Development of More Efficient Traps for the North West Shelf Fishery

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FINAL REPORT

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Contents

A Introduction

The North West Shelf of Australia, which covers an area of approximately 67 000 km^2 from 114^o E to 119^o E and extending out to 200 m depth, has been exploited by foreign fisheries since the late 1950's (Sainsbury 1987). The main fish groups taken by these fisheries are threadfin bream (*Nemipterus*), emperor (*Lethrinus*), tropical snapper (*Lutjanus*), tropical cod and coral trout (*Epinephelus* and *Plectropoma*). Since the 1970's, the catch rates of the highly desirable species such as the large *Lutjanus*, *Lethrinus* and Serranidae have decreased while the catch rates of less desirable fish (e.g. Mullidae, *Saurida* and *Nemipterus*) have increased (Sainsbury 1987).

Australian fishing in the area has recently increased though the domestic fisheries are at present small (the 1988–89 catch was 990 tonnes, mostly of *Lethrinus*, Serranidae and *Lutjanus*; Northern Fisheries Research Report, November 1989), but have about doubled their catch over the past three years and are expected to expand further.

One of the promising domestic fisheries in the area is a demersal trap fishery. Fishing operations are centered mainly on the towns of Onslow, Port Samson and Port Hedland. The fishery uses circular or 'O' traps (see Bowen 1961 and Moran et al. 1988).

Preliminary observations of the trap fishery by the Western Australian Department of Fisheries (M. Moran, pers. comm.) and preliminary trials with 'O' traps on the North West Shelf by CSIRO (RV *Soela* Cruise Report 6/86) indicated some unusual features of trap fishing on the North West Shelf. In particular, the duration of trap–sets on the North West Shelf were very short compared to those used in trap fisheries elsewhere, and escapement of fish from the traps appeared very much higher than that reported for other tropical trap fisheries. Wolf and Chislett (1974) and Crossland (1976) found that the 'O' trap was not as effective as either the Antillean 'Z' or the Caribbean 'S' trap, and it was suspected that the unusual operation of traps on the North West Shelf was related to the low effectiveness of 'O' trap. Consequently, CSIRO applied for funding from the Fishing Industry Research Trust Account in 1987 to examine the factors affecting fish capture by 'O' traps on the North West Shelf, compare the performance of various trap designs, and use the results to suggest improvements in the design and use of traps on the North West Shelf.

The research program had five specific objectives:

(1) To compare North West Shelf traps and trapping techniques with those of northeastern Australia and the world.

(2) To observe in situ fish behaviour to various fish trap designs, using underwater cameras.

(3) To compare the catching performance of various fish trap designs and baits.

(4) To develop models to predict the relative catch rate and efficiency (i.e. proportion of fish retained) of various trap types.

(5) To use the above observations to suggest improvements to the design of fish traps and techniques for their operation on the North West Shelf.

The general operation of the fisheries and trap types used in northwestern and northeastern Australia (Objective 1) were examined during a 'fact–finding' visit to each area in 1988, which included participation in commercial fishing trips. Objectives 2 and 3 were addressed with two trapping experiments conducted around the Lowendale Island group during 6–20 May and 12–26 August 1988. The relationship between catch and soak time was determined for four trap types ('O', 'Z', 'S' and 'Rotational') and two bait types (pilchards, *Sardinops neopilchardus*, and chopped *Lethrinus choerorynchus*). Previous studies of the operation of fish traps have relied solely upon analysis of catch versus soak time data. This approach has some drawbacks. In particular, the number of trap–sets must be large to make statistically significant conclusions possible. There are no direct observations on fish turnover within the traps, so this must be calculated by assuming a mathematical model of the fish ingress and egress processes, and the exact role of the bait in the capture process is difficult to ascertain.

In this study, video cameras were mounted above some traps during the trials to provide direct observations of the separate processes involved with fish capture: arrival of fish at the trap site, fish ingress, use of the bait, and fish egress (escapement). Direct observation of these processes allows development of models of the operation of baited traps that are based on observed, rather than assumed, processes (Objective 4). The processes that affect the effectiveness of different trap types can then be identified. Also, the relative efficiency of different trap types can be assessed from fewer trap–sets if process–related models are used, because parameter estimation of these models is based on a large number of observations of individual events rather than the small number of observations of the catch resulting from these events.

B Summary

The most significant findings of the study were:

1 A method was developed to rapidly assess the effectiveness of trap designs and identify the causes of differences in effectiveness.

2 Fish entry and escape probabilities are correlated across trap designs. The probabilities are very high for 'O' and 'S' trap designs and are much lower for the 'Z' design. Traps with high entry and escape probabilities are best for a fishing strategy based on short soak times, while traps with low probabilities are best for strategies using long set times. 'Z' traps provide a greater catch per set than 'S' traps for soaks longer than about 4 h, while 'S' traps provide better catches for soaks shorter than about 4 h.

3 The escapement of fish from the North West Shelf 'O' trap is high, with 40% of fish escaping in the first hour.

4 Bait type and the development of a large bait plume of bait particles in the water (burley) are very important to the operation of the trap. Bait effectiveness is strongly influenced by the ease with which fish already in the trap can disperse the bait into the water by their feeding activities.

5 Pilchard bait is 4–5 times as effective as trash fish bait, with the pilchard bait being lost to the trap within 4 to 5 hours.

6 Trap catches show a gear saturation, or volume limiting, effect.

7 Water current direction, relative to the trap entrance, affects the probability of fish entry to the trap. When the entrance faces away from the current the probability of entry is about 50% higher than when the entrance faces into the current.

8 Large predator fish (cods) enter traps to feed on captured fish rather than the bait.

9 The fishing strategy used on the North West Shelf (i.e. few traps, short soak times, expensive but effective bait) provides a higher catch per day and relative revenue per day than the trap fishing strategy commonly used elsewhere (i.e. many traps, long soak times, cheap but ineffective bait). The catch rate on the North West Shelf is very high compared to other trap fisheries.

10 The combination of the bait plume effect and gear saturation results in trap catch rates not being proportional to fish density, as they are often assumed to be in stock assessment and resource surveys. Methods of calculating an index that is proportional to density have been developed.

11. A prototype trap was developed to try to increase catch rates by using the information and results obtained from the study. However, the catch rates of this protoype were not significantly different from those of the 'O' trap, but they are expected to improve with minor modifications to the design.

C Summaries, Results and Conclusions by Component

C1 Comparison of North West Shelf traps and trapping techniques with those of northeastern Australia and the world

Details are provided in Sections E1, E2 and E4.

The trap fishery on the North West Shelf of Australia is unique in its trap design and trapping operation. The 'O' trap is not used in any other fishery. No other commercial trap fishery operates the traps so intensively (i.e. using a small number of traps pulled frequently to give very short soak times), and the bait used on the North West Shelf is of unusually high quality (and cost). The 'O' trap was found to give a lower catch per set than other trap designs during both scientific trials in the caribbean and less formal industry trials in northeastern Australia. Despite this, the catch per boat day obtained by trap fishermen on the North West Shelf is very high by world standards, and about four to five times higher than that obtained by similar–sized vessels on the northeast coast of Australia.

Attempts were made to use the northeastern style of trap fishing on the North West Shelf. Large (1.2 x 1.8 x 1.4 m) rectangular traps were baited with chicken offal and deployed with long soak times (see Section D2.2) from FRV *Soela* on the North West Shelf in September 1988. The results were very disappointing. The average catch per trap–set was 2.75 kg for 20 trap–sets with from one to three days soak time (average 1.8 days). The large size and poor manoeuverability of FRV *Soela* often resulted in traps being set away from the bottom features identified acoustically and targeted for trapping, and this undoubtedly contributed to the low average catch rate. However it was also clear that the rectangular traps with offal bait and long soak times provided much lower catch rates on the North West Shelf than the intensively worked and pilchard–baited 'O' traps. Some difficulties were encountered during long sets with 'lice' (assorted isopods) attacks on fish in the traps. It was not uncommon to find all the flesh of trapped fish removed by these animals.

The northeastern and northwestern trap fisheries differ greatly in the port and marketing infra–structure available, with the North West Shelf fishery being relatively poorly supported. This is to be expected because the northeastern trap fishery is just one of a number of established fin fisheries in the area, all of which share the same infra–structure to reach relatively nearby markets. By comparison the North West Shelf fin fisheries are recent developments, small and far from markets. The fishermen in both fisheries repeatedly emphasised the importance of good marketing arrangements to the well–being of their fisheries, and that lack of these arrangements can limit the development of their fisheries.

C2 In situ observations of fish capture by traps, using underwater cameras

Details are provided in Sections E4 and E6.

Video camera deployment

Two self–contained Sony video cameras were used to record the movements of fish in and around the traps. Each camera was fitted with a semi–fish eye lens and mounted in an aluminum waterproof housing (see appendix 1) above a trap. The camera was mounted over the trap on a tubular aluminum frame clamped to the side of the trap. It was positioned about 1.5 m above the trap and offset 0.75 m from the trap centre, giving a field of view of the sea floor of about 2.5 m diameter, which was about 1 m more than the diameter of the traps.

The cameras were used in the long–play mode and after a modification to their power pack could provide up to 3 h of continuous video recording. No artificial light was used and no cables were attached to the cameras, so that fishing operations for traps mounted with a camera were conducted normally.

Flowmeters were used on 22 of the trap sets to give quantitative information on the speed and direction of the current during the trap set. The current meters were secured inside the trap frame and oriented so that the trap entrance was at zero degrees on the flowmeter directional scale. A fine yellow ribbon was attached to the top of all traps being video–recorded, which enabled a qualitative indication of current speed and an estimate of current direction to be obtained from the video images.

Analysis of video tapes

All video recordings were recorded on 3 h video 8 tapes and analysed with a Sony EV–S850PS recorder. A time code was put onto all video tapes with a Skotel TCR–80 time code reader, so that all events could be easily recorded in real time.

Each video tape was examined and the following data were recorded:

- the time of each fish's entry and fish's exit from the trap, and the type of fish

- the number and type of fish in the 0.5 m region around the trap in each 30 sec interval; this area was regarded as containing the local 'pool' of fish available for entry to the trap.

- the direction of the current relative to the trap entrance and a qualitative assessment of current strength (none, weak and strong).

•any specific aspects of fish behaviour in relation to the bait, other fish (interspecific and intraspecific), and searching for the trap entrance/exit.

Fish types were recorded as *Lethrinus*, *Lutjanus*, Serranidae, Carangidae, large non–commercial fish (unable to pass through the trap meshes), small non–commercial fish (can pass through the trap mesh, but are longer than about 10 cm), and very small non–commercial fish (less than about 10 cm long). It was not possible for the viewer to reliably follow all individual fish, and so it was not possible to record how long each fish remained in the trap or whether it escaped.

Accurate recording of these data often involved multiple re–runs of the video images, and required about 350 h of video observations to record the data from the 204 h of trap fishing time observed across 104 trap–sets.

Video results

The use of video cameras to observe the behaviour of fish around the traps was very successful. The cameras and housings proved to be very robust under field conditions, with a high–quality record of the observations being permanently and cheaply stored.

The results of detailed quantitative analysis of the video data and the processes involved with capture of the fish by traps are provided in Sections C5 and E6. However, some general points emerged from examination of the video tapes:

•Escapement of fish from the traps is very high. trap–sets of commercial duration (1–2 h) catch only about 40% of the fish that enter the trap.

•*Lethrinus* and *Lutjanus* fishes enter the traps to eat the bait, whereas serranids (including coral trout, *Plectropomus maculatus*, and Rankins cod, *Epinephelus multinotatus*) were very rarely seen eating the bait; instead they preyed on smaller fish (primarily *Lethrinus*) in the trap. Nearly all the coral trout and cod observed spent their time pursuing smaller fish around in the trap, or, when they were outside the trap, often attempted attacks through the walls of the trap. After feeding in the trap, coral trout and cod had little difficulty finding the trap entrance/exit; most captures of these fish resulted when the trap was pulled while the fish was still hunting. *Lethrinus* and *Lutjanus* fishes usually feed at the bait immediately upon entering the trap, then show a pattern of behaviour that included swimming around within the trap, resting and then further feeding. A group of non–feeding fish in the trap often began to feed again when any one fish began to feed.

•Current direction has a very strong effect on the angle (with respect to the trap entrance) at which fish first encounter the trap, and strongly influenced the time it took a fish to find the entrance after arriving at the trap. Almost all fish arrived at the trap site from down current, and fish entered the trap most readily when the trap entrance faced away from the current. Fish resting in the trap mostly faced into the current.

C3 Comparison of the catching performance of various fish trap designs and baits

Details are provided in Section E5.

It was expected that the relatively small number of trap–sets possible during this study would not allow a powerful test of comparative catch rates across trap designs and bait types, and that comparisons of gross catch rates would be of limited value in determining why different trap type–bait combinations performed differently. These limitations were overcome by development of the process model of fish capture and using the video observations. However, direct comparison of catch rates allows identification of major differences in the performance of trap and bait types, and provides direct observations of the relationship between catch and soak time against which the predictions of the process model can be assessed.

Methods, traps and baits

Two fish–trapping experiments were conducted off Lowendale Island, on the North West Shelf. The first study, in May 1988, was to determine the effects of soak times (1, 2, 3, 6, 9, 12 and 24 h) on total catch rate and species composition of the catch for 'O' traps with pilchard (*Sardinops neopilchardus*) bait. The second study, in August 1988 was to examine the catch rates of 4 trap types and 2 bait types over a narrower range of soak times (2, 4 and 6 h).

The four trap types examined were;

1)The 'O' trap. This trap, which is unique to Western Australia, is used in the Snapper fishery of Shark Bay and the North West Shelf (Bowen 1961, Moran et al. 1988, Dews 1990a).

2)The 'Z' trap, which is commonly used in the Caribbean (Hull 1981, Von Brant1972, Wolf and Chislett 1974).

3)The 'S' trap, which is used in Cuba (Munro 1983).

4) A CSIRO–designed 'Rotational' trap (see Section E5).

The rotational trap consisted of a standard 'O' trap mounted on a spindle to allow free rotation, with vanes fitted internally to ensure that the trap entrance always faced into the prevailing current. It was developed to take advantage the fish behaviour seen in the videos (i.e. that fish encounter the trap coming upstream, that entry to the trap is easiest if the entrance faces downstream, and that fish in the trap tend to rest facing upstream).

The two bait types were pilchard (*Sardinops neopilchardus*) and chopped fish (mainly lesser spangled emperor, *Lethrinus choerorynchus*). Traps were set with about 4 kg of bait. On retrieval the proportion of bait remaining was estimated.

Results

Statistically significant differences were found in the catch of pilchard–baited 'O' traps with season and soak time. The highest catches per set were obtained in May from 2–9 h soak times. The highest catch per unit soak time resulted from a soak time of 1 h. For the soak times examined in August (up to 6 h), no significant difference was detected in the catch per set of the different trap types. There were significant differences in the total catch between the cruises. There was a significant difference in the catch per set between the 2 bait types, with pilchard bait giving considerably larger catches than chopped Emperor. The amount of pilchard bait remaining in the trap decreased rapidly to about 35% after the first 3 h of soak time, then reduced more slowly to leave about 20% remaining after 6 h. The amount of fish bait remaining in the trap showed no evidence of reduction after 6 h of soak time.

The species composition of the catch of all trap and bait types showed no overall significant change with soak time.

C4 Development of a model to predict the catch rates of various trap types

Details are provided in Section E6.

The video tapes allowed continuous records to be made of the number of fish within 0.5 m of the outside of the trap (i.e. the 'pool' of fish available to enter the trap), the entry of fish into the trap, the exit of fish from the trap, the abundance of small non–commercial fish, and the current speed and direction. These data allow direct calculation of the probability of an individual fish from the pool entering the trap over any time interval and the probability of an individual fish escaping from the trap over any time interval. Mathematical models of four processes were developed and the model parameters estimated from these data.

The four processes modeled were:

(1) the loss of bait from the trap
(2) the attraction of the fish from the general environment into the pool of fish available to enter the trap
(3) the entry of fish into the trap from the pool of available fish
(4) the exit of fish from the trap.

Together these models make it possible to predict the change in catch with soak time for the trap and bait types examined. The reliability of the combined model was determined by how well it predicted the catch vs soak time relationship for trap–sets that were not video–taped and so were not used in estimating model parameters.

Process model 1: the loss of bait from the trap

This model predicts the quantity of bait lost during the course of a trap–set. The parameters were estimated by minimising the sum of squared deviations between the observed and predicted amount of bait remaining at the end of a trap–set. Bait loss was considered to result from two processes: dissolution and the action of fish in either eating or dispersing the bait. The loss of bait due to fish activity was considered to be fish–type specific, and also to depend on the time since the fish entered the trap (i.e. a hunger–satiation effect). With a measure of the amount of bait actually eaten, this model allows calculation of the amount of bait that is dispersed into the water to act as 'burly' for the attraction of fish to the trap site.

The observed variables used to calculate the predicted bait loss were the number and type of fish in the trap per 2 min interval; auxiliary information on the amount of bait consumed per fish was also used.

All the examined processes contributed significantly to explain the observed data. For pilchard bait in 'O' traps the rate of bait dissolution was 1 g /min, while the bait loss was 52 g/min for each lethrinid that entered the trap, 227 g/min for each lutjanid, and 61 g/min for each individual of the large non–commercial fish type. After entering the trap, fish were found to spend, on average, the first 3 min eating at the bait, and about 84% of the bait was dispersed rather than eaten.

Process model 2: attraction of fish to the vicinity of the trap

This model predicts the arrivals of fish at the trap site. The parameters were estimated by minimising the sum of squared deviations between the observed and predicted numbers of fish in the 0.5 m wide region around the trap (i.e. the 'pool' of fish available for capture) during each 2 min time interval.

Two processes were regarded as resulting in fish arrival at the trap: fish either 'randomly' encounter the trap or are attracted to it when they detect a plume of bait–derived material in the water. The rate at which bait is added to this attracting plume (the bait flux) is determined by the dissolution rate of the bait and the rate at which the bait is dispersed by feeding fish (given by process model 1). The area influenced by the bait plume was related to the bait flux in a given time interval in a manner consistent with a diffusion process in a current with an unknown minimum detectable concentration. Bait flux and fish arrival to the pool were related with time lags of 0, 1 and 2 time intervals. The number of available fish in the broad environment of the trap (i.e. responsive fish that are outside the pool but could be reached by the bait plume) is considered fixed by the fish density at the start of the trap–set, and fish that escape from the trap are assumed to be unavailable to further capture because they are satiated. Consequently the number of fish available for attraction to the trap is finite and will diminish as fish are attracted and 'processed' by the trap. The 'random' arrivals of fish at the trap also come from the fish in the broad environment of the trap, and so are also influenced by local depletion. In each time interval, fish in the pool around the trap have a certain probability of remaining in the pool, entering the trap, and returning to the group of available fish in the broad environment around the trap.

The parameters of the processes modelled were assumed to be the same for all trap–sets, but the density of available fish in the broad environment of each trap–set was regarded as being trap–set specific. The model of the attraction process for n trap–sets contains n+6 parameters, but the estimates of the n parameters giving the trap–specific density can be expressed in terms of the other parameters and the observations, so that all estimates are reasonably easily found.

The observed variables used to calculate the predicted number of fish in the pool were the number and type of fish in the trap per 2 min interval and the number and type of fish entering the trap; the predicted bait flux from model 1 was also used. Separate estimates of all model parameters were made for the data collected in May and August because the catches and observed pool sizes were much higher in May than in August.

Both random arrival and bait–flux attraction were found to be significant processes in determining the number of fish in the pool around the trap, and for pilchard bait the bait–flux effect is more than 10 times as important as random arrival. The very strong feedback between the bait–flux generated by fish already in the trap and the attraction of additional fish to the trap site has many consequences, including:

- easily dispersed baits would be very effective while they last, but there will be a trade–off between bait effectiveness and bait longevity

- bait containers that prevent fish accessing the bait will greatly decrease bait effectiveness, but increase bait longevity

- identically set traps at the same location can give highly variable catches, because the feedback mechanism will operate to differentially increase the catch of traps already containing fish; and consequently the entry of the first fish into one trap will increase the chances of that trap receiving subsequent fish from the same area.

- baited traps in areas of high fish density will fish a larger area than traps in areas of low fish density.

- the catch per unit effort from baited traps will not give a proportional measure of fish density, even if standardised for soak time; this has important implications to assessment of fisheries that use baited traps.

The parameters of the process model determining the area of influence of the trap and the probability of fish returning to the broad environment of the trap from the pool were consistent between seasons. The large seasonal difference in the number of fish attracted to the trap was interpreted as being due to a large difference in the density of available fish, rather than to a change in the process of attraction and retention at the site of the trap. Whether this difference was due to a seasonal difference in absolute fish density or a difference in fish responsiveness cannot be determined from the available data.

It is very interesting to notice that it was possible to estimate a relative density specific to a trap–set, as this indicates that baited traps could be calibrated to provide a density index. The density index obtained is most easily interpreted as an estimate of the arrival rate of fish at an unbaited trap at that location. The index removes the feedback effect of fish in the trap on the arrival of additional fish, which would introduce high variance and bias to the index, but still allows use of baited traps so that the index for a particular site can be quickly determined (it would take many hours or days of observation to directly measure the rate of arrival of fishes at an unbaited trap). However the estimate of a trap–specific density can be readily confounded with the parameters determining the area of influence of the bait plume (i.e. a large plume in a low density area is difficult to distinguish from a small plume in a high density area) and the estimation is most successful if each trap–set provides observations over a wide range of bait fluxes. For ideal estimation of a density index the bait should be removed for some, relatively brief, period during each trap–set.

Process model 3: entry of fish into the trap from the vicinity of the trap

This model predicts the probability that a fish in the pool around the trap will enter the trap. The parameters were estimated by minimising the sum of squared deviations between the observed and predicted probabilities of entry for 2 min time intervals. Two approaches were taken: estimation of a simple, constant, probability of entry, and development of a more complex model with which to test the importance of particular mechanisms. The constant entry probability approach allows for easy initial comparison across trap designs, and can be related to the estimates of previous research. The more complex model investigated a dependence of the entry probability on the bait flux, the presence of very small fish in the trap, the number of fish in the pool, trap saturation (a limit on fish density within the trap), the entrance alignment with respect to the current direction, and the biomass of serranids already in the trap.

The observed variables used to calculate the predicted entry probability were the number and type of fish in the trap per 2 min interval, the number and type of fish in the pool and the current direction with respect to the trap entrance; auxiliary information from the bait flux model (process model 1) was also used.

The data allowed parameter estimates with good precision and low correlation (i.e. little confounding among parameters). The best estimate of the overall (constant) probability of a fish in the pool entering the 'O' trap per 2 min was 0.09. The probability of fish entry was found to be (1) strongly increased by the bait flux (and hence by the number of fish already feeding at the bait), (2) increased by the presence of small fish in the trap, and (3) decreased by a trap–saturation effect. The probability of entry with the trap entrance facing away from the current was more than twice that with the entrance facing into the current. No significant effect on entry probability with the presence of serranids in the trap was detected.

Process model 4: exit of fish from the trap

This model predicts the probability that a fish in the trap will leave the trap. The parameters were estimated by minimising the sum of squared deviations between the observed and predicted probabilities of exit for 2 min time intervals. As in the treatment of entry probability, two approaches were taken: estimation of a simple, constant, probability of exit, and development of a more complex model with which to test the importance of particular mechanisms. The more complex model investigated a dependence of the exit probability on the bait flux, the number of fish in the trap, the entrance alignment with respect to the current direction, the number of entrants during the same time interval, and the time since the trap was set.

The observed variables used to calculate the predicted exit probability were the number of fish in the trap per 2 min interval, the number of fish entering the trap and the current direction with respect to the trap entrance; auxiliary information from the bait flux model (process model 1) was also used.

The exit process was found to be considerably simpler than the entry process. No fish were observed to leave any trap during the first eight minutes of the soak. After this time there was a sharp rise and fall in the probability of exit followed by a relatively constant probability after 25 minutes. The initial rise in the exit probability was influenced by the event of a single fish entering the trap during the 2 min interval, but only during the first 20 mins of soak time.

C5 Use of the observations to improve the design of fish traps and techniques for trapping fish on the North West Shelf

The methods of observation and analysis developed for the examination of baited traps were used to estimate the parameters of the capture process for four trap designs and two bait types. The results were used to calculate and compare the performance of long and short soak times with different trap designs and baits.

Comparison of trap and bait types

Details are provided in Section E6.

The four trap types compared on the North West Shelf were the 'O' trap (which is standard on the North West Shelf), the Antillean 'Z' trap and Caribbean 'S' trap (which are common in other tropical trap fisheries), and a 'rotational O' trap. The rotational trap was a standard 'O' trap mounted on a spindle so that the entrance always faced away from the current. The two bait types compared were pilchard (*Sardinops neopilchardus*) and chopped emperor (*Lethrinus choerorynchus*) taken from the trap catch. All were compared for soak times of up to 2 h. For each trap and bait type the parameters of the fish attraction and entry probability models were estimated from video observations and compared.

(i) Comparison of trap types

With pilchard bait, the entry and exit probabilities per 2 min interval were 0.131 and 0.028 for the 'S' trap, 0.090 and 0.22 for the 'O' trap, 0.080 and 0.17 for the 'Rotational' trap, and 0.056 and 0.005 for the 'Z' trap. The exit probabilities can be expressed as the percentage of fish in the trap that escape per hour. These are 57% for the 'S' trap, 40–49% for the 'O' and rotational traps, and 14% for the 'Z' trap.

The entry and exit probabilities for the 'S' trap were both higher than those for the 'O' trap, while the entry and exit probabilities for the 'Z' trap were considerably lower than those of the 'O' trap. The entry and exit probabilities are strongly correlated (this is not a statistical artifact), and it is clear that a trap that is easily entered is also easily left. The equilibrium catch is determined by the ratio of the entry and exit probabilities, and the almost proportionality between these probabilities means that the equilibrium catch for each trap type is very similar. However, the turnover rate of fish in the trap and the time taken to reach equilibrium differs between trap types: traps with high entry–exit probabilities will have a higher fish turnover, reach their maximum catch faster, and use up bait faster than traps with low entry–exit probabilities. Consequently the 'S' trap is somewhat better than the 'O' trap for short duration sets, while the 'Z' trap is better than the 'O' trap for longer sets. The difference between the trap types is small for soak times of 1–3 h, but is considerable for sets of 5–12 h. This difference for long sets is presumably responsible for the conclusion of earlier workers that 'Z' traps are superior to 'O' traps. However, as indicated below, the 'O' and 'S' traps can give higher daily catches than the 'Z' trap if operated to take advantage of their ability to rapidly reach their maximum catch.

From examination of the entry and exit probabilities across trap types it appears that a simple geometrical interpretation of these probabilities is possible. For the vertical slit entrance 'O' and 'S' traps, both probabilities are predicted very closely from the ratio of the entrance area (modified to account for the shape and size of the funnel) to the total wall area of the trap. If generally applicable, such a relationship would be very useful in rapidly assessing the catching characteristics of a trap design.

There was no significant difference in the performance of the 'O' and rotational traps. While disappointing, this result was strongly influenced by failure of the rotational mechanism to operate as intended. The trap often failed to rotate because the friction was too high or because it caught on irregularities on the sea–bed. Consequently it is not surprising that it performed very much like an 'O' trap. Unfortunately the very tight schedule of the research program allowed only one cruise for testing different trap designs and so there was no opportunity to redesign and retest the rotational trap. The principle of the rotational trap still appears reasonable.

There is obviously an advantage to be derived from development of a trap that reduces exit probability without proportionately reducing entry probability, and this aspect of the capture process should be closely considered in the development of an improved trap design. The strong relationship between exit probability and the number of fish entering in a given time interval suggests that the exit probability is increased when fish in the trap observe other fish entering the trap. This suggests that a physical means or illusion may have to be used to differentially reduce fish exit.

The study was limited in the number of alternative trap designs that could be compared. While the comparisons that were made are useful in themselves, the major contribution of the study is the development of a methodology that allows rapid testing of new trap designs. Using this methodology a new design can be quantitatively evaluated from about 30 trap–sets (provided of course reasonable numbers of fish arrive at the trap sites). The opportunity now exists for efficient and quantitative evaluation of the numerous suggestions for trap designs that abound among trap fishermen and researchers. The present study indicates that significant improvements in catches would result from trap designs that maintained the optimal entrance–current direction alignment and/or had an entrance that disrupted the observed correlation between entry and exit probabilities.

(ii) Comparison of bait types

The pilchard bait was very much more effective in providing a catch than the chopped emperor bait, but the mechanism for this difference was related to attraction of fish to the trap site rather than to the processes of entry or exit. For 'O' traps with chopped emperor bait the probability of entry per 2 min was 0.091 and the probability of exit was 0.023 (compared with 0.090 and 0.022 respectively for Pilchard bait). Clearly the different bait types did not effect the entry or exit probabilities for fish at the trap. However the rate of loss of emperor bait was very small, and this in turn gave a low bait flux, a very small bait plume and a very small area of influence of the trap. Consequently the arrivals of fish at the emperor–baited traps was very low, and this in turn caused low catches.

Out of a total of approximately 24 h (11 sets) of video observations on emperor–baited traps, no lethrinids were seen entering the traps and only one lethrinid was seen around the traps (within the pool).

The comparison of bait types illustrates the importance of the burly effect of fish feeding at the bait in the attraction of additional fish to the trap site. The emperor bait lasts longer than the pilchard, but is less effective in increasing the rate of arrival of fish to the trap. The effectiveness of a bait for use with short soak times is strongly dependent on its ability to be dispersed by fish in the trap. Pilchard has soft, oily flesh, and this combined with a bait bag that allows easy access for feeding fish is ideal for short soak times.

Expected performance of fishing strategies with long and short soak times

Details are provided in Section E7.

It is apparent from the results of this study that a number of features of the traps and baits examined change with the soak time used. Notably:

- traps with high entry–exit probabilities were best for short soak times, while those with low entry–exit probabilities were best for long soak times

- the pilchard bait is expensive, very effective and will only last through short soak times, whereas the chopped emperor bait is inexpensive, less effective and will persist through long soak times

- fishermen using short soak times can operate only a few traps because of space limitations on vessels and time taken for setting and retrieval of traps, whereas fishermen using long soak times can operate more traps because they need never have all their traps on board at once.

These various constraints suggest that the soak time selected will strongly determine costs, catches and the best trap–bait combination. This was examined by linking a simple model of the fishing strategy (choice of the soak time, number of traps that can be worked and the trap–lifts per day) with the fish–capture model developed during this study.

The effect of using different soak times on the catch and an index of the value of the daily catch were examined for 'S' and 'Z' traps, using pilchard and chopped emperor baits. The daily value index is given by the dollar value of the days catch less the cost of bait used to obtain that catch. The results clearly showed the superiority of 'Z' traps over 'S' traps for trap–sets longer than about 3 h, and the high catch rates that are obtained from short sets and pilchard bait with either trap type. Short soak times with Pilchard bait gave the highest catch per day and highest value index per day. Short soak times with pilchard bait gave daily retained catches of 650–700 fish and a value index of about 1200 for both 'S' and 'Z' traps, but the 'S' traps gave best returns for trap–sets of 1–3 h, whereas 'Z' traps gave best returns for trap–sets of 2–5 h. Fish bait in 'S' traps gave very poor returns (at most a daily catch of about 100 fish and a value index of about 200), but fish bait in 'Z' traps gave moderate results for trap–sets of 9–11 h (daily catches of about 200 fish and a value index of about 500). Very long soak times (i.e. 1–3 days) gave very poor results, primarily because the bait is mostly gone from traps after about 24 h on the North West Shelf.

The fishing strategy adopted by trap fishermen on the North West Shelf is very different from that commonly used in trap fisheries elsewhere. However, at least on the North West Shelf, this strategy gives a higher daily catch and catch value index than strategies used elsewhere. The success of the North West Shelf strategy depends upon the combination of a very effective bait and a trap with high fish turnover.

D Future research priorities

The major achievement of this project was to develop a method of observation and analysis that allows for the rapid and quantitative assessment of the performance of a trap design in terms of the processes of fish capture. Consequently it opens the way for a large number of applications and further research. These can be conveniently grouped under the headings of (1) improving trap designs, (2) finding the best trap–fishing strategy, (3) improving the methodology for assessing trap designs, and (4) using trap catches to provide an index of fish density.

(1) Improving trap designs

There is considerable scope for improvement in trap performance by taking advantage of some critical features of the capture process. In particular improvements would result if the optimal trap–current direction alignment can be maintained, and if an entrance design can be found that removes the dependence of exit probability on the number of fish entering. An appropriate research program would both devise and assess new trap designs and assess the designs suggested by commercial trap fishermen. Perhaps a competition could be run in which fishermen provide suggestions of designs they think would work. The method of assessment developed in this study would make it possible to test a reasonably large number of trap designs in a relatively short time.

(2) Finding the best fishing strategy

The fishing strategy here refers to selection of the trap design–bait type–soak time combination. The present study found that high turnover traps (i.e. those with high entry and exit probabilities) with pilchard bait and short soak times provided the best strategy of those examined. If this is generally true then it has implications for trap fisheries elsewhere, and so this generality should be examined. In particular this should be examined for regions with different target species and lower fish densities. The Timor/Arafura Sea area is an obvious choice relevant to the fishing industry, but it would also be valuable to conduct trials in an area in which fish density has been greatly reduced by fishing. Perhaps some of the heavily fished areas of the Great Barrier Reef would be useful for such trials. The comparisons could be quickly and easily made using the methods now available.

The pilchard (*Sardinops neopilchardus*) bait tested was greatly superior to chopped *Lethrinus* bait, apparently because the pilchard was easily broken up by the feeding activities of fish and formed a large bait–plume. There are many other species of fish in Australia, at present under–utilised, that should be similar to the pilchard as bait. In particular the tropical clupeoids and *Rastrelliger* are both abundant and have similar flesh to *S. neopilchardus*. The quality of these baits should be examined, as if suitable they could provide the basis of small new fisheries.

(3) Improving the methodology for assessing trap designs

The video–based method developed in this study allows robust assessment of the processes that occur at the trap site, but is weak in its treatment of the bait plume and fish arrival at the trap site. These processes were found to be very important in the assessment of bait types, and so improvement of the method for these processes is highly desirable. This would involve developing a more detailed model of the bait plume, and developing methods of estimating the parameters of this model.

The reliability of the model's predictions of catch for long soak times (i.e. greater than 24 h) and with no bait were somewhat weak because few such trap–sets were made. These predictions should be more thoroughly tested.

The geometrical interpretation that provided a good prediction of the entry and exit probabilities for 'S' and 'O' traps warrants further examination. If this approach can be shown to be general then it would form the basis of a general approach to the design of traps for particular purposes.

(4) Using trap catches to provide an index of fish density

Indices of fish density are needed for the assessment of exploited fish populations. In trap fisheries the usual index is the catch per trap–set (standardised for soak time) calculated from commercial catch and effort data or from independent (scientific) surveys. The results of the present study imply that these indices will be biased. Both indices will be 'hyperstable', in that they will indicate a relatively constant density when in fact the density is declining.

This situation can be avoided for an index based on scientific surveys by using the methods described here to remove the effects of trap saturation and the density–dependence of the area influenced by the trap. The bait plume model should be developed in more detail for this application. Methods to avoid, or account for, this bias in density indices based on commercial data should be developed.

E Reports

E1 Fish traps and fish–trapping techniques

'Any fish that is caught by any method can be regarded as having been outwitted by man and trapped. A trap is a place to which the fish is lured . . . and where it is caught by a special arrangement.' (von Brant 1972)

Background

Trapping for fish is an ancient form of fishing that has been used for many centuries. Traps or pots were one of the earliest types of fishing gear used by ancient man, and have been an effective method of fish capture in both sophisticated and primitive cultures (High 1971, Hipkins 1974). In Australia, archaeologists have uncovered evidence that the Aborigines built complex stone wall traps in the late Holocene period on the sea coasts (Walters 1987). The principles of these early traps still underlie modern fisheries technology.

The development of such materials as wire mesh, polypropylene mesh, and flexible steel rod has aided the construction and design of traps. Munro (1974) noted that modern fish traps are probably similar in shape to ancient designs, and that they have changed very little since ancient times, except for the use of modern materials.

With modern materials, traps can be easily constructed, are more durable, and require less skill to construct. This, combined with the development of more efficient fishing vessels with more deck space, extended operating range, faster cruising speeds and mechanical hauling devices, has resulted in an increase in the effectiveness of fishing traps. Hull (1981) pointed out that in times of cheap fuel, traps were considered to be a less efficient method of fishing than methods such as trawling, but recent increases in fuel costs now make trapping more attractive to commercial fishermen, gear technologists and fisheries managers.

Advantages of fish traps

Von Brant (1972) classified fishing gear into either active or passive, and defined passive gears as 'those which the fish accept voluntarily'. A trap is a form of passive fishing gear which is static and relies on the movement of fish into it (Craig in prep). Von Brant (1972) distinguished artificial shelters from traps, in that traps are fitted with a device that deters the fish from leaving once they have entered.

Passive fishing gear, such as fish traps, have some advantages over active gear (e.g.. trawls) in that they have low energy requirements, low construction cost and low replacement cost. Traps do little damage to the benthos, keep fish undamaged until they are retrieved (Hull 1981) and generally land a superior quality of fish than can be trawled or hooked (Hipkins 1974).

Traps can be species and size specific, and can be used in areas that are unsuitable or restricted for trawlers.

Trap fisheries and traps

Although fish trapping is often associated with subsistence fishing in tropical waters (Hull 1981), it has also been successfully applied at an industrial level in temperate regions. Trap fisheries operate in all depths between the shoreline and 800–1400 m (Hipkins 1974, Hull 1981). Given this wide range of geographical, depth, and economic environments for trap fishing, it is hardly surprising that there is considerable variation in the design and operation of traps. A good review of trap types and their operation is provided by von Brant (1972).

Industrial trap fisheries exist in North America, the Caribbean Islands, The Arabian Gulf, South East Asia, Australia, Africa and Japan. These fisheries rely on the use of modern boats with a high level of mechanisation and electronic equipment, and provide a catch that is sold as a high quality table fish. The published information on trap types and target species for the industrial trap fisheries is summarised in Table 1. Approximate trap shapes only are listed because a large number of local variations exist.

Trap designs

Shape

Historical factors combined with the availability of materials, bait, vessel design and the abundance of the target species are the main aspects in the design of a fish trap (Munro 1974). The size of traps vary from region to region. Extreme examples are the very large beehive shaped Kuwait traps (2.5 m high, Mathews et al. 1987, Hull 1981), the 2.4 x 0.9 m collapsible rectangular traps used to catch Sablefish *(Anaplopoma fimbria)* in the northeastern Pacific Ocean (High 1971), and the small heart shaped Maderia trap (0.25 m high) which is thought to have originated in Ceylon and India (von Brant 1972). Some designs have traditional influences which have been duplicated using modern materials such as plastics, steel rods and interlocking wire mesh. Other designs have developed from successful crustacean traps. For example the Black cod trap, as used off northwestern USA was a converted spider crab trap (Hull 1981), and the NSW 'rectangular' and 'D' trap developed from the lobster traps used in the same area (Radley pers comm).

The North West Shelf trap fishermen and the Shark Bay snapper fishermen use an 'O' trap that is unique to Western Australia. The origin of the 'O' trap design is not clear, although it may have been developed by fishermen requiring a trap with the same diameter as the local lobster traps in order to allow the same 'trap tipper' be used on both trap types (Bowen 1961).

The 'O' trap design of Western Australia has been tested against other designs in other fisheries, both within this study and others. Munro (1974) tested 4 designs in the caribbean and discarded the 'O', and the New South Whales 'D' shaped trap (see section E2 of this report) in favor of the 'Z' and 'S' designs. Crossland (1976) compared the 'O' and 'Z' traps in the New Zealand snapper fishery, and concluded that the 'Z' design was superior. Taylor & McMichael (1983) concluded that the 'O' trap was less effective than Rectangular or 'D' shaped traps from his studies in Florida. Commercial fishermen in NSW tried a variety of trap designs under commercial conditions and rejected the 'O' trap in favor of 'D' and rectangular traps (pers. obs.).

Other trap shapes in common usage throughout the world include the Arrowhead or Chevron traps, which are popular around Puerto Rico, the Virgin islands, the Seychelles and P.N.G. (Hull 1981, Sylvester and Dammann 1972, de Moussac 1986 and Dalzell & Aini 1987). The arrowhead traps are usually constructed of wire mesh over either a wood or metal frame, depending on the availability of materials. Rectangular traps are used in the N.E. Pacific ocean for Sablefish (High 1971 and Hipkins 1974) and around Florida (Taylor & McMichael 1983) for catching reef fish. The beehive trap is also used around Malta, though in this case the entrance is positioned on the bottom and the trap is set on it's side. This trap is also sometimes set in mid water (Hull 1981).

Entrances

The various trap designs use a variety of different shaped entrances and can either have one entrance or a number. Most trap entrances are conical or 'horse neck' in shape such as the Rectangular traps of the N.E. Pacific ocean, N.S.W. and Florida (High 1971, Henry, pers comm., and Taylor & McMichael 1983), the arrowhead or Chevron shaped traps of the Seychelles and the Virgin islands (de Moussac 1986 and Sylvester & Dammann 1972), the Kuwait and Korean beehive traps (Mathews et al. 1987 and Hull 1981) and the Z traps of the Caribbean (Munro 1974), while the South Australian rectangular trap used for the leatherjacket fishery has a rectangular funnel which is positioned half way up the end of the trap (R. Grove–Jones pers. comm.). The 'O' trap of Western Australia is the only trap, to the authors knowledge, which has a single entrance consisting of an incurving vertical slit running the entire height of the trap.

The beehive, 'O' and arrow head traps traditionally have only the one entrance while the 'Z', 'S' and some Rectangular traps, normally have 2 positioned diametrically opposite each other.

Munro (1974) stated that the rate of escapement of fish from traps was proportional to the size of the funnel and the trap. Professional fishermen off the Florida coast reported that they obtained better yield from traps with a curved conical shaped funnel rather than straight funnels (de Moussac

1986). It has been found on the North West Shelf and off the East coast of Australia that when soft 'chicken wire' is used to form the funnel entrances to traps, that it tends, especially if large fish have entered the trap, to become distorted and lose its conical shape, so inhibiting the further entry and exit of fish from the traps. This is one of the reasons why the South Australian trap fishery uses a metal reinforced incurving rectangular funnel.

Trapping techniques

Soak times

Soak times vary between the different trap fisheries. Wolf and Chislett (1974) showed that the best total catch from baited 'Z' traps in the Caribbean was obtained with a soak time of 1 day or less, but that most trapping in the area was for more than 4 h. The Sablefish fishery on the West Coast of North America uses 24 h sets for intensive fishing although 48 h is the average (Hipkins 1974). New Zealand Snapper fishermen use 12 h soak times, hauling morning and evenings. Florida based fishermen targeting Cod (*Epinephelus morio*) use a variety of soak times ranging from 1h to 60 days, but averaging 24 h (Taylor & McMichael 1983). Soak times of 1–2 days (occasionally 4–7 days) are used in conjunction with baited rectangular and 'D' traps in New South Whales (Dews 1990b). On the North West Shelf the baited 'O' traps are usually fished with a soak times of about 1h during daylight hours, but often traps are also put down at dusk and retrieved at dawn to give an overnight soak of about 12 h.

Bait

There has been much debate concerning the necessity or otherwise of using natural or artificial baits in fish traps (Hull 1981), and there are large variations in bait types used in fish traps in different fisheries. Wolf & Chislett (1974) concluded from results obtained during exploratory fishing trials in the caribbean that bait is a necessary attractor in deep water (up to 200 m), but is less important in shallow water trap–sets (less than about 20 m). Wolf & Chislett (1974) also concluded that change in catch rates were closely linked with changes in the amount of bait available in the trap and that bait is a much greater and more necessary attraction in deep water than in shallow. Munro (1974) concluded from his studies in the caribbean that ingress of fish to the trap was enhanced until the bait was consumed. He also suggested that chopped fish bait was ineffective in increasing trap catches, and that curiosity, inadvertent entrance and attraction to con–specific fish already in the trap are more important than bait in determining fish catch. Conversely, Taylor & McMichael (1983), examined the catches in baited rectangular traps deployed with short soak times (< 2 days), and concluded that fish entered the traps primarily to eat the bait (lobster, shrimp, mackerel heads and chopped trash–fish in this case).

The literature lists a number of different bait types used in traps including, broken shells, crockery, fruit, bread, sea urchins, crushed up crustaceans, trash fish, herring, pilchards, shrimp heads, mackerel heads, cooked eels, squid, canned fish and canned cat food. The North West Shelf trap fishermen mainly use the pilchard (*Sardinops neopilchardus*), which is imported frozen from southern Western Australia. The NSW fishermen use chicken offal, fish frames, and occasionally pilchards. Sable fishermen off North America use herring placed in perforated jars (Hipkins 1974), and New Zealand fishermen targeting Blue Cod (*Parapercis colias*) use fresh fish (Crossland 1976). Subsistence trap fisherman in Papua–New Guinea use slaughter house offal, particularly bones split in half to expose the bone marrow (Dalzell & Aini 1987), while subsistence fishermen in the Seychelles use crushed rotting shells and fish guts (de Moussac 1986). Fishermen in the Virgin islands use trash–fish, cactus, animal skins, fruit, bread and vegetables (Sylvester & Dammann 1972).

Not all traps rely on baits as an attractor; some rely on attracting fish to a place of shelter. Johannes (1981) noted that Palauan Islander traps are sometimes baited, but that there is no consensus of opinion among the fishermen as to whether bait really helps catch fish. The Kashiki Island fishermen of Japan cover their 'D' shaped traps with leaves and moss, and fish capture relies on the fish using the traps as shelters (Anon 1987).

Catch rates

Catch rates vary markedly from fishery to fishery and season to season, and many different trap type, bait type and soak time combinations are used. Catch rates for various combinations are shown in Table 1.

Table 1. Trap catch rates reported in published papers

Location	Trap type	Depth(m)	Bait	Ave catch rate (kg/haul)	Ave soak (h)	kg/trap/h	Fish type
South Florida (2)		3–40	None	12.3	108	0.11	Serranidae Pomadasidae Holocentridae Scaridae Carangidae Lutjanidae Mullidae Monocanthidae Balistidae Chaetodontidae Acanthuridae Lethrinidae
Offshore Jamaica banks (9)		40–60		8.4	18h	0.47	
Puerto Rico (E. coast) (9)		40–200		2.25	24	0.09	
Puerto Rico (W. coast) (9)	'S', 'Z' Arrowhead	40–250	None	2.7 – 5.7	96	0.08	
Mona Isl (Puerto Rico) (9)		60–200		3.4	12	0.28	
Pedro Bank (Jamaica) (11)	'O'		Scombridae	2.7	12 (o/night)	0.23	
Pedro Bank (Jamaica) (11)	'Z'		& Decapterus	30.0	4	7.5	
Pedro Bank (Jamaica) (11)	'D'		'	13.0	4	3.25	
US Virgin Islands (9)		12–25		1.8	1.5	1.20	
Papua New Guinea (3)		10–25	slaughter house offal	2.32	168	0.01	
Kuwait (6)	'Bee hive'			11.0	72–96	0.13	
Seychelles (4)	'Arrowhead'	10–40	shells & fish guts	4 .0	48	0.08	
Florida (10)	'Rectangular'	6–73	lobster heads	4.9	24	0.20	Lutjanidae Serranidae Rachycentridae Lutjanidae Gymnocranius Epinephulus Congridae
Vanuatu (1)	'Z'	100–215	Scombridae	7.4	24.0	0.31	
Lesser Antilles (7)	'Z'	200		24.8	24	1.03	
Various locations around Jamaica (8)				1.0–4.0	24	0.08	
New South Wales (5) (Australia)	'Rectangular'	30–100		2.5	24–96	0.05	Sparidae Cheilodactylidae Monocanthidae
Northwest Shelf	'O'	20	pilchard	9.9	1	9.9	Lethrinidae Lutjanidae Serranidae
'	'	'	'	9.6	24	0.40	

References: (1) Blanc, 1988; (2) Craig, 1976; (3) Dalzell & Aini, 1987; (4) de Moussou, 1986; (5) Henry, 1990; (6) Mathews, 1987; (7) Munro, 1974; (8) Munro, 1983; (9) Stevenson & Stuart-Sharkey, 1980; (10) Taylor & McMichael, 1983; (11) Wolf & Chislett, 1974.

E2 Australian Tropical Trap Fisheries

Prepared by G. Dews

Australia presently has four trap fisheries that target fin–fish: (1) the Snapper (*Chrysophrys auratus)* fishery in New South Wales, (2) the Snapper fishery in Shark Bay, Western Australia, (3) a Chinaman leatherjacket (*Nelusetta ayraudi)* fishery in South Australia, and (4) a tropical 'reef–fish' fishery on the North West Shelf of Western Australia targeting primarily spangled emperor (*Lethrinus nebulosus*), red emperor (*Lutjanus sebae*) and rankin cod (*Epinephelus multinotatus*). Recently, Northern Territory vessels have begun using fish traps in the Arafura and Timor Seas targeting species similar to those taken in the North West Shelf fishery.

Descriptions of the Shark Bay trap fishery can be found in Moran & Jenke (1989) and a short description of some aspects of the South Australian trap fishery can be found in R. Grove–Jones (1989).

The two trap fisheries in tropical Australia were visited to observe and compare the traps used, the way the traps are operated, and the general operation of the fishery.

E2.1 Observations of the North West Shelf trap fishery, October 1987

The Western Australian trap and line fishery was recently described in detail by Moran et al. (1988). At present approximately 50 vessels (i.e. vessels that have landed > 50 tonnes) operate on the North West Shelf (Moran et al. 1988). The fishery extends from King Sound (17°S, 123°E) in the north to North West Cape (22°S, 114°E) in the south, with most fishing concentrated in the Monte Bello and Barrow Island region. The area to the northeast of these islands is only intermittently fished by line and trap fishermen, although foreign vessels have successfully trawled the area since 1959.

Other fisheries in the region include pearl culturing, prawn trawling, a small recreational fishery, and recently, fish trawling by Australian vessels.

Area of operation

Most trap boats concentrate their operations around the Monte Bello and Barrow Island groups and use Onslow, and to a lesser extent Point Sampson, as service ports. These are small communities of less than 600 people. The larger towns of Karatha, Port Hedland and Broome are unable to cater to small vessels and are too far from the fishing grounds to be commonly used as fishing service ports.

Seasons

The line and trap fishery season begins in March to April and continues through to November. The number of boats in the fishery increases during the winter months mainly because of an influx of itinerant boats from southern ports, mainly Shark Bay. Anecdotal information suggests that catch rates are low between December and March. The weather conditions at that time, with frequent cyclones and high temperatures, make fishing from small vessels difficult and uncomfortable.

The seasonal fluctuation of the number of boats working in the fishery varies annually, and makes accurate monitoring of the fishery difficult.

Catch composition

The total annual catches in 1986/87 and 1987/88 were both about 550 tonnes of fish (Moran et al. 1988), mainly spangled emperor (*Lethrinus nebulosus*) red emperor (*Lutjanus sebae*) and Rankin cod (*Epinephelus multinotatus*). Other commonly caught commercial species are sweetlip (Haemulidae), trevally (Carangidae) and tuskfish (Labridae). Average catch rates were 172 kg / boat day in 1986/87 and 196 kg / boat day in 1987/88, although catches of 1500 kg / day have been made (Moran et al. 1988).

Vessel and gear

Vessels range from 13 to 22 m in length and are crewed by a skipper and one or two deck hands. The boats are either semi–displacement hulls designed for the southern lobster fishery or modified prawn trawlers. The common configuration on the vessels is that the aft deck is used for trap storage and fish holds of either Refrigerated Sea Water (RSW) ice or freezers. The trap hauler and tipper are normally midships while the wheelhouse and sleeping quarters are forward. The boats usually remain on the fishing grounds from one to three weeks, and use the numerous small islands as sheltered anchorages.

All fishermen use the 'O' shaped trap (see section E5), as in the Shark Bay fishery. The dimensions vary slightly from vessel to vessel but are generally 1.5 m in diameter and 1 m in height and covered with 800 mm cyclone mesh. The entrance is a vertical opening approximately 115 mm wide extending the height of the trap with incurving sides. Variations adopted by some fishermen include 'whiskers' (plastic electrical ties) mounted facing inwards on the trap entrance to deter fish escapement.

Bait

The preferred bait of the North West Shelf trap fishery is the southern pilchard (*Sardinops neopilchardus*), which is transported frozen to the North West Shelf from Perth in 15 kg cartons. The present cost of this bait is around $1.60/kg and approximately 4–5 kg is used for each trap–set. Some fishermen have tried cheaper alternative baits, though catch rates were not as high, and consequently almost all fishermen now use the pilchard bait.

Mode of operation

Fish trapping is carried out during daylight hours in depths of 10 to 100 m, although the average is less than 50 m. Concurrent line fishing occurs predominately in the evening or occasionally between trap–sets. Trolling for spanish mackerel (*Scomberomorus commerson*) is carried out between trap–sets. If spanish mackerel are landed in sufficient quantities, trap fishing is suspended and all effort is put into trolling.

Each boat uses 5 or 6 traps simultaneously with soak times of approximately 1 hour throughout daylight hours. Often all the traps are set at dusk and retrieved the following morning. The overnight set is intended to catch the last feeders of the afternoon and the first feeders of the morning.

When investigating a new fishing area, skippers may deploy up to 10 traps to locate areas of maximum fish density. If an area is producing good catches only 5 or 6 traps can be effectively deployed. This is the maximum a vessel can successfully handle because of the time necessary to remove the catch, refill the bait cage, relocate the target area and put the catch in RSW, while simultaneously trying to keep trap soak time to approximately 1 hour.

Favored fishing areas are on drop–offs, sharp rises and pinnacles, although flat areas are often worked with good results with skippers relying on radar and colour sounders to determine likely fishing areas. Catches are highly variable even within a small area, although the better catches seem to occur in the morning or late afternoons. Because of this large variability in catch rates different fishermen have different modes of operation designed to optimise catch rates, and these may be varied with circumstances. Having located fish marks by echo sounder, most skippers attempt to set their traps up current of the marks.

On–board operation

Each trap is marked with 2 floats or clusters of floats, a larger one preventing the lifting rope from being pulled under by currents and a smaller one separated by a short retrieval line.

trap–setting methods vary between boats due to differences in deck layout. Generally the traps are baited and stationed on the gunwale with the ropes and buoys connected. As the vessel move over a mark the trap, rope and markers are cast overboard. The rope is left to un–coil on the sea surface as the trap–settles. This technique allows the skipper maximum search time and to target on fish aggregations.

Traps are retrieved by grappling the rope and buoys onboard, then feeding the rope onto the capstan and automatic rope coiler. As the trap is hauled over the gunwale it is pulled onto a cradle which then tips the trap horizontal at gunwale level. From this position the bait can be adjusted and the catch removed before The trap is reset or stowed aft. Not all boats have rope coilers but each boat attempts to maximise the rate of hauling to minimise the chance of fish escape through the entrance and to increase the number of sets per day. Traps are hauled at a rate of at least 40 m per minute.

Catch processing

Most vessels use RSW or freezers to store the catch. Whenever possible the catch is processed on–board to maximise the use of storage capacity and to increase the value of the catch.

As the fish are landed they are placed in holding bins with recirculating water or refrigerated sea water (RSW) before processing. This allows time for other traps to be retrieved and re–set again. Placing the fish in RSW causes the flesh to solidify, and this allows easier filleting.

Processing in done on an opportunistic basis through out the day or when the boat is at anchor in the evenings. The fish are sorted into different market types. The red emperor, snapper and coral trout are either gilled, gutted and placed in ice, or are filleted and frozen. Some are packed individually or in pairs in plastic bags before freezing. Smaller fish are boxed whole and sold as 'mixed reef fish', while the cod are filleted and frozen in boxes.

Some vessels extend their time at sea by filleting and freezing all the landed fish, while other vessels fish for only about 6 days and supply an iced product.

Fishermen are expressing an interest in the Japanese practice of Iki Jime to produce a premium quality product. Iki Jime involves driving a spike into the brain of the fish so as to cause immediate death and prevent prolonged stress in the fish. This treatment results in the fish retaining its natural skin colour, and gives the flesh a superior texture and colour. The improved product resulting from the combination of Iki Jime, rapid chilling in ice slurry, careful handling and good onboard storage can result in a higher price to fishermen. At present the practice is not widespread, probably because the market is extensive and stable enough to promote this method of fish handling.

Vessel management

Management of the vessel is normally under the control of the skipper, who often owns the vessel. The skipper is not restricted to particular outlets for the catch. Some fishermen consign their fish directly to Perth or Fremantle, but most sell their catch to the local processors/buyers. The processors then sell to the city markets. There can be large fluctuations in prices because of intermittent supply and variations in the quality of the fish offered for sale.

Finding suitable markets for the fish catch is difficult because there are few local fish processors / buyers (one in Onslow and one in Point Sampson) and the large distance between the fishing ports are major city markets. This can result in boats having long turn–around times in port, which in turn reduces vessel catching capability, makes product quality control difficult and exacerbates the inconsistency of product supply.

Conclusion

The industry, at present, is small and poorly supported by limited shore facilities. Fishing boats within the area are not purpose built and consequently operate at restricted levels of efficiency. To fully utilise the trap fishery vessels would need to be equipped with GPS navigation systems, have large deck operating space, good fish holding facilities for the product and suitable crew facilities for extended periods at sea.

With adequate navigation aids and larger boats, skippers will be able to search further offshore and be able to locate shoals which are presently out of their range and under utilised. Purpose designed vessels would be able to spend longer periods on the fishing grounds without having to shelter in rough seas as they do at present.

With an increase in vessel size and capacity, an increase in shore facilities would also be necessary. This is occurring to a moderate extent as a result of the construction of off–shore oil platforms being in the region. An alternative to this may be the use of 'mother ships' servicing the existing types of vessels.

Trap landed product is a highly regarded table fish. Development of the fishery requires a combination of a more reliable supply of product and more reliable markets.

E2.2 Observations of the Northern New South Wales trap fishery, February 1988

Fish trapping has been carried out in NSW for many years (Henry 1990), and it has been suggested that the fishery developed as lobster fisherman discovered snapper (*Chrysophrys auratus*) as a by–catch in their lobster traps (Radley per. comm). Expansion of the fishery was associated with increases in vessel size and operating capacity which enabled fishermen to operate further from port.

Seasonal variations in fish availability and the multipurpose designs of most boats, result in trap fishing being combined with other fishing methods (particularly wet line fishing, gill netting and trawling).

Area of operation

The fishery extends from the coast to the continental shelf break (hand lining is restricted to beyond 3 n. miles of the coast) and extends along the coast from Eden (37°S 150°W) in the south to the Queensland border (27°S 154°W) in the north, although the majority of fishing effort is located north of Port Stevens. Fish trapping is prohibited in Queensland waters by legislation.

The numerous rivers in northern NSW provide excellent deep water ports, close to the fishing grounds and with easy access to fish marketing cooperatives and port services.

Seasons

Demersal fish trapping occurs mainly in August, September and October, although some trapping is carried on throughout the year. This corresponds to spawning aggregations of fish and favorable prevailing sea conditions.

Catch composition

The major target species is the snapper (*Chrysophyss auratus*), and over the past 30 yrs an average of 714 tonnes has been landed per year (Henry in prep). The average catch per vessel day in 1986 was 37.25 kg, and in 1987 was 33.92 kg (Henry 1990).

Other fish caught by the trap fishery, in ranked order of weight landed, are morwong (*Nemadactylus douglasi*), leatherjackets (Monacanthidae), kingfish (*Seriola ilalanda*), bar cod (*Epinephelus septemfasciatus*), carpet shark (*Orectolus ornatus*), sweep (*Scorpis lineolatus*), morwong (*Cheilodactylus vestitus*), pigfish (*Bodianus vestitus*) and tarwhine (*Rhabdosargus* *sarda*).

Snapper is a highly prized restaurant fish and thus returns high prices on the markets, although all other fish landed are readily sold through the local fisherman's cooperatives. Relatively minor fluctuations in price to the fishermen are caused by the effects of weather conditions on the number of days per year the fisherman can get to the fishing grounds.

Vessel and gear description

Fishing trips are of one day's duration, with boats leaving port early in the morning and returning the same afternoon. This type of fishing requires only small boats with a single operator, or in some cases with one assistant.

A surf zone at the entrance to most of the rivers restricts the navigation of these river bars to calm or slight sea conditions only. Large swells and rough seas on the 'sand bar' at the entrance of most ports often close the the port and restrict the number of days that fishermen can get to the fishing grounds. Negotiating the bar is hazardous; this is reflected in the designs of most boats. They are fast–planing, easily manoeuvered and capable of running through breaking waves in shallow water. They have a short travelling time to the fishing grounds.

The boats vary in length from 9 to 15 m and are usually constructed of fibreglass or aluminum and powered by high–speed diesels that are both economical and reliable.

In most designs the wheel house is forward, and the aft area provides space for a working area, trap storage, bait storage, a hydraulic trap hauler, and ice box. The small cabin is used mainly for engine controls and navigation equipment, with some cover also afforded for the crew and helmsman.

Trap designs

The traps are either 'D' or rectangular in shape with an entrance at one end with a wire mesh bait bag suspended at the entrance end of the trap. Both the 'D' and 'Rectangular' traps are approximately 1.7 m long and 1.3 m high, with the top of the 'D' trap being rounded. The traps are constructed with either timber or steel frames covered with interlocking mesh (average 50 mm). The entrances are of similar mesh and funnel inward for about 15 to 20 cm in an elongated–oval cross–section. The traps are marked and identified with polystyrene floats on the surface and tethered with nylon rope.

Individual fisherman have adopted variations to the basic trap design, including trap size, different construction materials (eg metal frames instead of wood), bait combinations (e.g. fish and chicken offal) and the colour of traps.

Bait

Bait is predominantly chicken offal, or occasionally fish frames, pilchards or a mixture of frames and pilchard. Chicken offal has advantages of being very inexpensive, easily available, and has good durability in the traps. The traps are normally baited with approximately 10 kg of chicken offal or fish frames.

Mode of operation

Each boat operates with an average of 20 traps, although only 1 or 2 traps can be carried on a boat at any one time. Most fisherman keep the remainder of their traps at sea throughout the season, rebaiting and setting each trap on a rotational basis. The summer months are used to repair the traps, maintain the boats and engage in other fishing activities (e.g. handlining or gill netting).

Traps are placed or set on the inshore reefs and outcrops which are normally within a few hours steaming of their home port. Legislation allows traps to be set at any depth and distance from the coast, in contrast to handlining which is prohibited inside the 3 n. mile limit. The positioning of the traps is usually determined by using echo soundings and visual land marks. Few of the vessels have radar or colored acoustic depth sounder.

Soak times (the period a trap is left fishing) are normally 1 to 2 days, or occasionally 3 to 4 days. Occasionally longer sets are used (usually unintentionally), with some good catches being achieved from set times up to 7 days.

Traps are set in depths ranging from 30 to 100 m depending on the season (deeper in winter) and the velocity of the currents. Trap loss due to external factors (e.g. passing freighters) is believed to be low although strong currents can hold the marker floats and lines under water for a number of days.

trap–setting strategies vary from fisherman to fisherman. Some fishermen attempt to position the entrance of the trap down current in the belief that the fish can more easily find the entrance as they follow the bait scent up current. Some fishermen insist on aligning their traps in a north–south direction to take advantage of the prevailing East Australian Current. Other fishermen believe the current is not consistent enough around their local reefs to warrant the placing of traps in any particular direction. However most maintain that the presence of current increases the chance of a good catch.

Catch processing

Because the boats operate on a daily basis, the catch can easily be kept in small deck mounted ice–bins while at sea. The fish is gilled and gutted soon after landing and is packed in ice. At the completion of each days fishing the catch is unloaded at the local fish Co–operative. These

Co–operatives sell the seafood on behalf of the fisherman by consigning them overnight to the city markets where they are sold at auction. Legislation requires all fish to be sold through the cooperative system, thereby providing a consistent market outlet for all ports.

The methods of the fishery and product distribution allow for a very fresh product to be transported to the major markets in eastern Australia.

Conclusion

The fishery is well established and provides the market with an excellent fresh product which is always in demand for the restaurant and domestic trade. It is closely monitored and strictly managed by the NSW Department of Agriculture and Fisheries and as such is unlikely to expand any further. As catch rates are expected to remain constant (Henry per. comm.), fishermen anticipate increasing returns for their product as a result of an increasing demand for high quality fresh fish. The only competition on the market may come from the Western Australian or New Zealand fishery.

E3 Cruise reports

E3.1 Cruise report 1: North West Shelf trapping project (FIRTA), FV *Judy B* May Cruise

Scientific staff

Mr AW Whitelaw (Scientist–in–charge)
Mr GJ Dews
Mr J Jenke (W.A. Fisheries)

FV *Judy B* crew

Mr N Baker (skipper/owner)
Mr J Baker

Duration

Departed Onslow 0530 h, 6 May 1988
Arrived Karatha 1500 h, 19 May 1988

Locality

Area around Varanus and Barrow islands W.A., (approx. 115° 30'E, 20° 45'S)

Aims

(1) To observe in situ fish behaviour to various fish trap designs using underwater cameras, including time of attraction to the trap, interspecific reactions and rates of fish ingress and egress.

(2) To examine the effect of current direction (with respect to fish trap entrance position) on fish ingress and egress.

(3) To examine the effect of 'soak' time on the catch.

(4) To perform 'bait removal' experiments from traps to determine the effect of bait on fish ingress and egress.

(5) To determine catch compositions and weights.

(6) To collect length–frequency data on all species caught.

(7) To obtain tide measurements.

Narrative

The cruise commenced one day late due to the non–arrival of important equipment (including half of the photographic and flowmeter equipment) at Onslow. We departed on the morning of May for Varanus island, and arrived at 1700 h.

Commenced trapping at dawn on the 7 May in perfect working conditions (approx. 30°C and no wind). We experienced some initial problems with the underwater video housings and the current meters, but these were mainly rectified over the next couple of days. Most trapping was done at 20–30 m depth over coralline sand with occasional coral outcrops.

By Tuesday (10 May) the weather had blown up and we were forced to continue our trapping program at a more protected site where catch rates were not as high. This rough weather (winds 30–40 knots) continued for 4 days and increased the water turbidity, which decreased the quality of some of the video footage obtained during this period.

It was possible to work the better fishing grounds to the east of Varanus Island from 14 May until the end of the cruise, which enabled the full program of trapping to be completed.

The Sony 'Handycam Video 8' cameras worked extremely well under fairly harsh and damp conditions and gave very good results.

Results:

(1) A total of 203 trap–sets were made during the cruise, (Table 1) gives a breakdown of the duration and type of trap–set.

Table 1. Duration and number of trap–sets

Duration of set (h)	Sets completed
24	11
12	11
6	21
3*	17
3	34
2*	17
2	31
1*	19
1	40
2 bait removal*	2
2 bait removal	0

* denotes video camera attached

(2) A total of 55 video sequences of different lengths were completed. In most cases this resulted in suitable footage for later analysis of fish ingress and egress rates and of how the fish reacted to the traps and trap entrances. A total of around 106 h of footage was obtained.

(3) A total of 16 current velocity and direction recordings were made in relation to the trap entrance, with an additional current direction indicator (ribbon) being observed on the remaining video trap–sets.

(4) Bait removal experiments were attempted on a number of occasions, but due to the current strength and variability in fish presence, these were not successfully completed .

(5) The composition and weight of the catch were obtained on all trap–sets. A total of 2113 kg of fish was caught during the charter period. The catch consisted of Lethrinids (1325.5 kg), Serranids (292 kg), Lutjanids (125.9 kg) and others (369.65 kg).

(6) Length–frequency measurements were taken of all fish caught (Table 2). These data are provided in Table 3.

Table 2 Number of length frequencies measured

Family	Number of length frequencies
Lethrinid	1777
Serranid	123
Lutjanid	80
Other	415

(7) Tide measurements were taken over only two days, due to a faulty tide gauge.

A special thanks must go to the personnel on Varanus Island, who assisted us greatly in many ways. The skipper and first mate of the *Judy B* were also especially helpful and enthusiastic throughout the cruise.

(Scientist–in–charge)

(Date) 16 June 1988

Table 3 Length frequencies (fork length) of trapped fish measured on May cruise

Length (cm)	Carangid	*Symphorus nematophorus*	Mullids	*Siganus fuscens*	Other lethrinids
20	0	0	0	0	0
21	0	0	0	0	0
22	0	0	0	3	0
23	0	0	0	4	0
24	1	0	0	4	0
25	0	0	0	9	0
26	0	0	0	6	0
27	0	0	0	4	0
28	1	0	0	3	0
29	1	0	1	1	1
30	1	0	0	0	0
31	0	0	1	0	0
32	2	0	1	0	0
33	5	0	0	0	0
34	2	0	0	0	0
35	2	0	3	0	0
36	0	0	3	0	0
37	8	0	0	0	0
38	0	0	0	0	0
39	2	0	0	0	0
40	2	0	0	0	0
41	4	0	0	0	0
42	2	0	0	0	0
43	3	0	0	0	0
44	1	0	0	0	0
45	3	0	0	0	0
46	3	0	0	0	0
47	2	0	0	0	0
48	0	0	0	0	0
49	0	0	0	0	0
50	1	1	0	0	0
51	0	0	0	0	0
52	0	0	0	0	0
53	0	0	0	0	0
54	0	0	0	0	0
55	0	0	0	0	0
56	0	0	0	0	0
57	0	0	0	0	0
58	0	0	0	0	0
59	0	0	0	0	0
60	0	0	0	0	0
61	0	0	0	0	0
62	0	0	0	0	0
63	0	0	0	0	0
64	1	0	0	0	0
65	0	1	0	0	0
66	0	0	0	0	0
67	0	0	0	0	0
68	0	0	0	0	0
69	0	0	0	0	0
70	1	0	0	0	0
71	0	0	0	0	0
72	0	0	0	0	0
73	0	0	0	0	0
74	0	0	0	0	0
75	0	0	0	0	0
76	0	0	0	0	0
77	0	0	0	0	0
78	0	1	0	0	0
79	0	0	0	0	0
80	0	0	0	0	0
	48	3	9	34	1

Length (cm)	*Epinephelus maculatus*	*Epinephelus microdon*	*Scolopsis monogramma*	*Diagramma pictum*	*Pentapodus porosus*
20	0	0	0	0	0
21	0	0	0	0	0
22	0	0	1	0	0
23	0	0	0	0	0
24	0	0	0	0	1
25	0	0	0	0	0
26	0	0	0	0	0
27	0	0	1	0	0
28	1	0	1	0	1
29	0	0	0	0	3
30	1	1	2	0	1
31	2	0	0	0	1
32	2	0	0	0	2
33	1	0	1	0	0
34	3	0	0	0	0
35	7	0	0	0	0
36	5	0	0	0	0
37	9	0	0	0	0
38	3	0	0	1	0
39	2	1	0	0	0
40	0	0	0	0	0
41	0	0	0	2	0
42	0	0	0	0	0
43	0	1	0	0	0
44	0	0	0	1	0
45	0	0	0	0	0
46	0	0	0	1	0
47	0	1	0	0	0
48	0	1	0	2	0
49	0	0	0	3	0
50	0	0	0	1	0
51	0	1	0	1	0
52	0	0	0	1	0
53	0	2	0	1	0
54	0	0	0	2	0
55	0	1	0	0	0
56	0	0	0	2	0
57	0	0	0	0	0
58	0	0	0	0	0
59	0	1	0	0	0
60	0	1	0	4	0
61	0	0	0	0	0
62	0	0	0	0	0
63	0	1	0	1	0
64	0	0	0	0	0
65	0	1	0	0	0
66	0	0	0	1	0
67	0	0	0	0	0
68	0	0	0	0	0
69	0	0	0	1	0
70	0	0	0	0	0
71	0	0	0	0	0
72	0	0	0	0	0
73	0	0	0	0	0
74	0	0	0	0	0
75	0	0	0	0	0
76	0	0	0	0	0
77	0	0	0	0	0
78	0	0	0	0	0
79	0	0	0	0	0
80	0	0	0	0	0
	36	13	6	26	9

Length (cm)	*Lethrinus fraenatus*	*Lethrinus lemniscatus*	*Lethrinus mahsena*	*Lethrinus nebulosus*	*Lethrinus choerorynchus*
20	0	0	0	0	2
21	0	0	0	0	8
22	0	0	0	0	12
23	0	0	6	0	28
24	0	0	6	0	93
25	0	0	10	1	175
26	0	0	8	3	219
27	1	0	3	7	217
28	0	0	2	8	220
29	0	0	0	6	187
30	1	1	1	14	113
31	0	0	0	24	54
32	0	0	1	16	17
33	0	2	0	12	2
34	1	3	0	11	1
35	1	3	0	14	2
36	4	2	0	17	0
37	4	2	0	24	0
38	4	2	0	15	0
39	4	1	0	23	2
40	3	1	0	20	1
41	4	0	0	16	1
42	1	0	0	26	0
43	3	0	0	4	0
44	5	0	0	11	0
45	3	0	0	9	2
46	1	0	0	11	0
47	0	0	0	20	1
48	1	1	0	17	0
49	1	0	0	8	0
50	0	0	0	13	1
51	0	0	0	16	0
52	0	0	0	9	0
53	1	0	0	12	0
54	0	0	0	9	0
55	0	0	0	10	0
56	0	0	0	6	0
57	0	0	0	8	0
58	0	0	0	3	0
59	0	0	0	2	0
60	0	0	0	2	0
61	0	0	0	0	0
62	0	0	0	0	0
63	0	0	0	1	0
64	0	0	0	0	0
65	0	0	0	0	0
66	0	0	0	0	0
67	0	0	0	0	0
68	0	0	0	0	0
69	0	0	0	0	0
70	0	0	0	0	0
71	0	0	0	0	0
72	0	0	0	0	0
73	0	0	0	0	0
74	0	0	0	0	0
75	0	0	0	0	0
76	0	0	0	0	0
77	0	0	0	0	0
78	0	0	0	0	0
79	0	0	0	0	0
80	0	0	0	0	0
	43	**18**	**37**	**428**	**1358**

Length (cm)	*Epinephelus multinotatus*	*Lutjanus sebae*	*Abalistes stellatus*	*Plectropomus maculatus*	Labrid	*Lutjanus carponotatus*
20	0	0	0	0	0	0
21	0	0	1	0	0	0
22	0	0	3	0	0	0
23	0	0	2	0	0	0
24	0	0	3	0	0	0
25	0	0	16	0	0	0
26	0	0	10	0	2	0
27	0	0	10	0	2	0
28	0	0	13	0	3	0
29	0	0	14	0	2	1
30	0	0	27	0	8	1
31	0	0	24	0	8	1
32	0	0	26	0	6	1
33	0	1	22	0	12	2
34	0	0	15	0	11	3
35	0	1	13	0	3	3
36	0	1	9	1	7	3
37	0	1	4	0	4	0
38	0	0	5	0	2	0
39	0	4	6	1	0	1
40	3	1	6	0	1	1
41	0	3	3	1	1	0
42	1	1	1	0	0	0
43	1	3	0	1	0	0
44	0	1	2	0	0	0
45	0	5	0	1	0	0
46	0	5	0	1	0	0
47	1	4	0	0	0	0
48	1	1	0	2	0	0
49	0	2	0	1	0	0
50	2	0	1	2	0	0
51	1	4	0	3	0	0
52	1	0	0	0	0	0
53	1	2	0	1	0	0
54	0	0	0	1	0	0
55	0	0	0	2	0	0
56	1	1	0	0	0	0
57	2	0	0	8	0	0
58	0	2	0	1	0	0
59	0	1	0	5	0	0
60	0	2	0	1	0	0
61	0	0	0	4	0	0
62	1	0	0	2	0	0
63	0	1	0	0	0	0
64	0	0	0	3	0	0
65	0	1	0	0	0	0
66	0	0	0	2	0	0
67	0	0	0	1	0	0
68	0	0	0	4	0	0
69	0	0	0	6	0	0
70	0	1	0	1	0	0
71	0	0	0	1	0	0
72	0	0	0	0	0	0
73	0	0	0	1	0	0
74	0	0	0	1	0	0
75	0	0	0	1	0	0
76	0	0	0	0	0	0
77	0	0	0	0	0	0
78	0	0	0	0	0	0
79	0	0	0	0	0	0
80	0	0	0	0	0	0
	16	**49**	**236**	**60**	**72**	**17**

E3.2 Cruise Report 2: North West Shelf trapping project (FIRTA), FV *Judy B* August cruise

Scientific staff

Mr AW Whitelaw (Scientist–in–charge)
Mr GJ Dews
Mr J Jenke (W.A. Marine research laboratories)

FV *Judy B* crew

Mr N Baker (skipper/owner)
Mr D Baker

Duration

Departed Onslow 0030 h, 13 August 1988
Arrived Onslow 0030 h, 26 August 1988

Locality

Area around Varanus and Barrow islands W.A., (approx. 115^{o} 30'E, 20 ^{o}45'S)

Aims

(1) To observe, using underwater cameras, the behaviour of fish to traps of different designs, including time of attraction to the trap, interspecific reactions and rates of fish ingress and egress.

(2) To examine the effect of the direction of the current (with respect to fish trap entrance position) on fish ingress and egress.

(3) To examine the effect of 'soak' time on the catch.

(4) To determine catch compositions and weights.

(5) To collect length–frequency data on all species caught.

(6) To obtain tide measurements.

(7) To determine catch rates with various bait types.

(8) To collect electrophoretic samples for the W.A. Marine Research Laboratories on *Lutjanus sebae*, *Lutjanus nebulosus*, *Lutjanus choerhynchus* and *Epinephelus rankini*.

(9) To tag specimens of *Lethrinus nebulosus* where possible.

Narrative

The cruise started one day late due to bad weather, but this enabled us to put the finishing touches to the traps that we were going to deploy on the cruise. We eventually departed at 0030 h on Saturday 13 August and arrived at our Lowendale Island study site at 1000 h, whereupon we set up our tide gauge station and started trapping.

The weather conditions were good, with only a slight SE wind blowing. The wind and sea conditions remained fairly constant, though workable, for the duration of the cruise except for one day when a 30 km easterly wind forced the trapping operations into the lee of some of the islands.

Fairly consistent, though not large, catches of fish were trapped during the cruise. The purpose–designed and built traps worked very well, as did the underwater video cameras . The current meters worked well to start with, but were giving a bit of trouble towards the end, probably due to the harsh conditions.

Results

(1) A total of 257 trap–sets were made during the cruise utilising 4 different trap types and 2 types of bait (muleys (*Sardinops neopilchardus*) and lesser NW snapper (*Lethrinus choerhynchus*)). The 4 trap types used were:

- Standard NW shelf 'O' trap
- Antillean 'Z' trap
- Improvised double entrance 'S' trap.
- Directional or current–seeking rotating 'O' trap (CSROT)

Table 1 gives a breakdown of the duration and type of trap–set.

Table 1. Duration of trap–sets and types of traps

Trap Type	2h sets	4h sets	6h sets	2h sets with camera
'O'	13	10	11	12
'S'	12	11	10	15
'Z'	15	11	11	12
CSROT	16	11	10	14
Bait 'O'	13	13	10	12

(2) A total of 68 video sequences of varying time periods were completed. In all cases this resulted in suitable footage for later analysis of fish ingress and egress rates and general fish behaviour towards trap types and entrances. Approximately 132 h of footage was obtained.

(3) A total of 20 current velocity and direction recordings were made in relation to the trap entrance, with an additional current direction indicator (ribbon) being observed on the remaining video trap–sets.

(4) Catch composition and weight information was obtained on all trap–sets. A total of 1353 kg. of fish were caught during the charter period. The catch consisted of Lethrinids – 755.2kg, Serranids – 278.7 kg., Lutjanids – 135.2 kg., others – 135.2 kg. and trash – 184.1 kg. The others category comprised mainly Labrids and Carangids while the trash category consisted mainly of Balistids and Siganids.

(5) Length frequency results were obtained for all fish caught (table 2). These data are provided in Table 3.

Table 2 Number of fish measured

Family	Number of length frequencies
Lethrinid	1004
Serranid	112
Lutjanid	55
Other	123
Trash	319

(6) Tide measurements were completed over the duration of the cruise with the Aanderra tide gauge kindly supplied by the Division of Oceanography.

A special thanks must go to the personnel on Varanus Island who assisted us greatly in many ways. The skipper and first mate of the *Judy B* were also especially helpful and enthusiastic throughout the cruise.

(Scientist–in–charge)

(Date) 1 Sept 1988

Table 3 Length frequencies (fork length) of trapped fish measured on August cruise – all trap types combined

Length (cm)	*Plectropomus maculatus*	*Scolopsis monogramma*	*Pentapodus porosus*	Labrid	*Abalistes stellatus*	*Lutjanus sebae*
18	0	0	0	0	0	0
19	0	0	0	0	1	0
20	0	0	0	0	1	0
21	0	0	0	0	0	0
22	0	0	0	0	1	0
23	0	0	0	0	3	0
24	0	0	0	0	1	0
25	0	0	0	0	11	0
26	0	0	0	0	10	0
27	0	0	0	0	9	0
28	0	0	3	2	12	0
29	0	0	3	2	8	0
30	0	1	0	3	27	0
31	0	1	1	11	18	0
32	0	0	0	4	24	3
33	0		1	9	26	0
34	0		0	3	14	0
35	0		0	5	10	0
36	0		0	4	17	0
37	1		0	2	15	0
38	0		0	1	8	0
39	0		0	0	5	1
40	0		0	0	3	2
41	0		0	0	3	2
42	0		0	0	4	1
43	0		0	0	1	2
44	0		0	0	0	4
45	2		0	0	0	3
46	0		0	0	0	4
47	3		0	0	0	2
48	3		0	0	0	0
49	3		1	0	0	0
50	2		0	0	0	1
51	4			0	0	1
52	2			2	0	1
53	1			0	0	0
54	5				0	3
55	1				0	0
56	2				1	1
57	3				0	0
58	3					0
59	2					1
60	3					1
61	1					0
62	1					1
63	1					0
64	0					0
65	2					0
66	1					0
67	2					1
68	2					0
69	0					
70	2					
	53	2	9	48	233	35

Length (cm)	*Lutjanus lemniscatus*	*Symphorus nematophorus*	*Siganus fuscens*	*Epinephelus multinotatus*	*Epinephelus maculatus*	*Epinephelus microdon*
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	0	0	1	0	0	0
21	0	0	1	0	0	0
22	0	0	0	0	0	0
23	0	0	5	0	0	0
24	0	0	3	0	0	0
25	0	0	18	0	0	0
26	0	0	21	0	0	0
27	0	0	16	0	0	0
28	0	0	11	0	0	0
29	0	0	1	0	0	0
30	0	0	0	0	0	0
31	0	0	0	0	0	0
32	0	0		0	0	0
33	0	0		0	2	0
34	1	0		0	2	0
35	0	0		0	4	0
36		0		0	3	0
37		0		0	1	0
38		0		0	1	0
39		0		0	1	0
40		0		0	1	0
41		0		1	0	0
42		1		0	0	0
43		0		0	0	0
44		0		2	0	0
45		0		2	1	0
46		0		0	0	0
47		1		2		0
48		0		3		0
49		0		0		0
50		0		1		0
51		0		0		0
52		0		3		0
53		1		2		0
54		0		1		0
55		0		5		0
56		0		0		0
57		0		3		0
58		0		2		0
59		0		1		0
60		0		0		0
61		0		2		2
62		0		1		0
63		0		0		
64		0				
65		0				
66		0				
67		0				
68		0				
69		0				
70		0				
71		1				
72		1				
73		0				
74		0				
75		0				
76		0				
77		0				
78		1				
79		1				
	1	**7**	**77**	**31**	**16**	**2**

Length (cm)	*Lethrinus choerorynchus*	*Lethrinus nebulosus*	*Lethrinus mahsena*	*Lethrinus fraenatus*	*Lutjanus carponotatus*
18	0	0	0	0	0
19	0	0	0	0	0
20	0	0	0	0	0
21	2	0	0	0	0
22	0	0	0	0	0
23	1	0	0	0	0
24	7	1	0	0	0
25	30	0	1	0	0
26	87	1	0	0	0
27	125	0	2	0	0
28	103	3	2	0	0
29	122	7	0	0	0
30	96	11	0	0	0
31	42	10	0	1	0
32	15	7	0	1	0
33	4	15	0	2	1
34	1	14	0	1	2
35	1	17	0	5	2
36	1	18	0	2	1
37	0	12	0	6	0
38	1	11	0	6	1
39	1	19	0	2	0
40	0	11	0	5	1
41	0	15	0	5	0
42	0	16	0	4	0
43	0	18	0	3	0
44	0	10	0	2	0
45	0	12	0	2	0
46	1	11	0	5	0
47	0	11	0	2	0
48	0	12	0	3	0
49	0	6	0	0	0
50	0	8	0	1	0
51	0	3	0	0	0
52	0	6	0	0	0
53	0	2	0	0	0
54	0	3	0	0	0
55	0	1	0	0	0
56	0	1	0	0	0
57	0	0	0	0	0
58	0	1	0	0	0
59	0	0	0	0	0
60	0	1	0	0	0
61	0	1	0	0	0
62	0	0	0	0	0
63	0	0	0	0	0
	640	**295**	**5**	**58**	**8**

Length (cm)	Carangids	other serranids	*Epinephelus malabaricus*	Mullids	*Diagramma pictum*
27	1	0	0	0	0
28	0	0	0	0	0
29	1	0	0	0	0
30	0	0	0	0	0
31	0	0	0	0	0
32	0	0	0	1	0
33	0	0	0	0	0
34	1	0	0	1	0
35	2	0	2	0	0
36	0	0	1	0	0
37	0	0	0	1	0
38	0	0	0	0	0
39	1	0	0	0	0
40	1	0	0	0	1
41	2	0	0	0	0
42	1	0	0	0	1
43	2	0	1	0	0
44	0	0	0	0	1
45	0	0	0	0	1
46	0	0	0	0	2
47	0	0	0	0	1
48	0	0	0	0	1
49	0	0	0	0	0
50	0	0	0	0	0
51	0	0	0	0	0
52	0	0	0	0	2
53	0	0	0	0	2
54	0	0	0	0	1
55	0	0	0	0	4
56	0	0	0	0	2
57	0	0	0	0	0
58	0	0	0	0	2
59	0	1	0	0	3
60	0	0	0	0	3
61	0	0	0	0	3
62	0	1	0	0	2
63	0	0	0	0	1
64	0	0	0	0	0
65	0	0	0	0	1
66	0	0	0	0	0
67	2	0	0	0	1
68	0	0	0	0	0
69	0	0	0	0	0
70	1	0	0	0	0
71	0	0	0	0	0
72	0	0	1	0	0
73	2	0	0	0	0
74	1	0	1	0	0
75	0	0	0	0	0
76	0	0	0	0	0
77	1	0	0	0	0
78	0	0	0	0	0
79	0	0	0	0	0
80	0	0	0	0	0
81	0	0	0	0	0
82	0	1	0	0	0
83	0	0	0	0	0
	19	**3**	**6**	**3**	**30**

E4 New Ideas about Trap Fishing

A Draft Article for *Australian Fisheries* by Whitelaw A. W., Campbell R. A., Sainsbury K. J. and Dews G. J.

While undertaking a study on the North West Shelf (Sainsbury 1987), it was noticed that the North West Shelf trap fishery differed from others around the world; anecdotal information suggested that catch rates were greater and trap soak times were shorter than elsewhere. Most tropical demersal trap fisheries obtain catch rates in the order of 2.5 kg of fish per trap per day and use soak times of one to several days, while the North West Shelf fisherman obtain catches in the order of 100 kg per trap per day and use soak times of one to a few hours. In most trap fisheries each fisherman works 10–50 traps, while fishermen on the North West Shelf work 8–10 traps. The North West Shelf fishery uses an 'O' style of trap (Bowen 1961), while fisheries elsewhere mostly use 'Z', 'Arrow' or 'Rectangular' traps.

During 1988/89 CSIRO undertook a FIRDC funded project to determine what affects the performance of these 'O' traps, to carry out experiments to determine the reasons for the different catch rates and to try and develop a trap design which would take advantage of information gleaned from the study.

Two fish trapping experiments were conducted off Lowendale Island, on the North West Shelf. The first study (May 1988) determined the effects of soak times on total catch rate and species composition of the catch for 'O' traps. The second study (Aug. 1988) examined the catch rates of four trap types and two bait types over a restricted range of soak times.

Underwater video cameras were placed above the trap on a number of sets to quantitatively determine the rate of ingress (fish going into the trap) and escapement of fish from the trap by time, and to observe fish behaviour both inside and outside the traps.

The four trap types examined were: (1) the 'O' trap, which is unique to Western Australia and is used in the snapper fishery of Shark Bay and the North West Shelf (Bowen 1961, Moran et al. 1988, Dews 1990a), (2) the 'Z' trap, which is commonly used in the Caribbean (Hull 1981, Von Brant 1972, Wolf and Chislett 1974), (3) the 'S' trap, which is used in Cuba (Munro 1983), (4) a CSIRO-designed 'Rotational trap' (Whitelaw et al. in prep), which is a modified 'O' trap in which the trap entrance constantly faces away from the current direction (Fig. 1b).

All trap frames were constructed from 12 mm diameter rod steel and covered with 50 mm interlocking galvanised wire. The entrances to the 'O', 'S', and 'Rotational' traps were vertical slits which were incurving and tapered to a width of 130 cm and extended the height of the trap. The 'Z' trap entrances were 'horse neck' in shape with a diameter of 400 cm on the outer side tapering to 150 cm on the inside and protruding 200 cm into the trap. The entrances were constructed using thin malleable hexagonal 'chicken' wire mesh which was molded into the desired shape. The 'O' and 'Rotational' traps had one entrance, while the 'Z' and 'S' traps had 2 diagonally opposing entrances (Fig. 1a–d).

The rotational trap consisted of a standard 'O' trap on top of a spindle and base. The spindle, in the centre of the trap, allowed free rotation. Vanes were fitted internally on either side of the entrance, so allowing the trap entrance to be orientated away from the prevailing current. The 'Rotational' trap, was developed to take advantage of the fishing characteristics of a trap together with the behaviour of the fish which results in their usually facing into a current.

The two bait types were pilchard (*Sardinops neopilchardus*) and fish that was caught in the traps but normally trashed (mainly Lesser spangled emperor, *Lethrinus choerorynchus*). The commercial fishery on the North West Shelf almost exclusively uses pilchard bait, which is a major portion of the cost of the fishery.

The 14 metre, Onslow based trap fishing boat, the *Judy B*, skippered by Neil Baker, was chartered for both studies, and was equipped with a hydraulically driven capstan mounted midships, a trap 'tipper', colour echo sounder, radar, freezers and brine tanks.

All trapping was carried out within daylight hours, from 0700h to 1730h and while trapping the skipper was encouraged to follow his usual fishing practices in selecting trapping sites, moving between areas, and setting and hauling the traps. When set, each trap was separately tethered by a nylon rope attached to individually numbered polystyrene floats.

All traps were baited with 4 kg of bait which was replaced after every set. The bait was held in bags made of net – mesh, which were suspended by rubber inner–tubes and twine midway between the top of the trap and base. The proportion of bait lost during the trap–set was recorded when each trap was lifted.

Upon trap retrieval the catch was sorted into 5 categories (Table 1). The fish were all identified, measured, and then aggregated by category and weighed.

Table 1. Catch categories

Lutjanidae (sea–perch, snappers)	**Lethrinidae** (emperors)	**Serranidae** (cods)	**others** (trevally, wrasse etc)	**trash** (trigger & butterfly fish)
L. sebae	*L. nebulosus*	*P. maculatus*	carangids	*Abalistes stellatus*
L. vittus	*L.c hoerorynchus*	*E. multinoratus*	labrids	chaetodontids
L. carponotatus	*L. mahsena*	*E. areolatus*	nemipterids	
S. nematophorus	*L.fraenatus*	*E. microdon*	rachycentrids	

To observe behaviour within and around the traps, video cameras were placed on a stand above the trap, so giving a field of view of the trap, its entrances and area surrounding. The number of fish around the trap were counted by category over soak time intervals and all events of fish leaving or entering the trap were recorded by time. The current direction in relation to the trap entrance was observed by attaching a ribbon to the trap and recording the direction by soak time.

A mathematical model was developed using the data from the video observations. The model focussed on the process by which interactions between the bait, fish feeding and current direction (in relation to the trap entrance) effect fish entry and exit from the trap.

Results

Catch rates vs soak time

The effects of long soak times on catch rates were examined during the May cruise and the effects of short soak times were examined during both the May and August cruises. Average total catch by the 'O' traps with pilchard bait varied significantly with soak time; catch increased rapidly in the first hour to about 10 kg, plateaued at about 15 kg between 3 and 9 h, then decreased to about 7 kg after 15 h (Fig. 2). trap–sets of 1h have the greatest catch per unit effort (CPUE, Fig. 2) of the soak times tested.

The numbers of fish caught per trap followed a similar pattern to the catch in weight. The number of fish caught increases rapidly to a maximum of approximately 15 fish per trap at about 3 hours after trap–setting, remains reasonably constant at this level until about 9 hours and rapidly decreases to approximately 5 fish after 15 h (Fig. 3). There is clearly a high rate of fish escapement from the trap after 9 h, which is probably related to bait depletion.

The proportion of pilchard (*Sardinops neopilchardus*) bait remaining at the end of a trap–set changed significantly with the duration of the set; half of the bait was lost within approximately 2 h and essentially no bait remained after 17 h (Fig. 3). The dismembered trash–fish bait was more persistent, and there was no reduction in the proportion remaining in trap–sets up to 6 h.

Seasonal changes in catch rates

The average total catch weight differed significantly among seasons, with the average catch in May being about twice that in August. The average catch (kg/trap/set) for 'O' traps with pilchard bait in May and August are shown in Table 2.

Table 2 Average catch in 'o' traps by season and soak time with pilchard bait
se=standard error; n=number of sets

soak time (h)	May	se	n	August	se	n
1	9.9	1.46	47	0.85	0.06	2
2	13.2	1.49	34	6.2	1.51	21
3	15.3	2.19	26	–	–	–
4	–	–	–	7.7	2.20	9
6	13.5	1.78	15	18.4	5.51	6

Trap type comparisons

There was no significant difference between the 4 trap types tested in August 1988. However, the video tapes of the 'Rotational' trap showed that the entrance often did not align with the current direction as designed, possibly because of low current speeds or because rotation was prevented by protruding coral. Because few of the 'Rotational' trap–sets were successful and trap catch rates are highly variable, the analysis has little power to detect any differences that may exist.

Comparisons between bait types

There was a significant difference in catch rates between bait types, with pilchards producing a larger average total catch than dismembered fish bait. Catch rates with fish bait averaged approximately 26% of the total catches obtained with the same trap type using the pilchard bait. Average catch rates per trap for 2 h sets were 2.15 and 6.22 kg for fish and pilchard bait respectively (Table 3).

There appeared to be no significant change in the species composition of the catch with soak time for the 'O' trap with pilchard bait; the bulk of the catch was composed of emperors followed by cods, others (mainly trevally and wrasse), trash (trigger fish) and snappers. Trash–fish bait appeared to catch a different species composition, with the proportion of trash being higher, and the corresponding proportion of emperors being lower (Table 3). The pilchard baited traps caught significantly more emperors than did the trash–fish baited traps.

Table 3. Catch composition of 'O' traps (%) with fish and pilchard bait (2, 4, 6 hour sets)

	Fish bait			Pilchard bait		
	2h (n=20)	**4h** (n=9)	**6h** (n=8)	**2h** (n=21)	**4h** (n=9)	**6h** (n=6)
Lutjanids	34	0	6.9	1.9	1.0	5.3
Lethrinids	11	37.2	14.8	52.9	50.7	67.4
Serranids	32.7	31.8	56.9	25	23.3	10.5
Others	0	12.2	2.4	6.9	17.8	3.3
Trash	22.3	18.8	19	13.3	7.2	13.5

Video results

The video recordings enabled observations of the accumulation of fish in a trap, together with the behaviour of fish within and around the traps. Ingress and escapement rates were found to be highly variable and there was a high turn over of fish in the traps. The resultant catch for any trap and soak time was found to be the result of a strong interaction between some variables and processes (Fig. 4).

• The rate of arrival of fish to the trap site was strongly influenced by the number of fish already in the trap, the number of very small fish in the trap, the rate of bait loss, and local depletion of fish in the vicinity of the trap. The rate of arrival of fish at the trap site is particularly strongly influenced by a 'burley effect' caused by the interaction of the number of fish already in the trap and the rate of bait dissipation; fish already in the trap eat at the bait and increase the rate of bait dispersal which in turn attracts more fish.

• Ingress was strongly influenced by the current direction in relation to the trap entrance, the rate of bait dispersal (i.e. the 'burley effect'), and the number of fish already in the trap (i.e. trap saturation).

• The escapement rate was relatively constant, but was significantly increased by the number of fish already in the trap.

• Ingress and escapement rates were found to be highly variable, and the former was strongly influenced by the release of a bait stimulant. Different trap designs were found to have significantly different average ingress and escapement rates. The video results show that the average time spent by a fish swimming around the trap is approximately 12 minutes. The probabilities of a single fish entering or leaving the various trap types are given in Table 4.

Table 4. probabilities of a single fish entering or leaving different trap types in a 2 min or 1 h interval.

	Trap type			
	O	Z	S	Rot
Ingress probability				
per 2 min	0.09	0.06	0.13	0.08
per 1 h	0.94	0.84	0.98	0.92
Escapement probability				
per 2 min	.022	.005	0.28	0.17
per 1 h	0.49	0.14	0.57	0.40

• There were significant differences in ingress and escapement rates between the trap types, but no significant difference in the overall catch rates. This is because traps with high ingress also had high escapement rates, with the two rates remaining in almost constant proportion across trap types (Fig. 5). The equilibrium catch is approximately determined by the ratio of these rates, and so all trap types give about the same equilibrium catch despite the large difference in the turnover of fish among trap types.

Further information on the modelling processes can be found in Campbell et al. (in prep).

Feeding of fish at the bait is a important process, causing loss of bait, increased attraction of fish to the trap site, and increased ingress. The attraction is presumably caused by development of a 'plume' of bait particles dispersed in the water. It was estimated that around 20% of the bait lost from the trap was consumed by the fish, with the remaining 80% dissipated into the water to form the bait 'plume'. The two baits examined differed greatly in their effectiveness, and this difference can be explained by the differences in the ease with which the bait types can be broken up by the fish and dispersed. pilchards are easily broken up, and considerable weight of bait is dispersed, whereas the trash–fish bait was very resistant to dispersal. Traps with trash–fish bait did not show the strong positive feedback of fish already in the trap on the arrival and entry to the trap of additional fish. There is an obvious trade–off in the choice of bait between a highly effective, short lived (and expensive) bait and a less effective, long–lived (and cheap) bait.

Fish nearly always approached the trap from the downstream side of the trap, which is presumably the direction of greatest influence of the bait 'plume'. On arrival at the trap fish tended to 'mill about', and if the trap entrance was not on the downstream side the probability of fish entering the trap per unit time was significantly reduced (Fig. 6).

Various patterns of behaviour of fish around the traps were observed. In many instances the fish, after arriving at the trap from down current, remained on the downstream side of the trap within the bait 'plume'. From this position, some fish, mainly emperors, made 'random sorties' around the trap in search of an entry to the bait. Other species (e.g. trigger fish), displayed a more active search pattern, tending to swim repeatedly around the trap.

It was also noted from the video observations that some fish, especially the coral trout (*Plectropomus maculatus*) and Rankins Cod (*Epinephelus multinotatus*), tended to enter the traps to prey on trapped fish rather than the bait itself. In nearly all observations of cod and coral trout, the fish spent their time in the trap actively pursuing smaller fish. If the cod were outside the trap they would attempt to either gain entry to the trap via the entrance or would attempt to make their own, sometimes damaging the trap in the process. The video often showed that after they had consumed their fill they had little difficulty in escaping from the trap.

Other fish, such as the emperors and snappers, would start feeding at the bait as soon as they entered the traps. They tended, after feeding for a few minutes, to rest for a while, just circling the trap or facing into the current, whereupon they would commence feeding again after about 5–10 minutes. It was seen that if there were a few non feeding fish in the trap and one started feeding, then the others would commence as well. Other interesting visitors to the traps included sea snakes, which fed on the bait, curious turtles, and the occasional shark and large ray.

Discussion

Our results show a rapid and significant decrease in catch rates and depletion of the pilchard bait in the trap between 9 and 16 hours. Catch rates are dependent on a significant bait presence within the trap.

The rate of escapement of fish found in our studies for the 4 trap types (approx. 45% **per hour**) greatly exceeds those found in other studies. For example, Munro (1974, 1980) found that escapement was about 11.6% **per day** for unbaited 'Z' fish traps in Jamaica. Luckhurst and Ward (1987), reported from SCUBA observations of both baited and unbaited arrowhead traps (in Bermuda), that escapement from traps with straight funnels was far higher than from those with horseneck funnels. Our data suggests, that for the trap types studied, fears of lost traps harming the fish stocks by 'ghost fishing' are unfounded.

Our catch rates, using pilchard bait, of around 10 kg/trap for 1h sets are far in excess of those reported for other tropical trap fisheries (Stevenson & Stuart–Sharkey, 1980), where catches in the order of 0.35 kg/trap/h are achieved. This difference is probably due in part to the density of fish available; most other trap fisheries have been operating intensively for many years, whereas the North West Shelf fishery is fairly recent and low intensity. Consequently the density of fish on the North West Shelf is likely to be higher than that available to most other tropical trap fisheries. However, it is also clear that the high catch rates and major differences in fishing practices between the North West Shelf and other tropical trap fisheries (i.e. the short soak time) are related to the use of a effective, but short–lived, pilchard bait. Most other trap fisheries use no bait at all or a low quality bait such as trash fish. The effectiveness of the pilchard bait is due to a combination of its relative attractiveness to the target fish and its ability to be easily broken up and dispersed, especially as a result of the feeding action on the bait.

Ingress is very high while the bait is being dissipated as 'burley', but decreases markedly as the bait is exhausted. Consequently the catch with pilchard bait is high while the bait lasts and ingress exceeds escapement, but declines rapidly as the bait is exhausted because fish escapement then exceeds ingress.

If baited traps are to be set for extended periods it is important that sufficient bait be set to maintain high rates of ingress until the trap is hauled. Long duration trap–sets should use traps with low ingress and escapement rates, and of the 4 trap designs we examined, the 'Z' trap is by far the best for long sets. Traps with high ingress and escapement rates are best for short trap–sets, because they rapidly reach their peak catch. Our results show that the 'S' trap is slightly better than the 'O' trap in this regard.

The application of video techniques to the study of fish traps has proved very effective. It not only allowed observations of interactions and events that would otherwise be unknown, but it has greatly increased the ability to quantify the performance of traps. This increase is because the analysis is based on events, such as an entry or exit from the trap, rather than the resultant catch from the trap–set. Many events can be observed per trap–set, enabling characterisation of the relative efficiency of any trap design from only a few 10's of trap–sets, rather than the several hundred needed to quantify a difference from catch rates.

Conclusions

Catch rates were found to change with area, season, duration of trap–set and bait type, while bait type changed both catch rate and species composition. There was no difference in catch rates by trap type because the rates of ingress and escapement are closely related in each trap type, so that the resultant catch is similar.

Ingress, and especially escapement, rates from our traps were shown to be far greater than previously thought. Trap–sets of commercial duration (1–2 h) only catch about 40% of the fish that pass through the trap. Significant 'ghost fishing' by traps for the species considered is very unlikely.

Emperors and snappers enter the traps to feed on the bait, while cods (including coral trout), enter the traps to mainly prey on fish already present. The 'burley' effect of fish eating at the bait increases both the probability that a fish will be attracted to the trap site and of a fish entering the trap.

Current speed and direction in relation to the trap entrance affects the probability of fish ingress and escapement from the trap. The current speed affects the size and concentration of the bait 'plume', and so increasing current speed increases fish arrivals at the trap site. Fish ingress is greatest when the current flows away from the trap entrance, while escapement will be greatest when the current flows into the trap entrance.

The high catch rates on the North West Shelf result from use of a highly effective, short lived bait; to our knowledge the North West Shelf fishery is the only trap fishery in the world which utilises this combination of short soak times and an effective short lived bait to optimise catch rates. The North West Shelf trap fishery is still developing, so stocks are probably unexploited compared to other tropical demersal trap fisheries.

Acknowledgements

We would like to thank the captain and crew of the FV *Judy B* (Neil, John and Dave Baker), the staff at Varanus Island terminus and J. Jenke of the Western Australian Deptartment of Fisheries for their invaluable and enthusiastic assistance. We would also like to thank S. Wayte, K. Haskard, J. Cordell, I. Helmond and N. McQueen for their assistance.

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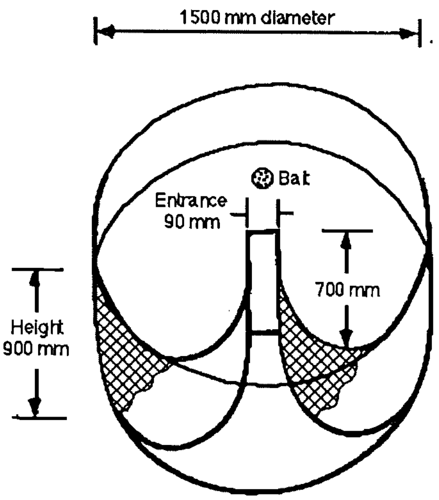
'O' trap

Fig. 1a



'O' trap
single entrance
volume 1.6 m^3

'Rotating' trap

Fig 1b

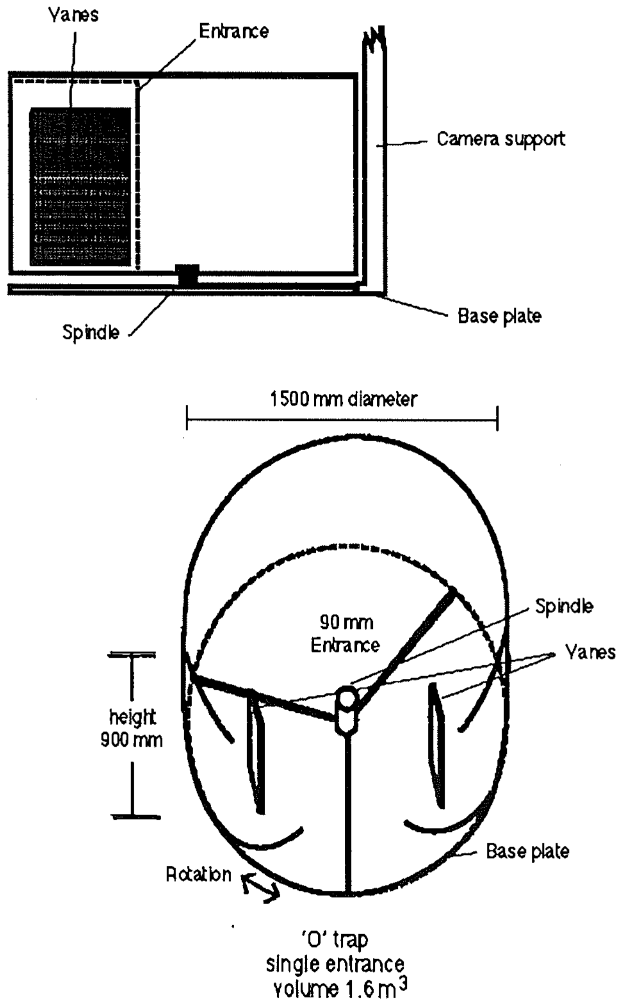
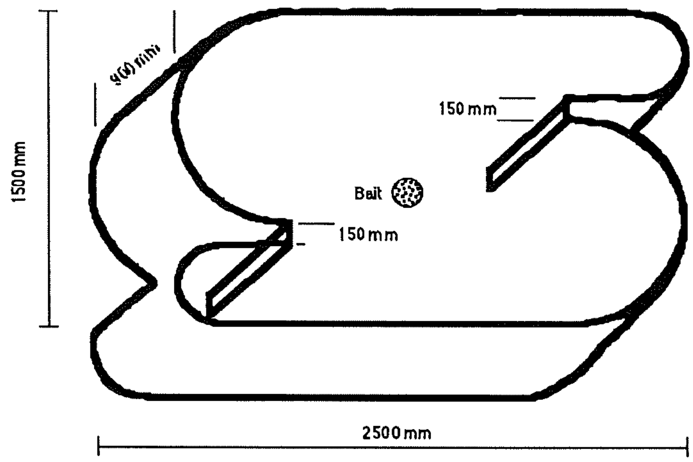


Fig. 1c 'S' trap



'Z' trap

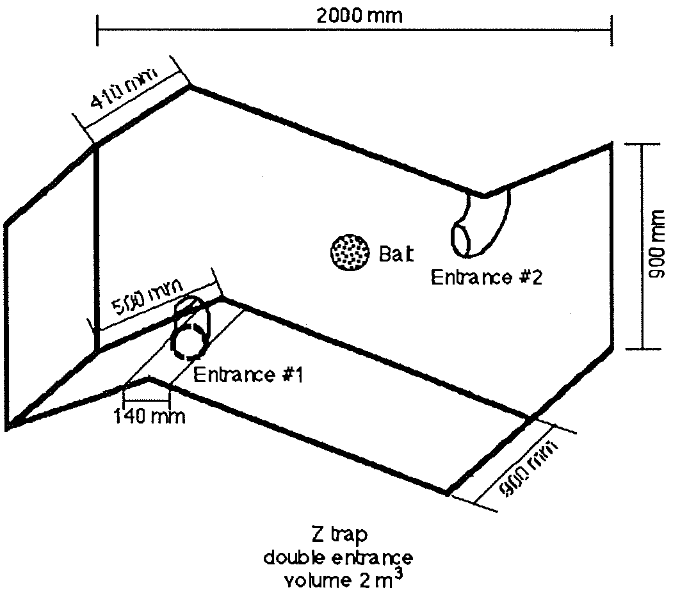

2000 mm
410 mm
500 mm
Bait
Entrance #2
900 mm
Entrance #1
140 mm
900 mm
Z trap
double entrance
volume 2 m3

fig 1d

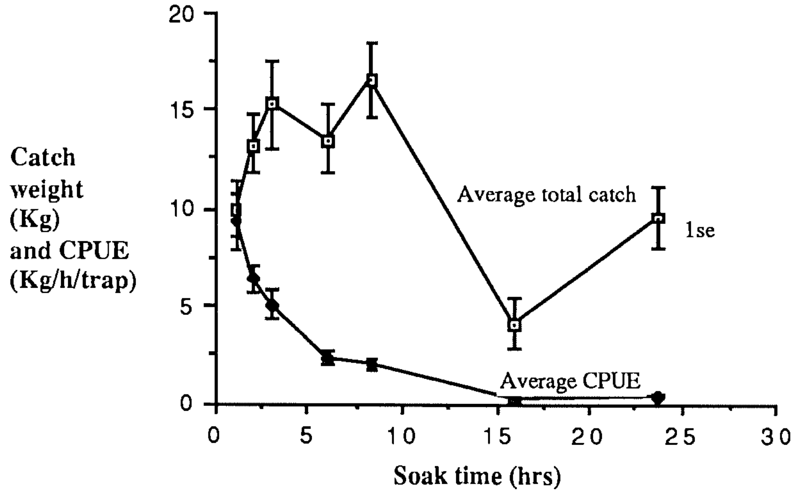

Catch
weight
(Kg)
and CPUE
(Kg/h/trap)
20
15
10
5
0
Average total catch
1se
Average CPUE
0
5
10
15
20
25
30
Soak time (hrs)

Fig. 2

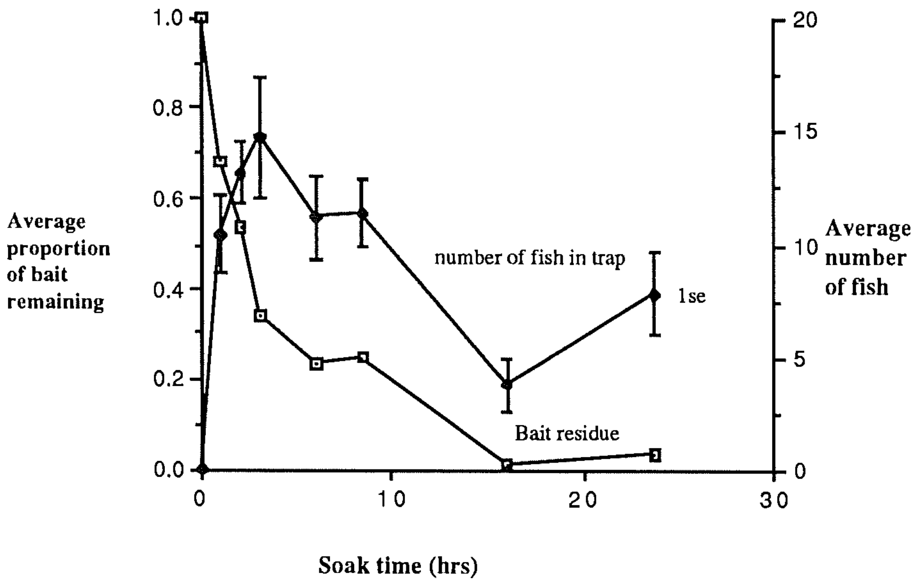

Average
proportion
of bait
remaining
1.0
0.8
0.6
0.4
0.2
0.0
number of fish in trap
1se
Bait residue
20
15
10
5
0
Average
number
of fish
0
10
20
30
Soak time (hrs)

Fig. 3

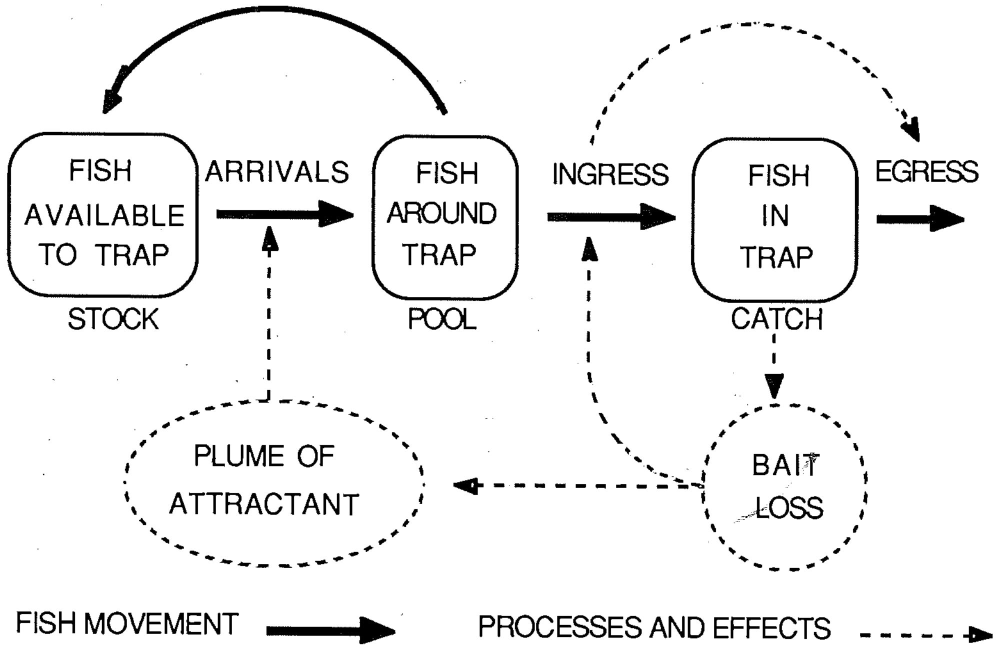


Fig. 4 Schema of fish movements and trap processes

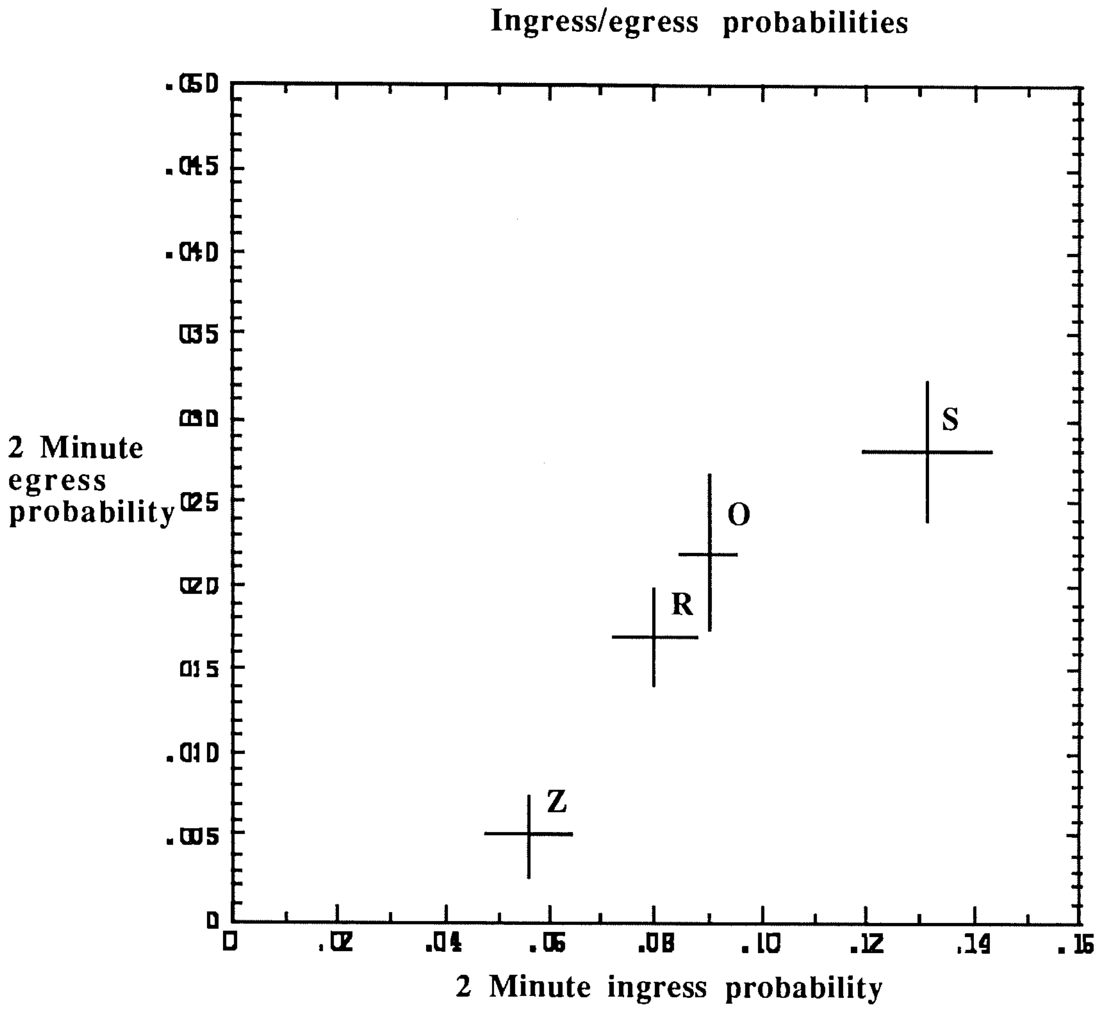


Fig. 5 Comparison of constant 2 min ingress and escapement probabilities for different trap types.

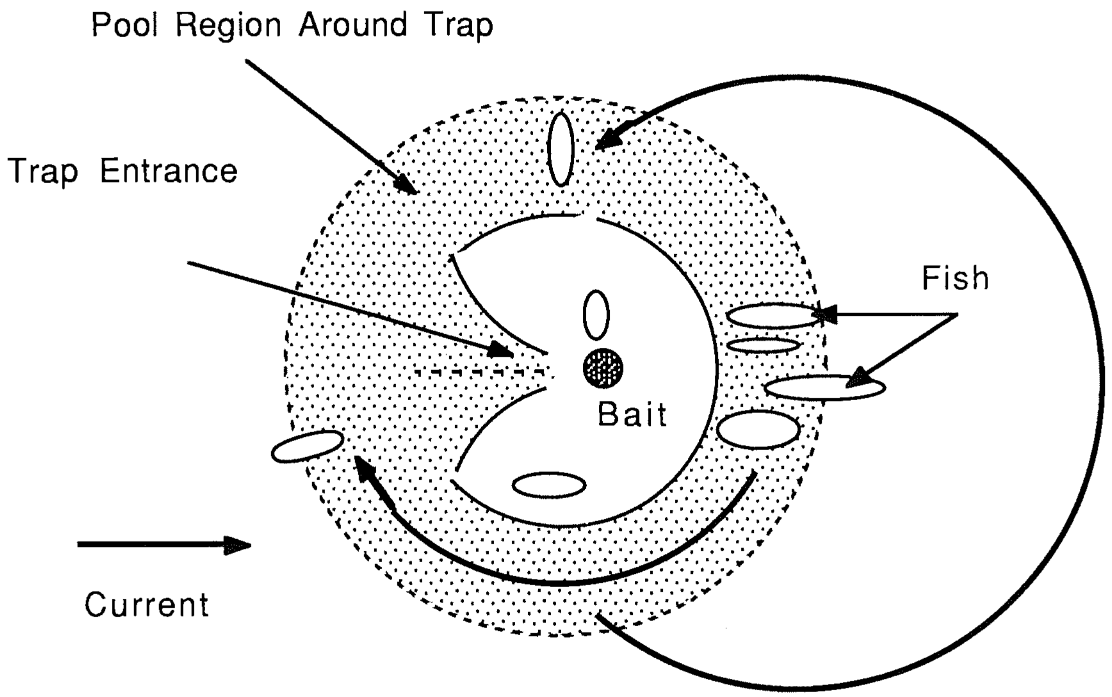


Fig. 6 Fish behaviour around trap

E5 Catching Characteristics of Four Fish Trap Types on the North West Shelf

A Draft article for the *Australian Journal of Marine and Freshwater Research* by Whitelaw A. W., Sainsbury K. J., Dews G. J. and Campbell R. A.

Abstract

Two fish trapping experiments were conducted off Lowendale island (N.W. Australia) to study the catching rates of 4 trap types ('O', 'Z', 'S' and 'Rotational') and two different bait types (pilchard, *Sardinops neopilchardus* and fish caught in the traps (a lethrinid, *Lethrinus choerorynchus*)). The first study determined the effects of soak times of from 1 hour to 1 day on the total catch rate of 'O' traps, the changes in species composition within the traps over time, the longevity of pilchard bait, and the effects of bait depletion on catch rates. The second study compared the catching characteristics of the four trap types and two bait types.

There was a significant difference in the total catch with soak time. Catches increased rapidly for the first 4 hours, levelling off and then decreased with time to 24 h. Significantly different catch rates were detected between season and bait type, but not between trap types.

Pilchard bait was depleted within 10 h of the trap having been set, whereas *Lethrinus* bait was considerably more durable and persisted through all trap–sets. However catch rates were significantly higher with pilchard bait than with *Lethrinus* bait.

The catch rates obtained on the North West Shelf are in excess of those reported for similar trap fisheries elsewhere.

Introduction

The NW shelf of Australia, which covers an area of approximately 67000 km^2 extending from 114^{o}E to 119^{o}E and extending out to 200 m depth, has been exploited by foreign fisheries since the late 1950's (Sainsbury 1987). Most of the fish caught were from the families Nemipteridae, Lethrinidae, Lutjanidae and Serranidae. Since the 1970's, the catch rates of highly desirable fish families such as the large Lutjanidae, Lethrinidae and Serranidae have decreased, while other, less desirable families e.g. Mullidae, Synodontidae and Nemipteridae have increased (Sainsbury 1987, Thresher et al. 1986). Recently there has been an increase in the level of Australian fishing in the area. This level of involvement, though presently low, is increasing.

One of the fisheries developing in the area uses demersal fish traps, and is centered mainly around the towns of Onslow, Port Samson and Port Hedland. The fishery uses circular or 'O' traps (Bowen 1961).

The catch rates obtained from 'O' traps in this fishery are larger than those reported for similar trap fisheries elsewhere (Moran et al. 1988, Dews 1990a). However Wolf and Chislett (1974) and Crossland (1976) stated that 'O' traps are not as effective as other trap types, such as the Antillean 'Z' trap (Munro 1974, 1983, Munro et al. 1971) and the Caribbean S trap (Munro 1974, 1983, Wolf and Chislett 1974). Consequently CSIRO undertook a FIRDC funded project during 1988/89 to compare the catch rates of different trap and bait types on the North West Shelf, determine what affects the performance of 'O' traps, and use the information obtained to suggest improvements to fish trap design. This paper reports on the first of these objectives.

Methods and materials

Two trapping experiments were conducted around the Lowendale Island group on the North West Shelf (Fig. 1), the first between 6 and 20 May and the second between 12 and 26 August 1988. During the first experiment the the effect of soak time on catch rate and bait loss was determined for the trap/bait combination used by commercial fishermen in the area, and during the second experiment different trap and bait types were compared.

Trap designs

The 4 trap designs used were;

(1) **'O'** or cylindrical shape which is unique to Western Australia and used in the Snapper fishery of Shark Bay and the North West Shelf (Bowen 1961, Dews 1990a)
(2) **'Rotational' or 'R'**, which is our modification to the above trap which enables the trap entrance to constantly face away from the prevailing current direction.
(3) **'Z'** shape commonly used in the Caribbean (Hull 1981,Wolf and Chislett 1974, Von Brant 1972)
(4) **'S'** shape commonly used in Cuba (Munro 1983)

Complete dimensions and specifications are given in Fig. 1a–d. All frames were constructed from 12 mm diameter rod steel and covered with 50 mm interlocking galvanised wire.

The rotational trap was developed by mounting a standard 'O' trap on top of a spindle and base. The spindle, in the centre of the trap, allowed free rotation through 360 degrees. Vanes were fitted internally on either side of the entrance so allowing the trap entrance to be orientated away from the prevailing current (Fig. 1b).

The entrance to the 'O', 'S', and 'Rotational' traps were vertical slits which were incurving and tapered to a width of 90 mm and extended the height of the trap. The distance the entrance protruded into the trap varied from 500 mm for the 'S' trap to 700 mm for the 'O' and Rotational trap. The 'O' and Rotational traps had one entrance, while the 'Z' and 'S' traps had two diagonally opposite entrances (Fig. 1 a–d).

The 'Z' trap entrances were 'horse neck' in shape with a diameter of 400 mm on the outer side tapering to 150 mm on the inside and protruding 200 mm into the trap. The entrances were constructed using thin flexible hexagonal wire mesh (chicken wire) which was molded into the desired shape (Fig. 1d).

Each trap was separately tethered by nylon rope attached to individually numbered polystyrene buoys as surface markers.

Vessel, equipment and sampling strategies

The 14 metre, Onslow based fishing boat, the *Judy B*, was chartered for both cruises and carried three scientific staff and two fishing crew. The *Judy B* was a purpose built aluminium barge set up for trapping the NW shelf area. It came equipped with a hydraulically driven midship mounted capstan which pulled the traps over the side using a 'tipper', which is a pivoting frame mounted to the gunwale and operated by the assistant on the capstan. It allowed the traps to be tipped over the gunwale into a position of bench height where the catch could be removed and the bait replaced efficiently and easily.

All trapping was carried out within daylight hours, from 0700 h to 1730 h. During sampling the *Judy B* skipper was encouraged to follow his usual fishing practices in regards to the location of trapping sites, movement between areas and the setting and hauling of the traps. The skipper determined the location of each trap–set using the coloured echo sounder traces and radar bearings. The distance between each trap varied from 20 to a few hundred metres. The different trap and bait combinations were set randomly.

The two baits used were the Western Australian pilchard (*Sardinops neopilchardus*) and a small readily available fish, the lesser spangled emperor (*Lethrinus choerorynchus*) which was dismembered and used as bait.

Each trap was baited with approximately 4 kg of bait which was replaced for every set. The bait was held in net–mesh bags (210 denier * 45 ply, commonly used as cod ends for prawn trawls), which were suspended by rubber inner–tubes and twine midway between the top of the trap and base.

The amount of bait at the start of each set was assigned a score of 1. On retrieval the amount of bait remaining was scored between 0 and 1, thus the difference representing the amount of bait lost or consumed during the set.

Upon trap retrieval the catch was sorted into five categories (Table 1). The fish were all identified, measured to the nearest 0.5 cm and then aggregated by category and weighed. All total catch weights referred to in this paper are for all categories combined, not just commercial species.

Table 1. Catch categories

Lutjanidae	Lethrinidae	Serranidae	others	trash
(sea–perch, snappers)	(emperors)	(cods)	(trevally,wrasse etc)	(trigger & butterfly fish)
L. sebae	*L. nebulosus*	*P. maculatus*	carangids	*Abalistes stellatus*
L. vittus	*L.c hoeroryn chus*	*E. multinotatus*	labrids	chaetodontids
L. carponotatus	*L. mahsena*	*E. areolatus*	nemipterids	
S. nematophorus	*L.fraenatus*	*E. microdon*	rachycentrids	

In May 1988 'O' traps were set for various durations to examine the relationship of bait and soak time on total catch rates. Western Australian pilchards were used for bait throughout this part of the program. Soak times (the time the trap is fishing on the sea bed) were calculated from the time the trap was set over the side to the time it was hauled from the bottom. The time for hauling and setting was < 2 min per trap. Soak times varied from 1 h to 72 h; most were of 1, 2, 3, 6, 9, 16 and 24 h.

In August 1988 2, 4 and 6 h trap–sets were carried out to compare the catch rates of the four trap designs ('O', 'Z', 'ROTATIONAL' and 'S') and the two bait types (pilchard and fish).

A comparison was made of the catch category composition between the inshore and offshore areas for the May cruise and between trap and bait types for the August cruise.

As the study was carried out over two sampling periods (May and August 1988), it was necessary to determine whether there was any significant difference in catch rates by season. This was determined by comparing catch rates for various soak times (2 and 6 h) for 'O' traps using pilchard bait between the two cruises.

All analyses for this paper were carried out on a Macintosh computer using SYSTAT software (Wilkinson 1987), all analyses, unless stated otherwise, are performed on the the square root (to stabilise the variance and normalise the data) of the pertinent data.

Results

Due to weather constraints it was not possible to fish the one area for the duration of the studies.When the weather was too rough it was necessary to carry out the trapping in sheltered areas between the islands where water depth was approximately 7–10 m, compared to the 20 m depths of the outer area. A total of 4 out of 13 days during the May cruise were spent trapping in the more sheltered waters. Due to possible differences in catch rates between the two areas, it was necessary to determine if there were any significant difference in catch rates between these areas.

Comparison between areas by soak time

To test between the 2 areas (inshore and offshore) and soak times of up to 24 h, a two–way analysis of variance was performed on total catch weights from the May cruise for six time periods of 1, 2, 3, 6, 9 and 24 h (the 16 h cell could not be included due to lack of data).

There was no interaction between soak time and zone (F=0.528, P=0.755, df=5,189). The catch rates by area differed significantly (F=5.736, P=.018, df=1, 189) as did catch rates by soak time (F= 4.643, P=0.001, df=5, 189). The catch rates in the inshore area were significantly less than the offshore area (Fig. 2 and Table 2).

Since there were significant differences in the catch rates by area, and since most sampling was carried out offshore, only the data from the offshore sets will be used for the remaining analyses.

Table 2. Back–transformed means, 95% confidence interval (CI), and number of observations of total catch by area for the May cruise

Zone	Time	1h	2h	3h	6h	9h	24h
outer							
n		47	34	26	15	8	16
mean		7.91	12.19	13.89	13.18	16.61	7.01
95% CI		5.4–10.8	9.4–15.4	10–18.5	9.6–17.3	12.0–22.0	4.4–10.2
Inner							
n		18	10	15	1	8	3
mean		4.41	7.03	6.05	9	16.23	2.79
95% CI		1.9–8.0	4.8–9.6	2.9–10.3	–	10.0–23.9	0.1–9.4

Catch rates vs soak time

To test if there were differences in catch rates by soak time for the 'O' trap using pilchard bait in May, the data was divided into seven time intervals (1, 2, 3, 6, 9, 16 and 24 h) and a one way analysis of variance was carried out on the total catch weights for the seven time intervals.

The analysis showed a significant difference between soak times (F=3.241, P=0.005, df=6, 139). The total catch increased rapidly from about 8 kg in the first hour, plateaued at about 14 kg between 2 and 9 h, then decreased to about 4 kg after 16 h to then rise again to about 9 kg at 24 h (Fig. 3). T tests were carried out on the means to test for differences between the soak periods. It was found that soak times of 2, 3, 6, 9 and 24 h did not differ significantly from each other, nor did soak times of 1, 16 and 24 h, but soak times of 1 and 16 h did differ significantly (not highly) from soak times of 2, 3, 6 and 9 h.

Number of fish by soak time

The numbers of fish caught per trap followed a similar pattern to the total catch in weight data, with the number of fish caught increasing rapidly to a maximum of approximately 15 fish per trap at about 3 h whereupon the numbers remain fairly constant until about 9 h where they decrease to approximately five fish after 16 h, this number then rises to approximately eight fish after 24 h (Fig. 4).

Bait loss

To determine if there was a change in the quantity of pilchard bait lost to the 'O' trap by time for the May cruise, whether from dispersal of the bait due to currents or by consumption by fish, a one way analysis of variance was carried out on the ArcSin $\sqrt{\text{bait residue}}$ (to normalise the data, since it is a proportion) for the seven time periods of 1, 2, 3, 6, 9, 16 and 24 h.

The results showed a highly significant variation in the amount of bait remaining in the trap with time (F=16.677, P= <0.001, df=6,127). Figure 5 shows that there is essentially no bait remaining in the trap after 16 h, with half of the bait having been lost to the trap within approximately 2 h.

Changes in catch composition with soak time ('O' traps, May cruise)

A multivariate analysis of variance, was carried out on the relative proportions of the different catch categories by soak time (7 time intervals) to determine if there was any change in the catch composition within the traps by time.

The results showed that there was an overall significant change in the proportion of catch category with time, (Wilk's Lambda = 0.696, P= 0.002, df= 30, 502). Univariate F tests on the five catch categories (Table 3) showed that only the category 'serranids' could be detected as varying by time, while the others did not. Figure 6 shows the proportion of catch by category by time for the May cruise. It can be seen that the proportion of serranids appears to remain fairly constant for the first 4 h, then appears to increase till after about 9 h they decrease with time. The remaining catch categories, did not significantly vary with time.

Table 3. Significance of catch category changes by time

Catch category	P	F value	Degrees of freedom	Significance
Lutjanid	0.096	1.842	6,129	n.s.
lethrinid	0.555	0.821	6,129	n.s.
serranid	0.035	2.344	6,129	*
others	0.779	0.538	6,129	n.s.
trash	0.418	1.016	6,129	n.s.

Seasonal changes in catch rates

To determine if there was a change in catch rate by season a two–way analysis of variance was carried out on the total catch weights for the two time periods of 2 and 6 h (these two periods were used as they afforded the greatest number of sets for both cruises).

The analysis showed that there was a significant interaction between cruises and soak time (F=5.495, P=0.022, df=1, 72) and that there was no significant difference by cruise (F=1.346, P=0.250, df=1, 72), though there was by soak time (F=7.515, P=.008, df=1, 72). T tests were carried out on these means to test for differences between the respective set periods and cruises. These tests showed that there were differences between cruises for soak times of 2 h ($t_{53} = 3.519$, P<0.01), though not for soak times of 6 h ($t_{19} = 0.682$, P>0.05) and that there were significant differences in catch rates in August between 2 and 6 h sets (t_{25}= 3.06, P<0.01), but not in May (t_{47}= .356, P>0.05).The average total catch per trap for 2 h sets in May is approximately twice as much as August (Table 4), while the catch per trap for 6 h sets is similar.

These results seem to indicate that there were less fish available to be caught in August with the catch rate increasing more slowly than the May cruise, after 6 h the catch rates appear to have plateaued at the same level, which may indicate that there may be some saturation effect on the trap as suggested by Munro (1974) and Campbell et al. (in prep).

Table 4. Average catch (kg/trap/set) for 'O' traps with pilchard bait by season (back transformed)

Soak time	n	May	95% CI	n	August	95% CI
2 h	34	12.19	9.31–15.44	21	5.16	2.86–8.12
6 h	15	13.18	9.61–17.31	6	16.34	4.85–34.57

Comparisons between trap types

Trap type comparisons were carried out during the August cruise. A two–way analysis of variance, to test for differences between trap types ('O', 'Z', 'S' and 'Rotat') and soak times (2, 4 and 6 h), was carried out on the total catch weights of randomly positioned traps using pilchard bait.

Analysis showed that there was no interaction between soak time and trap type (F=0.659, df= 6,131, P=0.659). There was also no significant difference between trap types (F=1.121, df=3,131, P=0.343), though there was a significant difference by soak time (F= 5.163, df=2,131, P=0.007) for these three soak periods.

The total catch weights, by trap type and soak time are shown in Table 5 and Fig. 7

Table 5. Average total catch weights (95% CI) and *CPUE* by trap type and soak time (Back transformed)

Time (h)	Trap type			
	O	Z	R	S
2	5.16 (2.9–8.1), *2.58*	4.17 (1.7–7.7), *2.09*	4.06 (1.8–7.2), *2.03*	5.99 (3.4–9.3), *3.0*
4	7.0 (3.0–12.6), *1.75*	6.79 (1.9–14.8), *1.70*	5.52 (2.2–10.4), *1.38*	3.71 (1.3–7.5), *0.93*
6	16.34 (4.8–34.6), *2.72*	11.28 (4.9–20.2), *1.88*	6.57 (3.0–11.5), *1.09*	9.30 (0.2–31.8), *1.55*

Comparisons between bait types

A two–way analysis of variance, to test for differences between bait types (pilchard and dismembered fish) and soak times (2, 4 and 6 h), was carried out on the total catch weights of randomly positioned 'O' traps in the August cruise.

Analysis showed that there was no significant interaction between bait type and soak time (F=2.127, df=2,67, P=0.127). There was a significant difference by bait type (F=26.420, df=1,67, P=<.001) and soak time (F=4.404, df=2,67, P=0.016) with pilchard bait catching more fish than did the dismembered fish bait (Table 6, Fig. 8).

The various bait type soak time combinations are shown in Table 6. Catch rates with fish bait are about 20–25% of those with pilchard bait.

Table 6. Total catch rates (kg) by bait type for 'O' traps for 2, 4 & 6 h sets (back – transformed)

Soak time	pilchard bait Average total catch (kg)	95%CI	n	fish bait Average total catch (kg)	95%CI	n
2h	5.16	(2.8–8.16)	21	1.96	(1.0–3.2)	20
4h	7.0	(3.0–12.6)	9	1.59	(0.4–3.5)	9
6h	16.34	(4.9–34.6)	6	2.94	(0.6–7.2)	8

Table 7 shows the percentage of empty traps and number of trap–sets by trap and bait type for both inshore and offshore areas. This data shows that of the different trap types it appears as if the 'Rotational' trap has the highest proportion of empty traps (16–20%) with pilchard bait, while the 'O' trap with fish bait had a 50 and 35% empty trap rate for the inshore and offshore areas respectively. This high number of empty traps would consequently decrease the average total catch weight for these particular combinations.

Table 7. Percentage of empty traps by trap and bait type combinations for seasons and areas

Trap type	Bait type	Inshore	n	Offshore	n
May cruise					
'O'	pilchard	10.8	65	8.3	156
August cruise					
'O'	pilchard	0	4	10	50
'O'	fish	50	4	35	43
'Z'	pilchard	0	5	11.1	45
'S'	pilchard	20	5	10.4	48
'R'	pilchard	20	5	15.9	44

Catch composition; changes by trap and bait types with soak time

Multivariate analyses of variance was attempted on non transformed data, to determine if there were changes in the catch composition by category by soak time (2, 4 and 6 h sets) for each of the four trap types ('O', 'S', 'Z' and 'Rotat') and two bait types (pilchard & fish bait). Due to the low number of observations on the catch composition for the 'Rotating', 'Z' and 'S' traps it was not possible to perform multivariate analysis of variance on these data sets, so univariate F tests were performed instead on each commercial category by trap type.

Results for the 'O' trap with pilchard bait showed that there was no overall change in the catch composition with soak time (Wilk's lambda= 0.751, P=0.62, F=0.801, df= 10, 52), though the proportion of 'others' does appear to vary (F=2.391, P=0.04, df=2, 32, Fig. 9).

The results for the 'Z', 'Rotat' and 'S' traps showed that there may be a difference in the proportion of lutjanids (F=4.66, P=0.017, df= 2,30) for 'Z' traps, but there are no observable differences in the proportion of any other catch categories for the 'Z' or the 'S' and 'Rotat' traps (Figs 10, 11 and 12).

Results for the 'O' traps with 'fish' bait showed no significant change in the proportion of catch categories by time (Wilk's lambda= 0.592, F=1.017, P= 0.45, df= 10,34, Fig. 13).

Univariate F tests, rather than multivariate analysis of variance (due to missing data cells) were carried out to determine if there were any differences in the catch composition by bait type and soak time (Table 8). These tests showed that for lutjanids and serranids there was no change in proportions by time or bait types, while for lethrinids and trash there was a significant difference between the two bait types (F=9.821, P=0.003, and F=6.166, P=0.016, df=1,51 respectively). A higher proportion of lethrinids were caught with the pilchard bait (Fig. 9) with a corresponding higher proportion of trash caught with the fish bait (Fig. 13). The category 'others' showed a significant interaction between soak time and bait type (F= 4.229, P=0.020, df=51,2), indicating a time effect which varies with bait type.

This lower proportion of lethrinids caught with the 'fish' bait may suggest that the lethrinids are averse to feeding on bait composed of their own type or alternatively that the fish bait does not perform as well as the pilchard bait due to other factors, such as the dispersal rate of bait smell.

Table 8. Catch composition of 'O' traps (%) with fish and pilchard bait (2, 4, 6 h sets)

	Fish Bait			Pilchard Bait		
	2 h (n=20)	**4 h** (n=9)	**6 h** (n=8)	**2 h** (n=21)	**4 h** (n=9)	**6 h** (n=6)
Lutjanids	34	0	6.9	1.9	1.0	5.3
Lethrinids	11	37.2	14.8	52.9	50.7	67.4
Serranids	32.7	31.8	56.9	25	23.3	10.5
Others	0	12.2	2.4	6.9	17.8	3.3
Trash	22.3	18.8	19	13.3	7.2	13.5

Bait loss by trap and bait type

To determine if there was any significant change in the amount of bait remaining in the trap by soak time (2, 4, 6 h) and bait type (pilchard, fish) a two way analysis of variance, using un–transformed data, was carried out on the amount of bait remaining within an 'O' trap by bait type.

The results show that there was no interaction between bait type and soak time (F=0.242, P=0.786, df=2, 53), there was also no significant difference by soak time (F= 1.348, P=0.269, df=2, 53) though there is a significant difference by bait type (F=47.944, P<0.001, df=1, 53). Figure 14 shows that although there is no variation in bait residue by time for either bait type, there is in fact a significant difference between bait types in regard to the amount of bait that is present in the first and subsequent time periods. The results (Fig. 14) indicate that a significant proportion of the pilchard bait is lost to the trap within the first 2 h (approx 35%), while only about 5% of the 'fish' bait has been lost within this time period.

Discussion

Most tropical trap fisheries, both subsistence and commercial, tend to 'set' or soak their traps for periods of up to several days between hauling. Table 9 shows comparative catch rates derived from other studies with catches ranging from 1 to 30 kg per soak with the catch per trap/hour ranging from 0.01 in PNG (Dalzell & Aini, 1987) to 3.25 in Jamaica (Wolf & Chislett, 1974). This compares to our catch rates of up to 9.9 kg/trap/h for one hour sets. Where our traps were set for 24 h, the average catch weight per 'O' trap with pilchard bait was 9.56 kg, which has a resultant catch per hour of 0.40 kg/trap. This result is comparable to some of the other reported catch rates.

Although our extended trap–sets (>24 h) exhibit slightly higher catch rates than other results reported in the literature, it is the shorter soak times which exhibit the greatest CPUE. A study by Wolf and Chislett (1974), using 'Z' and 'D' traps where they set the traps for 3–5 h in the Caribbean, show that some of their catch rates are fairly comparable to ours (Table 9), in that they are achieving catch rates, using Scombrids or Decapterids as bait, of up to 30 kg/ 3–5 h set for 'Z' traps and 13 kg/ 3–5 h set for 'D' traps. Most other studies (e.g. Munro 1983, Dalzell and Aini 1987, Blanc 1988), use set times of 24 h or more, which consequently produce much lower catch rates.

Munro (1974, 83) states that 'daily escapement of fishes from traps is a fixed proportion of the number of fishes contained within a trap and that provided the daily rate of ingress is constant, the catch will reach an asymptote at which time ingress is equalled by escapement'. He computed the rate of escapement as 0.116 per day on the fish remaining in the trap. As our results show (Fig. 4) the total catch within a trap increases rapidly in the first 2 h to about 14 kg/trap whereupon it levelled out to around 9 kg/trap, till after approximately 9 h it decreased to a low of 4 kg/trap and then appeared to increase slightly to around 9 kg/trap. This rapid and significant decrease in catch

Table 9. Trap catch rates reported in published papers

Location	Trap type	Depth(m)	Bait	Ave catch rate (kg/haul)	Ave soak (h)	kg/trap/h	Fish type
South Florida (2)		3–40	None	12.3	108	0.11	
Offshore Jamaica banks (9)		40–60		8.4	18h	0.47	Serranidae
Puerto Rico (E. coast) (9)		40–200		2.25	24	0.09	Pomadasidae
Puerto Rico (W. coast) (9)	'S', 'Z'	40–250	None	2.7 – 5.7	96	0.08	Holocentridae
	Arrowhead						Scaridae
Mona Isl (Puerto Rico) (9)		60–200		3.4	12	0.28	Carangidae
Pedro Bank (Jamaica) (11)	'O'		Scombridae	2.7	12 (o/night)	0.23	Lutjanidae
Pedro Bank (Jamaica) (11)	'Z'		& Decapterus	30.0	4	7.5	Mullidae
Pedro Bank (Jamaica) (11)	'D'		'	13.0	4	3.25	Monocanthidae
							Balistidae
US Virgin Islands (9)		12–25		1.8	1.5	1.20	Chaetodontidae
Papua New Guinea (3)		10–25	slaughter house offal	2.32	168	0.01	Acanthuridae
							Lethrinidae
Kuwait (6)	'Bee hive'			11.0	72–96	0.13	
Seychelles (4)	'Arrowhead'	10–40	shells & fish guts	4 .0	48	0.08	
							Lutjanidae
Florida (10)	'Rectangular'	6–73	lobster heads	4.9	24	0.20	Serranidae
							Rachycentridae
							Lutjanidae
Vanuatu (1)	'Z'	100–215	Scombridae	7.4	24.0	0.31	Gymnocranius
							Epinephulus
							Congridae
Lesser Antilles (7)	'Z'	200		24.8	24	1.03	
Various locations around Jamaica (8)				1.0–4.0	24	0.08	
							Sparidae
New South Wales (5) (Australia)	'Rectangular'	30–100		2.5	24–96	0.05	Cheilodactylidae
							Monocanthidae
Northwest Shelf	'O'	20	pilchard	9.9	1	9.9	Lethrinidae
'	'	'	'	9.6	24	0.40	Lutjanidae
							Serranidae

References: (1) Blanc, 1988; (2) Craig, 1976; (3) Dalzell & Aini, 1987; (4) de Moussou, 1986; (5) Henry, 1990; (6) Mathews, 1987; (7) Munro, 1974; (8) Munro, 1983; (9) Stevenson & Stuart–Sharkey, 1980; (10) Taylor & McMichael, 1983; (11) Wolf & Chislett, 1974.

rates and depletion of available bait in the tra- between 9 and 16 hours seems top indicate that catch rates are dependent on a significant bait presence within the trap.

The catch composition of the traps vary significantly by time (Fig. 6) with serranids seeming to increase slightly in relation to lethrinids (after approximately 3 h). This may be due to a predator/prey relationship existing between the two families with the serranids inhibiting the ingress of lethrinids into the trap. This is substantiated by underwater video observations of trap–sets (pers. obs, Campbell et al., in prep) and by anecdotal information obtained from professional trap fishermen in the area.

The presence of bait significantly affects the catch rates, with the pilchard bait effecting larger catches than the dismembered fish bait. Wolf & Chislett (1974), commented that they found trash fish relatively ineffective as a bait as we found also. Although the pilchard bait is fairly expensive (A$1.60/kg) and tends to break up fairly quickly, the increased catch rates would appear to justify its use in this fishery for commercial operations.

There were no significant differences in catch rates by time for the four designs of traps tested, though it was thought that the 'Rotational' trap may have exhibited a higher catch rate due to the fact that its entrance would continuously be pointing down current, where it was hoped it would provide easier entry for fish into the trap. This assumes that the fish approach the trap from down current following the bait odor plume (Ferno et al. 1986) and that their normal mode or direction of swimming into the current would ensure that while they are in the trap they would always be facing and swimming into the blind or non entrance side of the trap. This behaviour coupled with the design characteristics of the rotating trap should have resulted in higher catch rates, though they this was not the case. Whether our assumptions were in–correct, which underwater video footage would suggest they were not (pers. ob. and Campbell et al, in prep) or whether the movement of the trap frightened the fish, which again video footage suggests did not occur, or whether the rotational aspect of the trap did not work as anticipated, we cannot explain, except that possibly once the fish are within the trap their movement is random so enabling a constant probability of escape regardless of the trap orientation and current direction.

The results of the project have helped explain the dynamics of the trap as a fishing tool and shown that it can be used in a quantitative fashion in certain situations. It has gone a long way to explain why our results differ from those obtained by others, which in itself poses questions as to the validity of some of the conclusions others reached, which in turn have implications on using their results to try and manage tropical trap fisheries.

Traps as we used them, appear to have high escapement rates, as can be seen by the decrease in numbers (or weights) of fish with time and since the species composition of the traps do not appear to alter significantly over time, one can then assume that most species encounted in this study are escaping at the same rate, consequently, it is suggested that traps would not ghost fish to any great extent if lost or left in place for too long. Traps as a fishing tool, are economical, produce a good product, are size selective and most importantly, do not appear to harm the habitat of the fishery they are utilising.

Summary

The performance of four types of wire fish traps ('O', 'Z', 'S' and 'Rotational') and two bait types (pilchards, *Sardinops neopilchardus* and dismembered fish) were studied on the Northwest shelf trap fishing grounds off Lowendale island during two sampling periods in 1988. The numbers and weight of approximately 20 species were recorded for 336 trap hauls.

Changes in catch rates were related to area, season, duration of trap–set and bait type while changes in species composition were related to bait type and to a lesser extent, soak time.

Catch rates by area (inshore and offshore) were significantly different with the offshore deeper sets producing larger catches.

Catch rates by soak time showed a significant variation, with catch rates increasing for the first 2 h, then levelling off at around 15 kg/trap to then fall again after about 9 h to reach a low of approxiately 4 kg/trap at 16 h soak time, the total catch then rose (non significantly) to approximately 9 kg/trap after 24 h. The corresponding CPUE varied significantly from a high of 9.31 kg/trap/h after soaking for 1 h to a low of .25 kg/trap/h after soaking for 16 h.

The number of fish caught per trap followed the same trend as the total weight per trap with the numbers ranging from a high of approximately 15 fish per trap after 3 h to a low of four fish per trap after 16 h.

Trap type comparisons showed no significant difference in total catch weights by trap type, though there was a significant difference in catch rates by soak time with total catch weights tending to increase with length of soak time up to 6 h. Total catch weights for the 'Z' trap types ranged from 5.8 kg/trap for a 2 h soak to 12.43 kg/trap for a 6 h set, the 'S' trap ranged from 7.45 kg/trap for a 2 h soak to 12.3 kg/trap for a 6 h soak and the 'O' trap ranged from 6.22 kg/trap for a 2 h soak to 18.4 kg/trap for a 6 h soak and the 'Rotating' trap ranged from 5.2 kg/trap (2 h) to 6.22 kg/trap for 6 h sets.

Bait loss (pilchard) within the trap showed a significant change in the proportion of bait available within a trap by time with the quantity of bait decreasing to about 1/2 after approximately 2 h and all bait effectively lost after 16 h. The dismembered fish bait did not vary significantly in quantity by time over 6 h sets.

There was a significant difference in catch rate by bait type with the pilchard baited traps catching approximately 4–5 times as much as the ‘fish’ baited traps.

There appeared to be no significant overall change in the species catch composition by time for the 'O' trap with pilchard bait, although the proportion of serranids within the trap varied with time. Lethrinids made up the bulk of the catch followed by serranid, others, trash and lutjanids. Fish bait appeared to show a difference in the proportion of species caught by time with a higher proportion of lethrinids being caught with pilchard bait and a corresponding higher proportion of trash caught with the fish bait.

Acknowledgements

We would like to especially thank the captain and crew of the FV *Judy B* (Neil, John and Dave Baker), the staff at Varanus Island terminus and J. Jenke of the Western Australian Department of

Fisheries for their invaluable and enthusiastic assistance. We would also like to thank S. Wayte and K. Haskard for their statistical and computing assistance.

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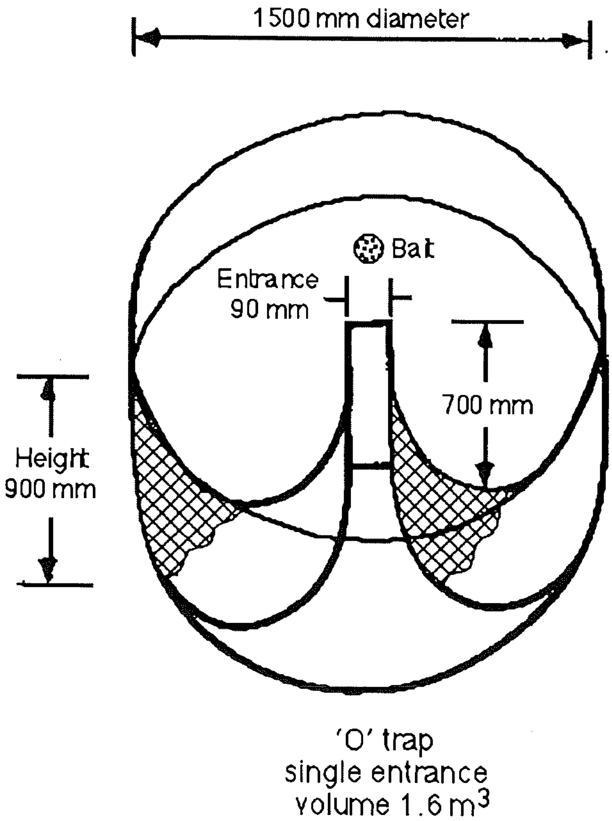

1500 mm diameter
Bait
Entrance
90 mm
700 mm
Height
900 mm
'O' trap
single entrance
volume 1.6 m3

Fig. 1a 'O' trap

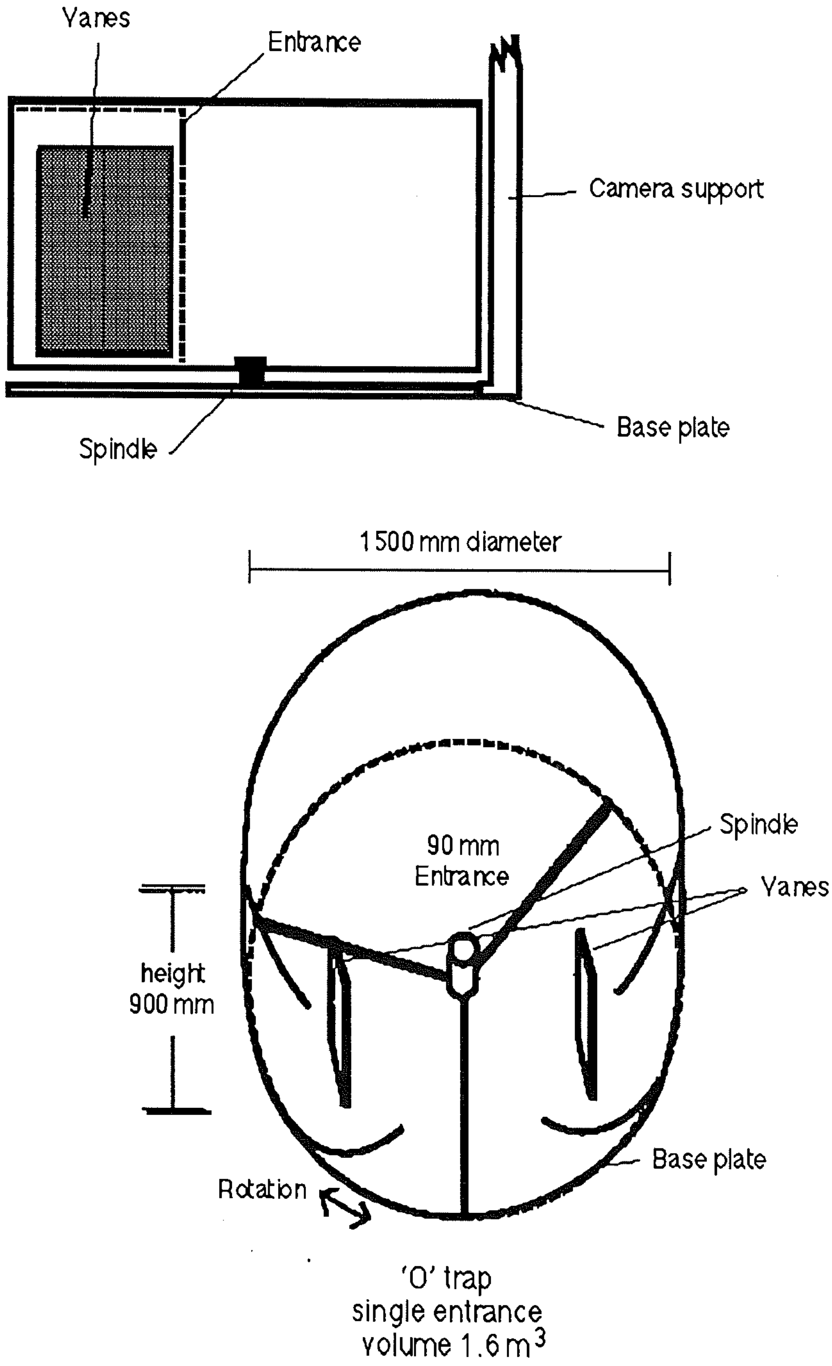


Fig. 1b 'Rotating' trap

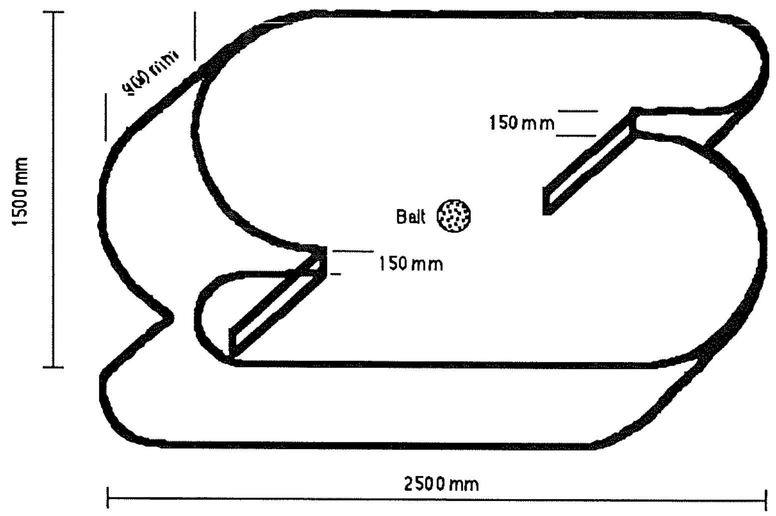
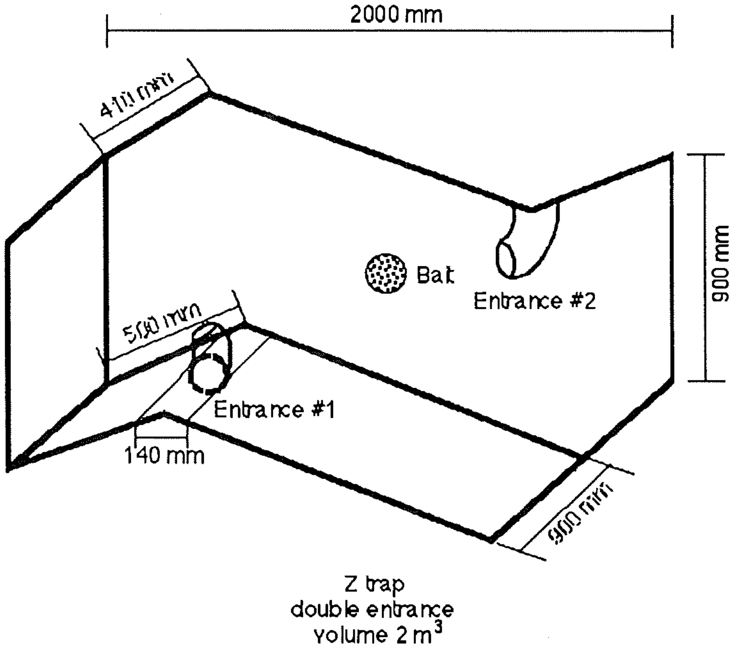


Fig. 1c 'S' trap



2000 mm
410 mm
900 mm
Bait
Entrance #2
500 mm
Entrance #1
140 mm
900 mm
Z trap
double entrance
volume 2 m3

Fig. 1d 'Z' trap

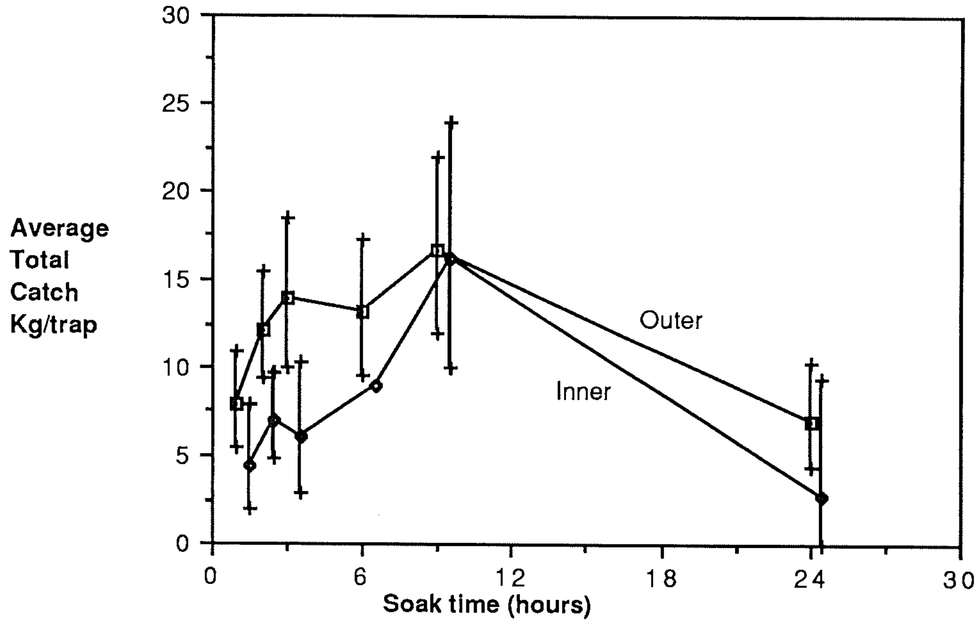


Fig. 2 Average total catch weights by area (back calculated, May)

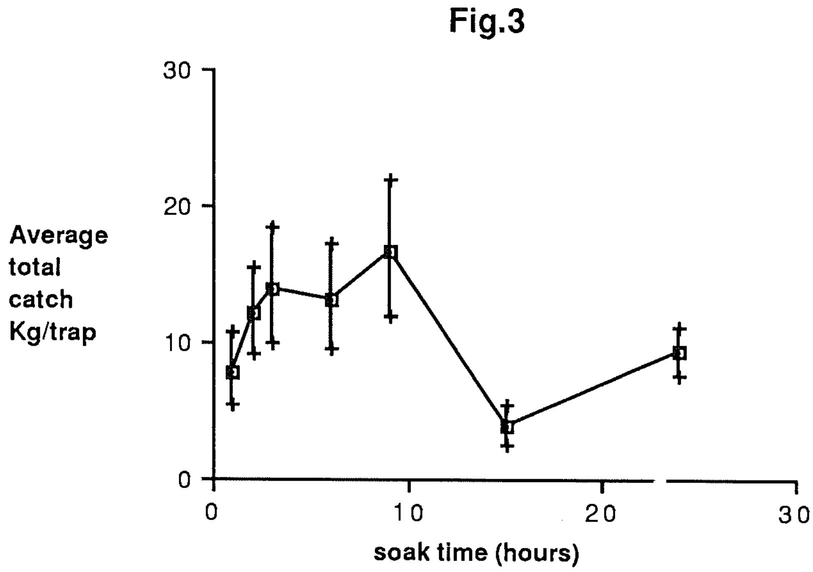


Fig. 3 Average total catch weights - offshore (back calculated, May)

Fig. 4

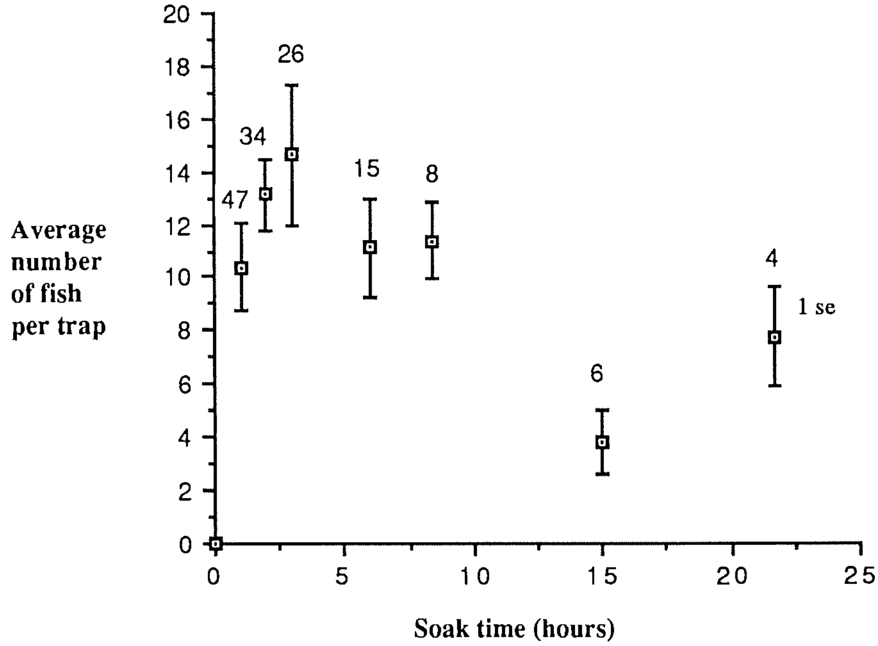


Fig. 4 Average number of fish/trap (May)

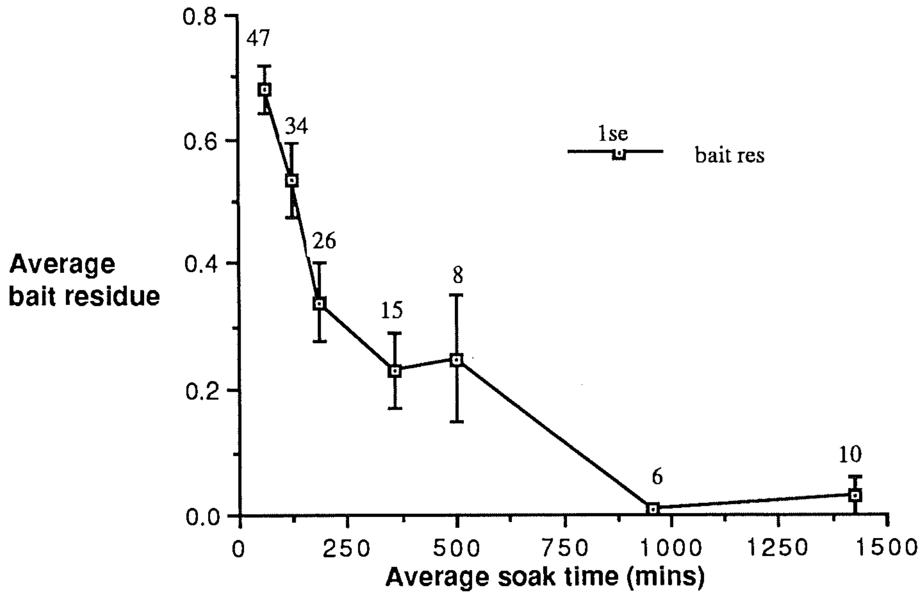


Fig. 5 Bait loss by time (May)

Fig. 6

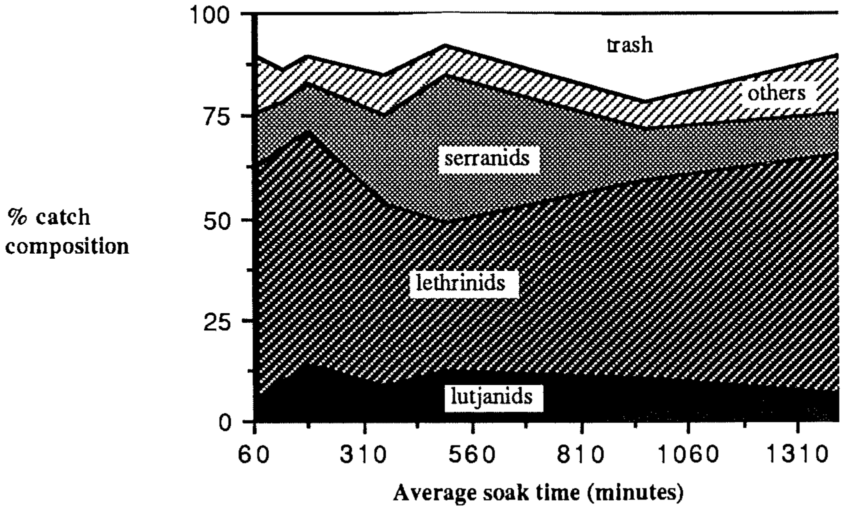


Fig. 6 Catch composition by time (May)

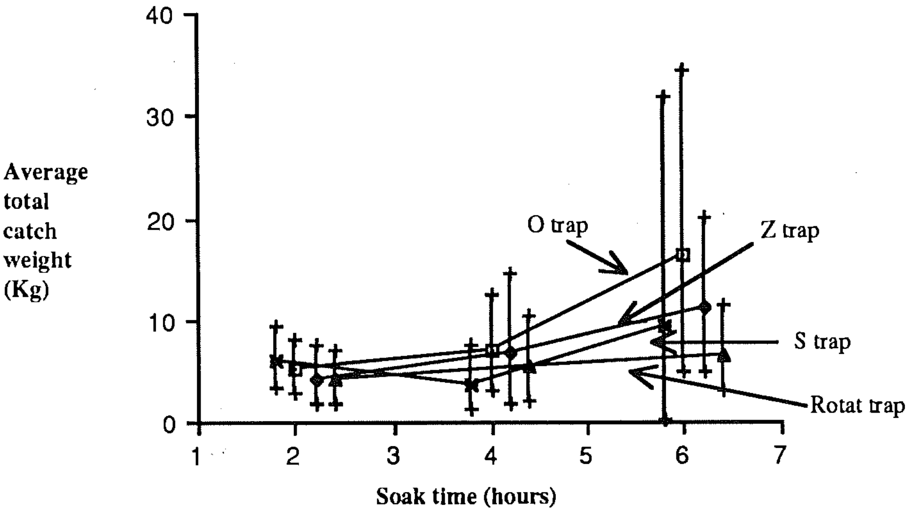


Fig. 7 Average total catch by trap type / set time (back calculated)

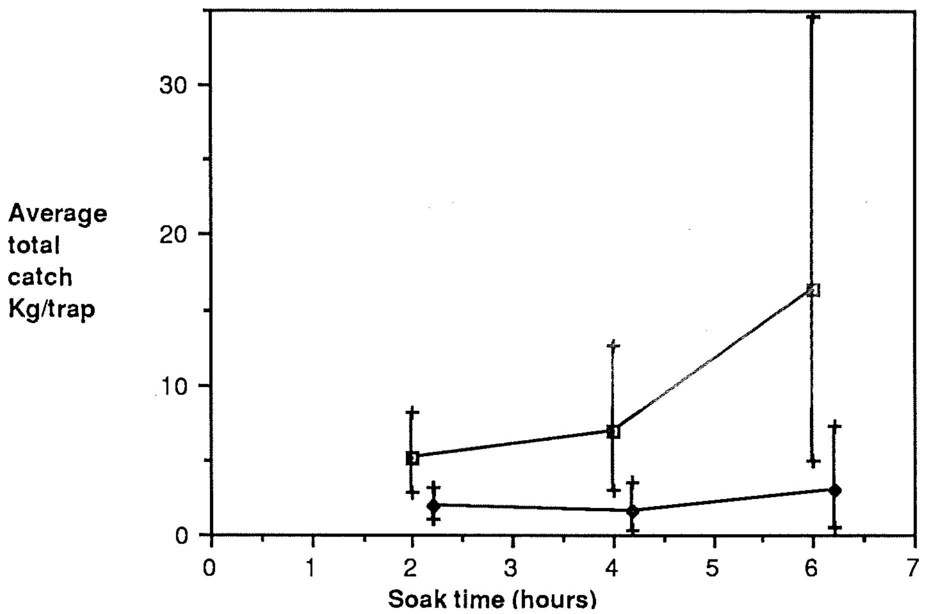


Fig. 8 Average total catch by bait type (back calculated)

Fig. 9

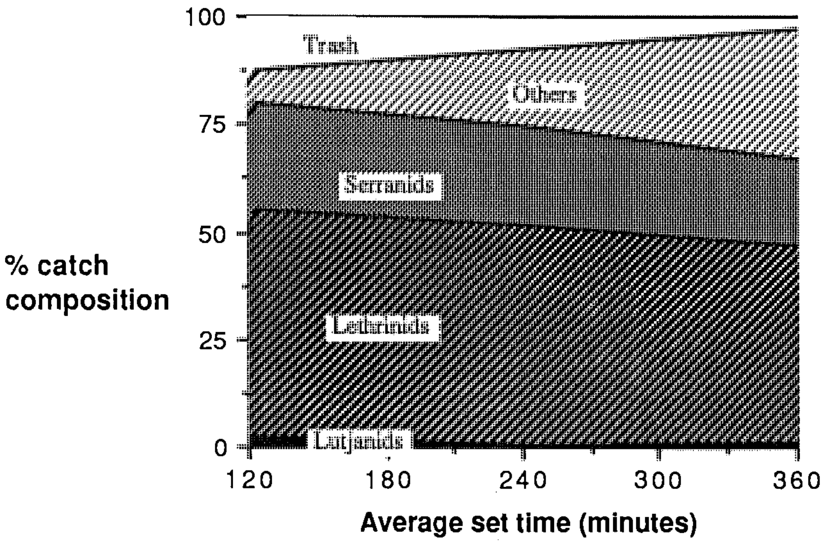


Fig. 9 Catch composition - August, 'O' trap, pilchard bait

Fig. 10

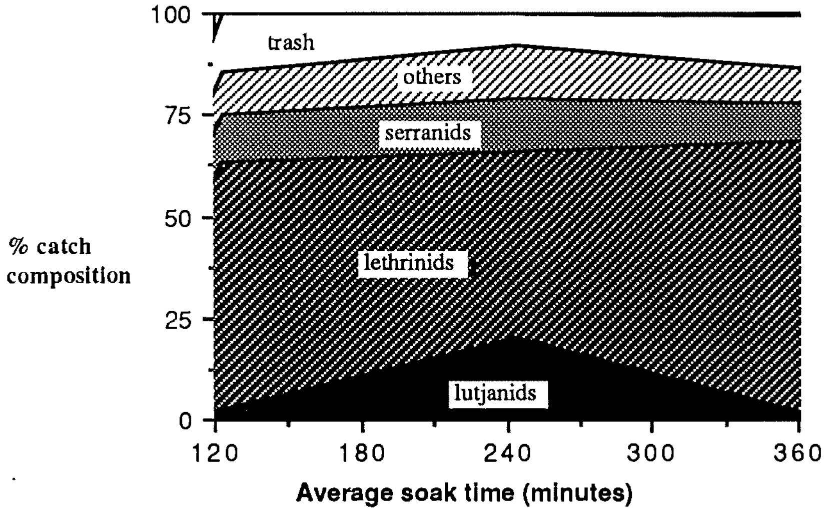


Fig. 10 Catch composition - August, 'Z' trap, pilchard bait

Fig. 11

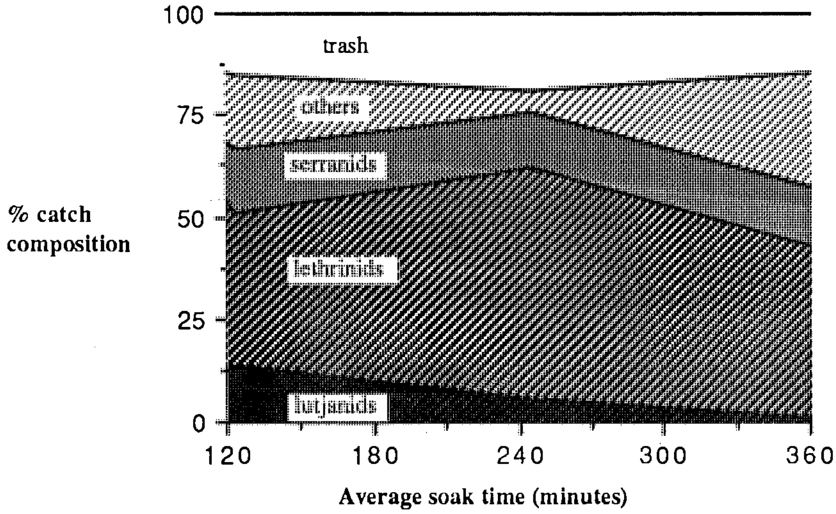


Fig. 11 Catch composition - August, 'S' trap, pilchard bait

Fig. 12

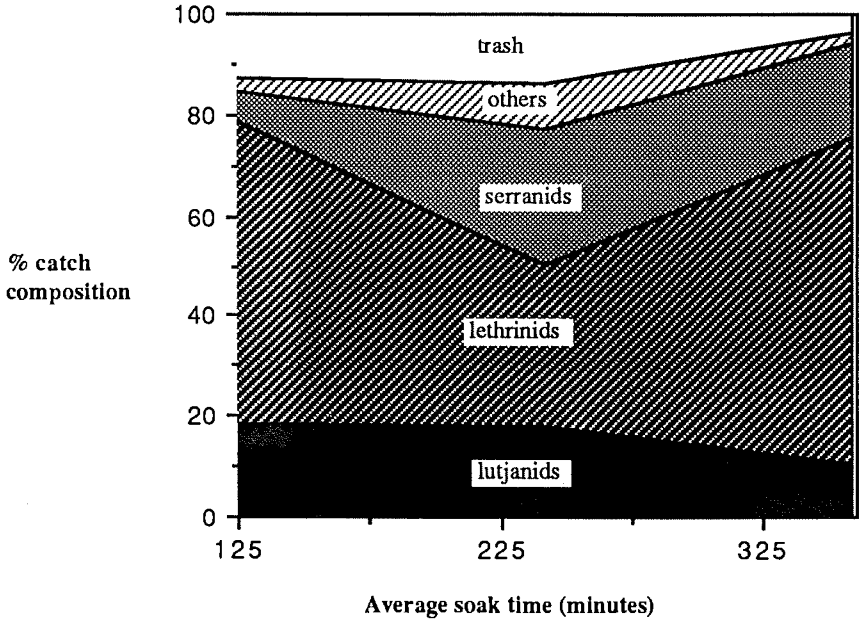


Fig. 12 Catch composition - August, 'Rotat' trap, pilchard bait

Fig. 13

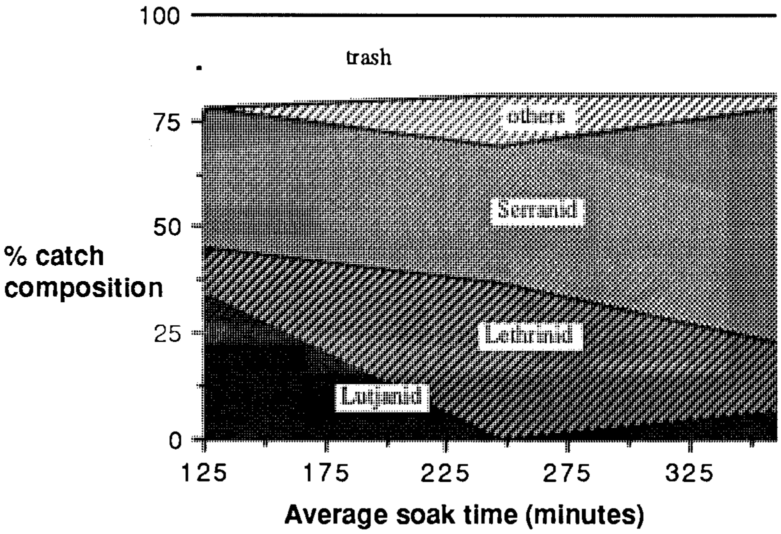


Fig. 13 Catch composition - August, 'O' trap, fish bait

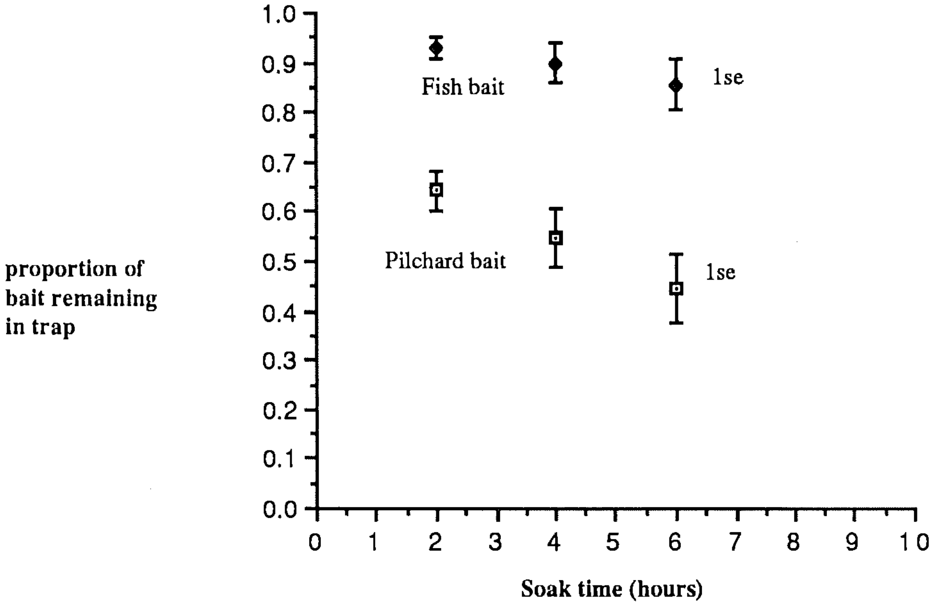


Fig. 14 Bait residue - August, pilchard and fish bait

E6 A Process Model of Fish Trapping on the North West Shelf of Australia

A Draft Article by Campbell, R. A., Sainsbury, K. J., Whitelaw, A. W., and Dews, G. J.

Abstract

Previous studies of the operation of fish traps have relied upon relating the catch to the trap's soak time. This has several drawbacks that make modelling of the processes difficult. Furthermore, because the turnover of fish in a trap is not observed, it is most likely that the ability of fish to escape from a trap has been under–estimated. The role of the bait has also been difficult to ascertain. To overcome these limitations, video cameras were mounted above a number of baited traps during trials on the North West Shelf of Australia. Four different trap types and two bait types were used. Mathematical models were developed to explain the dispersal of the bait, the arrival of fish at the trap and the subsequent ingress into (and egress from) the trap.

Catches were observed to increase with soak time before levelling out at some trap–specific limit. The turnover of fish in a trap was usually high, with ingress and egress rates highly correlated and related to trap design. Average hourly escape probabilities for fish varied between 0.14 for 'Z' traps up to 0.57 for 'S' traps. Those traps with a high ingress rate may be best for short soaks. Loss of bait was mainly due to feeding by fish, and a concommitant burley effect was found to be a major influence on increasing both the rate of fish arrivals at the trap and the rate of ingress into the trap. For single entrance traps, the alignment of the entrance with the prevailing current direction was also found to be important and there appears to be scope for a rotating trap to take advantage of this.

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§1 Introduction

Fish traps, the principal fishing device throughout the Bahamas and Caribbean Islands, are efficient devices for capturing fish in areas where coral formations prevent the use of trawls and other nets. The operation of such traps, which results in a catch after a certain soak time, is based on a sequence of events involving the arrival of fish at the trap and their eventual entry into (and possibly escapement from) the trap. It is generally accepted that a trap's performance will be improved with the use of a suitable bait. The bait operates by creating a plume of attractive stimuli which will draw fish to the trap from a considerable distance.

Once around a trap, entry into the trap will be influenced by trap design, the presence of a bait, conspecific behaviour and mere curiosity. The presence of the bait may also help to lengthen the stay of an individual fish in a trap. Different trap designs have been developed over the years and used within different fisheries in order to facilitate this process. Effective trap designs should not only assist ingress but hinder escapement.

Most studies concerning the operation of fish traps have relied upon sampling the catch at the time of retrieving the trap. This has had a number of drawbacks, both in the time needed to carry out a sufficient number of trials and the small number of observations obtained which has made any modelling of the processes difficult. Furthermore, because the turnover of fish in a trap is not observed, the ability of a fish to escape from a trap has had to be assumed. It is most likely that this escape probability has been under–estimated. The role of the bait has also been difficult to ascertain.

To overcome these limitations, video cameras were mounted above a number of baited traps during trials carried out on the North West Shelf of Australia. The continuous nature of the observations made with the video cameras allowed for the accumulation of any catch within a trap to be fully documented. Furthermore, the behaviour of fish both in and around the traps could be observed and described.

The large number of observations obtained in this manner made it possible to test more accurately the assumptions underlying the trap model developed by Munro (1974). New mathematical models were also developed to account for the dispersal of the bait, the arrival of fish at the trap and the subsequent ingress into (and egress from) the trap. These models were used to compare the influence of trap design on ingress and escapement for four different trap types.

§2 Munro's trap model

A large study using Antillean fish traps was carried out by Munro and his co–workers at Pedro Bank off Jamaica during the early seventies (Munro et al.,1971 and Munro,1973, 74, 83). These workers observed that catches tended to level off asymptotically after some optimum soak time (Figure 1). This behaviour was explained in terms of a simple relationship between ingress, escapement (or egress) and resultant catch. They postulated that fish continue to enter a trap at a fairly constant rate α throughout the soak, but that daily escapement is a fixed proportion β of the number of fish in the trap.

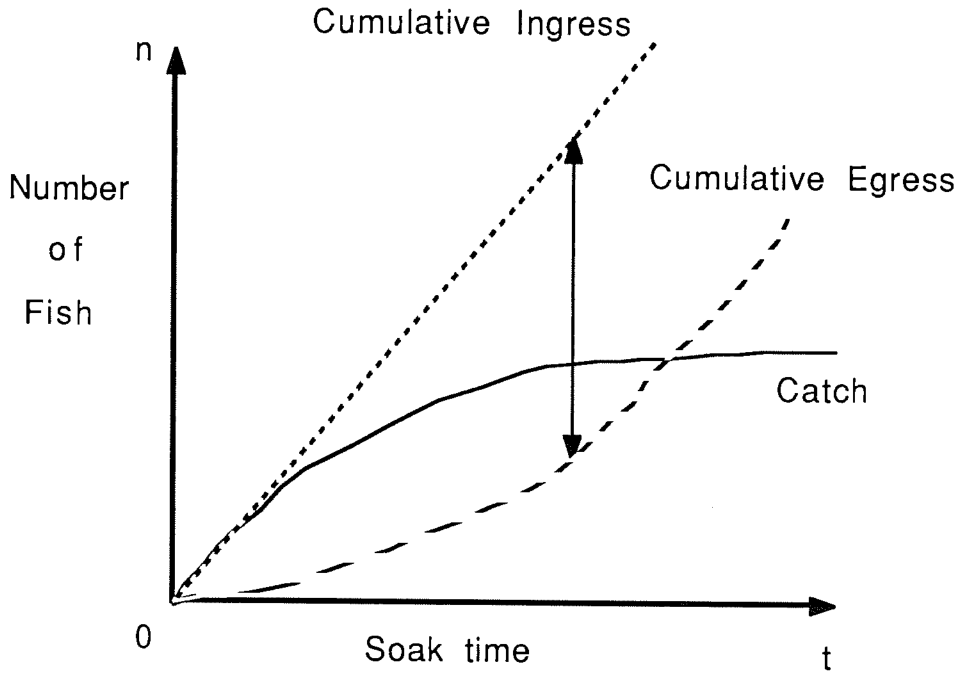


Figure 1 Typical catch versus soak time

Using this argument, the daily rate of increase in the catch C is given by the expression

$$\frac{dC}{dt} = \alpha - \beta C \qquad (1a)$$

giving a catch C_s after s days of;

$$C_s = \frac{\alpha}{\beta}\left(1 - e^{-\beta s}\right) \qquad (1b)$$

The catch attains its maximum level C_∞ when the ingress of fish into the trap equals escapement and from equation (1b) is seen to be given by

$$C_\infty = \frac{\alpha}{\beta} \qquad (1c)$$

This equilibrium catch is determined by the ratio of ingress to escapement and the same equilibrium catch could be obtained with a high turnover of fish (large α and large β) or with a low turnover of fish (small α and small β). However, either an increase in the rate of ingress or a decrease in the probability of escape will lead to a greater catch (or vice versa). Munro concluded from his studies that the overall daily rates of escape from the traps varied between three percent and 22.3 percent of the catch, with an average of 11.6 percent for all fish species observed.

The rate of ingress into the trap is assumed to be largely a function of the stock density within the area in which the trap is set. Furthermore, Munro (1974) states that a positive attractant in the form of a bait in a trap would increase the rate of ingress of those species which are attracted to the bait. However, when the bait is completely consumed, the rate of ingress is expected to fall to levels equivalent to those observed in unbaited traps.

Despite its intuitive appeal, this model remains untested and at best a first approximation given the limited nature of the data available to Munro. No doubt, the catch of any trap will be the result of a more complex set of interactions between the fish, the trap and the local environment. For example, the design of the trap, the nature and condition of the bait, feeding behaviour, tidal flow, the availability of alternative food sources, and climatic conditions will all help influence the response of a fish to a trap. Many of these influences are beyond the control of the trap operator. Nevertheless, if trap fishing is to develop to be more efficient, it is desirable for the operator to gain some understanding of the basic processes involved and, where possible, to add design features to a trap in order to enhance its catch effectiveness.

A major hindrance to the development of more sophisticated models of the operation of fish traps is the lack of adequate data. Most studies rely upon setting a large number of traps and then hauling them after a range of soak times. An average catch number versus soak time is then determined. This approach, however, only gives a catch upon haul and leaves the build up of the catch with time completely unknown.

To help overcome this obvious limitation, a number of workers have made use of scuba divers to make infrequent but repeated visits to the traps. During these visits, counts are made of the trap contents. In the large study reported by Munro (1974) where the use of such observations were made, the interval between successive counts varied between one and five days, with a mean of 2.3 days. The catch versus soak was presented on a daily basis. Nevertheless, such an approach still suffers from three problems.

First, the number of fish deemed to have entered a trap (the observed ingress) is equated with the observed number of fish within the trap plus those fish which have previously been observed and have subsequently escaped or died. The ingress calculated in this manner, however, cannot account for fish which enter the trap and also leave or are eaten during the interval between observations, or for fish which have previously been observed and which have been replaced by a conspecific. The observed ingress will therefore be an underestimate of the number of fish which have actually entered the trap. Indeed, it is possible to have a high turnover of fish with a relatively constant number being in the trap.

Secondly, baiting a trap is assumed to increase the rate of ingress whilst the bait remains effective. However, if a bait is depleted within a matter of hours or less, then one requires much more frequent observations if one hopes to correctly account for the influence of the bait on the catch. Soak times as small as 20 minutes are sometimes used because of rapid depletion of the bait (Moran and Jenke, 1989; Rivers, 1966). Other factors may also require more frequent observations. For example, trap saturation has been reported by Miller (1980) to start limiting catches in as little time as one hour.

Thirdly, the use of underwater divers to make observations may effect the fish under study. The presence of a diver and the exhaust bubbles from conventional scuba gear may frighten the fish. High and Beardsley (1970) claim that most fish seem to adjust to the presence of such a diver but no comparative index was given to prove this assertion.

As a consequence of these limitations, the assumptions underlying Munro's model must be considered tentative and at best first approximations until substantiated by a more reliable data set. Indeed, Hartsuijker (1982) in a re–survey of the Pedro–Bank data, argued that without extensive and continuous observations underwater, it was difficult to model how trap catches were built–up over time.

§3 Trap design and trials

Two experimental cruises were undertaken, from 6–20 May and from 12–26 August, 1988, around the Lowendale Islands group off Western Australia. All trapping was carried out during daylight hours, from 0700 h to 1730 h. During sampling, the boat skipper was encouraged to follow his usual fishing practices in regard to the location of trapping sites, movement between the areas and the setting and hauling of the traps. The distance between each trap depended on the catch rates achieved on the previous trial, with this distance ranging from 20 to a few hundred metres.Two baits were used. Muley or Western Australian pilchard (*Sardinops neopilchardus*) and a small readily caught fish, the Lesser Spangled Emperor (*Lethrinus choeroryncbus*) which was sectioned and used as bait. This latter bait is referred to as trash bait.The four trap designs used were:

(1) 'O' or cylindrical shape which is unique to Western Australia and used in the Snapper fishery of Shark Bay and the North West Shelf (Bowen, 1961).
(2) 'R' or rotational trap, which is a CSIRO modification to the above trap which enables the trap entrance to constantly face away from the prevailing current direction.
(3) 'S' shape commonly used in Cuba (Munro et al. 1971).
(4) 'Z' shape commonly used in the Caribbean (Wolf and Chislett, 1974).

All frames were constructed from 12 mm diameter steel rods and covered with 50 mm interlocking galvanised wire.

The rotational trap was developed by mounting a standard 'O' trap on top of a spindle and base. The spindle, in the centre of the trap, allowed free rotation through 360 degrees. Vanes were fitted internally on either side of the entrance, allowing the trap entrance to be orientated away from the prevailing current.

The entrances to the 'O', 'R' and 'S' traps were vertical slits which were incurving and tapered to a width of about 130 mm and extended the height of the trap. The distance the entrance protruded into the trap varied from 500 mm for the 'S' trap to 700 mm for the 'O' and 'R' traps. The 'O' and 'R' traps had one entrance, while the 'Z' and 'S' traps had two diagonally opposite entrances. The 'Z' trap entrances were 'horse neck' in shape with a diameter of 400 mm on the outer side tapering to 140 mm on the inside and protruding 200 mm into the trap. The entrance was constructed using thin flexible hexagonal wire mesh which was molded into the desired shape.

During May, 201 trials using 'O' traps were carried out. The traps were set for various soak times to examine the dependence of catch and bait degradation on soak time for this trap type. Muley bait was used throughout this program. Video recordings were carried out during 40 trap trials with soak times of one, two or three hours. In August, 194 trials were undertaken to compare the catch rates of the 4 trap types mentioned above. Most trials were for a standard two hours and used muley for bait. Forty–seven additional trials were carried out using the trash bait and 'O' traps to compare the effectiveness of the two bait types. In total 64 video recordings were carried out.

Due to weather limitations it was not possible to fish in the one area for the duration of the studies, so consequently when the weather was rough it was necessary to limit trapping to sheltered areas between the islands where the water depth was less (approx. 7–10 m) compared to the norm of approximately 20 m in the offshore regions. A total of four out of 13 days were spent trapping in the more sheltered inshore waters on the first cruise and on only 1 out of 14 days in the second cruise.

Table 1. Number of trials for each trap, bait and location

	Bait	Inshore		Offshore	
May		**Total**	**Video**	**Total**	**Video**
'0'	Muley	55	8	146	32
August					
'O'	Muley	4	0	43	13
'O'	Trash fish	4	0	43	11
'R'	Muley	5	2	45	11
'S'	Muley	5	0	43	15
'Z'	Muley	5	3	44	9

In total, video cameras were used during 104 trap trials and the distribution of these trials for the different trap type, bait type and locations is given in Table 1. Due to some early malfunctions, the video observations were not completed for some of the May trials. Of the total soak time of 13, 146 minutes (219 hours) of traps with videos, 93% was successfully recorded.

§4 Data tabulation

All video recordings were recorded on 3 hour video 8 tapes and analysed using a Sony EV-S850PS recorder. A time code was put onto all video tapes with a Skotel TCR-80 time code reader, so that all events could be easily recorded in real time.

A schematic representation of the video field of view around each trap is given in Figure 2 together with some of the various patterns of behaviour observed for the fish around the traps. In many instances the fish remained on the downstream side of the trap within the bait plume. Random sorties around the trap in search for the entrance were then made from this position. Other fish, eg. trigger fish (*Abaslistes stellatus*), displayed a more active search pattern, tending to swim repeatedly around the trap. Whilst most of the above behaviour took place close to the trap itself, some fish often swam in and out of the field of view spending only short intervals of time around the trap on each excursion. In order to standardize the count of fish outside the trap, a region around each trap was identified, extending out about 0.5 m in all directions. This region was regarded as containing the local 'pool' of fish available for entry into the trap. Most fish observed around the traps confined their activity to this region.

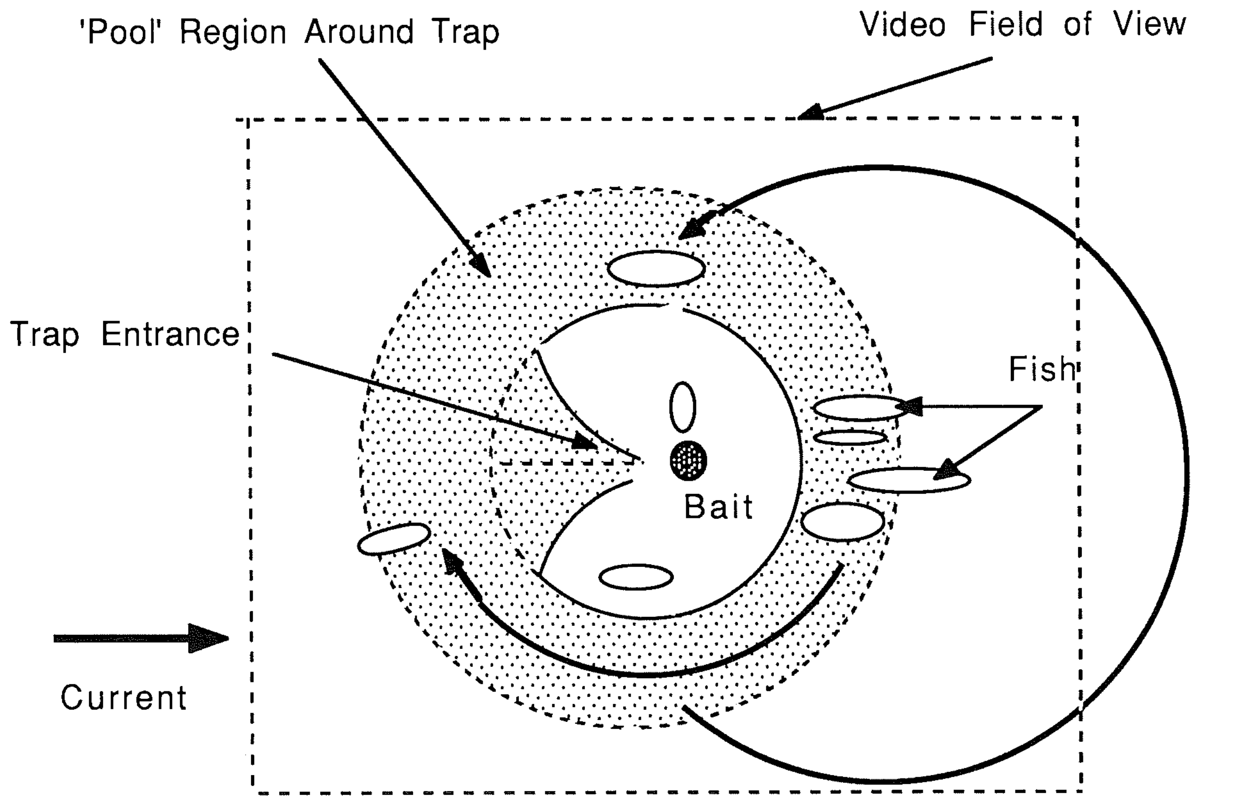


FIGURE 2. Video field of view and 'pool' around each trap with schematic representation of fish movements.

Each video tape was examined and the following data were recorded;

1) The time of each fish entry and exit from the trap, and the type of fish.

2) The number and type of fish in the 0.5 m region or 'pool' around the trap in each 30 second interval. When 6 or more of one fish type were present, an estimate of the approximate number of fish by 5 fish intervals was made (eg. 6-10,11-15,16-20 etc).

3) The current direction relative to the trap entrance.

4) Any specific aspects of fish behaviour in relation to the bait, and other fish (interspecific and intraspecific), and searching for the trap entrance.exit.

Fish types were recorded as *Lethrinus*, *Lutjanus*, Serranidae, Carangidae, large non-commercial fish (unable to pass through the trap meshes), small non-commercial fish (can pass through the trap mesh, but are longer than about 10 cm), and very small non-commercial fish (less than about 10 cm length). By recording the entry and exit times of fish the cumulative ingress, egress and catch for each type of fish was established for all times during any soak. It was not possible for the viewer to reliably follow all individual fish, and so it was not possible to record how long each individual fish remained in the trap or whether it escaped.

All the above results were tabulated on a two minute interval basis so that for each two minute interval since the start of the soak (taken to be the time the trap settled on the seafloor), the number of fish of each type around the trap, together with those entering, leaving and within the trap, were tallied.

A continuous record of the angle between the axis of the trap entrance and the prevailing downstream current direction was also recorded.The current direction was identified using a small length of ribbon which was tied to the vertical pole on which the camera was mounted and was readily observable during the reading of the videos. The current direction remained constant throughout most soaks.

§5 Catch versus Soak Time

On retrieval of each trap, the catch (if any) was sorted into five categories – Lethrinids, Lutjanids, Serranids, Other Commercial and Trash. The fish were individually measured and identified and then collectively weighed by category. Utilising the total catch from all trials the number and average weight of each fish type is given in Table 2.

Table 2 Total catch numbers and average fish weights for all trials

Species	Number caught	%	Weight caught	%	Average weight
Lethrinids	2878	69.2	2187	55.3	0.76 kg
Lutjanids	143	3.4	323	8.2	2.26 kg
Serranids	241	5.8	593	15.0	2.46 kg
Others	897	21.6	850	21.5	0.95 kg
Totals	4159	100	3953	100	0.95 kg

Of the total fish caught, 69% were Lethrinids by number consisting mainly of Lesser Spangled Emperor (*L.choerorynchus*) and a smaller number of spangled emperor (*L.nebulosus*), yellow–tailed emperor (*L.mahsena*), and blue–lined emperor (*L.fraenatus*). The serranids, which made up about 6% of the total catch, comprised Rankins Rock Cod (*Epinephelus multinotatus*), Malabar Rock Cod (*E. malabaricus*), Smooth Flowery Rock Cod (*E.microdon*), and Coral Trout (*Plectropomus maculatus*) while the Lutjanids were mainly Red Emperor (*Lutjanus sebae*), One–Band Sea Perch (*L.vittus*), Gold–Striped Sea Perch (*L.carponotatus*), and Chinaman Snapper (*Symphorus nematophorus*). The other commercial species consisted mainly of Trevally, Threadfin bream, Wrasse and Kingfish whilst Trigger fish (*Abalistes stellatus*) and Butterfly fish comprised the major portion of the trash.

As expected, the variation amongst the individual catches was large. In 19 of the 104 trials with video observations (18%), no fish entered the trap during the entire soak. Five of these trials were when the trash bait was used (45% of all trials with trash bait). Furthermore, no fish were observed around the traps during the entire soak of 4 trials (4% of all trials), with one of these trials using trash bait. Of the total soak time recorded by the video cameras for all traps, at least one fish was observed to be in the trap on 66% of occasions and at least one fish was present around the trap during 67% of this time

For the remainder of this report we shall consider only those trials for which a video coverage was obtained. Because of the small number of inshore trials during August, we shall restrict our attention to the offshore trials only for this month. The results for each of the seven remaining combinations of month, location, trap type and bait type are given in Appendix A. As there are many features in common between these results we shall limit our initial discussion to the data set for the offshore trials carried out during May using 'O' traps and muley bait . This set contains the greatest number of trials (32).

5.1 May offshore results

The results for the May 'O' trap trials are reproduced in Tables 3, 4 and 5. The average cumulative total ingress, egress and catch numbers versus soak time for these traps are given in Figure 3a. Note that after two hours, the more sporadic behaviour of the curves is due to the smaller number of trials. The most striking feature of these results is the high rates of ingress and egress of fish, combined with the relatively constant catch after the first hour.

Table 3 Results for May offshore 'O' trap trials

Species	Total	Ingress		Egress		Average
	Caught	Total	/Hour	Total	/Hour	Catch Wt.
Lethrinids	213	573	8.9	360	5.6	4.42
Lutjanids	9	12	.19	5	.08	0.62
Serranids	10	19	.29	7	.11	0.53
Other commercial	15	>63	.98	>15	.23	0.48
Non-commercial	43					1.08
Totals	290	667	10.4	387	6.01	7.13 kg

The cumulative hourly totals of the number of fish of each type which entered into and escaped from the traps, and the percentage loss, are given in Table 4. A total of 667 fish were observed to enter these traps (averaging one fish for every 5.0 minutes) and of these fish 387 (58%) were seen to leave (averaging one fish every 8.6 minutes). However, the rate of ingress into the traps is not a constant, having an initial value of about one fish entering every three minutes, then tapering off slowly to about one quarter this initial rate after approximately ninety minutes (Figure 3c). On the other hand, the average rate of egress displays a more complex behaviour. As the catch builds up, the rate of egress of fish steadily increases, reaching a rate of one fish leaving every six minutes after one hour, then steadily decreases as the soak continues (Figure 3d). This egress rate represents a fairly high and steady loss of fish from the traps. As a consequence, a loss of 38% of total ingress was averaged at the end of the first hour, increasing to 59% after two hours.

TABLE 4. Cumulative ingress,egress and percentage loss totals for May offshore trials

Species	Total Ingress	Total Ingress	Percent Loss
After 1 Hour			
Lethrinids	470	196	41
Lutjanids	8	3	37
Serranids	11	1	9
Others	37	5	13
All Fish	526	205	38
After 2 Hours			
Lethrinids	556	338	60
Lutjanids	11	4	36
Serranids	18	7	38
Others	55	10	18
All Fish	640	359	56
After 3 Hours			
Lethrinids	573	360	62
Lutjanids	12	5	41
Serranids	19	7	36
Others	63	15	23
All Fish	667	387	58

The increase in the rate of egress to a value equal to the rate of ingress after the first hour (9.6 and 9.9 fish respectively during the second hour) explains the fairly constant catch versus soak after this time. This is consistent with Munro's observations, although the rates of both the ingress and egress processes are far in excess of those reported during his studies. This may be due to the use of a very effective bait as compared to the use of unbaited traps. In addition, Munro's study possibly underestimated the rate of the processes involved during a trap soak due to the non–continuous nature of the observations made. On the other hand, the variable rate of ingress and the complex egress rate behaviour are not consistent with his model and raise further questions as to the influences on both the rates of ingress and egress with time.

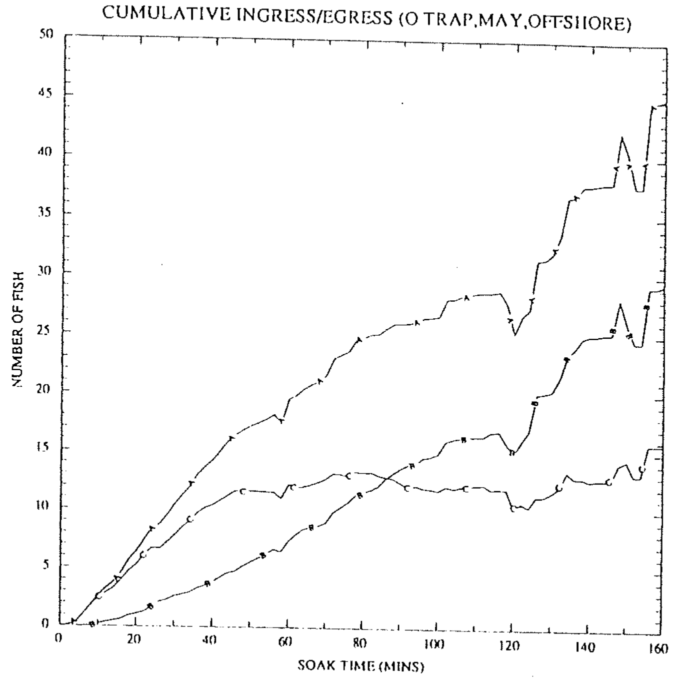


Figure 3a Cumulative ingress, egress and catch versus soak time

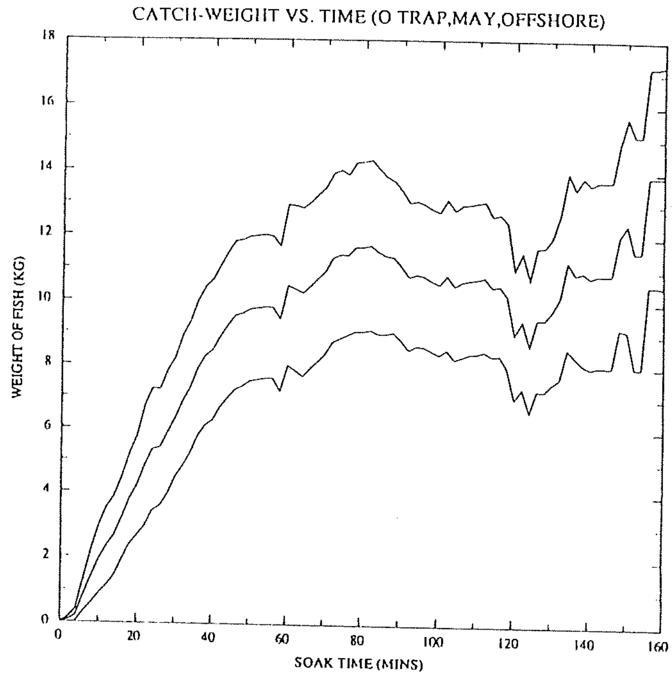


Figure 3b Catch weight (with standard errors) versus soak time

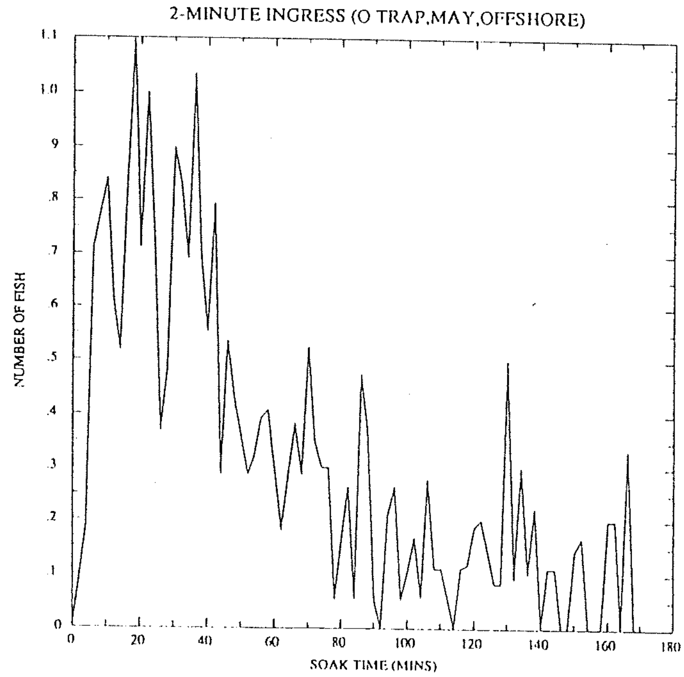


Figure 3c Average 2-minute ingress

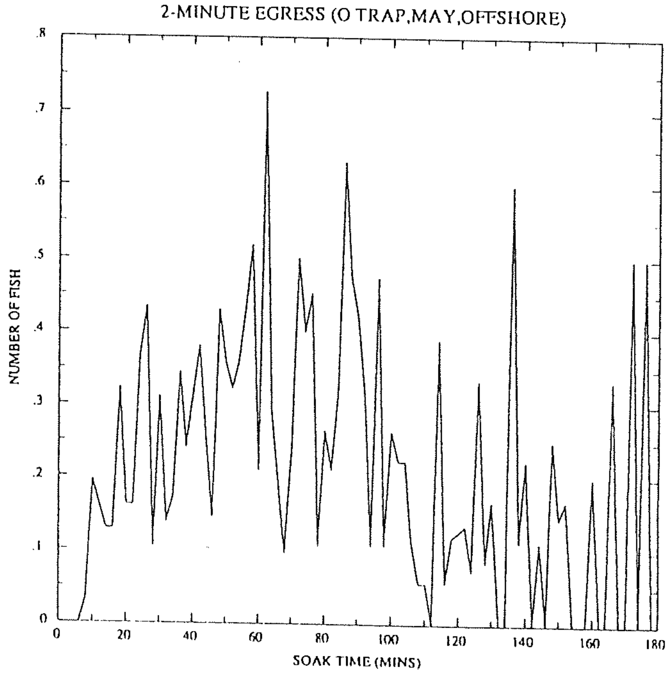


Figure 3d Average 2-minute egress

The average catch from the 'one hour' trials was 9.9 (±2.9) kg and from the 'two hour' trials was 13.2 (±3.0) kg. Using the average catch numbers versus soak time observed for each fish type and the average weight of each fish type (cf. Table 2), an expected average trap catch weight versus soak curve for this trial can be calculated (Figure 3b). The upper and lower curves give measures one standard error either side of this mean. After the first hour, this mean expected catch is 10.1 (± 2.5) kg, decreasing slightly to 10.0 (± 2.0) kg after two hours. The slight increase in the actual catches over the expected catch after two hours is not significant but some replacement of smaller fish by larger fish may take place as the soak time progresses. This may be due to an increased difficulty larger fish have in finding the exit combined with a subsequent attraction of larger fish at the trap due to the initial arrival of smaller fish. Evidence that the escapement potential of trapped fish decreases with increasing size leading to the increased retention of large specimens of some species has been presented by Hartsuijker and Nicholson (1981).

5.2 Comparison of May and August catches

The average ingress, egress and catch results for each of the four different trap types tested during the August cruise are given in Figures 4(a,b,c,d). Each displays a similar result to the above trials with catch rates levelling off after about one hour. The exception to this rule are the 'Z' traps, for which the average catch was still increasing markedly after two hours. The reasons for this behaviour are investigated later and is due to the different ingress/egress characteristics of this trap type.

A summary of the observed catch statistics and calculated catch results for both the May and August trials are given in Table 5. A detailed analysis of the observed catch rates failed to show any significant differences between trap types (Whitelaw et al., 1990). The catches for May, however, were found to be significantly higher than those for August, as were the catches at the offshore location in comparison to the inshore location.

In order to find an explanation for the differences between the May and August catches, consider Figures 5a and 5b which display the average number of fish outside the traps versus soak for the May and August offshore trials respectively. Note that arrivals at the trap, unlike catches, should only be location specific and not depend on trap type. For the May traps, there are about double the number of fish around the trap during the soak, and this fact is responsible for the higher catches during this month. Furthermore, whilst the numbers for May remain high and fairly constant, the numbers for the August trials show a definite tapering off after the first hour.

Two processes may be at work here. The ability of the May traps to fish longer could be due to the greater release of further attractant from the bait as a consequence of the feeding activity of the fish entering the trap. Given a large enough density of fish within the vicinity of the trap

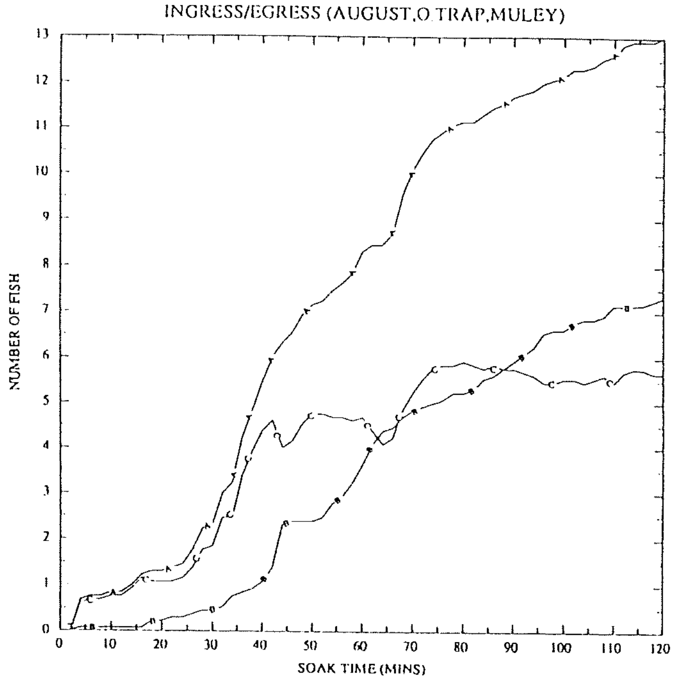


Figure 4a Cumulative ingress, egress and catch for August 'O' trap trials

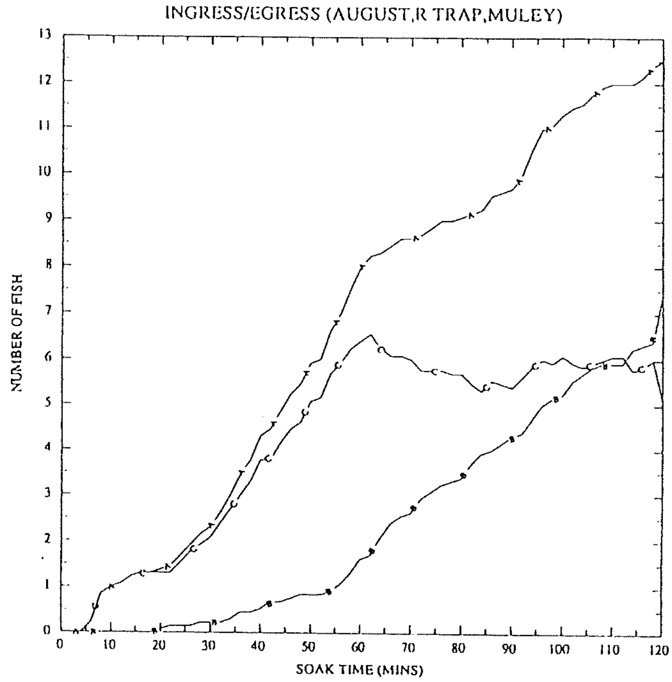


Figure 4b Cumulative ingress, egress and catch for August 'R' trap trials

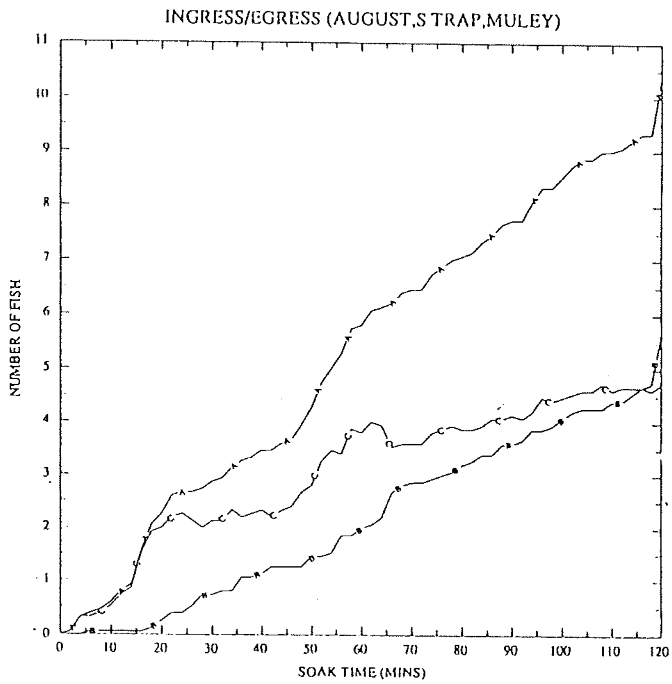


Figure 4c Cumulative ingress, egress and catch for August 'S' trap trials

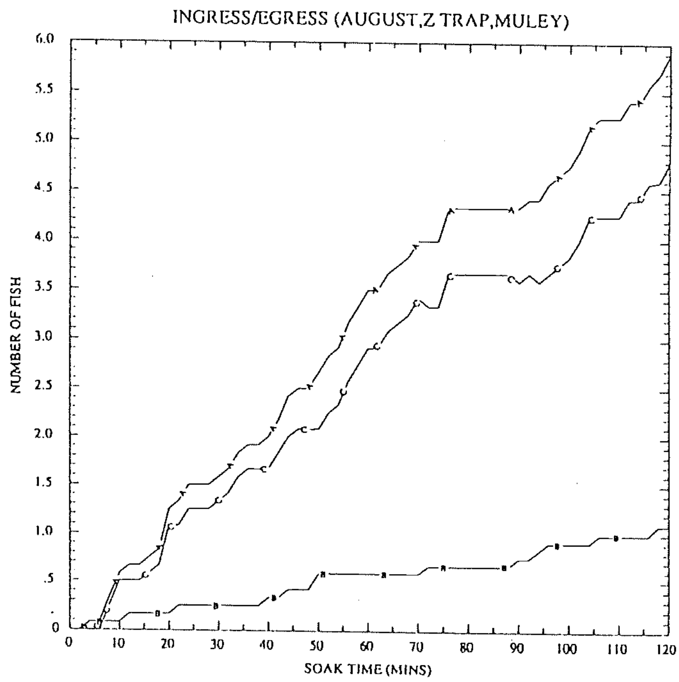
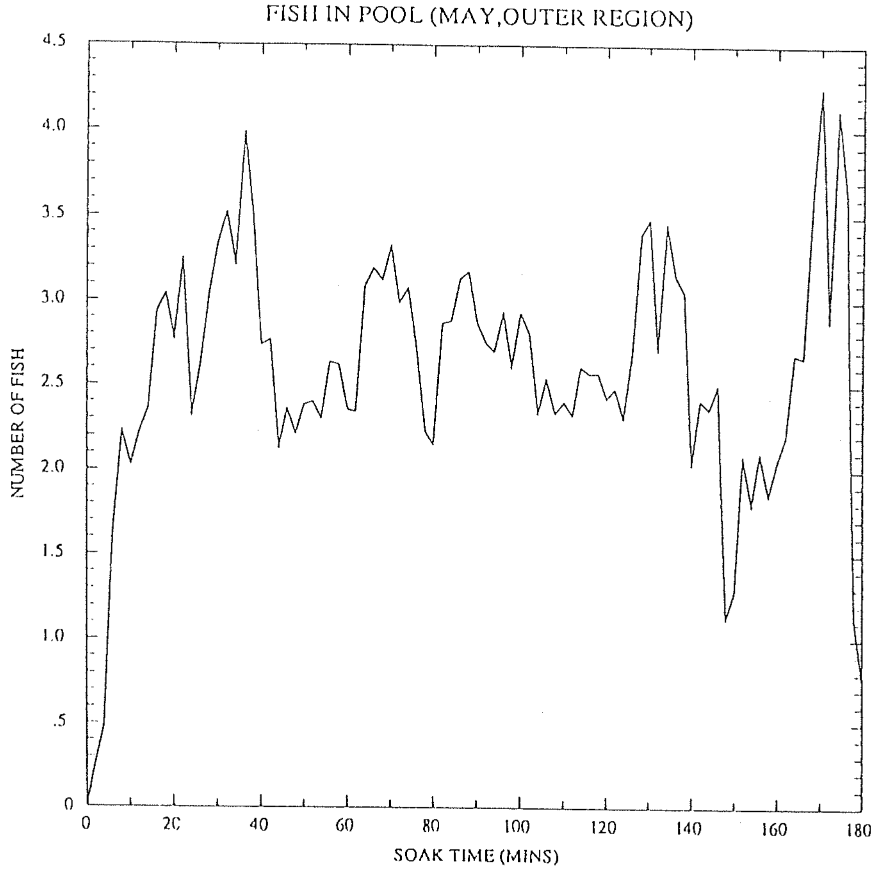


Figure 4d Cumulative ingress, egress and catch for August 'R' trap trials



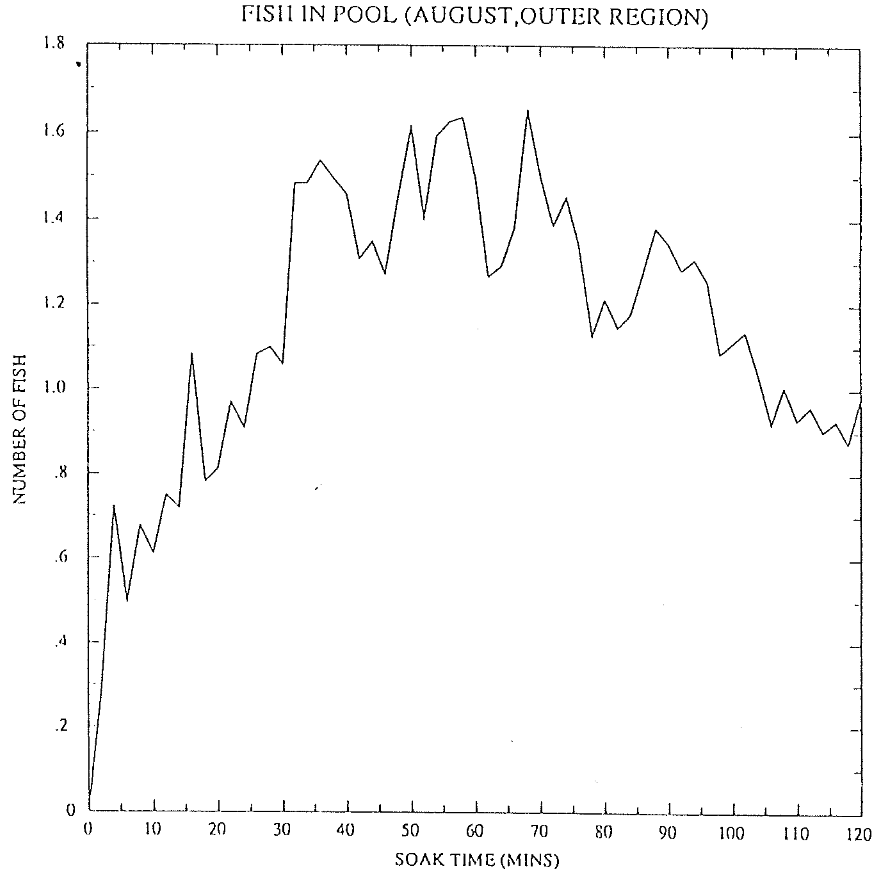


Figure 5 Average number of fish in the 'pool of availability' outside the trap for the two months May and August

location, such a trap should continue to attract and capture fish until either the bait is exhausted or the fish stock becomes depleted. On the other hand, if the surrounding abundance is low, the area of the sea–bed influenced by the attractant bait can become fished out in a relatively short time. Whether or not these traps are bait limited or stock limited is uncertain from these results, and a full investigation of these processes is left until later.

Table 5 Catch statistics for all video trials

	May 'O' Trap		August - Offshore				
	Muley Bait		Muley Bait				Trash
	Offshore	Inshore	'O'	'R'	'S'	'Z'	'O'
After 1 hour							
No. of trials	24	4	13	11	15	9	11
Total Ingress	19.0	3.9	8.3	3.9	5.6	3.4	.87
Total Egress	7.2	.63	3.6	.81	2.1	.67	.07
% loss	38	17	43	20	34	18	11
Expected Catch	10.1	2.6	4.3	3.7	4.1	2.3	1.1
Actual Catch	9.9	-	-	-	-	-	-
After 2 hours							
No. of trials	17	4	12	11	15	9	11
Total Ingress	28.6	7.9	13.8	5.7	10.5	5.5	1.5
Total Egress	17.1	2.1	8.1	2.0	5.8	1.1	.61
% loss	56	25	55	35	50	18	40
Expected Catch	10.0	5.0	6.3	3.9	5.9	3.6	1.2
Actual Catch	13.2	-	6.2	5.2	7.5	5.8	2.1
2nd Hour Ingress	9.6	3.9	5.6	1.9	4.9	2.2	.64
2nd Hour Egress	9.9	1.4	4.5	1.1	3.8	.45	.53

5.3 Trap model processes

The high levels of fish activity observed around the traps can be attributed to the use of an effective bait. The bait releases a chemical stimuli into the water creating a plume of attractant downstream from the trap. Consequently, the operation of a baited fish trap which gives a certain catch can be considered the result of four main processes;

1. Bait loss and dispersal
2. Attraction and retention of fish around the trap
3. Entry of fish into the trap (ingress)
4. Escape of fish from the trap (egress)

Schematically, the chain of events leading to the capture of fish by a trap is shown in Figure 6. We consider each of these processes separately.

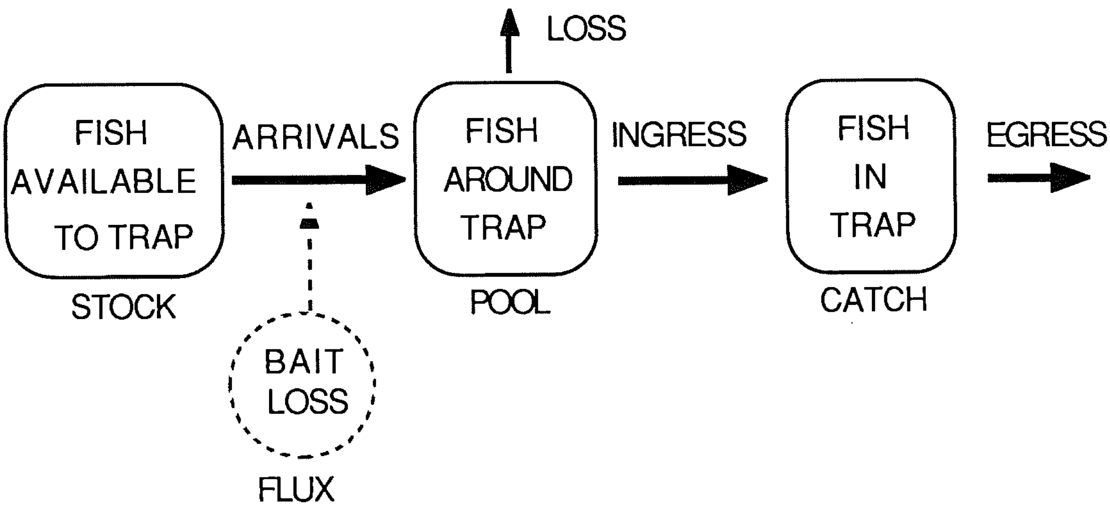


Figure 6 Schematic outline of trapping processes

§6 The use of baits

Research has confirmed that in most fish the distant location of food is by olfactory stimuli (Atema, 1980), and a number of past studies (Munro, 1974, Powles and Barans, 1980, Wolf and Chislett, 1974) have demonstrated the effectiveness of baited traps over unbaited traps. It has also been reported that bait is a much greater and more necessary attraction in deep water than in shallow due to a loss of the visual impact of the trap in the deeper water (Wolf and Chislett, 1980). A bait works by releasing a chemical stimuli (usually water soluble proteins) into the surrounding water which is dispersed by the prevailing currents. The interaction between the changing rate of bait loss and the prevailing currents will result in a changing distribution of attractant downstream of the trap, which will affect the attraction of fish to the trap. Three operational features will help determine the overall effectiveness of the bait:

1) how long the bait lasts
2) how attractive is the chemical stimuli released to the target d=fish, and
3) does the bait emit stimuli at levels of intensity sufficient to induce the fish to search for the source.

If a bait is effective, then upon depletion one would expect subsequent arrivals to decline to levels equivalent to those observed for unbaited traps. At this time entries into the trap should also decrease. Possibly the catch will decline as the egress rate exceeds the new rate of ingress. The optimum soak time therefore depends upon the time of bait depletion. This in turn will depend upon the amount of bait set and the rate at which the bait is lost or consumed, which itself depends upon the numbers of fish within the trap.

6.1 Bait loss model

Two processes are seen as contributing to the major loss of bait during any soak; dissolution of the bait and feeding by fish.

<u>1. Dissolution:</u> We assume that the rate of dissolution, at time t after the start of the soak, is proportional to the amount of bait B(t) remaining at that time.

$$\frac{dB}{dt} = -\lambda B \tag{2a}$$

where λ is the rate parameter. The loss of bait is therefore exponential with

$$B(t) = B(0)e^{-\lambda t} \tag{2b}$$

where B(0) is the initial amount of bait set. The initial dissolution of the bait gives the flux of size $\lambda B(0)$ and leads to the creation of a plume of attractant downstream of the trap.

<u>2. Feeding Activity:</u> Contrary to some of the literature (eg High and Beardsley, 1970) most fish upon entering the trap were observed to eat from the bait. The loss of bait due to this activity will

consist of an amount actually consumed and an amount lost to the abrasive action of eating. The presence of very small fish which were able to pass through the mesh will also contribute to bait loss. However, these fish were only observed during the early stages of some soaks and disappeared with the appearance of the larger fish. The manner of feeding on the bait showed consistent behaviour with some variation between fish type. For example, Lethrinids spent an initial period feeding at the bait and during the remainder of their stay in the trap usually stayed away from the bait. Lutjanids tended to eat from the bait for a longer period and at times were observed to attack the bait quite aggressively, sending out a large burley of bait. On the other hand, Serranids seemed to ignore the bait, preferring to prey upon smaller fish (primarily *Lethrinus*) within the trap. On several occasions, smaller fish were seen to be eaten.

It was not possible to document accurately the feeding behaviour of each fish around the bait. In order to model this behaviour, however, we assume that the length of time that a fish spends feeding from the bait after entering the trap has an exponential distribution;

$$\text{Pr(still feeding after time t)} = \exp\left(-\frac{t}{\kappa_i}\right) \tag{3}$$

where $\kappa_i \ln 2$ is the 'half-time' feeding parameter for fish of type i. If one assumes a constant rate of bait loss f_i due to feeding by fish of type i, then the bait lost after a time t since the entry of one fish into the trap will be

$$L_i(t) = \kappa_i f_i (1 - e^{-t/k_i})$$

The total amount eaten by any fish will be $\overline{\sigma_i} = \kappa_i f_i$ so that the average rate of bait loss due to feeding by a fish of type i is $f_i = \overline{\sigma_i}/\kappa_i$. Knowing the number of each type of fish feeding at the bait at any time will allow the total rate of bait loss to be known.

To carry out the necessary integration numerically the soak time was divided into time intervals of length Δt. The probability that a fish which enters at time t=0 will be eating at the bait during the nth interval is taken to be $e^{-(n-1)\Delta t/\kappa_i}$. Given the entry of E_{ij} fish of type i at the start of the jth interval, then the number of such fish eating at the bait during the (n+1)st interval of time will be.

$$eat_i = \sum_{j=1}^{n} E_{ij}\, e^{-(j-1)\Delta t/k} \tag{4}$$

The entrants during each two minute period were divided evenly into 16 intervals. Multiplying by the average feeding rate f_i for each species, and totalling for contributions from all previous intervals, the average rate of bait loss Q_n due to the feeding activity of the fish during any subsequent 2 minute period can be determined. Thus if p_j is the probability of a fish still eating at the bait after j intervals of time since entering, then the rate of bait loss due to feeding during the nth interval will be

$$Q_n = \sum_{i=1}^{s} f_i \sum_{j=1}^{n} p_{n-j} E_{ij} = \sum_{i=1}^{s} \frac{\overline{\sigma}_i}{\kappa_i} \sum_{j=1}^{n} p_{n-j} E_{ij} \qquad (5)$$

The rate of bait loss will be dependent upon the parameters $\overline{\sigma}_i$ and κ_i only. Furthermore, by multiplying this rate by the length of each interval and summing over all time intervals the total loss of bait will be known.i.e

$$B_N = \sum_{n=1}^{N} \left[\Delta t \sum_{i=1}^{s} \frac{\overline{\sigma}_i}{\kappa_i} \sum_{j=1}^{n} p_{n-j} E_{ij} \right] = \sum_{i=1}^{s} \frac{\overline{\sigma}_i}{\kappa_i} \left[\sum_{n=1}^{N} \sum_{j=1}^{n} p_{n-j} E_{ij} \Delta t \right] \qquad (6)$$

Now the term in brackets is equivalent to the total time spent feeding upon the bait by the fish which have entered the trap up until interval N. After a few hours the number of fish still feeding at the bait will be a small fraction of the total number of entrants Hence we can approximate this latter term by $\kappa_i n_i(N)$ where $n_i(N)$ is the total number of fish of type i which have entered up until interval N. Because of this feature equation (6) could not be used to simultaneously estimate the parameters $\overline{\sigma}_i$ and κ_i. Combining equation (2b) and (8) the amount of bait remaining after a soak of S minutes will be

$$B(S) = B(0)e^{-\lambda S} - \sum_{1}^{F} \overline{\sigma}_i n_i(S) \qquad (7)$$

During the two cruises, 4 kg of bait was set with each trial and the residual B(S) was recorded for a number of trials upon completion of the soak. The totals $n_i(S)$ are given from the results of the video analysis. Equation (7) was fitted to the 51 trials for which there was a complete video coverage and a non-zero residual. The results are given in Table 6. In fitting the model, the loss due to Serranids was assumed to be zero.

TABLE 6. Bait loss parameter estimates

Parameter	Est	(std err)		Mean Weight
λ	1.1	(.22)	/min	
$\overline{\sigma}$(lethrinid)	52.	(4.3)	g	0.76 kg
$\overline{\sigma}$(lutjanid)	227.	(68.)	g	2.35 kg
$\overline{\sigma}$(others)	61.	(27.)	g	0.95 kg

For both Lethrinids and others (which make up the great majority ,80 percent , of all fish entering the traps) these results indicate that the amount of bait lost due to the feeding action of a single fish is equal to about seven percent of its body weight. The higher result for Lutjanids accords well with the more aggressive feeding behaviour observed for these fish. The measured amount of bait remaining for each trial is plotted against the calculated amount lost due to the action of feeding in Figure 8a. This demonstrates that the major loss of bait is due to the feeding activity of the fish.

The proportion of the loss due to each fish which is actually eaten is unknown, but will most likely be small. The proportion not eaten can be assumed to increase the bait flux which is responsible for the creation of the downstream plume of attractant, and consequently is important in influencing additional arrivals at the trap. A study of the stomach contents of Lesser Spangled Emperor (*Lethrinus choerorynchus*) has indicated that the average maximum prey weight of full stomachs with a fish only diet is around 15-20 grams (Stanley, per. comm.). If one assumes a normal distribution of stomach fullness in the fish upon entry, and that each fish eats from the bait until full, then on average each fish of this type will consume between 7.5 - 10 grams of bait. Since this species accounted for a high proportion of the Lethrinid catch, only about 17 percent of the 52 grams of bait lost due to each Lethrinid is seen to be consumed. A similar proportion can be assumed for the other species present in the trap.

In order to find an estimate of the average feeding time κ_i for each species, the eight trials for which the residue bait was observed to be zero were used. The catch curves for one of these trials are given in Figure 7. This catch curve shows a rapid build up of fish in the trap followed by an abrupt cessation of ingress and a greater rate of egress. It seems reasonable to suggest that the change in behaviour observed in this trial is due to the depletion of the bait. This assumption anticipates a latter result that the ingress of fish into a trap is greatly enhanced by the creation of a burley due to previous entrants feeding at the bait. This positive feedback mechanism, which reinforces the rate of ingress into the trap, is terminated with the depletion of the bait. Fitting the above feeding model to a best guess of the time of bait depletion for each trial (taken as the time of last entry), and approximating the average feeding time to be the same for each species, an average period of feeding of about 3 minutes was estimated corresponding to $\kappa_i = 4$.

Using these results, the rates of bait loss due to feeding and dissolution of the bait during any interval can be found from equations (6) and (2a). The average results for each month are given in Table 7. Note that in estimating the total proportion of the soak time during which there is feeding at the bait, feeding was considered finished after the probability p_j became less than one percent. The greater loss of bait due to feeding for the May trials is consistent with the higher catches during these trials. Given that around 85 percent of this loss will contribute to the flux available to the attracting plume, we would expect the creation of large plumes during intervals of high feeding activity and an increased arrival rate of fish at the traps.

To illustrate the amount of bait remaining versus soak time we use the above results together with the average ingress result for the May trials shown in Figure 3a. The result is shown in Figure 8b. After 3 hours, 1.87 kg (47 percent) of the initial 4 kg remain. This compares with an amount remaining of 3.3 kg (82 percent) if only the loss due to dissolution is considered. The total time a given amount of bait remains effective will depend, however, upon the cumulative ingress of fish over time. With no fish entering the trap the bait should remain

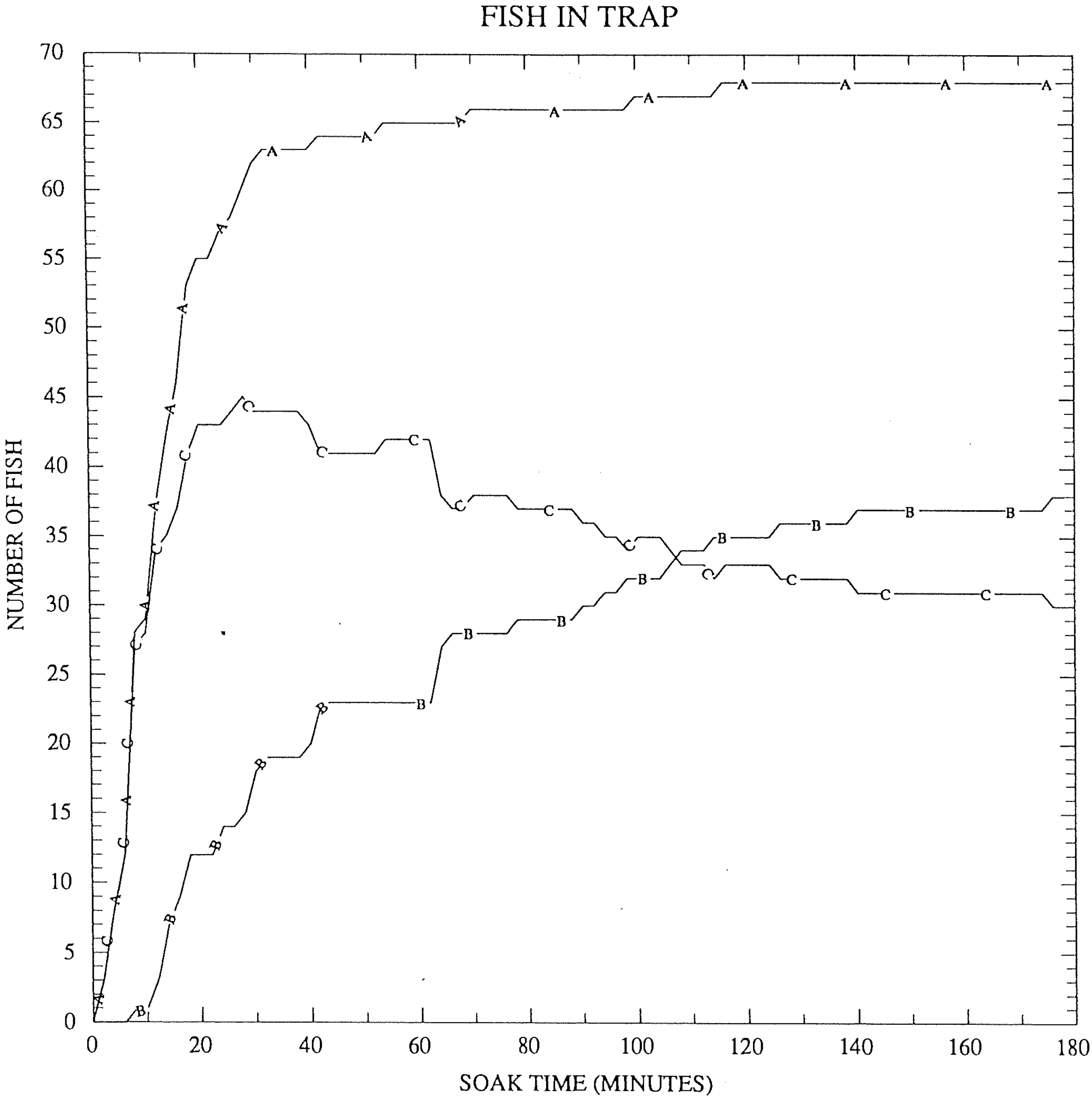


Figure 7 Cumulative ingress, egress and catch for trial with total bait depletion

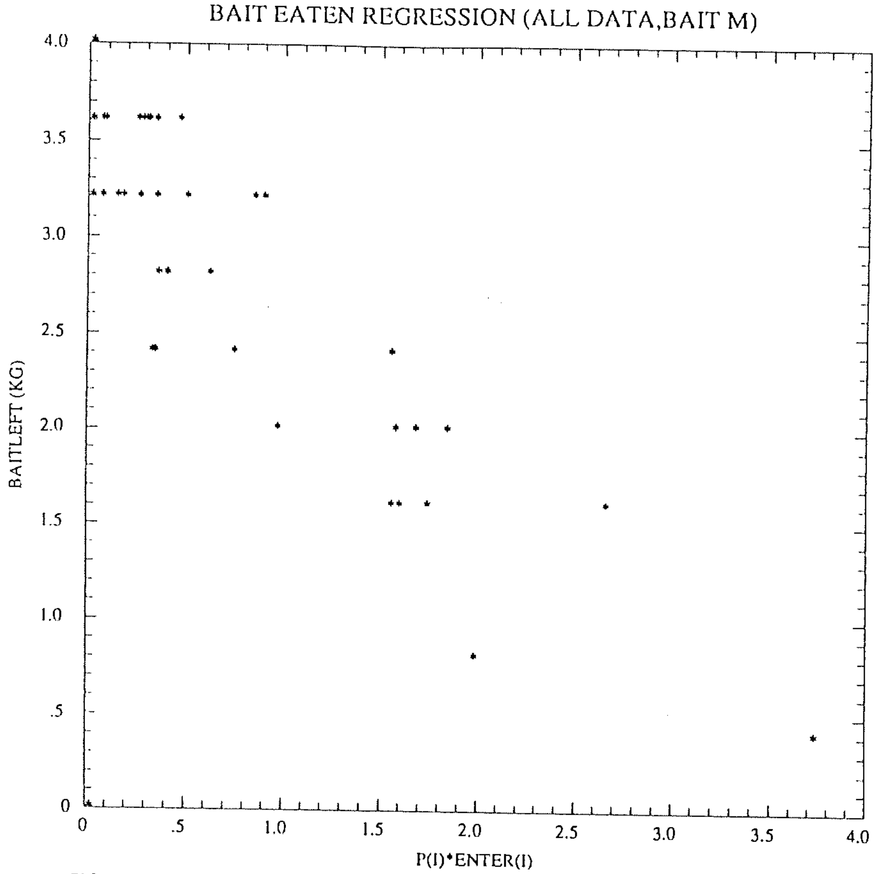


Figure 8a Regression of bait residue against estimated amount of bait loss due to action of fish feeding

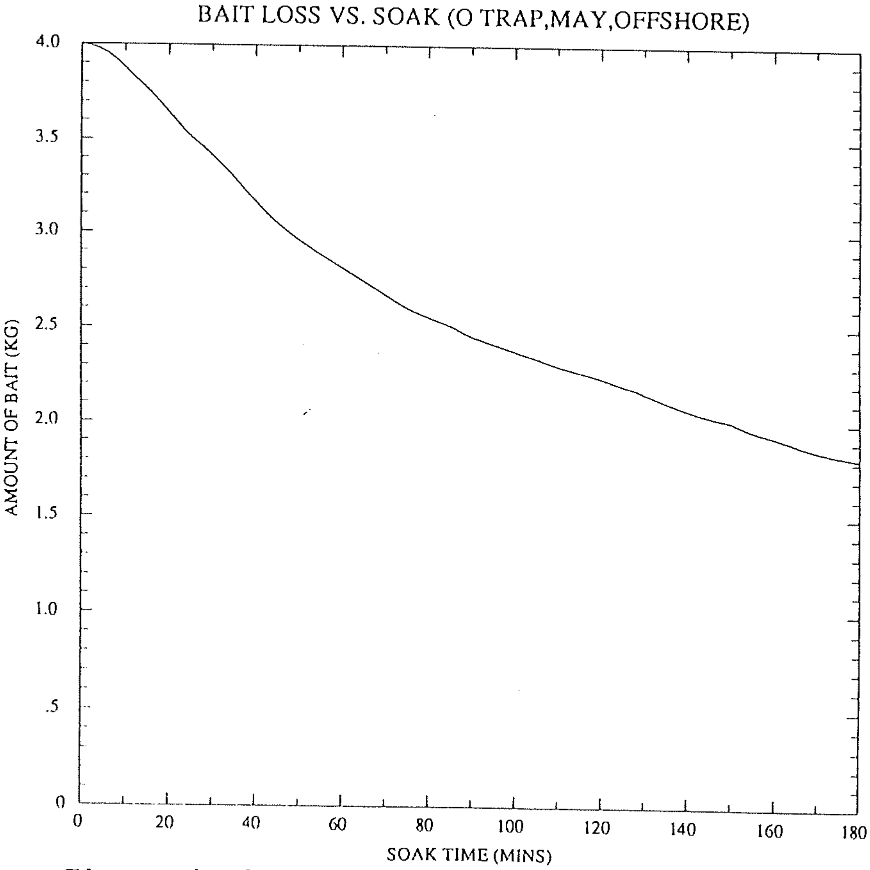


Figure 8b Average amount of bait remaining versus soak for May trials

TABLE 7. **Average bait flux terms**

FLUX TERM	MAY	AUGUST
Average bait dissolution rate	3.4 g/min	3.8 g/min
Average rate of loss due to feeding	18.9 g/min	8.9 g/min
Percentage of total soak with feeding	54%	47%

intact with 50 per cent remaining after 10.7 hours. These results support the general belief that the presence of an effective bait in the trap is a major influence on the effectiveness of a fish trap.

6.3 Rate of bait emission

The variable flux of bait emanating from the trap due to feeding may increase the likelihood of localised plume maximums being created downward of the trap (Figure 9). Such localised maximums of stimulant can be created as a result of a rapid decrease in the flux emitted by a bait (Olsen and Laevastu, 1983). Such decreases in the rate of bait emission will occur during intervals of time immediately after fish stop feeding from the bait. Indeed, one such maximum may be created each time there is a break in feeding activity.

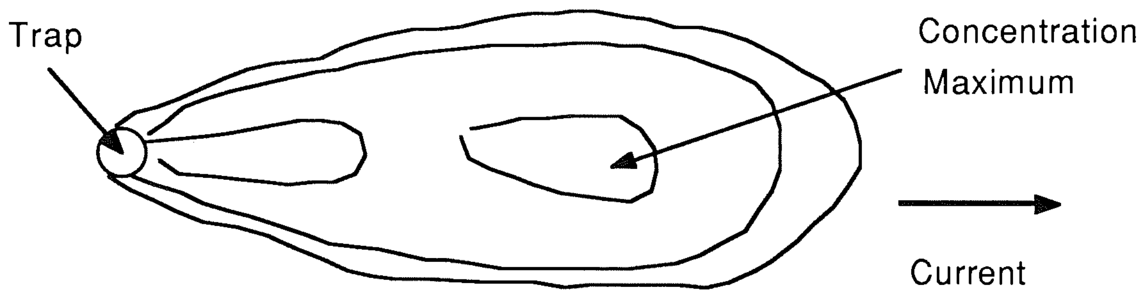


Figure 9 Formation of downstream concentration maximum

For a fish swimming towards the bait, the presence of localised maximums of attractant will possibly confuse the fish as to the source of the smell as it would begin to swim into decreasing stimuli intensities. However, as these concentration will also help to minimise the effect of any sudden drop in the bait flux, their influence on arrivals is likely to be small. Furthermore, there are possibly more important factors in the likelihood of a fish arriving at the trap, such as the directional intensity of the prevailing currents.

6.4 Bait type

The influence of bait type was investigated by using the readily available fish, Lesser Spangled Emperor (*Lethrinus choerorynchus*), as bait. The results are given in Table 8. A significant difference was found between the catches with this bait and those using muley. Overall, the average number of entrants into the traps with the trash bait was only 1.5 compared with 14 when muley was used as bait.

A major reason for this difference is the almost total absence of Lethrinids attracted to those traps with the cut trash bait. Indeed, no Lethrinids were observed (during the 24 h of observations) to enter any of the traps and only one such fish was recorded as being present outside. One concludes that Lethrinids will avoid their own dead. Whilst this is obviously not a desirable feature of a bait on its target fish, the way in which certain species appear to avoid their own dead also has a potential when considering the incorporation into an artificial bait of a substance repellent to unwanted species (Hancock, 1974). Some traps are seen as self–baiting due to instances of fish dying or being eaten within a trap. Obviously the effectiveness of such 'self–baiting' will depend upon the attractiveness of this 'bait' to the surrounding fish communities.

TABLE 8 Comparison of catch statistics for trash and muley bait

Species	Trash Bait			Pilchard Bait		
	Mean Catch	Ingress /hour	Egress /hour	Mean Catch	Ingress /hour	Egress /hour
Lethrinids	0	0	0	4.42	8.9	5.59
Lutjanids	0.68	.12	0	.62	.19	.08
Serranids	0	.12	.12	.53	.29	.11
Others	0.42	.46	.16	1.56	.98	.23
Totals	1.10 kg	.70	.28	7.13 kg	10.4	6.01

Another factor influencing the attraction of fish to the traps is the ability of the bait to be broken up and dispersed. As will be outlined in the next section, the downstream plume of attraction created by the bait is enhanced by the feeding action of fish in the traps. This is due to the bait being broken up and exuding a larger burley effect. Whilst this influence was found to be quite significant with the use of muley, this did not appear to be the case when the cut trash fish was used as bait due to its inability to be easily broken up and dispersed. This contributes to ineffectiveness of this bait when compared with the use of Muley. A similar lack of success was reported by Wolf and Chislett (1974) who found the use of trash fish relatively ineffectual as bait. Munro et al. (1971) also reports that unbaited traps were more effective than when trash fish were used as bait

Baiting practices vary from fishery to fishery depending upon the target species, local custom and the availability of bait. At the simplest level, the use of visual stimuli such as shells or broken crockery can be used. The next step of is the use of some local bait fish, typified by the use of trash fish to rebait the trap. In light of the result above this practice may not be successful. Most fisheries, however, have progressed to a more sophisticated level of identifying and using those baits which are most attractive to the species being sought. In this manner, the use of Muley appears to be very successful.

§7 Arrival and retention at the trap

In the operation of a baited trap, arrivals of fish at the trap will be influenced by the creation and spread of a chemical field of attractant downstream from the trap. For modelling purposes, this dispersal of the attractant can be thought of as leading to the creation of a plume of attractant, the size of which will be dependent upon the rate of release of the bait and the prevailing currents. For a fish influenced by this plume of attractant, the subsequent processes leading to the arrival of that fish at the trap or not will no doubt be complex. Bait freshness, search pattern, appetite and response time will influence the probability of arrival within a certain interval of time. Furthermore, the effects of water temperature on locomotory speed, availability of alternative sources of food, sheltering response, diurnal, tidal feeding rhythms and reproductive condition will also influence the reaction of a fish to the bait stimuli. The influence of these effects remains unknown however.

Arrivals from upstream of the trap will be influenced by the bait to a much lesser extent, if at all. In most instances, such arrivals can be assumed to be due to chance foraging alone. However, vision may also assist fish in locating the trap and has been a reason given by some workers for greater catches being obtained by traps with more solid features. This effect may be more pronounced when traps are placed on a relatively large area of flat sandy bottom for they then become the most prominent bottom feature. By comparison, any advantage due to sight appears to be lost in deeper water, and unbaited traps are, in general, not successful (Hull,1981). However, with the use a an effective bait, distant attraction is probably nearly always based on olfactory stimuli and in the following we shall assume that olfactory stimuli is the principal cause the far–field attraction of fish to the trap.

7.1 Simple model of trap arrivals

Two main processes then will contribute to arrival at any baited trap--those influenced by the bait and those due to chance foraging or more random events. Both these rate of arrivals will most likely depend on a measure of the surrounding density of fish. A simple model of fish arrivals at a trap can thus be assumed to have the form;

$$\text{Arrivals} \propto \text{Density} \times (\text{Random factor} + \text{Bait factor})$$

The influence of the bait plume (or bait flux) can be seen in the distribution of first arrival times of fish at the traps (Figure 10a) Assuming these times have a Poisson distribution, then the point estimate of the mean time of first arrival is found to be 8.7 (± 0.9) minutes. Often before the arrival of these commercial sized fish, other very small fish were seen swarming around the bait. It is most likely that these small fish increase the flux of attractant from the bait due their feeding activity. To test whether the presence of these small fish influenced the arrival of larger fish, the mean time of first arrival was compared between those trap trials in which small fish were observed and those in which they were not. The mean time of first arrival was found to be 6.0 (±0.9) minutes and 9.9 (±0.8) minutes respectively, and the difference is significant at the one

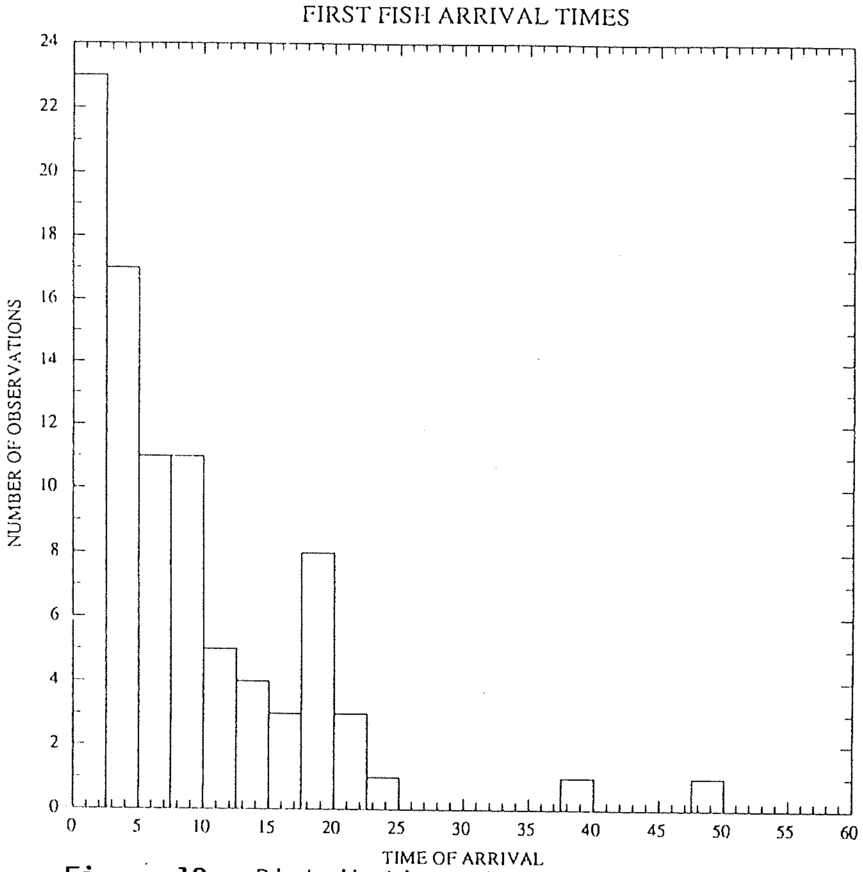


Figure 10a Distribution of first arrival times of fish at the trap

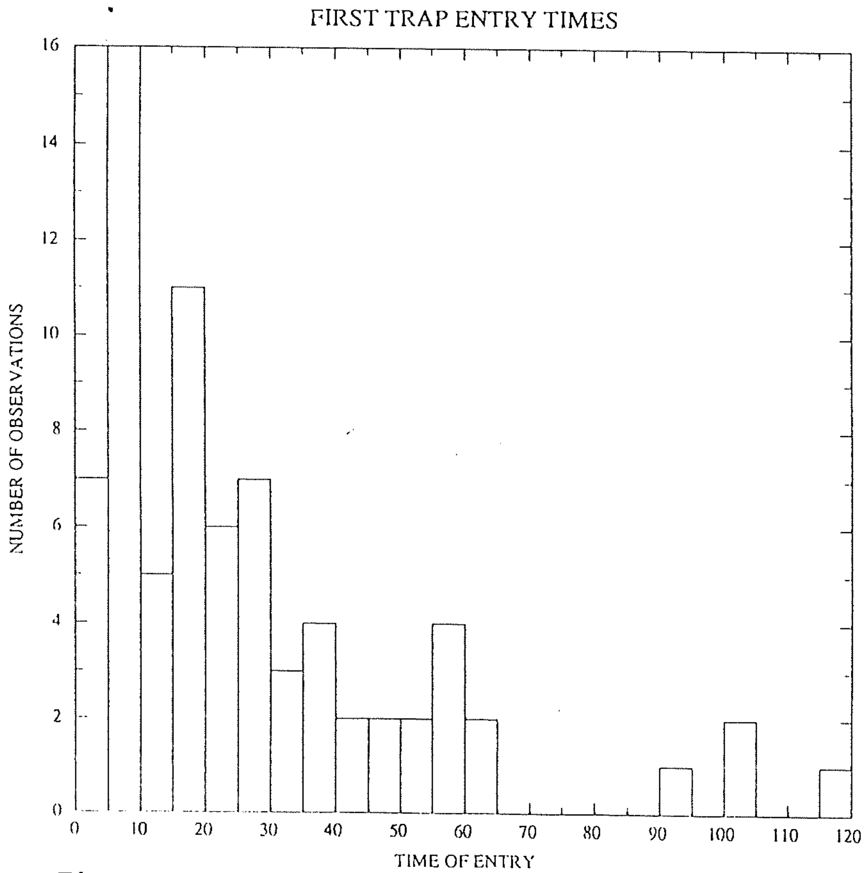


Figure 10b Distribution of first entry times of fish into the trap

percent level using a two-sided t-test. This result illustrates an aspect of the expected relationship between bait flux and arrival rate around a trap. Observations by Fernö et.al. (1986) showing increased arrivals at baited long lines due to the presence of fish already hooked can be attributed to a similar increase in the bait flux. Hull (1981) also cites reports of shoals of pelagic fry holding station in the middle of traps during trials in the Arabian Gulf. These fish, together with the others browsing off the growths on the trap, are seen as serving to attract the commercially valuable species.

To model the effect of the plume of attractant on the arrival rate of fish at the trap, we shall assume that the number of arrivals at the trap during an interval of time is proportional to the average area of the plume during this interval. In turn, we assume that this area is proportional to some power of the average flux emanating from the bait during that interval i.e.

$$\text{Area}_n = k_1 (F_n)^P \tag{8}$$

where F_n is the flux during the nth interval. Thus a flux of greater intensity travelling downstream of the trap will result in greater arrivals. This model assumes that the interval of time to be considered is adequate to allow for the dispersal of the bait downstream together with the travel time of the fish to the trap. The flux of bait is due to the dissolution rate of the bait and the rate at which the bait is dispersed b feeding fish. Since all the loss due to feeding will not be available to the downstream flux, we model the flux during the nth interval as follows

$$F_n = \lambda B_n + \mu \sum_1^s f_i \sum_1^n p_{n-j} n_j \tag{9}$$

where, as before, B_n is the amount of bait remaining at the start of the nth interval and the parameter μ represents the proportion of the bait lost due to feeding which contributes to the flux.

The number of arrivals at the trap A_n during the nth interval is now taken to be proportional to the product of the area of the downstream plume of attractant during this interval and the local density of fish within the plume;

$$A_n = rD_n \times \text{Area}_n = rD_n \times k_1 (F_n)^P \tag{10}$$

where D_n is a measure of the surrounding density of fish during the nth interval and r is some measure of the responsiveness of the fish. Arrivals at the trap due to random foraging can also be assumed to be proportional to the surrounding density. Hence, the total number of arrivals at the trap during the nth interval will be given by

$$A_n = rD_n \times \left[R + k_1 (F_n)^P\right]$$

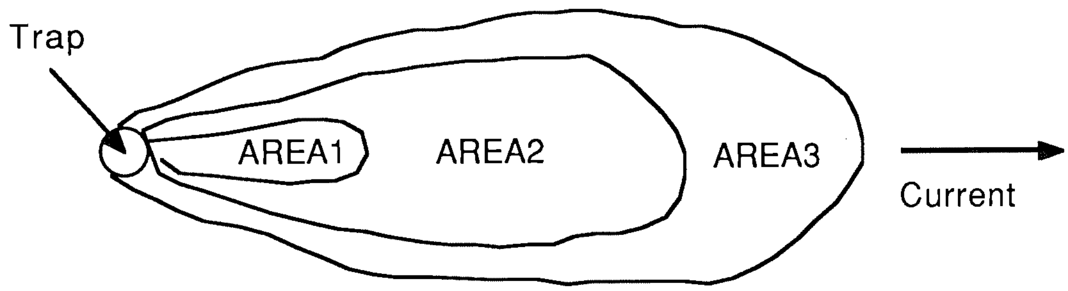


Figure 11 **Downstream expansion of attracting bait plume**

It was suggested earlier that some depletion of the available fish stock takes place as fish are attracted and caught by the trap. Such a depletion of available fish is likely to influence arrivals in two ways. Firstly, if the attracting plume expands from one interval to the next, then there may be some depletion of the local density of fish because of arrivals during the preceeding intervals and a lag in the time needed for more fish to move into the area (Figure 11). Furthermore, the response of the remaining fish in this area may be different than those fish in the area into which the plume expands. Thus, in order to account for the effects of an expanding plume, bait flux and fish arrivals are related with time lags of 0, 1 and 2 time intervals and the depletion terms k_2 and k_3 represent the fractional effect of each preceding plume on the most recent.

$$A_n = rD_n\left[R + k_1\left[(F_n)^P - k_2(F_{n-1})^P - k_3(F_{n-2})^P\right]\right] \qquad (11)$$

The second manner in which a depletion effect may influence the number of arrivals at the trap is through a general diminishing of the number of fish available to the trap. This is likely to occur as a result of depletion of the fish in the area around the trap as fish are 'processed' by the trap. Since it was not possible to keep track of individual arrivals around the traps, the number of entrants into the traps is taken to be a measure of the depletion of the available stock (even if these fish subsequently leave the trap because they are satiated).The 'random' arrivals of fish at the trap also come from the fish in the broad environment of the trap, and so are also influenced by local depletion The surrounding density of fish during any interval is consequently assumed to be;

$$D_n = \frac{D_0}{\left[1+(\Sigma E_n)/N\right]} \qquad (12)$$

where ΣE_n is the cumulative ingress of fish into the trap after the nth interval, N is a relative measure of the total number of fish available to the trap and D_0 is the initial density of fish at the beginning of the soak.

Arrivals at the trap due to random foraging can also be assumed to be proportional to the surrounding density. Hence, the total number of arrivals at the trap during the nth interval will be given by

$$A_n = \frac{rD_n\left[R + k_1\left[(F_n)^P - k_2(F_{n-1})^P - k_3(F_{n-2})^P\right]\right]}{\left[1 + (\Sigma E_n)/N\right]} \quad (13)$$

New arrivals join those which have previously arrived but which remain around the trap. The length of stay for a fish around the trap was observed to be highly variable but in general longer than the two minutes used to summarize the observations. To model the behaviour of fish around the trap, assume that each fish in the pool at time t will be found in one of the following states at time $t + \Delta t$.

1) remain in the pool
2) left the pool and returned to the stock of fish available to the trap
3) entered the trap

Since the number of fish entering the trap is a variable itself but is observable, we model the remaining two states by assuming that a fraction δ of the fish which don't enter the trap remain in the pool. Hence, given a pool size P_n at the start of the nth interval and given that E_n of these enter the trap during the given interval of time, then

$$P_{n+1} = \delta(P_n - E_n) + A_n \quad (14)$$

To proceed with parameter estimation we need to simplify equation (14) because of the multiplicative nature of some of the unknowns. Furthermore, since the dissolution of the bait, λB_n, term is relatively constant for most trap trials and small relative to the flux resulting from the effects of feeding, the contribution from this term can be expected to be fairly constant and small. Hence, we incorporate it with the random arrival term R. Scaling this combined term to unity leaves the following equation to be fitted to the data;

$$P_{n+1} = \delta(P_n - E_n) + \frac{\tilde{D}_d\left[1 + \tilde{k}_1\left[(Q_n)^P - \tilde{k}_2(Q_{n-1})^P - \tilde{k}_3(Q_{n-2})^P\right]\right]}{\left[1 + (\Sigma E_n)/N\right]} \quad (15)$$

where the flux Q_n is now only that contribution due to the feeding (the unknown parameter μ is incorporated into the k_i's) and is given by equation (5).

The parameters of the processes modelled were assumed to be the same for all trap sets, but the density of available fish in the broad environment of each trap set was regarded as being trap set specific. The model of the attraction process for n trap sets contains n+6 parameters, but the estimates of the n parameters giving the trap specific density can be expressed in terms of the other parameters and the observations, so that all estimates are reasonably easily found. The observed variables used to calculate the predicted number of fish in the pool were the number and type of fish in the trap per 2 min interval and the number and type of fish entering the trap; the predicted bait flux from the model above was also used. Parameters were estimated by minimizing the sum of squared deviations between the observed and predicted numbers of fish the 'pool' of availability during each 2 min time interval. Separate estimates of all model parameters were made for the data collected in May and August because the catches and observed pool sizes were much higher in May than in August suggesting a noticeable difference in arrivals at the trap between these months. Furthermore, because of differences in tidal currents etc between the offshore and inshore locations only the former were considered. The results of fitting the model are given in Table 9. Note that an average $\overline{D_0}$ is given for the trap specific relative density parameter. The correlation matrices are given in Appendix A.

The parameters of the process model determining the area of influence of the trap and the probability of fish returning to the broad environment of the trap from the pool are consistent between seasons. Given average feeding rates of 19 g/min and 9 g/min for May and August respectively, the bait flux effect is found to be about 26 and 13 times as important as the constant term. The parameters k_2 and indicates the extent of the local depletion of fish within the two previous plumes, and are found to average about 90 and 20-30 percent respectively. On average, a fish will spend about twelve minutes around the trap before leaving the area. The percentage of those which return is not known. The large seasonal difference in the number of fish attracted to the trap is then interpreted as being due to a difference in the density of available fish and the size of the bait plume, rather to a change in the process of attraction and retention at the site of the trap

TABLE 9. Trap arrival and retention parameters

PARAMETER	MAY	AUGUST
Retention factor,	0.89 (0.01)	0.89 (0.01)
Area factor, k1	371 (49.)	447 (56.)
k2	0.89 (0.01)	0.89 (0.01)
k3	0.27 (0.03)	0.38 (0.04)
P	0.67 (0.02)	0.76 (0.03)
Stock, ' N	201 (55.)	42. (5.0)
Density index, D	0.125	0.092
Goodness of Fit	0.79	0.75
Degrees of freedom	1643	2960

The average two hour catch observed in May was 13.2 kg compared to 6.2 kg in August. This 113 percent difference correlates well with the 116 percent difference in the average number of fish in the 'pool of availability ' around the trap during each two minute interval, being 2.6 and 1.2 during May and August respectively. This difference in fish around the traps may be initially explained by a difference in the density of the responsive fish under the influence of each trap, as is seen in the 36 percent higher density found for May. However, the model above indicates the presence of a feedback mechanism operating between the catch, the size of the attracting plume and the number of new arrivals at the trap. This is driven by the loss of bait due to the presence of fish feeding. Given the relation between plume area and flux for May, an initial increase in flux of 36 percent will expand the plume by 23 percent and together with the greater density lead to a 70 percent increase in the arrival rate. Thus, with a greater initial catch for May there will be a greater loss of bait due to feeding contributing to a larger downstream plume of attractant. This,in turn, leads to the attraction of more fish. The process will continue until some limit is reached, presumably as a result of stock depletion, bait depletion, or trap saturation.

To further compare the two months, consider the average rate of bait loss due to feeding during each trial. The doubling of this loss during May will create a plume on average 59 percent larger and with the greater density of responsive fish lead to a 116 percent increase in arrivals. This increase explains the similar differences in both the number of fish observed around the traps and those caught between the two months.

The total area fished by a trap will depend upon the flux and the threshold concentration level needed to influence a fish to search for the trap. The bait flux will continue to be carried downstream, and although it will be diminishing in strength, it may keep influencing fish to travel towards the source of the attractant. Because the rates of bait loss were higher for May, the area fished during this month should also be greater. Some indication of the comparative differences in size of this area between the two months can be seen from the stock parameter N. Allowing for the difference in the fish densities and assuming a homogeneous distribution of fish, the area fished during May is found to be about 3.5 times as large as that for August, indicating that the total area of influence may be more closely proportional to the square of the average flux.

Current speed may also influence the area fished due to a greater downstream dispersal of the bait. In a study off Florida, Craig (1976) reports that the best catches were associated with rough seas and strong bottom currents, especially when these conditions prevailed for several days. For the duration of the August trials a current meter was attached to a trap and left on the sea bed. This provided a reading every ten minutes of the current speed and direction. Unfortunately, due to an obstruction in the meter, only eight days of reading were obtained. However, over the continental shelf, and especially in shallower waters, tidal currents dominate. Using the published tidal height data (Australian Department of Defence, 1987) the tidal heights within the vicinity of the trapping trials were found. Taking the hourly differences of these tidal heights as a measure of current speed, a current speed was determined for each hour of all the trapping trials. The average speed for May was 6.5 m/min (10.8 cm/s) compared with 5.5 m/min (9.2 cm/s) during August. Although the difference in the average current speed between these months is not great, the higher value for May could have influenced the higher catch rates during this month.

The density D_0 in the model is a trap-set specific relative density, and indicates that baited traps could be calibrated to provide a density index density of fish around the trap which are responsive to the attractant within the time frame of the model. The distribution of these densities for each month are given in Figure 12. The density index obtained is most easily interpreted as an estimate of the arrival rate of fish at an unbaited trap at that location during any two minute interval of time. The index removes the feed-back effect of fish in the trap on the arrival of additional fish which would otherwise introduce high variance and bias to the index, but still allows use of baited traps so that the index for a particular site can be quickly determined (it would take many hours or days of observation to directly measure the rate of fish arrival at an unbaited trap). However the estimate of a trap specific density can be readily confounded with the parameters determining the area of influence of the bait plume (ie. a large plume in a low density area is difficult to distinguish from a small plume in a high density area) and the estimation is most successful if each trap set provides observations over a wide range of bait fluxes. For ideal estimation of a density index the bait should be removed for some, relatively brief, period during each trap set.

The average density index for May is found to be .062 fish/minute and 0.046 fish/minute for August. Whether or not the difference in the average of this measure between the two months is due to actual differences in the absolute numbers of fish in the vicinity of the traps remains unknown. High and Bearsley (1970) have concluded that the distance between traps and reef patches is a highly important factor determining catch rates and Hartsuijker and Nicholson (1981) indicate that trap catches largely depend upon the behavioural characteristics of the various reef fish, especially territorial behaviour, diel patterns of activity and home ranges. The seasonality of such influences is known to be an important factor affecting fish trap success (Craig,1976) and it is the practice of Carribean trap fishermen to generally shift their traps to take advantage of seasonal changes in fish abundance at different locations.

In conclusion, the higher catches during May are seen to be due to a combination of a higher background density of responsive fish, a greater effect due to the positive feedback mechanism between the catch and the number of arrivals at the trap, and a greater area around the traps fished as a result of the greater loss of bait. These operational features have a number of consequences. First, the feedback mechanism between catch and increased arrivals is driven by the bait in a manner such that any process which results in a greater flux of stimulant will substantially enhance the rate of arrivals at the trap. With the use of baited traps then it is important to achieve as early an entry of fish into the trap as is possible. Easily dispersed baits would be very effective while they last, but there will be a trade-off between bait effectiveness and bait longevity. On the other hand, bait containers that prevent fish access to the bait will greater decrease bait effectiveness, but increase bait longevity. Secondly, identically set traps at the same location can give highly variable catches because the feed-back mechanism will operate to differentially increase the catch of traps already containing fish. Thus the entry of the first fish into one trap will increase the chances of that trap receiving subsequent fish from the same area. Thirdly, baited traps in areas of high fish density will fish a larger area than traps in areas of low fish density. Consequently, the catch per unit effort from baited traps will not give a proportional measure of fish density, even if standardized for soak time. This has important implications for assessment of fisheries that use baited traps.

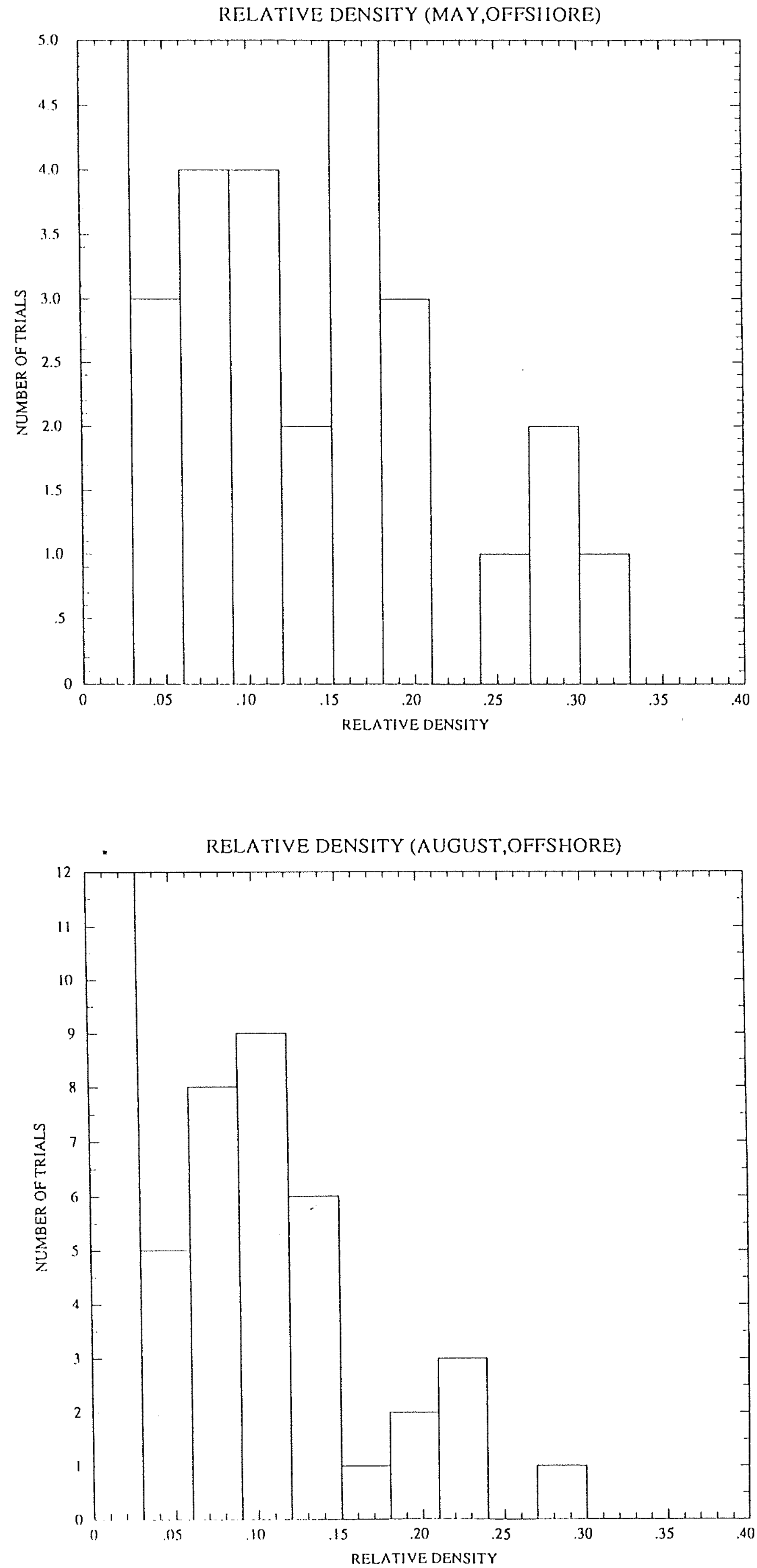


Figure 12 Distribution of relative fish densities around the traps for May and August

§8 Ingress and egress

According to the model developed by Munro (1974) and outlined earlier, the rate of ingress of fish into a trap is considered to be fairly constant with time, dependent only on the surrounding local abundance of fish. Whilst this may remain an adequate first approximation for modelling the behaviour of unbaited traps with a soak time measured in days, the results above indicate a more complex behaviour shown by fish towards baited traps.

Upon arriving at a trap most fish were observed to congregate on the down–current side of the trap. This behaviour is most likely due to the presence of the downstream bait flux on this side. We have previously identified the region around each trap in which the fish were usually observed to be found, and we define the fish within this region as belonging to a 'pool of availability' for entry into the trap. Fish within this pool tended to make random sorties around the trap sides, searching for the way in. The search time for a fish to find the entrance varied widely, and the factors influencing their eventual entry was often not clear from the video observations. Obviously, any features of the trap design that will entice these fish to enter is desirable.

In Munro's model, the constant rate of entry into the trap is given to be proportional to some unspecified measure of the local density of fish around the trap. It appears more sensible, however, to regard the ingress rate as depending upon the number of fish in the pool of availability outside the trap. In this manner, the number of fish available to enter the traps is changed from some unknown measure of local fish density to a known number of fish immediately around the trap. As the number of fish within the pool around any trap fluctuates during the duration of any particular trial, so will the rate of ingress. Hence, instead of assuming a constant rate of ingress into a trap, which would depend upon a constant pool of fish around the trap, the following model is proposed;

$$\left(\frac{\text{ingress}}{\text{during } \Delta t}\right) \alpha \left(\frac{\text{average number of}}{\text{fish around trap during } \Delta t}\right) \qquad (16a)$$

Similarly,

$$\left(\frac{\text{egress}}{\text{during } \Delta t}\right) \alpha \left(\frac{\text{number of fish}}{\text{initially in trap at t}}\right) \qquad (16b)$$

where the factors of proportionality are some measure of the probability of entry and escape of the fish respectively. Changes in the ingress and egress rates of the fish are therefore related to the changes in these probability measures.

Considering the fish within the pool of availability around the trap, we define the probability of a fish entering the trap within a given interval of time Δt.

$$\Pr\ (\text{entry during a time } \Delta t) = \frac{\text{number of fish entering during } \Delta t}{\text{average number of fish in the pool during } \Delta t} \quad (17a)$$

Similarly,

$$\Pr\ (\text{escape during a time } \Delta t) = \frac{\text{number of fish which escape during } \Delta t}{\text{initial number of fish in the trap before } \Delta t} \quad (17b)$$

For any interval of time Δt for which the denominators in expressions (17a) and (17b) are non–zero, entry and exit probabilities are defined. The two minute interval used to summarise the video observations, provides a suitable interval of time for the above calculations and is used throughout. Calculation of the ingress and egress probabilities for each of the different trap designs allows comparison of the ability of each to catch and retain fish.

8.1 Constant ingress and egress model

If the ingress and egress probabilities depend on trap design alone, then we would expect to find the calculated probabilities to be distributed about trap specific constant values. These constant probabilities will also give some indication as to the average operating parameters for each of the trap designs. Hence we fit the following models to the data set for each trap design:

Pr(entry) = constant
Pr(exit) = constant

The results are given in Table 10 (n is the number of observations). Since there should be no seasonal or location dependence on these probabilities, all observations from all trials for each trap type were used.

The probability of a fish entering a trap is found to be greatest for the 'S' trap and least for the angular 'Z' traps, with the 'O' and 'R' traps operating between. For the 'O' trap, nine percent of the fish around the trap will, on average, enter every two minutes, rising to 13% for the 'S' traps, and decreasing to 6% for the 'Z' traps. Given that a fish spends about ten minutes around the trap before leaving the area, the probability of entering the trap during this time is 38, 27, 50, and 34% for the 'O', 'R', 'S', and 'Z' traps respectively.

The 'R' traps were designed so that ingress would be enhanced by having the entrance facing down current (see §8.2). However, the video observations showed that this alignment was achieved for only 35% of the total soak time for these traps. The ingress probability between the 'R' traps and the 'O' traps was not found to be significant indicating that the operation of the two trap types was similar. The superiority of having two entrances into the traps is displayed by the high ingress rate of the 'S' traps. Using a two–sided t–test the difference between the 'S' and 'O' traps was significant at the 1% level. The much smaller horseneck funnels used with the 'Z' traps explains the small ingress rates observed with these traps. The difference for 'Z' and 'O' traps was

Table 10 Constant ingress and egress probabilities (with standard error) for all traps

Trap	Ingress 2-min	n	Egress 2-min	1-hr	n
Muley					
'O'	.090 (.005)	2077	.022 (.0045)	49%	1949
'R'	.080 (.008)	595	.017 (.0029)	40%	470
'S'	.131 (.012)	537	.028 (.0041)	57%	624
'Z'	.056 (.008)	418	.005 (.0024)	14%	442
Trash Fish					
'O'	.091 (.021)	161	.023 (.0089)	50%	221

significant at the 0.1% level.

Similar relationships are also found between trap design and egress probability. Thus, the 'S' trap displayed the greatest ability of a fish to leave with the 'Z' traps showing the least likelihood. The egress values for these two trap types corresponds to a fish having a 57% chance of leaving an 'S' trap within the first hour after entry, compared to only 14% for a 'Z' trap. The differences between the 'S' and 'O' traps was significant at the 5% level, and between the 'Z' and 'O' traps at the 0.1% level. As with the ingress probability, the egress probability of the 'O' traps has a valve midway between the results for the 'S' and 'Z' traps. There appeared to be some difference between the 'O' and 'R' traps, being significant at the 10% level using a one–sided t–test. Note that these egress rates are far in excess of those rates reported by Munro (1974) who gives the average *daily* probability of escape as only 0.12! This discrepancy is most likely due to the inability to observe the high turnover of fish within a trap due to the methods used by Munro and his co–workers.

The ingress and egress probabilities observed with the use of the trash bait and 'O' traps appear to indicate that the behaviour of those fish which have been attracted to the trap is independent of bait type. The major difference in bait types is thus seen to be their relative attractiveness to those fish away from the trap. By the selective use of baits, desirable species of fish may be able to be targeted with the numbers of non desirable fish kept to a minimum.

Overall, the catch obtained with any trap will depend upon the combined ingress and egress rates of the trap, and the catch at any time should display characteristics dependent upon trap type. For example, 'S' traps should, in general, catch more quickly than the other three types, but at the

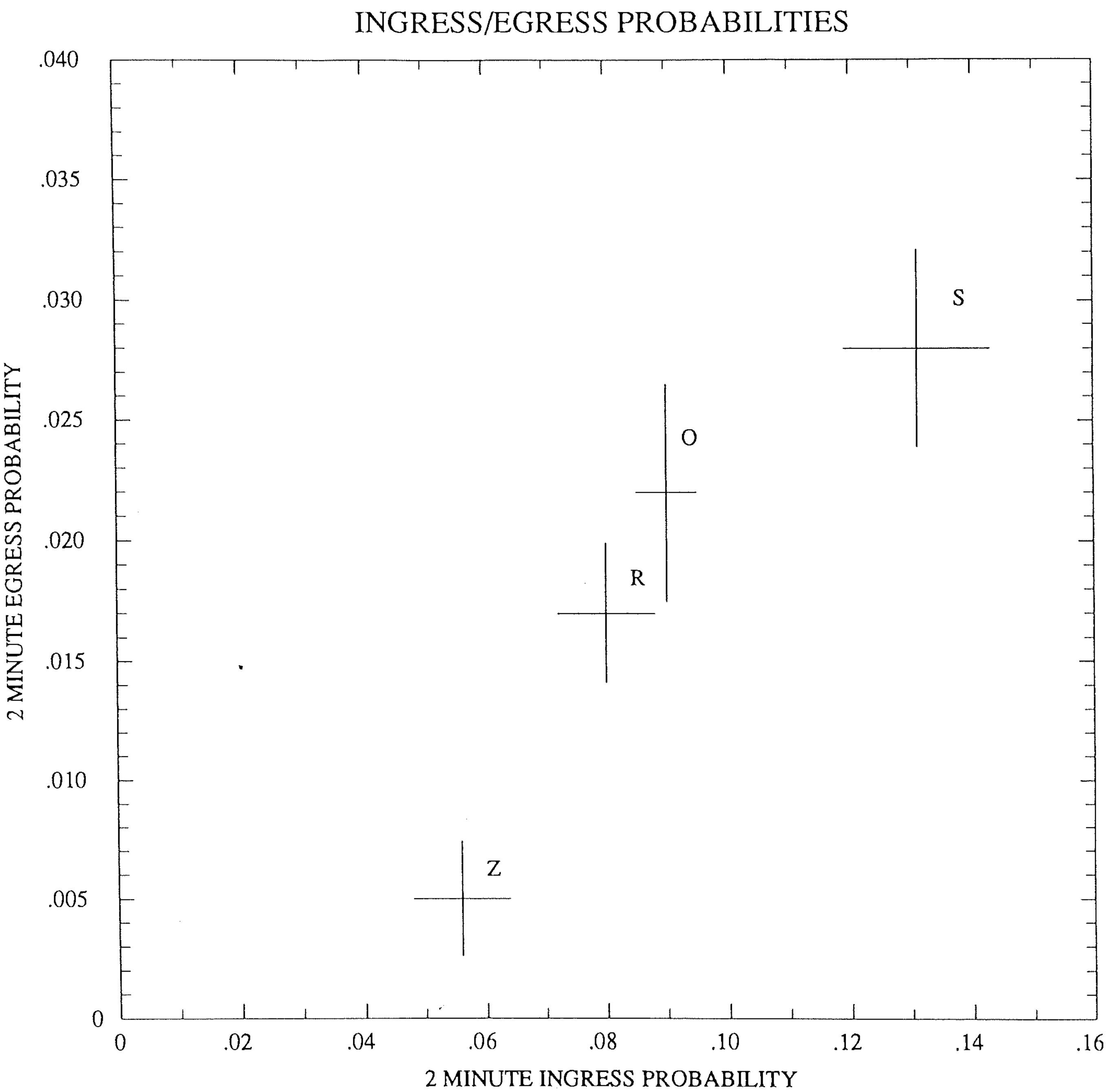


Figure 13 Comparison of constant 2-minute ingress and egress probabilities for different trap types (one standard error shown)

same time will lose fish more quickly. This type may be best for short soaks of one hour or so. On the other hand, 'Z' traps catch fish at a slower rate but have a superior retention rate. They may be best for long soaks. Indeed, there appeared to be a direct relationship between the probabilities of entry into and exit from the traps; that is, easy come, easy go. This relationship is displayed in Figure 13. This high degree of correlation between ingress and egress explains the failure to observe any significant differences in overall catch rates between the trap types. Again, any advantage due to the greater ingress rates of the 'S' traps is largely off–set by the greater ability of fish to escape from these traps.

The differences in behaviour between the 'S' and 'Z' traps is primarily due to the use of vertical entrances of the former and the horse–neck entrances of the latter. The much smaller 'horse–neck' entrance allows smaller rates of ingress but simultaneously allows the trap to retain the catch much more successfully. Similar results have been reported by Luckhurst and Ward(1986) who studied the effect of funnel type on the retention of trapped and concluded that the horseneck funnel is more effective in preventing escape and that funnel design will affect the way in which trap catches are built up over time.

8.2 Factors influencing ingress into the trap

The factors which influence the ingress of fish into a trap are no doubt more numerous than a simple dependence on trap design. Utilising the data from all the 'O' trap trials for both months, the average ingress probability for each two minute interval of the soak is displayed in Figure 14a. Ingress rates as high as 30 and 40% are observed from the first 10 minutes decreasing steadily to a level around 5% after 90 minutes after which time it fluctuates around this value. The ingress rate thus displays almost an order of magnitude decrease during the duration of the soak.

This decrease in the willingness and/or ability of fish to enter the traps after one hour seems unexpected at first, given that the fish within the pool of availability outside the trap remains relatively constant for most of the soak (cf. Figure 5a). A decrease in the attractiveness of the bait may influence the rate of ingress (though one would expect a decrease in the number of fish around the trap if this was the case). On the other hand, it may be a result of the fact that those fish which find the entrance relatively easily comprise the majority of the initial entrants into a trap, leaving those fish types which have more difficulty finding the entrance to ingress at a slower rate. Unfortunately, the length of time fish remained outside the traps was not observable.

Other factors influencing the ingress may include the accessibility of the entrance, the activity of the fish within the trap, such as their feeding behaviour, and catch limiting effects such as trap saturation. High and Beardsley (1970) suggest that fish are also influenced to enter a trap for a number of reasons other than the pursuit of bait, such as random movement, adoption of the trap as a shelter, curiosity, intraspecific social behaviour, or predators pursuing prey. In developing a model of the observed ingress behaviour the following four factors were considered;

1. Funnel alignment

Work in the past has indicated the importance of having the entrance funnels of baited traps facing downstream. Fernö et al. (1986), studying the behaviour of whiting (*Gadus merlangus* L.) towards baited hooks, reported that 90% of the fish approached the bait from downstream. The behaviour of most fish having arrived at the trap was to station themselves on the down current side of the trap (cf. Figure 2a). If the entrance funnel similarly faces downstream, the likelihood of entry is increased. On the other hand, if the entrance is diagonally opposite, the likelihood of entry would seem to be diminished.

The design of a rotational 'R' trap was an attempt to actively influence the alignment of the entrance with the downstream direction. The use of multiple entrances, as in the the 'S' and 'Z' traps, is a more passive design feature to ensure that at least one entrance faces the predominant direction of approach to the trap. However, the former approach may be more effective on the overall catch rate as the use of multiple entrances will tend to greatly assist the escape of fish from the trap. The influence of the entrance alignment may not be as pronounced using unbaited traps. Observations around such traps have shown that fish tend to mill around all sides of the trap (Powles and Barans,1980).

2. Intensity of bait flux

Once a bait has served its initial purpose of enticing fish to the trap, the bait may further encourage a fish outside the trap to more actively seek and find the entrance (and thus gain its reward). With the depletion of the bait, any such increase in ingress would be lost. As with the attraction of fish to the trap, the effectiveness of the bait should be enhanced during those intervals with fish feeding at the bait and such a correlation between feeding activity and ingress rate was observed on viewing the videos. This increase in ingress due to the enhanced bait loss due to the feeding activity of the fish is referred to as a burley effect.

The presence of very small fish feeding at the bait illustrates this effect. The time interval between the first arrival of a large fish at the trap and the first entry into the trap (cf. Figure 10b) was compared for those traps influenced by very small fish and for those traps not influenced. In each case, the time interval was assumed to be a Poisson variable. For those trap trials with very small fish present, the point estimate of the mean elapsed time was 4.2 ($\pm$ 0.9) minutes compared with 8.5 ($\pm$ 0.8) minutes for the other traps. Such an increase in flux of bait stimulant similarly explains the more frequent arrivals around baited hooks due to the agitation of fish already hooked (Ferno et al. 1986).

3. Trap size

The effectiveness of a fish trap is often assumed to be dependent upon its size (Crossland, 1976) (Munro, 1983). A trap of greater volume is seen as having a higher retention rate due to the reduced likelihood of a randomly fishing fish finding the entrance, as long as the number and size of the exits remain constant. Hence, according to Munro's model, by decreasing the egress parameter the asymptotic catch should increase. Another feature of size which could influence the ingress probabilities is the concept of gear saturation. Whilst this is an old concept when dealing with fishing gear, its importance in limiting catches in trap fisheries may be greater than is generally appreciated. High and Beardsley (1970) reported such an effect in their study with traps, where when the number of fish within a trap approached 25, the rate of entry would drop sharply. It appeared that large numbers of fish in a trap frighten other fish from entering. Miller (1980) also argues for a saturation effect, limiting catches in as little as an hour. The saturation level can possibly be increased by increasing trap size but may also depend upon the size of the target fish. Because of this latter factor, the weight of fish within the trap will be taken as a measure of the level of saturation.

4. Behavioral factors

Whilst the trap size and entrance alignment are to some extent under the control of the person fishing, behavioral characteristics, which can have a large influence on the final catch, are not. Fish participate in an environment of predators and prey, and so the entry of particular fish types into a trap may further enhance or deter the entry of more fish. For example, presence of small fish within a trap may enhance the entry of Serranids ('self–baiting' of a trap), whilst the presence of a Serranid within a trap may deter the entry of other fish. The gregarious nature of some fish types may also affect the behaviour of fish in and around the traps. For example, this may account for the very large ingress of Lethrinids observed during some trap trials. On the other hand, the congregation of fish around the traps may impede movement of individuals into the traps.

After investigating the influence of the above factors on the probability of a fish entering a trap, the following model was found to best explain the observations;

$$\Pr(\text{ entry during nth interval }) =$$

$$\left[\frac{P(1)+P(2)\times(\text{Feeding loss}_n)+P(3)\times\text{Small}_n}{(1+\text{Catch}_n/P(4))}\right]\times\frac{\exp[P(5)\cos(\theta-P(6))]}{I_0[P(5)]} \qquad (18)$$

where each of the terms represents the following process

1) P(1) measures of the unassisted ingress probability (due to random entries and the presence alone of the bait)

2) $P(2)\times(\text{Feeding loss}_n)$ measures the influence of the feeding flux on ingress where the loss of bait due to feeding Q_n is given in equation (5)

3) $P(3)\times\text{Small}_n$ measures the contribution of those small fish which were often since within a trap before the arrival of more commercial sized fish

4) $(1+\text{Catch}_n/P(4))$ measures the influence of 'crowding' within the trap on further ingress. Since different fish types have different characteristic sizes, the weight of the catch is possibly a better measure of trap saturation. The catch weight is given by

$$\text{Catch} = \sum_{i=1}^{s} w_i N_{ni} \tag{19}$$

where w_i is the average weight of a fish of type i and N_{ni} is the number in the trap during interval n . Note that this term will halve the probability of entry when the catch weight reaches P(4).

5) $\exp[P(5)\cos(\theta\text{-}P(6)] / I_0[P(5]$ = circular normal distribution (von Mises distribution). P(5) measure the size of the distortion away from the constant circular distribution and P(6) is the angle where the circular normal distribution takes its maximum. $I_0\{P(5)\}$ stands for the modified Bessel function of the first kind of order zero. In the model above the angle is defined as the difference between the current direction and the entrance funnel direction. Favorable ingress may be expected when this angle is zero.

The model parameters were estimated by minimizing the sum of squared deviations between the observed and predicted probabilities of entry for each 2 minute interval. The average weights w_i are known from the catch data, whilst the catch numbers N_{ni} ,entrant numbers E_n and the alignment angles of those fish θ can be obtained from the video observations. The bait loss due to feeding Q_n is given from the bait loss model presented previously. The results obtained are given in Table 11. The stochastic nature of the ingress of the fish into the traps underlies the low goodness of fit of this and any other such model.

TABLE 11. Ingress parameter estimates for the 'O' trap

ESTIMATE		(STD. ERR)	CORRELATION MATRIX					
P(1)	0.049	(0.009)	1.0					
P(2)	10.9	(1.7)	-.08	1.0				
P(3)	0.095	(0.019)	-.31	.13	1.0			
P(4)	13.1	(3.3)	.23	-.74	-.04	1.0		
P(5)	0.47	(0.081)	-.20	-.25	.01	-.01	1.0	
P(6)	0.31	(0.26)	-.41	-.32	-.12	-.32	.44	1.0
Goodness of fit = 0.34								
Degrees of freedom = 2069								

In order to gain some appreciation of the magnitude of the modelled influences on the ingress probability, we consider the average predicted flux of 0.017 kg/min. and the observed averaged 2-minute ingress probability of 0.096 for these trials. Using this latter probability, the parameters P(5) and P(6) determine a baseline probability distribution around the trap which ignores averages over the other influences.

$$\text{Pr(entry)} = \text{Av.Prob.} \times \frac{\exp\{P(5)\cos(\theta\text{-}P(6))\}}{I_0\{P(5)\}}$$

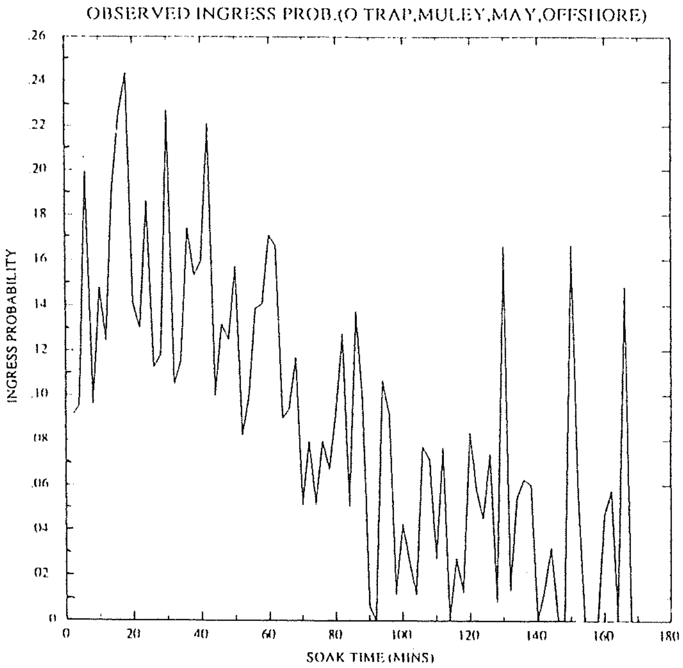


Figure 14a Average of observed 2-minute ingress probability versus soak time for '0' trap trials

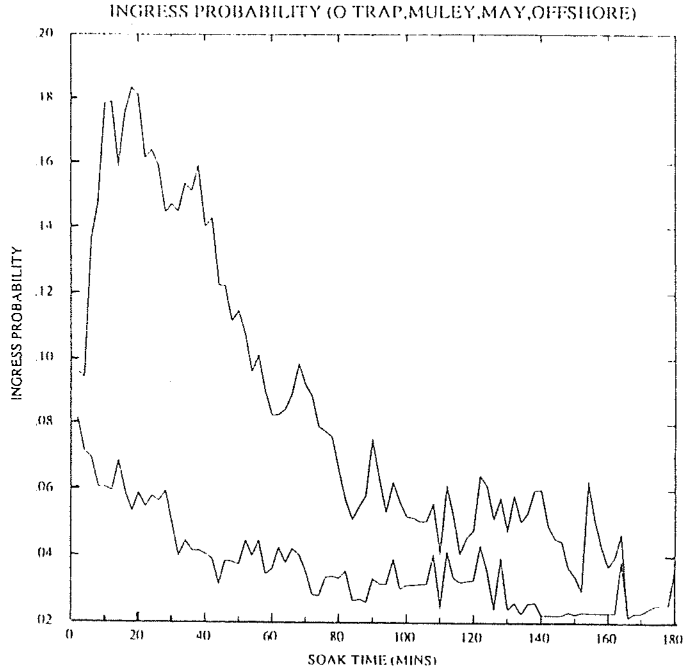


Figure 14b Comparison of fitted ingress probability versus soak time (upper curve) and expected probability with 'burley' influence removed

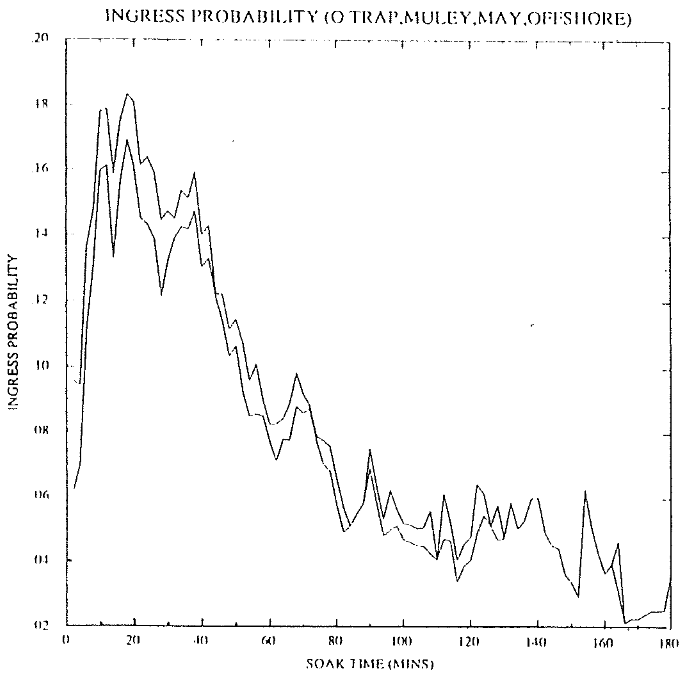


Figure 14c Comparison of fitted ingress probability versus soak time (upper curve) and expected probability with small fish influence removed

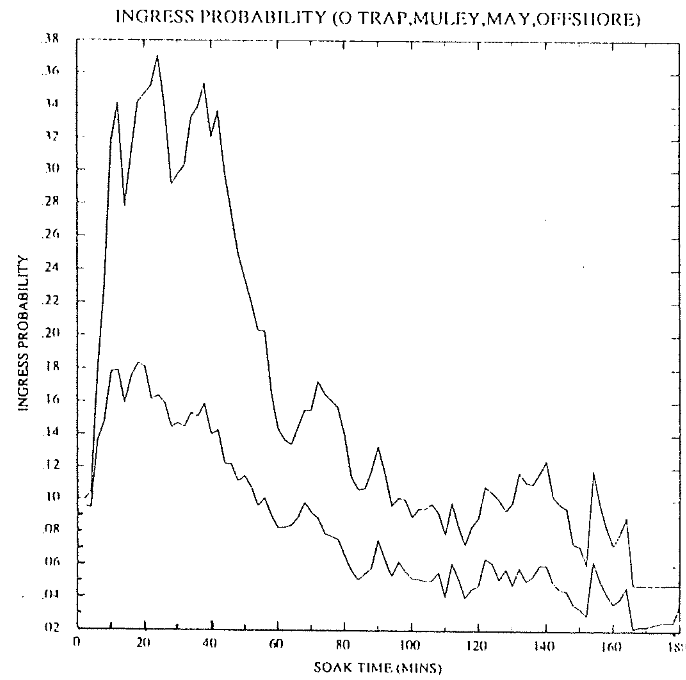


Figure 14d Comparison of fitted ingress probability versus soak time (lower curve) and expected probability with trap saturation influence removed

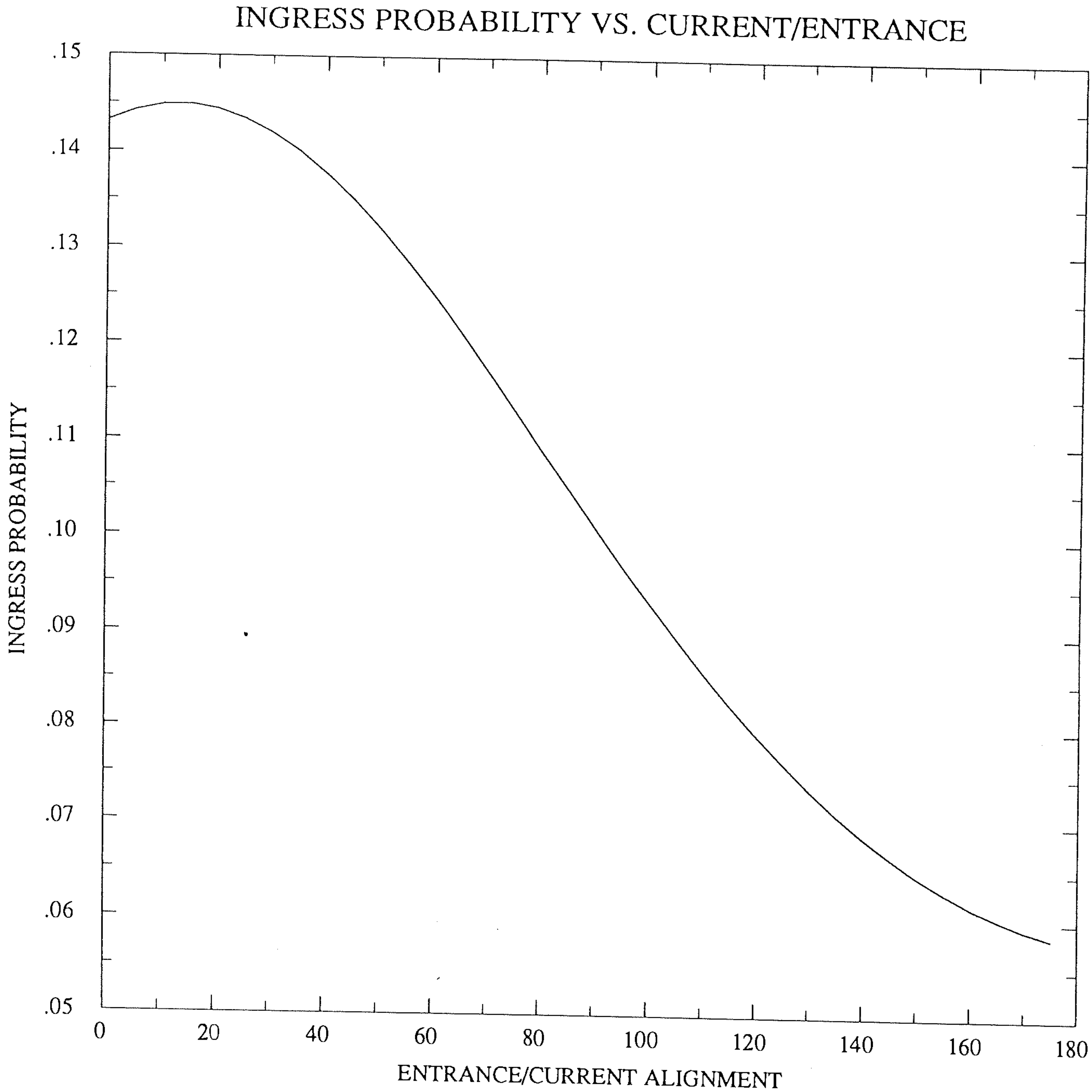


Figure 15 Distribution of constant ingress probability component around '0' trap as a function of the entrance funnel/current direction angle of alignment

This distribution is displayed in Figure 15. The size of the distortion in this distribution due to a favourable alignment of the entrance funnel and the current direction is given by the parameter P(3).The ingress probability increases from 0.058 during an opposing alignment to 0.145 with a favourable alignment. This 150 percent increase indicates the potential enhanced catching ability of a correctly aligned trap. The parameter P(5) indicates that the most favourable alignment is achieved with the current direction and entrance about 22 degrees apart. Given the error on this estimate and the wide entrance apron on the 'O' traps, this estimate is near the zero angle alignment expected. Nevertheless, given that the fish downstream of the flux would be facing an incurving wall with a current alignment of 22 degrees, this result may indicate that the most favoured alignment is slightly off having current and entrance totally aligned.

At the start of each soak there is an ingress probability of 0.049 for the first fish to arrive around the trap. This increase to 0.144 with the presence of small fish in the trap which entice the larger fish to enter. As fish enter the trap and eat from the bait this probability will increase as the flux increases. Using the average predicted flux from the traps for May of 0.017 kg/min, the baseline probability of ingress is increased by 0.186 to 0.235 (or 380 percent above the constant initial probability). Indeed the increased flux due to feeding accounts for the large increases in the probability during the first 20 minutes. This is easily seen by comparing the two curves in Figure 14b. The lower curve represents the ingress probability due to the dissolution of the bait alone, while the upper curve is the fitted curve to the observations. From Figure 3c it is seen that ingress into the traps is greatest during the first 40 minutes, decreasing to a slower rate thereafter. This slow down in ingress rate contributes to a smaller number of fish feeding at the bait and this in turn further decreases the likelihood of entry and explains the fall off in the ingress probability after 40 minutes. This increase in ingress rates due to the feeding of fish at the bait is a good example of a burley effect on catch rates.

With no impediments on ingress ,any increase in the baitflux has a very positive feedback effect on the rate of ingress which then leads to further increases in the baitflux. This process would only end with the depletion of the bait. However,the build-up in the catch appreciably decreases the ingress rate and curbs the unhindered build up of the catch due to the influence of the bait alone.

The saturation parameter value, P(4)=13.1, represents a halving in the entry probability when about 13 kg of fish are present in the trap. The influence of the build up of the catch on the ingress probability is seen in Figure 14d, where the lower curve now represents the fitted curve to the observations and the upper curve represents the expected probability with no saturation effect, i.e.P(4)=0. At most times the rate of ingress is effectively halved due to the presence of fish in the trap.This effect helps to explain the levelling off of the average catch at a level of around 11 kg observed in these trials. Note that saturation levels within a trap are different from the states of equilibrium between the rates of ingress and egress which lead to the asymptotic catch levels in Munro's model. These latter levels are dependent upon the general abundance of fish in the vicinity of the trap. Furthermore, it must be remembered that both the concepts of saturation and asymptotic equilibrium do not necessarily mean a constancy of the catch composition and/or the commercial value of the catch, due to the continuing turnover of fish in both situations.

8.4 Comparison of ingress parameters and trap type

In the ingress model outlined above, the saturation term should be related to trap size. Furthermore, the magnitude of the burley effect term could be related to trap design, as the increase in entry probability is likely to be related to the natural ease of entry into the trap. In order to investigate some of the differences in the ingress characteristics for each trap design, a comparison of the parameter estimates of each design was undertaken. Since the 'S' and 'Z' traps have double entrances to overcome the entrance/current direction effect mentioned previously, the following model we fitted to the data set for each trap type.

$$\text{Pr(entry during nth interval)} = \left[\frac{\text{P(1)+P(2)}\times(\text{Feeding loss}_n)}{(1+\text{Catch}_n/\text{P(3)})}\right] \qquad (20)$$

The results for each of the trap types are given in Table 12. Comments on the value of the constant term P(1) are similar to those above for the constant 2-minute value. The only difference is that the term for the 'R; trap is now lower. This result is disappointing as with a correctly operating trap this term should be greater than that for the 'O' trap which depends randomly upon current/ entrance alignment. A factor limiting the operation of the rotating trap may be that the movement of the trap itself as it turns with fluctuations in the current may frighten fish off. The value of P(2) may give some indication of the importance of the influence of a 'burley' to encourage fish to enter. For the 'O' and 'R' traps this influence is about the same whilst for the 'S' and 'Z' traps it appears to be less. For the 'S' trap this is possibly due to the larger constant term diminishing the importance of the 'burley', whilst for the 'Z' trap the explanation is likely due to the more difficult ingress due to the 'horse-neck' funnel.

TABLE 12 Comparison of ingress parameter estimates and trap type

Term	Constant P(1)	Flux P(2)	Catch P(3)	n
'O'	0.059 (0.011)	8.2 (2.8)	13. (8.2)	2071
'R'	0.048 (0.010)	7.5 (2.2)	35. (32.)	592
'S'	0.109 (0.015)	4.3 (1.6)	Insuff data	537
'Z'	0.044 (0.010)	3.8 (1.6)	Insuff data	605

The absence of many (if any) large catches for traps other than the 'O' traps accounts for the poor estimates of the the saturation term for these other traps. However, if one assumes a direct relation between trap size and the effects of saturation then, given that the average volume of the 'O' and 'S' traps were 1.4 m^3 and 2.4 m^3 respectively, the expected value of P(3) of the 'S' traps is 22. Thus the catch of 13 kg which halves the probability of ingress for an 'O' trap only decrease the 'S' trap probability by 37 percent. Obviously trap size will help determine the equilibrium catch within a given trap. Hence with long trap sets, one should use large traps so that any saturation effect does not limit the catch at an early time during the soak. Otherwise, much of the soak time available to catch fish will be wasted.

An investigation of the factors influencing the egess of fish from a trap was also undertaken. Whilst some of these factors where successfully modelled for the 'O' trap (Campbell et al 1990) attempts to model the influence on the egress probabilities for the three other trap designs were not successful.as the data for each of these other traps were not sufficiently strong to discern any significant influences. The constant model values for these traps thus remain the best first approximations to the egress parameter.

There is obviously an advantage to be derived from development of a trap that reduces exit probability without proportionately reducing entry probability, and this aspect of the capture process should be closely considered in the development of an improved trap design. The strong relationship between exit probability and the number of fish entering in a given time interval suggests that the exit probability is increased when fish in the trap observe other fish entering the trap. This suggests that a physical means or illusion may have to be used to differentially reduce fish exit.

8.5 Factors affecting egress from the trap

As with the entry of fish into the trap, the factors influencing the escape of fish from a trap can similarly be investigated. The observations of fish within the trap displayed a range of behaviour, with some fish eating from the bait, some swimming randomly about, and others congregating in corners of the trap. Fish were observed to spend little time near the entrances. Furthermore, most fish appeared to coexist quite easily with different fish types in the trap, apart from some aggression displayed by Serranids.

The average of the two–minute egress probabilities versus soak time for the 'O' traps are displayed in Figure 16a and display quite an unusual behaviour. No fish were observed to leave the trap during the first eight minutes, even though fish entered well before this time. After about ten minutes the probability of a fish escaping from a trap jumps to the high value of about 0.25 then rapidly decreases to the almost constant value of 0.02 for the remainder of the soak.

The zero egress probability during the first eight minutes could be explained by the fact that most fish on entering the trap feed upon the bait, and would only start searching for the entrance some

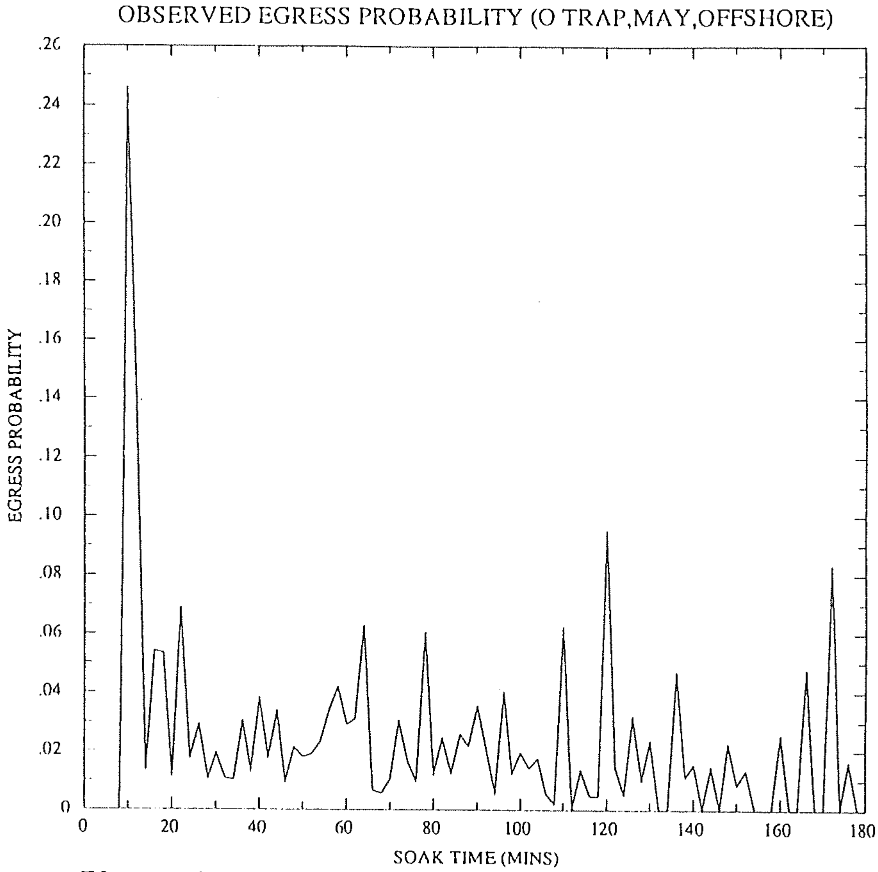


Figure 16a Observed average of 2-minute egress probabilities versus soak time for '0' trap trials

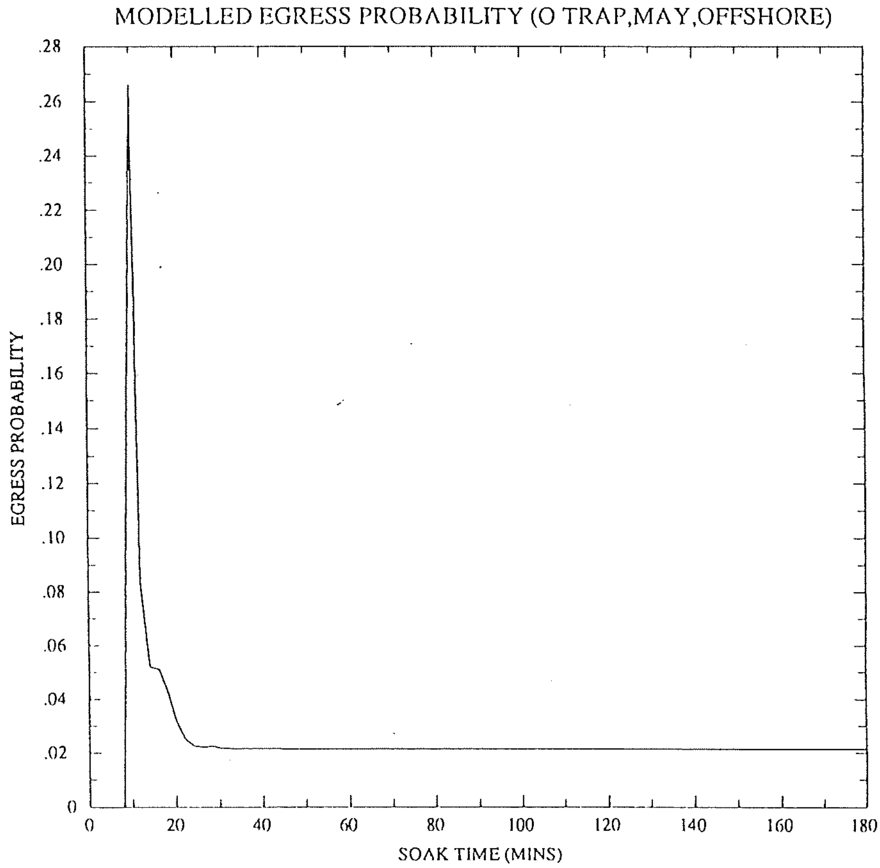


Figure 16b Regression results for egress probability

time after first entering. Alternatively, each fish will spend some average time searching for the exit and no escapements by a fish shorter than eight minutes were observed. Using these arguments, one may expect the rate of egress to increase with time since most fish will have finished eating from the bait and be searching for the entrance. However, this is not observed. On the other hand, fish may decrease their effort of searching for the entrance with time as they become accustomed to being within the trap. Mention has also been made of the evidence for the increased retention of larger specimens of some species. Hence, if these larger specimens make up an increasingly larger proportion of the catch with time, the average probability of escape of the fish within the trap can be expected to decrease over time. Unfortunately, since the size of each fish within the traps at any time is not known, such an effect was not able to be investigated.

Fish searching for the exit may also be assisted by observing other fish entering the trap. Furthermore, we have seen from examining the ingress probability that fish behaviour is influenced by the number of other fish around. Hence, the high probability of escape after ten minutes may be due to a combination of fish entering the trap increasing the probability of escape for those fish already in the trap whilst initially there is only a few fish in and around the trap to entice a fish to stay. Finally, observations also showed that many fish faced into the current whilst stationary within the trap. It may be possible that there is some dependency of the egress probability and current direction/entrance funnel alignment (as was found with the ingress probability). However no significant effect was found.

After investigating the influence of the above factors on the probability of a fish escaping from a trap, the following model was found to best explain the observations;

$$\Pr(\text{leave trap during nth interval})$$

$$= P(1)+\frac{P(2)\times E_n(0,1)}{[\text{Catch}_n+\text{Pool}_n]}\times\exp\left\{-\frac{[\text{Soak}_n-P(4)]}{P(3)}\right\} \qquad (21)$$

where the subscript n refers to the value of the respective number during the nth interval of time and P(1) gives some measure of the constant probability of escape. The second term gives the increase in the probability of escape when one fish enters the trap during the interval of interest. Only those intervals during which one fish entered the trap was found to increase the probability of escape, and so the value of the term $E_n(0,1)$ is such that it takes the value one when one fish enters the trap and is zero otherwise. The parameter P(4) gives a threshold time before which the probability of escape is also zero.

Parameter estimates using the data set for the 'O' traps is given in Table 13.and the average of the fitted probabilities to the data are displayed in Figure 16b. From 30 minutes onwards the probability of escape is found to have a constant value of about 0.021. A threshold time of 10 minutes is found before which the probability of escape is zero. The second term in equation (20) above explains the jump in the probability immediately after the first ten minutes. The fact that there

Table 13. Egress parameter estimates for the 'O' trap

Parameter	Estimate	Std. Error	Correlation Matrix		
P(1)	0.0215	0.0026	1.0		
P(2)	2.97	0.21	–.04	1.0	
P(3)	3.52	0.49	–.10	–.35	1.0
P(4)	10				
Degrees of Freedom = 1946					

is found to be an increase in the escapement during those intervals for which only one fish enters may be due to the fact that with more entering the fish already within the trap are more likely to stay. Also, with multiple entries there is a greater chance that the entrance apron of the trap is 'blocked' by other fish positioning themselves to enter. This influence is most significant initially when there are few fish in the trap, and decreases rapidly as the catch builds up (as indicated by the small value of P(3)). This effect may be likened to being in a crowded room where one is less likely to notice new entrants, and thus see the entrance, as the number of people in the room increases.

Attempts were made to model the influence on the egress probabilities for the three other trap designs. However, the data trials for each of these other traps were not sufficiently strong to discern any significant influences. As before, this is a result of the small number of trials, as well as the absence of many large catches and longer soak times. The constant model values for these traps thus remain the best first approximations to the egress parameter.

8.6 Geometrical basis to the ingress and egress probabilities

The ingress and egress models of the previous sections have both included constant terms. The corresponding values of these terms are dependent on the trap alone and should be related to design. Any knowledge of this relation should assist in the design of more effective traps. Obviously, a trap with the entry characteristics of an 'S' trap and the exit characteristics of a 'Z' trap would be a good start.Munro (1974) explains the superior ingress fish in 'S' trap compared to 'Z' trap as due to the continuous curves of the 'S' trap helping to guide fish more effectively to the entrances. Escapement is seen to be proportional to the size of the entrance funnel and inversely proportional to trap volume.

From the video observations fish appeared to move randomly around the outside of the traps in searching for the entrance. Very little time, if any, is spent above the traps. It seems plausible then that the probability of a fish entering a trap is related to the ratio of the area of the entrance (s) to the total surface area of the trap sides. Consider the model:

$$\text{Pr (entry into trap)} \propto \frac{\text{Area of entrance(s)}}{\text{Total surface area of sides}}$$

The 'O', 'R', and 'S' trap designs incorporate entrances which have a wide outer opening funneling down to a narrower opening within the trap.From viewing the videos it was obvious that not all fish which find the wide outer opening will enter the trap. To each portion of the outer entrance we therefore associate a probability of ingress.

Consider the entrance drawn schematically in Figure 17. To an element dx of the outer opening the probability of ingress is defined to be the ratio of the depth of the funnel at this point to the total depth of the entrance. The 'effective' width of the entire entrance opening is then given to be

$$W = \int_0^L \frac{y(x)}{D}\, dx$$

where y(x) is the depth function of the opening and L is the width of the outer entrance.A similar geometrical interpretation was also used in calculating the probability of exit, with the area of the inner opening to be divided by the total inner surface area of the trap sides.

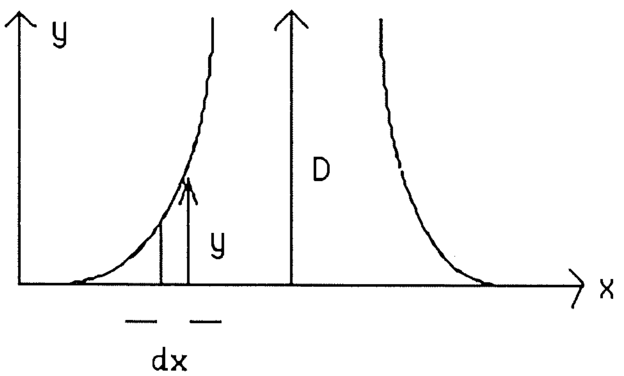


Figure 17 Entrance funnel design

The results are given in Table 14 for the 'O' and 'S' traps. For comparison, the observed two minute constant model probabilities are also given. In each instance, the ratio r of the observed and the geometrical probabilities is similar and seems to indicate a high degree of correlation between the observed ingress and egress probabilities of a particular trap type and its geometrical design. An optimal trap design would be achieved by maximising the 'effective' entrance surface area of the trap and minimising the surface areas through which fish can escape from the trap.

Table 14 Relation between trap design and ingress/egress probabilities

Trap	Ingress Probability			Egress Probability		
	Calc.	Obs.	r	Calc.	Obs.	r
'O'	.081	.090	.90	.026	.022	1.2
'S'	.113	.131	.86	.036	.028	1.3

8.7 Ghost fishing

The influence of trap design on escape from a trap also has a bearing on what is know as 'ghost fishing' — the ability of lost traps to continue trapping fish, many of which may subsequently die because of their inability to escape from from the trap. The study by Munro and his co–workers (Munro et al, 1971) found that fish which did not escape lived for varying lengths of time and after two weeks showed signs of physical deterioration from predators and contact with the wire mesh. In another study off Florida (Taylor and McMichael, 1983) five traps that had soaked for approximately two months and 55 traps that had soaked for 20 days were sampled. Seventeen percent of the fish collected in the traps that soaked for two months were dead or injured while 27% of the fish from the traps that soaked for 20 days were dead or injured. These observations have helped to create concern that fish resources can be severely depleted by such losses due to lost traps.

However, these latter results lack meaning as the true measure of ghost fishing is the percentage of total fish which enter the traps which subsequently die. For example, if a trap is hauled after two months and contains ten fish, two of which are dead, then the reported death rate is 20%. On the other hand, if 1000 fish had been through the traps during this time, then the true measure of the death rate would be closer to 0.2%.

Because of their higher egress rates, traps fitted with straight funnels are seen to be less wasteful of the fish resource if left for long soak times, as most fish learn to escape and will not die in the traps. Indeed, from the results above, the probability of escape is around 50% per hour for such traps, indicating that there is a very high turnover of fish in the traps with little chance of any one fish remaining in the trap for a day or more. An important point to note here is that even though many catches will approach some asymptotic level, dependent upon the density of the fish around the trap, this does not mean that the no new fish enter the trap. The concept of a balance being attained between the ingress and egress rates is a dynamic one, and implies a steady turnover of the fish within the trap. As such, a lost trap should not harm the resource.

Traps with horseneck funnels have been found to retain their catch much better and concern has been expressed that if left for long periods the trapped fish may become injured and subsequently die. Luckhurst and Ward (1986) warn that 'traps with horseneck funnels will undoubtedly increase the impact of lost traps on fish stocks'. Again, using the results above, this concern may seem to be overstated.With an average hourly escapement of 14%, there is only a 3% chance of a fish remaining in the trap after one day. However, there was some indication that the probability of escape may decrease with time, and if indeed this is the case then some ghost fishing may occur, especially in relation to larger specimens of some species. Because observations were made only up to three hours, such an effect over a matter of days,weeks or even months is not known. Nevertheless, from the results above one may expect the loss to be minimal.

§9 Further Comments

The model developed by Munro (1974) to describe the build up of fish within a trap is based upon the following two processes;

1. Fish enter at a more or less constant rate
2. Escapement per unit time is a fixed proportion of the number of fish in a trap.

A rationale for this model was to obtain some measure of the local fish abundance. However, whilst the total catch will be proportional to the surrounding density D of the fish, the asymptotic form of the catch versus soak renders the catch per unit time or cpue meaningless. To circumvent this problem, Munro uses the daily ingress rate, which he defines to be an index of availability, to provide a useful comparative index of stock densities. From (1b) we have the availability S_i of species i to be

$$S_i = \frac{\beta_i C_i(t)}{\left(1-e^{-\beta_i t}\right)}$$

where $C_i(t)$ and β_i are the species specific catch at time t and egress parameter respectively. This measure of availability is used for describing and comparing the abundance of the fish stocks. However, it will not give an absolute measure of fish stocks but a measure of that component of the fish stocks which are responsive to the trapping gear. This response can be increased by the use of a bait. Hence, we have the situation where the stock of fish may remain unchanged, but the effectiveness of the trap in catching fish can be increased. The availability measure S_i can therefore lead to quite incorrect measures of true availability.

If one could assume equal attractiveness amongst the different fish species to the bait or trapping gear, then S_i would give a measure of the relative abundance of each species in the vicinity of the trap. In general, though, this will not be the case. The S_i must be seen then to give only a relative measure of the attractiveness of the trapping gear on each of the species present, dependent on the interactions between each species and the trap.

It must be remembered that the estimates of the availability based on equation (21) will only be valid if the rate of ingress into the traps is constant. In general this is not the case with baited traps, and this may also follow for unbaited traps. We have seen that the rate of ingress is affected by the rate of bait loss due to feeding, saturation effects, conspecific behaviour and depletion of the local stock of fish. Our analysis has also indicated that instead of viewing the catch to be a result only of the ingress and egress of fish from the trap, it is the result of a four stepped process, with the above ingress and egress processes preceded by the loss and dispersal of the bait, and the arrival and retention of the fish around the trap. The measure of relative availability of fish species has been shown to depend in a much more complex manner on the time series of arrivals at the trap and the loss of bait.

9.1 Trapping Model Equations

By combining the above process models a complete set of equations can be given to explain the operation of any series of trapping trials. If we let A_n represent the number of fish which arrive at the trap during the nth interval of time, and P_n be the size of the pool of fish outside the trap at the start of this interval, then the arrival and retention of fish around the trap has been modelled as follows

$$P_{n+1}=\delta(P_n-E_n)+A_n \tag{22}$$

where δ is the probability of remaining in the pool between intervals. The catch equation then becomes

$$C_{n+1} = C_n+E_n-L_n \tag{23}$$

where C_n is the catch at the start of the nth interval of time and E_n and L_n are the number of fish which enter and leave the trap during this interval of time respectively. Now, the number of entrants is proportional to the number of fish around the trap, whilst the number leaving is proportional to the number in the trap. Therefore $E_n=\alpha P_n$ and $L_n=\beta C_n$ where α and β are the ingress and egress probability factors respectively. Substituting these expressions into the above equations (22)and (23) gives

$$P_{n+1}=\delta(1-\alpha)P_n+A_n \tag{24a}$$

$$C_{n+1}=(1-\beta)C_n+\alpha P_n \tag{24b}$$

In general the parameters α,β and possibly δ are dependent on a number of processes and are not constant. Furthermore, as the parameters α and β are trap specific, the solutions to the set of equations (24) will depend upon trap type.

The arrivals during any interval A_n have been modelled previously to depend upon the downstream area of the plume of attractant and the density of fish. The area of the plume of attractant depends upon the rate of bait loss which in turn depends on the number of fish feeding at the bait during each interval. Since the number of fish feeding at the bait depends in part upon the number of entrants during the interval of interest, i.e. A_n, P_n, and α, the system of equations for A_n, P_n, and C_n is therefore highly non-linear and offers no easy solutions.

Some idea of the different catch characteristic of each trap can be seen by solving these equations (24) assuming a given gamma distribution of trap arrivals (Figure 18a) which is independent of the number of fish in the trap. Using the ingress and egress parameters for each trap given in Table 12 the solutions to equations (28) are given in Figures 18b and 18c. Note that because of the poorer data set used to estimate the parameters for the 'R', 'S' and 'Z' traps, these solutions should not be taken as giving a realistic comparison between each of the trap types. However, given reasonable trap estimates such an approach should illustrate the characteristic catch curves for each trap type and in so doing help to determine the optimum trap design.

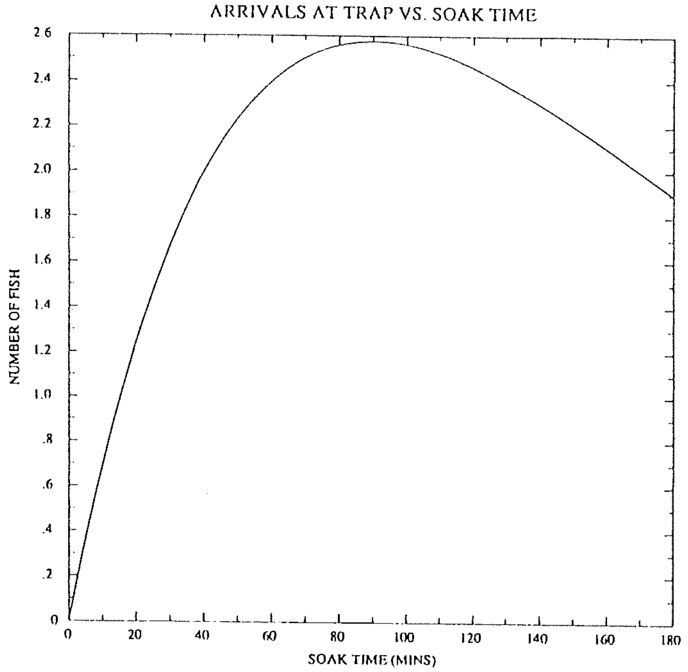


Figure 18a Arrival rate of fish at trap

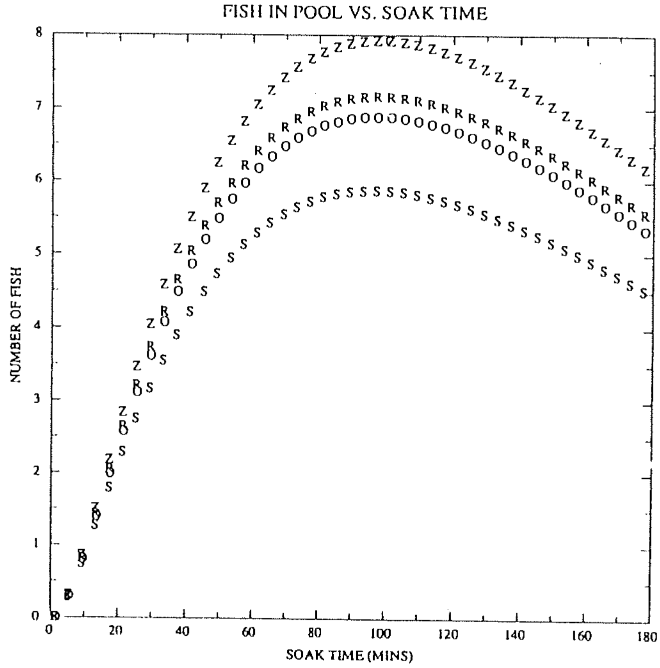


Figure 18b Fish in pool around trap versus soak time

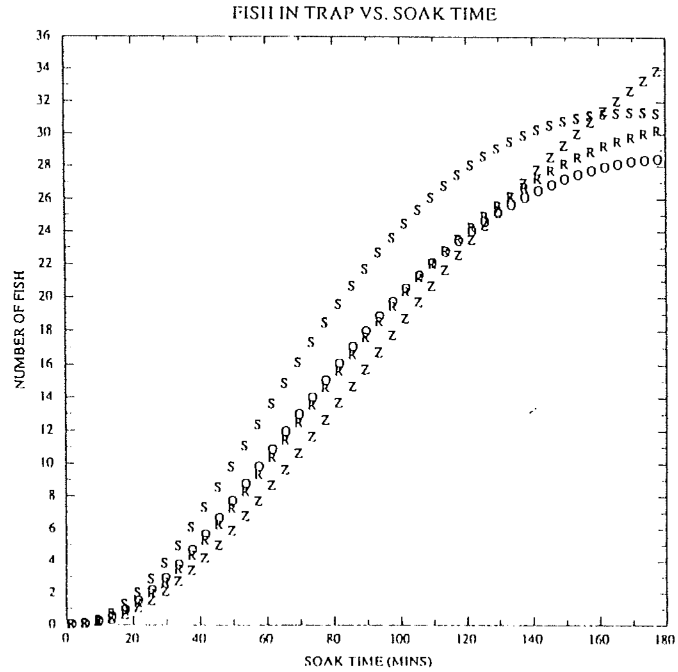


Figure 18c Number of fish in trap versus soak time

O = 'O' trap results
R = 'R' trap results
S = 'S' trap results
Z = 'Z' trap results

§10 Conclusions

This study has focused on the processes which underlie the operation of baited fish traps. The use of video cameras has allowed the behavioral dynamics of fish in relation to the traps to be observed continuously and the elucidation of factors considered to be important in determining trap catches. By greatly increasing the number of observations available from each trial, the use of videos has proved to be a useful tool. Thus, instead of relying upon several hundred catch versus soak observations, videos allow the complete analysis of relevant trap parameters with as few as thirty or forty trials. The use of videos in this way is also seen as a means of calibrating and assessing new trap designs.

Catches were observed to increase with soak time before levelling off at some trap specific trap limit. The turnover of fish associated with any catch was high. The resultant catch of any trap for a given soak has been found to be the consequence of a highly coupled system of interactions driven to a large extent by the loss of bait. The main feedback mechanisms linking the various processes are displayed in Figure 19.

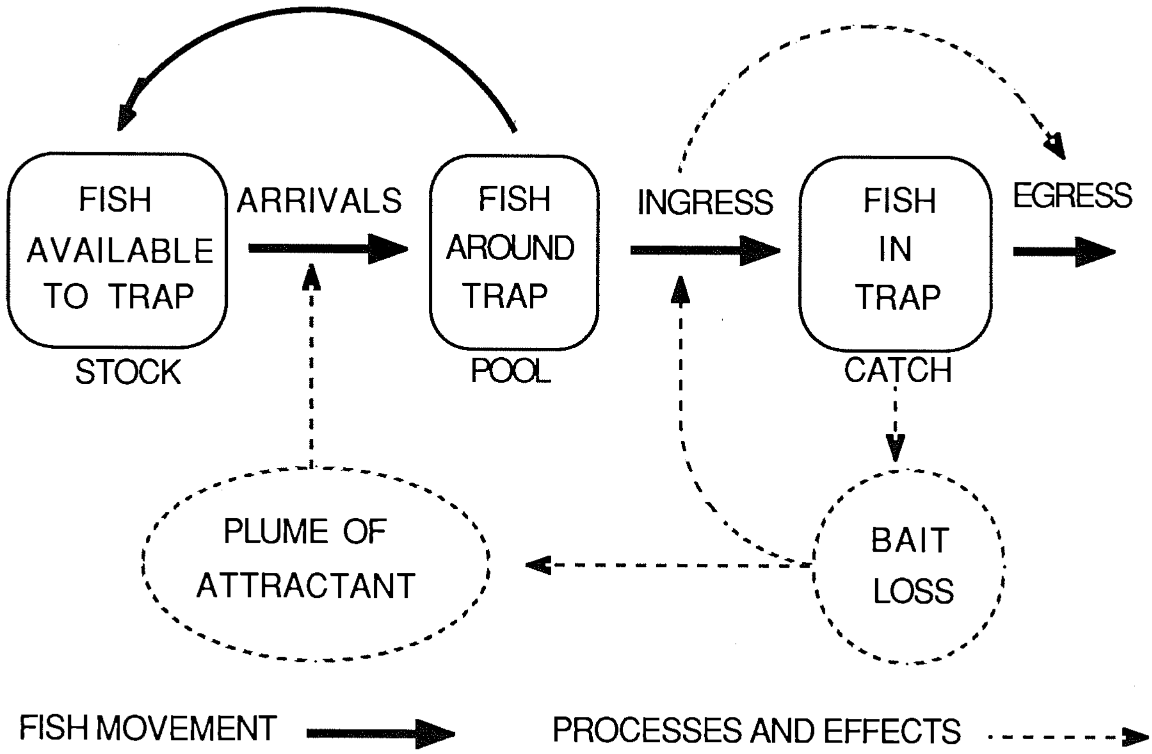


Figure 19 Schema of fish movements and trap processes

Loss of bait was mainly due to feeding by fish, and a concommitant burley effect was found to be a major influence on increasing both the rate of fish arrivals at a trap and the rate of ingress into the trap. As such the fish seem to be caught as a result of their efforts to find food rather than shelter.

This is opposed to other trap fisheries where unbaited traps are utilised. Furthermore, because of the more complex behaviour of the fish in response to the bait, the simple model developed by Munro to describe catch versus soak has been found to be inadequate for baited traps. Several models were therefore developed to account for the processes of arrival at the trap, retention around the trap and the subsequent ingress and egress into and out of the trap. The use of these models allows a relative measure of surrounding fish stock densities to be found.

Of the two baits tested the most effective (Muley) was due to a combination of its relative attractiveness to the target fish and its ability to be easily dispersed, especially as a result of the feeding action of fish upon the bait. In order to ascertain the increase in catch rate due to the presence of the bait, comparison with unbaited trap catches would be worthwhile. Lower catch rates can be expected for extended soaks due to the depletion of the bait and the consequent lower rates of ingress. Hence, if baited traps are to be set for extended periods, it is important that sufficient bait be set to maintain high rates of ingress until the trap is hauled.Individual trap designs have been shown to have characteristic ingress and egress parameters which are highly correlated and can to a large extent be related to the shape of the entrance funnels and trap volume. Given a number of fish around any trap, ingress is measured in terms of the probability of a fish entering in a given interval of time. During the estimated ten minutes which a fish, on average, spends around a trap the probability of entrance was found to average 0.38 for 'O' traps, 0.50 for 'S' traps, and 0.25 for 'Z' traps. The average hourly escape probability for fish varied between 0.14 for 'Z' traps up to 0.57 for 'S' traps, and was 0.49 for 'O' traps. Although no trap design offered a better overall design, in general, 'O' and 'S' type traps with straight entrance funnels capture fish more quickly and should be hauled after short soaks. Traps with smaller horseneck funnels build up catches at slower rates, but possibly to higher levels, principally due to reduced escapement, and seen as being better suited to extended soaks. For single entrance traps, the alignment of the entrance with the prevailing current direction was also found to be important and there appears to be scope for a rotating trap to take advantage of this. The high loss of fish observed from most traps substantially reduces the potential catch. Large increases in the catching power of traps could possibly be obtained by modifying the entrance funnels to minimise escapement whilst not impending ingress. Munro (1983) and Hull (1981) report the testing of effective non–return gate devices fitted to the entrance tunnels, but with various degrees of success. Continued work on this subject is certainly called for, since catch rates, particularly over long soak periods, would be greatly improved if escapement could be significantly reduced.

Whilst factors such as trap design (including funnel design) and soak time must be included to ensure the best catch rates, optimal fishing strategies must also include other fishing practices if the economic return from trap fisheries is to be optimised. It is now accepted that traps can be quite selective in terms of the fish species which are captured and the interactions between depth, soak time, design, and mesh size may significantly affect the values of trap catches as much as design alone will affect overall catch rates. For example, high catch rates alone will not provide the best economic return if the trap is filled with low–valued species. Optimal management decisions should thus consider the effects of different trap fishing strategies and the likely effects on catch composition.

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Appendix A: Video catch statistics

Experimental Trials 1

Month ; May

Trap–type ; 'O'

Bait type ; Muley

Location ; Offshore

Number of trials = 32

Total soak time = 3870 minutes

Total video time = 3328 minutes

Total time fish observed around trap = 2436 minutes (73 % of video time)

Total time fish observed within trap = 2320 minutes (69 % of video time)

<table>
<tr><th>Species</th><th>Mean Catch Weight</th><th>Number Caught</th><th>Total Ingress</th><th>Total Egress</th><th>Max. in Trap</th><th>Max. in Pool</th></tr>
<tr><td>Lethrinids</td><td>4.42</td><td>213</td><td>573</td><td>360</td><td>60</td><td>23</td></tr>
<tr><td>Lutjanids.</td><td>0.62</td><td>9</td><td>12</td><td>5</td><td>3</td><td>10</td></tr>
<tr><td>Serranids.</td><td>0.53</td><td>10</td><td>19</td><td>7</td><td>3</td><td>4</td></tr>
<tr><td>Other Commercial</td><td>0.48</td><td>15</td><td rowspan="2">63</td><td rowspan="2">15</td><td rowspan="2">7</td><td rowspan="2">3</td></tr>
<tr><td>Non Commercial</td><td>1.08</td><td>43</td></tr>
<tr><td>Totals</td><td>7.13 kg</td><td>290</td><td>667</td><td>387</td><td></td><td></td></tr>
</table>

One Hour Catch Statistics

Sampled catch = 9.9 ± 1.46 kg

Number of trials = 47

Observed mean ingress =19.0 fish

Observed mean egress = 7.2 fish

Percentage loss of fish = 37 %

Expected catch = 10.1 ± 2.4 kg

Two Hour Catch Statistics

Sampled catch =13.2±1.42 kg

Number of trials = 34

Observed mean ingress = 28.6 fish

Observed mean egress = 17.1 fish

Percentage loss of fish = 59 %

Expected catch = 10.0 ±2.2 kg

Experimental Trials 2

Month ; May

Trap–type ; 'O'

Bait type ; Muley

Location ; Inshore

Number of trials = 8

Total soak time = 1161 minutes

Total video time = 804 minutes

Total time fish observed around trap = 506 minutes (62 % of video time)

Total time fish observed within trap = 554 minutes (68 % of video time)

<table>
<tr><th>Species</th><th>Mean Catch Weight</th><th>Number Caught</th><th>Total Ingress</th><th>Total Egress</th><th>Max. in Trap</th><th>Max. in Pool</th></tr>
<tr><td>Lethrinids.</td><td>1.55</td><td>25</td><td>45</td><td>11</td><td>26</td><td>13</td></tr>
<tr><td>Lutjanids.</td><td>0.</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td></tr>
<tr><td>Serranids.</td><td>0.44</td><td>1</td><td>1</td><td>0</td><td>1</td><td>2</td></tr>
<tr><td>Other Commercial</td><td>0.51</td><td>5</td><td rowspan="2">> 6</td><td rowspan="2">1</td><td rowspan="2">3</td><td rowspan="2">3</td></tr>
<tr><td>Non Commercial</td><td>0.55</td><td>8</td></tr>
<tr><td>Totals</td><td>3.05 kg</td><td>39</td><td>52</td><td>12</td><td></td><td></td></tr>
</table>

One Hour Catch Statistics

Sampled catch = – kg

Number of trials = 5

Observed mean ingress = 4.2 fish

Observed mean egress = 0.7 fish

Percentage loss of fish = 17 %

Expected catch = 2.8 ± 1.4 kg

Two Hour Catch Statistics

Sampled catch = 3.1 kg

Number of trials = 3

Observed mean ingress = 7.3 fish

Observed mean egress = 1.9 fish

Percentage loss of fish = 25 %

Expected catch = 4.7 ±3.0 kg

Experimental Trials 3

Month ; August

Trap–type ; 'O'

Bait type ; Muley

Location ; Offshore

Number of trials = 13

Total soak time = 1658 minutes

Total video time = 1658 minutes

Total time fish observed around trap = 1216 minutes (73 % of video time)

Total time fish observed within trap = 1114 minutes (697 % of video time)

<table>
<tr><th>Species</th><th>Mean Catch Weight</th><th>Number Caught</th><th>Total Ingress</th><th>Total Egress</th><th>Max. in Trap</th><th>Max. in Pool</th></tr>
<tr><td>Lethrinids.</td><td>1.82</td><td>42</td><td>136</td><td>87</td><td>36</td><td>13</td></tr>
<tr><td>Lutjanids.</td><td>0.39</td><td>3</td><td>4</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Serranids.</td><td>2.06</td><td>8</td><td>15</td><td>9</td><td>4</td><td>11</td></tr>
<tr><td>Other Commercial</td><td>0.35</td><td>3</td><td rowspan="2">24</td><td rowspan="2">14</td><td rowspan="2">7</td><td rowspan="2">4</td></tr>
<tr><td>Non Commercial</td><td>0.35</td><td>12</td></tr>
<tr><td>Totals</td><td>4.97 kg</td><td>68</td><td>179</td><td>111</td><td></td><td></td></tr>
</table>

One Hour Catch Statistics

Sampled catch = – kg

Number of trials = 13

Observed mean ingress = 8.3 fish

Observed mean egress = 3.6 fish

Percentage loss of fish = 43 %

Expected catch = 4.3 $\pm$1.4 kg

Two Hour Catch Statistics

Sampled catch = 5.0 kg

Number of trials = 12

Observed mean ingress = 14.3 fish

Observed mean egress = 8.5 fish

Percentage loss of fish = 56 %

Expected catch = 6.4 $\pm$1.8 kg

Experimental Trials 4

Month ; May

Trap–type ; 'R'

Bait type ; Muley

Location ; Offshore

Number of trials = 11

Total soak time = 1405 minutes

Total video time = 1405 minutes

Total time fish observed around trap = 944 minutes (67 % of video time)

Total time fish observed within trap = 710 minutes (51 % of video time)

Species	Mean Catch Weight	Number Caught	Total Ingress	Total Egress	Max. in Trap	Max. in Pool
Lethrinids.	2.91	20	40	20	29	12
Lutjanids.	2.33	7	8	1	5	2
Serranids	0.12	1	12	11	3	2
Other Commercial	1.09	6	> 20	3	4	4
Non Commercial	0.38	11				
Totals	6.73 kg	45	80	35		

One Hour Catch Statistics

Sampled catch = – kg

Number of trials = 11

Observed mean ingress = 3.9 fish

Observed mean egress = 0.8 fish

Percentage loss of fish = 20 %

Expected catch = 3.7 ± 1.9 kg

Two Hour Catch Statistics

Sampled catch = 6.7 ± 1.75 kg

Number of trials = 8

Observed mean ingress = 5.2 fish

Observed mean egress = 1.7 fish

Percentage loss of fish = 56 %

Expected catch = 3.6 ±1.5 kg

Experimental Trials 5

Month ; August

Trap–type ; 'S'

Bait type ; Muley

Location ; Offshore

Number of trials = 15

Total soak time = 1892 minutes

Total video time = 1892 minutes

Total time fish observed around trap = 1074 minutes (56 % of video time)

Total time fish observed within trap = 1276 minutes (67 % of video time)

Species	Mean Catch Weight	Number Caught	Total Ingress	Total Egress	Max. in Trap	Max. in Pool
Lethrinids.	2.39	29	97	68	15	4
Lutjanids.	0.91	6	9	3	2	4
Serranids.	1.29	8	26	18	13	4
Other Commercial	1.14	10	18	4	10	2
Non Commercial	0.24	4				
Totals	5.97 kg	57	150	93		

One Hour Catch Statistics

Sampled catch = – kg

Number of trials = 15

Observed mean ingress = 5.6 fish

Observed mean egress = 2.1 fish

Percentage loss of fish = 34 %

Expected catch = 4.1 ± 1.3 kg

Two Hour Catch Statistics

Sampled catch = 6.0 ±1.6 kg

Number of trials = 11

Observed mean ingress = 11.8 fish

Observed mean egress = 7.1 fish

Percentage loss of fish = 54 %

Expected catch = 6.2 ±2.2 kg

Experimental Trials 6

Month ; August

Trap–type ; 'Z'

Bait type ; Muley

Location ; Offshore

Number of trials = 9

Total soak time = 1101 minutes

Total video time = 1096 minutes

Total time fish observed around trap = 636 minutes (58 % of video time)

Total time fish observed within trap = 658 minutes (60 % of video time)

Species	Mean Catch Weight	Number Caught	Total Ingress	Total Egress	Max. in Trap	Max. in Pool
Lethrinids.	2.96	30	42	12	28	8
Lutjanids.	0.	0	0	0	0	0
Serranids.	0.	0	0	0	0	1
Other Commercial	1.26	10	22	3	3	3
Non Commercial	0.56	9				
Totals	4.78 kg	49	64	15		

One Hour Catch Statistics

Sampled catch = – kg

Number of trials = 9

Observed mean ingress = 3.4 fish

Observed mean egress = 0.7 fish

Percentage loss of fish = 18 %

Expected catch = 2.3 ±1.3 kg

Two Hour Catch Statistics

Sampled catch = 4.8 ±2.1 kg

Number of trials = 9

Observed mean ingress = 5.5 fish

Observed mean egress = 1.1 fish

Percentage loss of fish = 18 %

Expected catch = 3.6± 2.1 kg

Experimental Trials 7

Month ; August
Trap–type ; 'O'
Bait type ; Trash fish
Location ; Offshore

Number of trials = 11
Total soak time = 1442 minutes
Total video time = 1442 minutes
Total time fish observed around trap = 322 minutes (22 % of video time)
Total time fish observed within trap = 458 minutes (31 % of video time)

<table>
<tr><th>Species</th><th>Mean Catch Weight</th><th>Number Caught</th><th>Total Ingress</th><th>Total Egress</th><th>Max. in Trap</th><th>Max. in Pool</th></tr>
<tr><td>Lethrinids .</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td></tr>
<tr><td>Lutjanids</td><td>0.68</td><td>3</td><td>3</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>Serranids.</td><td>0</td><td>0</td><td>3</td><td>3</td><td>1</td><td>1</td></tr>
<tr><td>Other Commercial</td><td>0</td><td>0</td><td rowspan="2">>11</td><td rowspan="2">4</td><td rowspan="2">4</td><td rowspan="2">2</td></tr>
<tr><td>Non Commercial</td><td>0.42</td><td>7</td></tr>
<tr><td>Totals</td><td>1.10 kg</td><td>10</td><td>17</td><td>7</td><td></td><td></td></tr>
</table>

One Hour Catch Statistics

Sampled catch= – kg
Number of trials= 11
Observed mean ingress = 0.87 fish
Observed mean egress = 0.07 fish
Percentage loss of fish = 11 %
Expected catch = 1.1±0.6 kg

Two Hour Catch Statistics

Sampled catch = 1.1 ± 0.68 kg
Number of trials = 11
Observed mean ingress = 1.6 fish
Observed mean egress = 0.7 fish
Percentage loss of fish = 40 %
Expected catch = 1.2 ±0.6 kg

Appendix B. Correlation matrices

ARRIVAL PARAMETERS : MAY— 'O' TRAPS

PARAM	EST	STD.ERR	CORRELATION MATRIX					
δ	0.89	0.008	1.0					
k1	371.	49.	.77	1.0				
k2	89.	0.010	.32	.52	1.0			
k3	24.	0.027	.53	.57	.34	1.0		
P	0.67	0.022	.02	.39	.44	.45	1.0	
N	201	55.	.02	-.30	-.26	-.10	-.27	1.0

Degrees of Freedom=1649

ARRIVAL PARAMETERS : AUGUST—ALL TRAPS

PARAM	EST	STD.ERR	CORRELATION MATRIX					
δ	0.89	0.011	1.0					
k1	447	56.	.71	1.0				
k2	0.89	0.012	.10	.54	1.0			
k3	0.34	0.037	.60	.47	.05	1.0		
P	0.76	0.022	-.48	-.30	-.08	.13	1.0	
N	42	5.0	.03	–.27	–.18	-.17	–.24	1.0

Degrees of Freedom=2966

E7 Comparison of some trap–fishing strategies

The understanding of the processes involved with the capture of fish by baited traps gained in the course of this study can be used to examine the consequences of some simple differences in trap fishing strategy. Important elements of the fishing strategy are the choice of trap type, bait type and soak time. The selection of these will determine the number of traps that can be worked from a vessel, the number of times per day each trap is pulled, the daily catch, and will influence the value of the catch landed on the deck (i.e. the value of catch minus cost of bait). To examine these effects a simple model of the fishing and capture processes was developed.

Fish capture model

This was based on the 'S' and 'Z' trap parameter estimates for May 1988. The models and their parameter values are based on those described in Section 6, and all processes were treated as operating on a two minute time interval. Fish were considered to gather around the trap, from which they could enter the trap. The pool size was treated as being trap independent, but influenced by bait type and the presence/absence of bait. pilchard bait was considered to last for 3 h, and chopped fish bait for 24 h. The pool size for pilchard bait was three fish for soak times less than or equal to 3 h, and 0.3 for longer soak times. The pool size for chopped fish bait was 0.4 for soak times less than or equal to 24 h, and 0.3 for longer soak times. While any bait was in the trap the probability of entry to the 'S' trap was 0.131 and to the 'Z' trap was 0.056. When the bait was exhausted the entry probabilities reduced to a tenth of their baited levels. The probability of exit was 0.028 for the 'S' trap and 0.005 for the 'Z' trap.

The number of fish in the trap at time T+t was determined from the recursive relationship

$$C_{T+t} = p_e P_T + C_T (1 - p_l)$$

where C_T is the number in the trap at time T ($C_T = 0$ for T=0), P_T is the pool size at time T, p_e is the probability of a fish entering the trap, and p_l is the probability of a fish leaving the trap.

Fishing model

This is essentially a time budget for the fishing operation, and is used to determine the number of traps that could be worked and the number of trap–sets per day that is possible for a chosen soak time.

There are assumed to be 12 h available for fishing per day, and traps cannot be set or pulled in the other 12 h. The time to haul a trap, store the catch, and reset the trap (t_h) is taken to be on average 10 minutes and independent of the number of fish caught. The independence assumption is probably reasonable because usually the catch is simply stored in refrigerated sea water (RSW) until the end of the day and processed in non–fishing time.

In a day $12/t_h$ trap lifts are possible. For soak times (τ) of up to $12-t_h$ h the number of sets per trap that are possible per day is $int[12/(\tau+t_h)]$, where int gives the truncated integer value. So for soak times up to $12-t_h$ h the number of traps that can be operated is $int[(\tau+t_h)/t_h]$. Soak times between $12-t_h$ h and $24-t_h$ h are not possible. Operations extending over more than 24 h usually require a complex mixture of different soak times, and so soak times are not easily compared by the daily catches. However fishing operations that use only soak times of exactly 24 h, 48 h, 72 h etc are possible, and these are used to examine the effects of long soak times.

An index of revenue from the catch was obtained from the sale value of total catch per day minus the cost of bait used to obtain that catch. No attempt was made to account for fuel, labor, capital, or opportunity costs, and so the index relates to one aspect of the daily on–board catching operation only. The revenue index is calculated assuming that 1/3 of caught fish are retained (about 2/3 of the fish caught are *Lethrinus choerhynchus* which are not retained), a value of $7 per retained fish, a bait cost of $6.40 per set for pilchards and a zero bait cost for fish.

Results

The predicted catch of a trap for various soak times is given in Table 1. The predicted catches are in reasonable agreement with the observed catches, indicating that the highly simplified model is acceptable. The effect of pilchard bait in providing a large catch for short soak times with either trap is clearly illustrated, and the superiority of the 'Z' trap for long soak times is clear.

The predicted number of traps operated, number of sets per trap per day, daily catch and daily value index are given in Table 2. Short trap–sets with pilchard bait gave the highest catch and highest value index per day. Both 'S' and 'Z' traps with pilchard bait gave daily catches of 650–700 fish and a value index of about 1200. 'S' traps gave good returns for trap–sets of 1–3 h whereas 'Z' traps gave good returns for trap–sets of 2–5 h. Fish bait in 'S' traps gave very poor returns (at most a daily catch of about 100 fish and a value index of about 200), but fish bait in 'Z' traps gave moderate results for trap–sets of 9–11 h (daily catches of about 200 fish and a value index of about 500). Very long soak times (i.e. 1–3 days) gave very poor results, primarily because the bait is mostly gone from traps after about 24 h on the North West Shelf.

The fishing strategy adopted by trap fishermen on the North West Shelf is very different from that commonly used in trap fisheries elsewhere, but on the North West Shelf at least this strategy gives a higher daily catch and catch value index than the strategies used elsewhere.

Table 1. The predicted catch per trap (numbers of fish) of trap–bait type combinations for different soak times.

	'S' trap		'Z' trap	
Time (h)	Pilchard	Fish	Pilchard	Fish
1.0	8.05	1.07	4.69	0.63
2.0	11.48	1.53	8.73	1.16
3.0	12.95	1.73	12.20	1.63
4.0	5.60	1.81	10.54	2.03
5.0	2.47	1.84	9.12	2.37
6.0	1.13	1.86	7.89	2.66
7.0	.56	1.87	6.84	2.92
8.0	.32	1.87	5.93	3.13
9.0	.22	1.87	5.15	3.32
10.0	.17	1.87	4.48	3.48
11.0	.15	1.87	3.90	3.62
12.0	.15	1.87	3.40	3.74
13.0	.14	1.87	2.97	3.85
14.0	.14	1.87	2.61	3.93
15.0	.14	1.87	2.29	4.01
16.0	.14	1.87	2.02	4.08
17.0	.14	1.87	1.78	4.13
18.0	.14	1.87	1.58	4.18
19.0	.14	1.87	1.41	4.22
20.0	.14	1.87	1.26	4.26
21.0	.14	1.87	1.13	4.29
22.0	.14	1.87	1.02	4.32
23.0	.14	1.87	.92	4.34
24.0	.14	1.87	.84	4.36
26.0	.14	0.46	.71	3.31
28.0	.14	.20	.61	2.54
30.0	.14	.15	.54	1.97
32.0	.14	.14	.49	1.54
34.0	.14	.14	.45	1.23
36.0	.14	.14	.42	1.00
38.0	.14	.14	.40	.83
40.0	.14	.14	.38	.70
44.0	.14	.14	.36	.53
48.0	.14	.14	.35	.44

Table 2. The consequences to daily catch and an index of daily revenue of the selection of different trap/bait type combinations and trap soak time (τ in hours). For each trap and bait type in the table, 1=the number of traps that can be operated, 2= the number of sets per operated trap per 24 h day (traps can only be operated during 12 h of daylight), 3= total catch per 24 h day (numbers of fish) 4= index of daily revenue (value of catch – cost of bait). The revenue index is calculated assuming that 1/3 of caught fish are retained, a value of $7 per retained fish, a bait cost of $6.40 per set for pilchards and a zero bait cost for fish.

Trap type	'S' Pilchard				'S' Fish				'Z' Pilchard				'Z' Fish			
τ	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1.	6	10.	483.	742.	6	10.	64.	150.	6	10.	281.	272.	6	10.	38.	87.
2.	12	5.	689.	1222.	12	5.	92.	214.	12	5.	524.	837.	12	5.	70.	163.
3.	18	3.	699.	1284.	18	3.	93.	217.	18	3.	659.	1190.	18	3.	88.	205.
4.	24	2.	269.	320.	24	2.	87.	202.	24	2.	506.	872.	24	2.	97.	227.
5.	30	2.	148.	–38.	30	2.	111.	258.	30	2.	547.	891.	30	2.	142.	331.
6.	36	1.	41.	–135.	36	1.	67.	156.	36	1.	284.	432.	36	1.	96.	223.
7.	42	1.	24.	–214.	42	1.	78.	183.	42	1.	287.	401.	42	1.	122.	286.
8.	48	1.	15.	–271.	48	1.	90.	209.	48	1.	285.	356.	48	1.	150.	351.
9.	53	1.	12.	–312.	53	1.	99.	231.	53	1.	273.	297.	53	1.	176.	410.
10.	59	1.	10.	–354.	59	1.	110.	257.	59	1.	264.	238.	59	1.	206.	479.
11.	65	1.	10.	–393.	65	1.	122.	284.	61	1.	253.	175.	65	1.	236.	549.
24.	70	.5	5.	–213.	70	.5	65.	153.	70	.5	29.	–155.	70	.5	153.	356.
48.	70	.3	3.	–142.	70	.3	3.	8.	70	.3	8.	–130.	70	.3	10.	24.
72.	70	.25	2.	–106.	70	.25	2.	6.	70	.25	6.	–98.	70	.25	6.	14.

E8 Video; Trap fishing on the North West Shelf

A 15 minute audio/visual presentation (video tape) was prepared that highlights the results of this trapping study.

The video shows how the study was carried out, including deployment of the traps, baiting procedures, catch processing, and overall fishing practices. It also dramatically shows the activities of the fish at the trap site. The fish are shown entering and leaving the traps, feeding on the bait, interactions between fish (e.g. larger predatory fish such as cods feeding on smaller prey species), the effects of current direction in relation to the trap entrance, and fish reactions to the trap and the bait once they have been attracted by the bait 'plume'.

The video explains the results obtained by the study using a variety of graphs, figures, slides, sequences of fish behaviour and verbal explanations.

One copy of the video is held by the FIRDC and a copy is available for borrowing from the CSIRO Marine Laboratories library.

The mailing address for loan of the video is: Librarian, CSIRO Marine Laboratories, GPO Box 1538 Hobart, Tas 7001. The video can be personally collected from CSIRO Marine Laboratories, Castray Esplanade, Hobart.

F Details of Grant Application

Fishing Industry Research Trust Account
Application For Grant
1987/88

1/ Title of proposal
Development of more efficient traps for the North West Shelf fishery

2/ Name of applicant
CSIRO

3/ Division
Fisheries research

4/ Proposal
To observe and analyse fish behaviour to various trap types, baits and techniques. From the results design and or modify traps to optimise catch rates.

5/ Name of person responsible for program
Dr. F. R. Harden Jones, Chief of Division
Division of Fisheries Research,
GPO Box 1538,
Hobart, Tasmania, 7001
Phone (002) 206222

6/ Qualifications of staff to be employed on the program

K. J.Sainsbury, SRS (leader)	5%
G. J.Dews, Experimental Scientist, Dip. Sc., Grad.Dip.Fish.Tech.	100%
A. W.Whitelaw, Experimental Scientist, B.App.Sc., B.Sc.	10%

7/ Objectives
a) in situ observations of fish behaviour to various fish trap designs using underwater cameras.

b) Compare the catching performance of various fish trap designs.

c) To use the above observations to improve the design of fish traps and techniques for trapping fish on the N.W. shelf of Western Australia.

8/ Justification

The NW Shelf trap fishery is a fledgling industry that is presently harvesting 2–300 tonnes of prime fish for the Australian market, but there is considerable potential for this to increase (Sainsbury 1987).

The NW Shelf trap fishery is an extension of the Shark Bay fishery and began in the 1980's using 'O' shaped traps and targeting on Lethrinids, Lutjanids and Serranids.

At present the trap fishermen of the NW Shelf are attempting to maximise gear efficiency by trial and error modifications to gear and fishing strategies. Initial observations of fish traps by Dews et al. (1987) using underwater cameras, showed that 'O' and rectangular shaped traps have many disadvantages. Results show that fish can enter and exit freely. Catch rates could be improved by design changes and increased understanding of fish responses to bait, current and trap soak time.

At present, the fishery uses 'O' shaped traps which Wolf and Chislett (1974) have shown are less efficient that 'Z', 'S' and Chevron types. Rectangular traps are used successfully by the Sable fishery (High 1971) in the United States, some sections of the NSW trap fishery and preliminary trials in Tasmanian waters (Bulman and Dews, in prep).

For efficient use of the resource and economic expansion of the trap fishery in the North West Shelf it is essential that research be carried out to determine the factors important in affecting the performance of traps in this region. This information be made available to the industry for managing this and other potential trap fisheries such as in the Gulf of Carpentaria and the Torres strait.

9/ Location of operation

The research scientist and experimental scientists will be based at the CSIRO Marine laboratories in Hobart.

10/ Proposal in detail

A/ Two fact finding cruises will be undertaken by G. Dews (fisheries technologist) on the East and West coast trap fisheries where he will accompany professional trap fishermen from Coffs Harbour (QLD) and Onslow (W.A.) to study the gear, technology and methodology currently being used.

B/ Following this, conventional traps will be constructed, following proven designs (e.g.. U.S. National marine fisheries service rectangular, Korean conical and N.S.W. shallow water traps). A vessel will be chartered for two weeks in October 1987 from Onslow.

The object of this cruise will be to:

1/ Use underwater video system, as described by Dews et. al (in prep), to observe;

a) Fish reaction to trap types by species

b) Time of attraction to the fish trap

c) Time of first entry of various species to conventional trap types (e.g. 'O', 'Z' and 'D').

d) Optimum soak time to maximise catch.

e) Effects of a small number of different bait types

f) Interspecific reactions

g) Escapement from the conventional trap types

h) Effects of currents and trap entrance positioning

2/ Comparisons of catch from different trap types.
The traps will be fished using different designs combined into a string and setting several strings in close proximity. The experiments will be carried out at a small number of representative locations and will examine a variety of trap designs, baits and soak times. Environmental information collected will include depth, bottom type, current direction and turbidity. Biological information obtained will include total weight of catches by species and individuals.

Data collected from the first cruise and the information gained by observations of the East and West coast commercial trap fishermen will be used to, modify and improve trap designs. Special emphasis is expected to be placed on prevention of fish escapement from traps. These new designs would then be evaluated on the second charter cruise from Onslow in March 1988 using the same experimental methodology as on the first cruise.

C/ The findings of the research will be prepared for publication, both in Scientific journals and Australian fisheries.

11/ Proposed commencement date and anticipated completion date

1 July 1987 – 30 June 1988 – work described as A/ and B/ in section 10

1 July 1988 – 31 Dec 1988 – work described as C/ in section 10

A subsequent application may be made for further development and resource exploration in 1988 – 89.

12/ Funds requested

	1987–88	1988–89
	$	$
Salaries, wages, allowances	44 455	22 562
Operating expenses	49 000	2 000
Travel	10 900	
TOTAL	104 355	24 562

13/ Funds to be provided by applicant

	1987–88
Salaries of CSIRO staff	7 114
Salaries of supporting staff on charter vessel	2 400
Underwater camera	36 000
Personal computer and software	8 000
	53 514

14/ Co-operating agencies
West Australian Department of Fisheries.

15/ Similar work in Australia
No similar work is being undertaken.

16/ Plans for reporting and publishing results
The results will be available for publication in Australian Fisheries and recognised scientific and technical publications.

17/ References

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Details of funds requested

	1987–88	1988–89
Salaries and wages and allowances;		
Experimental scientist (ES 2)		
salary	31 166	15 583
superannuation	6 389	3 194
leave loading	400	200
accrued leave on cessation		3 585
Marine survey allowance ($450/week)		
10 weeks * $450	6,500	–
total salaries	44 455	22 562
Operating expenses;		
1. Vessel charter		
Charter trap vessel for 2 weeks *2	28 000	–
Fuel for charter vessel	6 389	–
2. Other operating expenses		
Freight of equipment and samples	1 500	–
Hire and installation of DECCA equipment	1 200	–
Underwater video cameras	6 000	–
Computer charges (CSIRONET)	–	1 000
Materials for trap construction	2 400	–
Strobes, bouys, fittings etc for traps	900	–
Total operating expenses	49 000	2 000
Travel and appointment expenses		
Appointment expenses	5,000	–
Air Fares		
Hobart – Coffs Harbour	500	–
Hobart – Dampier * 5	4,500	–
Travel allowance ($75 / day)		
75 * 12	900	–
Freight of equipment and samples	1,500	–
Hire and installation of DECCA navigation system	1,200	–
Total Travel & appointments	10 900	–
Gross Total Cost	**104 355**	**24 562***

*** Note**

Additional funds were requested and received in 1988–89 for the production of a 15–20 minute publicity videotape that presents the results of the study. The total of these additional funds approved was $2,800.

G Appendixes

G1 Video and underwater housing specifications

Video camera system

The camera system consisted of a SONY CCD–V30E (VIDEO 8) domestic video camera. The camera, within it's housing, was positioned approximately 1.7 m above the trap by attaching it to an aluminium pole which was bolted to the side of the trap. The pole and camera were stabilised by two restraining wires attached from the top of the pole to the top of the trap. During operations, the camera was used in its 'long Play' mode which allowed continuous recording for 180 minutes. While there is some degradation in quality while in this mode, the advantages of recording longer traps sets was considered a higher priority.

In its normal configuration the camera draws approximately seven watts which means that the existing batteries would only power the camera in 'record' mode for approximately 40 minutes. Extra battery packs consisting of six 4000 mAhr ni–cad batteries were constructed to allow the camera to record for up to 3 h. The battery packs had quick release four pin captive connectors to allow the quick exchange of recorded video tapes and used batteries for new video tapes and recharged batteries, so enabling the quick re–deployment of the camera. The batteries were soldered together and encased in 57 mm heat–shrink tubing.

Spare packs of 'Energiser' cells were constructed for use if the ni–cad packs could not be recharged, these packs could operate for up to 12 h of recording. These backup packs were in case the cameras were used in areas where no 240 volt power supply was available to power the nicad battery pack chargers. Inserting the Sony handycam batteries in their normal receptacle on the side of the camera, as well as the constructed battery pack, would extend battery life.

The camera was modified to allow the external battery pack to be connected via a cable soldered to the battery pack. Turning the camera on and off was accomplished, rather than by a mechanical lever to actually press the record button, instead by a magnetic switch which was imbedded in the front perspex panel. The switch was located in the front to allow the rear removable cover to be completely removed without having cables attached to it. The camera is switched to RECORD or OFF by a magnet passing over this magnetic switch . A magnet was imbedded in a plastic lever on the outside of the camera housing with its pivot point positioned so that the magnet would pass over the magnetic reed switch when required. This allows the camera to be set up and positioned on the fish trap and externally put in record mode as the trap is being deployed.

The red tally LED on the cameras view finder or the text displayed on the viewfinder's screen confirmed that the camera was recording. The cabling from this switch formed a loom with the cabling from the battery connector and was connected via a three pin captive connector. A schematic diagram and details of the modifications are attached.

Battery chargers

Two nicad battery chargers were constructed, with one being mains powered and able to charge up to four battery packs simultaneously while the other charger was powered off 12v D.C. and charged two packs simultaneously. The second one was built as an alternative should there be any problem with the main charger. The 12v D.C. supply could be obtained from any car battery which would allow charging if mains power was not available. The 12v charger used a '12 volt D.C. panther Power Supply' which is available off the shelf from any 'Dick Smith Electronics Store', although any domestic car battery charger would probably work satisfactorily.

Underwater housing for Sony Handycam and external battery pack

The underwater housing was constructed from 13 mm thick anodised aluminium tubing. The rear of the housing was threaded onto an aluminium back plate which had a perspex centre which butted (with one 'O' ring) to the back of the remainder of the housing. The perspex front of the housing was screwed to the remainder of the housing, also with an 'O' ring in situ.

A dome port (essential when using a wide angle lens) was positioned (glued) to the perspex front cover, over the centre of the camera lens. On each side of this dome port were screwed two stainless steel 'guards' to protect the dome from damage (essential).

The camera was held to the inside of the housing via a track system (adopted from yacht fittings), which should ideally be internally attached to the housing with either short screws, which do not penetrate the housing, or some form of strong adhesive. This then enables the camera to be slid in and out of the housing as required for film and battery changes.

The major principle of this housing was to have no source of leaks within the system, consequently there are no holes within the housing, with the only access to the camera being via the back plate – the on / off switch is magnetic and all the remainder of the controls are sealed inside the housing. No controls are needed when using a wide angle lens as the camera is set on auto light control and does not need focusing. The zoom control cannot be used externally while inside the housing, our survey work did not require it.

The dimensions of the housing can be adapted to suit the size of camera to be deployed. Our dimensions were 35 cm long with a 23 cm diameter (external measurements). The overall weight of the housing was approximately 5 kg (without camera) and has positive buoyancy, but once the camera and external battery pack are in place, it is fairly neutrally buoyant and therefore quite easy to handle underwater.

Although our housing is made of aluminium, there is no reason, assuming its not going to be abused too much or used too deep, for the housing not to be made of PVC e.g. sewer pipe (which have screwed end caps etc already fitted).

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