ENHANCEMENT OF A LAGOON PRAWN FISHERY AT REKAWA, SRI LANKA

(ODA ref: 627)

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FINAL REPORT

Executive summary

- Fishery monitoring data showed that *Penaeus indicus* makes up > 90% of the catch in Rekawa Lagoon (by numbers).

- *Penaeus monodon* consists of <1% of the lagoon fishery catch by numbers, but due to their larger size compared with *Penaeus indicus* they represent 2.5% of the catch by weight and hold a premium price. Neither penaeid breeds in the lagoon.

- A technique for long-term marking of released shrimps was developed to permit population estimates.

- A major stock-enhancement trial was carried out in July 1996 with the release of ~65,000 post larval *Penaeus monodon* into the lagoon. A second release of 70,000 PLs took place in July 1997 and is being monitored outwith the contract period.

- Approximately 3.5% of the released shrimps from the first trial were caught by the fishery when they had grown to a catchable size. Capture, starting in September 1996, occurred 6 months out of phase with the expected tiger prawn fishery (March-May), indicating successful enhancement.

- This catch of released *Penaeus monodon* represented an increase of 1400% in the catch of *Penaeus monodon* compared with the previous year, and a 166% increase in total shrimp catches for the lagoon.

- Because the lagoon mouth was breached between release of PLs and the start of the fishery, it remains possible that some of the recruitment of *Penaeus monodon* could be due to incoming prawns from the sea.

- Early results from the second trial confirmed the biological success of stock enhancement. Adult *Penaeus monodon* started to be caught in the fishery when it opened on Sept 15th 1997 - yet no breach of the lagoon mouth had occurred between PL release and opening of the fishery.

- The timing of the entrainment of the released *Penaeus monodon* to the fishery was important to the fishermen as catches of the dominant shrimp, *Penaeus indicus*, were seasonally low at this time. Evidence of the social value of out-of-phase stock enhancement is given.

- Production costs of the stock enhancement amounted to Rs 127,390, whereas the catch value was Rs 120,000 (not including unreported catches). 86% of the production costs were for supply of postlarvae. Equipment costs (Rs 65,900) were high, mainly because the project used expensive imported rearing cages (93% of equipment costs). Lower PL costs and use of local materials for cages would be essential for economic viability.

- A scenario-modelling exercise indicates that up to 4 release of PLs per year could be conducted without risking damage to the *Penaeus indicus* fishery; this would be preferable to releasing larger numbers of *Penaeus monodon* on a single occasion.

The model demonstrated that improving catchability should be a major objective for future studies.

- Professor Ekaratne gave a presentation on the programme at an international meeting Delhi, India. It is intended that paper(s) will be prepared for submission to peer-reviewed journal(s) within the next few months.

• INDEX

1. GENERAL INTRODUCTION

1.1 Preamble

This report summarises the conduct and performance of a two-year programme jointly carried out by the University Marine Biological Station Millport and the Department of Zoology, University of Colombo. The programme was designed to address two major objectives. First, a programme at Rekawa Lagoon offered the opportunity to determine whether stock-enhancement of a prawn fishery could be biologically-effective (i.e. whether released juveniles recruited to the fishery in sufficient numbers to be detectable). This objective was expected to be of significance beyond Sri Lanka. Second, the programme was carried out to determine whether stock-enhancement of the Rekawa Lagoon prawn fishery was of socio-economic benefit to the local fishing community.

In most respects the programme was successful. Two stock enhancement trials took place, the second largely outwith the period of the contract. During the first trial released post-larvae grew and recruited to the fishery even though some post-larvae were probably washed out to sea. Catches of the released species (*Penaeus monodon*) were much higher than in the previous year (by 1400%), while overall prawn catches were 166% higher than in the previous year. This strongly suggested successful enhancement, and indicated that the presence of tiger prawns had not depressed *Penaeus indicus* catches (a concern of local fishermen). However, a) historical catches had been even higher and b) a short-duration breach between the lagoon and the sea suggested that some of the apparent enhancement could be due to natural recruitment from the sea. Set against these reservations, it must be emphasised that the post-enhancement *Penaeus monodon* catches occurred 6 months out of phase (mainly September and October) with the normal tiger prawn catch (March-May); local fishermen had never previously caught tiger prawns at this time, even though late summer breaches of the lagoon mouth are routine. At the time of writing, *Penaeus monodon* are being caught following the second release of PLs (70,000). Release occurred in July 1997. When the fishery opened in September, adult tiger prawns were immediately caught, though no breach in the lagoon mouth had taken place. In this case no source of tiger prawns other than the PLs can be postulated, so significant enhancement must have taken place.

The programme was not cost-effective in its present form for three reasons 1) equipment costs were greatly-inflated because imported cage (hapa) materials wre used for speed and convenience 2) a number of PLs were lost during the first restocking exercise 3) PL purchase price was high. All three factors are susceptible to amelioration (by use of local materials, more experience of handling PLs, and rearing of PLs from a smaller (cheaper) size respectively). After initial caution the fishing community found the programme of great value.

Because the fishing community were concerned about competition between released *Penaeus monodon* post-larvae and the natural population of *Penaeus indicus*, and because of some delays in equipment delivery, it was only possible to conduct one major post-larval release during the contracted part of the programme. However, the delayed second release took place (in July 1997) once all community concerns had been allayed. The consequences of this second release are being monitored (in as much detail as is feasible now that financial support has ceased) outwith the contract by Professor Ekaratne and his staff.

A modelling exercise was conducted to consider how the restocking exercise might be improved. It was concluded that a 4-times per year restocking exercise at the current level (*ca* 70,0000 PLs per release) would be the best from a point of view of maximizing economic return and maintaining occupation of fishermen, whilst minimizing interference with the *Penaeus indicus* fishery.

Dissemination of information has so far been limited to local meetings in Sri Lanka and a contribution to an international meeting at Delhi, India. The latter will be published, but Professors Davenport and Ekaratne will (with their co-workers) write one or more papers to be submitted to international peer-reviewed journal(s) in the early part of 1998.

1.2 Summary of activities of previous annual report (April 1995 - December 1995):

- Recruitment of staff (Mr D. Lee in UK and Mr S.Walgama in Sri Lanka).
- Gaining approval of stock-enhancement project from Rekawa Development Committee
- Identification of a stable dye for marking released shrimps.
- Commencement of monitoring of annual fishery catch dynamics

1.3 Summary of activities of second annual report (January 1996 - March 1997):

- Continued monitoring of the fishery at Rekawa lagoon to determine annual changes in species caught, fishing methods, catch per unit effort (CPUE) and their economic impact on the fishing community.
- Developing a procedure for the holding, release and subsequent monitoring of *Penaeus monodon* PLs using a relatively small scale release.
- Performing a major stock-enhancement release of *Penaeus monodon* PLs and monitoring the fishery to determine the biological and economic impact of the stock enhancement.

2. DESCRIPTION OF LAGOONAL FISHERY

2.1 Fishery data sources: Data concerning the number of active net fishermen in the lagoon, their methods and landings were obtained from the three active shrimp buyers. The shrimp buyers meticulously record each fisherman's name and landings; access to all of the records was obtained. Kraal fishermen tended to market their catch using other channels, so accurate estimates of their activities could not be made, although their catch was <30% of the total lagoon catch.

In addition to using the data obtained from the buyers, fortnightly fishery monitoring trips were made to Rekawa. These trips involved visiting fishermen to inspect their catches and to determine:

- catch quantity
- size distribution
- species composition
- prices

- level of fishing effort
- occurrence of marked individuals

The only reliable quantitative, historical data are for 1993 and 1994 following the investigations of Jayakody (1994). His data (**TABLE 1**, supplemented by data from present study) are summarized in two reports which we have had access to, but all attempts to obtain the raw data to assess changes in species composition and size-frequency distribution through the year have failed.

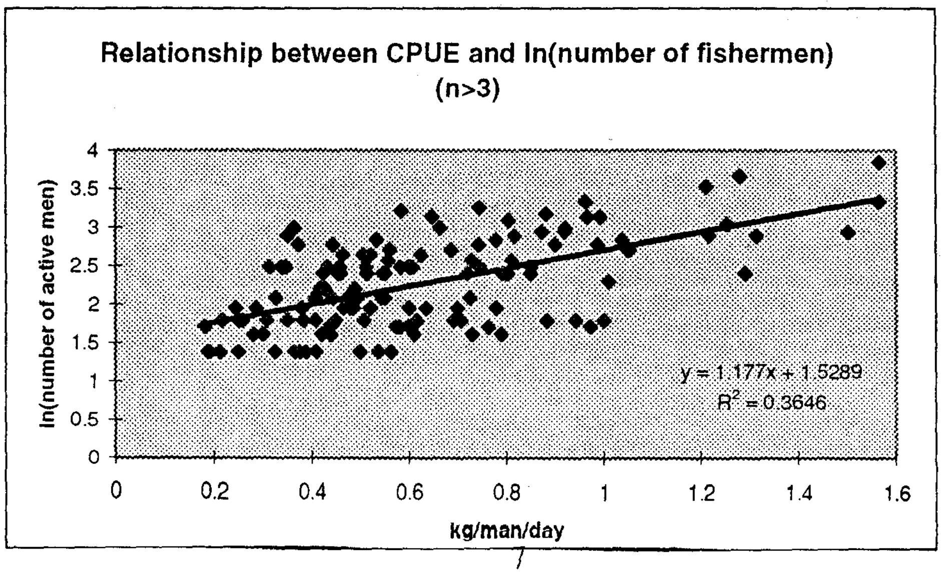
TABLE 1. History of catches of *Penaeus monodon* at Rekawa Lagoon

Season	Total shrimp catch	Percentage catch of *Penaeus monodon*	Catch of *Penaeus monodon* (Kg)
1993/94	6200	4.9	304
1994/95	5177	2.0	103
1995/96	1800	0.9	16
1996/97	1540	15.6	240 (after enhancement)

2.2 Numbers of fishermen in Rekawa lagoon: The following estimates of numbers of fishermen were gained largely by inspection of records of the 3 major shrimp buyers at Rekawa lagoon: 96 gillnet fishermen, 27 castnet fishermen and 14 kraal operators (assuming 2 men per kraal). This makes a total of 137 men actively employed in fishing in this lagoon. It is clear from the pattern of addition of new names to the shrimp buyers' records that many fishermen are not active until the catches for the lagoon start to rise seasonally.

2.3 Productivity of kraal and gillnet fisheries: CPUE for the gillnet / castnet fishery has been estimated in kg/man/day and ranged from 0-1.038 (mean 0.517). There was a trend for CPUE to rise with increasing numbers of active fishermen **(FIG 1).** A plot of CPUE against the number of active fishermen shows a positive relationship, with the mean number of active fishermen rising from 7.3 at a CPUE of 0.4 kg/man/day to 23.9 at a CPUE of 1.4 kg/man/day

FIG 1



Kraal/trap fishing had to be considered in terms of catch/trap/day and related to gillnet CPUE by ratios (because kraal fishermen sold their catch through other routes). On 22nd February (1996) catches from 10 traps were measured, the ratio between catch/trap (kg) and gillnet CPUE was 0.55. On 31st March and for the next 9 days a total of 8 traps were inspected daily, the mean catch ratio was 0.15 (range 0.02 to 0.27). These two ratios from February and March / April were used as lower and upper estimates, respectively, of the relationship between catch from kraal / trap fishing and gillnetting.

Overall, in 1995/96 the gillnet fishery yielded 1237 Kg shrimp; castnets 182 kg and kraals an estimated 169-576 kg. The gillnet fishery is thus the dominant method for removal of stock taking over 60% of total catch weight.

2.4 Annual dynamics of fishery: Annual dynamics of the shrimp fishery were dealt with in detail in the 7th Progress Report. The fishery extends from October to April/May. **FIG 2** shows the annual pattern of catches. This is for the total shrimp catch which (until the enhancement exercise) was predominantly of *Penaeus indicus* (ca 94%). *Penaeus monodon* catches (0.8% of total) were too low to permit construction of an annual dynamics picture, particularly as fishermen did not supply reliable data for the species.

2.5 Species characteristics of shrimp catch: *Penaeus indicus* made up 93.6% of the catch (by numbers); *Penaeus monodon* only 0.8% (the balance consisted of two metapenaeid species, *Metapenaeus monoceros* and *M. dobsomi*) (**FIG 3**). By weight *Penaeus indicus* was also dominant, though *Penaeus monodon*, despite being only 0.8% by individuals, represented 2.5% by weight of the total catch weight indicating that the individuals were, in general, heavier than *Penaeus indicus.*

FIG 2.

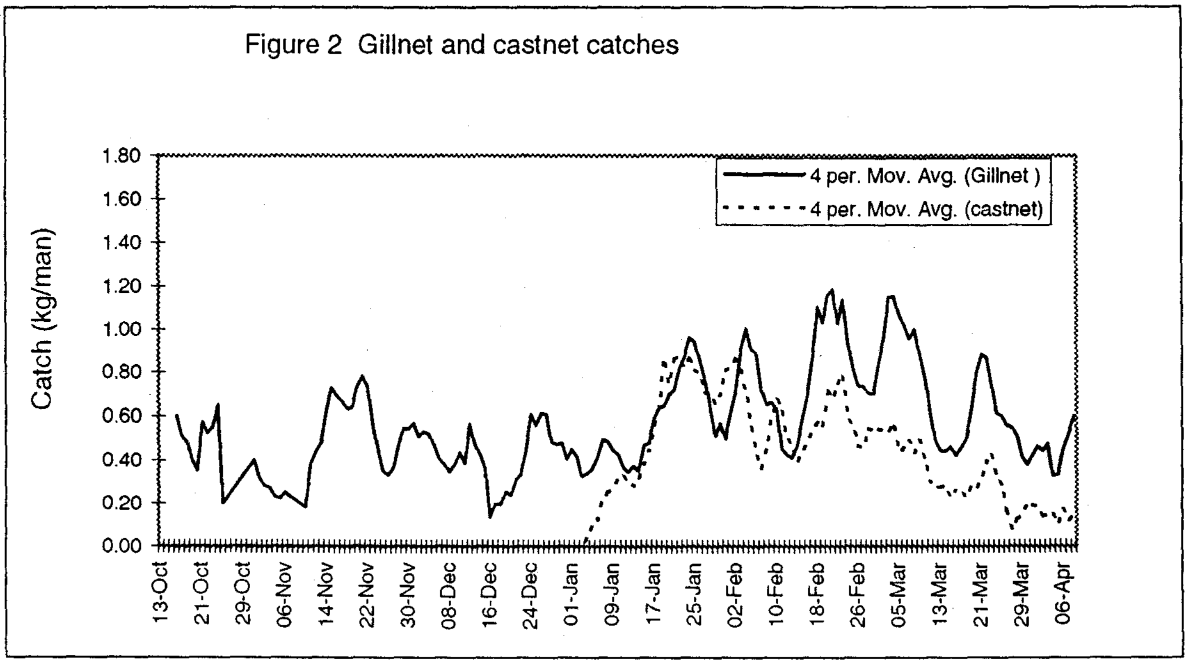
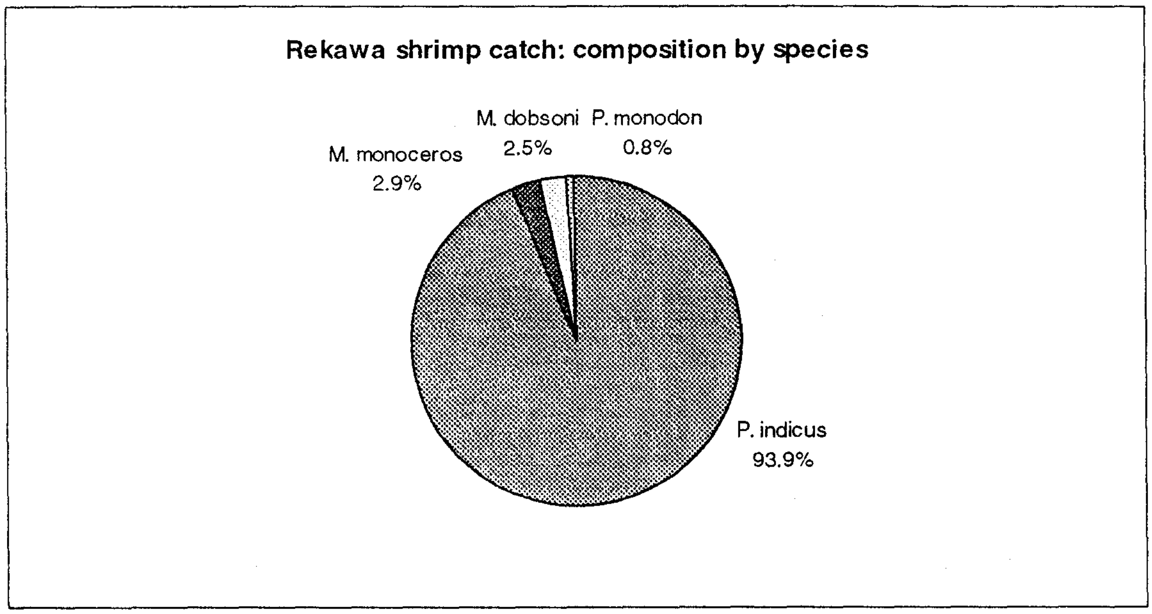
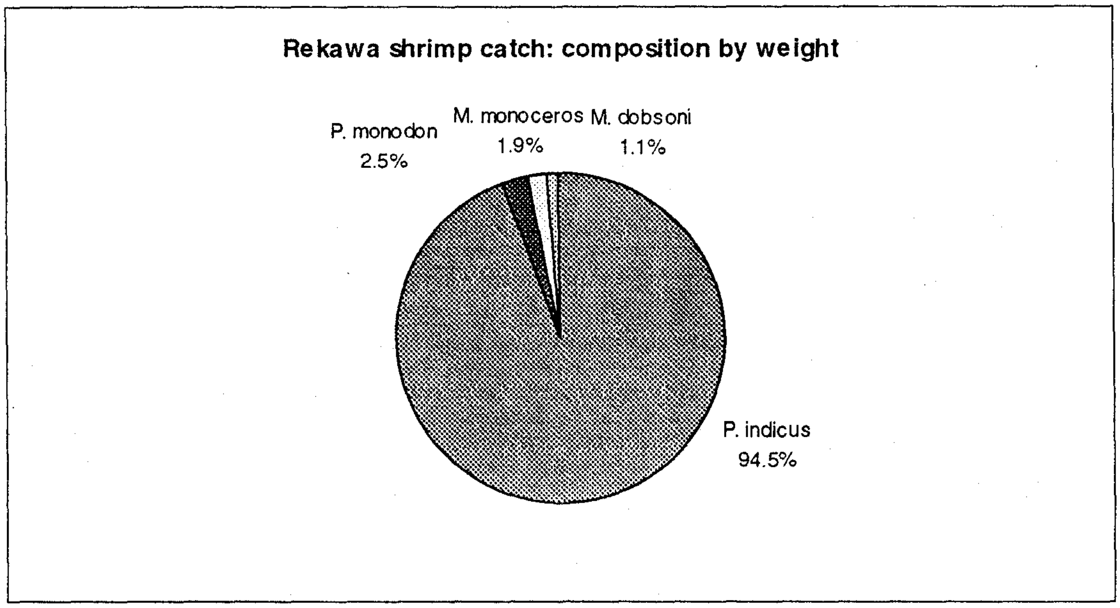


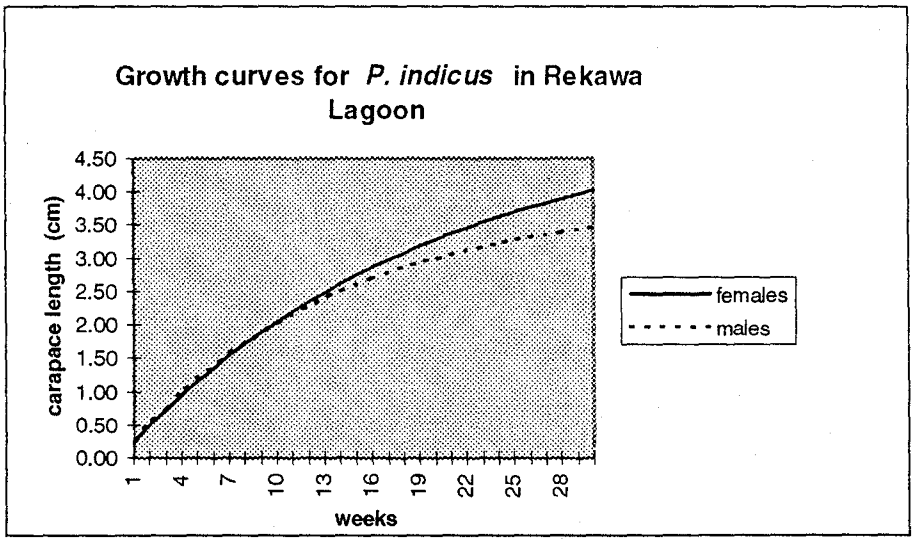
FIG 3





Cohort analysis of *Penaeus indicus* was carried out on the gillnet catches. Growth of *Penaeus indicus* was rapid **(FIG 4)** reaching a carapace length of over 3 cm within 20 weeks. It was evident that mortality (including capture) rises as shrimps grow; by the time female shrimp reach 3-4 cm carapace length, about 90% are captured. F (instantaneous rate of fishing mortality) is around 22 (cf <10 for the Kuwait *P. semisulcatus* fishery), demonstrating extremely high fishing pressure. In some ways the Rekawa Lagoon fishery functions rather like a shrimp farm pond, but with stocking being dependent upon intermittent breakdown of the sand barrier to the sea, and feeding being due to inherent lagoon productivity. *Penaeus monodon* data were fewer, but available data suggest that growth rates are very high (more than twice those seen in shrimp farms) - possibly because prawn density is low (1380 /ha). In 1995, *Penaeus monodon* PLs from the sea entered the lagoon in November.

FIG 4



2.6 Preliminary estimate of *Penaeus monodon* shrimp population size: To get an idea of the size of shrimp population we have made use of previous reports on the lagoon fishery (Jayakody unpubl. and Ganewatte *et al.* 1995) which put the total annual yield of all shrimp at 6,200 kg and the average shrimp size at around 26 g. Only 5% of the catch was *Penaeus monodon*, most of the rest being *Penaeus indicus*. The total number of *Penaeus monodon* caught in a year can be estimated at 13,269.

Data collected from fishermen from 10/10/95 to 7/5/96 involving a total of 14 visits to Rekawa suggested a much lower percentage of *Penaeus monodon* than suggested by Jayakody. Of a total of 1155 individuals surveyed (caught using all methods), a total of 9 individuals were *Penaeus monodon* representing 0.8% of the sample. It is clear however, that *Penaeus monodon*, although always represented, appears in relatively low numbers.

2.7 Detection of improvements in the fishery: In the case of stock enhancement in Rekawa lagoon we are perhaps fortunate in that there appear to be four largely independent ways in which any improvements to the fishery may be detected, namely:

- The recovery of marked individuals in samples and in the main fishery;
- Changes in the size distribution of the population of *Penaeus monodon* which should permit cohort analysis (The fact that natural shrimp recruitment in the lagoon occurs twice per year at broadly predictable times provides us with the opportunity of stocking juveniles out of phase with nature to increase the delectability of the released shrimp in the fishery).
- Changes in the total quantity of *Penaeus monodon* landed (total landings for 93/94 were 304 kg);

- Changes in the relative abundance of different species (In 1993/4 the catch by weight consisted of: *Penaeus indicus* 77.5%; *Metapenaeus monoceros* 13.0%; *Penaeus monodon* 4.9%; others 4.6%).

3. STOCK ENHANCEMENT

3.1 Staining trials for marking shrimps: To be able to estimate the population size of released *Penaeus monodon* it was necessary to use mark-recapture techniques. A thorough literature search did not offer any practical and tested method for long-term staining of individuals so a variety of suitable approaches were tested. The following summarises the conclusions:

1. for injection, distilled water and silicone grease both seem to be adequate dye carriers.

2. injected alcian blue solution (0.5-5%) is not suitable because it is less persistent than fast green FCF and seems to kill most of the prawns.

3. injected neutral red solution (1%) is not suitable because it does not impart a strong or lasting coloration.

4. unilateral eyestalk ablation (using nail clippers) leaves a readily visible and enduring mark without causing high mortality but is unsuitable for Rekawa Lagoon because fishermen already land large numbers of shrimp with eye damage (due to crabs/eels).

5. an injection of calcafluor mixed with silicone imparts a mark which is very pale in daylight but which can be detected in the dark with a fluorescent light for up to 2 weeks;

6. injected fast green FCF solution (5-10%) imparts a readily visible mark which lasts for at least 40-50 days.

7. an injection of fast green FCF mixed with silicone leaves a readily visible mark at the injection site and also imparts a distinct coloration to the gill region lasting for periods in excess of 50 days.

8. steady mortality in controls and most treatments suggests the need to improve water quality and general husbandry.

It was considered that fast green FCF silicone was the best option for this study and, subsequently, all "marked" individuals were treated with this technique.

3.2 Buying and release of post-larval penaeids:

3.2.1 Purchase and transport (details for first release): *Penaeus monodon* postlarvae at 22 days post-metamorphosis (PL22 stage) were purchased from a commercial hatchery. They had a mean total length (TL) of 1.27 cm, with a sample range of 1.0 to 1.6 cm. They were transported overnight to the study site at Rekawa lagoon in 40 double plastic bags containing 7 to 9 litres of water and inflated with oxygen. To prevent heating, most bags were packed in pairs in polystyrene boxes with a cube of ice outside the plastic bags. This served to reduce the temperature by 3 to 4 °C. The mean shipping density was 344 PLs per litre. The journey lasted 6.75 hrs but the PLs spent 11 hrs in the bags from packing at the hatchery to their eventual release from the plastic bags. At the hatchery, the PLs had been acclimated to a salinity of 19 ppt. No dead animals were seen at any stage of the transport.

3.2.2 Acclimation, stocking and nursery rearing: On arrival at the lagoon, the PLs and the shipment water were divided equally between 4 plastic tanks of 90 litres each. They were acclimated for 3 hrs by repeatedly siphoning out water from the tanks and replacing it with lagoon water which had a salinity of 12 ppt. and a temperature of 28.5°C. The temperature of the PL water at arrival at the lagoon was 26.5 °C. No mortality of PLs was observed and after acclimation they were transferred by bucket to the hapas (nursery cages) at 9.15 am to give an initial mean density of 15,700 PLs per hapa. **TABLE 2** summarizes the environmental conditions encountered by PLs during the stocking process.

Seven hapas had been placed in the lagoon 8 days before stocking so that their nets became partially fouled with algae which reduced the effective mesh size as well as provided some grazing matter for the PLs. These hapas, measuring 1.8 x 1.2 x 1.2 m deep, were suspended from poles driven into the lagoon bottom in water 1.0 to 1.1 m deep. Their tops were open and their bases were in contact with the bottom. The mesh opening was of 2mm and net material was made of woven nylon. These hapas were surrounded by a fence of interwoven slatted bamboo material of the type used by the local fishermen for making kraal traps; these in fact were disused kraal trap material and were donated by the fishermen. This fence served as a wind break and a barrier to large fish, whilst allowing ready water exchange. Each hapa was equipped with a feeding tray which consisted of mosquito netting stretched across a circular wire frame of 60cm diameter. These were suspended 0.3 to 0.8m below the water surface in the hapas using polystyrene floats.

The size of the PLs was less than was anticipated which resulted in large numbers of the smaller PLs escaping from the hapas and these were found outside the hapas on subsequent days.

TABLE 2. Water quality experienced by restocked shrimp postlarvae

FACTOR	AT HATCHERY	DURING TRANSPORT	ON ARRIVAL	IN LAGOON
Temperature (°C)	30-31	26.5	26.5	28.5
Oxygen (ppm)	supersaturated	supersaturated	>20	4
Salinity (ppt.)	19	10	19	12

3.2.3 Feeding: The PLs were fed with a combination feed consisting of dry, formulated feed and fresh food that was made up from minced clams and fish caught from the lagoon. The dry formulated feed contained 39% protein and 3.5% fat (Gold

Coin post larval feed 901) and was fed at 22.5% body weight per day. PLs were fed at 8.00 am, 1 p.m. and 7.00 p.m. Based on a visual reassessment of the PL biomass and left-over food made on the 10th day of rearing, the feed quantities were readjusted and considerably reduced, as seen in **TABLE 3**. An excess of feed always remained on the trays. Although the reared shrimp nearly always appeared to have full alimentary tracts, most PLs grazed on the algae which grew on the hapa mesh enclosure rather than appearing to feed on the trays. However, no consistent night-time observations were made on feeding activity.

TABLE 3. Feed given during hapa rearing

	Feed (Kg)		
Day	**Dry Diet**	**Clam Meat**	**Fresh Fish**
1	0.23	0.0	0.0
2	1.75	0.1	0.1
3	1.75	0.95	0.0
4	1.75	1.05	0.0
5	2.45	1.1	0.0
6	2.45	1.05	0.0
7	2.45	1.1	0.0
8	2.59	0.8	1
9	3.92	0.3	2.9
10	1.26	0.45	3
11	1.26	0.45	3
12	1.26	0.5	3
13	1.26	0.45	3
TOTAL	24.38	8.3	15.9

Over the rearing period, the water temperature in the hapas ranged from 28 to 31°C and salinity from 10 to 12 ppt.

3.2.4 Cleaning: Cleaning of the cages was required to remove excess fouling so that water exchange was not impeded. This was done on days 8 and 9 (i.e. 16 to 17 days after immersion in the lagoon) when all cages were removed from their moorings and scrubbed clean with a soft-bristle brush. During this first cleaning, the animals were held separately in empty cages, but subsequent cleaning operations were carried out simply by brushing the outside of the cages, *in situ.*

3.2.5 Growth: Measurement of TL from daily samples of 10 to 20 shrimp were carried out, but cannot be considered as representative since the larger shrimp always tended to remain at the bottom, while smaller PLs. tended to be on the sides of the cages. From these measurements, it can be stated that the PLs grew from a 1.27cm starting size (range of 1.0 to 1.6 cm) to a 2.07 cm TL (range from 1.6 to 3.0 cm).

3.2.6 Release: On the 14th day after their purchase from the hatchery, the PLs were released (see **TABLE 4**). Hapas were lifted to concentrate the juveniles and a plastic cup was used to scoop them into plastic bags filled with lagoon water. The plastic cup was previously calibrated by sample counts as to the expected number of PLs it would hold. Approximately 1500 shrimp were placed in each of 37 plastic bags containing 10 litres of lagoon water. The bags were transferred to dugout canoes (4 to 8 per canoe) and transported to 3 different release sites along the lagoon margin near to lagoon edge vegetation. The total number released in this way was estimated at 55,000.

TABLE 4. Numbers of juvenile *Penaeus monodon* released in Rekawa Lagoon

RELEASE SITE	NUMBER
Boraluwa	33,000
Hetiyapokuna	10,000
Godigamuwa	12,000
Kapuhenwala	10,000*
Total Released Manually	55,000

* It is probable that total release number was around 65,000 including those which escaped from the hapas, assuming 40% of initial number escaped and 22.5% survival rate when feeding on natural food and without being afforded protection from predators (i.e. outside hapas)

3.2.7 Survival: During the early part of nursery rearing an unknown number of smaller-sized PLs escaped through the mesh of the hapas. Many of them were found subsequently in the submerged lagoon vegetation nearby. Therefore, it is difficult to calculate an accurate survival rate for this nursery rearing period. It can be said, however, that the daily observations revealed that there was little mortality in the cages: only on 4 mornings a few dead PLs were found on the feeding trays (5 to 30 per tray) but there were no dead PLs found on the cage bottoms. After about the 5th day of nursery rearing, a large size fishing net (given by the fishermen) was used as a top cover for the hapas, since fears were expressed that birds such as cormorants and herons could be attracted and could enter the cages to make short work of the shrimp.

On this basis, survival in the hapas was high and was probably around 80 to 90% (though note that during holding for the second release [see **section 3.5**], mortality was 30%).

3.3 Release-recapture pilot experiment: A trial small-scale pilot experiment was carried out, prior to a full scale experiment, to confirm the validity of the methodology and to give an initial estimate of fishing mortality.

<u>Methods</u>: Live *Penaeus indicus* for the experiment were obtained from a series of kraals (barriers and traps) operated by lagoon fishermen. Rather than marking the shrimp and releasing them directly into the lagoon, they were retained in cages immediately prior to and after marking. In this way, any shrimp which succumbed to the stress of handling and marking could be excluded from the experiment and only the strongest animals be released. The cages (2 x 2 x 1m deep) were made of

nylon netting (10 mm mesh) and were suspended from wooden frames in water about 1.3m deep. Live shrimp were received on successive mornings and each afternoon survivors were marked by injecting 0.02 ml of a 10% solution of the dye fast green FCF in distilled water. The dye was injected with a 1ml insulin syringe laterally into the muscle of the second abdominal segment and it spread rapidly to give the whole animal an intense, dark green/blue colour. Marked shrimp were returned to cages and held overnight for survivors to be transported in the morning to one of three release sites along the length of the lagoon. Whilst in captivity, shrimp were fed with fresh cockle meat at about 10% body weight day^{-1}. A total of 91 shrimp were marked and released between 3 and 9 April 1996. Examples of marked shrimp were shown to fishermen and a premium price was offered for any recaptures.

Results: The fishermen proved to be very co-operative throughout the experiment and recorded a total of 57 recaptures. Of these, 47 were kept frozen and when inspected they clearly showed a concentration of the green dye in the gills and a mark at the site of injection. The recaptures fell into three groups: those (n = 14) accompanying catches delivered to the Fishermen's Co-operative Association; those (n = 6) caught in kraals; and those (n = 37) delivered to the main independent shrimp buyer. Unfortunately, the quality of the data from the last two sources was reduced because they did not include the quantities of unmarked shrimp also captured. However, the Fishermen's Co-operative Association provided complete records from which a simple population estimate could be made using the method of Petersen (Begon 1979). The Petersen estimate can be made without reference to the recaptures from non Co-op sources under the assumption that marked and unmarked shrimp are equally vulnerable to capture. This assumption implies that fishing activity does not alter the proportion of marked to unmarked shrimp.

Petersen estimate: If a random sample of r individuals is marked and released in a population, N, and allowed to mix thoroughly and a random sample of size n taken which contains m marked individuals, then the marked proportion should remain the same (i.e. m/n = r/N) and an estimate of N can be calculated as rn/m. A Petersen estimate usually involves just one release and one recapture so it is necessary to regroup the Co-op data to provide the values of r, n and m.This required the experiment to be split into two distinct phases: releases (3-9 April), and recaptures (10 April - 7 May). The two recaptures made on April 7 have been discounted from the totals. The numbers of unmarked shrimp caught have been estimated indirectly by dividing the weight of *Penaeus indicus* caught by the mean size of individuals observed in samples.

The following population estimate calculations were made:

Total marked, released and at large on April 10 (r)= 89
Total recaptures: 10 April-7 May (m)= 12
Total number of unmarked *Penaeus indicus* captured 10 April-7 May = 454
Total of marked and unmarked *Penaeus indicus* caught 10 April-7 May(n)=466

The Petersen estimate for the *Penaeus indicus* population on April 10th is thus:
(466 x 89)/12 = 3,456

An estimated 95% confidence interval for the Petersen estimate can be given by:

nr/[m+1.96((m(1-m/n))] and nr/[m+1.96((m(1-m/n))] following the assumption that m is normally distributed with variance nr/(N(1-r/N)) (Cormack 1968). In this case the 95% confidence intervals are 2,218 - 7,828 individuals.

Estimate of fishing mortality: If the fate of the marked shrimp is taken to be representative of the fate of the shrimp population as a whole, the recapture data can be used to make an estimate of F, the instantaneous rate of fishing mortality. Although a total of 91 marked shrimp were released, 2 of these were recaptured before all releases had been completed, so it is simplest to discount these 2 early recaptures and just consider the fate of the 89 marked animals remaining at large on the 10th of April. No further releases were made after this date. The fishermen were not active for 12 days around the Sinhalese and Tamil New Year but by May 7, after 16 days of fishing, a total of 55 marked shrimp had been recaptured. After time t, the number of marked animals captured, following a constant rate of fishing mortality, is given by Nt = No(1- e-Ft), where No is the number of marked animals at large at time 0, and F is the instantaneous rate of fishing mortality. Rearranging the equation gives:-

$$F = \frac{-\ln((No-Nt)/No)}{t}$$

And solving in this case in which t = 16 days; No = 89; and, Nt = 55, gives an estimate of F (daily) as 0.0601 and F (annually) as 21.97.

Assumptions

The assumptions underlying the Petersen estimate and the estimate of fishing mortality are listed and discussed below. In general, it is felt that certain aspects of the experimental design and features of Rekawa lagoon and its fishery have combined to support the validity of these assumptions.

1. Marked shrimp retain their mark

There are several reasons to trust the adopted marking method: It was tested in laboratory trials and found to impart an easily detectable stain lasting at least 50 days. All recaptures considered in the analysis were made within 35 days of the first releases. In the field, all shrimp received almost identical quantities of dye and there was found to be very little variability in the intensity of the stain within groups of both released and recaptured animals. After marking, the use of holding cages allowed the intensity of the mark to be checked at least 14 hours after injection and just prior to release.

Numbered tags are an alternative marking method for shrimp and they can yield valuable information on movement and growth (Buckworth 1992). Nevertheless, there is always the problem of tag shedding which can occur at an unknown rate and interfere with the precision of a population estimate.

2. All recaptures are reported correctly

The likelihood that recaptures would be reliably reported is enhanced by the fact that the lagoon fishermen are very supportive of the research programme which will eventually be of direct benefit to them. The nature of the CRR experiment was explained in advance to representatives from all fishing villages and examples of marked shrimp were displayed. The Rekawa fishing community, of about 130 men, is relatively closed and news tends to spread quickly. Of the total of 57 recaptures, 46 were kept in a freezer and returned to us. The remaining 11 recaptures were recorded by people who are well known to the project and who are considered reliable. A premium price, 4 x market value, was offered for marked shrimp. Whilst recaptures have been reliably recorded, the data for catches of unmarked shrimp are incomplete, with only the Co-op making detailed records. Even the Co-op data are imperfect. Unmarked shrimp were weighed rather than counted, and the weights were subsequently converted into numbers of individuals by dividing daily total weights by the average size of prawns observed in samples. This technique may have introduced small errors, though hopefully not bias.

3. Either the population is closed or there is neither immigration nor recruitment

For most of each year, there is little or no chance for shrimp to enter Rekawa Lagoon from the sea. This is because the channel which connects lagoon and sea is interrupted at two points. Firstly there is a bar of beach sand which usually blocks the mouth of the channel and effectively creates a 'closed' body of water with only freshwater input. Secondly, there is the Kapuhenwala Causeway which, though perforated by a series of pipes, cuts across the channel and restricts the movement of water in and out of the lagoon. There is no evidence that *Penaeus indicus* can complete its life-cycle in the lagoon. Earlier studies (Ganewatte *et al.* 1995; Jayakody 1994, 1995) have revealed that it only enters the lagoon in the form of larvae or postlarvae during the brief periods when the mouth of the channel is open. As a result, discrete batches of juvenile shrimp are detectable and the progress of fishery cohorts can be tracked through each fishing season. The CRR experiment was performed at the end of the fishing season and it was evident from size-frequency data that there were no new cohorts recruiting to the fishery.

4. Death and emigration affect marked and unmarked animals equally

The possibility of differential death rates is a potential weak point for the experiment. All the same, laboratory trials, using the same dye and delivery method used in fieldwork, have shown there to be no significant difference between the mortality rates of marked and unmarked prawns. Though labwork focused on small palaemonid prawns rather than adult *Penaeus indicus*, it did suggest, for a period of at least 50 days, that there were no obvious toxic effects of marking. In the field, to eliminate any problems with immediate mortality after handling and injection, shrimp were held in cages before and after marking.

In theory, emigration could have taken place towards the end of the experiment because, for the last 10 days, the lagoon mouth was open. However, the Kapuhenwala Causeway probably impedes shrimp movements and there were kraals located in the lagoon channel to catch any shrimp which moved towards the sea. Even if significant emigration did take place, it would only undermine the validity of a Petersen estimate if marked and unmarked shrimp emigrated at different rates.

There is a possibility that marking shrimp could increase their vulnerability to visual predators. However, in Rekawa Lagoon there are reasons why this probably does not represent a significant problem: visual predators are hampered by the fact that the lagoon is typically very turbid, with Secchi disc readings of 20-50 cm near the surface and even lower visibility deeper down; *Penaeus indicus* is captured by passive methods at night and seems to be most active by night, probably remaining buried for most of the day; There is very heavy fishing pressure in the lagoon which serves to deplete the populations of possible crab and fish predators and also ensures that very few fish (except eels) ever achieve more than 25 cm TL; stained *Penaeus indicus* stand out no more than other penaeid species such as *Penaeus monodon* which has a strong banding pattern and which also occurs in the lagoon.

5. Marked and unmarked shrimp are equally vulnerable to capture
Vulnerability to capture is strongly influenced by shrimp size. In Rekawa lagoon, evidence for this is clearly provided by catch size-frequency data which indicate that small animals (2.4cm CL or less) are under-represented. Thus, for the validity of the experiment, it is important that the sizes of marked animals be representative of those in the main population. Unfortunately the mean sizes of marked shrimp (2.49cm males; 2.56cm females) were significantly less than those of shrimp being caught in gillnets at the same time (2.70cm CL males; 2.92cm CL females). This difference arose because live shrimp for marking were obtained from kraals which typically catch more small shrimp than gillnets. A sample of 26 shrimp at the time of marking included 4 animals of just 2.3cm CL. These smaller animals could have become a source of bias in recapture data but the period between releases and recaptures (minimum 13 days) would have permitted growth from 0.23 to 0.29cm CL (assuming normal growth rates observed in the lagoon) and brought the smaller shrimp into size categories which are fully represented in landings.

Vulnerability to capture would also be influenced by behaviour. If marked and unmarked shrimp displayed different activity levels then they would be caught at different rates by the passive fishing methods of gillnets and kraals. It is difficult to know if this is a significant possibility or not.

6. Marked and unmarked shrimp mix randomly and all sampling is random
To promote random distribution of marked shrimp, they were released at 3 different sites, on 6 separate occasions. In addition, all but 2 marked shrimp, which were recaptured early on, had a 12 day period without any fishing in which to disperse. The randomization of sampling effort was probably improved by the fact that we relied upon many different fishermen from different locations to make recaptures.

Discussion: The Petersen estimate used in this capture-release-recapture experiment is a single census method of population analysis which is usually considered inferior to multiple census methods such as the Schumacher-Eschmeyer or the Jolly-Seber (Cormack 1968; Ricker 1975). However, in a multiple census, samples (unless of a negligibly small fraction of the population) are usually replaced, because if they are not the population is decreasing and the population estimate cannot refer to any definite period of time. Thus a multiple census would have been inappropriate for this experiment since all samples were artisanal catches of significant sizes and neither marked nor unmarked animals were returned to the lagoon. The Jolly-Seber method also requires that different marks be applied for releases made on different days, so it is also inappropriate because the staining method used in this case does not differentiate between one shrimp or another.

The Petersen estimate of 3,456 is a useful guide to the size of the *Penaeus indicus* population on 10 April, near the end of the fishing season, and along with cohort and catch data, it helps to build a picture of the shrimp population and the impact of fishing. However, the wide 95% confidence limits (2,218 - 7,828) reveal that the estimate lacks precision. This lack of precision has arisen principally because recapture data for unmarked shrimp were incomplete and it suggests that more effort was needed during the monitoring phase of the experiment.
The experiment successfully demonstrated that only a relatively small number of marked shrimp, around 100, need be released in the lagoon to get significant numbers of recaptures in the fishery. This is due to the high levels of fishing pressure. The estimate of fishing mortality, 21.97 (annual), is a more satisfactory calculation than the Petersen estimate because it makes use of all recapture data rather than just that recorded by the Co-op. All the same, by the standards of shrimp populations exploited in the sea, it may at first appear excessively high. For example, the greatest F values calculated by Jones and van Zalinge (1981), who made a cohort analysis of the Kuwait fishery for *Penaeus semisulcatus*, are in the range 5.7 - 6.3 for the larger shrimp size categories. The difference can be attributed to the fact that Rekawa lagoon is a body of water which is largely closed and which is exploited more in the manner of an extensive farm than a typical renewable fishery resource. Each season, fishing effort, which can be equated with harvesting a shrimp aquaculture pond, continues until there is virtually nothing left (probably fewer than 1,000 *Penaeus indicus*). The arrival of new recruits in the lagoon is dependent upon reproduction in the sea rather than in the lagoon itself. The validity of the fishing mortality estimate from this CRR experiment is supported by independent cohort analysis following the method used by Jones and van Zalinge (1981). This has estimated F values to be in the range 14-34 during the most active period of fishing in the first three months of the year.

In this CRR experiment, the fact that 16 days of fishing returned 55 of 89 released animals, in a period when fishing effort was not even at its peak, has important implications for stock enhancement work. It strongly suggests that low catchability is not a problem in Rekawa lagoon and that as long as released animals survive to enter the fishery they stand a high probability of being captured. This has not been the case in all stock enhancement work. Trials with lobsters in the UK have revealed that low catchability can interfere with overall return rates even when a good proportion of released lobsters survive to market sizes (Bannister *et al.* 1994).

The use of cages was a valuable feature of the CRR experiment but it transpired that they were not ideally suited to the job of holding the shrimp. They were made of nylon fishing net and catfish were able to tear holes and scavenge dead animals and some shrimp probably escaped. This problem was eventually solved by erecting a 'fence' around the cages using the same barrier material used by kraal fishermen. Some shrimp also escaped during handling and transfer. Though 91 shrimp were successfully marked and released, these represented only about a third of the total number of live shrimp received. Cages would also be valuable for running controlled experiments. If marked and unmarked shrimp were held for extended periods, they could provide valuable information on the possibility of differential death rates and on the durability and reliability of marking methods. The injection method employed cannot convey as much information as individually numbered tags but, since the site of injection remains visible, it could be used for marks which need to be differentiated for different days or sites of release. The 2 sides of the 6 abdominal segments of a penaeid shrimp provide 12 different injection sites.

3.4 Large scale *Penaeus monodon* restocking: A total of 55,000 post larval (PL) *Penaeus monodon* were definitely released into Rekawa lagoon; it is estimated that a further 10,000 stemmed from post-larval escapes, and the subsequent fishery was monitored to assess the success of the restocking programme. The increase in catch rate of tiger shrimp in the fishery harvest from the Rekawa lagoon has shown that the restocking programme was successful in terms of harvested tiger shrimp numbers, increased income to fishermen as well as in terms of recovering the cost of the immediate costs of the restocking exercise:-

Over the sampling periods (each of 2 weeks duration), data revealed the following tiger shrimp catches (**TABLE 5**):

TABLE 5 Catches (kg) of *Penaeus monodon* following stock enhancement

DATE	Weight (Kg)
22 Sep. to 13 Oct.	130.50
14 Oct. to 26 Oct.	25.20
27 Oct. to 5 Nov.	11.15
6 Nov. to 15 Nov.	9.05
17 Nov. to 28 Nov.	7.74
29 Nov. to 8 Jan.	1.90
TOTAL	**185.54**

Subsequently small numbers of *Penaeus monodon* have continued to be caught, recently supplemented by naturally-recruited small tiger prawns (March 1997).

TABLE 6 shows the most up-to-date catch and income statistics:-

TABLE 6 Catches of *Penaeus indicus* and *P. monodon* before and after enhancement

	Fishing Season	
	Oct 95 - May 96 (before enhancement)	Oct 96 - May 97 (after enhancement*)
P. monodon catch (Kg)	16	240
P. indicus catch (Kg)	1,775	1,871
P. monodon sale price (Rupees)	8,000	120,000
P. indicus sale price (Rupees)	399,375	420,975
TOTAL Sale Price	**407,375**	**540,975**

*Season not complete, though all released *Penaeus monodon* appear to have been caught.

NOTES

1) Enhanced stocking was done in July 1996; released animals recruited to catches from October 1996.
2) Naturally recruited *Penaeus monodon* only appeared in March 1997.
3) Sale prices assumed *Penaeus indicus* at Rs 225/kg, *Penaeus monodon* at Rs 500/kg

The data presented in **TABLE** 6 reveal that the restocking programme has been associated with a 1400% increase in tiger shrimp catch over the tiger shrimp harvesting period. Based on records from the last fishing season when naturally recruited *Penaeus monodon* appeared in catches only during the latter part of fishing season (despite late-summer breaching of the lagoon-sea connection), it seems probable that all tiger shrimp caught after the restocking programme have been derived from restocked shrimp. In January 1997 a comparison of the naturally recruited *Penaeus indicus* harvests between the fishing seasons of the two years indicated that there had been a reduction in catch for this year (from 1775 to 1253 kg; see Annual Report, 1997), i.e. after the restocking programme. This raised concerns that enhanced stocking with *Penaeus monodon* might be damaging the *Penaeus indicus* fishery. However, the fishing season continued and, at the end of the monitoring period, *Penaeus indicus* catches reached 1871 Kg (with the season still ongoing). It is now clear that restocking of tiger shrimp had not adversely affected catches of this species. Reasons for increased *Penaeus indicus* catches could include stochastically increased recruitment and/or increased productivity of lagoon waters.

3.5 Second stock enhancement: A second release of postlarval *Penaeus monodon* took place on 8th July 1997 after completion of the contract period. 70,000 PLs were released following hapa rearing. 100,000 PLs had been placed in hapas at the start of the rearing process, so pre-release mortality was 30%. Mean PL size at release was 2.9cm (range 2.1-3.8 cm). Shrimp fishing was banned by community decision until September 15th. Between 15th September and September 30th 49 kg of *Penaeus monodon* were **recorded** as caught (no further data are available at the time of writing). During the period between PL release and onset of the fishing season there **were no breaches of the lagoon mouth.** A short duration breach (4-5 days) took place between September 26th and September 30th, but substantial catches of *Penaeus monodon* had already taken place before the breach was made - providing further evidence of the biological efficacy of stock enhancement. As in 1996, the September/October post-enhancement captures of *Penaeus monodon* were 6 months out of phase with the 'natural' fishery that occurs in March/April.

During the September fishery it was discovered that a shrimp buyer had been conducting illegal night fishing with the aid of fishermen brought in from outside the community. The police made several arrests, and it is now clear that unreported *Penaeus monodon* catches have taken place during **both** stock enhancements.

4. Stock Enhancement Economics

4.1 Introduction: The following analysis is based upon expenditure incurred during the ODA-supported project. It should be appreciated that this was an exploratory programme, with the main aim of determining whether released PLs recruited in detectable numbers to the fishery. Optimal economic performance was not part of the the project design. In addition, great efforts were made to secure the co-operation of the local fishing community. This made intrusive questioning (e.g. to determine likely earnings from illegal activities such as coral mining or turtle poaching) quite unacceptable. The analysis is therefore indicative only.

4.2 Costs involved in stock enhancement: Costs may be categorised under 2 headings: equipment and production costs (**TABLES 7 & 8**).

Equipment costs are an initial investment and equipment can be reused, though it undergoes depreciation. The most significant cost of the equipment component in the present study was the outlay for rearing cages (93% of equipment cost). The cost was high since these custom-made hapas were imported from the USA. Small-scale fishermen in Sri Lanka receive fishing net from the government on a subsidised basis and for any large-scale introduction of a programme, similar to the one carried out by this project, material for hapas could initially be given to the fishermen on a subsidised or later-cost-repayment basis. Local hapa manufacture would also bring substantial (but presently unquantifiable) cost reductions. It is presently impossible to give a sensible estimate of equipment costs for a sustained programme - depreciation would be severe for the hapa materials, but local manufacture + subsidized netting would decrease the initial investment dramatically.

Production costs could be regulated depending on the need of a particular lagoon, or of the fishermen, or on the numbers that require to be restocked or financial resources that are available to a fishing community. 86% of the production costs during the present exercise were devoted to purchasing PLs. The PL cost would also go down with the opening up of more cost-effective hatcheries (the Sri Lankan shrimp culture community is currently dominated by small scale producers, but the National Aquatic Resources Agency, NARA has recently recommended clustering). This could be further reduced if PLs of a size that would not escape through the hapa mesh were bought. **TABLE 8** shows costs for purchasing **all** PLs (i.e. 100,000) despite the fact that operational losses caused by the exploratory nature of the programme meant that only 55,000 PLs that were retained in the hapas until their final release into the lagoon. It is this latter cost that would really be incurred if a carefully managed restocking programme was implemented, since the hatchery would be told that a certain sized PL would be purchased and size would be screened at purchase. If the production cost was calculated on the basis of a purchase price for 65,000 PLs from the hatchery (55,000 PLs that were restocked plus 10,000 PLs that may have survived from escaped stock) it would fall to Rs 85,890. Another loss of restocked PLs may have occurred since the lagoon mouth was breached due to pressure from upstream farmers around the time that PLs were released into the lagoon. Such a loss also could be prevented (and costs for effectively-released shrimp reduced) by careful timing of PL restocking.

TABLE 7 Equipment costs (in Sri Lankan rupees and in £ sterling)

ITEMS	Rs.	£ Sterling
rearing cages x 8	61,600	733
feeding trays	300	4
poles, netting, palmyrah kraal fence*	0	0
food mincer and other tools	3000	36
ropes	1000	12
buckets, jugs, sieves	800	10
TOTAL	**65,900**	**785**

*these items were provided by fishermen without charge; accurate costing is impossible, but would be trivial.

TABLE 8 Production costs

ITEMS	Rs.	£ Sterling
postlarvae (100,000)	109,000	1298
vehicle hire (600 km x Rs 15)	9,000	107
PL feed (30kg x Rs 80/kg)	2,400	29
fish (16kg x Rs 40/kg)	640	8
clams**	350	4
oxygen	3,000	36
Labour*	3,000	36
TOTAL	**127,390**	**1,518**

*labour input: **actual**:2 biologists x 14 days and local fishermen for installing cages, assisting in feeding, transport of PLs at release. **Costed** value (Rs 3000) is for 3 men paid at local rates
**clams were collected, not purchased, but have been costed

4.3 Economic return from stock enhancement: The economic return from the stock enhancement was described in the 1997 Annual Report. The data given in that report were effective to end of February 1997. Monitoring of the fishery in March 1997 did not reveal any further appreciable input into the catch from the stock enhancement, although small sized tiger shrimp were recorded which could not have been individuals grown from the stock enhancement, but rather from naturally recruited stock.

TABLE 9 shows a redrafted version of the data, taking into account the upgraded release number assessment of 65,000.

TABLE 9 Recoveries in terms of shrimp and finance from restocking

Estimated Restocked Number	65,000
Estimated Recaptured Number (125g per shrimp)	1,920
Recaptured Percentage	3
Money Recovered from Enhanced Recaptures	Rs 120,000
Production cost of restocking (65,000 PL purchase)	Rs 85,890
Financial Surplus (65,000 PL purchase)	**Rs 34,960**
Production cost of restocking (100,000 PL purchase)	Rs 127,390
Financial Loss (100,000 PL purchase)	**Rs 7,390**

In relation to **actual** production costs, the restocking exercise lost money (Rs 7,390), primarily because of wastage of PLs that would be avoidable given more experience of operating hapas. **Projected** production costs led to a notional profit, since the sum realised from sale of recaptures was greater than the Rs 85,890.00 required for releasing the estimated 65,000 tiger shrimp (**TABLE 9**). Considering an average weight of 125g per shrimp, the table shows that a 3 percent recapture-and-harvest rate has been possible. There is now (October 1997) compelling evidence that unreported tiger shrimp recaptures have been made by some fishermen, particularly during the period that the Fishermen's Association had banned shrimp fishing. If this is also considered, then financial recovery from the stock enhancement exercise would be increased as would the recapture rate of shrimp.

The second tiger shrimp PL release exercise (in July 1997) attempted to test some of the possibilities for improving recruitment of PLs to the fishery. These include: releasing PLs further away from the lagoon mouth, timing releases in relation to lagoon mouth opening and purchasing PLs of sizes that would be retained by 2mm hapas. Full information will not be available until early 1998.

The above analysis takes no account of capital/equipment costs. As explained earlier, the initial equipment costs for the present study were substantially higher than could be achieved using local materials, particularly as it is probable that government-subsidized netting would be available; conversely, depreciation would have to be taken into account. It is likely that depreciation would be high - it is improbable that a hapa would last more than 3-5 years without total renewal. Because the restocking exercise was carried out during the season when the fishermen have no other source of income (even including illegal coral mining which is impossible during the monsoon because of rough weather), labour costs for construction of hapas would be effectively zero from a community viewpoint. Developing local manufacture of hapas was not an objective of the present study, so it is impossible to present a realistic picture of how cheaply the equipment could be produced and replaced, though conversely the capital expenditure involved in the present study should not be regarded as the norm for an on-going operation.

4.4 Effect of stock enhancement on fishery The effect of stock enhancement on the fishery was also described in the 1997 Annual Report. The relevant parts, after updating with data collected since the last report, are reproduced in **TABLE 6.**

The statistics presented in **TABLE 6** reveal that (see columns 2 and 3) the restocking programme was associated with a 1400% increase in tiger shrimp catch over the tiger shrimp harvesting period in comparison with the previous year. Based on records from the last fishing season where naturally recruited *Penaeus monodon* appeared in catches only during the latter part of fishing season, and the early results of the second restocking exercise, it can be assumed that almost all tiger shrimp caught after the restocking programme have been derived from restocked shrimp. A comparison of the naturally recruited *Penaeus indicus* harvests between the fishing seasons of the two years indicate that there have been increased harvests over the preceding year for this species also, showing that restocking of tiger shrimp has not adversely affected catches of this species. Therefore, restocking tiger shrimp at the level that was carried out does not harm naturally recruited penaeid stocks. Reasons for increased *Penaeus indicus* catches could include stochastically increased recruitment and/or increased productivity of lagoon waters.

4.5 Effect of stock enhancement on fishermen When income levels of fishermen before and after tiger shrimp restocking are considered (**TABLE 6**, last row, columns 2 and 3), there was a clear increase in income which is a 32.8% greater than the preceding season when all shrimp species are considered. Since the fishing season was still progressing, a further slight increase would be expected. When the restocked species alone is considered, a 1400% increase in income from this species has been recorded over the preceding season.

A more interesting and valuable observation is that 96 per cent of the increased income associated with restocked tiger shrimp was realised over a 2.5 month period, from October 1996 to early 1997, which was a period when income from the *Penaeus indicus* fishery was very low. The increased income during this period was therefore very useful and important for the welfare of the fishermen's families. Further, compared with the harvested *Penaeus indicus*, the tiger shrimp is larger and realises a market price that is twice as great, so fishermen prefer a harvest of tiger shrimp.

Responses from a questionnaire survey that was conducted amongst the lagoon fishermen in **April 1997** revealed that of the 85% of fishermen who were engaged in full-time lagoon fishing, all recorded an increase in income from the shrimp fishery following the stock enhancement programme. About 8% of the fishermen stated that there had been an increase in income from fish and shrimp while 92% of those who responded to the question stated that increased income was derived from the shrimp fishery alone. This increased income had been mostly used for purchase of new fishing gear, school uniforms and books for their children as well as for house repairs and purchase of transport facilities such as bicycles, showing that the enhanced incomes helped the community socio-economically.

About 62% of fishermen regarded the restocking programme as "very good" while 31% stated it to be "good", the others not having responded to the question in any way. Their liking for the restocking programme was either because of increased incomes that were derived from the programme (23%) or because it brought in an income during a period of the year when they would otherwise not derive an income from the lagoon-based shrimp fishery (70%). Thus, restocking to derive a shrimp harvest during the "off-season" has clear socio-economic benefits and is extremely attractive to the fishermen. The benefit to the fishermen and their grasp of the sustainability concept of a fishery were succinctly illustrated when 92% of the fishermen stated that they would agree to management measures such as gear limitations imposed by the Fishermen's Association for the long-term sustainability of the shrimp stocks that would be introduced to the lagoon as part of a future stock enhancement programme.

4.6 Summary of stock enhancement economics

The increase in catch rate of tiger shrimp in the fishery harvest from the Rekawa lagoon has shown that the restocking programme was successful in terms of harvested tiger shrimp numbers, increased income to fishermen and recovered most of the production costs of the restocking exercise.

The *Penaeus monodon* restocking programme had 3 major economic concerns on which its success could be evaluated economically and socially, particularly by the fishing community (see below). Another aspect to be looked at, mostly by outside environmentally-conscious parties, was the **environmental benefit** that would accrue from an environmentally-friendly farming practice as opposed to the intensive prawn farming that is practised in the north-western areas of the Sri Lanka. The latter has led to decreased biodiversity and environmental degradation. The SEMBV prawn disease which forced the majority of shrimp farms to close down and has posed a threat to prawn farm sustainability is ascribed to environmental degradation. FAO has recently been pressurised by international pressure groups not to lend financial support to such environmentally unsound, non-sustainable prawn farming practices. The success of the present programme would therefore present a tenable alternative to ecologically-unfriendly prawn farming. Other environmental benefits could include reduction in the pursuit of illegal activities such as coral-mining or turtle-poaching (by reducting the economic pressures in favour of them), though obtaining economic evidence to confirm/deny such a reduction was not possible during the current programme.

The first of the economic concerns of significance to the local community was the extent of **direct economic benefit** that the fishermen could derive as a result of the restocking programme. The **financial sustainability** of the programme depended on whether the financial expenditure for restocking could be recovered through marketing the recaptured tiger shrimps. This report shows clearly that the fishermen derived a greater economic benefit during the "with project" situation when compared with the "without project" situation. It also shows that income realised from sale of restocked tiger shrimps was comparable with the production costs of the restocking exercise itself, though further investigation would be needed to determine whether a financially viable long-term programme (taking into account capital and depreciation costs) can be devised. Part of such an investigation would have to consider the degree to which the cost of PLs could be subsidized as an alternative to welfare payments.

The **time of year** at which the fishing community could derive the economic benefit from shrimp recaptures was also important in a social context because, during the non-fishing season that extended from May/June to Sept/October, incomes of lagoon fishermen were low and they experienced serious financial and social difficulties. This is because the lagoon fishery at Rekawa is the major source of income to the lagoon fishermen and because this fishery was seasonal since it depended on natural recruitment from the sea. Consequently, fishermen do not have any income over the off-season and only a low income at the start of the fishing season. The fishing season commences around October/November and extends to about April/May, with the more valuable tiger shrimps only becoming available at the end of this period. If restocked tiger shrimp could realise a harvest over the low or no-income period, such an income would exert a much greater beneficial impact socially than could be judged through financial benefit alone. The stocking that has been carried out was done so that economic returns from the project were channelled to the fishermen in the October to December period which coincided with the lean-income period from the traditional prawn fishery. The desirability of such timing was amply illustrated when, in a very recent survey, 69% of fishermen favoured the programme because it brought in income over a lean-income period.

The other economic-related concern, that was expressed by some of the fishermen, was whether the introduction of prawn stocks in addition to naturally recruited numbers would **depress productivity** from the lagoon in relation to the traditional *Penaeus indicus* naturally-recruited fishery. A comparison of prawn yields over the pre-stocking and post-stocking periods from the lagoon based on the naturally-recruited *Penaeus indicus* stocks, shows that the restocking programme appeared not to depress the *Penaeus indicus* fishery of the lagoon. Indeed, post-project *Penaeus indicus* harvest has so far exceeded pre-project harvest quantities, due perhaps to improved recruitment and/or aquatic productivity patterns.

5. SCENARIO MODELLING OF STOCK ENHANCEMENT

5.1 Summary:

- The model is based on data collected from a release and subsequent monitoring of 65,000 post-larval *Penaeus monodon* in Rekawa lagoon. Economically, it is based on projected production costs for 65,000 PLs, not the 100,000 purchased.

- Total length of a stock-enhancement event was estimated as 139 days, which involved 14 days' acclimation of prawns, 71 days of on-growing in the lagoon and 54 days of fishing.

- Catching of >2.5% of the released prawns led to a profit (with costs including the larvae, transport and 20% wear-and-tear in equipment). Profits increased linearly with increased proportion caught.

- Two options for increasing the economic stock-enhancement potential for the lagoon were considered: a) increase the numbers released in a single release and b) performance of more releases.

- Increasing the numbers of prawns released was rejected as a option on ecological and socio-economic grounds.

- Two options for multiple releases per year were proposed which did not interfere with the period of fishing for wild *Penaeus indicus*, 1) Semi-intensive (2 releases per year), and 2) Intensive (4 releases per year).

- The intensive multiple release procedure led to a 20% increase in lagoon fishing 'profit' over a year. Increased profit was evenly spread and also kept the fishermen actively fishing for all the year.

- Profit was very sensitive to the proportion of released prawns caught. Further work should aim to determine how to maximise the proportion caught.

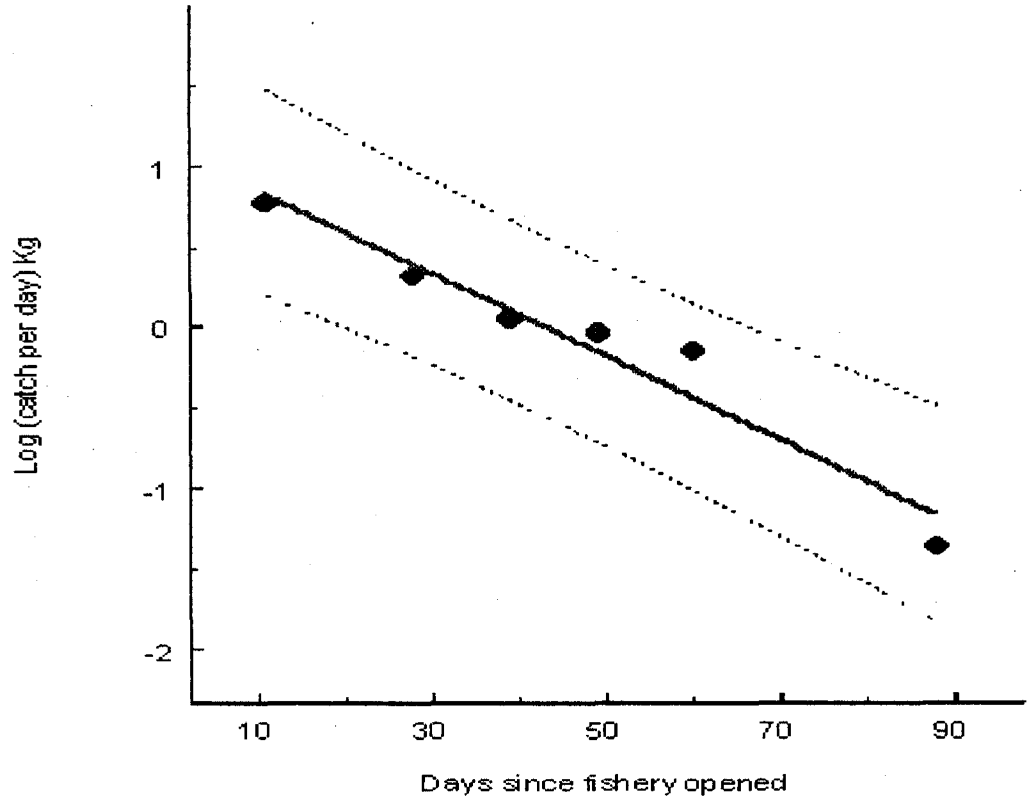
5.2 Introduction to model: The potential for stock-enhancement in Rekawa Lagoon was investigated using scenario-based simulation modelling. The data used in this theoretical investigation were from the study reported here, in which a single large scale stock enhancement was carried out in 1996/7 (full data not being available for the second release in July 1997). The aims of modelling were, assuming that the dynamics of this single large scale release would be representative of further releases, 1) to assess the sensitivity of the stock-enhancement programme to changes in catchability, increased frequency of stock-enhancement and, 2) to determine the effect of these operations on the economic situation of the local fishermen.

5.3 Description of the stock-enhancement procedure: The stock-enhancement procedure was a three stage process: 1) acclimation of PLs in netted cages (or "hapas") in the lagoon, 2) the ranching stage where the prawns grew to catchable size in the lagoon and 3) the stage where the prawns were available to the fishery. In the procedure adopted at Rekawa the acclimation stage lasted 14 days and the ranching stage was 71 days long. The period when the prawns were available to the fishery was open-ended as it was probable that small numbers of released prawns were caught a long time after release. However, the lagoon suffers strong fishing pressure and instantaneous fishing mortality has been estimated at 22, thus most released prawns would be caught soon after release.

The decay in logged catch (in Kg) of released *Penaeus monodon* per day over the course of the fishing of the released prawns can be adequately described using a least squares regression, explaining over 94% of the variation in catch over time (**FIG 5.**). It was considered that the stock-enhancement fishery was unsuitable for further exploitation when the catch rate was < 0.5 kg of prawn per day. The regression equation predicted the day at which catch rates dropped below 0.5 kg per day for the whole fishery as day 54 following opening of the fishery. This model therefore assumes the following time periods for the three stages of the stock-enhancement procedure:

Acclimation	14 days
Ranching	71 days
Fishing	54 days
TOTAL	139 days

FIG 5. Relationship between catch of prawn per day and days since the fishery was opened showing a dramatic decline over time.
(95% confidence limits displayed, r2 = 0.944, P <0.001)

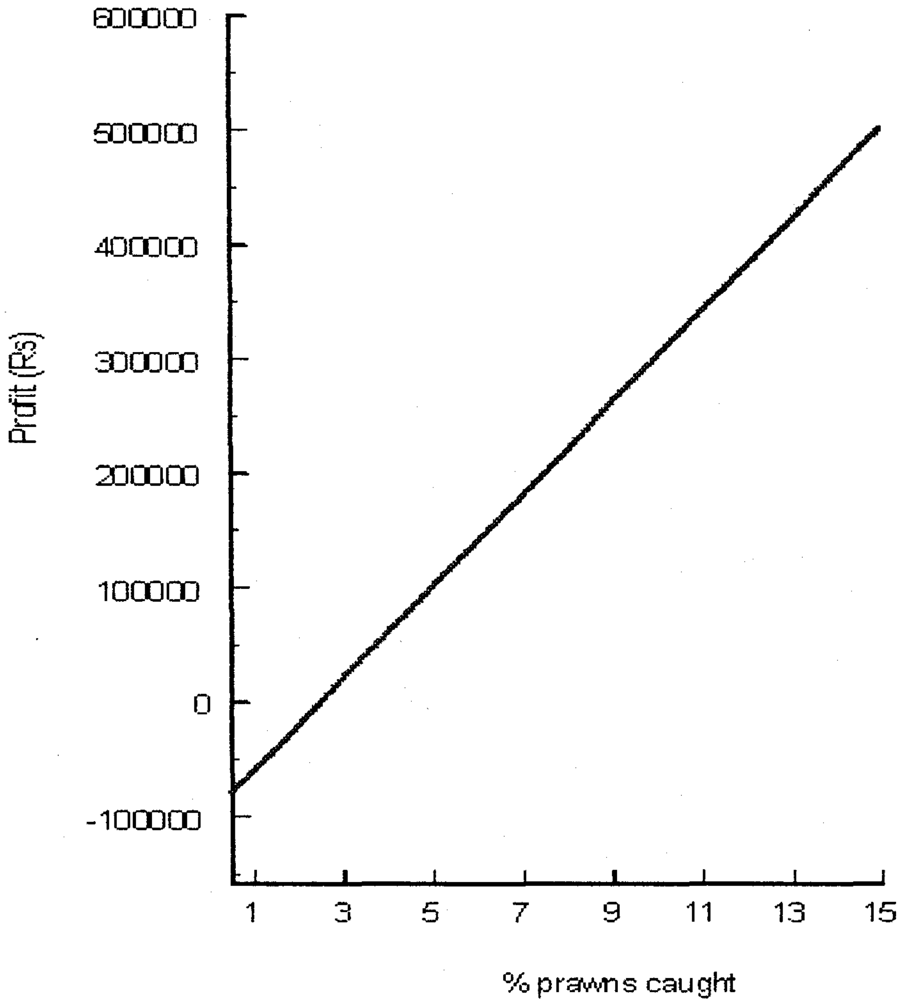


5.4 The effect of catchability on 'profit': The stock enhancement procedure resulted in a capture of a total of 3% of the 65,000 PLs that were released. Clearly, increased capture rates of released PLs would increase the net economic gain of the stock-enhancement procedure. The profit of the stock-enhancement procedure was simulated using different levels of catchability from 0.5 - 15% of the PLs released, assuming similar weight per prawn. The market cost of the captured prawns was estimated and the costs of buying and transporting the PLs to the lagoon and 20% of the equipment costs were subtracted. It was considered reasonable that 20% of the equipment costs were included in this analysis as cages and netting would tend to wear out with use and need repair. Due to the short-term nature of this project, data were not available on the depreciation of equipment, and, as already explained, the equipment costs are exaggerated because of importation of hapa netting.

FIG 6 shows the effect of increased capture of prawns as a percentage of those that were released. A regression equation fitted to this calculated the break-even point corresponded to 2.5% capture. Profit increased linearly with catch rates above

2.5%. During the stock assessment exercise the capture rate was 3%, i.e. within the profit zone.

FIG 6. the relationship between the percentage of released prawns caught and profit from the fishery. Profit starts at 2.5% prawns caught.



Prawns were sub-sampled on their release to the lagoon to determine the actual numbers released. Thus the 3% catchability found from these data represents the proportion released to those captured. It was possible that there was some loss of PLs during the acclimation stage. Although dead prawns were experienced, their number was negligible. The main loss was likely to be due to escape from the cages. This loss is unknown in this case as the PL numbers were only estimated on release rather than prior to acclimation. Care must be taken during analysis of stock enhancement projects to sample the numbers at the point of release rather than relying on estimates from the suppliers.

All *Penaeus monodon* caught following the opening of the fishery were assumed to be "stocked" individuals. The reason for this is assumption is that a) there is no natural recruitment of *Penaeus monodon* from the sea during this period as the larvae are seasonally available and not present at the time of this stocking, b) numbers of PLs or juvenile prawns in near-shore oceanic waters outside the lagoon are negligible. Natural recruitment from the sea is a variable process reliant both on the availability of larvae in the sea and the frequency and duration presumably of the lagoon being breached. The high variability in the catches of wild *Penaeus monodon* (from 16 to 240 kg per season since 1993/4) reflect the stochastic nature of this process.

A number of factors can affect the percentage of prawns caught compared with those being released. It could be that the fishing technique means that the prawns were available but not caught by the fishermen. This is unlikely since instantaneous fishing mortality is extremely high in the lagoon, while catch, mark and release experiments (upon *Penaeus indicus*) have found a high capture rate in a matter of days. It is more probable that more adults were simply not available to the fishery. Likely possible causes of this are:

1. *High juvenile mortality.*

2. *Loss of released larvae* due to breach of the lagoon wall by the sea. A breach of the wall occurred during the ranching stage of the stock-enhancement and it is possible that larvae were lost to the sea and thus never became available to the lagoon fishery.

At present no further data are available on possible causes of catchability being as low as 3%. However, a further stock release is presently underway and if catchability is comparable with the 3% obtained in the previous study, then it can probably be attributed to juvenile mortality. If this is the case then further work should be directed into decreasing juvenile mortality since **FIG 6** shows the significant effect that catchability can have on the economics of the stock-enhancement procedure.

5.5 Increasing the productivity of the lagoon using stock-enhancement: This study has shown that stock-enhancement can raise the productivity of the fishery and the profit of the fishery in Rekawa lagoon. Possible ways to raise the productivity and profit of the lagoon using stock-enhancement involve:

1. Releasing more larvae. The present study released 65,000 PLs in to the lagoon. It would be possible to release more PLs into the lagoon and if the 3% catchability was maintained, then the productivity and profit would increase. However, there are a number of factors that suggest that single releases of high numbers of larvae would not be appropriate:

a). The higher the numbers of released prawns the greater the possibility of competition, or the greater the actual competition for resources between the released individuals. This could lead either to slower growth rates, and consequently slow recruitment to the fishery, or death due to, for example, starvation. There was no evidence for competition between wild *Penaeus indicus* and released *Penaeus monodon*, as the catch of *Penaeus indicus* was 1,775 kg in the 1995/96 season and 1,871 kg in the 96/97 when the *P monodon* release took place. This suggests that even at prawn stock-enhanced density (*Penaeus indicus* plus *Penaeus monodon*), competition was not limiting growth.

The carrying-capacity of the lagoon in terms of prawns is not clear. Jayakody & Jayasinghe (1992) estimated annual production of the lagoon fishery to be 36,000 kg, with approximately 70% consisting of fish and 30% of prawns (an estimated 10,800 kg). However, wild prawn catches were approximately 2,000 kg in 1995/96 and 96/97 seasons, well below the estimate made in the early 1990's. It is not clear if the carrying capacity has actually declined, or whether limited larval supply to the lagoon coupled with high fishing mortality maintains the prawns at densities well below the carrying capacity. However, to release very large numbers of prawns could prove to be a risky strategy in terms of potential competition between juveniles (note already the possibility of high juvenile mortality causing low catchability of 3%) leading to slow growth and high mortalities and also the possibility of inter-specific competition with wild *Penaeus indicus*.

b.) One of the advantage of the stock-enhancement procedure was that it extended the fishing season. Of the Rekawa fishermen questioned after the re-stocking exercise, 93% stated that the stock enhancement was "good" or "very-good". The reason for this was primarily (70% of cases) due to the increase of fishing incomes during a period when fishing for wild stocks did not normally take place because of poor catches of *Penaeus indicus.* A single large release would certainly achieve the result of extending the fishing season, however, it would still lead to periods of fishing inactivity when the fishermen turn to other forms of activity such as mining coral reefs. Thus to extend the fishing period to cover most of the season by multiple releases would appear to be sensible in terms of the annual activity patterns of the fishermen. In addition, it could be that a large release of PLs and a high catch following the ranching period could flood the market with *Penaeus monodon* and thus push market prices down, limiting the profitability of the exercise.

2. Carrying out more releases. It would appear for the biological and socio-economic reasons outlined above that multiple releases would be a better way to achieve higher productivity in Rekawa lagoon.

In the following analysis two annual procedures are compared with a) no release and b) the single release carried out in 1996/7. It was considered that it would be unwise to interrupt the main *Penaeus indicus* fishing season (Jan - March, a total of 90 days) with released *Penaeus monodon* both for market reasons and possible competition with wild stocks, which the fishermen were worried about.

Two further stock-enhancement regimes were envisaged:

a) *Semi-intensive*. This approach uses two stock enhancements over the course of the year. Each stock enhancement procedure, as shown above, takes 139 days (14 acclimation, 71 ranching and 54 fishing). Thus each year, starting January the 1st has 90 days fishing for wild *Penaeus indicus* followed by a first stock enhancement (day 90 to day 229) followed by another stock enhancement (day 230 to 369). The total days for this procedure is 369, but minor changes in the release dates can be accommodated to fit this procedure into a year.

b) *Intensive*. This approach uses a total of 4 releases over the course of the year but does not interfere with the *Penaeus indicus* fishery. The initial stock enhancement commences at the end of the main *Penaeus indicus* fishing season (day 90). A further stock enhancement programme is started 14 days prior to the commencing of fishing for the first release. This is repeated four times through the year. Each stock enhancement is thus nested within the previous one, with a cycle time of commencing releases every 71 days. A total of 4 releases can be made this way, with the 90 days of *Penaeus indicus* fishing followed by four 71 day cycles of stock enhancements. This makes a total of 374 days; again this plan can easily be modified to fit conveniently into a year. This design has a number of advantages:

1. The fishermen remain actively fishing for most of the year. The period of relatively intense work on acclimating PLs (which involves daily feeding etc.) occurs prior to the opening of the season for the previous stock-enhancement. This has two advantages in that (i) the fishermen will not be busy fishing for the prawns as there will very few left at this time, and will thus have time available for PL husbandry, (ii) on the commencement of fishing for the previous stock-enhancement, the PLs just released will be too small to catch in the nets. It is possible that catching of newly released PLs together with the adult prawns could be a problem. This could be solved by an increase in mesh size since, in a questionnaire of the Rekawa fishermen, 92% said they would agree to management measures such as gear limitations for the long term stability of stocks.

2. The income over the course of the year will be relatively constant -which is an important issue to the fishermen.

3. The release of the PLs from the cages coincides with the opening up of the fishery for ranched adults. The heavy fishing pressure on the recruits to the fishery will mean that there would be little possibility of competition between the on-growing PLs and those prawns recruited to the fishery. As the ranched prawns grow bigger, then removal of many of the individuals derived from the previous stocking exercise will open up available food resources. This should help to limit any possibility of competition between stock enhancement cohorts.

TABLE 10 gives an assessment of the semi-intensive and intensive stocking programmes in comparison to no stocking and a single stock exercise:

Programme	**Production (kg *Penaeus monodon*)**	**Stock Enhancement Profit* (Rs)**	**Total profit** (RS)**
No stocking	-	-	420,975
Single stock	240	20,930	441,905
Semi-intensive	480	41,820	462,795
Intensive	960	83,720	504,695
Intensive - 4% catchability	1280	243,720	664,695

* *Stock Enhancement 'Profit'* is the marketable value of the production of *Penaeus monodon* (1 kg = Rs 500), minus the cost of PL supply and 20% equipment costs per stocking.
** *Total 'profit* 'is the Stock enhancement profit plus the total catch of wild *P. indicus* and *Penaeus monodon* taken from Rekawa in the 1996/7 season.

This table shows that it would be possible, through an intensive stocking programme, to raise the profit in fishing from the lagoon by 20%. Due to the temporal separation of re-stocking and the main period of fishing for *Penaeus indicus* , no impact on the *Penaeus indicus* fishery would be expected.

If an intensive stocking procedure was adopted and the catchability raised by 1% (from 3% to 4%) then the potential profit from the lagoon would be in the order of 50%. The amount of profit was heavily reliant on the catchability because the production costs and 20% equipment cost per stocking were standard for a release, and from the analyses above the break-even point was 2.5% catchability.

Labour costs have not been included in the above analyses, because the system would not necessarily involve them. If an intensive stocking regime was carried out the fishermen could be fully employed in the process, either fishing or tending the acclimating PLs in the cages. The financial benefit gained from the stock enhancement by the fishermen would effectively pay for the labour involved in the tending of the PL prawns. In addition, the period of getting little pay during the 14 day acclimation process would be followed by the opening of the fishery with a new cohort, thus fishing during this period would entail high catches and profits. The other advantage to not using outside labour, beside the costs, is that the whole management of the fishery would be performed by the fishing community itself.

It would be important to carry out further work to determine the reason for the low catchability; efforts should be made to try to improve the proportion of released prawns that were subsequently caught because profit was sensitive to catchability. At present a further stock-enhancement is taking place at Rekawa, and, given that there was no breach of the lagoon wall during the ranching stage (a breach did not take place until after the fishery had opened), then the reason for the low catchability (loss of larvae to sea or high juvenile mortality) can be determined.

6. DISSEMINATION OF INFORMATION

6.1 Material already disseminated:

Professor Ekaratne has given presentations to local organizations at Rekawa. In addition, a paper (to be published) was presented at a UNESCO Regional Workshop on community based management of natural resources, New Delhi, India, in January 1997:

'Community Based Coastal Natural Resources Management as exemplified by the Lagoon Prawn Fisheries at Rekawa Lagoon'

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Abstract

The development of export-oriented *Penaeus monodon* farming in North-West Sri Lanka has led to the large-scale destruction and alteration of brackish-water coastal habitats such as mangroves, lagoons and estuaries . Effluents from prawn farms pollute brackish waters making farmed prawns susceptible to diseases such as white spot disease that has resulted in closure of many prawn farms. With increasing pollution resulting in depressed prawn farm production, entrepreneurs have considered extending farming operations to southern coastal areas such as around Rekawa lagoon, which the local community has resisted, fearing disruption of their traditional life styles and that pollution and habitat degradation would deplete lagoon resources to eventually deprive traditional fishermen of their livelihoods.

The 7-month traditional prawn fishery at Rekawa lagoon uses the traditional kraal (17%), cast nets (9%), gill nets (74%) and traditional non-mechanised boats. Predominantly *Penaeus indicus*, and lesser quantities of *Penaeus monodon*, are harvested by the closely-knit conservative rural fishing community practising conventional customs and beliefs.

The fishing community has adopted several community participatory measures to manage their aquatic resources sustainably against depletion and outside intervention. Fishermen have formed a Lagoon Fishermen's Association which now stores the prawn catch in a community freezer to sell it direct to consumers whereas it was traditionally sold at landing to itinerant middlemen. Periodically, the community reviews the lagoon prawn resource and regulates fishing gear. A recently started on-going programme of stock enhancement is viewed as an environmentally and socially friendly alternative to prawn farms with which the community is actively participating while learning the process.

6.2 Future plans: Professors Davenport and Ekaratne will ensure that paper(s) will be written for submission to international peer-reviewed journal(s) as soon as possible.. This will be done immediately after the full results of the second release of post-larvae become clear (in late 1997).

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Appendix 2

RNRRS PROJECT COMPLETION SUMMARY SHEET

Date Sheet Completed
17-4-97

TITLE OF PROJECT: Enhancement of a lagoon prawn fishery at Rekawa, Sri Lanka
R NUMBER: 627
PROGRAMME MANAGER (INSTITUTION): Professor John Davenport, UMBSM
SUB-CONTRACTOR (if relevant): Prof S U K Ekaratne, University of Colombo
RNRRS PROGRAMME PURPOSE: Yields from enhanced fisheries by optimal strategies for stocking and harvesting.
RNRRS PRODUCTION SYSTEM: Land-Water Interface
COMMODITY BASE: Fisheries/prawns
BENEFICIARIES: Artisanal fishing community
TARGET INSTITUTIONS: Fisheries Departments, Research Institutions, Regulatory Authorities
GEOGRAPHIC FOCUS: Sri Lanka

	Planned	Actual
START DATE:	**March 1995**	**March 1995**
FINISH DATE:	**March 1997**	**March 1997**
TOTAL COST:		

1. Project Purpose:

Prawn catch of lagoon increased and sustained by stock enhancement. Economic value of lagoon stocks increased to divert attention from coral mining and turtle poaching. These purposes were not changed. An additional purpose was to develop a good prawn marking system.

2. Outputs:

1. 'Evaluation of contribution of added PL seed to fishable stocks' (successfully achieved). 2. 'Estimation of lagoonal prawn stock size' (successfully achieved). 3. 'Development of models' (successfully achieved for *P. indicus* ; natural populations of *Penaeus monodon* too low to permit analysis). Additional outputs: 1. Considerable detail of economics of prawn fishery and financial benefit of stock enhancement gained. 2. Development of successful prawn marking technique employing injected Fast Green dye.

3. Contribution of Outputs to Project Goal:

1. Successful prawn marking allowed a good picture of the fishery to be obtained. 2. Out of season stock enhancement permitted a very accurate estimate of the contribution of PL seed to the fishery as seed could not be confused with natural *Penaeus monodon*. Collection of financial information allowed a good estimate of

the financial benefits to the community produced by the stock enhancement process.

4. Publications:

(in press). Published proceedings of a UNESCO Regional Workshop on community based management of natural resources, New Delhi, India, in January 1997:

'Community Based Coastal Natural Resources Management as exemplified by the Lagoon Prawn Fisheries at Rekawa Lagoon'

S.U. K. Ekaratne , John Davenport, D. Lee and R.S. Walgama

5. Internal Reports:

Progress Reports (25-6-95,19-9-95, 20-11-95, 13-2-96, 1-5-96 [Annual Report], 14-6-96, 11-9-96, 15-11-96, 19-1-97, 5-3-97[Annual Report]). Draft final Report 17-4-97. Supplementary Report 30-6-97. Final Report 30-10-97.

6. Other Dissemination of Results:

Professor Ekaratne has given presentations to the Rekawa community and local competent authorities at intervals during the programme (this maintenance of information flow has permitted subsequent meaningful questionnaire surveys). Professors Davenport & Davenport intend to work up the study for publication in refereed journals shortly.

7. Follow-up indicated/planned:

1. The Rekawa community is convinced of the value of prawn stock enhancement and is negotiating with Sri Lankan authorities for the programme to be maintained.
2. Prof Ekaratne and Prof Davenport wish to repeat the exercise, but in lagoon(s) with more communication with the sea. This will allow assessment of whether PLs can retain position within more open bodies of water. Prof Ekaratne is currently evaluating possible sites in southern Sri Lanka.
3. The State Fisheries Department is so impressed with the results of the Rekawa lagoon experiments that it is (October 1997) examining the possibility of a restocking exercise within the much larger and fully open Negombo Estuary (close to Katunayaka International Airport).

8. Name and Signature of author of this report.

Professor John Davenport