A Manual for Commercial Production of the Swordtail, *Xiphophorus helleri*




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Introduction

Establishing an ornamental fish culture industry has long been felt to be one means to diversify the aquaculture sector in Hawaii. Since 1993, this effort has been supported by the Center for Tropical and Subtropical Aquaculture (CTSA), the University of Hawaii Sea Grant Extension Service (SGES), and the State of Hawaii Department of Agriculture Aquaculture Development Program (ADP). Over the years, the producers of ornamental fishes have requested detailed yet user-friendly information in the areas of controlled reproduction, nutrition, disease, hatchery management, growout techniques, and economics. In response, CTSA, SGES, and ADP have pooled their resources for the publication of a series of "How To" manuals covering the commercial production of a variety of ornamental fish species. This manual on the commercial production of the swordtail, *Xiphophorus helleri*, is the latest in the series.

The information presented in these manuals should help farmers to overcome some of the difficulties encountered with the commercial production of ornamental fish in Hawaii. Unless stated otherwise, the methods described have been field-tested locally. The methods suggested in this manual should not be construed as the "only" methods. Hawaii has a diversity of habitats and microclimates. While one method may be suitable for one location, individual experience and expertise will most likely determine any necessary modifications in order to achieve similar results in another. Likewise, although this manual is directed to the culture of the swordtail *X. helleri*, the methods described could be applied to other livebearing fishes such as the molly, the guppy, and the platy.

Taxonomy

Taxonomy, or the phylogeny of fishes, is a very complex science incorporating information from the fossil record, anatomical and morphological research, genetics, protein electrophoresis, and DNA testing to establish relationships between groups of fishes. The swordtail is grouped within the family Poeciliidae or livebearing tooth carps. Interestingly, the poeciliid family contains some of the most popular ornamental species in the aquarium trade commonly known as the "big four." The genus *Xiphophorus* includes species of the swordtail and the platy. The genus *Poecilia* includes species of the molly and the guppy (particularly the guppy *Poecilia reticulata,* which many consider the most popular aquarium fish species.) The current taxonomic status of the swordtail is presented in Fig. 1. Within each of these five species are many hybrid color and fin variations. Many of the

- ORDER: **Cyprinodontiformes**
  - SUBORDER: **Cyprinodontoidei**
  - SUPERFAMILY: **Poecilioidea**
    - FAMILY: **Poecilidae**
      - SUBFAMILY: **Poeciliinae**
        - GENUS: **Xiphophorus**
          - SPECIES: **helleri**
          - SPECIES: **maculatus**
          - SPECIES: **variatus**
        - GENUS: **Poecilia**
          - SPECIES: **latipinna**
          - SPECIES: **reticulata**

Figure 1. Current taxonomic status of the swordtail and related livebearers.

culture techniques described for the swordtail are readily adaptable to other species in the family as they share many morphological and biological traits.

The Livebearers

For the purposes of this manual, the classification of fishes will be considered from a very broad context based upon the reproductive characteristics of the species. Fishes in general can be divided into two distinct groups. In one group, the eggs are expelled from the female prior to fertilization (egg-layers) and in the other group, the eggs are fertilized and incubated internally followed by expulsion of larvae from the body (livebearers). Those fish classified as livebearers include almost 1000 species. Generally, livebearing fish are considered viviparous meaning that fertilization and hatching of the eggs take place within the body of the female. Development of the embryos occurs within the female until live young are released from her body.

Biology of the Swordtail, *Xiphophorus helleri*

A detailed description of the internal anatomy of the swordtail is not presented here and the reader is encouraged to review the chapter on this topic in Evans (1992). This manual will provide enough information to help the reader understand the suggested production techniques.

Geographic Distribution

The natural geographic range of the common swordtail, *Xiphophorus helleri*, extends from northern Mexico to the central and western parts of Guatemala and Honduras in Central America (Axelrod and Wischnath 1991, Fig. 2). The species was introduced and has become established in southern Florida, California, the Lake Mead area of Arizona and Nevada, Hawaii, Canada, Puerto Rico, Africa, Sri Lanka, Australia, Guam and Fiji. Established populations have also been reported in the United Kingdom (Dawes 1991; Jacobs 1969).

Figure 2. Native geographic range of the swordtails (indicated in black).

Morphology

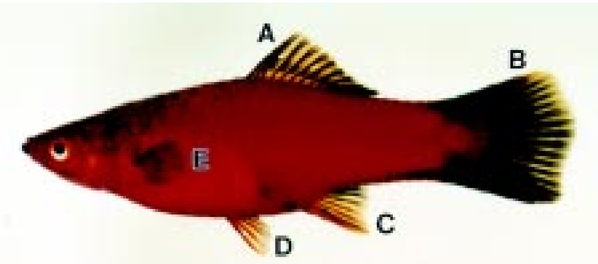

Figure 3. Adult female swordtail of the redwag variety.

The picture of an adult female swordtail of the redwag strain in Fig. 3 shows fin identifications. Starting from the dorsal portion of the body and moving clockwise are the dorsal fin (A), caudal fin (B), anal fin (C), pelvic fin (D) and the pectoral fin (E). Anatomical vernacular will be used in the following sections to describe certain fin and biological traits. The reader should become acquainted with the names of the various fins and their locations on the body, as modifications in the shape and size of the various fins occur between the sexes, various hybrids, and color strains.

The number of swordtail strains listed in various price lists of ornamental distributors ranges from 39 to over 50 (Worldwide Aquatics, and Dolphin International, Ltd., respectively, Table 1). In addition to the variations in body color, a number of fin variations (e.g., hi-fin, lyretail or combinations of both) have been developed. Hybridization, or breeding for the development of new strains plays a major role in the ornamental fish industry. In order to keep up with the constant demand for new varieties, commercial farmers are encouraged to collaborate with hobbyists or breeders who are constantly developing new strains in order to diversify their product.

Table 1. Various swordtails available on a wholesale price list (Worldwide Aquatics, Waimanalo, Hawaii).

Color Variety	Caudal Fin Modification	Dorsal Fin Modification
Red Velvet	Red Velvet Lyretail	Red Velvet HI-fin
Red Wag	Red Wag Lyretail	Red Wag HI-fin
Green		
Green Wagtail		
Red Tuxedo	Tuxedo Lyretail	Tuxedo HI-fin
Red Comet		
Red & White		
Gold & Black		
White		
Black	Black Lyretail	Black HI-fin
Neon	Neon Lyretail	Neon HI-fin
Neon Wagtail		
Pineapple		
Red Calico	Calico Lyretail	Calico HI-fin
Red Eye		
Golden	Gold Lyretail	Goden HI-fin
Pineapple	Pineapple Lyretail	Pineapple HI-fin
Lemon		
Golden Comet		
Golden Wagtail		
Marble		
Mixed Color	Mixed Color Lyre Tail	Mixed Color HI-fin

To provide an idea of the fluctuations in the livebearer market, varieties of the swordtail sold between 1980 and 2000 from one distributor are presented in Fig. 4. The greatest increase in the number of varieties of swordtails began after 1985 with approximately one new strain per year. This trend was also observed with the platy, *Xiphophorus maculatus* and *X. variatus*, although it appears that no new varieties have been added after 1995. Insight on the demand for swordtails can be obtained by reviewing the estimated farm-gate prices (see section on Economics) of various swordtails from 1980 to 2000. The estimated farm-gate prices presented are for fish that are 63.5 mm (2.5

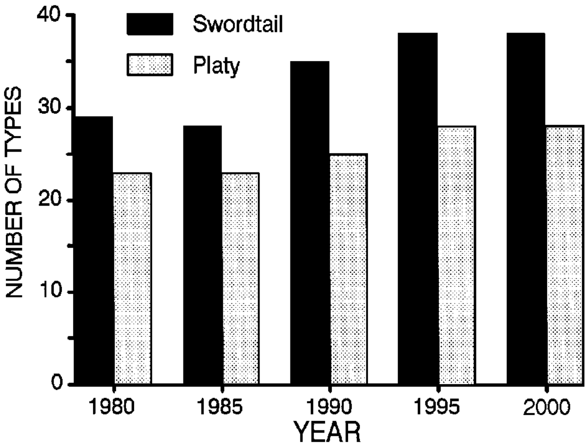

Figure 4. Changes in number of types of swordtails and platys between 1980-2000. Source: Worldwide Aquatics, Waimanalo, Hawaii.

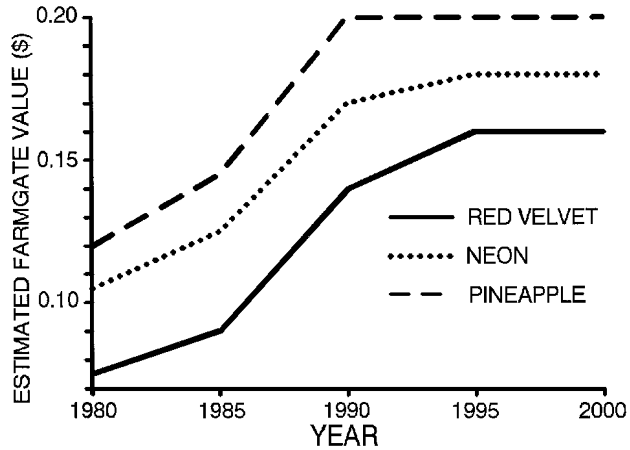

Figure 5. Changes in estimated farm-gate prices between 1980-2000 for three varieties of swordtails (2.5 in in body length). Source: Worldwide Aquatics, Waimanalo, Hawaii.

in) in total body length (TL) or approximately five to six months in age. (Total body length is measured from the tip of the snout to the end of the caudal fin. It does not include the "sword" on the tail of the male.) Two swordtails (the red velvet and neon) exhibited a continuous increase in value from 1980 until 1995 but the value has not changed since. The price of the pineapple variety has not changed dramatically over the last 10 years (1990-2000) but it remains as one of the higher priced swordtails (Fig. 5).

Reproductive Biology

Figure 6. Modified anal fin (arrow) used during mating.

One of the reasons the fish in the poeciliid family are popular is that they are sexually dimorphic, thus the males and females are easily identified. All poeciliid males possess a modified anal fin called a gonopodium (see arrow in Fig. 6), which is used during the mating process to insert sperm into the female. Sperm is directed through this tube in "packet" form (Fig. 7) and deposited into the female to fertilize the eggs. The shape of the gonopodium distinguishes *X. helleri* from other species within the genus (Dawes 1991). Poeciliid females have a distinguishing feature of their own. Just slightly above and forward of the anal fin is a dark area called the "gravid spot" (Fig. 8), which changes in size and darkness with the development of the embryos in a gravid female. The gravid spot can easily be identified in most species, however, some hybrid color patterns can make it difficult to distinguish. For *X. helleri*, another difference in morphology between the sexes is the elongation of the lower caudal fin rays of mature males from which the common name of the species, swordtail, is derived (Fig. 8). It is reported that *X. helleri* attains sexual maturity at 25-30 mm (1-1.2 in) TL or at 10-12 weeks of age (Milton and Arthington 1983; Dawes 1991). After attaining sexual maturity, swordtails do not form mating pairs but are completely polygamous. Not only will males court females of their own species, but also they will mate with females of other poeciliids, resulting in hybridization. Thus, in order to maintain a particular color or fin variety, different strains of swordtails must be isolated from one another. Alternatively, hybridization with

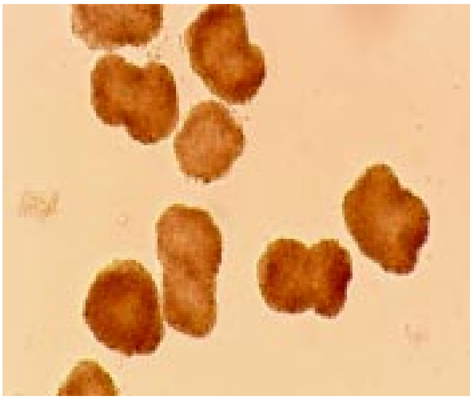

Figure 7. Photomicrograph of sperm packets obtained from a male swordtail.

Figure 8. Adult male (top) and female (bottom) swordtails.

other species has resulted in the development of a myriad of "new" strains. Hybridization of varieties of *X. helleri* for commercial purposes usually involves crosses with the platy, *X. maculatus* or *X. variatus* (Dawes 1991).

Sex Ratio

Sex ratio should be a consideration when choosing a species of freshwater ornamental fishes for culture. The male sex is often more ornately colored and more marketable. More investigations regarding sex determination have been done on the platy, *Xiphophorus maculatus*, than on the swordtail (Campton 1989). However, since the majority of colored varieties of swordtails are from hybrids between a swordtail and platy it would be appropriate to have at least a working knowledge of the underlying mechanism of control. According to Basolo (1990), the sex of a platy is determined by W, X, and Y genes. These genes can result in three female genotypes (WX, WY and XX) and two male genotypes (YY, XY). It is believed that in swordtails, sex determination is more complex, being polygenic and interactive (Basolo 1990). Sex determining genes found on several chromosomes interact with one another and the cumulative expression of these genes determines the sex of the fish. A survey of the sex ratio of five varieties of swordtail is summarized in Table 2. All varieties were being cultured in 12-ft diameter tanks at the same farm under the same conditions. The observed sex ratio was found to vary between the strains from an equal (1F:1M) ratio to a ratio of 4F:1M. The explanation for highly skewed populations of 9F:1M reported by some farmers is currently under investigation. Apparently, determination of sex ratio is partially linked to a particular strain of swordtail.

Table 2. Summary of sex ratio of various swordtails at a commercial farm site on Oahu, Hawaii.

Tank	Variety	Female	Male	Ratio (F:M)
A10	Red Wag	98	42	2:1
B10	Mystic Blue	100	82	1:1
B11	Red Velvet	138	54	3:1
B6	Neon	186	69	3:1
B1	Sunset	127	30	4:1

Gestation and Embryonic Development

Female swordtails can store viable sperm in the folds of their oviducts for fertilizing mature eggs when needed. This means that subsequent clutches of eggs in the females can be fertilized long after contact with a male. A single copulation can provide viable sperm for fertilization for up to two years, with a female giving birth to from five to nine consecutive broods from a single mating event (Axelrod and Wischnath 1991).

In all species of livebearers the gestation period is poorly documented. According to Milton and Arthington (1983), reports of embryonic development vary from 26 to 63 days (Table 3). They demonstrated that temperature is the major factor in the rate of development while photoperiod plays a minor role. Daylength can also influence the rate of development if it falls below 10 h. In Hawaii, however, the shortest daylength is just under 11 h and would therefore not be a factor.

Table 3. Classification of embryo stages during development.

Embryonic Stages	Duration (Days)	Description
Early Development	1-12	Embryo less than 1.5 mm, seen as a pale strip on the surface of the ovum
Early-eyed Embryo	13-16	Some retinal pigment, no body pigments
Late-eyed Embryo	22-24	Distinct neck strap of receding extra embryonic membranes
Mature Embryo	25-26	Neck strap absent, preparturition stage with fully developed fins

Effects of Temperature on Reproduction

Optimal temperatures for reproduction in all livebearers are reported to be between 22 and 26°C or 74 and 78°F (Dawes 1991). The optimal temperature for swordtail production in Hawaii has yet to be established. At the temperatures reported, the gestation period would range from 26 to 30 days. Investigations of the reproductive activities of wild populations of swordtails in Australia have revealed that temperature can also be a factor in the number of fry produced per female per month (Fig. 9). Analysis of the data resulted in a statistical model that does not explain a large amount of variation ($R^2 = 0.36$) in the average number of fry produced/female/month at temperatures between 22 and 29°C. However, the slope of the line generated from the model was significant ($P< 0.05$). On average, with every degree rise in water temperature, the number of fry per spawn will correspondingly increase by three, with the highest average number of fry occurring in water with a temperature of 29°C.

It has been reported that fry production ceases below temperatures of 15°C and slows considerably when temperatures drop below 18°C or rise above 29°C. The maximum and minimum air temperatures recorded at the University of Hawaii Institute of Marine Biology are presented in Fig. 10. Although there will be some depression in fry production during certain months of the year (December through March) swordtails can reproduce on a year-round basis in Hawaii. Annual changes in temperature are significant factors that need to be considered to ensure consistent production during periods of peak demand.

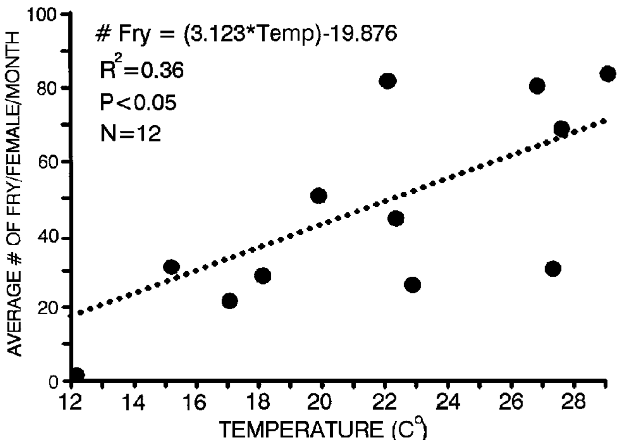

Figure 9. Relationship between fry produced and water temperature from wild populations of swordtails in Australia. Summarized from Milton and Arthington (1983).

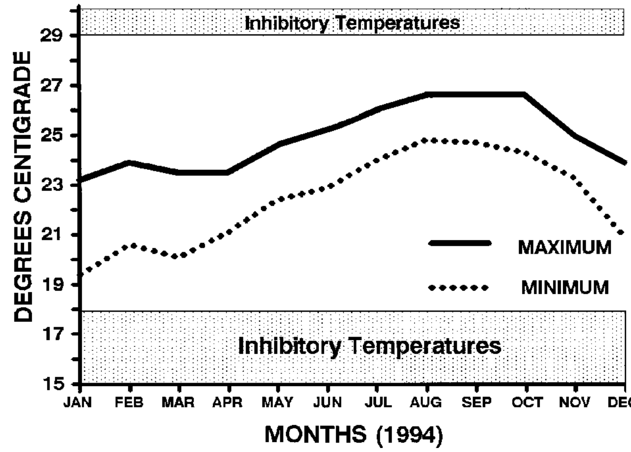

Figure 10. Average monthly maximum and minimum air temperatures recorded at the Hawaii Institute of Marine Biology, Kaneohe, Hawaii.

Fecundity

The fecundity of *X. helleri* has been reported to be as high as 242 fry/female (Breder and Rosen 1966); however, spawns of *X. helleri* average about 30 fry/female. The relationship of fecundity and body length varies among livebearers. The fecundity of *X. helleri* has been determined to be a curvilinear function of body length. The model:

Log Fecundity = ((Log X)*2.73) - 2.66

where Fecundity is the number of fry/female and X is body length (mm) has been reported to provide the best fit of the data (Fig. 11). For simplicity, the Y values presented in Fig. 11 have already been transformed to the number of fry/female and body length is presented in both millimeters and inches. In other species of the genera, fecundity is reportedly linearly related to body size (Milton and Arthington 1983).

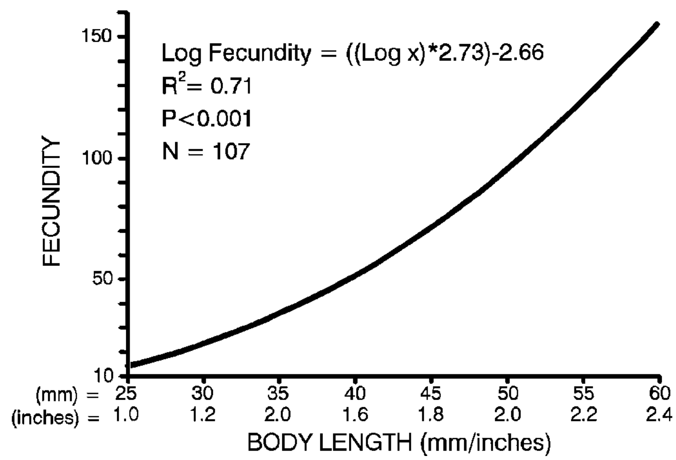

Figure 11. Statistical model relating fecundity and body length from wild populations of swordtails in Australia. Summarized from Milton and Arthington.

For the purposes of commercial farming, fry production should be monitored continuously to determine strategies for management. With large groups of broodstock, it is unfeasible to monitor sizes of individual fish. A simplified method of monitoring reproduction is to record the number of fry produced by a given number of females over a given period of time (e.g., days). Experiments in Hawaii have shown that swordtail fry production ranges from 0.8 to 2.2 fry/female/day (average = 1.0). For example, if 600 broodstock were stocked at a ratio of 5F:1M in a large cage inside a breeding tank and produced 5700 fry over a 12-day period, the calculation for determining fry production would be:

(5700 fry produced)/(500 females stocked)/(12 days) = 0.95 fry/female/day

Using this method and relating it to the observed water temperatures, a farmer can predict fry production from a given population of females over time. Likewise, it is a useful means of monitoring the production of the broodstock. Changes in the type and quality of feed, feeding rate, ammonia and dissolved oxygen levels, disease, and age of broodstock are all factors that can affect fry production. Optimal fry production is obtained from broodstock of 6-12 months in age or 63.5-76.2 mm (2.5-3.0 in) TL. Fry production diminishes after the broodstock reach one year of age as seen by the decrease in the number of fry/female/day. To prevent gaps in production, the farmer must plan 4-6 months in advance to ensure that sufficient fish are available for the next generation of broodstock.

Growth

A growth curve was obtained from swordtail fry stocked at a density of 1100 fry/m^3 in a cage culture system. Stocking was done during the month of August by placing 30-day-old fry in net cages, which were then placed into a 12-ft diameter tank provided with a continuous flow of fresh water and aeration. Fry were fed a commercial diet to satiation throughout the 90-day growout period. At approximately 30-day intervals, the body length and weight of a sub-sample of 30 individuals were measured. The data were subjected to regression analysis as summarized in Fig. 12. Note that total body length (TL) is presented in both millimeters (left axis) and in inches (right axis). Remember that the total body length of the swordtail is measured from the tip of the snout to the end of the caudal fin. It does not include the “sword” on the tail of the male. Survival during the 90-day growout trial was reported as 90.1%. The body length of 30 one-day-old larvae was measured and included in the analysis to complete the growth curve from the time of birth. The statistical model of growth, (TL = 8.71+(0.687*Day)-(0.0029*Day^2) where TL = total body length (mm) and Day = number of days in culture, was found to provide the best fit of the data. The quadratic equation is typical of growth curves, and on average, younger swordtail fry grow at a rate of just over 0.5 mm/day. The rate of growth slows after the fry attain sexual maturity. Accompanying growth is a dramatic alteration in morphology most notable in the males with the extension of their caudal fin or “sword.” Examples of the various growth stages during the growout phase are presented in Fig. 13.

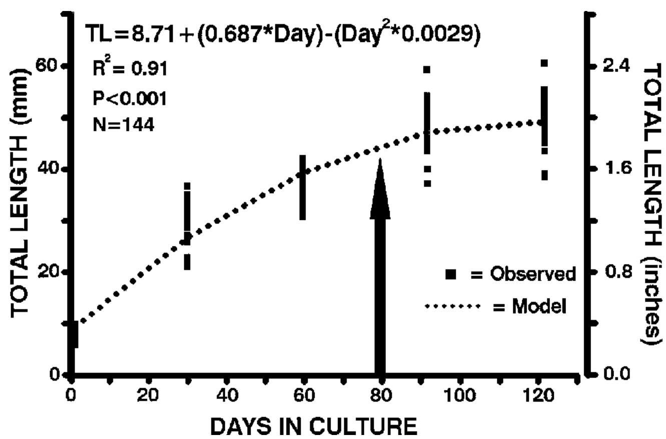

Figure 12. Observed growth of swordtails cultured at Windward Community College, Kaneohe, Hawaii (arrow indicates size/age at first maturity).

A high degree of variability in body length throughout the growout period can be seen from the data presented in the growth determination. The size frequency distribution of 120 swordtails obtained at the end of the growout period is summarized in Fig. 14. The fish ranged from 31.4 to 61.6 mm (1.2 to 2.6 in) TL with an average TL of 46.4 ± 6.7 mm (1.9 ± 0.3 in). Swordtails can be marketed at sizes ranging from 25.4 mm (1 in) TL, denoted as small on distributor price lists, to 76.2 mm (3 in) TL, denoted as large. As discussed in the following section on economics, although all sizes of the fish harvested at the end of the growout period are suitable for sale, the estimated farm-gate price per fish will vary depending upon body size. Likewise, because of the variation in body size, the cultured

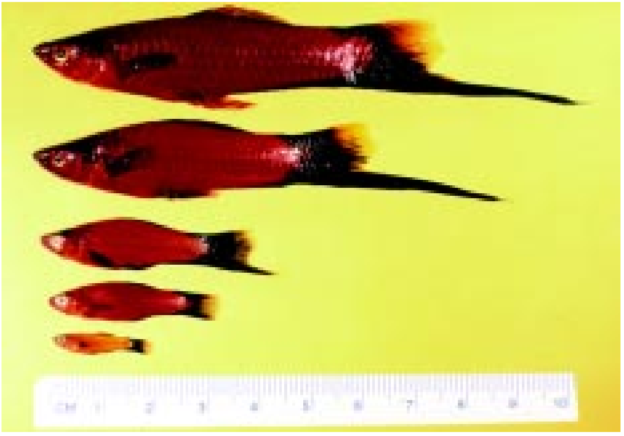

Figure 13. Changes in the morphology of male swordtails of the redwag variety during growout.

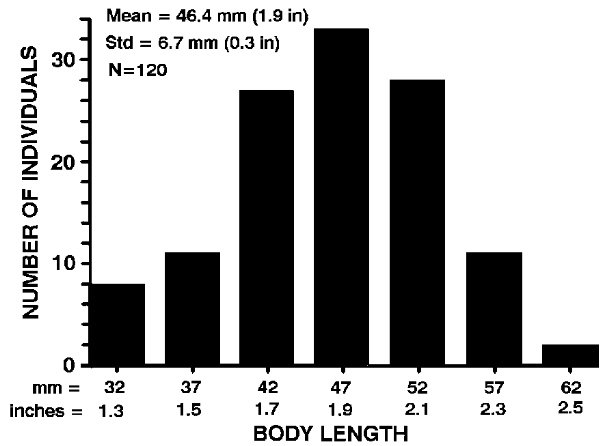

Figure 14. Size frequency distribution of swordtails after 90-day growout period (i.e., 120 days old) grown at Windward Community College, Kaneohe, Hawaii.

fish must be graded prior to being sold. The procedures for both techniques are presented in the following sections. After grading by size, the smaller fish can be placed with a younger cohort of similar size coming through the crop rotation. However, the farmer should always be aware of which groups include fish of mixed ages. Broodstock should be selected from fish of similar age which have a rapid growth rate and desired coloration.

Culture System

Breeding

Livebearers will reproduce when subjected to wide-ranging water quality parameters as long as adequate feeds are available and appropriate temperatures are maintained. Commercial production of livebearers has been principally performed in earthen ponds where broodfish are stocked and allowed to spawn freely for 6-7 months. After this period, the fish are harvested and graded for market and new broodstock are introduced into the ponds. As described in a later section, this type of large-scale production results in a greater percentage of fish that are off-color and/or deformed. These are culled during the sorting process and priced accordingly. Traditional pond culture does not take account for the brief time before livebearers attain sexual maturity (usually 2-3 months after birth). If these fish are allowed to mate freely, the number of culls harvested after the growout period will increase. To maximize the production of a desired color or fin variety, the broodstock should be isolated in traps or small cages within aquaria, tanks, or ponds. This reduces cannibalism of the fry by the broodstock and increases the survival of fry from one particular strain. These set-ups can range from a simple plastic net cage to an elaborate clear plastic box or any container with holes that allows fry to escape from the broodstock. Breeders and hobbyists to produce various hybrids or color strains use this technique. On a commercial scale, the traps are essentially large baskets, more appropriately called cages, suspended above the bottom of large ponds or tanks and stocked with males and females. Examples are provided below.

Commercial-Scale Production

The types of production systems vary based on available resources and conditions at individual sites. The various methods range from production in ponds to high-density culture in tanks or ponds with net cages. Ponds used for commercial production range from earthen to vinyl-lined. They can be quite variable in size, cost, and efficacy in vegetation control. The construction of earthen ponds can be quite expensive and usually requires several permits (not detailed in this manual). Alternatively, tanks (12-18 ft in diameter) can be used exclusively or in combination with ponds. The tanks can be constructed out of a variety of materials (e.g., plywood with canvas lining, high-density polyethylene). Szyper (1989) presents a guide to the layout and construction of ponds and tanks.

Pond Preparation: Unlined earthen ponds used for swordtail production should first be sun-dried until the bottom cracks. Emerging weeds should be removed. If herbicides are necessary, an agricultural extension service should be contacted for the proper permits and methods of use. Some of the recommended herbicides are:

- **Casaron**, a broadcast herbicide that is effective on rooted aquatic and terrestrial plants.
- **Diquat**, which is particularly effective on filamentous algae. It requires a license for purchase and use.
- **Rodeo**, a contact herbicide effective on a wide range of aquatic plants.
- **Sonar**, which is effective on rooted aquatic and semi-aquatic plants.

NOTE: WITH THE USE OF ANY HERBICIDE, FOLLOW THE DIRECTIONS ON THE LABEL.

Extreme care must be taken in ponds that are heavily infested with weeds to avoid possible oxygen depletion due to decomposing plant matter. Under these conditions, it is recommended that only half of the pond be treated at any one time. After elimination of the vegetation the pond should be filled as soon as possible and fertilized to obtain an alga bloom or “green water.” A liquid fertilizer with a N-P-K (nitrogen-phosphorous-potassium) ratio of 1-3-0 is recommended. Premixed fertilizers with a mix ratio of 10-30-0 or 12-36-0 can be purchased from local distributors (see Appendix 2.) The fertilizer is applied at a rate of one ml/5 ft^2 of surface area or 3-5 gal/acre. In tanks, fertilizer is applied at a rate of one ml/50 L of water. Once the alga bloom has been established, the fish can then be stocked into the pond. If delays in stocking the pond are encountered, the water should be checked for the presence of aquatic insects. Dragon fly nymphs and water boatmen can be eliminated with the use of boiled linseed oil applied at a rate of 1-2 ml per 5 ft^2 of surface area. The linseed oil will cover the surface of the water and essentially suffocate the aquatic insects. The linseed oil will slowly dissipate as it evaporates from the water surface. After a day or so, the fish can be stocked without harm.

Pond Culture: Commercial-scale pond culture begins by stocking brood fish directly into a pond at a density of one female per 4 ft^2 of surface area with a sex ratio of 4 or 5F:1M. Broodstock should be at least 63.5 mm (2.5 in) TL or at least six months of age. The fish are fed to satiation once a day with a commercially available ornamental fish diet or other suitable commercial diets that contain at least 28-32% crude protein. A list of suppliers of commercial feeds can be found in Appendix 2. A variety of live feeds (e.g., zooplankton) will naturally proliferate in pond culture and supplement the commercial feeds provided to the fish. Harvesting by trap or seine begins about six months post-stocking. Examples of these methods are covered in the following section on harvesting.

Cages in Ponds: An alternative to the open pond method is to keep the broodstock in cages inside the pond to allow only the fry to swim freely. The cages should be suspended at least a foot above the bottom of the pond to prevent an accumulation of uneaten feed or feces on the bottom of the cages. The cages should be stocked at 10-15 fish/ft^2 of cage surface area at a sex ratio of 4 or 5F:1M. Pond maintenance, feeding, and harvesting would be the same as described earlier. This particular system is equivalent to using traps to hold the broodstock within aquaria but on a much larger scale.

Intensive Culture: This manual will focus on the use of a modular system. The system consists of:

- two 12-ft diameter circular fry production tanks (6700 gal each)
- four 4-ft x 4-ft x 1.5-ft net cages with a mesh size of 1/4-inch for broodstock
- nine 6-ft x 4-ft x 4-ft net cages for fry growout

The four net cages are placed in one of the circular tanks and stocked with 300 broodstock at a sex ratio of 5F:1M (or 250 females to 50 males) each. The second tank is initially empty and held in reserve. The nine growout cages are placed in a pond of suitable dimension (a minimum size of 40 ft x 7 ft x 4.5 ft). It is recommended that during the first two weeks post-stocking, a 1/16-inch mesh lining be placed within a 1/8-inch mesh net cage. Two weeks after stocking, the smaller mesh netting can be removed so the fry can swim into the 1/8-inch mesh cage for continued growout. A schematic of the intensive culture module is presented in Fig. 15. The broodstock production tanks need not be circular but should have a depth of 4 ft and a volume of 6700 gal (25, 500 L). The production cycle is as follows:

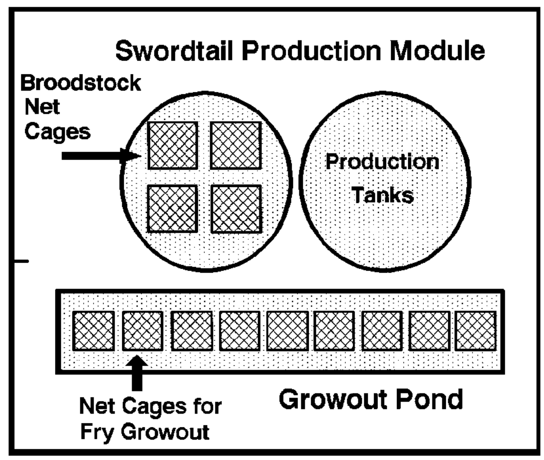

Figure 15. Schematic representation of the swordtail culture system.

Step 1. Suspend four broodstock net cages in one tank and stock all cages with 300 fish (250 females and 50 males) that are 63.5-76.2 mm (2.5-3.0 in) TL or from 6 to12 months in age. This should result in 1200 brood-stock fish at a sex ratio of 5F:1M. The bottom of the net cages should be at least 2 ft above the bottom of the tank. The fry production tanks should be provided with continuous aeration and enough water exchange to maintain water quality parameters within acceptable limits (e.g., $NH_3 < 1.0$ ppm). A rule of thumb is a water exchange of 10% per week. The tanks should be stocked soon after filling to avoid establishment of larval insects such as backswimmers, water beetles, and dragonfly nymphs. A linseed oil treatment to rid the ponds of these insects was described earlier. The early stocking of fry can offset the predator/prey size relationship and reduce mortality. The broodfish should be fed daily to satiation with an ornamental fish diet or other suitable commercial diet containing at least 28-32% protein. The broodfish will court and spawn in the net cages and the newborn fry will swim through the netting into the tank to escape predation by the broodfish. The spawning should be allowed to continue over a period of 12-15 days. Although the females can produce several broods from a single mating, the males are kept with the females throughout the production cycle to insure the highest percentage of fertilization. The tank or individual net cages should be covered with netting to prevent losses to bird predation. This is particularly true in Hawaii where one of the major bird predators is the black-crowned night heron, *Nycticorax nycticorax hoactli* or *'auku'u.*

Step 2. After the spawning period, the four net cages containing broodstock are then transferred to a second circular tank and the process described in step 1 is repeated. In Hawaii, the fry production from the system described typically ranges from 0.6 to 2.2 fry/female/day or approximately 7000-18,000 fry per spawning period.

Step 3. The fry in the first tank are reared for an additional 15-30 days. They should be fed a commercial diet having a particle size of 0.5-0.8 mm and the feed should be offered three times a day to satiation. After 15-30 days, the fry should be counted and transferred to a growout cage. The fry will remain in the growout cage until harvest, or approximately 90 days post-stocking. Appropriate stocking densities and feeding are discussed below.

Step 4. Repeat steps 2 and 3 to stock all of the growout cages. When the production system is in full operation, the nine net cages will contain fry approximately one month apart in age. At least three to four net cages will continually contain fish ready for harvest (25.4 -76.2 mm or 1-3 in TL).

Step 5. The swordtail should be harvested from the growout net cages 90-120 days after being stocked. As described previously in the section on growth, a wide range of sizes will result during this time interval and the fish will require sorting prior to being marketed. Harvesting and sorting methods are discussed in a later section.

Step 6. Market the cultured swordtail.

Stocking Densities for Growout

Stocking densities for growout in tanks or cages can reach as high as 10,000 per m^3 as long as acceptable water quality is maintained. Water quality parameters are discussed in a later section. The net cages for growout are just over 2 m^3 in volume and can accommodate at least 20,000 fry. However, lower survival and/or depressed growth can result from the high stocking density over the course of the 90-day culture period. The relationship between stocking density and survival over the course of a three-month growout period using 30-day-old fry is presented in Fig. 16. The data obtained from growout trials indicate a clear trend of decreasing survival (i.e., negative slope) with the increase in stocking density. The highest percent survival is obtained from stocking densities ranging between 1000 and 2000 fry/m^3. However, it should be noted that although a higher stocking density (e.g., 5000-10,000 fry/m^2) results in lower survival, the actual number of harvested fish is equivalent or higher than those stocked at the lower densities. For example, fry stocked at 2000 fry/m^3 were observed to have a survival of 90% or 1800 fry at harvest. Likewise, 5000 fry/m^3 @ 50% survival = 2500 fish at harvest and 10,000 fry/m^3 @ 35% survival = 3500 fish at harvest.

Growth is another factor that can be affected by stocking densities as seen in Fig. 17. Interestingly, initial growth among all treatments is relatively equal with a slight edge demonstrated at higher stocking densities (e.g., 5000 and 10,000 fry/m^2). However, at the end of the growout period the highest stocking density exhibits a depressed rate of growth. Based on this data, stocking densities of 1000-3000 fry/m^3 are recommended for growout in the net cages if the entire process is to be done in the same cage. To accommodate higher fry production, an increase in the number of cages or the size of the cage is necessary. A larger growout facility is the "Farm A" scenario to be described in the economics section in which nine 12-ft diameter tanks (6700 gal or 25 m^3) are used in place of the nine net cages. These growout tanks can accommodate 25,000 fry each, which would result in a stocking density of 1000 fry/m^3.

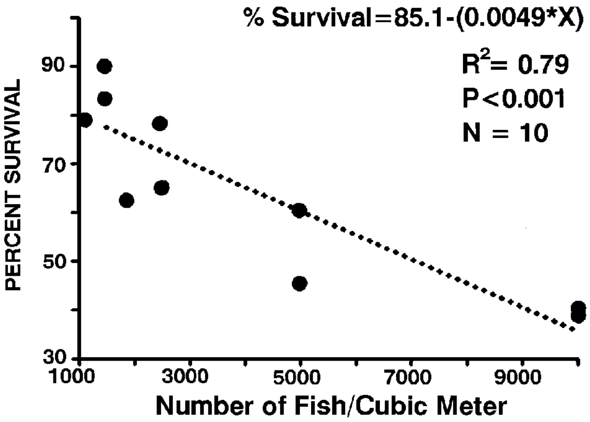

Figure 16. Relationship between stocking density and survival at 90 days post-stocking.

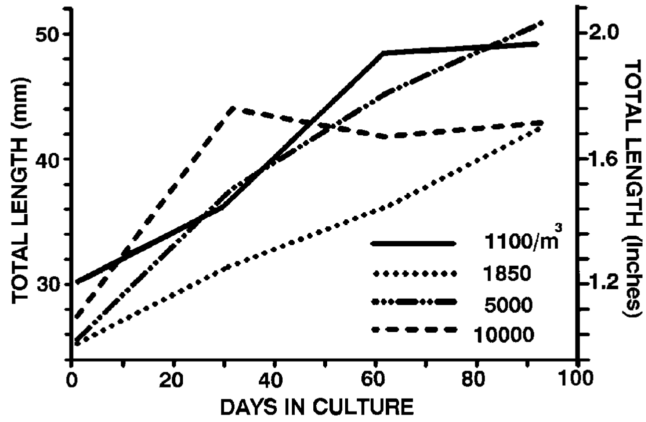

Figure 17. Comparison of growth between swordtail fry stocked at various densities in net cages.

Feeding

Although the nutritional requirements for livebearers are not well documented, all the species discussed are considered omnivorous, however, the molly prefers a diet of more plant material (Dawes 1991). Studies of the stomach contents of the swordtail, the platy, and the guppy indicate that both terrestrial and aquatic insects are eaten along with phytoplankton and some macro algae (Arthington 1989). The various feeds suitable for swordtail production and their manufacturers are provided in the Appendices. Because the feed mills in the U.S. design their products to meet the needs of the major food fish species cultured in the U.S., the majority of feeds are designed for catfish, salmon, and trout. Two things to take into consideration when choosing a feed are the size and composition of the feed. Because swordtail are smaller in size than the food fish species mentioned, the appropriate size feeds for swordtail will fall within the starter diets for the food fish species and are normally referred to as “start-up” or “swim-up” diets. Manufacturers of commercial fish feed use a grading system to classify the size of their feeds (e.g., 0,1,2,3), according to the size of mesh through which the feed is screened. A breakdown of the classifications and particle size is provided in Table 4. For swordtail fry, the 0-size start-up diet is appropriate.

Table 4. Classification of feed sizes for starter diets

Starter Diet Feed Classification	Particle Size (mm)
0	0.6
1	0.8
2	1.2
3	1.6

The composition of the feed should also be considered, as start-up diets vary in the amounts of protein, fat, fiber and minerals. For example, start-up diets for catfish and trout differ in their composition and a trout diet is recommended for use with swordtail culture. A breakdown of the main components of the feed is provided in Table 5. At high stocking density, the feed should be provided 2-3 times per day to maintain optimal growth and survival. The use of automated feeders can lower labor costs (see Appendix 1 for a list of distributors).

Table 5. Proximate analysis of feed recommended for intensive swordtail culture.

Ingredient	% Composition
Crude Protein	50.0
Crude Fat	16.0
Crude Fiber	5.0
Ash	12.0
Added Minerals	2.0

Many of the usual color pigments of the swordtail are derived from naturally occurring phytoplankton and zooplankton consumed when they are grown in ponds. In high-density tank culture or cages within ponds, this natural source of pigments (carotenoids) is not available due to the over-grazing of the natural live foods. Carotenoids are a group of naturally occurring lipid soluble pigments that are produced primarily in plants (including phytoplankton and algae). These pigments are responsible for the great diversity of color seen in nature. The carotenoids are usually associated with the various hues of yellow, orange and reds. While plants and algae can synthesize these pigments, animals are unable to produce them naturally and must obtain them from food. During the final month of growout it is recommended that feeds containing color enhancers or pigments such as astaxanthin should be fed to bring out the full color of the fish. Alternatively, commercially available alga products (Spirulina Pacifica™ and NatuRose™) can be incorporated into flake or pellet commercial diets (Ako and Tamaru 1999). When these alga products are incorporated into a flake feed at 2% of Spirulina Pacifica™ and 1% NatuRose™, an enhancement of coloration in the treated fish may be noticeable within two weeks (Fig. 18).

Figure 18. Red Velvet swordtails given regular flake feed (left) and flake feed enhanced with NatuRose™ (right).

Water Quality

The maintenance of broodstock includes monitoring water quality parameters, the most important of which are water temperature, dissolved oxygen (DO), and total ammonia. A thermometer, DO meter, and a water quality test kit to measure total ammonia nitrogen and pH in fresh water are used to measure these parameters, respectively. These parameters need not be measured daily, but should be done on a routine basis (2-3 times/week) and the values should be logged in a manner that the data can be easily summarized or scrutinized for changes in the ponds or tanks. If need be, corrective action can be taken to alleviate a potential disaster. For low DO increase aeration and the rate of water exchange, for high ammonia increase rate of water exchange and check for buildup of detritus, and since high pH signals a potential phytoplankton crash an immediate water exchange is necessary.

All livebearer species tolerate a wide range of water quality parameters, but different species have slightly different optimal ranges. The optimal water quality parameters for X. helleri are presented in Table 6. Swordtail generally prefer slightly alkaline conditions with hardness ranging between 60-80 mg/l $CaCO_3$, while *X. maculatus* and *X. variatus* also prefer slightly alkaline conditions but a hardness of 40-50 mg/l $CaCO_3$ (Dawes 1991). Oxygen levels should be maintained above 3.0 ppm. Total ammonia levels should be kept below 1.0 ppm with pH near neutral. Optimum temperatures for production are between 22 and 29ºC or 74 and 84ºF, although they do tolerate temperatures as low as 10º C or 50º F. Livebearers thrive in alga-rich water having a Secchi disk reading near 35 cm.

Table 6. Optimal water quality parameters for the culture of swordtails.

Water Quality Parameters	Optimal Values
Water Temperature	22-29º C or 74-84º F
Hardness	60-80 mg/l $CaCo_3$
Salinity	0 o/oo
pH	7.0 - 8.1
Total Ammonia	< 1.0 ppm
Dissolved Oxygen	> 2.0 ppm
Phytoplankton	Secchi reading of 35 cm

Harvesting Livebearers

Preparation for harvesting

Step 1: Prior to any harvesting from a pond, the pond should be inspected for aquatic weed infestation and the appropriate herbicides should be applied if necessary with the proper lead-time. Tank culture systems eliminate problems with emerging aquatic plants and lessen the degree of management and harvesting problems.

Step 2: One week before harvest, the fish should be sampled and examined for any disease and treated if necessary. (The treatment of disease is included in the following section on disease.) The fish should also be sampled on the day of harvest to guarantee that the fish are still in good health. Following these procedures ensures a smooth harvest and minimizes mortality.

Harvesting Gear

Livebearers cultured at commercial scale are harvested with traps or seines. Currently, three basic traps are used on livebearer farms. The first is a clear plastic trap with a funnel on one end and a sliding screened gate on the other (Fig. 19). The traps are built to retain an inch or two of water when they are removed so that injuries to the fish are kept at a minimum. The second is a common minnow trap made of a wire mesh cylinder with cones on each end (Fig. 19). This trap is split around the circumference and locked together with a simple hinge and hook mechanism, which can be easily opened to remove the fish. The third is referred to as a heart-shaped trap, which is a much larger trap, with sides that curve around into the center creating a slight gap where the fish enter. The heart-shaped trap is constructed with a smooth piece of sheet metal down the entire length of one side, so the fish can be poured out of the trap without causing damage to the scales of the fish. The traps are baited by placing feed formulated into a paste near the entrance funnels. The baited traps are then

Figure 19. Examples of plastic and wire mesh minnow traps used for harvesting swordtails.

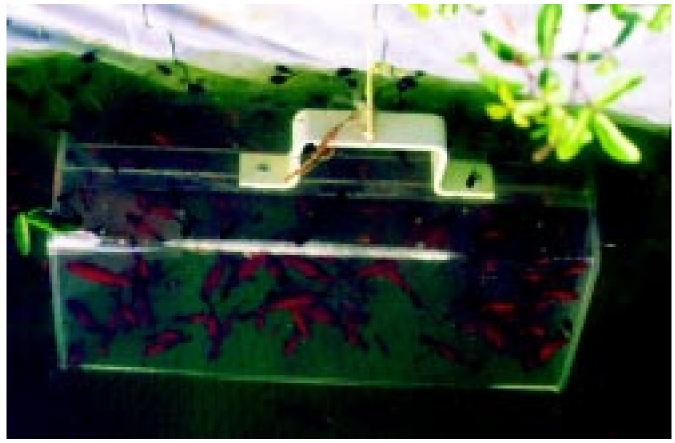

Figure 20. Plastic trap with swordtails ready to be harvested.

placed along the perimeter of the pond, tank, or net cage near the surface of the water (Fig. 20). In high-density systems, the traps should be checked every hour or so to avoid overcrowding. A large number of fish in a trap can rapidly deplete the dissolved oxygen, resulting in a loss of fish. During the monitoring of the traps, the contents can be periodically emptied into a bucket of fresh water and taken to the holding area where the fish will be sorted and purged. The trapping of fish can be done throughout the day but the best time is prior to their normal feeding time.

Harvesting by Seine

NOTE: WHEN USING A SEINE, A LARGE NUMBER OF FISH WILL BE CONCENTRATED INTO A SMALL AREA. UNLESS THE COLLECTION PROCESS PROCEEDS IN A SMOOTH AND ORDERLY MANNER, THE OUTCOME CAN BE CATASTROPHIC.

Livebearers can also be harvested with a seine net made of knotless nylon Ace or Delta weaves with a mesh size of 1/8-inch. Seine nets should have a length 2.5 times the width of the pond being harvested, and a depth 2 times the depth of the pond. Seines used for harvesting ornamental fish contain twice as many floats and bottom lead weights than a standard seine. It is essential that all debris and filamentous algae be manually removed from the pond prior to seining. Prior to entering the pond, a clear plan of action (e.g., sorting at pond side, direct stocking all collected fish into the holding tank) should be formulated. All equipment including nets, buckets, and tanks should be ready for use before the first pass of the seine through the pond is done. After the vegetation and debris have been removed, the seine is pulled through the pond. Particular attention should be paid to pulling the seine near the pond bank to ensure that the fish are not overcrowded. If the fish are to be graded at the side of the pond, the fish should be removed from the seine and graded immediately. Selected fish can then be placed into respective holding tanks and the rest can promptly be returned to the pond.

If all the fish are to be removed from the pond, the fish caught in the seine should be placed into buckets containing fresh water and transported immediately to holding tanks. Several passes through the pond can be made until there is a noticeable decline in numbers of fish. The water in the pond can be dropped by 50% and the process repeated. Lastly, the pond should be drained of all water and any remaining fish should be collected and placed into holding tanks.

Holding Tanks

During harvest or after grading, the fish should be immediately placed into 300-500 gal holding tanks equipped with running fresh water and aeration. The drains should be covered with screening to prevent fish from escaping. However, since some debris will invariably be placed into the tank with the incoming fish, the drains should be watched so that they do not become clogged, causing the holding tank to overflow. After the fish are placed in the holding tanks, any floating debris and dead or injured fish should be removed. Salt is added to the water to bring the salinity up to 9 ppt (9 kg/m^2 or 20 lbs/250 gal). This isotonic solution can help reduce the stress from handling by stimulating the fish to produce a slime coat. Harvested fish can be maintained in the holding tanks for one to two weeks. Feed should be withheld from the fish two days prior to shipping to allow their guts to be purged for sorting, packaging, and transport.

Grading for Size

The morphology and market for a particular species determine grading methods. Fish are usually first graded by size using a bar grader (Fig. 21) followed by sorting by sex and color. Commercial bar graders are made with incremental widths between the bars (see Appendix 1 for sources). The preferred type is manufactured with interchangeable baskets that fit into a floating frame. They are sold in size increments of 2/64 inches with each size representing a number grade size (e.g., 10/64 is a No. 10 grader and 12/64 is a No. 12 and so forth). Fish are netted from the holding tanks and placed into the floating grader box. The smaller fish will swim through the grader bars while the larger ones are retained in the box (Fig. 22). By changing grader widths, any size fish can be easily sorted by increments as small as a quarter inch in body length. Market size swordtails with a body length of 25.4-76.2 mm (1-3 in) are sorted with grader sizes No. 10 to No. 16. Female swordtail tend to have wider girths when gravid, therefore care must be taken so that a large ratio of females is not selected. These sizes are only suggestions, and a test should be performed to identify the appropriate grader to size fish according to market demands. An initial grading is recommended at the pond to reduce the number of fish that are handled in the sorting area.

Figure 21. A floating container and interchangeable grading basket for sorting swordtails by size.

Figure 22. Floating bar grader being used to sort harvested swordtails by size.

Preparation of Anesthesia

Fish farmers have learned to employ a means by which fish can be anesthetized while they are undergoing length/weight determinations, staging of sexual maturation, tagging, administration of hormones or medication, or in the case of ornamental fish, sorting. This allows a specimen to be physically handled without the trauma that can be inflicted if no anesthesia is used. The most common anesthetics are quinaldine, MS-222 (Tricane Methanesulfonate), 2-phenoxyethanol, and clove oil. Sources of these reagents are listed in Appendix 2.

NOTE: THE READER SHOULD READ THE PRODUCT SAFETY SHEETS THAT ACCOMPANY THE PURCHASE OF EACH REAGENT, AS SOME POSE HEALTH HAZARDS WHEN NOT USED PROPERLY.

Quinaldine: To make a stock solution of quinaldine for use in anesthetizing fish, mix 1 ml of quinaldine with 2.5 ml of acetone in a 1-L bottle, making certain to mix the solution by shaking vigorously. Add water to bring the volume up to 1 L. This stock solution can be stored for prolonged periods. Be sure to label the bottle and keep it in a safe place. To use this stock solution to sedate fish for sorting, add 2.5 ml of solution per liter of the water in which the fish are being held and slowly increase the dosage until the fish begin to lose their equilibrium (indicated by the fish turning over) but continue to breathe. Recovery time is short and quinaldine is generally safe for most fish up to a concentration of 100 ppm. The procedure is recommended for use when sorting fish, *not for shipping fish*.

Tricane Methanesulfonate (MS-222): MS-222 is considered to be one of the most effective anesthetics. MS-222 is usually sold as a water-soluble white powder. To make a stock solution, simply add 5 g MS-222 to 1 L of water and mix until the powder is dissolved. If stored at 5°C, the stock solution can be stored for at least six months. Use 10 ml of stock solution for every liter of water in which the fish are being held. Increase the amount of MS-222 slowly to attain the same effect as described when using quinaldine.

2-Phenoxyethanol or Clove Oil: Another anesthetic that is gaining in popularity for use with fishes is 2-phenoxyethanol or its natural analog, eugenol, that is found in clove oil (Tamaru et al. 1995). 2-phenoxyethanol is purchased as a clear liquid that is diluted to a concentration between 200-300 ppm. At this concentration, fish lose their equilibrium within 1-2 minutes and will recover within 2-5 minutes. 2-phenoxyethanol and clove oil have been found effective in anesthetizing freshwater and marine fish species.

Sorting

After grading for size, the sorting procedure is one of the more laborious activities. It is necessary to ensure that only fish of suitable color and body shape are marketed by excluding individuals that are deformed or undersized. A pictorial guide is presented in Appendix 2 to illustrate this critical procedure, and a systematic description of the process is as follows:

Step 1. Harvested fish that have already been sorted by size are collected from the holding tank and anesthetized.

Figure 23. Normal colored Red Wag swordtail (top) and abnormal color variants found during the sorting process.

Figure 24. Alternative sorting method for livebearers.

Step 2. A sorting table has a glass plate on top that has been coated with a commercially available synthetic slime (see Appendix 1 for sources) to reduce injuries from handling. Several 5-gal buckets containing fresh water are placed along one edge of the sorting table to catch the sorted individuals. The number of buckets used depends on the number of traits (e.g., size, color, sex) for which the fish are being sorted.

Step 3. Once the fish are properly sedated, remove a small number from the anesthesia by dip-net and place them on the sorting table. To sort for sex, color, and deformities, slide the sedated fish across the tabletop into the separate buckets (e.g., males, females, undersized, and culls). Examples of some of the culled fish are presented in Fig. 23. Discoloration and body deformities are the main reasons for separating culls from fish to be marketed. This process is continued until all of the fish in the holding tank have been sorted. The culled fish can be sold as "mixed" sword tails or as feeder fish, albeit, the price will likely be lower for these (e.g., \$0.03-\$0.05/fish for feeders) than for those with desired traits.

Sorting can also be done without the use of anesthesia by placing 50-100 fish from the holding tank in several small (e.g., 3-gal) glass aquaria filled with fresh water. Unwanted fish are removed with a dip-net and placed in a separate tank (Fig. 24). The remaining fish are then placed into a separate tank until they are ready to be packed and shipped. This is continued until all of the fish have been screened. In either case, sorting is labor-intensive but necessary to ensure the quality of the fish to be marketed.

Bagging and Shipping

Shipping practices are an essential part of getting the product to market and a separate manual by Cole et al. (1999) has been devoted to that topic. Only a general overview will be presented here. On the farm site, a section should be designated as the packing area consisting of a set of 10-15 gal tanks or tubs. Each tank or tub should be equipped with a continuous source of fresh water; aeration and standpipe that will allow the tank volume to adjust to a particular volume (e.g., 20% of the shipping bag). Swordtails are generally sold in pairs (one male and female). Livebearers are traditionally shipped with a 10% over-pack to offset for possible mortality during shipping or miscounts. An equal sex ratio of fish are counted into box lot quantities (e.g., 250 individuals/box) and placed in separate holding tanks or aquaria where their guts can be purged. When it is time to ship, the fish and water are gently poured into the shipping bag. The bag is squeezed from the top to the water level to remove the air then inflated with oxygen and sealed with a rubber band or banding machine. The sealed bag is placed in a Styrofoam box, which is then placed in a cardboard box and taped shut for air cargo shipping.

Disease

NOTE: IT CANNOT BE OVEREMPHASIZED THAT PREVENTION OF AN OUTBREAK OF DISEASE IS THE BEST METHOD OF TREATMENT.

The monitoring of fish health is one of the most consequential activities in the culture of fish. Procedures for production, feeding, and handling of any kind must be designed to minimize the risk of infection or transfer of disease and parasites. Daily observation of the feeding and swimming behavior at all stages of the production cycle is the first step in detecting a problem. Loss of appetite and especially erratic swimming behavior (flashing), listlessness (floating on the surface) and clustering near water and/or aeration outlets are signs of impending problems. These symptoms usually precede mortality and if an infection is caught in the early stages, the probability of restraining a disease outbreak is high. Since microbial pathogens propagate in logarithmic fashion, each passing day during which a disease outbreak is allowed to progress will severely decrease the chances of minimizing mortality. If mortality has occurred, the dead fish should be examined. A sample of fin or gill tissue should be clipped and placed on a slide along with a drop of water. A cover slip is then placed over the sample before it is examined under a compound microscope. A farmer with minimal training can diagnose most parasitic infections. Fungal and bacterial cultures along with the proper sensitivity tests can be done on site with some additional training. The commercial availability of prepared diagnostic kits has simplified this process. Viral epizootics usually lead to extensive mortality or require destroying the fish. Disinfecting (with chlorine) the holding facilities (e.g., tanks, aquaria) and equipment (nets, buckets) is necessary to control the spread of the disease. It is recommended that if diagnostic facilities are not available on site, or if an adequate diagnosis cannot be made, samples should be sent to a local veterinarian familiar with fish pathology.

The three most common disease problems that commercial farmers encounter in the culture of the swordtail result from infections from Protozoa (*Trichodina*), Monogenea (*Dactylogyrus* and *Gyrodactylidae*) and Fungi (*Saprolegnia*).

Trichodina are a round-saucer- or dome-shaped protozoa with cilia that are constantly in motion, moving quite distinctly and rapidly, as seen through a microscope. They are most commonly found on the gills and soft tissue such as the fin rays of the fish. Heavy infestations can cause respiratory problems by causing the gill tissue to produce excess mucus. Several methods can reduce and/or eliminate this parasite from the culture system. The most common procedure is to use a chronic treatment of formalin at 25 ppm. (See the following section on Formalin Preparation for proper use of this reagent.) Once diagnosed and treated, the fish should be checked daily to monitor the effectiveness of the treatment. If necessary, the treatment can be repeated.

Transmission of *Monogenea, Dactylogyrus* and *Gyrdactylidae* is usually by direct contact. After the eggs of the parasite hatch, free-swimming larvae seek out a host such as the gills and fin rays (soft tissue) of the fish. They attach themselves using a series of hooks and sucking valves at the base of the organism and appear worm-like under the microscope. Infected fish usually exhibit flashing behavior, which is actually the fish rubbing itself on a hard surface or shaking its body in an attempt to remove the parasite. There are two common treatment methods. The first is a formalin treatment at a concentration of 250 ppm for 1 h. This is the preferred method when treating large numbers of fish since no handling is required and the tank is simply flushed after treatment. The second method is a sodium chloride (non-iodized salt) dip at a concentration between 25,000 and 35,000 ppm (or 25 g/L and 35 g/L). It is recommended that preliminary tests be run on small samples of fish to determine the proper length of time and concentration. The duration of the dip is determined by the tolerance of the individuals to high salinity and the effectiveness of the treatment. The fish should be held in the saline bath until they lose equilibrium then transferred to a clean tank. The aquaria or tanks where the outbreak occurred and the nets and buckets used during handling should then be disinfected with chlorine.

An infection from the Fungi, *Saprolegnia*, usually occurs as a result of injuries incurred during handling. It usually appears as a white or light gray patch on the surface of the fish. When viewed under a microscope it is best described as having a cotton-like strand appearance. *Saprolegnia* can be problematic to treat since some of the most effective compounds have been regulated out of use. One of the tried and true methods is a formalin bath at a concentration of 250 ppm for 1 h/day for five consecutive days. Alternatively, placing the fish in a bath of methylene blue at a concentration of 3-5 ppm for 2-72 h has also been shown effective.

Formalin Preparation

NOTE: USE EXTREME CAUTION WHEN USING CONCENTRATED FORMALIN. THE READER SHOULD REVIEW THE PRODUCT SAFETY SHEET THAT COMES WITH THE CONCENTRATED FORMALIN.

All of the diseases mentioned above employ formalin as one means of combating the disease. Formalin is a colorless liquid generally used as a fixative for preserving tissues. It consists primarily of water into which formaldehyde gas has been bubbled. Concentrated formalin normally contains 37-40% formaldehyde. Concentrated formalin should always be handled in a well-ventilated area or fume hood. For use as a disinfectant and/or treatment of parasites, concentrated formalin is usually diluted to very low concentrations (10-300 ppm).

To treat large volumes of water (>100 L or >26 gal) concentrated formalin is mixed directly into the holding facility. The equation normally used to determine the amount of formalin needed to treat a disease outbreak does not employ the percent active ingredient because by convention 37-40% formalin is considered to be a 100% active solution. An example of the calculation to determine the amount of formalin to be used to make a 100-ppm solution in a 100-L (26-gal) tank is as follows:

Note: 1 ppm = 1 ml/1000 L

100 L = volume of tank to be treated

100 ppm = desired concentration of formalin

Concentrated formalin = (100 L) x (1 ml/1000 L) x (100 ppm)

From the above calculation, 10 ml of concentrated formalin must be added to the 100-L (26-gal) container to obtain a final concentration of 100 ppm. First, measure 10 ml of concentrated formalin and then pour it into the tank being sure to distribute it evenly. To calculate the amount of concentrated formalin needed to result in a 250-ppm solution in the same 100-L tank, substitute 250 ppm for the 100 ppm in the above formula. The result is 25 ml of formalin.

For smaller water volumes, a stock solution of 10% formalin (i.e., 90 ml of concentrated formalin + 910 ml of water) is first made. By adding 1 ml of the 10% formalin stock solution to 1 gal (3.8-l) of water a 25-ppm formalin solution is obtained. Adjust the amount of stock solution to the gal of water to result in the desired concentration (e.g., 2 ml/gal = 50 ppm, 4 ml/gal = 100 ppm and so forth). Multiply by the number of gal of water to be treated to obtain the proper amount of stock formalin solution needed (e.g., 4 ml/gal = 100 ppm). For a 10-gal tank, a 4 x 10 (40 ml) of 10% formalin stock solution will result in 10 gal of 100-ppm formalin solution.

Recommendation: Test trials with healthy fish should be attempted prior to any disease outbreak to become familiar with the calculations described above.

Economics

The production of ornamental fish has been one of the more profitable types of aquaculture outside the State of Hawaii (e.g., Florida, Singapore, Taiwan, and Japan). CTSA, the Pacific Business Center, and SGES produced an in-depth study entitled “Report on the Economics of Ornamental Fish Culture in Hawaii” to examine the economics of owning and operating an ornamental fish culture endeavor. This report is available through CTSA or SGES. In summary, the report modeled three different farm sizes using two pricing scenarios and found that “All three farms in the study proved to be profitable to own and operate.” Hawaii farmers can match the landed cost (of fish from suppliers in Asia) in Los Angeles, Dallas, and Seattle and still turn a profit. Hawaii farmers have a substantial advantage over the competitive suppliers of fish from Asia because Hawaii-raised fish require less time in transit. Consequently, Hawaii farmers can emphasize product quality (e.g., lower percentages of dead on arrivals, high health) as a primary marketing strategy and need not rely on price competition to sell their products. For the purposes of this manual, we will focus on the start-up costs and gross production. The breakdown of the equipment and supplies required for the larger farms are presented in the, “Report on the Economics of Ornamental Fish Culture in Hawaii.” Distributors for the various equipment and supplies can be found in Appendix 1.

Start-up Costs for Small-scale Module

A detailed breakdown of the equipment and supplies needed for a small-scale (e.g., two 12-ft diameter tanks and nine growout net cages) livebearer farm with consistent year-round production along with the associated start-up costs are presented in Table 7. It should be emphasized that the values were based on a farm site that already had an earthen pond or tank system large enough to hold the nine growout net cages.

Undoubtedly, the construction of the growout pond or tank system is an additional cost that must be taken into consideration by prospective farmers that do not have these facilities. A closer estimate to the initial start-up costs in the latter case is presented as Module No. 1 in Table 7, where the difference in costs is the construction of additional tanks to account for the growout phase. The values presented are for start-up costs only and do not reflect operational costs such as labor, electricity, water, insurance, fuel, lease rent, and interest, as many of these parameters will be quite variable on a case to case basis. The reader should account for these factors in the projected start-up costs to estimate the profits that can be realistically obtained.

Estimates of profitability can be made based on the production data at the Windward Community College aquaculture project site and, if available, the gross sales of other farmers. The estimates summarized in Table 8 are based upon the production of 12,500 30-day-old swordtail fry in Hawaii. This value is the average fry production over a four-month period. Obtaining farm-gate price lists is difficult, as they are confidential between various distributors. However, estimates can be made from a distributor’s price list for retailers by allowing for a fixed percentage of mark-up (e.g., 50%). Prospective farmers will need to establish prices with their own distributor(s).

A median value of $0.16/fish measuring 63.5 mm (2.5 in) TL was used to produce the estimate for monthly and annual gross values. Included in the table are the estimates for monthly and annual gross sales resulting from varying percentages of survival and the annual return on investment (minus the estimated start-up costs of $10,220). It is clear that survival will have a major influence on profits, as a positive return on the initial investment is only achieved with survival of 45% or greater. Although the intent is to sell all the fish produced a percentage of deformities and off-color individuals will undoubtedly occur. These can be culled and marketed at a lower price. Not figured into the calculations are the associated operational costs of labor, energy, water, electricity, etc., as these will vary from farm to farm, especially if the farm operator will do all of the labor. From the data presented, a small-scale operation as described can recover the initial start-up costs with some profit by the end of its first year and the profit margin grows substantially during the second year of operation. It is quite reasonable to assume that the entire small-scale module can produce enough funds to serve as a second income.

Because swordtails are a “low-value” species, the volume of production must be scaled up to attain gross sales comparable to other agricultural products such as taro, papaya, or watercress. As mentioned previously, an economic analysis was conducted on three different farm scenarios that varied in size and each were forecast to be profitable. The initial capital investment, average yearly gross income, and the monthly fry production required to attain the projected values in different farms are summarized in Table 9.

Farm A is the most similar to the small-scale module presented in this report, differing mainly in using 13 12-ft diameter tanks for fry production and growout instead of nine. This particular scenario is most applicable for farms that do not have a growout pond described in the small-scale module, as the tanks serve as the growout facilities. Instead of alternating between two fry production tanks, the broodstock would be routinely moved from tank to tank after the 12-15 day spawning period resulting in growout tanks containing populations that differ in age by two weeks. The fry production units described in the small-scale operation are actually geared to produce the number of fry at stocking densities (such as 1000-3000/m^2) where there should be little concern about overcrowding.

Farm B is a much larger farm having 50 12-ft diameter growout tanks including a hatchery facility for the production of egg-layers in addition to livebearers. For the purposes of this manual, however, it is assumed that all tank facilities are used for swordtail production in order to estimate the number of fish that must be produced on a monthly basis.

Farm C is similar to Farm B but it encompasses 200 12-ft diameter growout tanks as well as a

Table 7. Breakdown of equipment and supplies and start up costs ($US 1994) for a small commercial livebearer ornamental fish farm.

Categories	Quantity	Module #1 Price ($)	Quantity	Module #2 Price ($)
Equipment				
12' Diameter Tanks	12	5200	2	90C
Ground Liner	1 Roll	90	1 Roll	9C
Regenerative Blower	1	430	1	43C
Air Stones	12	106	12	10C
Air Tubing (HDPE 3/4")	500 ft	65	500 ft	65
O_2 Bottle Rental	1	50	1	50
O_2 Regulator	1	70	1	70
PVC Pipe & Fittings		1500		720
Bird Netting	3 rolls	90	1 roll	30
Bar Grader	1	300	1	300
Thermometers	2	50	2	50
Field Microscope	1	20	1	20
Breeding Net Cages	4	160	4	160
Growout Net Cages	0	0	9	360
Used Pickup Truck	1	4000	1	4000
Supplies				
Chlorine	5 gal	100	5 gal	100
Fertilizers	gran	135	gran	135
Broodstock	55 gal	650	55 gal	650
Feed	1200 fish	440	1200 fish	440
Rubber Bands		10		10
Transport Bags		25		25
Transport Boxes (inner)	40	240	40	240
Transport Boxes (outer)	40	440	40	440
Water Test Kits	1	195	1	195
Misc. Chemicals		300		300
Dip Nets		10		10
Misc. Expenses		250		250
Totals		15016		10236

Table 8. Monthly and annual gross sales of swordtails at varying percentages of survival.

Percent Survival @$0.16/piece ($)	Monthly Gross Sales @$0.16/piece ($)	Annual Gross Sales Year 1	Return on Investment ($)
30	600	7200	-3020
35	700	8400	-1820
40	800	9600	-620
45	900	10800	580
50	1000	12000	1780
55	1100	13200	2980
60	1200	14400	4180
65	1300	15600	5380
70	1400	16800	6580
75	1500	18000	7780
80	1600	19200	8980
85	1700	20400	10180
90	1800	21600	11380
95	1900	22800	12580
100	2000	24000	13780

The sale price of $0.16/piece (farm-gate) was obtained from Report on the Economics of Ornamental Fish Culture in Hawaii.

Table 9. Farm type, capital investment, net income, and the required monthly swordtail production.

Farm Size	Capital Investment ($)	Yearly Gross Income ($)	Monthly Swordtail Production
Farm A	17,000	41,600	22,000
Farm B	65,000	297,792	155,100
Farm C	165,000	980,112	510,000

Source: *Report on the Economics of Ornamental Fish Culture in Hawaii.*

hatchery facility. As is the case for Farm B, it is assumed that all tanks are used for swordtail production.

Factors Affecting the Price of Swordtails

Price sheets from one wholesaler reveal that the farm-gate price of swordtail differs depending upon the strain, body size (Fig. 25), and body shape (Fig. 26). Another factor affecting the farm-gate price is whether one sells directly to a retailer (highest price), to a wholesaler (moderate price) or through a transshipper (lowest price). The culture of higher-value swordtail varieties (e.g., albino, veil, lyretail, hi-fin, or combinations) can be a way to increase earnings. It must be emphasized, however, that the higher value swordtail varieties are also more difficult to produce and grow. The lyretail swordtail was first reported to appear as a mutant in at Florida fish farm (Whitern 1983). In this variety the upper and lower rays of the caudal fin are elongated, giving rise to the term “lyretail.” Through selective breeding, it has been determined that the lyretail trait is a dominant genetic characteristic meaning that an individual only needs one gene for the lyretail trait to appear (Norton 1967). Interestingly, the elongation of fin rays is not restricted to the caudal fin as the dorsal and anal fins can also become extended. This genetic change in the fins results in the inability of the male swordtail to mate due to the over-development of the gonopodium (Axelrod and Wischnath 1991). The male is physically incapable of copulating with the female; thus, the most common method of reproduction is one in which the lyretail female is mated with her male offspring that have not developed the lyretail characteristic. Using the method of backcrossing, theoretically, a maximum of only 50% of the next brood will possess the lyretail trait thus limiting the number of progeny that can be produced per generation. A method to artificially inseminate livebearers has been developed and used by hobbyists for quite a while to shorten the time frame in the development and fixing of a trait (Takeshita 2001). The artificial insemination of lyretail females with sperm from lyretail males is one means to improve the production of lyretail swordtails. However, some constraints must be eliminated before this method is used at a commercial scale (Tamaru et al. 2000).

In reality, the difficulties in producing the color and fin varieties that are in high demand are reasons why they command a higher price. Alternatively, substituting other species of livebearers and their variants with regard to color and fin varieties using the same technologies can increase profitability. Although the techniques described focus on the commercial production of swordtail, the module is flexible enough to be adapted to a host of other livebearers.

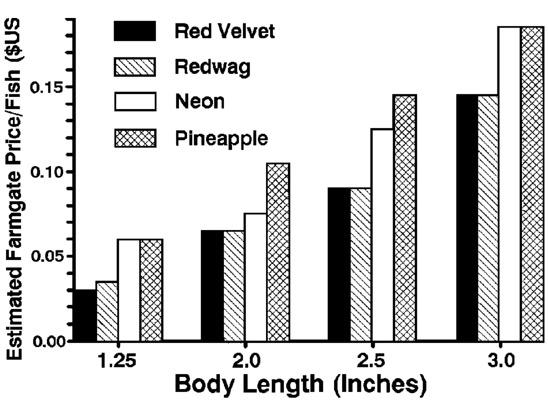

Figure 25. Estimated farm-gate prices of different varieties of swordtails at various sizes.

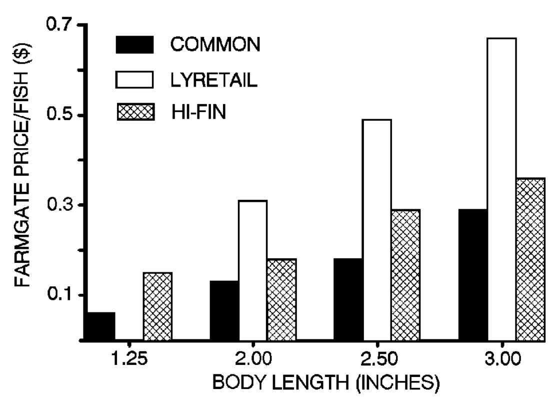

Figure 26. Estimated farm-gate prices for various body types of the red swordtail at various sizes.

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Milton, D.A. and A.H. Arthington. 1983. Reproductive Biology of *Gambusia affinis holbrooki* (Baird and Girard), *Xiphophorus helleri* (Gunther) and *X. maculatus* (Heckel) (Pisces; Poeciliidae) in Queensland, Australia. *J. Fish. Biol*., (23):23-41.

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Appendix 1. List of Distributors for Equipment and Supplies

Listing in this appendix does not constitute an endorsement of products or services. For a more comprehensive listing, consult your local extension agent or the Aquaculture Magazine Buyer's Guide and Industry Directory.

General Aquaculture Products

Aquacenter, Inc
166 Seven Oaks Road
Leland, MS 38756
(800) 748-8921
FAX: (601) 378-2862
E-mail: aqcenter@tecinfo.com
Web Site: www.aquacenterinc.com
Aeration equipment, water pumps, PVC fittings, filters, nets, water quality test kits, tanks

Aquanetics Systems, Inc.
5252 Lovelock St.
San Diego, CA 92110
(619) 291-8444
FAX: (619) 291-8335
E-mail: aquanetics@aquanetics.com
Web Site: www.aquanetics.com
Aeration equipment, water pumps, sterilization equipment, chillers, heaters, PVC fittings, recirculation systems and components

Aquatic Eco-Systems, Inc.
1767 Benbow Court
Apopka, FL 32703
(407) 886-3939/800-422-3939
FAX: (407) 886-6787
E-mail: aes@aquaticeco.com
Web Site: www.aquaticeco.com
Aeration equipment, water pumps, monitors, and controls, recirculation systems, laboratory equipment, nets, tanks and liners

AREA
P.O. Box 1303
Homestead, FL 33090
(305) 248-4205
FAX: (305) 248-1756
E-mail: areainc@aol.com
Web Site: www.areainc.com
Aeration equipment,valves and test equipment, filtration, disinfecting equipment

Florida Aqua Farms
33418 Old Saint Joe Road
Dade City, FL 33525
(352) 567-0226
FAX: (352) 567-3742
E-mail: fafusa@fafusa.com
Web Site: www.fafusa.com
Aeration equipment, water pumps, laboratory equipment, biological filtration, alga nutrients, inoculants, rotifer starter kits

Grainger
4397 Lawehana Street
Honolulu, HI 96818-3138
(808) 423-0028
FAX: (808) 423-0031
Web Site: www.grainger.com
Pumps, filters, hoses, electrical supplies

Chemical Products

Argent Chemical Laboratories
8702 152nd Ave. N.E.
Redmond, WA 98052
(425) 885-3777/(800) 426-6258
FAX: (425) 885-2112
E-mail: email@argent-labs.com
Web Site: www.argent-labs.com
Therapeutics, chemicals, formalin, quinaldine, MS-222, specialty feeds, laboratory equipment, reference books and manuals

Brewer Environmental Industries, Inc.
311 Pacific St.
Honolulu, HI 96718
(808) 532-7400
Web Site: www.BEIWEB.com
Herbicides, insecticides, fertilizer, agricultural products

Chemaqua
P.O. Box 2457
Oxnard, CA 93033
(805) 486-5319
FAX: (805) 486-2491
Therapeutics, water conditioning products

Crescent Research Chemicals
4331 E. Western Star Blvd.
Phoenix, AZ 85044
(480) 893-9234/(800) 893-9234
FAX: (480) 244-0522
E-mail: crescent@aqualogy.com
Web Site: www.aqualogy.com
Therapeutics, bacterial cultures, water-conditioning products, hormones (i.e., CPH, HCG, LHRH-a) test kits, meters

Fritz Industries, Inc.
Aquaculture Division
P.O. Drawer 170040
Dallas, TX 75217
(800) 527-1323
FAX: (972)-289-9534
E-mail: petsales@fritzind.com
Web Site: www.fritzpet.com
Therapeutics, water conditioning products, commercial slime

Hawaiian Fertilizer Sales, Inc.
91-155 C Leowaena Street
Waipahu, HI 96797
(808) 677-8779
Fertilizer, herbicides, agriculture products

Netting Products

Memphis Net and Twine Co., Inc.
2481 Matthews Ave.
P.O. Box 8331
Memphis, TN 38108
(901) 458-2656
FAX: (901) 458-1601
E-mail: memnet@memphisnet.net
Web Site: www.memphisnet.net
Seines, dip nets, gill nets, floats, lead weights, aprons, knives, rope, baskets, commercial fishing supplies, bird netting

Nylon Net Co.
615 East Bodley
P.O. Box 592
Memphis, TN 38101
(901) 774-1500
FAX: (901) 775-5374
Seines, dip nets, gill nets, floats, lead weights, aprons, knives, rope, baskets, commercial fishing supplies, bird netting

Tenax Corporation
4800 E. Monument St.
Baltimore, MD 21205-3042
(410) 522-7000
FAX: (410) 522-7015
E-mail: sales@us.tenax.com
Web Site: www.tenax.com
Plastic netting, tank liners

Water Quality Kits

Hach Company
P.O. Box 389
Loveland, CO 80539-0389
(970) 669-3050/(800) 227-4224
FAX: (970) 669-2932
Web Site: www.hach.com
Laboratory equipment, chemical reagents, test kits, meters

LaMotte Company
P.O. Box 329
802 Washington Avenue
Chestertown, MD 21620
(800) 344-3100
FAX: (410) 778-6394
E-mail: mkt@lamotte.com
Web Site: www.lamotte.com
Laboratory equipment, chemical reagents, test kits, meters

Tanks and Liners

Integrated Construction Technologies 1
50 Poopoo Place
Kailua-Kona, HI 96734
(808) 261-1863
FAX: (808) 262-3828
Concrete holding tanks

Lim Foo W and Sons
1130 Wilder Ave. Suite 102
Honolulu, HI 96822
(808) 521-5468
Fiberglass tanks

Lomart Tanks Liners and Filters
114- Kekaha Place
Honolulu, HI 96825
(808) 395-5786
FAX: (808) 395-7175
Prefabricated tanks and PVC liners

Pacific Lining Systems

74-5606-F Pawi Place
Kailua-Kona, HI 96740
(808) 326-2433
FAX: (808) 329-9170
High Density Polyethylene (HDPE) custom fabricated tanks

Plas-Tech, Inc.
Sand Island Access Road
Honolulu, HI 96819
(808) 847-2339
Fax: (808) 845-4337
Fiberglass tanks

Rainwater Resources
P.O. Box 62015
Honolulu, HI 96822
(808) 947-3626
Permalon tank/pond liners

Fish Graders

Commerce Welding and Manufacturing Co.
2200 Evanston
Dallas, TX 75208
(214) 748-8824
FAX: (214) 761-9283
Aluminum interchangeable bar graders

Magic Valley Heli-Arc and Mfg.
P.O. Box 511
198 Freightway St.
Twin Falls, ID 83301
(208) 733-0503
FAX: (208) 733-0544
Aluminum adjustable bar graders

Feeds

Feed and Farm, Inc.
91-319 Olai Street
Kapolei, HI 96707
(808) 682-0318
FAX: (808) 682-0639

Fritz Industries, Inc.
Aquaculture Division
P.O. Box Drawer 170040
Dallas TX 75217-0040
(800) 955-1323
Fax: (972) 289-9534
E-mail: petsales@fritzind.com
Web Site: www.fritzpet.com

Land-O-Lakes, Inc.
91-254 Olai Street
Campbell Industrial Park
Kapolei, HI 96707
(808) 682-2022

Waimanalo Feed Supply
41-1521 Lukanela
Waimanalo, HI 96795
(808) 259-5344
Fax: (808) 259-8034

Rangen, Inc.
P.O. Box 706
Buhl, ID 83316-0706
(208) 543-6421/800-657-6446
FAX: (208) 543-4698
E-mail: aquaculture@rangen.com
Web Site: www.rangen.com

Feed Additives

Dawes Laboratories
3355 N. Arlington Heights Rd.
Arlington Heights, IL 60004
(847) 577-1898
FAX: (847)-577-1898
E-mail: hq@daweslab.concoffice.com
Nutrients, trace elements, vitamin premixes

Hoffmann-LaRoche, Inc.
45 Eisenhower Drive
Paramus, NJ 07652-1429
(201) 909-5593
FAX: (201) 909-8416
Nutrients, trace elements, vitamin premixes, color enhancing additives

Red Star Specialty Products Division of
Universal Foods Corp.
433 E. Michigan Street
Milwaukee, WI 53202
(414) 347-3968
Nutrients, trace elements, vitamin premixes, color enhancing additives

Cyanotech Corporation
73-4460 Queen Kaahumanu Hwy #102
Kailua-Kona, HI 96740
(808) 329-4677
FAX: 808-329-4533
NatuRose, Spirulina

Shipping Materials

Diverse Sales and Distribution
935 Dillingham Bl.
Honolulu, HI 96817
(808) 848-4852
Plastic transport bags

Koolau Distributors, Inc.
1344 Mookaula
Honolulu, HI 96817
(808) 848-1626
Plastic transport bags

Pacific Allied Products, Ltd.
91-110 Kaomi Loop Rd.
Kapolei, HI 96707
(808) 682-2038
Styrofoam boxes and Styrofoam sheet material, corrugated outer boxes

Unisource
91-210 Hanua
Wahiawa, HI 96786
(808) 673-1300
Corrugated foam core boxes

Broodstock

Worldwide Aquatics
41-653 Poalima Street
Waimanalo, HI 96795
(808) 259-7773
FAX: (808) 259-5029

Ty's Tropicals
99670 Kaulainahee Pl.
Aiea, HI 96701
(808) 488-0716
FAX: (808) 487-7104

Florida Fish Coop.
10503 Cone Grove Road
Riverview, FL 33569
(813) 677-7136

5-D Tropicals, Inc.
6507 Bob Head Road
Plant City, FL 33566
(813) 986-4560
FAX: (813) 986-6792

Dolphin International Ltd.
1125 W. Hillcrest Blvd.
Inglewood, CA 90301
(213) 645-2046
FAX: (213) 337-1393

Other listings are available from Pet Business Magazine *Directory Issue.*

Wholesale/Distributors are available from:
Pets Business Magazine
5400 NW 84th Ave.
Miami, FL 33166
(305) 592-9890
FAX: (305) 592-9726

Aquaculture Magazine Buyer's Guide
P.O. Box 2329
Ashville, NC 28802
(704) 254-7334

Appendix 2. Pictorial Guide of the Sorting Procedure

Step 1. Fish being sedated with quinaldine.

Step 2. Applying commercial slime to the sorting table.

Step 3. Preparation of sorting table.

Step 4. Sorting of the swordtails -- Buckets contain (from left to right) females, males, undersize and culls.

Appendix 3. Glossary

Anesthesia: loss of sensation or consciousness without loss of vital bodily functions artificially produced by the administration of one or more agents.

Astaxanthin: a violet crystalline carotenoid pigment found combined with proteins in the shells of crustaceans and the feathers of birds.

Chromosomes: one or more rod like bodies that contain the genes of a particular organism. Most visible during cell division .

Cull: to collect and separate out as inferior.

Dimorphic: occurring in two distinct forms.

Dorsal: belonging to or situated on or near the back of an organism.

Epizootic: affecting many animals of one kind at the same time.

Fecundity: the potential reproductive capacity as measured by the individual production of mature eggs and sperm.

Formalin: a clear aqueous solution of formaldehyde that contains about 37 percent by weight.

Herbicide: an agent used to inhibit or stop plant growth.

Genes: one of the elements of cells that serve as specific transmitters of hereditary characteristics.

Gestation: the period of time for carrying young from conception to birth.

Hardness: a quality exhibited by water containing various amounts of dissolved salts (e.g., calcium and magnesium).

Lyre tail: a tail that has the shape of a lyre which is a stringed instrument of the harp class used by the Greeks that was made with a hollow body and two curved arms.

Modular: plan or construction based on a standard pattern or dimension.

Morphological: related to or concerned with form or structure of an organism.

Pathogen: a specific cause of a disease (as a bacterium or virus)

Phylogeny: the evolution of a race or genetically related group of organisms.

Phytoplankton: plankton consisting of plant life.

Polygamous: having more than one mate at the same time.

Sexual Maturity: state/age of development when offspring can be conceived.

Wholesaler: a merchant middleman who chiefly sells to retailers.

Zooplankton: animal life belonging to the group collectively called plankton, that drift or wander in the water column.