7 FISHERY/AQUACULTURE

Chapter summary

This chapter discusses the principles of aquaculture and the various aspects to consider when designing a restoration. Items covered include water quality and supply, species selection and pond configuration. Ecological aquaculture is discussed which aims to produce high value products by non-intensive means without degrading the water quality or damaging the local environment.

Aquaculture – the farming of aquatic plants and animals – encompasses everything from plants to fish, molluscs, crustaceans, amphibians and reptiles. It is the world's fastest growing food production sector, increasing by 10% annually over the past decade. Approximately 40% of the fish consumed worldwide is now produced in farms (*Stirling University, 2006*).

7.1 Fish culture

Fish culture aims to increase the weight of fish in the shortest possible time, and commercial production is most commonly performed in open ponds, raceways, water re-use systems and cages. Potential production is in the order of 300 kg of fish per cubic metre.

Traditional extensive culture is being replaced by semi-intensive and intensive production systems with higher yields and faster growth. This has led to enhancing the natural food available by fertilisation (extensive systems), supplementation of natural food with moist or dry feed materials (semi-intensive systems), or supplying all the nutrients to the fish in a prepared diet (intensive systems). Under intensive production methods, fish typically grow one kilogramme for every 1.0-1.25 kg of feed eaten, whereas other warm-blooded livestock animals require 3-13 kg of feed for every kilogramme of weight gained.

7.2 Feed

A major determinant of successful aquaculture is the nutritional quality of feed, which accounts for a major part of the total operational costs of an average fish farm. Feed performance is dependent on feed management as well as its quality.

Feeding is the most important daily management function, ie no feed will mean no growth and therefore no profit. In cage culture, feed selection is extremely important. It should be nutritionally complete and, because fish cannot feed on the bottom, the feed used should float. Trout and salmon are fed floating diets with protein levels ranging from 40-46%. One method is to feed the fish as much as they will eat in ten minutes in the morning and again in the afternoon; if this is not practicable, a single feed of around 15 minutes mid-morning may suffice.

Cold-water fish are generally naturally carnivorous but warm-water species are generally more suited to plant food diets. Tilapia is a vegetarian species with significant potential, and vegetarian fish account for a growing proportion of annual production and plant ingredients are now found in most fish feed. Even carnivorous species such as salmon may accept diets rich in plant proteins and oils. Alternative protein sources such as soya meal, rapeseed meal, sunflower meal, lupin seeds and pea protein have been successfully included in fish food. In some operations the farmer may grow crops to supplement the aquaculture feed. A percentage of ground fish meal is still preferred for salmon and other carnivorous species, owing to its high protein content and similarity to natural diet.

7.3 Species selection for intensive aquaculture

Biological criteria include acceptance of commercial diets, temperature tolerance, good growth rates, ability to spawn repeatedly and high dress-out percentages (product recovered from processing). The desired species characteristics for cage culture are a fast growth rate under regional environmental conditions, tolerance for crowded conditions, native to the region and good market value.

7.4 Stocking

Aquaculture is usually stratified into producers of juveniles and feeder companies who bring them on to harvest size. Adult fish may be stocked and allowed to spawn naturally in ponds or complete harvesting and annual restocking may occur.

Stocking rates are impacted by the quantity and quality of feed, and by the water itself. Where cages are used and placed into flowing water (streams or rivers with a constant flow) it may be possible to increase the stocking rates. If ponds are not drained down annually, it is necessary to re-stock them with large individual young fish that will not become prey for the remaining fish from the previous year's stocking. Therefore, although water usage and discharge can be decreased, there is an increase in fingerling costs and consequent losses for the farmer.

7.5 Harvesting

Where water drawdown is possible, fish are concentrated in restricted areas and can be removed using dip-nets. In larger cages or pens and open ponds, harvesting is more complicated. Where drawdown is not possible, seine nets are required; ideally, they should be suited to regular pond configurations and bottom topography.

7.6 Outdoor cage or net pen culture

When an existing body of water cannot be drained for fish harvest or is too large to be economically emptied by pumping, floating fish pens or cages can be used. These are usually constructed of nylon or plastic netting designed to float at the surface where the enclosed fish can be observed and fed. The cages ensure that the fish can be easily harvested and allow much greater protection from predators than open-pond culture. Cages are easily covered with bird netting, and stocking rates for 6"-8" fingerling trout in a 4 x 4 x 4 foot cage may be in the order of 400-500 fish.

7.7 Aquaculture effluent management

Ponds that have through-flowing water from either a ground or surface water source support higher levels of production because of continual water replenishment. In ponds, productivity and water quality are boosted by aeration, which maintains levels of dissolved oxygen and aids the decomposition of waste products by natural micro-organisms and benthic invertebrates.

Where ponds are drained seasonally, the drain water flows through a buried pipe to a large receiving pond downstream where sediments are settled out and absorbed by aquatic plants. Some operators cultivate water plants for the garden trade in these basins. By-products from fish waste can also be used as a fertiliser that is guaranteed weed-seed-free.

An alternative to a retention pond is the use of a wetland area in the lowest portion of the fish farm, where a shallow embankment is sufficient to create a temporary basin for holding drawdown water. Here, it can slowly percolate through the soil or be drained off after clearing of suspended sediments. The most useful newly developed approach to aquaculture effluent management appears to be a combination sediment trap and composting technique in which a bed of wood chips is used to treat effluent wastes. The percolating water keeps this aquatic compost pile oxygenated and provides a nitrogen source to complement the carbonaceous wood fibres for the growth of desired decomposing microbes.

Fish waste excreted in floating cages is assimilated by the biota in the water. However, fish production is only about half of what a lake or pond could safely support if the fish were released and raised in open-pond culture. Also, a much higher level of water quality must be maintained because of the need for safe margins of adequate dissolved oxygen or low waste concentrations. If high water quality and aeration is not maintained, all of the fish within a heavily populated cage may die, whereas under similar conditions free-swimmers would suffer no casualties.

It is important that cage culture is conducted over lake bottoms that maintain aerobic conditions. In anoxic conditions, fish wastes are not "composted": they accumulate and detrimental gases will result from the action of anaerobic bacteria.

Another strategy with fish-cage effluent management is to move the cages around the lake over time to spread the waste produced. As cages typically occupy less than 0.5% of a lake's surface area, plenty of room is available to do this.

Nutrient recycling (converting nitrogen back to protein) through different polyculture systems could be more practical and efficient than controlling or treating the effluents associated with traditional, intensive monoculture practices. Phytoplankton and zooplankton occupy sizable respiratory (oxygen consumption) niches in the production pond environment – and have no market value. Careful selection of suitable filter-feeding fish and molluscs for polyculture could open up these niches for the production of species with greater economic value.

7.8 Water quality

High water quality is imperative to the success of any aquaculture operation, and water quality should be monitored on a regular basis, and steps taken if DO or ammonia levels are unacceptable.

7.8.1 Temperature

Unless natural or artificial mixing occurs, ponds will stratify when a warm layer of water forms above a cooler layer. Often the two layers will not mix, resulting in low oxygen and high ammonia in the cooler, bottom layer. Fish are cold-blooded and will have approximately the same temperature as their surroundings. Different species have different optimum growth temperatures. Cold-water species (such as trout and salmon) grow best within a temperature range of 8.9°-18.3°C. Cool-water species (such as hybrid striped bass, yellow perch and walleye) grow best at 15.6°-27.8°C. Warm-water fish (such as catfish and tilapia) grow best within a temperature range of 29.4°-32.2°C (*Swann et al, 1994*). Groundwater sources normally have constant temperatures year-round. The temperature of groundwater from shallow sources approximates the mean atmospheric temperature of the area.

By keeping water temperatures at optimum levels, fish growth can be enhanced and the growth period to market size reduced (*Rafferty, 1998*).

Heat-pump technology may be used to increase, or, in some cases, decrease water temperature. The required heating load will depend on the rate of heat loss from the pond, which is controlled by such factors as outside air temperature, evaporation, insulation and enclosure.

7.8.2 Oxygen

The amount of oxygen that can be dissolved in water depends on altitude and salinity, and decreases with increased water temperature. Optimal fish growth occurs when oxygen levels are maintained above 6 ppm for cool- and cold-water species, and above 5 ppm for warm-water species. Death may occur at levels less than 3 ppm.

7.8.3 pH

The acceptable pH range for fish culture is between pH 6.5 and 9.0. The pH increases during the day as photosynthesis removes free carbon dioxide (decreasing carbon dioxide levels result in decreasing levels of carbonic acid). At night, photosynthesis ceases and carbon dioxide produced by respiration decreases the pH.

7.8.4 Alkalinity and hardness

Alkalinity inhibits or "buffers" wide pH fluctuations. It is a measure of the carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-). Fish will grow over a wide range of alkalinities but values from 120-400 ppm are considered optimum. Alkalinities in natural water sources will vary depending on alkalinities of soils within the watershed. In some instances, where meteoric water is the predominant water supply, eg old hard rock quarries, very low alkalinities must be increased for fish production through the addition of some form of buffers, eg ground limestone.

Water hardness affects fish health because it influences osmoregulation. As a consequence of osmosis, freshwater fish are subject to a continuous influx of water. Against this continuous movement of water into or out of the body, fish have to maintain a constant internal body fluid concentration, ie osmoregulation. The greater the difference in concentration between the fish's body fluids and the surrounding water – the greater the osmotic effect. As hard water is more concentrated than soft, there will be less difference and therefore less water influx and consequently the fish will not have to work so hard at osmoregulation. The fish's health is therefore greatly improved by the presence of $CaCO_3$.

In invertebrate populations, recruitment and population numbers are more than twice as good in water with hardness of 350 mg/l (as $CaCO_3$), compared to invertebrate production at the lowest hardness of 50 mg/l (as $CaCO_3$) (*Lewis and Maki, 1981*). Different species of fish have varied water-hardness requirements, with an optimum hardness range for most pond fish of 100-300 mg/litre $CaCO_3$.

7.8.5 Ammonia

Fish excrete ammonia and a lesser amount of urea into the water as wastes. Two forms of ammonia occur in aquaculture systems, ionised and non-ionised. The latter is extremely toxic to fish whereas the former is not. The non-ionised form is dependent on pH and temperature, and higher pH and temperatures result in a higher percentage of the non-ionised form. In natural waters, such as lakes, ammonia may never reach toxic levels owing to the low densities of fish, but in cage culture, where water circulation is restricted, ammonia build-ups can occur. This can be reduced through proper spacing of cages and regular cleaning of the cage netting.

7.9 Water supply

Groundwater is the preferred supply source for aquaculture as it is usually stable in composition and relatively free of pollutant. Surface water has the disadvantage of being exposed to pollution, and seasonal or long-term changes in water quality. Also, it may contain potential predators, competitors and disease organisms.

7.9.1 Pre-treatment.

Incoming water may require treatment before use. The three main water treatments are: aeration and degassing, settling of suspended solids/precipitation of iron oxides; and the removal of unwanted organisms and debris. Site designs may need to incorporate holding ponds, aeration equipment or structures, and predator filters or similar features. Surface or groundwater sources low in dissolved oxygen can be aerated at the entry point to the farm, in holding ponds, or elsewhere in the water distribution system. The anticipated aeration system must be considered in the pond design, layout, assessment of power requirements, and water supply calculations. Facilities using surface water sources generally filter the debris from incoming water. Removal of debris is essential to prevent damage to pumps, piping, and water distribution systems. Removal of eggs, larvae, or adult organisms, potential predators, and competitors from the incoming water is essential for efficient operations when using surface water sources. In some cases, regulations may require that discharge waters be filtered to prevent the introduction of exotic or controlled species into natural waters. Filters for pond-based systems are generally limited to techniques that mechanically separate liquids from solids.

7.9.2 Water requirements

When planning an aquaculture system, adequate water must be available for initial and future needs (*MSU, 2006*), including any planned expansion of the facility, changes in species cultured, or management intensity. Ponds must be sited and designed to protect them from excessive run-off and flooding. If surface water is to be used, the quality of the intake water at the times that ponds would be filled should be known. The location and physical characteristics of the source body should also be known, especially with regard to fluctuations of quality and quantity with season, rainfall and other factors. Sufficient water for filling ponds must be available at the appropriate times. Variations in water quality and quantity influence the location and siting of intake pumps, water distribution systems, design of the predator control filters, and the need for storage reservoirs, sedimentation basins and other structures.

The annual water requirements of aquaculture ponds depend on soil conditions, environmental factors, species cultured, and the culture and harvest methods. Aeration needs also will have to be considered in planning water flow and exchange, pond design, and power needs on site including emergency aeration if necessary. Stocking densities and biomass are generally given as number or weight per unit of pond area. Carrying capacity and exchange rate requirements are calculated in units of biomass per unit volume of water.

Monthly water budgets will indicate how demand for fill and make-up water will vary seasonally. The amount of water that must be transferred (and pumping cost) to fill ponds will vary monthly, and pumping costs may be a major cost item. Optimum design of a quarry restoration may allow water transfer via gravity through pipes and groundwater seepage.

Earth impoundments are relatively porous, and ponds and canals above the watertable will lose water at rates that will vary with the porosity of the soil. Seepage is difficult to measure directly, and evaporation losses from fish ponds are significant and must be compensated for in determining total water needs. Adequate water depth and, in marine aquaculture, correct salinity levels, must be maintained.

7.10 Pond configuration

Aquaculture facilities may contain a number of ponds performing different functions. Sandy clays to clayey loam soils are best for construction of raised, bunded ponds. Ponds may be for phased grow out, multistage production, holding brood stock/breeding, nurseries, water storage, or other uses (*MSU, 2006*). Their relative positions and orientation depend on the management needs of the production system and their relationship to water supply, drainage system, power supply and road connections. Each pond should have separate drain and fill connections; drain and fill water should not be allowed to mix. These considerations will influence the general arrangement of the farm.

Pond bottoms should slope toward the drain with a minimum horizontal to vertical slope of 1000:1. Preferred slopes range from 1000:3 to 1000:6. A network of shallow ditches draining towards the outlet can facilitate drainage in large ponds that are difficult to grade. Areas less than 1 m deep under normal operating conditions should be avoided.

Ponds can be designed for drain harvest or for harvest by seining or trapping. Drain-harvested ponds may incorporate an internal harvest basin near the pond drain. As the pond drains, fish will be collected in this basin, facilitating harvesting. Other designs incorporate an external harvest basin. Internal harvest basins serve only one pond, while two or more ponds may be connected to one external harvest basin. External harvest basins may be located immediately outside the pond outlet or may be connected to the outlet by drainage canals of varying length. Nets placed within the basin are used to collect the crop. External harvest basins should be supplied with a source of water so the basin may be filled during harvest operations.

Moderate slopes simplify delivery of water and gravity drainage of ponds. Topography around ponds should allow gravity drainage of the pond in any season. Water heights in external ditches and adjacent waterbodies should be lower than the pond drain, even under expected high-water conditions. The main factors affecting pond size are, species cultured, management requirements, and cost considerations. Further details on pond design and aquaculture requirements and costs are provided in ***Appendix 9***.

7.10.1 Escape of non-native species

Escapes from aquaculture and the spread of non-native species can have far reaching and undesirable ecological consequences for animal and plant communities in rivers and lakes. Introduced non-native fish can have direct effects on native species, for example by predation, or can upset the natural balance that operates between species. Non-native species can also introduce and spread diseases and parasites to which our native species may have no resistance. According to DEFRA, Zander and signal crayfish are examples of non-native introductions that have already harmed native species in the UK. Cultivation of non-native crayfish is now banned in many river catchments in Britain as a result.

7.11 Sustainable aquaculture

In recent years the use of antibiotics in aquaculture has reduced and pollution levels have fallen. Sustainable and ‘organic’ production methods have moved up the agenda. Intensive aquaculture will degrade the water quality whereas a more ecological approach will enhance the aquatic environment and provide a far superior product. The Soil Association, an organic standards organisation, supports organic aquaculture, and is developing the standards further – focusing on priorities such as sustainable fish feeds, moving away from potentially polluting veterinary treatments, and farming multiple species of fish, sea-weed and crustaceans to minimise nutrient losses.

7.12 Ecological aquaculture and fisheries management

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Ecological aquaculture within an ecological framework can enhance restoration and conservation of waterbodies as complementary habitats for the surrounding environment, and improve the potential for leisure, tourism, wildlife and associated rural economic development.

7.12.1 The environmental legacy

Both the agriculture and aquaculture industries have been motivated by grant assistance to supply cheap and plentiful food. Ecological distress to the aquatic environment caused by intensive chemical farming and land drainage systems has increased effluent discharges of chemical and sediment into our river catchments, and in many cases fish populations have been reduced.

New EU Water Directives, and more sustainable agricultural practices are making positive changes to redress the environmental decline.

Encouragingly, more enlightened industries, county councils and local environmental groups are making a difference in protecting the environment.

7.12.2 Fish culture (ecological)

The purpose of ecological fish culture is to produce fish in the shortest possible time of the best possible quality under economically acceptable conditions, without degrading the water quality or damaging the local environment (*Hutchinson, 2005*). The fish need to be provided with a suitable habitat to reflect the species being farmed, in as much that their physiological and behavioural needs are adequately met. Their natural food supply is a vital part of this scenario. The production of fish is performed in open ponds, raceways, and water reuse systems. Fish are an integrated part of an ecological aquaculture production project.

7.12.3 Fish culture (intensive)

In intensive fish-farm systems, feed accounts for around 60% of operating costs, and up to 30% of the food may be wasted during feeding causing pollution and reductions in water quality. Also, 30% of the food eaten may not be digested and turned into growth benefit. Intensive systems are known to generate density diseases, and the stress factors that an intensive system faces remain as an obstacle to performance and more importantly, profit.

7.12.4 Ecological aquaculture

Ecological aquaculture is a modern farming system based on a planned ecological design. This framework is intended to enhance and support the restoration of local ecosystems, aquatic and terrestrial and encompasses everything from trees, plants, fish, molluscs, crustaceans, and amphibians to reptiles, and mammals. The inclusion of local terrestrial fauna and flora play a significant role and it is not a monoculture system. The natural food chains developed for aquatic organisms are vital for sustainable aquatic biodiversity.

Bio-diversity requires a fully integrated, supportive and protected eco-system in which living organisms can survive. An ecological approach to aquaculture provides multiple high-value products achieving diverse revenue streams from the same integrated system. The ecological quality of the farmed freshwater resource will ultimately be reflected in the quality of the receiving watercourses and habitats that they supply.

7.12.5 Natural aquatic food

A major determinant of successful ecological aquaculture is the nutritional quality and type of feed, primarily an aquatic organism that the fish most prefer, presented in a natural way. None of this food is ever wasted; if it is not eaten today it will grow bigger and may well be eaten subsequently. Moreover, this food source can be provided freely within an aquatic environment designed for the purpose, and provides the best possible product. Above all, it is free and self-sustaining

The feasibility assessment of a site's suitability for ecological aquaculture should include:

- Production target
- Culture method
- Species cultured (plants, fish and crustacea)
- Requirements for, fry, fingerlings
- Seed stock sources
- Feed requirements
- Nutrient requirement
- Pond management
- Pond design specifications
- Harvesting specifications
- Operations plan
- Revenue streams
- Marketing plan

7.12.6 Markets

Potential markets that may be considered include: sport-fish stocking (gene-pool considerations) and fee-fishing operations; rare and endangered freshwater species conservation; food fish and other specialist sectors, eg grayling, indigenous crayfish; ornamental and aquatic plants; invertebrates for the aquarium industry; scientific research; environmental and conservation training programmes for aquaculture; agri-tourism; and other outlets including educational (schools) training courses.

7.12.7 Substrates

Good substrates for fish production in open ponds are considered to be sand and gravel and hard rock. These medium to coarse substrates are also ideal for aquatic plants. Watercress beds, for example, are based on gravel substrates. On-site resources reduce the development costs, and shipping in large amounts of raw materials is usually too expensive when constructing aquaculture facilities. Crushed rock, sand and gravel may be used as natural filters in maintaining water quality. Gravels are ecologically important as part of the habitat for invertebrate populations. The diversity of the substrate encourages aquatic biodiversity.

7.12.8 Water resources

Lakes with low through flow will benefit some freshwater fish species such as perch, tench and pike whereas high flow lakes are ideal for salmonidae species which require more oxygenated water. Aquatic plants have similar characteristics and are subject to flow rate preferences.

Where flow rates are high, heat-pump technology and micro-hydro electric installations may be a consideration, either of which has the potential to expand the production envelope, eg greenhouses for plant propagation, heating and lighting, temperature control, perhaps also providing supplementary electricity for recycling and aeration systems.

7.12.9 Water flow rates

Increased levels of water flowing through a lake will enhance its natural carrying capacity. The more water that is available will support larger and more productive aquaculture projects.

Open-water resources that have no continuous overflow potential and that are dependant on surface-water aquifers to maintain their levels, are suitable for mixed species fish stocking. The species being stocked will depend on water depth, plant cover, fauna and flora etc.

Each waterbody has a maximum population level of fish that it can naturally sustain. This 'carrying capacity' is determined by the quality of the habitat and the space available to the resident fish. The table below gives the recommended stock densities for different types of still water. These figures allow for growth and reproduction of fish populations and are based on a mixed species fishery. Most water can sustain greater stock densities of mixed species than single species.

Still-water Types	Recommended biomass density
Mature acid/natural upland lake	100 Kg/Ha
Recently created lake/gravel pit	150 Kg/Ha
Mature gravel pit	250 Kg/Ha
Mature lowland estate lake	350 Kg/Ha
Rich farm pond	500 Kg/Ha

Table 7.1: Stocking densities (*Giles et al, 1997*)

The figures in the table improve when flow rates are increased, and even seasonal variation in water availability will make a difference to the biomass. Trout Farms (intensive) require 100,000 gallons per day to achieve one tonne of production; economies of scale would require small fish farms to have access to at least 2 million gal/d.

Aquatic plants generally are not as hungry for water as watercress and will require from 100,000 gal/d for a one acre site. A typical watercress operation will use about 500,000 gal/d for a one acre site. A one acre site will carry about 16 t of crop at any one time, harvested every three to four weeks throughout the growing season (*Vitacress UK, 2006*).

Crawfish production requirements include designed substrates as a refuge, heavy clay soils and 70-100 gal/min of water per surface acre of pond. Smaller crayfish ponds will naturally use less and make harvesting that much easier (*SRAC, 2006*).

7.13 Species selection

All species in the aquatic environment require a suitable habitat for sustainable colonisation. The development of such habitats can be designed and engineered to suit a specific species at a specific site as part of a conservation, restoration and aquaculture program. Aquatic plants, crustacean, fish and all other suitable aquatic organisms fall within the spectrum of ecological aquaculture.

7.13.1 Trout

Due to their tolerance of low temperatures trout would seem preferable for aquaculture in lakes with a high groundwater component. Groundwater temperatures are generally fairly constant, around 10°C, and influence lake temperatures, particularly in flow-through gravel pits. Rainbow, brown and brook trout have been reared in open ponds. Rainbow trout are often cultured because of the availability of fingerlings, established markets, and adaptability.

Brook trout are in fact a member of the Artic Char species left behind by the ice age. They prefer deep cold lakes; their re-introduction in certain suitable habits would be a significant enhancement. Basic culture of all three species is very similar.

There is a need to retain gene-pool identities for indigenous brown trout populations in certain river catchments. Stocking regimes over the past 40 years have diluted this gene-pool marker in many regions. High-quality fisheries would benefit from a more localised stocking regime. Fish reared in ecological fish farms are far more adapted to stocking in rivers, as they have already adapted to normal feeding patterns.

Trout are cold-water species that require well oxygenated waters. The optimum growth temperature for trout is 12.8-18.3°C, but acceptable growth is attained at 10-15°C. At 21.1°C severe heat stress begins, usually followed by death if exposure is prolonged. Below 7.2°C feed conversion drops significantly and therefore, growth. Stocking with a 6" to 8" fingerling trout may result in 1.5-2.0 lb trout by the end of the growing season. Trout in the wild are used to feed availability fluctuations as the seasons change. They build up reserves in the summer months to take them though the winter months. They are capable of surviving on a survival ration without loosing weight or condition.

7.13.2 Grayling

Grayling inhabit the same water as trout and are regionally spread. Their optimum water quality requirements and diet are also similar. The grayling (*Thymallus thymallus*) is a species of the salmon family (Salmonidae) and native to England and Wales. This fish spawns from April till June unlike trout, which spawn in late autumn, November and December. They are Ideal for farming and suitable for restocking in local rivers; adult fish will grow to 5.0 lb or more.

Perch, tench, pike and carp can all be considered for farming; they are good eating fish with niche market potential. Fishing is also a consideration.

7.13.3 Freshwater crayfish

Britain's only indigenous species of freshwater crayfish is the white-claw crayfish (*Austropotomobius pallipes*). This species is suitable for ecological aquaculture under specified conditions and in need of conservation. However, the Environment Agency should be consulted if considering farming of *A. pallipes* as there may be concerns about the impact of any escapes of farmed stock on indigenous populations. Signal crayfish and other non-indigenous crayfish species should not be considered and their cultivation is now banned in many river catchments because of the impact of escapees on the native species.

7.13.4 Stocking

The availability of fingerlings from conventional fish farms makes fish farming much easier for those who do not have the capability of fish hatcheries, which require large volumes of fresh clean water. Stocking rates are controlled to match the available natural food supplies.

7.14 Harvesting

Aquaculture facilities in specifically designed open ponds allow ease of harvesting. Plant harvesting and cropping of aquatic plants can take place throughout the growing season providing continual production from the aquaculture facility. Fish can be harvested to suit market demands.

7.14.1 Pond Culture

Ponds are designed in such a way as to provide for all the needs of the fish species being farmed. They are integrated to provide a food chain for the fish that is in constant production. A series of in-line ponds is used as though it were on a crop rotation system to give continual fish supplies to suit market requirements. These ponds provide aquatic plants and invertebrates at the same time as fish. The ponds are designed to provide a sustainable aquatic food source for continuous fish production.

7.14.2 Characteristics of the ideal pond

- Surface area minimum of 300 m^2
- Surface area for aquatic planting ponds 100-300 m^2
- Fish growing pond water depth of 1.5-2.5 m
- Plant growing pond to reflect plant species requirement

- Constant water level
- Water-flow rates seasonally adjusted to maintain optimum temperature and high oxygen saturation
- No direct access to pond for livestock
- Groundwater supported with no run-off from surrounding areas.
- Controlled run-off to prevent contamination and silting
- No aquatic weeds or alien plant species
- Bio-security rigorously maintained.

Aquatic plants

Aquatic plants are of vital ecological importance to freshwater habitat and can be: *submerged*, and anchored to the bottom; *rooted but floating* – similar to submerged plants but with leaves that float on the surface water (eg, water lilies); *free floating*, with roots that hang down into the water (eg, duckweed); *marginal*, having no leaves or stems under the water – they are important pond oxygen generators and their presence forms a significant link of the food web.

The commercial exploitation of these plants provides a wide range of products from edible, ornamental through to conservation and restoration. Details of costs and revenue streams are provided in ***Appendix 9***.