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Alternatives to Commercial Feeds in the Diets of Cultured Fish

William O. McLarney and Jeffrey Parkin

One of the major impediments to the further development of aquaculture in North America is the cost of conventional fish feeds. A partial solution to the problem is to grow fish less dependent on high-quality animal protein than the channel catfish (*Ictalurus punctatus*) and rainbow trout (*Salmo gairdneri*) that dominate commercial aquaculture on this continent. At New Alchemy this approach is best exemplified by the cultivation of blue tilapia (*Sarotherodon aureus*) in algal "soups" where these filter feeders derive much of their nourishment from the phytoplankton (algae) that surround them. However, if satisfactory yields are to be obtained, we find it necessary to supplement the diets of even these fish with animal protein.

We also must acknowledge that for many potential fish culturists tilapia are not the best fish. In some places they are illegal. In the deep South, where they might survive the winter in the wild, we discourage their use for ecological reasons. In some places it may be impractical to provide water warm enough for tilapia culture. And some people simply prefer other types of fish.

Yet in attempting to identify North American counterparts of the tilapia, one comes up against a quirk of evolutionary fate. With very few exceptions (notably the buffalofishes, *Ictiobus* spp.), the North American filter feeding fishes are small or otherwise unsuited for cultivation as food animals. Some of our native panfishes, for example the bullheads and sunfishes, have less-exacting dietary requirements than channel cats or trout, but they are carnivores nonetheless. In fact, it is our experience that the term *herbivore*, as applied to fish, lacks precision. Most "herbivorous" fish, including tilapia, are opportunistic feeders, and benefit from

Table 1. APPROXIMATE COSTS ASSOCIATED WITH A 4 FT × 3 FT × 8 IN. EARTHWORM BED.[a]

Initial stock (at maximum density)	30 lbs @ $4/lb = $120
Concrete block bed	35
50 lbs lime (powdered limestone)[b]	2
50 strips of litmus paper[b]	4
2 cubic ft peat moss (bedding additive)	3

[a]This cost can be reduced by half for each 3 months you allow the initial stock of worms to reproduce and grow under optimum conditions without harvesting. In fact, this is recommended not only for financial reasons but also to gain some working experience prior to relying on the worms.

[b]These qualities are sufficient for a minimum of 1 year.

inclusion of a certain amount of animal protein in their diets.

Faced with these facts, many beginning fish culturists give up searching for an alternative to commercial processed feeds. Others simply give up. There is no gainsaying the effectiveness of processed feeds in most situations. They offer a balanced diet and, when used properly, usually result in good growth, particularly of the species for which they are formulated. Of equal importance in their popularity is the convenience factor. It is just plain handy to feed a dry, packaged product that can be stored until needed, weighed precisely, and used without fuss or mess.

Over half of the production budget of a commercial catfish farmer goes for feed, and this is the rule throughout American aquaculture. The principal ingredients of commercial feeds include fish meal derived from marine fisheries, grains, and synthetic vitamins. In view of the costs of obtaining these materials (including the petroleum-related costs of fishing, agriculture, and vitamin manufacture) plus the costs of processing, packaging, and shipping, the price of fish feed is sure to rise.

Ecological reasoning also suggests the need for an alternative. The conversion of inexpensive fish into fish meal in order to make a feed for expensive fish may be economically justifiable in certain situations, but it is not going to result in cheap food or solve any human nutritional problems. In fact, as Israeli aquaculturist Gerald Schroeder points out, conventional North American aquaculture, using fish-meal-based feeds, results in a net loss of fish. Although alternative sources of animal protein might now prove impractical on a large scale, earthworms and flying nocturnal insects are already available to the small-scale fish producer.

Earthworms

The earthworm is the archetypical fish bait. Though its status as a favored food of freshwater fish is firmly entrenched in folklore, to our amazement we have not been able to find one paper in the scientific literature dealing with earthworms as a component of cultured fish diets, despite the ease with which they can be cultured. (Some of their other attractive features for the small-scale, diversified food grower as well as details of earthworm culture are discussed in the fifth *Journal*.[1] Common sense and access to a good resource book[2] should enable any interested person to raise earthworms successfully.

In brief, earthworm culture entails providing housing, routine feeding and watering, and maintaining an approximately neutral pH and suitable temperatures in the "bedding" where the worms live. Most cultured earthworms exhibit greatest vitality at 16°–27° C, or 60°–80° F. Inexpensive housing may be provided by scrounging an old sink, bathtub, or refrigerator liner, or by constructing a plywood or concrete block container. Feeding should be done every two to four days (depending upon the type of feed) with household garbage, paper products, animal manures—almost anything that is biodegradable. It is said that the average American family of four generates enough biodegradable "wastes" to feed a 4 ft × 3 ft × 8 in. earthworm bed generously. Maintaining a pH near neutral is easier than it may sound; buffering is accomplished simply by dusting the feed with lime at feeding time. Table 1 summarizes the costs associated with starting up a 4 ft × 3 ft × 8 in. bed.

We have assumed one of the more expensive types of housing; this cost can be substantially reduced by using one of the options mentioned in the preceding paragraph. No costs are assigned to feed, bedding, or water; most readers will be able to supply the first two free and will be ridding themselves of a potential nuisance in the process.

No monetary value has been assigned to labor, but during a two-week period with five feedings (including watering and buffering the pH) and one pH sample, a generous estimate of the time invested in our system was 1½ hours, or six minutes

[1]Jeffrey Parkin. Some other friends of the earth. *Journal of the New Alchemists*. 5: 69–72.

[2]Gaddie and Douglas. *Earthworms for Ecology and Profit*. Vol. I. Bookworm Pub. Co. 254 pp.

a day. To this should be added the labor of setting up a bed, which will vary quite widely according to the type of housing and bedding selected.

While harvesting earthworms will never be as convenient as pulling a handful of pelleted feed out of a bag, it is greatly facilitated by restricting food distribution to certain areas of the bed (e.g., along either side), which serves to concentrate the worms.

This practice also reduces the amount of bedding harvested with the worms. In weighing worms used as fish feed, some allowance must be made for the percentage bedding, which will remain relatively constant as long as the composition of the bedding and the method of feeding are not radically altered. So, after one or two samples, one can weigh the worms as they come out of the bed.

Unlike most artificial and many natural fish feeds, earthworms sink in water. A floating feed is essential in cage culture and desirable in most forms of fish culture, as it permits the culturist to observe feeding and prevents loss of feed in bottom sediments. We get around the problem with worms by using a special feeder, which consists of no more than a piece of perforated styrofoam on which the worms are spread. As worms instinctively flee the light, they pass down through the holes into the water and are eaten one by one. In addition to floating the worms, this system tends to equalize the distribution of worms among the fish. It also cleans the worms, since much of the bedding drops off as they slither down through the holes.

Bedding-free worms may be obtained simply by rinsing with water, but some allowance must be made for water clinging to the worms when they are weighed. A method that we prefer involves spreading the earthworms and bedding thinly over a sheet of burlap or other loosely woven material located under a light source and waiting 10–15 minutes. Seeking to avoid the light, the worms will crawl through the burlap and in the process be stripped of any bedding.

Flying Insects

There are many other organisms that may be cultured as fish food, but an alternative strategy is the capture of creatures that occur naturally in abundance. Among the most apparent sources are nocturnal flying insects, which may be captured with an ultraviolet light trap. Two types of traps are commercially available. The first, originally developed for pest control, employs an electrified grid that, with a flash of light and a crackle, electrocutes insects that light on it. On a "busy" night, the racket is considerable. A second, quieter type was developed specifically as a source of fish food. An impeller fan sucks in the attracted insects and blows them down through a duct into a collector bag or directly onto the water. (See Figure 1.)

We have used both types of bug traps, but prefer the fan type because it is quieter and safer. We are also not sure what "frying" does to the nutritional value of insects. Of the available impeller fan feeders we can recommend the Will-o-the-Wisp, made by Hedlunds of Medford, Wisconsin. We have operated several of these feeders for up to three years, with no maintenance beyond replacement of a bulb. As of spring 1980, the Will-o-the-Wisp sells for $140. It draws one kilowatt hour of electricity per 12 hours of operation, which at our present rate costs less than three cents a night.

The "bug season" on Cape Cod extends roughly from June through September. Even during this period nightly yields can vary dramatically, from literally nothing on a windy, wet evening to as much as 115 grams (g), or ¼ lb, on a warm, calm, dry night. Over the past seasons the average nightly yield of our feeders, equipped with collecting bags,

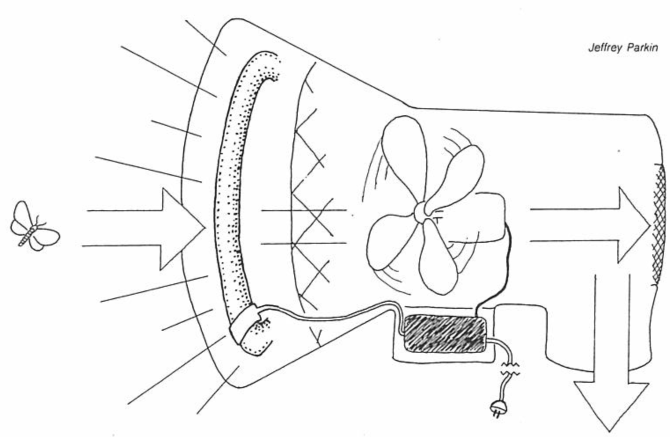

Figure 1. Cross-sectional view of Hedlund-like bug light.

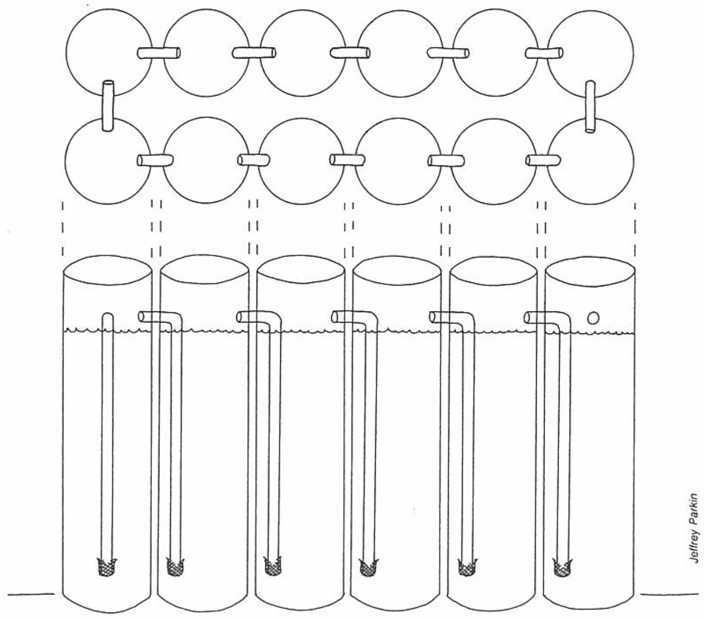

Figure 2. Recirculating aquaculture system. Tanks interconnected with airlift tubes.

has been 16.2 g. It is our impression that, when feasible, the lights should be operated without bags, and catches will improve. Certainly better results will be obtained directly over water; not only is the field of the light less obstructed than in most terrestrial locations, but one can take advantage of insects emerging from the aquatic larval stage.

The kinds of insects captured do not vary nearly as much as their quantity. Apart from a very occasional lacewing, we do not get known beneficial insects as long as the lights are turned off at dawn. The bulk of our catches is composed of midges and moths; over water other types might predominate.

The Fish

The fish species used in this study were the mainstays of New Alchemy aquaculture, the blue tilapia and the yellow bullhead (*Ictalurus natalis*). Blue tilapia, an African cichlid, is the principal fish in New Alchemy's solar-algae pond research, and is described elsewhere in this as well as past *Journals*. Its natural adult diet consists mainly of plant proteins. When young, however, it tends to be a more opportunistic feeder. The yellow bullhead, a native North American catfish, is similarly predominant in our cage culture research. It is a bottom-feeding carnivore whose natural diet consists of small invertebrates. The hardiness of both these species makes them ideal experimental animals.

The Experimental Set-Up

The seven feeding trials described in this article were carried out in a recirculating system composed of twelve 60-gallon cylindrical tanks interconnected with airlift tubes (see Figure 2).

By recirculating the water we attempted to equalize any effects of water quality on growth. The siphon intakes were covered with nylon screens to eliminate the exchange of fish and/or food between tubes. Water flowed through the system at an average of 1.9 liters/minute (0.5 gallons/minute). As there was no purification system, 25% of the water was siphoned off from the bottom of each tube every month and replaced with tap water. Light was provided 14 hours/day by two overhead fluorescent fixtures. The bottom 18 inches of the tubes was wrapped with black plastic to give the bullheads a refuge with some semblance of "cover."

Diets Tested

The experimental diets were made up of three components in varying percentages: mixed nocturnal flying insects, as captured by a Will-o-the-Wisp bug light fish feeder; cultured earthworms (*Eisenia foetida*); and the commercial feed Purina Trout Chow® (henceforth referred to as PTC). The purpose was to determine what portion, if any, of a standard PTC diet could be replaced by either of the two fresh feeds without loss of growth, and if a small fresh dietary supplement added to a normal PTC feeding regime could result in increased growth. Because of the size of our fish and the pellet size of feed available, we ground the PTC and used that portion retained by a 1.0 millimeter (mm) sieve. The earthworms also had to be chopped, into 2–4 mm lengths, to make them acceptable to the fish and to ensure even distribution of this feed among the individual fish. Insects were weighed and fed fresh, as captured, except that some of the largest moths were removed.

All feeding was done while the lights were on. At least four hours separated feeding of one component of a mixed diet from another, so that neither feed was wasted as a result of preference by the fish for one or another.

In each of the trials, one of four diets was fed to three tanks of fish. In the tilapia trials there were eight individual fish per tank, fin clipped so that they could be individually weighed. Twenty unmarked bullheads were kept in each tank and weighed as a group. After weighing, all fish were returned to their tanks, except following Trial 6, when all the bullheads were randomly redistributed among the tanks. No group of three tanks received the same diet in two consecutive trials.

Results: Tilapia

Two replicate trials were conducted with tilapia. Water temperatures over Trials 1 and 2 ranged from 21.9°–23.3° C (71.5°–74.0° F), and 23.0°–24.4° C (73.5°–76.0° F), respectively.

Diurnal fluctuations in temperature never exceeded 0.3° C (1.0° F). Table 2 and Figure 3 summarize the results of these two trials.

Although the results obtained with diet B in Trial 1 are inconsistent with the rest of the data, Trials 1 and 2 suggest that with increased replacement of PTC by earthworms, the growth rate of

Table 2. FEEDING TRIALS 1 AND 2 WITH TILAPIA.

Trial No.	Diets	%[a] PTC	%[a] Worms	%[a] Bugs	Mean Initial Wt. (g/fish)	Mean Gain (g/fish)	% Gain[b]	F[c]	Significance[c]
1	A	3.0	0	—	3.9	1.5	38.6	6.2	<97.5%
	B	3.0	0.5	—	4.6	1.2	26.3		
	C	2.5	0.5	—	4.1	1.5	36.6		
	D	1.5	1.5	—	4.5	1.1	23.7		
2	A	3.0	0	—	5.6	2.0	35.2	15.8	<99.5%
	B	3.0	0.5	—	5.4	1.8	34.2		
	C	2.5	0.5	—	5.8	1.7	29.2		
	D	1.5	1.5	—	5.6	1.2	21.9		

[a]Percent of total fishes' body weight fed daily (applies throughout tables).

[b]Based upon total weights, not the listed means (applies throughout tables).

[c]The two columns at the right in Tables 2–5 are the results of a statistical test called *analysis of variance*. This numerical manipulation basically takes into account variations (in growth rates) between the fish in individual tanks relative to variations between fish in tanks grouped by different diets; this is reflected in the F values. In so doing, one can get some measure of the probability that the overall observed results occurred as an outcome of the experiment and not by chance. The percentages in the Significance columns depict this probability. By statistical convention (and a conservative lot they are), any degree of significance less than 90% is considered chancy and of no statistical value.

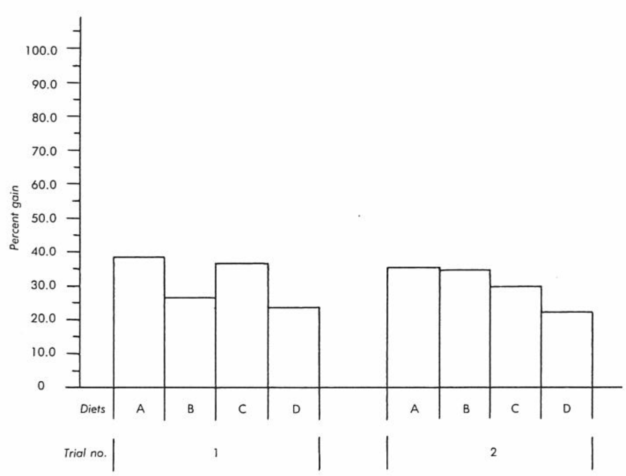

Figure 3. Results of tilapia feeding trials, nos. 1 and 2.

Table 3. FEEDING TRIALS 3 AND 4 WITH YELLOW BULLHEADS.

Trial No.		Diet % PTC	Diet % Worms	Diet % Bugs	Mean Initial Wt. (g/fish)	Mean Gain (g/fish)	% Gain	F	Significance
3	E	3.0	0	—	0.76	0.42	54.7	1.9	>90.0%
	F	3.0	0.5	—	0.79	0.51	64.3		
	G	2.5	0.5	—	0.80	0.47	58.4		
	H	1.5	1.5	—	0.76	0.40	52.5		
4	E	3.0	0	—	1.2	0.40	34.4	11.3	<99.5%
	F	3.0	0.5	—	1.2	0.61	52.1		
	G	2.5	0.5	—	1.3	0.54	41.8		
	H	1.5	1.5	—	1.3	0.44	34.8		

tilapia was reduced. Nor did the addition of a small percentage of worms to a 3% PTC diet improve the growth rate.

In a previous experiment at New Alchemy in which worms were fed to blue tilapia, similar amounts of earthworms were effective in increasing growth over that obtained with a base diet of roasted soy meal and rolled oats fed at the rate of percent of body weight per day.[3] Although the fish in this earlier experiment, unlike those in the current trials, were maintained in an algal "soup," their base diet contained no animal protein.

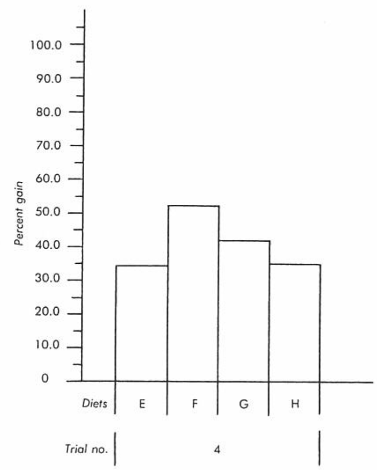

Figure 4. Results of yellow bullhead feeding trial no. 4. (Trial 3 not shown as the significance was less than 90%.)

Results: Bullheads

Trials 3 through 7 were conducted with yellow bullheads and yielded more encouraging results than the tilapia trials. Trials 3 and 4 formed a pair of replicates, as did Trials 5 and 6. Trial 7 was not replicated.

During Trials 3 and 4 water temperatures ranged from 22.2°–23.3° C (72.0°–74.0° F) and 21.7°–25.6° C (71.0°–78.0° F) respectively. Diurnal fluctuations in temperature did not exceed 0.3° C (1.0° F). The experimental diets used in these trials were the same as those used with tilapia in Trials 1 and 2.

The fact that the growth rates are greater in Trial 3 than in Trial 4 can be attributed to better water quality in Trial 3, to the early effect of increased feed rations (these fish had been kept at subsistence levels prior to Trial 3), and to the slightly smaller size of the test fish in Trial 3.

Table 3 and Figure 4 summarize the data from these two trials.

Unlike tilapia, yellow bullheads do appear to derive significant nutritional benefits from earthworms either as a supplement to a normal PTC diet, or as a substitute for PTC at least up to 50%. Since in both Trials 3 and 4 the growth rate for diets E (PTC with no supplement) and H (half PTC and half worms) were nearly identical, while supplementation with worms or substitution with a lower proportion of worms produced improved growth, it is possible that 50% represents the highest proportion of worms that can be substituted for PTC without adversely affecting growth. Higher proportions, or perhaps an all-earthworm diet, will be tested in future trials.

It is instructive to look at the feed conversion[4] in Trial 4. Commercial aquaculturists, using dry feeds, consider anything less than 2.0 respectable and aim to hit close to 1.0. In Trial 4, both diets E and H resulted in feed conversions of approximately 1.0. The small additions of earthworms in diets F and G produced conversions of 0.81 and 0.87 re-

[3]William O. McLarney and Jeffrey Parkin. Cage culture. *Journal of the New Alchemists*. **6**: 83–88.

[4]Feed conversion is the ratio of the amount of feed fed to the gain in weight of the animal. Theoretically, it is impossible to achieve a conversion less than 1.0, since that would indicate that output (growth) exceeded input (feed). However, when one is using an essentially dry feed, such as most commercial feeds, and measuring wet weight of fish, such figures are possible since the weight of fish includes the water in fish tissue. In almost all outdoor situations there is also some input of "natural" feed, which causes the conversion ratio of the feed supplied by the aquaculturist to appear lower than it really is. Input of "natural" feeds is virtually nil in indoor experiments.

Table 4. FEEDING TRIALS 5 AND 6 WITH YELLOW BULLHEADS.

Trial No.		Diet			Mean Initial Wt. (g/fish)	Mean Gain (g/fish)	% Gain	F	Significance
		% PTC	% Worms	% Bugs					
5	I	3.0	0	0	1.7	0.67	39.0	504.2	<99.5%
	J	3.0	0	1.0	1.5	1.6	100.8		
	K	2.0	0	1.0	1.8	1.6	84.7		
	L	2.0	1.0	0	1.8	0.89	49.8		
6	I	3.0	0	0	3.0	1.1	34.7	15.0	<99.5%
	J	3.0	0	1.0	2.7	1.7	64.1		
	K	2.0	0	1.0	2.9	1.5	50.4		
	L	2.0	1.0	0	2.9	1.2	42.1		

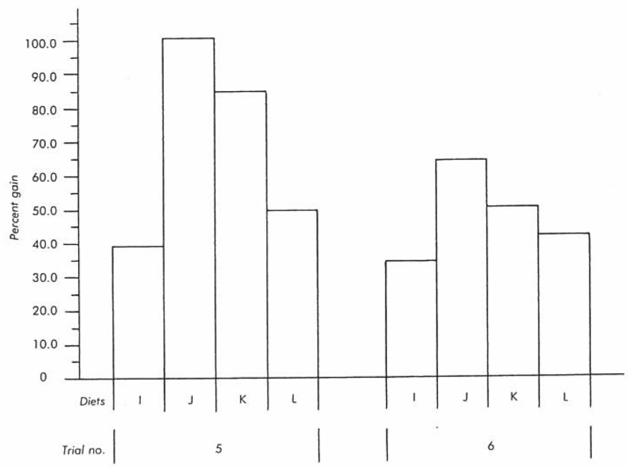

Figure 5. Results of yellow bullhead feeding trials, nos. 5 and 6.

spectively (based on dry weight of worms). It is evident that the effect of the earthworms cannot be accounted for in terms of their protein content alone. The addition of worms was, through some mechanism, improving the efficiency with which the fish were utilizing their feed. A similar synergistic effect was observed in feeding Chironomid midge larvae to tilapia.[5]

Replicate feeding Trials 5 and 6, incorporating flying insects as well as earthworms, were conducted with the same group of yellow bullheads. The water temperature ranges were 23.3°–25.6° C (74.0°–78.0° F) over Trial 5, and 21.1°–24.4° C (70.0°–76.0° F) over Trial 6. Diurnal temperature fluctuations did not exceed 0.5° C (2.0° F). Table 4 and Figure 5 summarize the information from these two trials.

There are a few published studies dealing with the use of ultraviolet bug lights in fish culture,[6] but to our knowledge these two feeding trials are the first in which measured amounts of insects captured by this means were fed to fish and compared with other feeds. It may surprise some readers that bullheads, which are not surface feeders in nature, would feed on flying insects, which float. However, in these trials and in other situations at New Alchemy, captive yellow bullheads learned to accept this food the first time it was presented.

As is obvious from Table 4 and Figure 5, Trials 5 and 6 resulted in significant and parallel trends. The control diet plus a supplement of captured insects (diet J) yielded by far the greatest growth. The partial substitution of insects for the control diet resulted in the next highest growth (diet K). When earthworms were substituted in the same proportion as the insects, resultant growth was less, but it was still significantly greater than for the control diet. The control diet (I) of PTC again produced the lowest growth, albeit good in its own right. There was once more an overall reduction in the growth rates (percent gains) between these first and second replicate trials. Greater initial size at the start of Trial 6 and a 0.8° C (3° F) temperature drop may have contributed to this.

[5] William O. McLarney, Joseph S. Levine, and Marcus M. Sherman. Midge culture. *Journal of the New Alchemists.* 3:80-84.

[6] Heidinger, 1971; Newton and Merkowsky, 1976.

Table 5. FEEDING TRIAL 7 WITH YELLOW BULLHEADS.

Trial No.	Diet	% PTC	% Worms	% Bugs	Mean Initial Wt. (g/fish)	Mean Gain (g/fish)	% Gain	F	Significance
7	M	4.0	0	—	4.0	1.9	47.4	13.8	<99.5%
	N[a]	4.0	0.5	—	4.1	2.2	54.8		
	O	3.0	0.5	—	3.8	2.0	51.3		
	P	3.0	1.0	—	3.6	1.9	53.0		

[a]The three tanks receiving this diet ranked first, second, and twelfth (last) overall. The tank that ranked twelfth (35.4% weight gain) appeared to be an anomaly and we have thus omitted it from the data presented here.

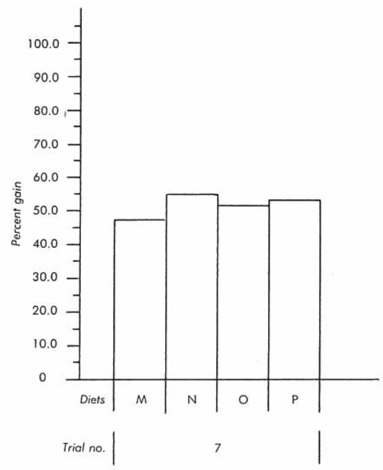

Figure 6. Results of yellow bullhead feeding trial no. 7.

Once again feed conversion was affected by supplementation or substitution of a portion of the PTC diet with fresh feeds. The conversion for diet I (all PTC) was 1.0; for the earthworm-substituted diet (L) it was 0.86, and the insect supplemented or substituted diets (J and K) produced conversions of 0.75 and 0.71 respectively.

Further trials with flying insects were not possible because of the end of our "bug season," but one more earthworm trial (Trial 7) was carried out. The purpose of this trial was to investigate the feasibility of further increasing the basic PTC ration to 4.0% of total body weight daily, with or without supplementation, and to compare such diets with supplemented diets based on the normal feeding rate of 3.0%. Table 5 and Figure 6 summarize the results of this trial.

The results indicate that even at higher rates of feeding, supplementation with worms increased the growth rate of yellow bullheads, and that diets O and P (3.0% PTC supplemented with 0.5% and 1.0% worms, respectively) were superior to a 4% daily feeding of PTC alone. Conversions for diets M through P were, respectively, 1.0, 0.98, 0.82, and 0.90, once again indicating that incorporation of earthworms in the diet increased the efficiency of utilization of other food.

Discussion

The ultimate goal of this sort of research is to enable aquaculturists to replace some or all of the costly and ecologically inappropriate fish-meal-based feeds with cheaper and more appropriate sources of protein. The studies reported here also suggest that the rate of growth and efficiency of feed utilization by fish receiving a full portion of a fish-meal-based commercial diet could be increased by supplementation with fresh feeds. This effect could be especially significant in the North, where getting a head start on the growing season can make the difference between a crop of "harvestable" or "subharvestable" fish in the fall.

Our work suggests that both earthworms and mixed flying insects could be used as substitutes or supplements for fish meal. Determining the economic feasibility of the two feeds and comparing them to other feeds in that respect is difficult. As consideration of Trials 1 and 2 reported here and the earlier work with blue tilapia and earthworms[7] shows, the appropriateness of a fresh feed supplement cannot be discussed apart from consideration of the base diet. Nor will the conclusions reached necessarily be the same for different species, size groups, or geographic regions. The most that can be done here is to discuss the economics of our operation.

Earthworms are the more complicated of the two feed sources to consider in economic terms. Although in our trials they were less valuable than insects as a supplement or substitute for commercial feed, they potentially confer three additional economic benefits. The first is the efficient disposal of biodegradable wastes, which leads directly to the second, provision of a superior potting soil and/or soil amendment. These benefits may be particularly significant in urban settings where space is limiting or in a highly diversified subsistence agriculture situation.

[7]William O. McLarney and Jeffrey Parkin. Cage culture. *Journal of the New Alchemists*. 6: 83–88.

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There is also the possibility of managing earthworms as a cash crop. (Earthworm casts or fecal matter are also incorporated into some of the best and most expensive commercial potting mixes.) Under optimal conditions, earthworm populations double every three to four months. In the case of the worm bed described earlier, this translates into 30 lb of worms every three to four months, or at least 90 lb of worms per year. With some luck in retailing, the costs listed in Table 1 could be covered within the first year, with worms to spare for the fish. From then on, the cost of worms would be minimal. Making back the costs solely through feeding the worms to fish and cutting back on commercial feed would require a long time.

At the present time, earthworm culture solely as a fish feed probably cannot be economically justified. (Much less can one justify the purchase of worms, at the current price of $4/lb, wet weight, compared to commercial fish feeds at 30 cents/lb, dry weight.) However, if worms are treated as a cash crop and/or if one quantifies the value of biodegradable waste disposal and agricultural use of the resulting product, worm culture can often be justified. As the price of commercial fish feeds increases, the economic incentive to grow earthworms as a fish feed seems destined to increase, and eventually earthworm culture for that purpose alone may be justifiable.

The economics of "bug light" fish feeders are comparatively straightforward. Amortizing the total materials cost ($140 for a Will-o-the-Wisp plus $36 for two replacement bulbs) over a 10-year period yields an annual cost of $17.60. Added to this is a season's worth of electricity, amounting to about $3.40 at current rates, netting a total cost of $21 for a year. Our total catch averaged over the past two seasons was 1,820 g (4.01 lb) per season. Taking into account that these bugs are 75% water, the corresponding dry weight is 455 g (1.0 lb).

On that basis it would be difficult to justify economically the use of such a feeder under our conditions. However, Cape Cod is not prime "bug country," and even here we are sure we would do much better if our lights were placed directly over an outdoor fish culture system. More studies of the economic feasibility of bug-light feeders need to be made. The earliest such study indicated that they were economically feasible in rearing bluegills (*Lepomis macrochirus*) in cages in southern Illinois.[8] However, a later study did not indicate positive results in open pond culture of fingerling channel catfish in Arkansas.[9]

We attempted to find out what an average nightly catch might be in the Midwest or South, where hot, sultry summer nights are the rule, but the only other data we could obtain came from Vermont. Barry Pierce of Goddard College reports approximately twice our average nightly catch, though their bug season is a month shorter. Contributing to their catches are the bug light's focus on the college's compost pile and a one-week mayfly "bloom" (during which they get well in excess of 100 g, wet weight, per night).

The studies reported here, and earlier feeding trials at New Alchemy, represent only a tiny fraction of the possibilities that could be explored. We feel that the most important aspect of our work is to affirm that, at least for the small-scale grower, there are options to total dependence on fish-meal-based commercial feeds.

[8] Heidinger, 1971.
[9] Newton and Merkowsky, 1976.