciation
	Dollars		*Dollars*
Ponds	71,247	20	3,562
Wells	3,600	20	180
Water storage tanks	14,263	20	173
Experimental, work, and storage shed	4,392	15	293
Pumps	3,000	2	1,500
Plumbing	2,000	20	100
Air compressor	2,800	20	140
Vehicle	10,000	5	2,000
Portable fish pump and transfer hoses	3,775	10	378
Water analysis kit	250	5	50
Refrigeration and food preparation	4,000	15	267
Generator	2,400	20	120
Total	121,727		9,303

Annual Operating Costs

Labor, food, electricity, and maintenance make up the major direct operating costs (Table 6). It is estimated that the 3,000 bucket/yr enterprise will require 40 man-hours of labor per week, and that the 30,000 bucket/yr enterprise will require 80 man-hours of labor per week. A wage rate of $4/h, exclusive of fringe benefits, is used in estimating annual labor costs.

The food[6] cost estimates are based upon the daily food requirements for both breeding and rearing topminnows at the 3,000- and 30,000-bucket levels of annual production (see Table 1). For purposes of this analysis an average price of 10 cents/lb is used in estimating food costs.

The estimated cost of electricity is based primarily on pumping rates for both well water and compressed air.

[6]During preliminary investigations topminnows were fed a mixture of 50% tuna fish meal and 50% chick mash.

Table 6.—Annual operating costs for selected topminnow enterprises.

Annual output	Labor	Management	Food	Electricity	Maintenance	Miscellaneous (gas, oil, etc.)
Buckets	*Dollars*					
3,000	8,320 (one man)	12,000	1,077	2,963	1,500	1,500
30,000	16,640 (two men)	20,000	10,768	13,579	7,500	3,000

Under normal operating conditions it is assumed that both water pumps and air compressor will be in operation 100% of the time. The rate used to estimate electricity costs is 3.76 cents/kWh.

Estimated land lease rental is based upon 1 acre required for the 3,000 bucket/yr output, and 7 acres required for the 30,000 bucket/yr output. Hawaii's agricultural land values are used in estimating the annual land lease expense. The value of agricultural land ranges from $4,000 to $30,000 an acre. In this analysis an acre valued at $13,000 is used, and lease rental as a percentage of land value is calculated at 6%.

Interest represents the expected return on the funds invested in topminnow production, and is therefore treated as an annual production expense. In this case interest expense is calculated at 20% of the total investment in capital and equipment.

The total estimated production costs for the first year of operation of a 3,000 bucket/yr and a 30,000 bucket/yr topminnow enterprise are summarized in Tables 7 and 8, respectively. In order to determine the cost of producing a bucket of topminnows, total cost of production is divided by total output. Based on the initial year's expenses and the levels of output under consideration, these are as follows:

Level of production	*Annual cost ($)*	*Cost/ bucket ($)*
3,000 buckets/yr	38,934	12.98
30,000 buckets/yr	110,595	3.69

SUMMARY AND COMMENTS

Total costs associated with a 3,000 and 30,000 bucket/yr topminnow production enterprise are estimated and the resulting cost per bucket for each level of output calculated. The results obtained indicate that there are economies of scale associated with topminnow production.

While the focus herein has been on the costs of producing topminnows for use as bait in the skipjack tuna fishery, the economic feasibility of establishing a topminnow production enterprise will also depend upon the revenues derived from the sale of topminnows to fishermen. Obviously, fishermen can only be induced to purchase topminnows (given availability of other baits) if the net return from fishing with topminnows is as great or greater than that from fishing with traditional baits. Thus the economic feasibility of a topminnow production enterprise will hinge upon the relative effectiveness of topminnows as bait, which in turn will be reflected in the price fishermen are willing to pay for topminnows. If fishermen are willing to pay in excess of the costs incurred in producing topminnows (as outlined above) then the topminnow production enterprise would be considered a success from an economic standpoint. In this respect, future research effort in the area of commercial topminnow production should focus on the effectiveness of topminnows as a live bait in the skipjack tuna fishery.

Table 7.—Estimated production costs for the first year of a 3,000 bucket/yr topminnow enterprise.

Item	Estimated annual cost in dollars
Depreciation	3,243
Labor and management	20,320
Food	1,077
Electricity	2,963
Maintenance	1,500
Interest	7,551
Lease rental	780
Miscellaneous	1,500
Total	38,934

Table 8.—Estimated production costs for the first year of a 30,000 bucket/yr topminnow enterprise.

Item	Estimated annual cost in dollars
Depreciation	9,303
Labor and management	36,640
Food	10,768
Electricity	13,579
Maintenance	7,500
Interest	24,345
Lease rental	5,460
Miscellaneous	3,000
Total	110,595

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Evaluation of Bait Substitution Schemes in Hawaiian Fishery for Skipjack Tuna, *Katsuwonus pelamis*

JERRY A. WETHERALL[1]

ABSTRACT

A systematic procedure is presented for judging the feasibility of bait substitution schemes in the Hawaiian fishery for skipjack tuna, *Katsuwonus pelamis*. Over the period 1968-73, the opportunity cost of nehu, *Stolephorus purpureus*, the bait now in use, peaked twice a year: during the first half of July when skipjack tuna catch rates were high and during the second half of December when the ex-vessel price of skipjack tuna was high. The opportunity cost averaged $4.78/lb, and increased by over 100% during the period, due mostly to a rise in ex-vessel price of skipjack tuna.

Feasibility of a bait substitution scheme during any season requires that unit production costs are less than opportunity costs of acquiring nehu and that the quantity of bait produced does not exceed the amount usable. Judgment of feasibility rests on some critical assumptions concerning such factors as the amount of nehu per bucket in the bait fishery, and the attractiveness of substitute baits relative to nehu. These must be substantiated through field experiments and sample surveys.

INTRODUCTION

For many years the Hawaiian fishery for skipjack tuna, or aku, *Katsuwonus pelamis*, has suffered a persistent case of stagnation. In spite of a rising consumer demand for tuna products and an ample exploitable resource, the average annual aku harvest has not been increased. Further, only one new vessel has entered the aku fleet in the last two decades, while many deteriorating boats have been retired and not replaced. The roots of this malaise were recognized long ago—a short supply of an essential ingredient, live bait, and failure of the fishing industry and supporting government agencies to develop substitute or alternative bait supplies in a rather high-risk investment environment.

The baitfish problem is a classic economic problem of technological substitution and its key elements may be conveniently summarized as in Figure 1. This shows the joint behavior of the two key variables, unit production costs and usage rate, for two hypothetical alternative baits and for nehu, *Stolephorus purpureus*, the principal bait now in use. In this two-dimensional phase space, the industry is now at "A," and moving upwards on the nehu curve with rising costs and essentially constant usage rate. The conversion path, illustrated by a dotted line, shows how an expanding aku industry would presumably switch from nehu to a first substitute bait, then to a second alternative bait as economic considerations dictated. Discontinuities in the conversion path represent points of substitution. Ideally we would be able to forecast such a path for a variety of alternative baits, or at least to determine the points of intersection which indicate conditions favorable to the introduction of substitutes. The illustration used here assumes that the two hypothetical substitutes are not yet feasible. In fact, the present positions of the cost paths for alternative baits, relative to the nehu curve, are uncertain. Research in progress may show, for example, that the "Alt 1" substitution scheme could now satisfy the present usage rate (about 170,000 lb/yr) at a unit cost less than the present opportunity cost of nehu (the opportunity cost for nehu used in fishing averaged $4.78/lb over 1968-73)

Figure 1.—Hypothetical relationships between unit bait cost and usage rate for nehu and two alternative baits. Dotted line is conversion path. Dashed line indicates uncertainty in position of "Alt. 1." In recent years the industry has been approximately at point "A."

[1]Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

Solution of the baitfish problem clearly depends on success in two area: 1) technical development of alternative bait supplies at unit costs permitting substitution and 2) practical demonstration of the effectiveness of new baits and the building of confidence in their use among aku fishermen. Several determined efforts have been made along both lines, without much success (e.g., Shomura 1964; Shang and Iversen 1971). At present, two technical alternatives are under consideration, one involving the transportation of northern anchovy, *Engraulis mordax*, from California to Hawaii in special tankers aboard roll-on/roll-off freighters and the other involving local mass-culture of the topminnow, *Poecilia vittata*. The anchovy transport alternative has been field tested rather extensively by the National Marine Fisheries Service, Honolulu Laboratory, for the past year, and topminnow culture, considered a possibility in Hawaii, is being pursued experimentally by the Hawaii Institute of Marine Biology of the University of Hawaii (Herrick 1977).

Before the feasibility of either of these schemes can be properly evaluated, the basic substitution curve for nehu must be elucidated. The purpose of this paper is to set out simple, systematic procedures for determining the present position of the nehu curve and for judging the feasibility of alternative bait substitution schemes.

THE OPPORTUNITY COST OF NEHU

The principal difficulty in constructing a substitution curve for nehu is that there is no free market mechanism to measure the unit cost of nehu, i.e., the value of nehu to fishermen. Instead, the worth of nehu must be appraised in terms of the value of opportunities foregone in the capture of the bait. The opportunity cost of a unit of nehu is simply the value of the aku catch which could be obtained if a unit of baiting time was spent in aku fishing, adjusted for the difference in operating costs. It is the price the fishermen could pay for nehu, in lieu of gathering bait themselves, with no difference in their potential profits.

If we let P_1 denote the fleet's profit under the present system of baiting, and let P_2 represent profit under a new system in which some fraction of bait needs is fulfilled by a substitute, we may state the basic relations as

$$P_1 = \pi \cdot CR \cdot B - k_1 DF - k_2 DB - \underline{K}$$

and

$$P_2 = \pi \cdot CR \cdot B \left(\frac{DF + DB}{DF}\right)$$

$$- k_1 (DF + \lambda DB) - k_2(1 - \lambda) DB$$

$$- \underline{K} - k_3 \lambda B \left\{\left(\frac{DF + DB}{DF}\right)\right\}$$

where π = ex-vessel prices of aku (\$/lb),
CR = catch rate; pounds of aku landed per pound of nehu used (lb/lb),
DF = number of days of fishing (old system),
DB = number of days of baiting (old system),
B = amount of nehu used in DF days of fishing (old system) (lb),
λ = proportion of baiting time in old system converted to fishing time in new system,
$\underline{K}$ = fixed costs, or costs independent of the number of days fished, the number of days baited or the amount of bait used (\$),
k_1 = operating costs for a day's fishing (\$/day),
k_2 = operating costs for a day's baiting (\$/day),
k_3 = price of bait purchased under new system (\$/lb used).

The problem now is to find the value of k_3 which satisfies $P_1 = P_2$. This value is the opportunity cost, OC, and is easily found to be

$$OC = \left(\frac{DB}{DF + DB}\right) \left\{\pi \cdot CR - \frac{DF}{B}(k_1 - k_2)\right\}$$

This is, in substance, equivalent to the result of Shang and Iversen (1971), but is put in a different form and is derived in a more direct and less convoluted manner. Note that the solution for OC is independent of the conversion rate, λ.

For most practical purposes the difference in operating costs may be neglected, and the opportunity cost may be approximated by

$$OC = \left(\frac{DB}{DF + DB}\right) \pi \cdot CR . \qquad (\$/lb)$$

Thus the opportunity cost of nehu may be considered as the product of three factors: 1) The proportion of potential fishing days now spent baiting, 2) the ex-vessel price of aku, and 3) the amount of aku landed per unit of nehu used.

TEMPORAL VARIATION IN THE OPPORTUNITY COST

Feasibility of any alternative to nehu will, of course, require that costs of that bait, per unit used in fishing, be no greater than the opportunity cost of nehu. Of particular significance will be any temporal variation in the value of nehu. A substitution scheme may be quite promising during seasons or years of high aku catch rates, say, but be altogether infeasible otherwise.

To establish the seasonality of the opportunity cost, data from the aku fishery and the baiting operations were analyzed. The data represented a 6-yr period, 1968-73, and were obtained directly from the catch records submitted by aku fishermen to the Hawaii Division of Fish and Game. The computations were based on statistics concerning all baitfishes taken in the daytime for aku fishing. Thus the label "nehu" on the results which follow is meant to indicate only that nehu is the predominant species involved, accounting for over 90% of the total bait catch.

Annual Variation

The range of annual variation in the opportunity cost of nehu and the three component factors is shown in Figure 2. From 1968 through 1973 the opportunity cost more than doubled. Over the same period there was a general increase in the proportion of days baited and in the average catch of aku per pound of nehu used. But the dominant force in increasing the opportunity cost has been a sharp rise in the average aku price. This increased by 80% over the 6-yr period.

The statistics plotted in Figure 2 are also given in Table 1 which presents, in addition, the monthly means of the opportunity cost for each year.

Seasonal Variations

Seasonal patterns of variation in the opportunity cost and its components were determined by computing 6-yr weighted averages of the appropriate biweekly statis-

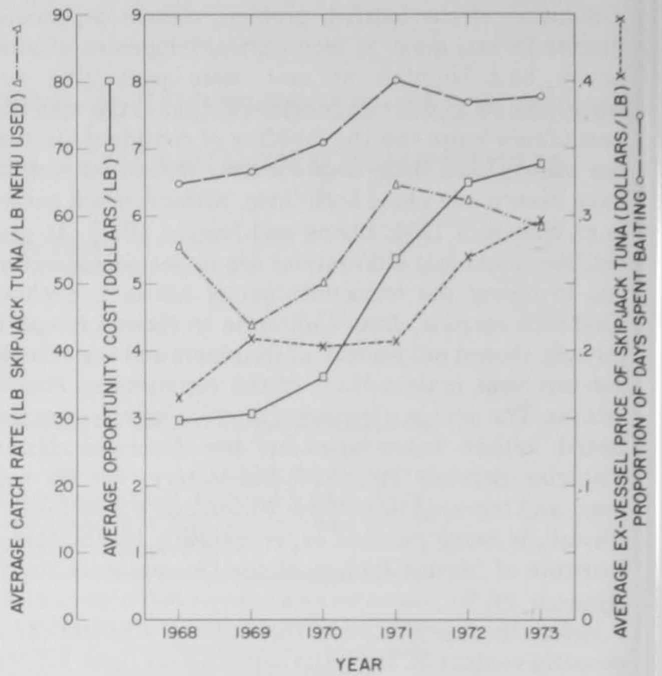

Figure 2.—Trends in the average annual opportunity cost of nehu and in its major components over 1968-73.

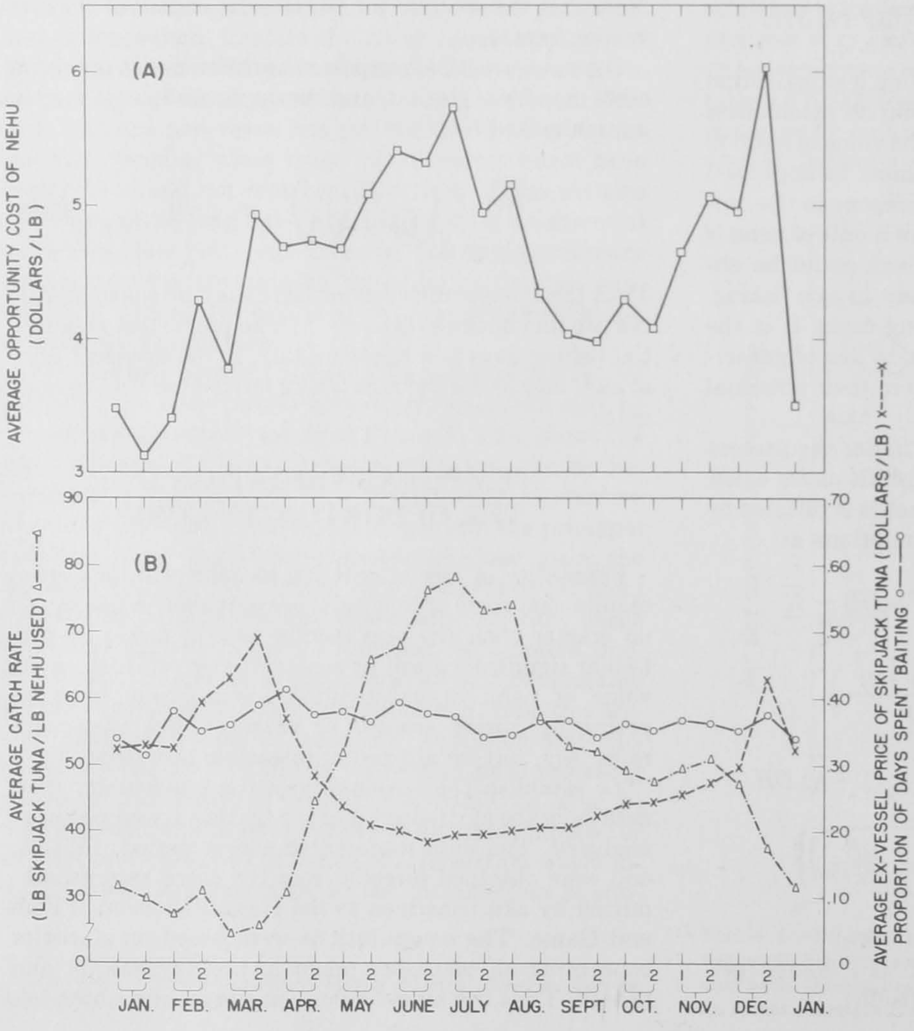

Figure 3.—Seasonal variation in (A) opportunity cost of nehu, and (B) its major components, based on biweekly statistics averaged over 1968-73.

tics. The results are shown in Figure 3 and Table 2. The top panel (A) of Figure 3 shows the seasonal pattern of the average opportunity cost of nehu. The *OC* rises from a low in the last half of January to a peak in the first half of July, drops sharply to another low in September and turns upward again to reach its highest value of the year in late December. There is a twofold variation in the average biweekly *OC* during a year.

In the bottom panel (B) of Figure 3, the seasonal behaviors of the three component factors are displayed.

Table 1.—Variation in average opportunity cost of nehu (by month), proportion of days baited, aku caught per nehu used, ex-vessel aku price, aku caught per trip, and annual aku catch for 6-yr period, 1968-73.

	1968	1969	1970	1971	1972	1973
Average opportunity cost ($/lb)						
January	2.25	4.39	1.60	3.27	4.46	3.43
February	2.22	3.48	4.63	2.58	4.83	7.05
March	2.80	3.30	2.22	4.50	7.43	6.18
April	2.83	3.58	2.49	4.59	8.60	7.78
May	2.84	2.84	2.85	6.17	7.85	7.58
June	3.01	3.50	2.74	7.40	6.87	7.93
July	2.66	3.05	4.24	6.08	7.23	8.34
August	3.32	2.50	3.43	4.67	7.85	6.86
September	2.85	2.61	4.80	4.51	4.97	3.35
October	3.34	2.56	4.01	5.02	4.37	4.96
November	3.16	2.58	4.79	7.00	5.41	6.60
December	5.10	2.89	3.78	6.72	7.31	7.37
Annual mean	2.98	3.05	3.61	5.38	6.51	6.80
Proportion of days baited	0.325	0.334	0.355	0.402	0.386	0.390
Aku caught per nehu used (lb/lb)	55.5	43.8	50.0	64.8	62.5	58.6
Ex-vessel aku price ($/lb)	0.165	0.209	0.203	0.207	0.270	0.297
Aku caught per trip (lb/trip)	4,163	3,327	3,836	6,475	5,763	5,588
Annual aku catch (metric tons)	4,218	2,692	3,332	6,004	4,948	4,859

Table 2.—Seasonal variation in proportion of days baited, aku caught per nehu used, average ex-vessel aku price, average opportunity cost of nehu, average aku catch, present bait usage rate and potential bait usage rate. Estimates are weighted means of biweekly statistics covering a 6-yr period, 1968-73.

Month	Biweekly period	Proportion of days baited	Aku caught per nehu used (lb/lb)	Average ex-vessel price of aku ($/lb)	Average opportunity cost of nehu ($/lb)	Average aku catch (10^3 lb/2 wk)	Present bait usage rate (lb/2 wk)	Potential bait usage rate (lb/2 wk)
January	1	0.340	31.6	0.325	3.49	1,126	3,562	5,397
	2	0.315	29.8	0.330	3.11	1,019	3,420	4,993
February	1	0.381	27.2	0.328	3.41	1,238	4,550	7,350
	2	0.351	30.8	0.397	4.30	756	2,455	3,782
March	1	0.361	24.3	0.432	3.78	642	2,640	4,132
	2	0.391	25.7	0.492	4.95	883	3,436	5,642
April	1	0.415	30.5	0.371	4.70	1,597	5,235	8,949
	2	0.378	44.2	0.284	4.74	2,651	5,997	9,642
May	1	0.380	51.9	0.238	4.69	4,520	8,709	14,046
	2	0.367	66.0	0.210	5.09	6,608	10,012	15,817
June	1	0.395	68.1	0.201	5.41	8,000	11,748	19,418
	2	0.378	76.4	0.184	5.32	9,995	13,083	21,033
July	1	0.375	78.5	0.195	5.74	9,931	12,651	20,241
	2	0.342	73.6	0.197	4.96	9,487	12,890	19,589
August	1	0.347	74.3	0.200	5.16	8,994	12,105	18,537
	2	0.367	57.5	0.207	4.36	6,090	10,592	16,733
September	1	0.367	52.9	0.208	4.04	4,177	7,895	12,472
	2	0.342	52.2	0.223	3.98	3,620	6,935	10,539
October	1	0.363	49.2	0.242	4.31	3,439	6,990	10,973
	2	0.352	47.4	0.245	4.09	3,435	7,247	11,183
November	1	0.369	49.6	0.255	4.66	2,767	5,579	8,842
	2	0.365	51.0	0.272	5.06	2,274	4,459	7,022
December	1	0.352	47.2	0.298	4.94	2,162	4,580	7,068
	2	0.377	37.3	0.430	6.04	1,268	3,399	5,455

The proportion of days baited does not vary over a wide range—from about 32% to 42%. It is not an important determinant of seasonal variation. Perhaps the most significant factor in fluctuations of the *OC* is seasonal change in the catch rate. From a low point in March this component more than trebles in the next 4 mo. The catch rate then begins a steady downturn which continues over an 8-mo period, except for a slight rise in November.

The third component of the *OC*, the ex-vessel price of aku, is very responsive to seasonal changes in the supply of aku on local markets and is thus inversely related to the catch rate (Fig. 3B, 4). The price considered here is the weighted average of the individual prices for fresh fish and for aku delivered to the Hawaiian Tuna Packers cannery. Though in recent years there has been a negotiated minimum price for aku sold on the fresh fish market, it is effective only during the summer season of high aku supply, when most of the aku landed are absorbed by the cannery. In months of short supply, when a relatively large share of the aku catch is sold fresh, the fresh fish price is well above the minimum level.

As shown in Figure 3B, the highest average prices occur in March, and these correspond to the annual minimum in catch rate. As the supply of aku is increased by the steady rise in catch rates during April, May, and June the aku price drops to a June low. During the second half of the "average" year the reverse pattern is observed. There is one brief deviation in the pattern; during the late December holiday season the high demand for aku bids up the price sharply, but by mid-January this effect disappears.

THE FEASIBILITY LINE

In the search for substitute baits, important decisions will have to be made concerning the scale of operations of transport or culture schemes and the extent of bait needs which the substitution schemes are intended to fulfill. A small pilot project might be viable only if its operation was restricted to the relatively brief period of highest opportunity cost for nehu. In most schemes it is likely that as the scale of operations is increased the unit costs of bait production or delivery will be reduced, though at a diminishing rate, and a greater share of total bait needs can be satisfied.

There are two obvious conditions which must be met to establish the feasibility of an alternative bait program: 1) During the period of each year when the substitution scheme is operating, the opportunity cost of nehu must not be less than the unit costs of the alternative bait (appropriately adjusted for mortality between delivery and usage), and 2) the quantity of bait produced by the scheme must not exceed the potential amount usable during the period. Figure 5 shows how a particular substitution scheme, producing bait at \$4.50/lb used, generates a feasible period of about 7 mo—5 mo in the spring and summer and 2 mo at the end of the year. During this period, according to Table 2, about 190,000 lb of bait could be used. For each point on the ordinate there is a different maximum usage rate. Together these form the feasibility line or demand curve shown in Figure 6. Substitution schemes producing more bait than can be used or producing bait at a cost exceeding the critical cost will fall in the infeasible region to the right of the line. As the opportunity cost of nehu increases, the curve will of course shift upwards.

EVALUATING ALTERNATIVE BAIT SYSTEMS

The feasible region of Figure 6 defines the set of substitution schemes which may be considered as alternatives to the current practice of using nehu only. Each (hypothetical) scheme in the region will produce an increase in profits to the aku fleet. In addition, there presumably will be benefits to the processing sector of

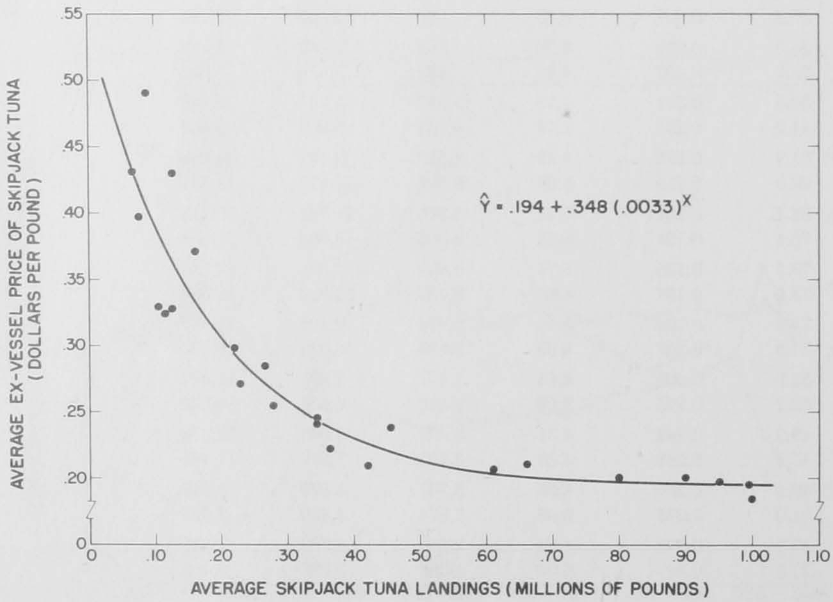

Figure 4.—Relationship between average ex-vessel aku price and average skipjack tuna landings, based on biweekly statistics averaged over 1968-73.

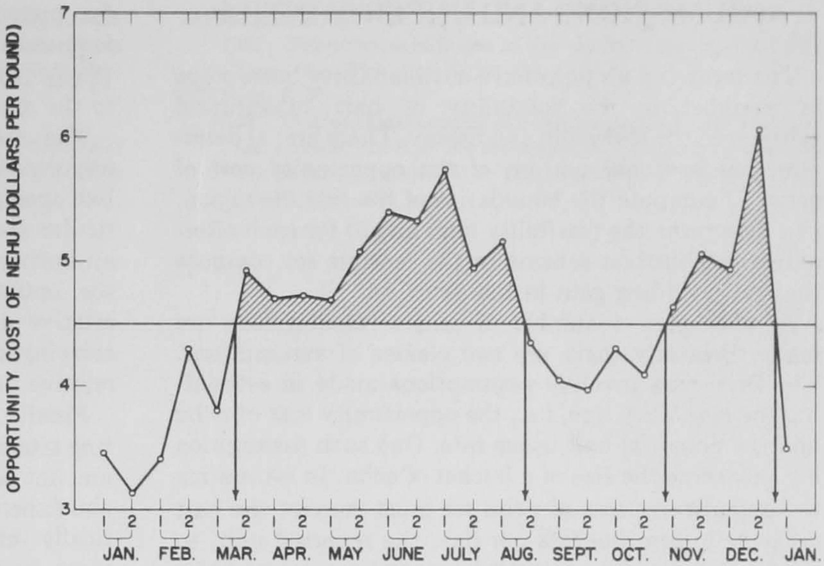

Figure 5.—Seasonal pattern in opportunity cost of nehu, averaged over 1968-73, showing the feasible period for bait substitution generated by a scheme producing bait at a cost of $4.50/lb used.

the industry, unmeasured by the opportunity cost analysis, due to the rise in aku production. We may define the "best" system as the one generating the greatest increase in the fleet's profits.

To compute the catch revenues and net costs under each alternative scheme we first determine the corresponding distribution of work days (potential fishing days). This partitioning is accomplished by solving the system of equations

$$DT = ADF + ADB$$
$$BD = \alpha ADF - \beta ADB$$

where DT = total work days during the feasible period,

BD = amount of bait delivered and used by the substitution scheme during the feasible period,

α = amount of bait used in a day of aku fishing,

β = amount of bait obtained in a day of baiting (after initial mortality),

ADF = adjusted days fishing,

ADB = adjusted days baiting.

It is easy to show that the only nontrivial solution is

$$ADF = \frac{(DB + \beta DT)}{(\alpha + \beta)}$$

and

$$ADB = DT - ADF$$

The coefficients α and β are different for each feasible period (delivery season) and are computed from current statistics.

With ADB and ADF determined for a particular substitution scheme we can compute the net gain to the aku fleet as

$$\text{GAIN} = P_2 - P_1,$$

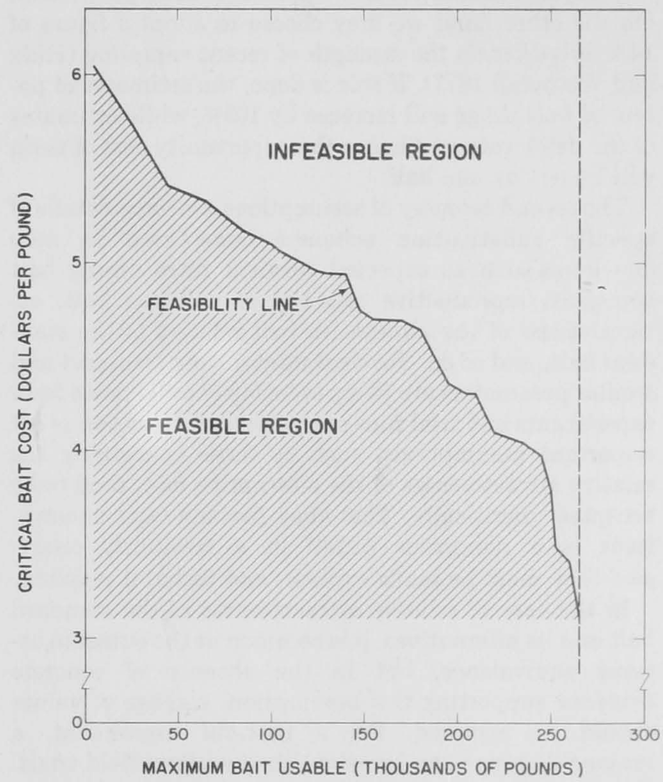

Figure 6.—Feasibility line for judging bait substitution schemes. Schemes falling in the infeasible region produce more bait than can be used in the feasible period generated. The feasibility curve is also the demand curve for bait in the Hawaiian aku fishery.

$$= (ADF - DF)\left\{\pi CR\left(\frac{B}{DF}\right) - k_3\left(\frac{B}{DF}\right)\left(\frac{DT}{DB}\right) - (k_1 - k_2)\right\},$$

$$= \text{Additional catch revenue} - \text{Costs of bait purchase} - \text{Additional net operating costs}$$

ASSUMPTIONS AND UNCERTAINTIES

The foregoing sections have outlined three basic steps in establishing the feasibility of bait substitution schemes in the Hawaiian aku fishery. These are: 1) determine the seasonal pattern of the opportunity cost of nehu; 2) compute the boundaries of the feasible region, i.e., determine the feasibility line; and 3) for each alternative substitution scheme in the feasible set compute the corresponding gain to the aku fleet.

At each step a number of critical assumptions are made. Basically there are two classes of assumptions. The first class involves assumptions made in estimating the feasibility line, i.e., the opportunity cost of nehu and the potential bait usage rate. One such assumption e.g., concerns the size of a bucket of nehu. In estimating the opportunity cost of nehu we must convert the bait usage rate from buckets per day, the reported unit, to pounds per day. The standard conversion rate used historically and in this paper is 7 pounds of nehu per bucket. On the other hand we may choose to adopt a figure of 14.2 lb/bucket on the strength of recent sampling (Hida and Wetherall 1977). If this is done, the estimates of potential bait usage will increase by 103%, while estimates of the catch rate and hence the opportunity cost of nehu will be cut by one-half.

The second category of assumptions concerns details of specific substitution schemes considered in step (3)—items such as expected survival rates during bait transport, reproductive capacity of cultured bait, attractiveness of the alternative bait relative to the standard bait, and so on. Survival rates during transport and similar parameters are likely to be fairly well known from experiments and trial runs of the system. However, other important assumptions, such as those concerning the relative attractiveness of the alternative bait, tend to be accepted uncritically. That they become tacit assumptions is a dangerous pitfall in a feasibility analysis—they must be made explicit, and tested if possible.

In the case of relative attractiveness of the standard bait and its alternatives, it is common at the outset to assume equivalence, but in the absence of concrete evidence supporting this assumption, a range of values should be explored. For a first-cut assessment, a reasonable range can be established without field trials. On theoretical grounds, e.g., we may expect that attractiveness of a pound of chummed bait is proportional to the surface area of the bait. The surface area of an individual fish is roughly proportional to the square of its length, so fish for fish the larger northern anchovy may be more attractive than nehu. But there are more nehu per pound. The number per pound is the reciprocal of average individual weight, and this is proportional to the cube of length. Combining the "surface area" and "number per pound" considerations, and noting the similarity in morphometrics between the two species, we may conclude that pound for pound the relative attractiveness of nehu versus anchovy is inversely proportional to the ratio of their average lengths. That is, if the anchovy are twice as long, they are only half as attractive as nehu, pound for pound. While this analysis ignores possible differences in behavior and other important characteristics (Yuen 1977), it provides useful guidance for setting limits to the assumption on relative attractiveness.

The effect of average size on relative attractiveness is important not only in choosing between two alternative bait species, but also in finding the best size for any particular species. Where a range of bait sizes is available, an optimum size surely exists. Of course, determining the optimum will involve consideration not only of relative attractiveness but also other factors such as carrying capacity of baitwells for different sized fish, relative production costs, and so on.

Finally, implicit in the earlier discussion on evaluating alternative systems is the assumption that the entire amount of bait delivered is purchased and used by the aku fishermen (or accepted and used, in the case of a vertically integrated system). If this is not the case, and some bait dies or is discarded between the time of delivery and fishing, then two important results follow. First, the unit cost of bait under the scheme is increased. If the fraction of bait ultimately used is μ, the cost will increase by a factor of $\frac{1}{\mu}$ over the unit cost under full utilization. Second, the net gain to the fleet will not be as great. The correct result is found using the equation given above for GAIN, but substituting a more general expression for adjusted days fishing,

$$ADF(\mu) = \frac{(\mu BD + DT)}{(\alpha + \beta)}$$

and, if the bait is purchased at cost, an amended cost figure, $\frac{k_3}{\mu}$.

It is clear, then, that in judging bait substitution schemes no meaningful conclusions can be drawn without a careful consideration of assumptions underpinning the analysis. Quoting appropriately from Chapman (1965), ". . . if far reaching assumptions are made, then strong conclusions are reached. But if these assumptions are not accepted, then the whole structure built upon sand collapses."

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