2. Materials and methods

This presentation is based on our laboratory and field observations as well as pertinent information collected from literature. During the last few years, we have undertaken a series of physiological experiments to study the possibility of mass culture of *R. tigrina* (Marian 1982; Marian *et al* 1983; Marian and Pandian 1985a; Pandian and Marian 1985 a, b, c, d, e). During these studies, we observed the hatchability and survival of tadpoles of several ranids. To compare these laboratory data, we extended observations on these ranids in the temporary puddles situated in the vicinity of our school. Relevant published information was also collected from scientific journals and institutional reports as well as from our enquiry with several universities and frog collectors of our area.

3. Results

3.1 *Expansion of frog's habitat*

Frogs inhabit swampy and low-laying areas, especially the irrigated fields (Abdulali 1985). Of 304 million ha land available in India, 7·26% (= 23 million ha) area was irrigated during 1951 (The Times of India 1982). To control flooding and to expand the irrigated agricultural land area, as many as 1554 large dams were constructed by the Government of India during the period from 1951 and 1980 (Agarwal *et al* 1982). Consequently, the expanse of irrigated land increased to 51 million ha; any effort made by man to increase the irrigated land area results also in the expansion of frogs habitat, which in turn, may enhance frog production. Thus within a period of about 30 years, the area of frog habitat and production has been inadvertently more than doubled. While we have no population census to support the increase of frog production, the parallel increasing trends obtained for the frog harvest by the export and education sectors (figure 1) provide a circumstantial evidence for the doubling of frog production during the last 30 years.

As it may be seen from table 1, the expansion of irrigated land area in the coastal states, where intensive harvest is being made for frog export, is comparable with the national average. Inland states like Punjab and Uttar Pradesh, in which frog harvest is restricted to education purpose have also more than doubled the irrigated land area. Hence, both at national level as well as in the coastal states, where frog is captured for export, the scope for frog production has doubled.

3.2 *Frog utilizing sectors*

Besides a constant fraction of frog population suffering predation in the natural habitats, recognizably large fractions of frog population were harvested and utilized in India from 1956 and 1967 by education and export sectors, respectively. Enquiries from several senior professors and students indicate that the syllabus of almost all Indian universities demands dissection of atleast 10 frogs by a biology student prior to his/her graduation. Hence a search was made to estimate the number of biology students graduated from Indian universities during the period from 1956–1980. The Times of

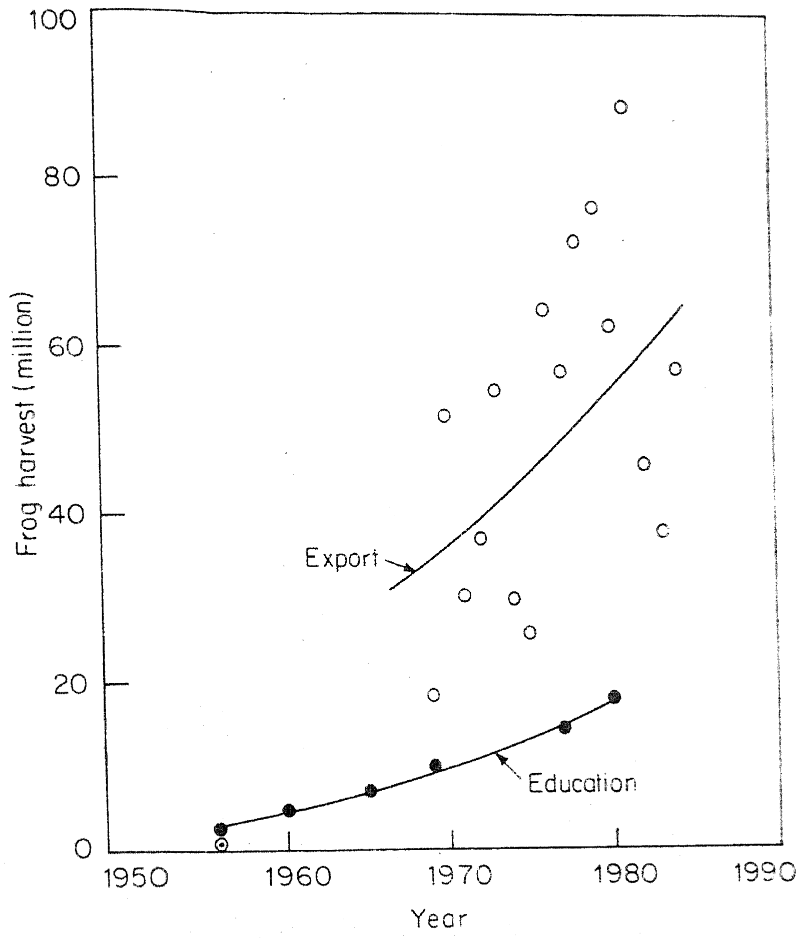

Figure 1. Increasing harvest of frogs by education and export sectors during the last 30 years. The symbol (⊙) represents the level of frog export initiated by Allen T Sherman (USA).

India (1982) reports that before independence, there were about 0·3 million students in 350 colleges affiliated to 20 universities in India. Today we have over 2 million students in 4500 colleges affiliated to 120 universities. Barring a singular exception of Aurangabad University, frog is continued to serve as the standard laboratory specimen in all these educational institutions for following reasons: (i) normally frogs do not feed under captivity and hence cost little to maintain them in the laboratory and (ii) the number of guide books available for the conduct of practicals on frog is far more than that available for any other laboratory animal. Understandably, frogs continue to serve as the most important laboratory animals for teaching biology students.

An assessment of the number and weight of frogs utilized in the biological education sector during the last 25 years was made by multiplying the number of biology students in India with 10 frogs each; this estimate indicates that the number of frogs harvested by the education sector increased from 2·6 million in 1956 to 18 million in 1980. A comparison of the trends obtained for the frog harvest by education and export sectors reveals that the first sector utilizes atleast 1/3 of that exported by the MPEDA sector (figure 1). It is therefore necessary to recognize that if frog populations have been overexploited in India, the export sector alone is not solely blamable, but the education

Table 1. Increase in irrigated land area in India as well as in its coastal and inland states during the period from 1956–1980 (from Times of India 1982)

Name of the State	Irrigated land area (in thousand hectares) 1951	1980	Increase (times)
India	23[b]	51[b]	2·2
Coastal states			
West Bengal	< 726	1541	> 2·0
Andhra Pradesh	2300	4691	2·2
Tamilnadu	2057	3819	1·9
Kerala	279	354	1·3
Karnataka	950	1718	1·8
Maharashtra	1431	2306	1·6
Gujarat[a]	740	1936	2·6
Inland states			
Punjab	2836	5506	1·9
Uttar Pradesh	< 4515	10575	> 2·3
Bihar	2279	3707	1·6
Madhya Pradesh	423	2413	5·7

[a]Frogs are also collected from Gujarat (see Abdulali 1985).
[b]Values given in millions.

sector has also been contributing its share to the alleged over-exploitation of frogs in India.

Unlike for the education sector, we have definite records for the number of frogs exported through MPEDA. Though frog export was commenced by Allen T Sherman, President of the International Fisheries Corporation, USA as early as in 1956, organized export of frog-legs was commenced in 1969, perhaps mostly through the efforts made by MPEDA (figure 1). The wide annual oscillations in the number of frogs exported certainly reflect the usual trend observed in capture fisheries (Jhingran 1975). Briefly the export sector increased the frog harvest from about 30 million in 1969 to 60 million in 1980. While the number of frogs harvested by export sector has consistently remained 3 times more than that harvested by education sector during 1969–1980, it is recognizable that both the export and education sectors almost doubled their harvest, i.e. export sector: from about 30–60 million; education sector from 10–18 million. The frog harvest by education sector has remained inconspicuous all these days; besides from the point of harvesting rate, i.e. doubling of frog's harvest in a decade, both these sectors have played an equal role.

Figure 2 shows the trend obtained for expanding frog's habitat area and the increasing cumulative frog harvest made by the education and export sectors of India. It may be noted that the rate, at which the cumulative frog harvest in India during 1970–1980 is far higher than the rate at which the frog's habitat, i.e. the irrigated area is increased. A projection of these trends certainly indicates that by 1981 our frog harvesting rate has exceeded the limit set by the habitat area and its frog production capacity. This is perhaps the reason for the decline in frog export since 1981.

Since we know the cumulative number of frogs harvested per annum and the annual expansion rate of irrigated area, it is possible to determine the rate of frog harvested in

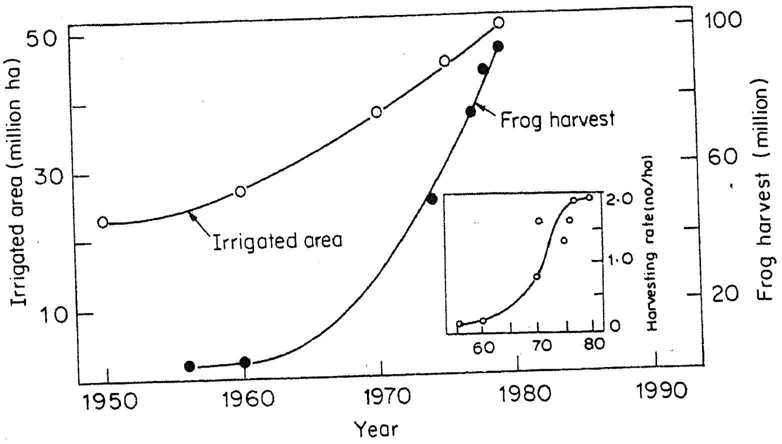

Figure 2. Expansion of irrigated area and increase in the cumulative frog harvest as a function of time. Window panel in the figure illustrates the harvesting rate of frogs as a function of time.

India. The window panel in figure 2 shows the trend obtained for the rate of frog harvest as a function of time. This analysis points out that the number of frogs harvested logarithmically increased from 0·2/ha in 1960 to 2/ha in 1978; subsequently the harvesting rate stabilized at that level showing that the maximum possible annual harvest of frog is only about 2/ha.

Mondal (1975) reported that the average size of frog exported by India is ≈ 100 g. From a series of experiments, Marian (1982) estimated the energy cost of living by an adult *R. tigrina* is 3·4 kJ/100 g/day, which is approximately equivalent to 1/16 of that reported for homeothermic mammals (Prosser 1973). McNab (1963) estimated the home range of a number of herbivorous and carnivorous mammals; using additional data obtained for the body weight and energy cost of living of these mammals, he showed that home range of these two groups of mammals linearly increases following with increasing body weight and that the home range of herbivore is smaller than that of a carnivore. Using the trend reported by McNab (1963) for the home range-carnivorous mammal relationship and considering the energy cost of living of the carnivorous frog, the home range of a 100 g *R. tigrina* was estimated to be in the range of 0·0357 ha; in other words, a ha of irrigated land may support 28 frogs. Since 2 frogs/ha can consistently be harvested per annum (figure 2, inset), it may be stated that a harvest of 7% of the population from a habitat during a period of one year will neither deplete the frog population nor upset the ecological balance i.e. a harvest of 7% of the frog population represents the optimum rate of utilization.

3.3 *Vector and pest control*

The role played by frogs in controlling the vectors like mosquitoes and pests like *Hieroglyphus banian, Oxya velox* may be assessed by observing the feeding habits or by analysing the stomach contents of freshly killed frogs. Sugumaran (1979) made a detailed study on the stomach contents of *R. tigrina* collected from the agricultural fields in and around Sholavandan, which is irrigated by the Vaigai river. His study is based on analysis of freshly killed *R. tigrina* collected around 2300 ha over a period of one year. He observed that insects and crabs form the major food items of *R. tigrina*, and the former constitute as much as 80% of the frog's food (table 2). He also grouped the different insects into the taxonomic order. Surprisingly he never recorded a mosquito nor even a dipteran (table 3). Incidentally, Pandian and Vivekanandan (1985) estimated the cost-benefit ratio of feeding, and concluded that a prey weighing 0·1% of the predator's body weight alone offers more energy to the predator than the energy cost of a foraging, subduing and handling the prey. As the average weight of a mosquito is (< 2 mg wet weight) smaller than 0·05% weight of even a freshly metamorphosed frogleg (> 1·8 g; Pandian and Marian 1985b,c,d; Marian and Pandian 1985a), it may not be a surprise that neither mosquito nor any Diptera contribute to the food of frogs. Hence the question of using frog as a vector controlling agent is almost ruled out. In recent years, Abdulali (1985) made an intensive study on feeding habits of *R. tigrina* collected from Maharashtra state. While, the pest controlling ability of frog was conclusively established, he too did not suggest a role for the frog in the control of vectors.

On the other hand, several important agricultural pests belonging to Orthoptera, Isoptera, Lepidoptera, Hemiptera and Coleoptera contributed the major bulk of the food organisms of frogs (table 2). Evidently, frogs do serve as an important controlling agent of agricultural pests. Frogs also consume a good percentage of crabs, which are known to destroy the agriculture land by their burrowing activity.

3.4 *Pesticides*

An average farmer in India depends more on pesticide application than using frog to control the pests in his agriculture fields. Since 1967–68, India has been producing and using as many as 55 varieties of pesticides; of them (i) DDT, (ii) BHC and (iii) carboryl (sevin) have been used extensively (David 1981). Application of pesticides poses a constant threat to non-target organisms, especially frogs. During the rainy season, pesticides sprayed on crops find their way to accumulate in temporary puddles by surface run-off and sediment transport from the treated soil. Since the frogs breed

Table 2. Monthly variations in the (%) composition of food of *Rana tigrina* (from Sugumaran 1979; modified)

Month	Insects	Crabs	Miscellaneous[a]
January	96·7	2·1	1·2
February	99·4	0·0	0·6
March	97·5	0·9	1·6
April	96·5	1·2	2·3
May	99·4	0·6	0·0
June	47·4	0·0	52·6
July	98·3	1·1	0·6
August	47·8	8·7	43·5
September	43·3	10·0	46·7
October	82·5	7·0	10·5
November	76·9	7·7	15·4
December	83·3	5·6	11·1

[a]Earth worm, spider, centiped, slug, frog and snake.

Table 3. Monthly variations in the taxonomic composition of insects consumed by *Rana tigrina* (from Sugumaran 1979; modified).

Month	Odonata	Orthoptera	Isoptera	Lepidoptera	Hymenoptera	Hemiptera	Coleoptera
January	0	21	32	4	0	7	36
February	3	1	76	2	0	3	15
March	0	0	15	49	0	0	36
April	0	0	25	0	0	0	75
May	0	5	36	29	0	0	30
June	0	0	12	72	0	0	16
July	0	0	15	10	6	0	69
August	0	0	0	0	32	0	68
September	0	0	0	25	0	0	75
October	0	0	10	27	0	24	39
November	0	0	0	28	0	14	58
December	0	12	38	18	0	0	32

during rainy season and release their eggs in the temporary puddles, the developing tadpoles face the ill-effects of the accumulated pesticides. Marian *et al* (1983) have reported the deleterious effects of carbaryl on survival, growth and size of metamorphosing *R. tigrina*. Unfortunately, field survey on the deleterious effects of pesticides on frog population is totally wanting. It must be indicated here that theoretical models of the deleterious effects caused by pesticide application on target as well as non-target organisms, show that non-target organisms like frogs are ultimately eliminated rather than the pests in a given ecosystem (see Rosenzweig 1977). While the enthusiastic harvesting by the education and export sectors can at best make the frogs as endangered species, the consistent application of pesticides in the irrigated fields may cause the total depletion of frogs from the fields. Hence strategies for conservation of frogs should also consider the possibilities of minimizing pesticide application to conserve the non-target organisms including frogs.

3.5 *Scope for employment*

Frogs are usually caught during night with the aid of bright lamp and scooping nets, and are sold by the catchers to frog-cutting centres; the following morning the hind legs of these animals are cut off after they have been duly anesthetised under hygenic conditions in processing factories. However, frog collectors do not hesitate to cut off the hind legs more or less in a crude manner to reduce the weight of the frog bag. Photographic and cinematographic evidences of this kind of activities have been made, and on the strength of them, the SPCA of England, Germany and other countries have been pressurizing the ban of frog export from India. Legal enforcement of an embargo on frog export is difficult; for the collectors do not hesitate to smuggle the frogs to neighbouring countries to export them from there. Frogs are mainly collected from Tamilnadu, Kerala, Andhra Pradesh, West Bengal and Maharashtra (Mondal 1975). Enquiries with several frog collectors from our area suggest that the collection lasts for a period of 6 months during the monsoon and post-monsoon periods, and the harvesting rate is in the range of about 50 frogs/collector/night. Therefore, the harvesting of 80 million frogs for the export sector would provide scope for employment of 0·16 million people in rural areas. A recommendation of the ban on frog export from India should therefore simultaneously consider the problem of finding an alternate job for these rural folks, perhaps in aquaculture and ranching farms of frogs.

3.6 *Need for aquaculture and ranching*

In general most precipitation in India occurs during the brief spell of the monsoon period. Consequently there is considerable overlap in the breeding season among the anuran species (figure 3) and heavy competition for resource utilization among the tadpoles owing to the overlap of microhabitat (table 4). In general, tadpoles are highly specialized suspension feeders adapted for utilizing the rapid increase in primary production as a food source (Seale 1985). The availability of these resources are usually coupled to the monsoon (Haniffa and Pandian 1978, 1980). Being adapted to feed on the temporary resources, tadpoles suffer loss of body weight or heavy mortality, when food source begins to shrink or is suddenly depleted owing to the drying up of the

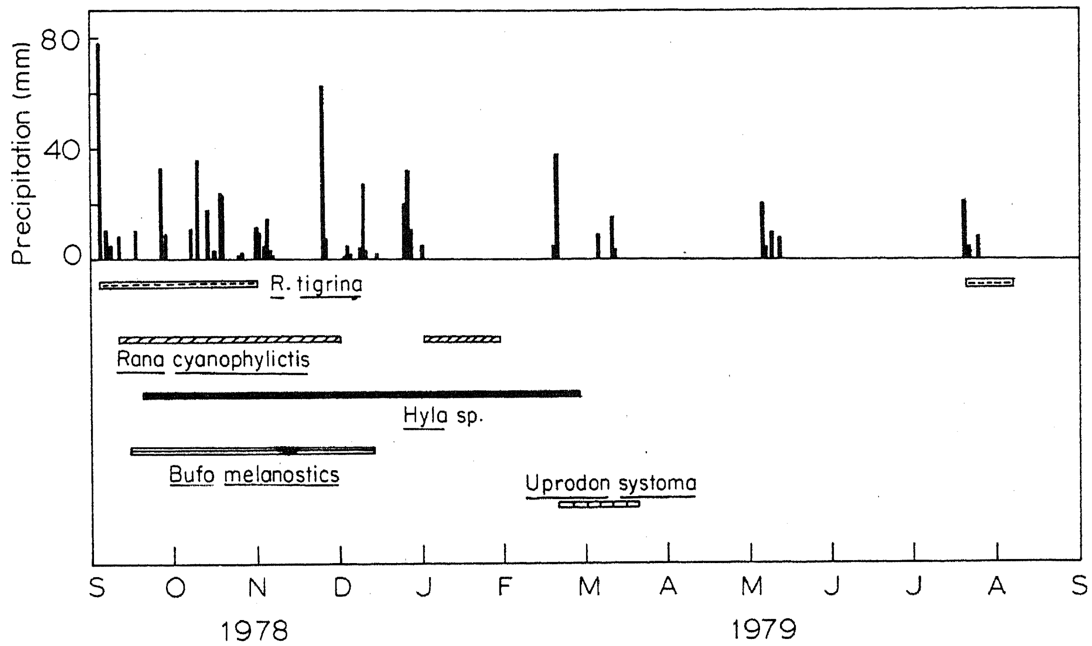

Figure 3. Upper panel: Daily changes in precipitation as a function of calendar months during 1978–1979. Lower panel: Spawning seasons of some anurans in the puddles of Madurai Kamaraj University as a function of calendar months. Horizontal bars represent the duration of spawning season by the respective species.

Table 4. Overlap of microhabitats of anuran larvae observed in the temporary puddles of Madurai Kamaraj University during 1977–1979.

Species pair comparison	Microhabitat overlap range
Rana tigrina – R. cyanophylictis	0·0168–0·3006
R. tigrina – Hyla sp.	0·0670–0·5646
R. cyanophylectis – Hyla sp.	0·2000–0·4706

Overlap in microhabitats is calculated using the formula:

$$\alpha jk = 2\sum_i pij \cdot pik \left(\sum_i pij^2 + \sum_i pik^2\right),$$

where $\alpha\, jk$ represents overlap of species jk, and pij the proportion of occurrence of species j in sweep i. Values 0 represent no overlap and 1 complete overlap.

puddles. Besides wide fluctuations in the commencement and distribution of monsoon reduce the successful emergence as well as the size of the emerging froglets (table 5).

The onset of monsoon triggers the spawning process in frogs; the clutch size of anurans ranges from 1280–1680 eggs/spawning and averages to 1474 ± 152 eggs (table 6). Our field observations show that the percentage of hatchability of *R. tigrina* is 60 ± 6%. Over 75–100% of tadpoles succumb to death during development due to infection or sudden drying-up of the puddles (Marian and Christopher 1985).

Table 5. Larval duration and froglet size of anurans emerging from the puddles of Madurai Kamaraj University during 1978–1979.

Species	Larval duration (days)	Froglet weight (mg)
R. tigrina	30–40	950–1100
R. cyanophylatis	70–75	1250–1500
Hyla sp.	25–30	150–200
Bufo melanostics	22–25	30–50
Uprodon systoma	20–26	300–350

Table 6. Clutch size and hatchability of anurans in the temporary puddles of Madurai Kamaraj University during 1977–1980.

Species	Egg (No.)			Hatchability (%)
	n	Range	x SD	
Rana tigrina	7	1280–1681	1474 ± 152	60 ± 6
R. cyanophlyctis	6	980–1538	1336 ± 212	67 ± 11
Hyla sp.	5	221–482	367 ± 86	79 ± 8
Uprodon systoma	6	858–955	910 ± 38	59 ± 4
Bufo melanostics	5	2000–5000	3500 ± 1224	92 ± 3

These field observations are neither adequate nor detailed but they point out the vicissitudes of environmental stress, to which the sensitive early stages of anurans are exposed in their natural habitats. On the other hand, reared under optimum laboratory conditions described by Pandian and Marian (1985a) more than 98% *R. tigrina* successfully complete metamorphosis and emerge. These laboratory and field observations clearly indicate the need for supporting aquaculture of frogs. The fact that frog harvest has begun to exceed the optimum harvestable limit since 1981, suggests the urgent need for massive inputs into frog culture and frog research in our country. There is vast scope for adoption of standard procedures like hypophysation, dry fertilization and mass rearing of tadpoles in high density cultures using tubifex as food. The most crucial problem in mass culture of tadpoles and adults is to find a 'live and kicking' prey in adequate quantity. Recently, Marian and Pandian (1984, 1985b) have described a simple procedure for the mass culture of tubifex using waste organic matter. Reared solely on *Tubifex tubifex*, a hatchling of *R. tigrina* attained a body weight of > 40 g in < 90 days requiring a feed of < 200 g *Tubifex* (Marian 1982). This is approximately the suitable size for release into the paddy fields to ensure conservation, and pests control as well as harvest by education and export sectors.

4. Discussion

Most conclusions drawn in this paper are not based on direct and adequate data. Therefore, the discussion is restricted to population census and aquaculture of frogs. Whereas the aquatic mode of life of Urodela (Merchant 1970; Fitzpatrick 1973; Burton and Likens 1975) and most anuran tadpoles (Licht 1974; Heyer 1976; Seale 1980) render the population census possible, the amphibious mode of life, the burrowing and aestivating habits of adult anurans make the population census a difficult task; added to these, the rapidity with which they dive into water or hop on land makes the task even more difficult. Besides no agency has come forward to identify population census of frog as priority area for funding. Therefore, it is not surprising to note the paucity of information on population census of frogs.

For want of information on mobility and home range of the Indian frogs, we have chosen to have an overall assessment of frog population census in a limited area. In the absence of pertinent information, we had to rely on the expanse of irrigated land area, i.e. the habitat of frog as an index of frog population and production. We have information on the number of frogs harvested by the export sector, but again we had to rely on an indirect assessment on the harvest made by education sector. We have brought to light that in recent years the education sector of India has become an important user of frogs and utilizes about 18 million frogs/annum. Culley (1973) reported that scholars and students in USA utilize about 15 million anurans annually (see also Gibbs *et al* 1971). Apparently biological education sector is an important user of anurans in many countries.

The need for aquaculture of frogs has been emphasized repeatedly (Culley 1973). However, frog culture has been found not a very successful enterprise (NAS 1974); the causes for this are: (i) incidence of heavy mortality of tadpole owing to cannibalism (Marian 1982; Marian *et al* 1985) (ii) the obligate requirement of proteinaceous feed for the grown-up tadpoles and (iii) the requirement of live, 'kicking' prey for the adult (Bardach *et al* 1972; Nace 1977). In India, Mondal (1975) attempted to mass culture frogs by providing illumination to attract phototropic insects. Unfortunately, no study was made on the quantity of attracted insects and the feed requirements of the frog population. Recently Marian and Pandian (1984, 1985b) have described a simple procedure to mass culture *Tubifex*, which is known to be the best feed ensuring maximum growth of *R. tigrina* (Marian 1982). As there is scope for solving the most critical problem, viz the frog feed, it should not be difficult to reventure into frog culture. Aquaculture of tadpoles may ultimately serve two purposes: (i) one for ranching programmes and (ii) harvesting for edible purposes. The former involves mass rearing tadpoles and release of juveniles into the irrigated field areas. Hence, it has the advantage of controlling agricultural pests but may render the scope for enthusiastic over-exploitation and killing of frogs under unhygenic conditions by unscrupulous collectors. On the other hand, mass culture of large frogs in aquacultural farms for education and export purposes may not contribute much to the control of agricultural pests but will still in the use of the carcass as feed and fertilizer. Both programmes require much scientific and governmental support, but the operation of these programmes in a judicious manner should provide maximum benefits.

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