# AN EXAMINATION OF THE FEASIBILITY OF BAITFISH CULTURE FOR SKIPJACK POLE-AND-LINE FISHING IN THE SOUTH PACIFIC COMMISSION AREA

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# PREFACE

This paper was prepared in response to requests from several South Pacific Commission countries for information on the feasibility of establishing commercial live bait culture programmes. In order to supplement information already available within the Skipjack Programme, Mr Michael Rivkin, acting as a consultant to the Programme, visited the major live bait culture projects within the region.

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## 1. INTRODUCTION

Countries of the central and western Pacific are aware of the significance of the availability of good supplies of live bait to the development of skipjack (*Katsuwonus pelamis*) fisheries. Not all of these countries have sufficient reliable baitfish resources and many of those planning skipjack fishing ventures are looking to alternative methods of catching skipjack or alternative sources of live bait. Several skipjack fisheries have been established without live bait by using pearl shell lures and the poling-trolling technique common in the Pacific, but these have all been small scale fisheries. Much larger vessels have taken good catches of skipjack with purse-seine nets but this technique has not yet been proven in all areas of the western Pacific. Furthermore, most small states do not have the great amounts of capital required to purchase and operate modern tuna purse-seiners.

In response to this problem many Pacific Island states have considered alternative sources of live bait for the development of skipjack fisheries. The most likely alternatives have been the importation of live bait from countries with a proven surplus, or the culture of baitfish in local natural or man-made ponds. The importation of live bait is apparently cost-effective only when the bait is carried by fishing vessels which use it themselves to catch skipjack and other tunas (e.g. the Japanese distant water pole-and-line fleet which fishes throughout the western Pacific), and therefore not suitable for developing locally based fisheries. Baitfish culture has, however, been considered by many Island states as a potentially viable source of bait upon which to base a local skipjack fishery.

A number of experimental bait culture projects have been established in the area of the South Pacific Commission over the past five years involving a variety of baitfish species, techniques, and conditions. Nevertheless, insofar as no commercial large-scale project is yet in operation, countries considering bait culture have little empirical evidence to suggest whether or not such a project would be economically viable.

This paper examines the important aspects of live bait culture for which data are available, and considers these in the context of overall fisheries development objectives. Moreover, it gives indications of the strategies countries might adopt in developing cultured baitfish resources. Factors influencing the extent to which live bait culture is possible are discussed and an estimation of the economic feasibility of baitfish culture is presented.

## 2. DEFINING THE GOALS OF SKIPJACK FISHERIES

At the present time, live bait fishing represents the best hope for many Pacific Island states wishing to substantially boost their skipjack catch. However, the development of a pole-and-line fishery involves more than securing a consistent supply of bait. New equipment must be acquired, fishing techniques changed, and expertise built up. Moreover, as skipjack catches grow, a whole new infrastructure is required to deal with the increased quantities of fish. Clearly, the development of a bait culture project as a basis for increasing skipjack landings can represent a substantial commitment to developing a whole new scale of fishing activity.

A prerequisite, then, to assessing the feasibility of a bait culture project is an analysis of the purpose and extent of the desired skipjack fishery. Those countries in which the aim of developing a skipjack fishery is to meet local demand for fish may be able to do so by expanding skipjack fisheries based on little or no live bait. Conversely, those countries desiring a pole-and-line fishery of sufficient size to enable an export industry to be maintained, and having little or no natural bait may consider making a substantial commitment to a bait culture programme. For all South Pacific countries in which the development of a skipjack pole-and-line fishery is a major objective, insuring adequate supplies of live bait is a critical concern.

Skipjack fisheries in most South Pacific Commission countries fall into one of the following four categories:

(i) fishing for local consumption only (includes recreational, subsistance, artisanal, and some commercial fisheries);

(ii) fishing for local consumption with export of surplus;

(iii) export dominated fishery;

(iv) foreign based fishery;

## 2.1 Fishing for Local Consumption Only

In a situation where skipjack are used exclusively for domestic consumption (i.e., no export of locally caught tuna), the optimal size of a skipjack fishery depends on the local population and per capita consumption of skipjack. Table 1 illustrates catch, import, export, and population data for various countries. Those areas with populations of less than 100,000 are rarely significant exporters of fish. Those that are fish exporters invariably rely on distant water fleets to supply quantities sufficient for export. Countries where the domestic catch is all consumed locally include Niue, Tonga, and Tuvalu. In 1977, these countries also had balance of payments deficits and imported substantial quantities of fish. If the domestic catch could be expanded, not only would more fresh fish be available for local consumption, but imports of fish could be reduced giving rise to improvements in trade balances.

## 2.2 Local Consumption with Export of Surplus

In this case, countries catching more skipjack than required for domestic consumption export the balance as frozen fish for processing abroad. Quantities of skipjack exported vary from year to year depending on seasonal variations and other factors. One country in this category is French Polynesia, which has a pearl-shell lure fishery for skipjack, but does not have an established live bait pole-and-line fishery.

## TABLE 1 - POPULATION, FISHERIES AND BALANCE OF TRADE DATA FOR SOME COUNTRIES IN THE AREA OF THE SOUTH PACIFIC COMMISSION

| Country | 1978[1] Population | Commercial fish[2] catch for domestic consumption (tonnes) | Total locally[3] registered fish catch (tonnes) | Total fish[3] catch from 200 mile zone (tonnes) | Total fish[5] imports ('76) (A$'000) | Total fish[1] exports ('77) (A$'000) | Balance of[1] trade ('77) (A$'000) |
|---|---|---|---|---|---|---|---|
| American Samoa | 31,500 | 220 | 220 | 636 | 496 | 67,979 | 22,860 |
| Cook Islands | 18,500 | N.A. | N.A. | 2,876+ | N.A. | - | -13,255 |
| Fiji | 607,000 | 4,332 | 11,594 | 13,380 | 7,000 | 4,705 | -131,151 |
| French Polynesia | 141,000 | 2,586 | 2,386 | 9,650 | 2,200 | - | -240,283 |
| Kiribati | 56,000 | 1,344 | 1,344 | 29,263 | 76 | - | 6,519 |
| Nauru | 7,000 | 0 | 0 | 10,069 | N.A. | - | 23,490 |
| New Caledonia | 138,000 | 499 | 499 | 2,357 | 1,100 | 121 | 17,841 |
| New Hebrides | 101,000 | 500 | 10,500 | 11,605 | 930 | 12,011 | -6,994 |
| Niue | 3,700 | 20 | 20 | 313 | 50 | - | -1,627 |
| Norfolk Island | 1,900 | N.A. | N.A. | 702+ | - | 2 | -6,125 |
| Papua New Guinea | 2,990,000 | 20,050 | 68,050 | 84,895+[4] | 21,826+ | 48,915+ | 56,187 |
| Solomon Islands | 214,000 | 1,657 | 17,444 | 37,401 | 150 | 7,895 | 3,861 |
| Tokelau | 1,600 | N.A. | N.A. | 2,095+ | N.A. | - | - |
| Tonga | 93,000 | 1,117 | 1,117 | 1,951 | 96 | 5 | -11,490 |
| Trust Territory of the Pacific Islands | 113,000 | 4,716 | 10,000 | 68,961 | N.A. | 3,265 | -24,419 |
| Tuvalu | 7,400 | 80 | 80 | 9,577 | 24 | - | - |
| Western Samoa | 153,000 | 1,700 | 1,700 | 1,884 | 700 | - | 23,767 |
| TOTAL | | 38,621+ | 124,954+ | 288,115+ | 34,624+ | 144,898+ | |

1 From Sevele and Bollard 1979
2 From Crossland and Grandperrin 1979
3 From Kearney 1979b
4 From Kearney 1979a
5 From Kent 1980.

N.A. = Not available

\+ = .... at least

Obviously countries in this category have sufficient skipjack for local consumption and live bait culture is likely only to be advocated to increase catches for export. However, it is possible that small scale live bait and pole fisheries could be developed which would be more economical than exisiting techniques for supplying skipjack for local markets.

2.3 Export Dominated Fishery

From Table 1, it is evident that in the south Pacific region as a whole, the value of fisheries exports substantially exceeds the value of fisheries imports. Countries with sizable skipjack exports through a local live bait fishery include Papua New Guinea, Solomon Islands, Fiji, and Palau (included under Trust Territory of the Pacific Islands in Table 1). For all such major pole-and-line fisheries, significant quantities of live bait are required. Fortunately for some, live bait availability is usually not a problem. Papua New Guinea annually catches on the order of 750,000 buckets (2000 tonnes) of natural bait to supply its pole-and-line vessels (Crossland and Grandperrin 1979; Dalzell and Wankowski, 1980). Solomon Islands, Palau, and Fiji are also usually able to catch needed quantities of live bait. For most other countries, however, such quantities of live bait are not taken. For bait-poor countries wishing to expand their pole-and-line fisheries, bait culture has been viewed as a possible alternative.

2.4 Foreign Based Fishery

Returning to Table 1, it is clear from the differences between Total Fish Catch from 200 Mile Zones and Locally Registered Fish Catch, that many countries have significant fisheries resources within their boundaries, but as yet do not have local fisheries which capitalize on this resource. Countries such as Tuvalu and Marshall Islands license distant water fleets to fish their waters using foreign vessels, capital and labour. However, the return from such agreements is only a fraction of the total return earned by the distant water fleets. Recognizing this, most Pacific Island states have investigated the potential for developing local tuna fisheries.

## 3. ASSESSING BAIT NEEDS

Once the objectives have been defined and the desired type of skipjack fishery has been agreed upon, bait needs must be defined based on the scale of operation intended. Of course, the lack of bait can often be the factor that limits development objectives. Countries wishing to develop large scale pole-and-line fisheries will require substantial quantities of live bait. It has been estimated from Papua New Guinea figures that a minimum of 240 tonnes of bait per year is necessary to maintain an economically viable export fishery based on skipjack catches from a catcher boat and mothership type operation (Kearney 1975). Much less bait will be required for smaller scale fisheries, particularly if smaller vessels are used.

Generally, bait needs are thought to be a function of supply, effectiveness in attracting tuna, and mortality. Various estimates and calculations have been made in attempting to quantify baitfish attractiveness to tuna (Herrick and Baldwin 1975, Kearney 1975, Baldwin 1977b, Vergne et al 1978). Although many wild baits tend to be very effective in attracting tuna, problems arise in obtaining adequate supplies and in keeping the bait alive for extended periods of time. Naturally occurring quantities of live bait vary depending on a variety of factors, including overall abundance, seasonality, cyclicality, and lunar phases (Hester 1973, Kearney 1977). Wild bait mortality in loading and storage can be as high as 100 percent in a 24 hour period, but varies with the species used and the methods and conditions of handling. Night loading in particular precipitates high losses (Smith 1977). In general these mortalities tend to be much lower with cultured bait which is one of its great advantages.

One of the most important factors affecting the efficient use of cultured bait is the maintenance of a consistent supply. Kearney (1975) found that in Papua New Guinea, most pole-and-line vessels require a minimum of 20 kg of bait per day to justify proceeding to the fishing grounds. With less than 20 kg, the boats stay in port. The value of the marginal bucket for smaller quantities of bait is greater than the value of the marginal bucket for large quantities (Kearney 1975).

## 4. TYPE OF BAIT

As yet, no single baitfish species has proven superior in all aspects of bait culture and usage. Between 1978-1980, there have been at least eight bait culture projects in operation in the South Pacific Commission region involving predominantly two different species of bait: mollies (*Poecilia mexicana*) and milkfish (*Chanos chanos*). Projects involving mollies have been undertaken in American Samoa, Fiji, French Polynesia, Palau, Tonga, and Western Samoa. Milkfish projects have been started in French Polynesia and Kiribati.

Although mollies and milkfish have been the only species cultured in quantity in this area to date, bait culture programmes elsewhere in the Pacific have experimented with tilapia (*Tilapia mossambica*), threadfin shad (*Dorosoma petenense*), mountain bass (*Kuhlia sandvicensis*) and other species. Baldwin (1977a) provides an extensive table giving biological data for these and other baitfishes.

### 4.1 Use Aspects of Cultured Baitfish

Small fish are most effective as tuna bait when they exhibit the following characteristics:

(i) bright or silvery colour;

(ii) behavior consisting of rapid movement, erratic motion in water, returning to boat after broadcast;

(iii) able to withstand handling and storage aboard ship for extended periods;

(iv) size is generally thought to be important, although appropriate limits might vary between 3 cm to 15 cm depending on fishing conditions.

4.2 Culturing Aspects

Baitfish suitable for culture must have most of the following characteristics (in order of importance):

(i) breed in captivity year round/fry readily available year round;

(ii) high productivity;

(iii) resistant to disease;

(iv) omnivorous but not cannibalistic;

(v) high survival during handling;

(vi) able to withstand crowding;

(vii) survives under euryhaline conditions;

(viii) amenable to polyculture;

Both the culturing and use aspects of a potential baitfish must be satisfactory in order to achieve good overall results.

4.3 Milkfish vs Mollies

As almost all bait culture projects in the western Pacific have dealt with either mollies or milkfish, it is appropriate to compare the use and culturing aspects of the two species. The following table compares milkfish and mollies to the criteria set forth above. Assessments have been based upon as yet unpublished results from the South Pacific Commission Skipjack Survey and Assessment Programme and the opinions of the managers of the bait culture projects in Western Samoa and Kiribati.

| Use Aspects | Mollies | Milkfish |
|---|---|---|
| bright or silvery color | no | yes |
| rapid movement in water | no | yes |
| erratic motion | no | yes |
| returning to boat after broadcast | slowly | yes |
| tolerates handling and live storage | yes | yes |
| falls within size parameters | yes | yes |
| **Culturing Aspects** | | |
| breeds in captivity | yes | no |
| high productivity | yes | yes |

| | | |
|---|---|---|
| fry available in large numbers | yes | variable |
| fry available year-round | yes | variable and seasonal |
| resistant to disease | yes | yes |
| omnivorous | yes | yes |
| able to withstand crowding | yes | yes |
| high survival during transfer | yes | yes |
| survives under euryhaline conditions | yes | yes |
| amenable to polyculture | yes | yes |

Although milkfish can, under some circumstances, be raised to bait size without external feeding, Gopalakrishnan (personal communication, 1980) found, in experiments in Kiribati, that feeding at a rate of three percent of body weight per day effectively doubles milkfish yields. Very high yields, normally of relatively large milkfish for human consumption, have been considered possible by some workers (Gopalakrishnan 1976, Herrick and Baldwin 1975) but constraints, such as the availability of great numbers of fry, may make it extremely difficult to obtain similar yields of a size suitable for live bait.

Milkfish are not easily bred in captivity (the rearing of larvae is very difficult and sexual maturation may take as long as six years as opposed to three months for mollies), and fry availability varies greatly from region to region. In the Kiribati pilot project, fry collection has been unnecessary due to the location of sluice gates such that sufficient fry collect naturally in the ponds at high tide. However, fry gathering will be necessary for full scale operation. While mollies breed well in a cultured environment and are extremely hardy, they do not peform as well as milkfish in attracting tuna.

Sea trials indicate milkfish are attractive to skipjack, while mollies are acceptable particularly when mixed with milkfish or wild bait. Compara- tive data for estimating the relative effectiveness of cultured mollies to cultured milkfish is available from the results of the South Pacific Commission's Skipjack Programme vessels, Hatsutori Maru Nos.1 and 5, (Tables 2a and 2b). In 12 days using only mollies, these vessels achieved a tuna catch-bait ratio of approximately 11:1. In sixteen days using only cultured milkfish, the ratio was 16:1. Various qualifications are necessary to any conclusions drawn: the data points are limited; the vessels were engaged in survey fishing and therefore the results understate the actual tuna-bait ratios possible (a conversion factor of 3.47:1 has been suggested (Kearney 1978) giving estimated yields from mollies and milkfish under commercial fishing of 38:1 and 56:1 respectively); the data are taken from different areas at different times of the year. Nevertheless, the basic relationship illustrating milkfish as being more effective than mollies in attracting tuna is in agreement with the opinions of the scientists and crew of the Skipjack Programme. In fact in their opinions, these results considerably overstate the value of mollies as a skipjack bait.

TABLE 2a - RESULTS FROM HATSUTORI MARU UNDER SURVEY CONDITIONS USING ONLY MOLLIES

| Date | Location | Amount Used (kg) | Catch (tonnes) | Tuna - bait ratio |
|---|---|---|---|---|
| 78/06/17 | American Samoa | 30 | 0 | 0 - 1 |
| 78/06/18 | American Samoa | 21 | 0.145 | 6.9 - 1 |
| 78/06/25 | Tuvalu | 135 | 3.242 | 24.0 - 1 |
| 78/06/26 | Tuvalu | 24 | 0.374 | 15.6 - 1 |
| 78/06/27 | Tuvalu | 57 | 1.803 | 31.6 - 1 |
| 78/06/28 | Tuvalu | 12 | 0.158 | 13.2 - 1 |
| 78/07/02 | Tuvalu | 21 | 0.376 | 17.9 - 1 |
| 78/12/16 | Tuamotu Archipelago | 39 | 0.193 | 5.0 - 1 |
| 78/12/18 | Tuamotu Archipelago | 26 | 0.166 | 6.4 - 1 |
| 80/02/28 | Niue | 150 | 0.011 | 0.1 - 1 |
| 80/02/29 | Niue | 80 | 0.333 | 4.2 - 1 |
| 80/03/01 | Niue | 20 | 0 | 0 - 1 |
| | TOTALS | 615 | 6.801 | 11.06 - 1 |

TABLE 2b - RESULTS FROM HATSUTORI MARU UNDER SURVEY CONDITIONS USING ONLY MILKFISH

| Date | Location | Amount Used (kg) | Catch (tonnes) | Tuna - bait ratio |
|---|---|---|---|---|
| 79/01/06 | Marquesas Islands | 122 | 1.270 | 10.4 - 1 |
| 79/01/28 | Society Islands | 105 | 2.034 | 19.4 - 1 |
| 79/12/02 | Tuamotu Archipelago | 38 | 0.343 | 9.0 - 1 |
| 79/12/04 | Tuamotu Archipelago | 27 | 0.011 | 0.4 - 1 |
| 79/12/22 | Marquesas Islands | 128 | 1.057 | 8.3 - 1 |
| 79/12/23 | Marquesas Islands | 180 | 3.355 | 18.6 - 1 |
| 79/12/24 | Marquesas Islands | 315 | 3.289 | 10.4 - 1 |
| 80/02/03 | Pitcairn Island | 38 | 0.127 | 3.4 - 1 |
| 80/02/04 | Pitcairn Island | 75 | 3.672 | 49.0 - 1 |
| 80/02/05 | Pitcairn Island | 30 | 2.064 | 68.8 - 1 |
| 80/02/06 | Gambier Island | 12 | 0 | 0 - 1 |
| 80/02/07 | Gambier Island | 3 | 0 | 0 - 1 |
| 80/02/08 | Tuamotu Archipelago | 2 | 0 | 0 - 1 |
| 80/02/10 | Tuamotu Archipelago | 87 | 0.737 | 8.5 - 1 |
| 80/02/11 | Tuamotu Archipelago | 75 | 1.033 | 13.8 - 1 |
| 80/02/12 | Tuamotu Archipelago | 165 | 3.398 | 20.6 - 1 |
| 80/02/13 | Tuamotu Archipelago | 83 | 1.470 | 17.7 - 1 |
| | TOTALS | 1,485 | 23.860 | 16.07 - 1 |

## 5. SITE LOCATION

When examining potential sites for a bait culture project, a critical factor is the cost of purchasing and developing the areas under consideration. Private parties may need to select a less suitable site if the cost of their first choice is excessively high. Although public projects may have the benefit of choosing between several public (and therefore "free") sites, in fact these sites may have a significant opportunity cost that is easily overlooked. Public lands used for bait culture are eliminated for use as housing developments, public parks, and other uses. In addition, pond construction often causes damage to the natural habitat. Great care should be taken when constructing ponds to limit unnecessary environmental damage, particularly if mangrove or tidal areas, which are natural breeding and nursery grounds for coastal baitfish or other fish species, are endangered. Other factors affecting area selection include (not in priority order):

(i) level topography;

(ii) ability to drain and allow to dry (important to kill predators and speed up mineralisation processes in top sediment layers - Korringa 1976);

(iii) good tidal range (provides food, aeration), but free from flooding;

(iv) soil type;

(v) stability of banks;

(vi) type and density of vegetation;

(vii) convenient access for vessels taking on bait;

(viii) fresh and salt water available (for brackish water baitfish);

(ix) water temperature appropriate to bait being cultured;

(x) land available for buffer zone;

(xi) avoidance of pollution from external sources;

(xii) local laws and regulations;

(xiii) regional planning goals;

(xiv) conflicts with traditional lifestyles.

Failure to allow for the effects of any one of these variables could endanger the whole project.

Critical design considerations recommended by Gopalakrishnan (personal communication, 1980) include:

(i) water supply adequate to sustain desired level of production;

(ii) provide for adequate pond drainage facilities;

(iii) create suitable environment for growth and reproduction;

(iv) take advantage of natural power systems in water supply and drainage;

(v) design ponds for easy harvest;

(vi) consideration of social and economic factors.

Generally, larger ponds make more efficient use of land and water and have lower construction costs relative to size, whereas smaller ponds require less maintenance and are more easily managed. Methods of construction include the use of earthen, cement, and fibreglass materials. For experimental or small scale projects, sections of a larger water mass have at times been closed off using netting. Common problems encountered with aquaculture projects and installations include:

(i) low oxygen levels;

(ii) unfavourable water temperatures;

(iii) increased salinity through evaporation;

(iv) vandalism and poaching;

(v) disease, parasites;

(vi) predation;

(vii) burrowing crabs (affects stability of earthen banks);

(viii) cannibalism;

(ix) algal blooms (can sometimes be toxic or can clog mesh net enclosures; sometimes can be beneficial as food for some bait species);

(x) severe weather conditions (cyclones, etc.).

## 6. ECONOMIC ANALYSES

Having briefly examined the goals and requirements necessary for bait culture, it now becomes necessary to consider the economics associated with establishing such projects. Clearly, accepted goals of bait culture are to enable a skipjack fishery to be initiated, or to increase skipjack catch by minimizing time lost due to lack of bait or time spent catching bait. Two scenarios are considered: first, where cultured bait is the only bait available, and second, where cultured bait serves as an alternative to natural bait.

## 6.1 Cultured Bait as Sole Bait Supply

As discussed previously, countries wishing to develop a skipjack fishery must initially decide on the desired scale of the fishery. Once the projected size of the skipjack fishery has been established (presumably based on national requirements and abundance of skipjack), bait needs can be estimated based on the anticipated return of skipjack per unit of bait used.

While large quantities of bait will not be required for small scale fisheries development, they are necessary to support commercial fisheries. For example, Kearney (1975) estimated that an export fishery based on Japanese-type pole-and-line vessels with mothership support would require a minimum throughput of 8000 tonnes of skipjack per year to be economically viable; this estimate is thought to be still applicable. Table 3 can be used to estimate the baitfish requirement for different scales of fishery under different fishing conditions. The need to assess the baitfish requirements for the desired scale of fishery before any commitment is made to large scale bait culture projects is again stressed.

TABLE 3 - ESTIMATING BAIT NEEDS USING TUNA-BAIT RATIO AND SIZE OF DESIRED SKIPJACK FISHERY

| Yield of skipjack in kg per kg of bait used | Size (in tonnes) of skipjack fishery | | | | |
|---|---|---|---|---|---|
| | 50 | 100 | 300 | 8,000 | 15,000 |
| | Bait required in tonnes | | | | |
| 12:1 | 4.2 | 8.3 | 24 | 667 | 1,250 |
| 15:1 | 3.3 | 6.6 | 19.8 | 533 | 1,000 |
| 20:1 | 2.5 | 5 | 15 | 400 | 750 |
| 30:1 | 1.7 | 3.3 | 10 | 267 | 500 |
| 50:1 | 1 | 2 | 6 | 160 | 300 |
| 100:1 | 0.5 | 1 | 3 | 80 | 150 |

As most of the projects planned for developing large scale skipjack pole-and-line fisheries in the western Pacific anticipate the use of Japanese-style live-bait and pole vessels, available figures for this type of vessel are probably the most appropriate to use when estimating costs. It has been shown that the bait costs for the average Japanese distant water pole-and-line vessel are approximately 10 percent of the total operating cost (Kearney 1979a). If this figure is reasonable for similar types of skipjack fisheries, the expected cost of bait under various fishing conditions can be estimated. If, for example, a pole-and-line boat operator can expect $800 per tonne for his skipjack and demands a five percent profit margin from his fishing, then the total operating expenses must be below $760 ($800 x 0.95) for every tonne of skipjack caught. If, as Kearney (1979a) estimated, 10 percent of total costs is spent on bait, then bait must not cost more than \$76 (\$760 x 0.10) for every tonne of tuna caught. At a 30:1 ratio of kilograms of skipjack caught per kilogram of bait used, the maximum allowable bait cost would be \$2.28 per kg (30/1000 x \$76). It would increase to \$3.80 if a ratio of 50:1 could be obtained (50/1000 x \$76). Estimates of maximum acceptable bait prices, based on different yield ratios and variable prices to the fishermen per tonne of tuna caught, are given in Tables 4a and 4b.

Yield ratios in existing skipjack fisheries in Papua New Guinea and Fiji normally range between approximately 20:1 and 60:1 using natural bait (Kearney 1975, Skipjack Programme Manuscript). Furthermore, the baitfish trials by the South Pacific Commission Skipjack Programme suggest that the Hatsutori Maru under commercial fishing conditions would have achieved yields of 38:1 and 56:1 with mollies and milkfish respectively (Skipjack Programme ms). In so far as commercial quantities of bait have not as yet been produced in the western Pacific for under \$3.80 per kg (the Kiribati pilot project has produced limited quantities of bait at \$2.88 per kg), these results emphasize the difficulties in making baitfish culture a viable enterprise.

### 6.2 Cultured Bait as an Alternative to Natural Bait

In situations where natural bait is normally available but fishing time is often lost, either catching bait or not fishing due to lack of bait, there is a potential for increasing yield and profits by using cultured bait.

Most baitfishing in the western Pacific is done at night. There are many instances when bait caught at night is insufficient to meet the needs for the following day's skipjack fishing and this can result in part or all of the next day being spent in search of bait or, more commonly, no skipjack fishing at all on the following day. Kearney (1977) showed that in Papua New Guinea in 1972 and 1973 the commercial vessels lost an average of 9.75 percent of their fishing time due to lack of bait. This figure is thought to be lower in Solomon Islands and higher in Fiji.

It should be noted that the commercial vessels presently operating in Papua New Guinea, Solomon Islands and Fiji do not pay large royalties for their bait. Furthermore, as there is only minimal fuel and equipment costs (probably less that \$10 per vessel per night) involved in catching bait, and the crew are required to be on board 24 hours a day regardless of whether baiting is attempted, there is little monetary cost or opportunity loss involved in catching bait.

The major consideration then is how to minimize the loss of skipjack fishing time due to the lack of bait. If cultured bait is available at a positive dollar cost, but with a saving in fishing time, profit-maximizing fishermen will focus on the value of the skipjack generated in the additional fishing time versus the cost of purchasing bait in determining their fishing strategy.

TABLE 4a - ESTIMATES OF THE MAXIMUM ACCEPTABLE BAIT PRICE UNDER DIFFERENT FISHING CONDITIONS AND DIFFERENT SKIPJACK PRICES.
A 5 percent profit on total fish sales and maximum bait costs equal to 10 percent of total operating cost are assumed.
(All prices are in $US).

| Kg of skipjack caught per kg of bait used | Skipjack price per tonne | | | | |
|---|---|---|---|---|---|
| | $500 | $800 | $1,000 | $1,200 | $1,400 |
| | Maximum bait price ($ per kg) | | | | |
| 15-1 | 0.71 | 1.14 | 1.43 | 1.71 | 2.00 |
| 20-1 | 0.95 | 1.52 | 1.90 | 2.28 | 2.66 |
| 30-1 | 1.43 | 2.28 | 2.85 | 3.42 | 3.99 |
| 50-1 | 2.38 | 3.80 | 4.75 | 5.70 | 6.65 |
| 100-1 | 4.75 | 7.60 | 9.50 | 11.40 | 13.30 |

TABLE 4b - ESTIMATES OF THE MAXIMUM ACCEPTABLE BAIT PRICE UNDER DIFFERENT FISHING CONDITIONS AND DIFFERENT SKIPJACK PRICES.
A 10 percent profit on total fish sales and maximum bait costs equal to 10 percent of total operating cost are assumed.
(All prices are in $US).

| Kg of skipjack caught per kg of bait used | Skipjack price per tonne | | | | |
|---|---|---|---|---|---|
| | $500 | $800 | $1,000 | $1,200 | $1,400 |
| | Maximum bait price ($ per kg) | | | | |
| 15-1 | 0.68 | 1.08 | 1.35 | 1.62 | 1.89 |
| 20-1 | 0.90 | 1.44 | 1.80 | 2.16 | 2.52 |
| 30-1 | 1.35 | 2.16 | 2.70 | 3.24 | 3.78 |
| 50-1 | 2.25 | 3.60 | 4.50 | 5.40 | 6.30 |
| 100-1 | 4.50 | 7.20 | 9.00 | 10.80 | 12.60 |

As an example, consider the situation when 25 percent of fishing time is lost due to lack of bait. It is assumed that tuna fishing, if possible in this 25 percent extra time, would yield 25 percent more catch and total revenue would increase by 25 percent. Because the vessel and crew are committed 24 hours a day, regardless of the loss of fishing time due to lack of bait, the only major additional expense as a result of fishing on these days is likely to be for fuel for the extra days fishing plus the costs of handling and refrigerating the catch (bonus payments for the crew may be a major expense in some cases and some lay days are necessary for routine ship maintainance and crew holidays). These expenses would vary depending on the fishing circumstances but in this example they are considered in total as marginal additional costs in which fuel is the major component. It has been estimated that fuel costs for Japanese pole-and-line vessels increased more than five fold between 1971 and 1976 to approximately 23 percent of total operating costs (Kearney 1979a). Fuel costs have certainly gone up since 1976 and probably now approximate 30 percent of operating expenses. Therefore in this example the total marginal additional expenses are estimated at approximately 33 percent of the operating cost.

Under the assumption that the marginal additional cost of fishing on a day when no bait is available is only 33 percent of total operating costs, which are in turn 95 percent of total revenue, a total of $506.7 from the revenue earned from every tonne of skipjack caught, is available for bait purchase (i.e. at $800 per tonne of skipjack = $800 x 0.95 x 0.666). At 20:1, 30:1 and 50:1 returns per kilogram of bait used, bait costs need only be less than $10.13 per kg, $16.89 per kg and $25.33 per kg respectively.

Of course these figures are only applicable if the bait can be loaded by the catcher boat with no significant time loss from the time the fishermen know natural bait is not available, to the time fishing must commence on the fishing ground. Alternatively they might be applicable if hardy, cultured bait can be carried by the skipjack catcher boat at all times and only used when natural bait is not available.

The maximum price the fishermen can afford to pay for bait is linearly related to the yield per kilogram of bait he can expect (Tables 4a and 4b). Therefore at times when he knows the skipjack fishery is particularly good, with yields perhaps as high as 100:1, the purchase of bait is a very attractive alternative to not fishing on that day. Of course, when catches and yields are very low fishing may not even cover fuel costs and the purchase of bait or the use of purchased bait on that day would not be attractive no matter how cheap the bait.

While the authors believe that these figures give an inflated estimation of the maximum price fishermen would be able to pay for bait, they do indicate a potential. They do not of course indicate the price fishermen would be prepared to pay. They also do not account for the difficulty and uncertainty in operating a bait culture enterprise which is dependent upon demand only when fishing for natural bait is poor.

### 6.3 Alternative Estimates of the Value of Cultured Baitfish

At the present time, the only area in the western Pacific where substantial quantities of bait are sold is Japan. Japanese pole-and-line vessels currently pay approximately $3.80-$4/kg for live bait. This price can probably be considered the maximum price these vessels would be willing to pay at present for a full load of bait; they might however be prepared to pay more for supplementary bait supplies closer to the fishing grounds. Furthermore, this price is related to the local price of skipjack in that the higher the local skipjack price, the more fishermen would be willing to pay for bait. The ratio of skipjack price-per-tonne to bait price-per-kg in Japan is approximately 350:1. ($1350/tonne for skipjack and $3.80/kg for bait). Insofar as bait suppliers in the South Pacific would be competing (at least indirectly) with Japanese suppliers, it is unlikely Japanese fishermen would be attracted by significantly different bait prices. Moreover, insofar as skipjack is freely marketed internationally, other skipjack fleets may have to remain competitive with the Japanese. It is therefore logical that other vessels would be unwilling to pay substantially more for bait than the Japanese (although perhaps a bit more, since wages and other costs may be lower for local and joint venture fleets). Thus, in areas where skipjack commands only $700/tonne, the value, and hence the price, of bait could be reduced to (700/1350) x (3.80) = $1.97. In regions where skipjack is worth $1000/tonne, the price of bait would be (1000/1350) x (3.80) = $2.81. It is of course probable that captains of Japanese vessels which come to the south-west Pacific to fish, and run out of bait before making substantial skipjack catches, may be prepared to pay higher prices rather than returning to Japan to obtain more bait. However, such customers might be irregular and it could be difficult to base a major bait culture programme on such activity. If it could be proven that the cultured bait was better than, or at least as good as, natural bait for catching skipjack, then the chances of attracting foreign vessels as bait buying customers would be greatly increased.

It should be noted that it is not known if very small vessels would be able to achieve higher yields per kg of bait than those presently used in the major skipjack fisheries in the western Pacific (i.e. 59 tonne class vessels). If higher yields can be achieved by small vessels, higher bait prices might be able to be met, particularly if skipjack catches are sold fresh at relatively high prices. In situations where local labour costs are low, total operating costs for small skipjack vessels are often relatively much less than for the larger Japanese type boats. In such cases substantial increases in expenses, due to the purchase of live bait, could be tolerated if skipjack catches are reasonable. Preliminary results from Western Samoa suggest that the use of cultured bait for small scale skipjack fisheries may be economically feasible even if bait costs account for more than 50 percent of total operating expenses (Philipp, Popper and Teppen 1980). The critical factor, of course, being that total operating expenses are still less than the value of the catch. On the other hand, there are problems in basing a bait culture project on modest demand from small vessels.

Numerous previous workers have indicated likely costs of production for several species of baitfish under differing conditions and assumptions. Table 5 summarizes these estimates.

TABLE 5 - SUMMARY OF PREVIOUS ESTIMATES OF BAIT CULTURE COSTS

| AUTHOR | DATE | CULTURED BAITFISH | ESTIMATED PRODUCTION COSTS PER KG (UNDER VARIOUS ASSUMPTIONS) | ESTIMATED MAXIMUM PRICE FISHERMEN WOULD PAY FOR BAITFISH - COST/KG | | ECONOMIC FEASIBILITY OF BAIT CULTURE |
|---|---|---|---|---|---|---|
| Shang and Iverson | 1971 | Threadfin | $11.00-$15.00 | Nehu | $12.20 | Qualified - Yes |
| Herrick and Baldwin | 1975 | *Poecilia vittata* | $ 2.69-$10.34+ | *Poecilia vittata* | $ 2.09 | Qualified - Yes |
| Herrick | 1977 | *Poecilia vittata* | $ 7.18 @ 18,000 lbs production<br>$ 2.05 @ 180,000 lbs production | | | |
| Crumley | 1977 | Tilapia | $ 5.52 | Nehu | $ 9.47 | Qualified - Yes |
| Vèrgne et al. | 1978 | *Poecilia mexicana* | $26.05 | Nehu | | Uncertain |
| CNEXO | 1979 | *Poecilia mexicana* | | | | No |

## 6.4 Private vs Public Sector Operations

The design and operation of a bait culture project depends heavily on the type of project operator, i.e. private or public.

### 6.4.1 Private Sector

The private sector bait culture entrepreneur has profit-maximization as his primary goal. He will attempt to maximize the difference between revenues and costs of baitfish production and sale. Like any other businessman, his success or failure will depend on how well this task is accomplished.

Should the entrepreneur also be an owner or operator of skipjack fishing vessels, he may choose to reduce the return on his baitfish operation in an attempt to maximize his overall return. For example, he might sell whatever bait required by his own boats at or below cost, allowing his vessels to fish consistently while paying less than the fair market value for bait. He would hope his fishing operation would show strong enough returns to more than compensate for the reduced returns expected from the bait culture operation.

In addition, some large bait culture operators may be able to take advantage of tax benefits accruing through land ownership and high initial start-up costs. By offsetting short term expenses from bait culture against short term gains from other ventures, attractive tax savings are sometimes possible.

When setting production goals, the profit-maximizing bait culture entrepreneur will set as his target a production level of N kilograms per year where the return from the N+1th kilogram = 0. Thus, assuming adequate resources, he will produce increasing quantities of bait until the highest price per kilogram that profit-maximizing fishermen would be willing to pay equals the cost of producing that kilogram. This quantity of bait may or may not equal the amount of bait necessary to sustain the desired skipjack fishery; however, if the skipjack fishery grows and bait demand increases, bait prices will rise and N may increase to where the return from the N+1th bucket is once again equal to zero. Nevertheless, if the opportunity cost of bait never exceeds the cost of production, the private sector will not enter the bait culture market unless other factors prevail (tax incentives, etc.).

### 6.4.2 Public Sector

Unlike the private sector, public sector motivation is less profit-oriented and more a result of political and other factors. Public motives ascribed to bait culture in the past include the generation of local jobs and income, developing local expertise, adding important infrastructure to the fishing industry, advances in research and development, and helping to exploit fisheries resources. The fact that aid money is often available for aquaculture projects in developing countries greatly influences government decisions to become involved in this type of activity. In most cases, no one goal dominates the decision to establish a publicly funded bait culture operation. Over the past five years, all baitfish culture projects initiated in the South Pacific Commission area have been under government sponsorship.

As governments are not necessarily burdened by the need to make a profit, the public sector can produce whatever quantities of bait it considers necessary for fisheries development. Using various tuna-bait ratios and tonnes of skipjack desired, tables such as Table 3 illustrate the range of production possibilities. Some level of production above the calculated needs is desirable to account for baitfish mortality through predation and other factors. Note, of course, that total skipjack catch is also limited by skipjack abundance, vulnerability, support facilities, and government's predetermined goals as discussed above for the type and size of the desired skipjack fishery.

The extent to which bait culture appears economically feasible in the future will determine whether governments or private enterprise continue to be involved in this field.

## 7. PRODUCTION COSTS-PER-KG OF CULTURED BAITFISH

Operating statements of three bait culture projects were examined to calculate costs-per-kg of cultured mollies (in American Samoa and Western Samoa) and milkfish (in Kiribati). In both Western Samoa and Kiribati, the Chief Biologists' salaries were paid by FAO-UNDP and therefore did not appear on project financial statements. If senior staff salaries continue to be met by aid projects, cost figures will probably continue to be close to those in Table 6. It should be noted that the position of the expatriate biologist in Western Samoa is being successfully phased out of the project in early 1981. Other costs which may or may not appear fully on these operating statements include government overhead and administration, purchases from other budgets, and miscellaneous services. To the extent that these costs are significant, costs-per-kg as calculated below will be noticeably affected.

TABLE 6 - SIZE, PRODUCTION, AND COSTS OF BAIT CULTURE PROJECTS IN AMERICAN SAMOA, WESTERN SAMOA AND KIRIBATI

| PROJECT | SIZE (ha) | TOTAL CONSTRUCTION COST | CONSTRUCTION COST PER HA. | CURRENT ANNUAL PRODUCTION (tonne) | PRODUCTION COST EXCLUDING CONSTRUCTION COSTS (1 kg) | TARGET ANNUAL PRODUCTION (metric tonnes) | TARGET COST (1 kg) |
|---|---|---|---|---|---|---|---|
| American Samoa* | 1.36 | US$ 28,500 | $20,955 | 3.5 | $23.28 | 6.36 | |
| Western Samoa | .72 | US$ 50,000 | $67,568 | 5.8 | $ 2.55 | 4/ha | $2.12 |
| Kiribati - Ambo (Pilot) | 8 | A$ 16,000 | $ 2,000 | 16 | $ 4.00 | | |
| Kiribati - Temaiku (Phase 1) | 40 | A$120,000 | $ 3,000 | 7.66 | $ 2.88 | 80 | .93 |
| Kiribati - Temaiku (Phase 2) | 40 | A$199,200 (estimated) | $ 4,980 | | | 80 | .69 |

An important qualification to the data presented above is that all projects examined were established as experimental or pilot projects. Costs, therefore, were not a major consideration and it is likely that cost-per-kg figures could be reduced with experience and increased attention to cost control.

Clearly from Table 6, construction costs vary greatly across projects and are a function of size of the project, local wages and prices, type of construction, suitability of site, and a variety of other factors. It is thus difficult to generalize about pond construction costs except to say that larger ponds do exhibit some economies of scale in production. Obviously a much

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* This project has recently been terminated.

larger pond system could be constructed in Western Samoa at a much lower cost per hectare than indicated by the figures in Table 6. Estimates of bait cost-per-kg also vary widely across projects. American Samoa's high cost-per-kg results from the high operating costs typically associated with mesh enclosures as used in that country, and also reflects high costs in dealing with a number of unanticipated and severe problems. Note again that these costs do not include all those associated with the project and as a result should be regarded with caution.

In Kiribati, the first 40 hectares of the 80 hectares of ponds planned for Temaiku are not yet complete. It is probable that when all of these ponds are operational, the unit production cost of $2.88 given in Table 6 may be able to be reduced. However, as natural stocking of all of these ponds by the sluice gate method will not be possible, fry collection, or production, will be necessary. This will of course add to production costs. Furthermore, it may be difficult for bait fish producers in other countries to achieve a production cost of A$2.88 per kg as these figures reflect the relative level of wages and prices in Tarawa and the substantial skills and experience of the project biologist. The results from American and Western Samoa also reflect the high level of skill of the two expatriate aquaculturists managing these projects. At this time, similar expertise is not available locally. This lack of qualified and experienced aquaculturists in the island countries of the western Pacific is considered to be one of the major constraints in the development a baitfish culture programme in this region.

## 8. CONCLUSIONS

This paper has emphasized the need for careful planning prior to undertaking a bait culture programme. Fisheries goals must be established, bait needs assessed, and site locations considered before bait culture is recommended. For some countries, bait culture may be the only alternative to accepting little or no local exploitation of skipjack resources. For others, there may be better ways of solving the problem of bait availability. For all countries, however, all aspects of bait culture should be carefully considered before any commitment is made.

Economic analyses have been restricted to cases in which bait is cultured for use on large commercial vessels. Little is known of the prospects for culturing bait for use on smaller vessels to catch skipjack for local fresh fish markets. There may be potential for higher returns from such operations, but maintaining the year-round scale of baitfish production at high enough levels to be economical could still be a major problem.

The numerous problems associated with bait culture and the relatively low price that fishermen will normally pay for bait have been highlighted. The tendency of fishermen not to want to pay for bait under any circumstances cannot be quantified but should not be overlooked. Even though a fisherman may lose a substantial amount of his fishing time due to lack of bait, he can often only see that purchased bait adds unnecessarily to costs. This approach is common and is difficult to overcome.

The lack of skilled aquaculturists and experienced entrepreneurs and managers in developing countries of the western Pacific is a major problem facing commercial bait culture projects. Unless appropriate personnel can be identified and retained to run baitfish culture projects which produce constant supplies of quality bait, the future of developing skipjack fisheries based on aquaculture will be in jeopardy.

The south Pacific region is fortunate in having two completely different baitfish culture projects which, if successful, can be regarded as models for other potential developments: firstly, the large scale programme in Kiribati, which is proceeding on schedule, and has already produced sufficient bait from its pilot phase to enable many fishing trials to be completed; and secondly, the project in Western Samoa, which concentrates on limited baitfish production for small scale skipjack fisheries. Other countries in this area are advised to consider future developments in the economics of baitfish culture in Kiribati and Western Samoa before proceeding with similar activities.

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