BIOLOGICAL MEANS OF INCREASING PRODUCTIVITY IN PONDS

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Many techniques must be employed by the fish culturist to obtain highest possible yields of fish from ponds. Unproductive natural waters and soils may be improved by the chemical means of liming and fertilization. Production can be further increased by supplemental feeding, and to the highest plateau by feeding in flowing waters to dispose of wastes.

At all levels of fishculture, stock manipulation and other biological means of increasing productivity are of greatest importance in obtaining maximum efficiency in use of the water and pond space. The various techniques found to be of importance in obtaining high productivity at this Station include use of efficient species, species combinations, disappearing species, rates of stocking, delayed stocking, control of reproduction, control of wastes, and use of cover.

1 USE OF EFFICIENT PONDFISH

Under this heading come three principal subheadings - species that are efficient because of their feeding habits, because of selective breeding or because of freedom from parasites and disease.

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1.1 Efficient species of pondfishes

It is well known in biology that highest production may be obtained by use of those species with the shortest food chains. In general this indicates that highest production may be obtained by use of plant-feeding species of fish. Results from a wide variety of species indicate that in general this is true. Maximum production obtained at this Station with species of various feeding habits in fertilized ponds were as follows:

Species	Feeding habit	Maximum production kg/ha
Laregmouth bass[1]	piscivorous	196
Channel catfish[2]	insectivorous	370
Bluegill[3]	insectivorous	560
Java tilapie[4]	plankton-feeder	1612

[1] Micropterus salmoides
[2] Ictalurus punctatus
[3] Lepomis macrochirus
[4] Tilapia mossambica

However, it should be pointed out that the Java tilapia is a plankton-feeder and not purely a plant-feeder. In fact, work by Tay (Prowse; 1961) has indicated that several species of phytoplankton ingested by this tilapia are apparently not digested. It is probably true that no species of fish is entirely herbivorous.

The mere fact that a species is at least in part herbivorous does not indicate that it will give highest production under various systems of management. The Congo tilapia (Tilapia melanopleura) feeds extensively upon submersed aquatic plants. However, when placed in an environment (fertilized water) where the plants are microscopic, it gives relatively low production because its gill rakers are too widely spaced to enable it to strain and utilize the phytoplankton. It does appear to hold true that highest production is usually obtained *with* plankton-feeding species. Where supplemental feeding was used, maximum production with Congo tilapia was 2240 kg per ha and with Java tilapia was 6048.

Again, it must be emphasized that a more efficient species at one level of management may not be the more efficient at another level. For example, the bluegill and the channel catfish are both principally insectivorous. In fertilized ponds, the bluegill was the more efficient, yielding 560 kg per ha as compared with 370 kg for the channel catfish. When placed in ponds receiving supplemental feeding, however, the order was reversed, with the channel catfish yielding up to 2,688 kg per ha and the bluegill 896. It appeared probable that the smaller mouth-size of the bluegill made it the more efficient in harvesting natural fish-food organisms, but this was no advantage when supplemental feed was supplied in the form of pellets.

These results emphasize that each species must be tested experimentally for efficiency at different levels of pondculture - in unfertilized ponds, in ponds receiving fertilization, and those receiving feeding. It is very important that this testing be done with the principal species present in each country to identify the most efficient fishes. There are at present relatively few species of fishes known to be suitable for pond culture, although many species in the great river systems of each continent would appear suitable. It is important to have a number of efficient yet different species to select from for use in ecologically different waters and for different human preferences.

1.2 Selection for efficiency

Most fish used in pondculture today have not been selectively bred for any purpose, let alone for efficiency. The common carp *Cyprinus carpio* have been selectively bred for shape, for extent of coverage by scales, and for color. Most other species used may be considered to be unselected strains of wild fish, although the fishculturist probably selects each year the larger individuals for spawning.

Prather (1951) selectively bred largemouth bass for efficiency of food conversion at this Station. Individual bass in circular pools were fed weighed amounts of small fish twice weekly for periods of 5 to 12 weeks, and efficiency of gain was determined by dividing weight of fish consumed by gain in weight. The most efficient individuals were spawned and the more rapid-growing of these progeny tested as above for efficiency. This was repeated during a 6-year period. Conversion ranged from 1.5 to 24.2 the first year, and the mean conversions were as follows:

Year	Mean Conversion	Standard deviation
1941	7.3	1.20
1942	3.1	0.28
1943	3.9	0.16
1946	5.1	0.50
1947	2.1	0.15
1948	3.4	0.26

Apparently after 1 year, the most inefficient individuals were eliminated and little change was produced subsequently. The work was discontinued because it was evident that little more could be done without an intensive fish breeding and selection program.

The changes that have occurred in agricultural animals through selection and breeding suggest that this should be a fertile field for improvement of fish stocks.

1.3 Use of parasite - and disease-free fingerlings for stocking

All fishculturists have experienced loss of all or part of a fish crop from parasites and/or disease. The most effective way to reduce or prevent such losses in ponds is to stock only fingerlings that are relatively free of parasites and disease. Clean fingerlings can be provided principally by two procedures. The first is the use of brood fish examined and treated where necessary to rid of parasites and/or disease, followed by early separation of the eggs or young from the parents, and their culture in uncontaminated waters. The second is the chemical treatment of all fingerlings for parasite and disease control before stocking them into production ponds.

At this Station, the earliest experiments with channel catfish were conducted with fingerlings obtained from a river and no treatments were given to free them of parasites. During a 3-year test period, each year 50 percent of all catfish died and it was concluded that this species was not suitable for culture in ponds. However, in later years channel catfish fingerlings were treated with acriflavin, formalin and potassium permanganate to rid them of external parasites and disease organisms, followed by treatment with di-n-butyl tin oxide to rid them of intestinal parasites before they were stocked into production ponds. When this was done, survivals ranged from 95 to 98 percent during their growth to marketable size (Swingle, 1958).

Allison (1957) has developed pond treatments that can be applied to control the protozoan ectoparasites on fish when epizootics develop in the production ponds. External parasites of catfishes have caused poor feed conversions or even extensive fish kills in ponds.

2 SPECIES COMBINATIONS

While the highest production of a single species may be obtained by raising a plankton-feeding fish, highest total fish production per hectare can only be obtained by using a combination of species of different feeding habits.

One of the most important problems in fishculture is to determine just what combinations of species are the most efficient in utilizing available fish feeds. Again, this can be determined only by testing in experimental ponds although a certain amount of preselection is possible.

The traditional fishcultures of China and India used species combinations, but these combinations resulted because of occurrence of these species in rivers from which the fish eggs and fry were obtained. Whether these combinations were the most efficient available in each country was not measured.

2.1 Combinations of fishes of different feeding habits

2.1.1 Channel catfish and Java tilapia

The channel catfish is insectivorous and utilizes efficiently pelleted fish feeds containing vegetable and fish meals. It was postulated that this species with Java tilapia, a plankton feeder, should make an efficient combination. Where the pond received supplemental feeding, the results per hectare were as follows in a 191-day experiment:

Species Stocked	Production kg	Catfish Feed Conversion
1. Channel catfish (4400)	1400.0	1.7
2. Channel catfish (4400) plus Java tilapia (1250)	1568 266	1.7

The combination of the two species yielded 1834 kg compared with 1400 from the channel catfish alone. There was no difference in feed conversion, assuming all feed was utilized by catfish. The tilapia apparently fed on plankton, wastes, and other fish feeds not utilized by channel catfish.

Both the Java and Nile tilapia (T. aurea) have been used repeatedly with channel catfish receiving supplemental feeding. Addition up to 2,500 tilapia with 7,500 channel catfish per ha has not measureably affected growth of catfish or feed conversion where it is assumed that catfish consumed all the feed added.

2.1.2 Common carp[1] and bigmouth buffalofish[2]

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[1] Cyprinus carpio [2] Ictiobus cyprinella

The common carp stocked at rates over 240 per ha into fertilized ponds often muddy the water during their feeding activities to such an extent as to interfere with phytoplankton growth. The buffalofish is an omnivorous feeder, which does not burrow in the pond bottom. The results per ha of a 10-month test were as follows when the pond received 10 applications of 8-8-2 fertilizer:

	Stocking	Production, kg	
1.	2500 common carp		313.6
2.	2500 buffalofish		896.0
3.	2250 buffalofish	745.0	
	plus 250 common carp	179.2	925.1

Here the combination of buffalofish-carp gave slightly higher yield than buffalofish alone, and much higher than carp alone;also the pond water remained translucent enough for good plankton production.

2.1.3 Fish and freshwater mussel

Other animals may be combined with fish in stocking to obtain higher total protein production. An edible soft-shelled mussel, *Lampsilis claibornensis*, was introduced into bluegill-largemouth bass ponds to determine if it could be successfully cultured along with fish. This mussel was used fried or in soups and considered to be a desirable species for this purpose.

Production of mussels (including shells) per ha in a 12-month period was as follows:

Unfertilized - - - - - - - 58.2 kg

Fertilized - - - - - - - - 1010.2 kg

The mussel was stocked into an 0.8-ha pond along with a standard stocking of per ha of 2500 bluegills, 1250 redear sunfish, and 250 largemouth bass. Mussels became very abundant over the pond bottom and were harvested for a period of 5 years along with the fish. At the end of the 6th year, the pond was drained with the following recovery per ha.

Total fish	464.4 kg
Total mussel meats	399.6 "

The total weight of mussel plus shells was 1270.8 kg per ha, of which the shucked weight of meats was 31.5 percent. In addition to the fish recovered on draining, an additional 139.7 kg per ha had been removed by fishing. The average standing crop of fish where no mussels were present was 316.6 kg per ha (Swingle, 1961). In this case the presence of mussels appeared to increase fish production.

It is postulated that the apparent increase was real and probably caused by cleaner water resulting from the filtering action of the 49,440 mussels per ha distributed over the pond bottom. Their combined effect in filtering out the detritus and organisms upon which they feed should have helped to reduce the waste materials that are limiting factor in fish production. The effectiveness of these and other animals in maintaining cleaner pond waters should be a rewarding field of research.

It is noteworthy that the difference in production obtained from Congo and Java tilapia receiving daily feeding, as mentioned in Section 1.1, appeared to depend upon their relative ability to maintain clean water. The Java tilapia feed upon artificial feeds, decaying organic matter, their own feces and upon plankton. Consequently, they can be fed at a high daily rate because the pond bottom and waters are kept clean.

2.2 Combination with fishes that disappear from the combination

A problem in maximum utilization of all food in a pond is that when fingerling fish are stocked,and their combined weight is small, much food currently available is not utilized. Food is lost by emergence of adult insects, by decay and incorporation into the bottom muds, by denitrification, and other processes. A small amount is recycled into fish foods at a later date, but not in amounts to make up for inability of fish to utilize it during this early period.

One solution would be to stock more fingerlings, but if too many are stocked, none may reach a desirable size. Another solution is to stock the desired species in combination with another species that reproduces very early, is efficient in harvesting the otherwise wasted fish-food organisms, and that remains small enough to be consumed when the principal species becomes larger and food per individual is more scarce.

2.2.1 Bluegills plus Gambusia

In a 7-month experiment in fertilized ponds using 3,900 bluegill plus 1623 Gambusia affinis per hectare, average production per ha was:

Bluegill	186.4 kg
Bluegill plus Gambusia	349.4 "

The 2-inch bluegills plus Gambusia adults were stocked May 2. The Gambusia began producing young on June 1, and became very abundant by late July, when their numbers began declining. When the pond was drained November 14, practically all topminnows had been consumed by bluegills.

2.2.2 Bluegill-bass plus fathead minnows

The fathead minnow (Pimephales promelas) appeared more desirable for this purpose than Gambusia since the former began spawning in March and the latter in June. Average production per ha for a 12-month period *in* fertilized ponds stocked with 3750 bluegill fingerlings (5cm), 134 largemouth bass (2cm), and with or without fathead minnows (1000 and 2500) were as follows:

Bluegill-bass	282.6 kg
Bluegill-bass-fatheads	470.6 "

The fathead minnows and bluegill fingerlings were stocked in December, with the small fingerlings bass added in May. Fatheads spawned in March and became exceedingly abundant. The numbers began to decline early in July, from predation upon them by both the bass and the bluegills. Few remained when ponds were drained in October-December. Their presence harvested enough extra fish foods to increase average production by approximately 66 percent.

2.2.3 Tilapia-bass plus fathead minnows

Tilapias at this Station are carried overwinter in warm water and stocked into ponds in April. Largemouth bass fingerlings are added in May. One year a pond was stocked with 2,500 Nile, 2500 Java tilapias plus 500 largemouth bass per ha. The next year it received the same stocking of Nile, Java tilapias and bass, plus 2500 Congo tilapia and fathead minnows. The fathead minnows were in the pond in January of the same year, being escapees from draining a fathead pond above. They were used to harvest fish-food organism produced in the pond prior to stocking the tilapias. Since tilapias were primarily plankton feeders, the fatheads plus any young tilapias hatched in the pond were principally feed for the young bass. Each year the fish received supplemental feeding from May to November, when the pond was drained. The results per ha were as follows:

Experiment	Production, kg Tilapias	Production, kg Bass
Without fathead minnows	2118.0	21.2
With	2182.7	108.6

The addition of fathead minnows resulted in an increase of 87 kg largemouth bass per ha, without reducing the production of tilapias.

2.2.4 Channel catfish-bass plus fathead minnows

Originally, 2,500 fathead minnows were added with 7,500 channel catfish per ha in ponds receiving supplemental feeding with the expectation that they would be eaten by catfish. This did not occur; therefore, they were utilized by stocking 125 largemouth bass per ha. In a period of 7 years this had added an average of approximately 45 kg per ha of bass to each crop of catfish without interference with the growth or production of the latter.

This method of making more efficient use of unused fish feeds in ponds would appear worthy of more extensive testing and use.

3 RATES OF STOCKING

Rates of stocking of fish are extremely important at all levels of fishculture. If too few are stocked, the results are large fish and low production. If too many are stocked, the result may be high production, with fish of undesirable size.

3.1 In unfertilized and fertilized ponds

The problem of how many fish to stock is most troublesome in unfertilized and in fertilized ponds. If the number of fingerling carps is stocked so that 200 g carp will be produced by the end of the growing period, then fish foods produced by the pond are being wasted during a considerable portion of this time. This is true because the carp normally eats not more than 5 to 8 percent of its own weight daily, and when small, little feed is required. In natural populations, this problem is solved by spawning; then thousands of young fishes are available for harvest of the fish-food organisms. As fish grow larger and require more feed, this problem is solved by reduction in small fishes by predation. This is a similar solution to that presented in section 2.2 by use of the fathead minnows as a disappearing species.

If sufficient carp are stocked to consume current fish-food production, then there will be insufficient food to raise them to a desirable size.

This was illustrated by experiments at this Station on rates of stocking Java tilapias in fertilized ponds during a 4-month period (Swingle, 1960). The results per ha were:

Number stocked	Fish production, kg Total	Harvestable[1]	Percentage harvestable
5,000	316.2	309.1	97.5
10,000	403.2	203.4	50.4

[1] Tilapias averaging 45 g or more.

In experiments with various rates of stocking bigmouth buffalofish, results from a 6-month growing period in fertilized ponds (Swingle, 1957b) were per ha:

Number stocked	Average weight stocked, g	Production kg	Average size
300	22.7	151.6	636
600	22.7	273.5	603
1080	22.7	656.5	590

In this case, since the final sizes were approximately equal the maximum rate of stocking probably could have been somewhat higher. The two lower rates of stocking (300 and 600) required another 7 month of growing season to reach approximately the same standing crop as was achieved in 6 months at the highest rate of stocking. It is evident that in determining rates of stocking for various levels of management, a range in rates of stocking must be tested to enable selection of the maximum rate producing desirable-sized fish in a minimum time period.

3.2 In ponds with feeding

Supplemental feeding enables the fishculturist to use natural fish-food organisms more efficiently. In a direct way he can do what nature does in natural populations in a round-about way. In section 3.1 it was pointed out that in natural populations small fishes hatching in the spring harvested economically the fish-food organisms and as some became larger, a larger share of the food was made available to them by reduction in the numbers of fish. This reduction is accomplished by predation, often ably assisted by various other causes of "natural mortality". With supplemental feeding, the fishculturist can stock larger numbers of fish per ha to more fully utilize natural fish-food organisms. As fish grow larger, he can supply increasing amounts of supplemental feed to bring them to harvestable size.

3.2.1 Experiments with catfishes

With daily supplemental feeding, large numbers of fingerling fish, or larger fish, must be stocked if high production is to be achieved. In early experiments at this Station, the channel catfish was stocked at 560 fish per ha and given supplemental feeding. The species was discarded as of little value for commercial use because production per ha was only 302 kg. Later work with the speckled brown bullhead (*Ictalurus nebulosus marmoratus*) demonstrated the important relationship between stocking rates and production with feeding (Swingle, 1957a). Results per ha are given below for a 1-year period during which fish received daily supplemental feed while water temperatures remained above 16° C:

Rate stocked	Fish produced, kg
2,500	631.7
5,000	840.1
7,500	1,011.8
15,000	1,387.0

With this information, it was immediately suspected that low production obtained with channel catfish and feeding was the result of the low rate of stocking. Testing with this species was thenzesumed at various rates of stocking and with supplemental feeding. The channel catfish was then found to be a high producer and most economical in food conversion, directly contrary to the former conclusion. Results for an 8.5-month experiment per ha were as follows (Swingle, 1958):

Rate stocked	Kg fish produred
2,500	1,076.7
5,000	1,709.7
7,500	2,646.6

3.2.2 Experiments with tilapias

Similar results were obtained in experiments with both the Java and Nile tilapias (Swingle, 1960). Fingerlings were stocked at various rates per ha in ponds that had been fertilized. In addition, the fish were fed a supplemental pelleted fish feed. Production per ha in a period from 111 to 123 days was:

Species	Number stocked	Production kg	A_T	"S" Conversion
Java tilapia	10,000	563.6	98.7	2.57
	20,000	1,601.7	99.7	1.67
	25,000	1,999.9	88.9	1.10
	50,000	3,299.1	67.7	1.10
Nile tilapia	20,000	1,546.7	98.5	1.80
"	40,000	2,665.5	91.9	1.35

The fishculturist still has several factors that limit the number of fish he can grow to harvestable size. He must stay within the feeding rates that give economical conversion,and the maximum amount of feed he can add daily is limited by the type of feed and by the "sewage disposal" system in his pond. With flowing water to remove wastes and and to supply oxygen, safe feeding rates rise to a high level. Without flowing water to remove wastes, he is limited by the capacity of his pond system to minimize and to destroy wastes. The Java and Nile tilàpias are among the most efficient of fishes in minimizing wastes; consequently they can be fed at high rates to obtain high production. However, even here a limit exists beyond which it is not safe to feed. Although the stocking per ha of 50,000 fingerling Java tilapias gave highest production, it was not possible to increase feeding to where more than 67.7 percent (AT) of the weight was fish of harvestable size (i.e. weighing 45 g or more). Combinations of species giving more efficient disposal of wastes in impounded water or other methods of waste destruction are needed to attain higher levels of production.

4 CONTROL OF REPRODUCTION

While control of reproduction would probably decrease weight of the entire standing crop, it makes possible production of fish of desirable size. This is especially important with the use of supplemental feeding where the feed must be utilized to produce marketable fish. Various methods of population control have been used in fisheries.

4.1 Change of environment

This method is widely used in pondfish culture. Milkfish (Chanos chanos), which spawn only in the oceans, are cultured in brackish water ponds along the Asiatic Coast. Chinese and Indian pondcultures used carps that spawned in flooded rivers but would not spawn in ponds. Channel catfish and buffalofish used at this Station also were river fishes and seldom spawned in production ponds. Lack of ability to spawn in the pond environment made many of these fish excellent species for pondculture.

4.2 Repressive factor

Both common carp and buffalofish normally failed to spawn in waters in which they had been held for several months prior to the spawning period, but spawned readily when transferred to fresh water. This effect was attributed to the repressive effect of excretions from these species (Swingle, 1956). A method of culture for speckled bullhead was devised by stocking fingerlings at different rates to determine the rate at which there was no or little spawning while the fish were still not too crowded for satisfactory growth. For this species the stocking rate of 7,500 per ha accomplished this purpose (Swingle, 1957a).

Nile tilapia fingerlings stocked at 20,000 or more per ha grew satisfactorily with supplemental feeding, but failed to reproduce (Swingle, 1960). However, Java tilapias still reproduced at stocking rates of 50,000 per ha.

4.3 Use of fish too young to spawn

A culture method was devised for the brown bullhead by stocking 2 to 5 cm fingerlings in June, feeding to obtain rapid growth, followed by harvest the next May before reproduction could occur (Swingle, 1957a).

A similar culture was used for Java and Nile tilapias by stocking in May and harvesting at 15 to 20 cm total length the following October (Swingle, 1960). Light spawning occasionally occurred with the Java tilapia, but insufficient young were produced before draining to interfere with production of larger fish.

These cultures have the disadvantage of producing relatively small harvestable fish (50 to 200 g), and harvest must be in a fixed period just before spawning. This prevents the fish culturist from holding his crop to obtain higher prices when the market is low.

4.4 Use of piscivorous fishes

Piscivorous fishes are used in a number of cultures to reduce the numbers of young so that the older fish may reach a desirable size. In European carp culture, the pike Esox lucius or pike-perch Lucioperca sandra was used to eliminate small carp that resulted from unexpected spawning and wild fishes that entered the pond (Schaeperclaus, 1933).

At this Station largemouth bass have been used with catfishes, tilapias, carp, and other species for a similar purpose and also to increase overall production of desirable species (Swingle, 1957a,b) 1958; 1960).

5 ADDITIONAL SURFACE FOR FISH-FOOD ORGANISMS

In many fertilized ponds, almost the entire bottom contains individual fish-food organisms in close proximity. It appeared, therefore, that "floor" space was a limiting factor and that the addition of various materials would greatly increase surface for attachment and might increase production.

5.1 Freshwater shrimp and bluegills

Experiments were conducted with freshwater shrimp Palaemonetes kadiakensis and the bluegill in ponds with and without cover in the form of brush piles or a mixture of aquatic plants Chara, Najas, and Cabomba. The stocking May 2 per hectare was 3750 bluegills weighing 53.7 kg and/or 65,000 shrimp weighing. 21.7 kg; ponds were drained in November. Fertilized ponds received 10 applications of 7-8-2 fertilizer at the rate of 112 kg per ha. The results per ha were as follows:

Unfertilized ponds	Production, kg Shrimp	Bluegill
Shrimp	45.4	
Shrimp with plants	236.7	
Bluegill		112.0
Bluegill plus plants		140.7
Bluegill plus shrimp plus plants	182.0	263.9
Fertilized ponds		
Shrimp	637.7	
Bluegill plus shrimp	104.9	235.9
Bluegill		154.3
Bluegill plus shrimp plus brush	1,173.5	236.8

The presence of rooted or attached aquatic plants filling less than 50 percent of the water volume increased both shrimp and bluegill production in unfertilized ponds. Subsequent experiments indicated that the increase came principally from the presence of Chara, while Najas did not increase production. Highest bluegill production was with Chara plus shrimp.

In fertilized ponds, the presence of shrimp increased bluegill production 60 percent. When cover (attachment surface) was provided by filling the pond to water level with loosely-piled brush, the added surface caused production of 10 times the weight of shrimp but no increase in weight of bluegills above that in the shrimp-bluegill pond without cover. However, all bluegills in the pond with cover were large, while those in the pond without cover included a high percentage of small bluegills. Cover was thus effective in greatly increasing a fish-food organism, the freshwater shrimp, and increased the harvestable crop of bluegills.

5.2 Bluegill-largemouth bass

Four ponds were each stocked per ha with 3750 bluegills in December plus 300 largemouth bass fingerlings in May. Three of these ponds were without cover and one was filled with brush to the water level in the shallow half of the pond. After draining in October, the latter pond was restocked the following season exactly as above, except 600 largemouth bass fingerling were added. All ponds received standard fertilization. The average results per ha were:

Stocking	Cover	Production kg
Bluegill plus bass (300)	None	282.6
Bluegill plus bass (300)	Yes	492.8
Bluegill plus bass (600)	Yes	439.0

Again, it is quite evident that "cover" or added surface provided by brush was effective in increasing total fish production very materially (65 percent). The amount of added surface or "cover" needed for highest production and methods of supplying it are interesting subjects for research. These experiments suggest that submersed aquatic plants and brush served the same purpose. It is postulated that the increased production resulted because of increased attachment surface for fish-food organisms. Since brush or flooded trees decay rapidly, they lose most of their effectiveness within a few years. It would appear that submersed rooted aquatic plants would be the cheapest and best for adding attachment surface, provided species can be found that do not become so abundant as to exclude fish from large areas of the pond.

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