USING COMMERCIAL FEEDS FOR THE CULTURE OF FRESHWATER ORNAMENTAL FISHES IN HAWAI‘I

Clyde S. Tamaru*
University of Hawai‘i, School of Ocean Earth Science and Technology/Aquaculture Development Program
Sea Grant Extension Service, 2525 Correa Road, HIG 205, Honolulu, Hawai‘i 96822 USA
*Tel: (808) 956-2689; Fax: (808) 956-2858; e-mail: ctamaru@hawaii.edu
and Harry Ako
University of Hawai‘i, College of Tropical Agriculture and Human Resources, Molecular Biosciences and Biosystems Engineering, 1955 East-West Road 511, Honolulu, Hawai‘i 96822 USA

ABSTRACT

Since 1993, various public and private institutions have supported the development of a freshwater ornamental industry in Hawai‘i which, based on current success, must be intensive and utilize the latest in culture technologies to remain competitive. Feeding and palatability trials using commercial feeds suggests that very little is understood about the nutritional requirements of the 1500 species that characterize the ornamental trade. Rather than focusing on a particular food for any one species, we examined feeds already developed for food fish to find whether they are suitable as feed for ornamental fish. Investigations on various aspects (price, palatability, color enhancement, growth supporting characteristics, maturation and spawning) of commercially available diets were conducted using a variety of species of freshwater ornamental fishes and form the basis for this report.

INTRODUCTION

Developing a freshwater ornamental fish industry in Hawai‘i is believed to be one means to diversify the agricultural output and stimulate the stagnant local economy. Approximately 75% of the freshwater aquarium fish imported into the United States originate from Southeast Asia (Chapman et al. 1997), reflecting a trade deficit of approximately US \$34 x 10^6 (Fig. 1). Of the nearly 1500 different species of ornamental fish that are imported yearly, the quantities are dominated by only a few species. The top 10 species of imported ornamental fish are listed in Table 1. Three of the top 10 species are live-bearing tooth carps belonging to the Poecilid family. The guppy *Poecilia reticulata* is considered by many to be the most popular aquarium fish (Whitern 1979) and in 1992, it alone accounted for nearly 26% of the total number of freshwater ornamental fishes imported into the United States.

In Hawai‘i, researchers and extension agents are often stumped when asked by growers of ornamental fish, “What is the best feed for my fish?” A closer examination of this question has revealed that, from an aquaculture standpoint, very little information is actually available about the nutritional requirements of the various ornamental fishes being cultured. In this report, some of the preliminary findings and experiences regarding fish food marketed for the freshwater ornamental trade and feed marketed for the culture of food fish are presented.

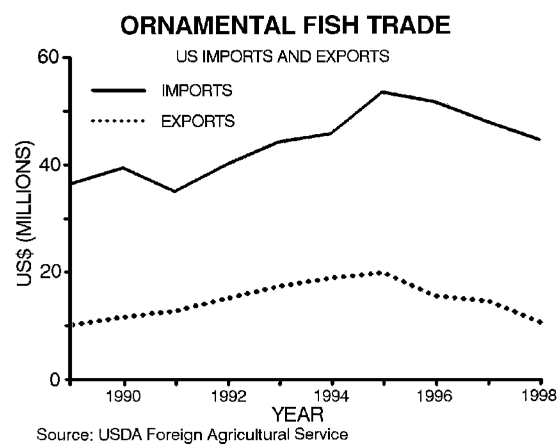

Figure 1. Summary of USA imports and exports of ornamental fish from 1990 to 1998.

Table 1. Summary of top 10 freshwater ornamental fishes imported into the USA in 1992 (from Chapman et al. 1997).

Common Name	Scientific Name	Percentage of Total Fish Imported (1992)	Number of Individuals Imported (1992) (x 10^6)
Guppy	*Poecilia reticulata*	25.8	51.9
Neon Tetra	*Paracheirodon innesi*	11.3	22.7
Platy	*Xiphophorus maculatus*	5.4	10.9
Siamese Fighting Fish	*Betta splendens*	2.7	5.4
Goldfish	*Carrasius auratus*	2.4	4.8
Chinese Algae-eater	*Gyrinocheilus aymonieri*	2.4	4.8
Shortfinned Molly	*Poecilia sphenops*	2.0	4.0
Cardinal Tetra	*Paracheirodon axelrodi*	1.5	3.0
Glassfish	*Chanda lala*	1.5	3.0
Tiger Barb	*Barbus terazona*	1.3	2.6
Total	10	56.3	113.1

Prices of Various Feeds

Not being conversant with the feeds currently marketed in the aquarium industry we asked basic questions such as "What about price?" Retail prices of nine feeds available for koi *Cyprinus carpio* were compared to prices of the few aquaculture feeds available in Hawai‘i. The prices were standardized in US dollars/kg (Table 2). A USA flake (staple) feed is also included as we used it in a feeding trial described later. Two conclusions are obvious in this initial examination of the feed groups. The first is that all the ornamental fish feeds are higher in price by 10-60 times the price of aquaculture feeds. Second, the prices of the feed targeted for a single ornamental species vary dramatically compared to prices of the food fish feeds, each of which is targeted for a specific species. Another major difference is that feeds for ornamental fish are marketed in much smaller packages, the largest being just over 0.5 kg. In contrast, the smallest commercial package of aquaculture feed we know of is 22 kg.

Since the prices of the various feeds designed for one species vary significantly, one would logically presume differences in their efficacy. Our presumption was viewed from an aquaculture standpoint where promoting growth and survival of the target species are primary concerns. This framework presented an opportunity to test whether observations gathered over several years of working with the marine food fish mahimahi *Coryphaena hippurus* and *moi* or *Polydactylus sexfilis* would stand as objective and quantitative. One finding was that fish do have definite preferences among feeds and attack the preferred feeds with greater gusto. They also feed vigorously for a longer period of time if they like the feed. It follows then that, nutrition being equal, more palatable feeds should yield faster growth and to test this hypothesis, a method to assess

Table 2. Comparison of retail prices for ornamental fish feeds and aquaculture feeds.

Type of Feed	US $ per Kg
Japanese Staple	15.18
Japanese Gold	24.09
Japanese Spirulina	41.56
"German" Pond Regular	24.16
"German" Pond Pigmented	28.60
"German" Pond Spirulina	74.34
USA Koi Staple	26.01
USA Koi Color	27.96
USA Koi Growth	29.77
USA Flake (Staple)	14.00
Mahimahi Feed	1.25
Salmon Fry	1.85
Catfish Chow	1.10

Retail prices in Honolulu, Hawai‘i, in 1997.

palatability was designed utilizing the various koi feeds.

Method of Assessing Palatability

Eight different koi feeds were investigated for palatability and each was assigned a code (e.g., Feed 1) to simplify presentation of the results. The various feeds in this study were provided by Rolf A. Hagen, Inc., USA. Some of the feeds are still undergoing testing and many aspects of the data (e.g., proximate analysis) are not available at this time. The proximate analysis provided by the manufacturers of the various feeds used in the current study is summarized in Table 3. The mix of ingredients include: minimum crude protein of 25-40%, minimum crude fat of 2-7%, maximum fiber of 2-5%, maximum moisture 7-12% and maximum ash of 10-12%. With the exception of protein content, no outstanding differences in the major components of the various feeds were found.

Testing for Differences in Palatability

Juvenile koi were purchased from a commercial breeder and kept in four 120-L tubs (7 fish/tub) equipped with aerators. Water was pumped through all tubs and changed 50% each wk. The water temperatures ranged from 19 to 25 C. The koi were fed twice/d (morning and evening) and the feeding schedules were maintained rigorously. Fish were offered a weighed amount of feed and if the feed particles were too large for the fish, the pellets were crumbled by hand. If the koi ate all of the feed (about 5 g in our tests) within 10 min, they were provided an additional 0.3 g of feed and the next meal was also increased by this amount. (If this was a morning feeding, the following morning 5.3 g would be offered). If 5-10 particles of feed remained in a tub at the end of the feeding period, the amount of feed in the next meal was the same. If more than 10 particles remained, the next meal was decreased by 0.3 g. Using this method, the quantity of feed fed morning and evening generally stabilized in 1 d, although there were occasional small variations (usually due to water temperature). Each wk, the feeds provided to a group of fish were rotated among the tubs. For example, to test four different feeds, group 1 was fed Feed 1, group 2 was fed Feed 2, group 3 was fed Feed 3, and group 4 was fed Feed 4 during the first wk. Then during the second wk, group 1 was fed Feed 2, group 2 was fed Feed 3, group 3 was fed Feed 4, and group 4 was fed Feed 1. Eventually, all fish in each tub sampled each feed.

The first 2 d of feeding were ignored in the calculations. Otherwise, daily feed consumption was averaged for the wk and daily feedings for each of the feeds were compared to the average on a weekly basis. These normalized data were subjected to statistical analysis to see whether a particular feed was eaten in greater or lesser quantity than the other feeds. Normalization was necessary because the fish grew to twice their size during the course of the test.

More than 400 meals were fed to the koi during the 8-wk experiment. The feed preferences are summarized in Fig. 2. It can be seen that feed preference surfaced in three statistically significant ($P<0.05$) groupings. A growth test was then performed using three of the feeds, two with the highest relative palatability and one on the

Table 3. Reported proximate analysis of koi feeds used in the current study.

Feed Type	% Protein Min.	% Lipid Min.	% Fiber Max.	% Moisture Max.	% Ash Max.
Feed 1	na	na	na	na	na
Feed 2	40	4	4	10	12
Feed 3	na	na	na	na	na
Feed 4	25	2	2	7	na
Feed 5	32	3	2	7	na
Feed 6	37	7	5	12	10
Feed 7	36	4	4	7	12
Feed 8	35	3	5	10	12

na = data not available

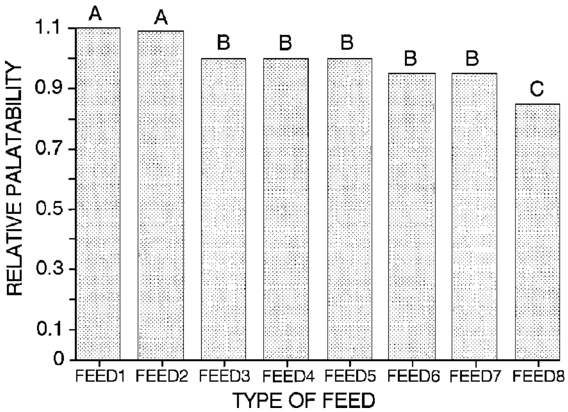

Figure 2. Relative palatability of various feed for koi. Bars with a different alphabet are significantly ($P<0.05$) different.

basis of its high market position. The koi were fed to satiation using the previously described method for 1 mo. At the beginning of the trial, the fish were about 15 cm in length and 80 g in weight. After the 1-mo trial, Feed 1 and Feed 2 supported an increase of about three times in fish length and about three times in weight gain (Table 4). This is consistent with the hypothesis that more palatable feeds should yield faster growth with nutrition being equal. Most interesting of the observations in this particular experiment was that the performance (e.g., palatability, growth) of a particular feed was not correlated to the retail price.

Comparing the Performance of Different Feeds

In the previous investigation, a method to compare the palatability of different feeds one would normally find in any pet shop was determined. Further investigation focused on feeds for one particular species of fish. However, the majority of feeds developed for use by aquarium hobbyists are in the form of flake food.

Table 4. Summary of body length and weight increases during the growth trial. Values that have different letters are significantly different ($P<0.05$).

Feed Type	Body Length (cm)	Body Weight (g)
Feed 1	1.5a	27.7a
Feed 2	1.1a	29.9a
Feed 5	0.4b	9.8b

Most brands of commercially available flake feeds (basic or staple) formulated for maintaining freshwater ornamental fishes meet the nutritional requirements of multiple species. It becomes obvious upon examination of the package label of these feeds that the long list of ingredients are combined to suit the diet for almost every species of ornamental fish. In this way, the manufacturer can satisfy a large consumer base. A problem with this approach is that this "all purpose" feed may not be suitable for fish that require a high-protein or high-vegetable diet. Similarly, these "basic" or "staple" diets appear to be designed to provide sustenance and not to optimize growth or reproduction, which is important in the food fish industry.

In contrast, formulated feeds designed for the aquaculture of food fishes are manufactured to result in optimal growth at minimal costs. They are subjected to extensive testing to insure maximum performance and also include a feed conversion ratio. To meet this criteria, aquaculture feed manufacturers in the USA have focused on feed for "popular fishes" such as channel catfish, salmon, and trout. The obvious drawback to the aquaculture farmers is that they are limited to feeds formulated for a limited number of fish species. In the next series of experiments we compared aquaculture feeds designed for mahimahi and salmon against a generic USA flake (staple) feed designed for maintaining many kinds of fish in the aquarium industry (Table 2). For our initial investigation we chose the angelfish *Pterophyllum scalare*. A comparison of the composition of the feeds used in this experiment is presented in Table 5. While there is a slightly higher crude protein content in the aquaculture feeds, the major difference appears in the fat (lipid) content.

All feeds used in the trial were subjected to amino acid analysis as described in Tamaru et al. (1992) and are summarized in Table 6. The mahimahi feed contained significantly ($P<0.05$) higher amounts of total amino acids than the other feeds used in the current study. Although the flake and salmon fry feeds were found to contain similar total amino acids, the salmon fry feed was found to contain significantly ($P<0.05$) higher levels of several essential amino acids (methionine,

Table 5. Proximate composition of various feeds used in the investigation of angelfish.

Treatment Feed	% Minimum Crude Protein	% Minimum Crude Fat	Moisture (%)	Ash (%)	Price US$/kg
Flake Feed	45	4	8	19	14.00[a]
Mahimahi Feed	56	14	-	-	1.25[b]
Salmon Fry Feed	50	23	6	10	1.85[b]

Superscript a relates to prices in Honolulu, Hawai‘i and superscript b relates to FOB factory prices.

histidine, and lysine). The mahimahi feed contained significantly (P<0.05) higher amounts of all of the essential amino acids, except methionine, when compared with the flake feed and has higher levels of several essential amino acids (i.e., threonine, isoleucine, and arginine) when compared with the salmon fry feed. The salmon fry feed contained the highest level of histidine of all the feeds investigated.

Fatty acid profiles of the various feeds used in the study of angelfish were determined as described in Tamaru et al. (1992) and are

Table 6. Essential amino acid profiles of flake feed, mahimahi feed, and fry feed (mg/100 mg dry weight). Numbers with different alphabetical suffixes are significantly different (P<0.05).

Amino acid	Flake feed	Mahimahi feed	Salmon fry feed
Thr	1.36 ± 0.24a	2.43 ± 0.13b	1.77 ± 0.16a
Val	1.11 ± 0.13a	1.58 ± 0.20b	1.19 ± 0.10ab
Met	0.73 ± 0.06a	0.91 ± 0.17ab	1.07 ± 0.08b
Ile	0.70 ± 0.08a	2.12 ± 0.15b	0.69 ± 0.06a
Leu	2.35 ± 0.14a	3.69 ± 0.25b	2.92 ± 0.58ab
Phe	1.14 ± 0.09a	1.89 ± 0.32b	1.38 ± 0.17ab
His	0.67 ± 0.04a	0.88 ± 0.09b	1.53 ± 0.10c
Lys	2.04 ± 0.11a	3.70 ± 0.37b	2.81 ± 0.27b
Arg	2.07 ± 0.31a	2.65 ± 0.18b	2.14 ± 0.15a
Total amino acids	30.5 ± 1.41a	45.5 ± 3.35b	33.0 ± 2.00a

Table 7. Fatty acid profiles of flake feed, mahimahi feed, and fry feed (mg/100 mg dry weight). Numbers with different alphabetical suffixes are significantly different (P<0.05).

Fatty acid	Flake feed	Mahimahi feed	Fry feed
14:0	0.86 ± 0.24a	1.36 ± 0.06a	1.83 ± 0.05b
16:0	1.70 ± 0.08a	2.71 ± 0.14b	4.48 ± 0.13c
16:1n-7	0.58 ± 0.02a	1.21 ± 0.05b	1.77 ± 0.02c
18:0	0.52 ± 0.05a	0.20 ± 0.00b	0.82 ± 0.01c
18:1n-9	1.45 ± 0.06a	0.52 ± 0.03b	1.76 ± 0.04c
18:2n-6	0.76 ± 0.04a	0.75 ± 0.45ab	0.90 ± 0.00b
18:3n-3	0.17 ± 0.01a	0.33 ± 0.01b	0.27 ± 0.01b
18:4n-3	0.19 ± 0.02a	0.34 ± 0.01b	0.42 ± 0.01c
20:1n-9	0.05 ± 0.00a	0.12 ± 0.00b	0.29 ± 0.01c
20:4n-6	0.05 ± 0.00a	0.21 ± 0.01b	0.23 ± 0.01b
20:5n-3	0.83 ± 0.03a	2.51 ± 0.08b	2.40 ± 0.19b
22:1n-11	0.32 ± 0.02a	0.08 ± 0.00b	0.08 ± 0.00b
22:6n-3	0.93 ± 0.03a	1.68 ± 0.10b	2.05 ± 0.21b
Total fatty acids	8.7 ± 0.61a	12.0 ± 0.05b	17.3 ± 0.19c

summarized in Table 7. In summary, the flake feed contained the lowest levels of essential (18:2n-6, 18:3n-3, 20:4n-6, 20:5n-3, and 22:6n-3) and total fatty acids. Mahimahi feed was found to consist of significantly ($P<0.05$) higher amounts of total fatty acids and all of the essential fatty acids, except 18:2n-6, in comparison to the flake feed. The salmon fry feed contained similar amounts of all of the essential fatty acids in comparison to mahimahi feed, but it is also significantly ($P<0.05$) higher in total fatty acids.

Palatability Trial Using Angelfish

The same experimental design described previously was used to test the palatability of the USA flake (staple), mahimahi, and salmon fry feeds using angelfish (marble variety). The angelfish were from multiple broods at the age of 8 or 9 wk after hatching, reared collectively in one tank. Three 10-gal glass aquaria equipped with a single sponge bio-filter and aeration were stocked at 50 individuals/ aquarium. Because only three feeds were investigated, the entire experiment was completed in 3 wk. For purposes of illustration, the actual levels of feed consumed during each rotation is summarized in Fig. 3. During all three rotations (i.e., three separate wk), the flake feed was consumed at significantly ($P<0.05$) lower levels than the other two feeds tested. In general, the mahimahi and salmon fry feeds were consumed at equal rates indicating similar preferences by the angelfish for both feeds.

Growth Trial Using Angelfish

For the growth experiments, the three 10-gal treatment aquaria were stocked with 50 angelfish each. Throughout the feed trials, the fish were fed three times/d during the weekdays and twice/d on weekends. Each treatment (i.e., feed) was replicated. Feeding to satiation was conducted by first offering a predetermined amount of food. If the food had been consumed entirely in 5-10 min, additional feed was then provided. If residual feed remained, feeding was terminated for that particular feeding and the amount of food provided during the next feeding was decreased. The goal was to provide just enough food and no more. The entire experiment was carried out for one mo and then repeated with a new set of fish.

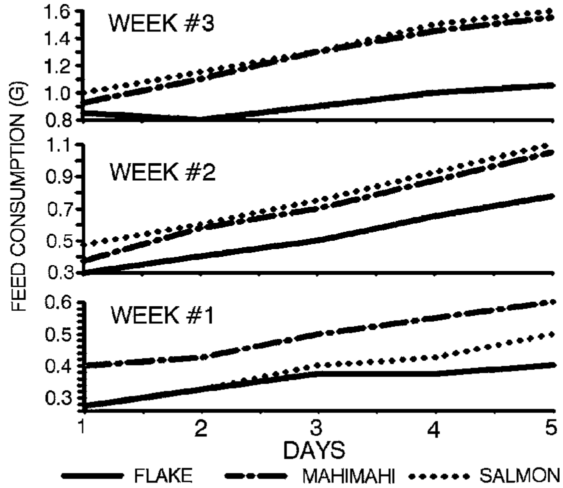

Figure 3. Summary of palatability trials of flake, mahimahi, and salmon fry feeds using the angelfish *Pterophyllum scalare*.

An artificial light source was on for 10 h and off for 14 h/d during the course of the experiment. Complete water changes were done approximately every 2 wk, and water chemistry measurements were taken weekly.

A summary of initial and ending body weights of angelfishes fed the various test feeds is presented in Table 8. Results of this investigation demonstrate that the mahimahi feed and salmon fry feeds are superior for growing marble angelfishes. Similar results were achieved with the golden angelfish variety. The average feed conversion ratios for USA flake (staple), mahimahi, and salmon feeds were 1.3, 0.8, and 0.8, respectively. The results show that although the mahimahi and salmon fry feeds result in superior growth of angelfishes, they are approximately 10 times more inexpensive than the flake food used in the current study. Once again, feed performance (in terms of growth, survival, and feed conversion) does not necessarily correlate with the price of the feed.

Maturation Diets

A continuous area of research interest for investigators and hobbyist alike is the maturation and spawning of freshwater ornamental broodstock. As reported in Tamaru and Ako (1997), investigations in this area rely heavily on the input of members of the Honolulu Aquarium Society who share their expertise in this domain as they have, through trial and error, found ways

Table 8. Feed trials with marble angelfish. Initial weights were 284 $\pm$ 69 mg and 300 $\pm$ 82 mg for Trial 1 and Trial 2, respectively. Numbers with alphabetical suffixes of a and b are significantly different (P<0.05). Numbers with alphabetical suffixes of c and d are significantly different (P<0.01). N

Treatment	# of Replicates	# of Individuals	Final Body Weight (mg)	Final Body Length (cm)	Survival (%)
Trial #1					
Flake Feed	2	25	525 ± 138a	3.1 ± 0.3a	100
Mahimahi Feed	2	25	994 ± 269b	3.5 ± 0.3b	100
Salmon Fry Feed	2	25	858 ± 331b	3.5 ± 0.4b	100
Trial #2					
Flake Feed	2	18	504 ± 176c	3.2 ± 0.4c	94
Mahimahi Feed	2	18	781 ± 229d	3.7 ± 0.4d	100
Salmon Fry Feed	2	18	840 ± 229d	3.7 ± 0.3d	100

to spawn their respective fish. In that report, the fatty acid profiles of both prepared and live feeds that are commonly used by Hawai‘i breeders in conditioning freshwater ornamental fish broodstock for spawning were investigated.

Live earthworms and mosquito larvae were obtained from a compost bin and bucket of rainwater, respectively, located in Maunawili, O‘ahu, Hawai‘i, USA. *Moina* was obtained from Lance Pang of Wainani Kai, Honolulu, Hawai‘i, USA. The beef heart preparation and black tubifex worms were obtained from Fred Lum of Pacific Discus Hatchery, Honolulu, Hawai‘i, USA. Red tubifex worms were obtained from Patrick Vahey of Hanohano Enterprises, Punaluu, Hawai‘i, USA. All live and prepared feeds were collected, rinsed in fresh water and stored frozen at -20 C until analyzed. Results for beef liver are from a previous investigation (Iwai et al. 1992). Fatty acid analysis was conducted as summarized in Tamaru et al. (1992). The values presented are the averages from triplicate determinations and, unless specified otherwise, are expressed in terms of mg/100 mg dry weight.

Essential Fatty Acid Profiles of Maturation Feeds

A summary of the total fatty acids and essential fatty acids found in the various feeds used for the maturation and spawning of freshwater ornamental fishes is presented in Table 9. Total fatty acids ranged between a low of 0.81 found in earthworms to a high of 8.95 found in beef liver. With the exception of the beef heart preparation, all other feeds were found to be deficient in 22:6n3. All feeds contained 20:5n3 ranging from a low of 0.07 found in *Moina* to a high of 0.61 found in black tubifex worms. Relatively high levels of 20:4n6 were observed in all of the feeds tested ranging from a low of 0.16 found in *Moina* to a high of 0.90 found in black tubifex worms. Both 18:3n3 and 18:2n6 ranged from 0.00 to 0.51 (beef liver, black tubifex

Table 9. Essential fatty acids of maturation feeds used for freshwater ornamental fishes. Values are reported in mg/100 mg dry weight.

Fatty Acid	Beef Heart Diet	Beef Liver	Black Tubifex Worms	Red Tubifex Worms	*Moina*	Earthworms	Mosquito Larvae
18:2n6	1.71	1.56	1.68	1.43	0.11	0.11	0.48
18:3n3	0.20	0.00	0.51	0.19	0.04	0.10	0.31
20:4n6	0.51	0.22	0.90	0.64	0.16	0.22	0.33
20:5n3	0.11	0.00	0.61	0.33	0.07	0.09	0.23
22:6n3	0.33	0.00	0.00	0.00	0.00	0.00	0.00
Total Fatty Acids	4.86	8.96	6.22	4.68	4.22	0.81	8.27

worms) and 0.11 to 1.71 (earthworms, *Moina*, beef heart), respectively.

The essential fatty acid data were summarized in a non-conventional fashion (i.e., percent composition) where each of the essential fatty acids within a particular feed was divided by the observed total fatty acids in the respective feed. The value was then multiplied by 100. Each of the essential fatty acids were then ranked on the basis of the percent composition of total fatty acids as summarized in Table 10. When the data are presented in this fashion, all feeds exhibit a high percent composition of either 18:2n6 or 20:4n6. On a percent composition basis, 18:2n6 ranged from a low of 2.61% found in *Moina* to a high of 35.19% found in the beef heart diet. On a percent composition basis, 20:4n6 was ranged from a low of 3.42% found in *Moina* to a high of 27.16% found in earthworms.

The various live- and fresh-feed preparations examined during the current study are invariably used by freshwater ornamental fish breeders who have found them to be effective in bringing about maturation and spawning of particular species. It is interesting to note the inclusion of skipjack tuna roe in the beef heart diet prepared for growth and maturation of discus *Symphysodon discus*. Discussions with numerous freshwater ornamental fish breeders reveal similar inclusions of marine products (e.g., blood worms, fish roe, squid, crustacean meat) with a preparation of beef heart or beef liver. While inclusion of marine products in freshly prepared diets is being practiced, many hobbyists rely solely on the live feeds under investigation. The results indicate that these feed items do not have detectable levels of 22:6n3. In addition, the live-feeds examined possess relatively low levels of 20:5n3. This would lead one to hypothesize that a large number of freshwater ornamental fishes do not require the long chain polyunsaturated fatty acids as reported to be essential for marine fish species (Watanabe et al. 1983, 1984). Both 18:2n6 and 20:4n6 were found to be the major essential fatty acids present in the live-feeds investigated in the current study, implying that they play a critical role in reproduction, as these feeds are used religiously by the hobbyists/breeders of ornamental freshwater fishes. It has been reported that juvenile chinook salmon do not exhibit the ability to convert dietary 18:2n6 to 20:4n6 (Dosanjh et al. 1988) and it remains to be demonstrated to what extent the conversion of 18:2n6 to 20:4n6 takes place in teleosts. If this situation is pervasive in freshwater teleosts, then it is not surprising that 20:4n6 is present in large quantities in the prey that the fish consume.

The genus *Corydoras* is one of two important genera of catfishes as far as freshwater aquarium enthusiasts are concerned. Members of the genus originally came from regions of South America, however, many other species have now been domesticated. Most of the ‘Corys’, as they are affectionately called, are hardy and highly adaptable to most aquarium conditions and it is often said that a community aquarium is not complete without a few armored catfishes. Their reputation as a bottom “cleaner” makes them one of the more sought after fishes in the aquarium trade. That this species is being cultured in Hawai‘i served as further justification to carry out this investigation.

Three 15-gal aquaria were individually stocked with two male and one female *C. aeneus*. The aquaria were part of a single recirculating system so that water quality parameters in each aquarium would be equivalent. Fish in each aquarium were fed one of the following treatment

Table 10. Summary of essential fatty acids found in maturation feeds ranked by percent composition.

Ranking	Beef Heart Diet	Beef Liver	Black Tubifex Worms	Red Tubifex Worms	*Moina*	Earthworms	Mosquito Larvae
1	18:2n6	18:2n6	18:2n6	18:2n6	20:4n6	20:4n6	18:2n6
2	20:4n6	20:4n6	20:4n6	20:4n6	18:2n6	18:2n6	20:4n6
3	22:6n3	18:3n3	20:5n3	20:5n3	20:5n3	18:3n3	18:3n3
4	18:3n3	20:5n3	18:3n3	18:3n3	18:3n3	20:5n3	20:5n3
5	20:5n3	22:6n3	22:6n3	22:6n3	22:6n3	22:6n3	22:6n3

diets (beef heart + seafood, beef heart only, or Nutrafry) for approximately one mo. For example, groups 1, 2, and 3 received beef heart + seafood, beef heart, and Nutrafry, respectively. In the second trial fish in groups 1, 2, and 3 received beef heart, Nutrafry and beef heart + seafood, respectively. Feed for each tank was switched again after one mo so that all trios were fed a particular diet. Fish in each treatment group were fed equal weights of each of the diets. This meant that they were fed equal amounts of Nutrafry and wet weights of the beef heart and beef heart + seafood diets. The fatty acid profiles of the three treatment diets are presented in Table 11. The commercial pellet, Nutrafry, was found to contain the highest amount of total fatty acids, EPA (C20:5n3), DHA (C22:6n3) and ADA (C20:4n6).

During the entire experiment, the d on which a spawn occurred and the number of eggs spawned were recorded. During the latter part of the experiment, eggs from each spawn were measured using a compound microscope equipped with an ocular micrometer. A summary of the spawning activities of the fish fed the various treatment feeds is presented in Table 12. From the data presented, some consistent patterns

Table 11. Fatty acid profiles of three maturation diets used for *C. aeneus*. Values are reported in mg/100 mg as fed.

Fatty Acid	Beef Heart + Seafood	Beef Heart	NutraFry
14:0	0.01	0.03	1.83
16:0	0.20	0.33	4.48
16:1n7	0.01	0.05	1.77
18:0	0.20	0.29	0.82
18:1n9	0.17	0.62	1.76
18:2n6	0.51	0.30	0.90
18:3n3	0.06	0.03	0.27
18:4n3	N.D.	0.00	0.42
20:1n9	0.00	0.02	0.29
20:4n6	0.15	0.11	0.23
20:5n3	0.03	0.03	2.41
22:1n11	N.D.	0.01	0.08
22:6n3	0.10	0.00	2.05
Total Fatty Acids	1.46	1.82	17.30

Table 12. Summary of spawns for *C. aeneus* fed three different maturation diets.

Treatments	Total Number of Eggs Spawned	Number of Spawns	Average Number of Eggs/Spawn
Trial #1			
Nutrafry	331	9	37
Beef Heart	457	6	76
Beef Heart + Seafood	1127	7	161
Trial #2			
Nutrafry	56	1	56
Beef Heart	996	4	249
Beef Heart + Seafood	1750	6	292
Trial #3			
Nutrafy	57	1	57
Beef Heart	244	1	244
Beef Heart + Seafood	666	2	333

emerge. First, the fish fed beef heart + seafood produced a significantly larger number of eggs during the time they were fed the diet. The differences are approximately twice that of the nearest treatment (beef heart). The number of spawns, however, did not differ statistically. Although it appears that there may be a trend in the number of eggs/spawn, no statistical difference could be detected between fish fed beef heart + seafood and beef heart alone. The only statistical difference is with the lower number of eggs/spawn produced by individuals fed Nutrafry.

Spawned eggs were collected only from the latter spawns due to an oversight. However, a summary of the average (n=20) egg diameters from some spawns that were measured is presented in Table 13. Fish fed beef heart + seafood were found to have significantly larger eggs than fish fed any of the other diets.

Table 13. Average spawned egg diameters from *C. aeneus* fed three different maturation diets.

Treatment Diet	Number of Spawns	Egg Diameter (mm)
Beef Heart + Seafood	3	1.69 ± 0.04
Beef Heart	3	1.61 ± 0.01
NutraFry	1	1.63 ± 0.00

It is clear from the data that the beef heart + seafood diet does result in the production of a larger quantity of eggs from *C. aeneus* broodstock. It would appear that this is due to increasing the number of eggs/spawn and not by increasing the frequency of spawns. It should be noted however, that reasonably similar results can be obtained with the use of beef heart alone. Subjectively, the addition of seafood seemed to make the beef heart diet more palatable, i.e., the fish did not like the beef heart diet compared to beef heart + seafood. Although percent hatching for each spawn was not measured, hatching did occur in all nests that were put aside for observation. The egg size of the armored catfish fed beef heart + seafood also produced larger eggs, the biological significance of which remains to be determined.

At present there is no explanation for the increase in egg production and egg size observed when the armored catfish were fed the beef heart + seafood diet. Research activities always produce more questions than answers, at times, and this is definitely true for the current investigation. It is rather surprising that the reproductive performance of Nutrafry was so poor compared with the other diets tested. Nutrafry, however, does well against other commercial pellets. It is also clear that the essential fatty acids EPA (C20:5n3), DHA (C22:6n3) and the total fatty acids are not correlated with the observed reproductive performance. Arachidonic acid (C20:4n6), however, is still correlated with the observed reproductive performance (i.e., increase in egg production and egg size) again suggesting it has an important role in the reproduction of fishes.

The relatively high levels of both 18:2n6 and 20:4n6 in the feeds investigated are consistent with their reported biological roles. In higher vertebrates, metabolic conversion of 18:2n6 is the source of 20:4n6 (Galli 1980; Kinsella 1987) and 20:4n6 has been identified as the precursor for prostaglandins (Kinsella 1987). Prostaglandins have been demonstrated to play a critical role during the ovulatory process in teleosts or serving as pheromones that stimulate mating behavior in fishes, synchronizing both the physiological and physical components of the spawning event between both sexes (Goetz 1983; Kobayashi et al. 1986; Stacey et al. 1986). Investigations into the fatty acid profiles of spawned eggs from striped mullet *Mugil cephalus* maturing under natural and artificial conditions suggest a link to the observed low levels of 20:4n6 detected in spawned eggs and the reproductive process (i.e., lower percent fertilization) observed in striped mullet (Tamaru et al. 1992). The data on the essential fatty acids observed in the various live feeds and prepared diets presented in the current investigation strongly suggest that 20:4n6 plays an integral part in the reproductive mechanism of a large number of freshwater ornamental fishes. A concerted effort should be initiated to determine the function of 20:4n6 in the reproductive processes of teleosts.

ACKNOWLEDGMENTS

Partial funding was provided by the United States Department of Agriculture, Center for Tropical and Subtropical Aquaculture under the project entitled, "Expansion and Diversification of Freshwater Tropical Fish Culture - Year 3", Contract No. 97-105, Grant No. 97-38500-4042. Partial funding was also provided by a grant from the National Oceanic and Atmospheric Administration, project #A/AS-1 sponsored by the University of Hawaii Sea Grant College Program, Institutional Grant No. NA86R60041, Department of Commerce. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its sub-agencies. Support for the project was also provided by the Aquaculture Development Program, Department of Agriculture, State of Hawaii, as part of their Aquaculture Extension Project with University of Hawaii Sea Grant Extension. The authors wish to thank Christine Tamaru of Hawaii C's Aquaculture Consultant Services for her editorial comments. Mention of any commercial feed in these studies is not an endorsement of the product.

LITERATURE CITED

Chapman, F.A., S.A. Fitz-Coy, E.M. Thunberg and C.M. Adams. 1997. United States of America trade in ornamental fish. Journal of the World Aquaculture Society. 28: 1-10.

Dosanjh, B.S., D.A. Higgs, M.D. Plotnikoff, J.R. Markert and J.T. Buckley. 1988. Preliminary evaluation of canola oil, pork lard and marine lipid singly and in combination as supplemental dietary lipid sources for juvenile fall chinook salmon, *Oncorhynchus tshawytscha*. Aquaculture. 68: 325-343.

Galli, C. 1980. Dietary influences on prostaglandin synthesis. Advanced Nutritional Research. 3: 95-126.

Goetz, F.W. 1983. Hormonal control of oocyte final maturation and ovulation of fishes, pp. 117-169. *In*: W.S. Hoar and D.J. Randall (eds.), Fish Physiology, Vol. 9B. Academic Press, New York.

Iwai, T., H. Ako and L.E. Yasukochi. 1992. Use of beef liver in the diet of juvenile mahimahi, *Coryphaena hippurus* L. World Aquaculture. 23(3): 49-51.

Kinsella, J.E. 1987. Eicosanoid metabolism: General Background and overview, pp. 25-39. *In:* Seafoods and fish oils in human health and disease. Food Science and Technology, Marcel Dekkar, Inc., New York and Basel, USA.

Kobayashi, M., K. Aida and I. Hanyu. 1986. Pheromone from ovulatory female goldfish induces gonadotropin surge in males. Gen. Comp. Endocrinol. 63: 451-455.

Stacey, N.E., A.L. Kyle and N.R. Liley. 1986. Fish reproductive pheromones, pp.119-133. *In*: D. Duvall, D. Muller-Schwarze and R.M. Silverstein (eds.), Chemical signals in vertebrates. Vol. IV Ecology, evolution and comparative biology. Plenum Press, New York.

Tamaru, C.S. and H. Ako. 1997. Essential fatty acid profiles of maturation feeds used in freshwater ornamental fish culture. I'a O Hawai'i, Vol. 1997, Issues 8, 9.

Tamaru, C.S., H. Ako and C.-S. Lee. 1992. Fatty acid and amino acid profiles of spawned eggs of striped mullet, *Mugil cephalus* L. Aquaculture. 105: 83-94.

Watanabe, T., C. Kitajima and S. Fujita. 1983. Nutritional values of live food organisms used in Japan for mass propagation of fish: A Review. Aquaculture. 34: 115-143.

Watanabe, T., T. Arakawa, C. Kitajima, and S. Fujita. 1984. Effect of nutritional quality of broodstock diets on reproduction of red sea bream. Bulletin of Japanese Society of Scientific Fisheries. 50(3): 495-501.

Whitern, W.A. 1979. Livebearers. Tropical Fish Hobbyist Publications, Inc. Neptune City, New Jersey, USA. 93 pp.