8. Conclusions

This section provides some overall conclusions from each section of this review.

8.1 ALGAE

From the studies conducted to date it may be concluded that:

- Only about 10-15 percent of dietary protein requirement can be met by algae in test diets without compromising growth and food utilization. There is a progressive decrease in fish performance when dietary incorporation of algal meal rises above 15-20 percent. Total replacement of fishmeal by algal meal generally shows very poor growth responses. Apart from commonly observed impaired growth, the use of algae as the sole source of protein in fish feed can also result in malformation.
- The poor performance of fish fed diets containing higher inclusion levels of algae may be attributable to high levels of carbohydrate, of which only a small fraction consists of mono- and di-saccharides. A preponderance of complex and structural carbohydrates may cause low digestibility.
- The collection, drying and pelletization of algae require considerable time and effort and algal cultivation is costly. Cost-benefit analysis is needed before any definite conclusions on the future application of algae as fish feed can be drawn. The use of algae as fish feed additives may be limited to the commercial production of high value fish.

8.2 *AZOLLA*

The following conclusions can be drawn:

- Laboratory feeding trials on the use of fresh or dried *Azolla* as a complete diet for fish show inconclusive results. Adequate consideration should be given to the preference of each target fish to particular species of *Azolla* before they are used as feed.
- Similarly fresh *Azolla* as a complete diet for high-density cage culture may not be economically viable. However, *Azolla* may be useful in low density and low input cage culture.
- As fish food in *Azolla*-fish pond culture, *Azolla* contributes directly to weight gain of macrophytophagous fish. At the same time, increased production of fish faeces from *Azolla* fodder may be directly consumed by bottom dwellers in addition to being used as an organic (nitrogenous) fertilizer to increase overall pond productivity. However, it should be understood that although the contribution of *Azolla* to aquaculture is interesting, it alone could not ensure high productivity. It can be a useful supplement to natural feed in low-input aquaculture.
- The high rates of decomposition of *Azolla* make it a suitable substrate for enriching the detrital food chain or for microbial processing such as composting, prior to application in ponds.
- The results of several studies indicate that rice-fish-*Azolla* integration increased the yield of both rice and fish compared to rice-fish culture alone. The likely reasons for the increase in rice yield are improved soil fertility resulting from the increased production of fish faeces from *Azolla* fodder; reduced weed growth; and a decreased incidence of insects and pests. Fish yields increase through the direct consumption of *Azolla*.

The advantages of rice-fish-*Azolla* integration may be summarized as follows:

- o increase in fish and rice yields;
- o decrease in need for inorganic fertilizers and pesticides;
- o decrease in incidence of pests and weeds; and
- o improvement of soil fertility.

However, the adoption of rice-fish-*Azolla* integration depends on the attitude and capacity of the farmers, the capacity of support services, including the *Azolla* inoculum availability, and the overall economic feasibility of the system.

8.3 DUCKWEEDS

Duckweeds have received much attention because of their potential to remove mineral contaminants from wastewater. Definitive information has been published on the production and chemical composition of these plants, and their environmental requirements have been clearly determined. Information on the cultivation techniques of many duckweed species is also available. Due to their rapid growth, attractive nutritional properties and relative ease of production, duckweeds have generated renewed interest among fish nutritionists on their use as possible alternative sources of fish feed. It can be concluded that:

- The results of laboratory and field studies and on-farm utilization of these macrophytes clearly indicate that duckweed can provide a complete feed package for carp/tilapia polyculture.
- Successful use of duckweed as fish feed will ultimately depend on the appropriate integration of duckweed production and aquaculture. A preliminary model on duckweed-based aquaculture has been developed and tested under experimental and farming conditions in Bangladesh. However, there is clearly room for fine-tuning this model. Further research towards optimization of the species mix and quantification of feed application for sustainable yield may be necessary.
- The production costs of duckweed, whether as a by-product of wastewater treatment or produced through farming, will ultimately dictate the success of duckweed-based aquaculture. It must be emphasized that sufficient quantities of wastewater may not be available throughout the year to support duckweed production. Therefore, farmers should have the option of using both wastewaters and fertilizers (both chemical and organic) to produce duckweed. The market value of potential fertilizers will eventually determine the economic feasibility of duckweed cultivation. In many countries, including Bangladesh, duckweed cannot be grown all year round because water bodies dry up in the dry season. The availability of fish feed/fertilizer during the dry season needs also to be addressed in a duckweed-based aquaculture model.

8.4 WATER HYACINTHS

A large number of experimental studies have been carried out on the use of fresh or processed water hyacinths as fish feed. In general, water hyacinths have been proven to be moderately successful as a fish feed, although the results are variable. Most of the laboratory studies carried out on the use of water hyacinth as fish feed concentrated on the use of dried meal in pelleted feeds. The results of these studies indicate that water hyacinth leaf meal cannot be used as a fishmeal replacer without compromising growth and food utilization. It has also been noted that, like all other plant ingredients or non-conventional feedstuffs, high dietary inclusion levels (75 percent or above) of water hyacinth meal in complete diets is not feasible, as the minimum dietary protein requirement for most fish species is above 30 percent. Dried water hyacinth leaf meal contains 20-23 percent and whole meal 13-16 percent crude protein (DM). It also must be emphasized that complete diets are not generally used in semi-intensive aquaculture practices in most of the developing countries of the world. Nevertheless, it is clear from the results of many laboratory studies that dried water hyacinth meal has been used successfully as an alternative to rice bran and/or the rice bran-oil cake mixture that is traditionally used as fish feed in many developing countries.

In many of the studies, diets with high water hyacinth inclusion levels performed poorly when compared to fishmeal-based control diets. It must, however, be pointed out that it was only the direct nutritional benefit of water hyacinth that was assessed in these controlled aquarium studies. In natural pond systems, the indirect nutritional value resulting from the production of natural food enhanced by the fertilization of uneaten feed and fish faeces should not be overlooked.

Although few studies report the successful use of fresh water hyacinth as fish feed, it is apparent that the use of processed water hyacinth holds much better promise. However, the question to be answered is: what processing method would be the most viable alternative? If a comparison between water hyacinth processed by different techniques is to be made, we must first consider if the use of dried water hyacinth meal in pelleted diets is feasible under semi-intensive aquaculture in tropical countries. From the experience of the first author of this document, the milling of dried of water hyacinth is labour intensive and pelletization would be even more complicated. Will fish feed manufacturers come forward to use water hyacinth meal to make the feeds cheaper? It is unlikely. Therefore, it is conjectured that the use of dried water hyacinth meal in pelleted feed is not a viable option for tropical small-scale semi-intensive aquaculture. Similarly, the labour-intensive process of drying and milling of water hyacinth may also discourage farmers to use this ingredient in farm-made aquafeed.

On the other hand, water hyacinth processed by composting or fermentation provides similar or higher nutritional benefit but is much less labour intensive. The preparation of water hyacinth paste requires a high-speed blender and the provision of electricity, however, and may therefore be less attractive for smallholder aquaculture. Thus, under the current state of knowledge, it is concluded that composted or fermented water hyacinth used singly or in combination with other traditional dietary ingredients holds promise as a supplemental feed for use in semi-intensive fish culture systems where natural food, produced by fertilization, provides a substantial part of nutrition for fish. The level of its inclusion, when used in combination with other ingredients, will vary and will depend upon its availability, processing costs, the fish species in question and the availability of other ingredients in the locality.

It can therefore be concluded that:

- The use of fresh water hyacinth as an aquafeed is unlikely to be successful.
- The use of dried water hyacinth, though having nutritional value, is unlikely to become viable for use in small-scale aquaculture.
- The use of composted or fermented water hyacinth, however, does hold promise as a dietary ingredient in aquafeeds for small-scale aquaculture.

8.5 OTHER FLOATING MACROPHYTES

Floating macrophytes such as water spinach, water fern, and water lettuce are reasonably rich in protein. However, apart from some general observations (a) in Bangladesh that fresh water spinach is a preferred macrophyte for grass carp and that fresh water lettuce is sometimes given to grass carp and Java barb and (b) that mashed and/ or fermented fresh water lettuce is used in China for feeding carp fingerlings, no detailed investigations have been carried out on any other qualitative aspects of their use.

A limited number of research studies on the use of these other floating macrophytes in pelleted diets for grass carp, common carp and rohu have been carried out. The results generally indicated that higher inclusion rates were not able to produce good growth if the feeds were the only source of nutrition in controlled experimental conditions.

However, when used in a natural or semi-natural rearing system, where plankton and benthos formed a component of the consumption of the fish, diets containing up to 50 percent water lettuce and water fern produced reasonably good growth for grass carp and common carp. These studies also apparently indicate that the FCRs of these macrophytes are reasonably good, varying between 2.0-2.5, when used they are as a dried meal at maximum inclusion level of 50 percent in combination with other proven dietary ingredients/protein sources.

The information currently available is insufficient to draw any definite general conclusions on the suitability of these floating macrophytes for fish feeding in small-scale aquaculture.

8.6 SUBMERGED MACROPHYTES

A large number of research and field studies have been carried out on the utilization of various submerged aquatic macrophytes. These have included monitoring the growth performance, food conversion and digestibility of fish fed different macrophytes; the determination of their nutritional composition; and the consumption and preference of various macrophytes by herbivorous fish. Most of these studies, however, were carried out with grass carp and to a lesser extent with tilapia. The macrophyte species evaluated so far have been oxygen weed, hornwort, pondweeds, *Chara*, water velvet and water milfoil.

Submerged macrophytes were fed to fish either in fresh form or as dried meal in pelleted diets. Reports on other processing techniques designed to improve their nutritional qualities are not available. The number of studies have been conducted to evaluate dried submerged macrophytes as fish feed are extremely limited; so far only dried hornwort meal has been fed to Nile tilapia in a pelleted diet. The results of the above feeding trials were inclusive. Fish reared on fresh submerged macrophytes as the only diet in a clear water rearing system generally produced lower growth responses than fish reared in cement cisterns or ponds where plankton and benthos formed a substantial part of the nutrition of the fish. Submerged aquatic macrophytes usually contain about 13-16 percent crude protein (DM) and were therefore unable to support good growth if used as the only source of dietary protein. However, when submerged macrophytes were fed to fish in natural or semi-natural rearing system, they supported moderate to good growth with fresh weight food conversion ratios varying from 60-125 percent. Most of the fresh submerged macrophytes were well digested by fish, dry matter and protein digestibility being 40-60 percent and 60-80 percent, respectively.

Consumption rates for different macrophytes varied between different fish species. Usually, lower consumption rates were recorded for fish reared in a clear water indoor rearing system. It is also emphasized that the palatability of the same macrophyte species may vary considerably, depending on the environmental conditions under which they grow. Consequently, consumption rates may differ for the same macrophytes for the same fish species owing to variations in environmental conditions, as well as fish size. A wide range of consumption rates of hornwort and oxygen weed were reported for grass carp ranging from 25-200 percent, depending on the fish size. Therefore, to avoid discrepancy, *ad libitum* feeding may preferably be practised for feeding fresh submerged macrophytes.

It is difficult to generalize the preference of submerged macrophytes by different macrophytophagous fish species, because research studies or field observations were conducted under different environmental conditions and in different parts of the world using fish of different age groups. However, it is apparent that grass carp generally prefer fresh soft submerged macrophytes, preferring oxygen weed and *Najas* over *Potamogeton*, *Ceratophyllum*, *Elodea* and *Myriophyllum*. Tender leaves of eelgrass (*Vallisneria*) are also eaten by grass carp. Tilapia (*T. zillii*) feed on *Najas*, *Chara*, *Potamogeton*, *Elodea* and *Myriophyllum*, although it has shown to have preference for *Najas* and *Chara* over other macrophytes. The submerged macrophyte preference of Java barb has not been documented; it generally feeds on *Hydrilla*, *Ceratophyllum* and *Potamogeton*, although it is likely that it will feed other soft fresh macrophytes as well.

8.7 EMERGENT MACROPHYTES

The limited number of observations reported so far is inadequate to draw any conclusions on the use of emergent macrophytes as fish feed; further studies are needed.