HUSBANDRY OF ANIMALS ON LAND AND IN WATER:  
SIMILARITIES AND DIFFERENCES

E. W. Shell

Alabama Agricultural Experiment Station², Auburn University 36849-5419

ABSTRACT
The husbandry of aquatic animals originated in China in approximately 1,100 B.C., 
thousands of years after the beginning of animal agriculture. The practice did not reach 
Europe until the Middle Ages. Aquaculture apparently was not very important in Western 
Europe. The early immigrants from that region did not include fish with the other food 
animals that they brought with them to the New World. The practice of aquaculture finally 
came to the United States in the mid-nineteenth century, where it was used for the 
production of trout for stocking coldwater ponds and streams for sport fishing. Later, 
cultural practices were extended to warmwater species such as the largemouth black bass 
and the channel catfish. Thus, aquaculture in the United States was derived from 
recreational fishing rather than from food production, and from fisheries management 
rather than from animal science. There are important differences in the hydrosphere and 
atmosphere as cultural environments. Differences in composition, density, response to 
physical force, latent heat of fusion, specific heat, transparency, viscosity, and erosiveness 
of air and water result in different problems for land animal and aquatic animal culturists. 
Aquaculturists work primarily with “cold-blooded” (“lower”) animals, whereas agricul-
turists work with “warm-blooded” (“higher”) animals. In comparison with warm-blooded 
land animals, cold-blooded aquatic animals are less independent of changes in their 
environment. The many differences in the hydrosphere and atmosphere as cultural 
environments are reflected in the biological characteristics of the two groups of animals. 
Differences in body support and locomotion, thermoregulation, water regulation, fecundity, 
care of the young, and metabolic waste management result in different problems that must 
be dealt with during husbandry.
Key Words: Aquaculture, Hydrosphere, Fish Husbandry


Introduction
Aquaculture may be defined as the intentional intervention in the production of animals 
and plants in water. This paper will limit the definition to the husbandry of animals in 
water.
The husbandry of animals on land or in water is similar in many respects. Both require 
many of the same inputs and involve many of the same processes, and both share the primary 
goal of producing animal protein for human consumption (utilization). Animal scientists 
have been involved in only a minor way in the rapidly developing field of aquaculture. Aqua-
culture, especially in the United States, developed out of recreational or sport fishing rather 
than out of animal science.
There is relatively little that animal scientists can learn from aquacultural scientists, but 
aquacultural scientists can benefit immensely from establishing and maintaining close working 
relationships with their animal science counterparts. Much of the basic science of the 
husbandry of land animals (genetics and breeding, nutrition, growth, pathology) is applicable to the culture of aquatic animals.
The purpose of this paper is to provide animal scientists with a brief exposure to

1Presented at a symposium titled “Aquaculture in Animal Science” at the ASAS 82nd Annu. Mtg., Ames, IA.
2Dept. of Fisheries and Allied Aquacultures.
Received August 27, 1990.
Accepted April 26, 1991.
A Short History of Aquaculture

Our earliest ancestors harvested, processed, and used both land and water animals (Lewin, 1988a,b). This predator-prey relationship goes back even further into prehistory. This process is the basis for the development of hunting, fishing, and gathering by our ancestors, and in the case of aquatic animals, it is still important. Between 80 and 90% of the aquatic animals that we consume as food are obtained through hunting (fishing) and gathering (Sasson, 1983). In contrast, the percentage of the wild land animals obtained in this manner for food is only a small fraction of the total quantity that we consume.

We can only guess why our ancestors shifted more rapidly from the predator-prey relationship in the case of land animals than aquatic animals. Of course, our ancestors and the food animals shared the same environment (the atmosphere). Also, I suspect that early humankind concluded that if they were going to have land animals available regularly, they would have to husband them. Aquatic animals presented them with a different perspective. They probably concluded that the quantity of salmon, milkfish, oysters, clams, and shrimp was as limitless as the seas seemed to be. In fact, we learned that their conclusion was incorrect only during the last 30 yr. Until the late 1960s, we assumed that to harvest more aquatic animals we had only to build larger ships, equip them with longer nets and send them farther from shore.

The cultivation of aquatic animals can be traced to approximately 1,100 B.C., when it was practiced with common carp in China (Hickling, 1968; Costa-Pierce, 1987; McLarney, 1987; Parker, 1989). However, because the common carp is native to Central Asia, not China, it has been suggested that aquaculture may not have originated there, but rather somewhere in ancient Europe (Costa-Pierce, 1987). Aquaculture persisted in China for some 1,300 yr before its use began to spread into adjoining countries. Fish farming spread to Japan via Korea perhaps as early as 200 A.D. (McLarney, 1987). There is little information on the origins of aquaculture in Southeast Asia, but it probably was carried there by Chinese immigrants.

Fish farming appeared in Europe in the Middle Ages (Dyk and Berka, 1988). The culture of carp began in central Europe at the close of the 11th century. There is little information to suggest how it came to Europe. Fish farming grew slowly but continuously in central and eastern Europe. By the 16th century there were about 100,000 ha of fish ponds in Bohemia, a region in Czechoslovakia.

Carp (Cyprinus carpio) culture has been important in Central and Eastern Europe for 1,000 yr, but it has been of limited importance in Western Europe. Consequently, the culture of that species was not brought to North America along with the culture of swine, cattle, sheep, goats, and chickens with the first immigrants. In fact, carp were not introduced into the United States until around 1830 (Parker, 1989). Carp were being cultured and marketed in California in 1832; however, the culture of the species never gained acceptance, although they were reproduced and stocked throughout the country by the United States Fish Commission in the 1880s. This species is considered to be a "trash" fish and an aquatic "pest" in most areas of the country. Relatively few carp are marketed for food.

Although food fish culture originated in China, the culture of fish for use in recreational fishing originated in Germany in the middle of the 18th century (McLarney, 1987). The first trout hatchery was established there in 1741. Over a century later, trout farming came to the United States. The first trout eggs were fertilized artificially in this country in 1853, using European techniques. Trout farming has served the recreational fisherman as well as the housewife purchasing fish for food.

Government hatcheries for the production of warmwater fish were established in the early part of this century (Parker, 1989). A number of warmwater species were produced and stocked widely across the country; however, warmwater aquaculture was not of major significance until the "farm pond" boom that
swept across the country from East to West in the years following World War II. Virtually all the fish removed from these farm ponds by recreational fishermen became food for the family; however, the primary impetus for development of this culture system was sportfishing. The production of warmwater fish for food did not begin in the United States until the first channel catfish (Ictalurus punctatus) were grown in ponds in the early 1950s.

Although aquaculture is approximately 3,000 yr old, it has never provided more than a small fraction of the fish consumed by humans (Sasson, 1983). It has grown rapidly during the last 25 yr but still provides little more than 10% of world fish harvest (FAO, 1989).

The Nature of Land and Aquatic Animal Husbandry

Domestication and cultivation have resulted in predictable supplies of most types of plant and animal foods on land, but our ability to intervene in a similar manner in the production process of fish in large lakes, rivers, and the oceans is severely limited. We can regulate the harvest of those animals to some degree by setting open and closed seasons, by establishing catch quotas (limits), and by restricting the type of gear (nets or boats), but we have virtually no control of the kind, the size, or the number being produced. Production essentially must be left to the mercy of the natural order of things.

Because we have been unable to increase the production of aquatic animals in natural waters and because we have increased the efficiency and level of harvest, the yield of fish, shrimp, oysters, and clams cannot be increased appreciably without inflicting permanent damage on natural stocks. As a result, it has been estimated that demand for aquatic animals will exceed supply worldwide by 20 million metric tons at the end of this century. In the long term this unfavorable demand-supply relationship can be reversed only through husbandry.

The production, harvest, processing, marketing, and utilization of both aquatic and land animals is a complex of interdependent physical, chemical, biological, psychological, sociological, and economic processes. In these processes, genes, cell membranes, tissues, soil, water, climate, scientists, salespeople, butchers, bankers, equipment manufacturers, government agencies, food inspectors, advertising campaigns, food fads, and dieting concerns, along with many other components and inputs, are linked together in a multidimensional matrix. This matrix is called an ecosystem (Odum, 1983). This animal production, harvesting, processing, marketing, and utilization ecosystem can be compared to a sort of multidimensional spiderweb. In this analogy, each component is connected with all other components either directly or indirectly. Expanding this analogy, changing the position or deflection of any nexus (component) of the web results in a change in the relative position of every other nexus. As an example, when Pope Paul III announced the decision in 1966 to allow local Roman Catholic bishops to end, at their discretion, the rule requiring abstinence from meat, it set off reverberations throughout the entire animal production ecosystem ("web") (Bell, 1968). More recently, the discovery of a small amount of feces on a few broiler carcasses resulted in a similar reverberation.

Animal production in nature is relatively unpredictable because of the additive and interactive effects of density-independent (floods, droughts) and density-dependent (predation, competition) factors on populations. As examples, the abundance of rabbits in Alabama woodlands and shrimp in Mobile Bay vary widely from year to year. One of the primary purposes of intervening in the production process or engaging in animal husbandry is to reduce uncertainty. And, as the level of intervention increases, uncertainty decreases, at least to a point.

In the tropics, fishermen traditionally harvest fish, shrimp, and crabs from the incoming and receding water in tidal streams with the use of nets and traps. Occasionally they build earthen dams across narrow streams at high tide, impounding sea water in shallow, irregular ponds. Along with "capturing" sea water, they also capture small shrimp, crabs, and fish that come into the streams with the tide. The captured water and animals are "penned" for a time to allow them to feed on the natural pasturage (algae, diatoms) that is produced in the static-water ponds. Then, on a low tide, the dams are broken and nets are placed across the stream channel to catch the animals as they move out with the receding water.

Penning the shrimp, crabs, and fish and allowing them to feed on the natural aquatic
“pasture” increases the certainty, to a degree, of harvesting a worthwhile crop compared to simply “fishing” the animals from the ebb and flow of the tide. However, certainty can be increased even further by increasing the level of intervention. By building a levee or dam around an area in the tidal zone and pumping water from the stream into it, a permanent pond can be constructed. Known quantities of small shrimp can be stocked and prepared feed given to them. In many respects this now is a modified “feedlot” husbandry system. In this situation, the quantity of animals produced is several orders of magnitude greater than the quantity that could be “fished” from that area of tidal swamp or produced in the “pasture” culture system in the same period of time. By increasing the level of intervention, the certainty of production also has been increased.

These relationships are less apparent in the culture of land animals because so few are harvested from limited intervention systems. The most obvious example is the comparison of “grass-fed” and “feedlot” beef production. These two systems are somewhat comparable to the two tidal zone production systems, one based on pasturage and one based on prepared feeds, described previously. The level of intervention and the degree of certainty of outcome is lower for the grass-fed than for the feedlot system. Producing the feed supply (grass) at the same time and on the same area where the animals are being cultured represents a lower level of intervention. The problems encountered with grass-fed beef during the drought of 1987–1988 provide a good example of the level of uncertainty of outcome associated with lower levels of intervention.

Only a small fraction of the world’s cultured shrimp supply is produced in systems in which the “feed” (pasture) is grown simultaneously in the same container with the shrimp. Instead, soybeans, corn, and wheat are produced in the “grain belt” in the United States and shipped to the tropics, where they are processed as shrimp feed. At this level of intervention, animal culture and feed culture are decoupled. The level of certainty of supply (outcome) required for development and maintenance of international shrimp trade requires the higher level of intervention, just as the beef processing, marketing, and utilization ecosystem requires a greater level of outcome certainty than the grass-fed system could provide.

**Some Comparisons of Land and Water Animal Culture Environments**

It is generally concluded that environments shape the nature of living things through the process of evolution (Smith, 1977). In turn, the nature (biology) of living things determines the characteristics of the intervention required to effect their husbandry or culture. From this perspective, it is apparent that the intervention required for the husbandry of land and water animals in the atmosphere and the hydrosphere would be different because these environments are different.

Land animal husbandry takes place in the atmosphere. At its interface with the earth, the atmosphere is a mixture of nitrogen, oxygen, water vapor, carbon dioxide, and inert gases. Water, as contrasted to air, is a chemical compound, but although it has a specific composition, it seldom, if ever, exists in pure chemical form. It usually exists as a complex solution of salts and gases. It is called the universal solvent. It will dissolve more substances than any other liquid. As a result, the composition of water usually utilized in aquaculture is much more variable than air. Because of the nature of water, excretory products such as carbon dioxide and ammonia can build up to dangerous levels. Also, pesticides and other contaminants can cause serious problems.

Air is a highly fluid mixture capable of flowing and changing its shape at a steady state when acted upon by a force. Individual molecules of oxygen or nitrogen are constantly in motion, so their concentration remains constant. Water is not nearly as fluid as air. Because of the density of water, individual molecules move more slowly. For example, in undisturbed water, an oxygen molecule will move only approximately 6 m/yr. As a result, when the oxygen concentration in water being used for aquaculture decreases because of biological oxygen demand, it is difficult to replace it from the atmosphere.

Except under unusual circumstances, the transparency of air is much greater than water. Visibility in air is usually measured in thousands of meters. In water it is measured in centimeters. In many aquacultural situations,
the animals cannot be seen at all; consequently, the farmer cannot count the number of animals that are being fed until the pond is drained.

Air has a relatively low weight per unit volume, and it lessens with altitude. As a result of this phenomenon, objects in air have a low degree of buoyancy. Because of the density of water, objects submerged in it have a relatively high degree of buoyancy compared with objects in air; consequently, the effect of gravity on animals living in water is much different from gravity's effect on animals living in water.

Although the physical nature of air is changed (gas to liquid) with difficulty, water can be changed from liquid to solid (ice) or gas (water vapor) by changing its temperature from 0 to 100°C. As noted above, the temperature of air can be changed rapidly by exposing it to heat energy. The temperature of water can be changed in the same manner, but not to an equal degree. The amount of heat required to raise the temperature of water is greater than that needed to raise the temperature of almost all other substances. Similarly, it is necessary to remove more heat to lower the temperature of water than for all except a few other substances. As a result of this phenomenon, the temperature of the hydrosphere changes much more slowly than that of the atmosphere.

As heat energy is removed from air, its volume decreases and it becomes progressively more dense until it becomes a solid. The same thing happens to water, but only to a point. At 4°C above its freezing point, water reaches its maximum density. As the temperature is reduced further, density decreases. As a result of this phenomenon, ice forms at the surface of ponds. Ice cover can result in the reduction of oxygen production through photosynthesis, make it difficult to feed the animals, and restrict harvest.

Oxygen is present in water, but at a significantly reduced concentration compared to its concentration in air. In air, oxygen is present at a relatively constant level of 21 parts per hundred. In water, it is present in a range from 5 to 15 parts per million and its concentration is based on the temperature of the water. The concentration is lowest at high temperatures, when the metabolism and need for oxygen by aquatic animals are highest. As a consequence, aquatic animals have much more difficulty extracting oxygen from water for use in metabolism than land animals have extracting it from air.

Some Comparisons of the Biology of Land and Water Animals

The atmosphere and hydrosphere are different as cultural environments, and the biologies of land and water animals also are different. However, the role of water in the life processes of both land and water animals is essentially the same. Water plays the same role in the cellular metabolism of all animals; however, because of the physical and chemical nature of the two environments, evolution has provided the two groups with different mechanisms to carry on their life processes. The successful production of species in the two groups is dependent on our ability to effectively manage their biology. With the space available, I can comment on only a few of the differences.

In making these comparisons, I am including those species that "harvest" oxygen for use in metabolism from the atmosphere in the land animal group and those that obtain it from the hydrosphere in the aquatic animal group.

Higher vs Lower Animals. Although the terms "higher" and "lower" as applied to animals cannot be precisely defined, they do describe a general difference in animals cultured on land and in water. Cultured aquatic animals include "cold-blooded" crustaceans (shrimp and crabs), molluscs (oysters and clams), and some of the more primitive vertebrates (fish). Cultured land animals are primarily "warm-blooded," higher vertebrates, such as cattle, sheep, swine, and poultry. In general, the "lives" of aquatic animals are less independent of their environments than the "lives" of land animals.

Body Support and Locomotion. Because of the difference in the density of air and water, aquatic animals benefit from a considerable amount of buoyancy, whereas animals on land have virtually none. As a result, land animals have a heavy skeleton for bodily support and to provide the mechanical system required for locomotion. In contrast, aquatic animals require a less massive skeleton. However, there are compensating factors. Friction between body surface and water is high and considerable energy is required to overcome it.
Thermoregulation. "Cold-bloodedness" is an advantage to animals living in water. They do not have to use "precious" oxygen harvested at great cost from the hydrosphere to maintain a constant body temperature. Although it may be an advantage to the animal, it is a disadvantage to the aquaculturist. When water temperature drops during the colder months of the year, metabolism slows dramatically and growth virtually ceases. Even in the southern states of the United States, the growing season for channel catfish is only 6 to 9 mo. This problem is the driving force behind current efforts to develop "controlled environment" culture systems for aquatic animals. The controlled external environment would be substituted for the relatively "uncontrolled" internal environment.

Water Regulation. Cells of both land and water animals must be "wet" at all times if they are to survive. The transport of molecules in both directions through cell membranes cannot take place unless the membranes are wet. Also, nutrients and metabolic wastes are transported to and away from the cells in an aqueous medium. Although animals in both groups must exist as "bags" of water, they must deal with significantly different problems while doing so. The difference is especially obvious in the freshwater fish, for example, compared to land animals. The blood of channel catfish contains more "salts" than the water in which they live; consequently, because of the pressure differences on either side of semipermeable membranes of the gill, skin and gut, water molecules "flow" into the circulatory system. The catfish must "pump" water out continuously as a weak urine solution to keep from drowning. In contrast, land animals must drink water regularly to counter desiccation caused by the loss of water for body cooling and the transport of wastes from the cells out of the body.

Fecundity. Fecundity of aquatic animals used in culture generally is much higher than that of land animals. Although there are some exceptions, aquatic animal females produce from several thousand to several million eggs each year. Land animals generally produce only a fraction of those numbers.

Care of the Young. For most species of land animals used for culture, care of fertilized eggs and of the young is a significant life history characteristic. Usually the female, and to a lesser degree the male, provides a degree of care from the fertilization of the egg until the individual is essentially self-sufficient. For most aquatic animals there is no care of fertilized eggs or of recent hatchlings. Also, there is no pair-bonding during the egg fertilization process. The fertilized eggs are left to the mercy of the hydrosphere. Interestingly, however, a few species that do exhibit a degree of parental care have been chosen for culture. For example, in some species of Oreochromis, the tilapias, there is a transitory pair bonding when the eggs are being fertilized, and the female carries fertilized eggs in her mouth until they hatch, and the hatchlings are carried there for several days. Periodically, the young fish are allowed to move out of her mouth to feed, but they quickly dart back inside when danger threatens. Also, the Louisiana red crayfish, Procambarus clarkii, females carry fertilized eggs under their tails until the eggs hatch.

Management of Wastes. In land animals, urine and feces fall to the ground where they are decomposed. Their accumulation may be a messy, odorous problem or nuisance, but generally they do not cause life-threatening problems. In contrast, urine and feces of aquatic animals are released into the water, where microorganisms bring about their oxidation and decomposition. The animals must compete with the microorganisms for oxygen from the hydrosphere during this process. The presence of unutilized feed increases the severity of this problem. Under certain conditions, this competition becomes so severe that there is not enough oxygen to sustain life in the animals, and all of them die.

Implications

Animal scientists have provided limited input to the growth of aquaculture in the United States; however, they are in a position to make significant contributions to the development of the information base required by this rapidly expanding industry in the future. To have maximum impact they must be aware of differences in the biology of aquatic ("lower") and land ("higher") animals and in the environments (hydrosphere vs atmosphere) in which they are cultured.

Literature Cited