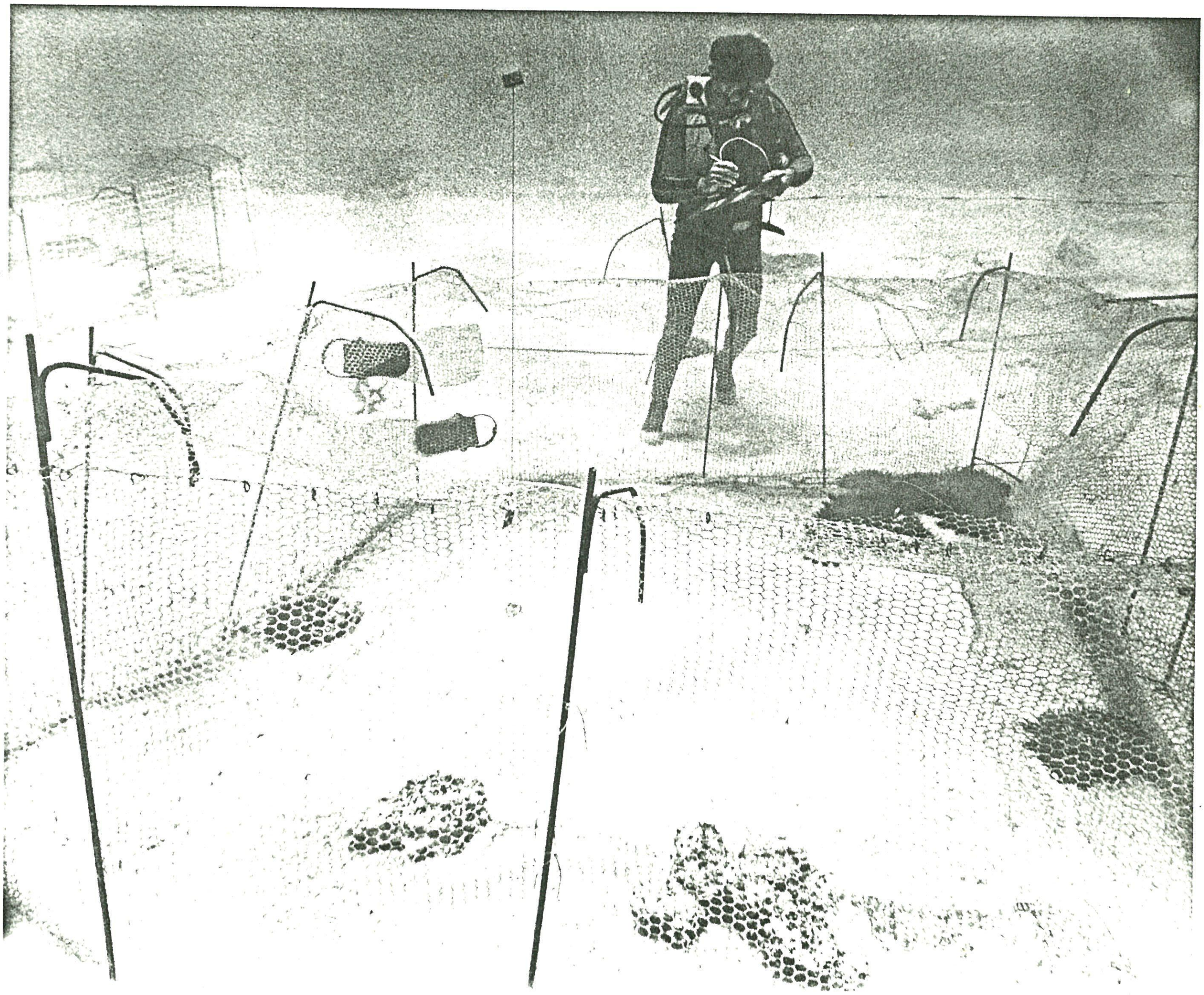
AN EVALUATION OF THE EFFECTIVENESS OF ARTIFICIAL BARRIERS IN MESO-SCALE CROWN-OF-THORNS MANAGEMENT AT JOHN BREWER REEF.

REPORT TO THE GBRMPA
OCTOBER. 1986.



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Photograph by L. Zann

ABSTRACT

Several workers have recently concluded that manual eradication programs for controlling *Acanthaster planci* populations have been largely ineffective (Yamaguchi, 1986, Moran, in press, Zann, pers. comm.). It has been shown that migration of starfish into controlled areas contributes significantly to the poor success of control programs (Kettle and DeVantier, unpub. rep. to GBRMPA). The need to preserve small areas of live coral for tourism and scientific purposes prompted investigation into the use of fences as artificial barriers to limit starfish movement. Trials of thirteen enclosures were conducted recently in the lagoonal area of John Brewer Reef (central section, Great Barrier Reef). These were constructed from 10 commercially available fencing and netting materials and utilized several different designs. Starfish placed within these enclosures were monitored hourly, over a continuous period of 4½ days. Starfish activity, escape rates and escape strategies were recorded, resulting in more than 10000 starfish observations. A rigid steel mesh enclosure (mesh size 1cm x 1cm), 1 metre in height and having a 60cm down-curved overhang was highly effective at retaining starfish. By contrast, flexible fishing net materials without an overhang had high starfish escape rates. Fouling and degradation rates of the various materials are being monitored for six months. The results suggest that artificial barriers are useful for limiting starfish movement.

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INTRODUCTION

Recent evaluations have concluded that both overseas and local *Acanthaster planci* control programs have been generally unsuccessful. Yamaguchi (1986) reported that despite intensive removal of some 13 million starfish from reefs around the Ryukyus Island (Japan) at a cost of 600 million yen, the programs were ineffective in preventing the destruction of considerable areas of coral. Similarly, attempts to protect a small coral viewing area at Green Island (GBR) Australia were unsuccessful, even though a diver was permanently stationed in the area to remove starfish (Moran, in press). Over 2 years 44000 starfish were removed from this area yet this failed to prevent considerable coral damage in the area. More recently large numbers of starfish (c. 2500) were destroyed on Grub Reef (Central GBR) by injection of lethal doses of copper sulphate. However long term control of starfish using this method was deemed to be unreasonable (Zann, pers. comm., Kettle, unpub. report to GBRMPA).

Assessments of these control programs have all reiterated similar problems which reduce the efficiency and feasibility of starfish control. Yamaguchi (1986) attributed the ineffectiveness of control programs in the Ryukyus Is. to two main reasons; a) only starfish which could be collected quickly from shallow water were killed, leaving behind large numbers and b) for fiscal reasons, programs of control were slow in commencement, which meant outbreaks had been identified for up to a year before control measures were implemented. Moran (in press) states that manual control programs represent only a short term solution to the widespread outbreak of

Acanthaster and their value should be seriously questioned. Moran suggests that population size, the potential for further recruitment, the importance of the area for tourism or other commercial ventures and the availability and timing of funding must be assessed to enhance the efficiency of *Acanthaster* control. Kettle and DeVantier (unpub. report to GBRMPA) highlighted the high migratory potential of *A. planci* as having a large effect on the efficiency of the control program conducted at Grub Rf. They suggested an assessment of population size, distribution and migration may enhance the effectiveness of control programs. The rate of starfish movement, directionality of movement, orientation of the control area with respect to the movement of starfish and the complexity of the topography were judged to have contributed to the inefficiency of controlling starfish numbers on Grub Reef. The solution to these problems may lie in either enhanced or alternative methods for preserving coral areas. Moran (in press), Yamaguchi (1986), Zann (pers. comm.) and Kettle and DeVantier (unpub. report to GBRMPA) have all suggested that smaller scale control of starfish maybe more effective. Artificial barriers to exclude starfish from small areas are by no means a novel strategy, indeed they have been recommended in various reviews of the *Acanthaster* problem. Walsh et. al. (1976) lists electric fences, copper sulphate impregnated tubing (which slowly releases the chemical into the water) and hessian nets as methods suggested for repelling *Acanthaster*. However it appears that these suggestions were deemed unsuitable or never pursued.

Pearson and Endean (1969) enclosed adult *Acanthaster* in a wire netting pen as part of a predation study. Pearson (pers. comm.)

states that very few or no starfish were observed to escape from this enclosure. However, the use of this material to contain starfish on a larger scale was not pursued. Zann (pers. comm.) trialled gill nets to delimit starfish control areas, though with limited success. The use of fences to exclude pest animals from commercially important areas has proved to be successful in several terrestrial applications but this project is the first attempt to assess the effectiveness of fences as barriers to *Acanthaster* movement. If an effective barrier to starfish movement can be found then these fences could be erected around small areas of live coral. Tourist ventures would be able to operate behind the protection of the fences in a similar manner to the way in which many farming properties operate behind the protection of rabbit and dingo fences.

John Brewer Reef has had two major adult *Acanthaster* infestations in the last 6 years (Moran, et. al. 1985). At present a large populatioon of juvenile starfish has been identified on the back reef area (Bell, unpub.), though the reef has a low adult population. Starfish 4cm to 14 cm in diameter, believed to be c.18 months old have been found on the tops of many back reef bommies. Very small starfish (19mm to 30mm diameter) were also found during the course of this experiment in similar habitats. Comparisons with data of juvenile starfish obtained in Fiji (Zann, in press.) suggest that these starfish are about 6 months old and were recruited to the reef this year. These observations also suggest that recruitment of *Acanthaster* has occurred on this reef for the past two years in succession. It is expected that large numbers of adult starfish will become noticeable by early 1987. Subsequently

John Brewer Reef may carry adult starfish for the next three to eight years. A small area of live coral is utilized by the "Reef Link" tourist enterprise for coral viewing. The remaining live coral in this area faces a major threat from large numbers of crown-of-thorns and therefore it was suggested that fences be tested to examine their ability to exclude starfish.

MATERIALS AND METHODS

Trials of the various enclosures were conducted over six days between the 20th and the 26th of September 1986 in the lagoonal area of John Brewer Reef.

A variety of ten materials was used to construct thirteen enclosures. These were designed to retain starfish rather than to preclude them from entering. In this manner a high incidence of encounters was expected as starfish moved about within the confined areas of the enclosures.

Details of the materials and design used for each enclosure are included in Table 1 and Appendix A. Reproductions of the materials can be found in Appendix B. Cages utilizing hard fencing materials (hexagonal chicken wire, Nylex plastic and ARC steel mesh) were each constructed with a skirt extending horizontally from the base (to prevent any escapes beneath the fence) and a down-curved overhang extending from the top of the wall.

Materials were cut to 10m in length and the ends fastened together using a special pair of crimping pliers (GERRARD Fastening Systems) and 18mm steel staples. The ends and edges of the steel mesh and nets were sewn together as required with either fencing tie wire or nylon whipping twine. All prefabricated enclosures were constructed aboard the "REEF LINK" pontoons. To facilitate construction all the enclosures were shaped into squares (2.5m sides) then submerged and guided into place by divers. Extra support was provided by fixing the walls and overhangs to prefabricated, recurved steel pegs hammered into the sand.

Soft materials, including prawn trawling net and gill nets were assembled into enclosures simply as single or double wall barriers with the ends sewn together. They were bouyed and weighted to maintain their erect shape. The double walled prawn net enclosure also incorporated monofilament gill nets attached to the floor of the barrier, between the walls to act as a tangle-net. (See Appendix A).

The site for the enclosures was chosen adjacent to the Reef Link pontoons because;

(i) If the enclosures had been erected on hard, irregular or fenestrated substrates there would have been great difficulty in preventing starfish from crawling beneath the wall. Enclosures were designed to prevent starfish from crawling underneath when constructed on sand substrates. Thus it was possible to test the cages in an environment resembling that for the proposed full scale fences.

(ii) A large expanse of sand, uninterrupted by bommies meant that cages could be set out in close proximity to each other for easier monitoring.

(iii) Close proximity to the pontoon was essential for erecting the cages and afforded a spacious diving platform,

and (iv) the depth of water under the pontoon was shallow enough so that safe diving practices could be followed throughout the exercise. † (see note after acknowledgements)

Enclosures were initially stocked to densities approaching two animals per square metre using adult starfish and juvenile starfish collected on the first day and night of the exercise. This density simulated the crowded conditions of a dense aggregation and ensured that an adequate number of animals encountered the fences. A minimum of cover was provided on the sandy substrate within the cages to provoke high movement rates, thereby maximising the number of encounters during the monitoring period.

Each hour a team of two divers using S.C.U.B.A. assessed changes occurring within each cage. One diver filled out a prepared proforma, while the other assisted by recapturing escapees and measuring their overall diameters. Observations were categorised into four classes to simplify the characterisation of behaviour.

(i) Each starfish was recorded as being either INSIDE (touching neither the skirt nor the wall) or ENCOUNTERING the wall (touching any part of the fence, including the skirt), so that an estimation could be made of the number of starfish that encountered the enclosure.

(ii) MOVING or QUIESCENT states were recorded to detect periods of activity.

(iii) The POSITION of the starfish on the wall (skirt, wall, overhang, lip, between walls was recorded to yield information on the various numbers of starfish retarded by each of the above wall elements.

(iv) To provide information on the relationship between starfish size, escape strategy and mesh size successful encounters were recorded as having climbed OVER the wall, THROUGH the mesh, or, when escapes had to be deduced from starfish found outside of the barrier, as UNKNOWN. Escapees had their diameter measured before being returned to their enclosure.

In addition to these observations the by-catch of each net was noted during every observation period.

Data was subsequently transferred to micro-computer for statistical analyses and graphical representation.

RESULTS

Table 1 defines the designs and materials used for the 13 cages.

Table 2 contains a summary of the 10254 observations made during the experimental period. Summaries for each day are included in

Appendix B. The table includes absolute totals for the number of observations, the number of encounters, the number of active encounters (excluding stationary starfish), the number of witnessed escapes and the number of suspected escapes (as deduced from decreases in the number of starfish in each enclosure). In addition this table contains calculated values for the overall efficiency of each fence at preventing starfish from escaping, the mean time taken to cross the fence per starfish and the number of active attempts that it took.

The overall efficiency of the fences as barriers to movement is defined as the percentage of all potential escapes that were thwarted by the fence.

$$\text{ie. gross efficiency} = 1 - \frac{\text{(total escapes)}}{\text{(total encounters)}} \times 100$$

The mean time taken for a starfish to cross the fence is inversely related to the number of starfish that escaped in a given time period.

$$\text{ie. crossing time} = \frac{\text{(number of starfish)} \times \text{(time in days)}}{\text{(total escapes)}} \text{ days}$$

The number of attempts per successful escape was considered to be equivalent to the number of starfish seen moving on the fence divided by the total number of escapes.

$$\text{ie. attempts / escape} = \frac{\text{(number of ENCOUNTER, MOVING observations)}}{\text{(total escapes)}}$$

Figure 1 graphically represents the gross efficiency for each cage. Values range from 99.6 to 79.8. On average there were four escapes for every 1000 starfish seen on the 5cm x 7.5cm steel mesh, whilst there were 202 escapes for every 1000 encounters with the single prawn netting fence. The least efficient cages were the six flexible netting enclosures. Each allowed in excess of 36 escapes per 1000 encounters.

Figure 2 shows the mean crossing time in days for a single starfish to scale an enclosure. The netting fences proved to be more readily climbed than the rigid mesh fences. On average none of the six nets retained starfish for more than 1.1 days, whilst the least efficient of the hard fences retained starfish for more than 1.4 days. Three enclosures retained starfish for longer than 3 days.

Figure 3 demonstrates the variation found in the number of attempts required before an escape. Eight fences failed to retain starfish after 5 attempts had been made. Included in these were the six flexible fences. Five of the hard fences required 7 or more attempts before an escape. The fence which required the most attempts was 5cm x 7.5cm steel mesh, requiring 37 attempts per escape.

Table 3 and Figure 4 detail the contribution of the various design elements (skirt/wall and wall/overhang flexures), of the hard fences as barriers to starfish movement. There appeared to be a positive relationship between the diameter of the holes and the effectiveness of the fence flexures in preventing starfish movement. Smaller diameter holes (1.3cm hex and 1cm x 1cm steel mesh) precluded between 45% and 50% of the starfish, 2.5cm holes prevented between 55% and 60% of crossings and 5cm holes (Nylex and hex) barred 70% to 75% of crossings. The 5cm x 7.5cm steel mesh result does not conform to this trend. The reasons for this anomalous result are set out in the discussion.

Table 4 summarises the observations made over a continous six hour period on day 2. There are observations for 5 of the 13 enclosures. Of the 31 separate encounters witnessed, 3 were succesful and 5 resulted in starfish falling off. Seven starfish showed no response when encountering a flexure of the fence (edge of skirt/wall, edge of wall/overhang, lip edge) whilst 24 starfish either changed direction or did not attempt to negotiate one of these flexures. Continuous observations were much more successful in determining the activity of starfish, as movement was often hard to discern during spot observations. It was interesting to note that starfish often displayed crepuscular activity, including heightened activity coinciding with the rising of the moon.

There were 18 incidents of animals other than crown-of-thorns being stopped by fences. Only three of these died as a result of the encounter (red bullseye, (*Priacanthus*)-cage B, fusilier, (*Caesio*)-cage B, fusilier-cage G). Without timely intervention by divers three tea-leaf trevally (*Carangoides* sp.), (cage B), a Bothid sole (cage B) and an additional fusilier (cage B) would also have died. Ten other encounters (helmet shell, hermit crabs, octopuses, cone shell, spider shell, pin-cushion star, sole) failed to entangle the animal including one where a 1.7m reef shark which became momentarily entangled before tearing free.

There were 5 predation records in the 6 days. A large Tetradontid puffer fish (pale silver sides, small blue spots, sp. undetermined) attacked 2 intact starfish and consumed them almost entirely within the space of a few hours.The remaining fragments of 2 other starfish were attributed to separate attacks by unknown predators. On one occasion a spangled sweetlip (*Lethrinus retulosus*) was observed eating fragments of a previously attacked starfish. There were two observations of the boxfish *Canthigaster valentini* picking mucus off the surface of *A. planci* without actually damaging the surface of the starfish.

TABLE 1. Enclosure materials, designs and sizes.

CODE	DESCRIPTION	DESIGN	SIZES(m)	OVERALL COST/m
A	NYLEX Instant trellis 48mmx48mm	overhanging	s=,4,w=,8,o=,4	$11,50
B	Monofilament gill net 42mm stretch, XX gauge	simple wall	w=1,5	$2,25
C	Brown terylene multifilament 58mm stretch, 18 ply	simple wall	w=1,75	$4,20
D	Brown terylene multifilament as above	double wall	w=2,5, 5cm gap	$5,20
E	Blue nylon multifilament 37mm stretch, 24 ply	simple wall	w=2,0	$6,70
F	1,3cm hex chicken wire 0,6mm diam, galvanized	overhanging	s=,4,w=,8,o=,4	$5,60
G	Monofilament gill net as above	double wall	w=1,5, 30cm gap	$4,40
H	2,5cm hex chicken wire 0,9mm diam, galvanised	overhanging	s=,4,w=1,0,o=,4	$5,50
I	1cmx1cm ARC steel mesh 1,2mm diam, galvanized	overhanging	s=,4,w=1,0,o=,4	$7,85
J	2,5cmx2,5cm ARC steel mesh 1,5mm diam, galvanized	overhanging	s=,4,w=1,0,o=,4	$9,40
K	5cm hex chicken wire 0,9mm diam, galvanised	overhanging	s=,4,w=1,0,o=,4	$3,90
L	5cmx7,5cm ARC steel mesh 1,3 mm diam, galvanized	overhanging	s=,4,w=1,0,o=,4	$7,75
M	Blue nylon multifilament as above, tangle of old 62mm fish net rolled loosely	double wall w/ tangle	w=1,0, gap=,3	$8,20

s = skirt w = wall o = overhang

TABLE 2. Summary of all observations.

	A	B	C	D	E	F	G	H	I	J	K	L	M
number in cage	10	8	5	8	4	9	6	9	13	9	5	5	7
observations	1004	828	515	929	449	972	630	904	1359	937	481	505	750
encounters	962	718	485	863	410	894	586	894	1246	872	446	499	738
moving on wall	75	84	125	91	110	103	89	145	134	96	47	74	63
escapes	18	41	71	31	83	16	31	16	10	12	16	2	40
efficiency (%)	98,1	94,2	85,4	96,4	79,8	98,2	94,7	98,2	99,2	98,6	96,4	99,6	94,6
crossing time (days)	2,4	0,85	0,31	1,1	0,21	2,4	0,85	2,4	5,6	3,3	1,4	11,1	0,68
tries/escape	4,17	2,05	1,76	2,94	1,32	6,44	2,87	9,06	13,4	8,00	2,94	37,0	1,57

A Nylex
B single mono
C single brown
D double brown
E single prawn
F 1,3 hex
G double mono
H 2,5 hex
I 1x1 ARC
J 2,5x2,5 ARC
K 5,0 hex
L 5x7,5 ARC
M double prawn tangle

TABLE 3.1 Contribution of the base of the wall, the overhang and the lip edge to total success of the hard fences.

Number of starfish scaling beyond the skirt(2), the base of the wall(3), the overhang(5) and the lip(6)

CAGES AND THEIR ELEMENTS

	A Nylex				F 1,3Hex				H 2,5Hex				I 1x1Arc				J 2,5Arc				K 5,0Hex				L 5x7,5Hex			
DAY	2	3	5	6	2	3	5	6	2	3	5	6	2	3	5	6	2	3	5	6	2	3	5	6	2	3	5	6
SU	152	42	8	8	146	80	26	8	160	72	23	6	225	126	39	3	190	87	23	3	92	30	5	4	98	70	16	0
MO	215	63	9	2	188	97	21	4	224	103	14	2	250	148	47	5	195	82	20	3	84	23	6	6	119	46	3	1
TU	210	72	8	3	193	94	13	1	210	91	11	2	252	139	16	1	201	76	22	2	102	30	5	4	118	40	7	0
WE	228	63	3	2	226	104	16	2	185	59	7	5	280	150	13	1	163	75	19	3	103	15	2	1	105	29	1	0
TH	96	18	4	3	84	50	5	1	76	21	3	1	115	79	10	0	65	35	5	1	38	8	2	1	41	22	6	1
Σ	901	258	32	18	837	425	81	16	885	346	58	16	1122	642	125	10	814	355	89	12	419	106	20	16	481	207	33	2
†	643	226	14	18	412	344	65	16	509	228	42	16	480	517	115	10	459	266	77	12	313	86	4	16	274	174	31	2
††	71	25	2	2	49	41	8	2	60	34	4	2	43	46	10	1	56	33	9	2	75	20	1	4	57	36	6	0

† Number excluded by the wall base(2), the overhang(3), the lip(5) and number escaping over the lip(6)
†† Percentage stopped by the wall base(2), the overhang(3), the lip(5) and those escaping(6)

TABLE 3.2 Contribution of the base of the wall, the first wall and the second wall to the total success of the doubled soft barriers.

CAGES AND THEIR ELEMENTS

	B S,Mono			C S,Brown			D Db,Brown				E S,Prawn			G Db,Mono				M Db,Prawn			
DAY	2	3	Es	2	3	Es	2	3	7	Es	2	3	Es	2	3	7	Es	2	3	7	Es
SU	139	92	5	115	94	14	114	90	16	4	83	64	16	119	91	26	9	88	66	7	1
MO	209	113	10	140	83	15	173	100	31	7	129	92	27	192	85	22	12	175	87	11	3
TU	197	133	13	105	44	11	203	155	26	6	97	26	19	117	35	5	5	202	143	41	11
WE	137	16	7	85	41	23	278	150	138	6	77	26	13	112	16	10	5	216	123	87	17
TH	30	4	2	30	19	5	95	71	48	6	25	18	7	44	39	35	6	60	33	14	6
Σ	712	362	37	475	281	68	863	566	259	29	411	226	82	584	266	98	37	741	452	160	38
†	350	325	37	194	213	68	297	307	230	29	185	144	82	318	168	61	37	289	292	122	38
††	49	46	5	41	45	14	34	36	27	3	45	35	20	54	29	11	6	39	39	16	6

† Number excluded by the wall base(2), the first wall(3), the second wall(7) and the number escaping(Es)
†† Percentage stopped by the wall base(2), the first wall(3), the second wall(7) and the number escaping(Es)

TABLE 4. Summary of continuous observations over six hours.

CAGE	TRIES	SUCCESSES	FALLS	INFLUENCED BY DISCONTINUITIES
A	3	0	0	2
E	2	1	0	1
F	8	0	2 †	7
H	10	1	3 ††	7
I	8	1	0	7
Σ	31	3	5	24

† diameters 22cm, 20cm
†† diameters 20cm (fell twice), 18cm

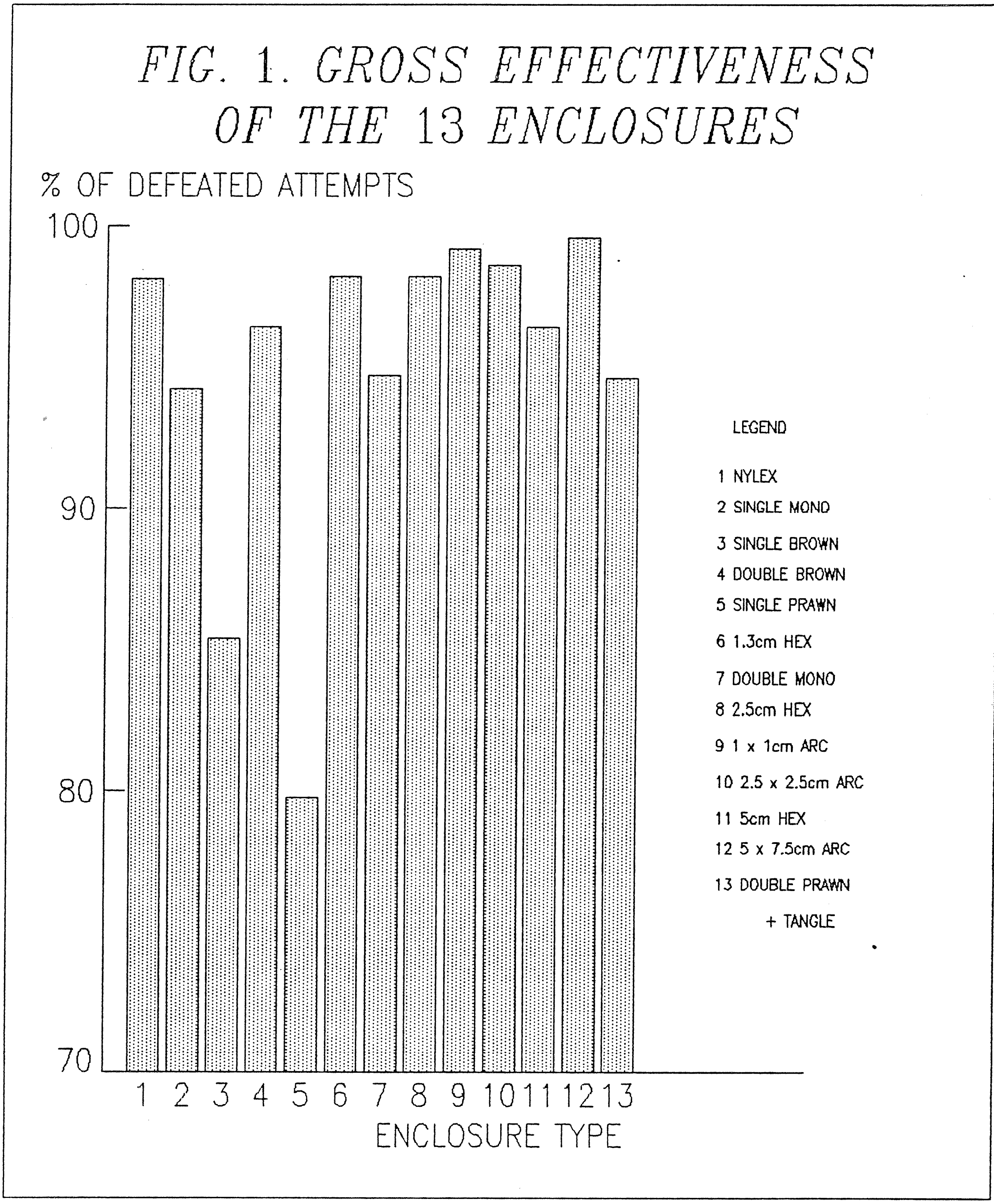
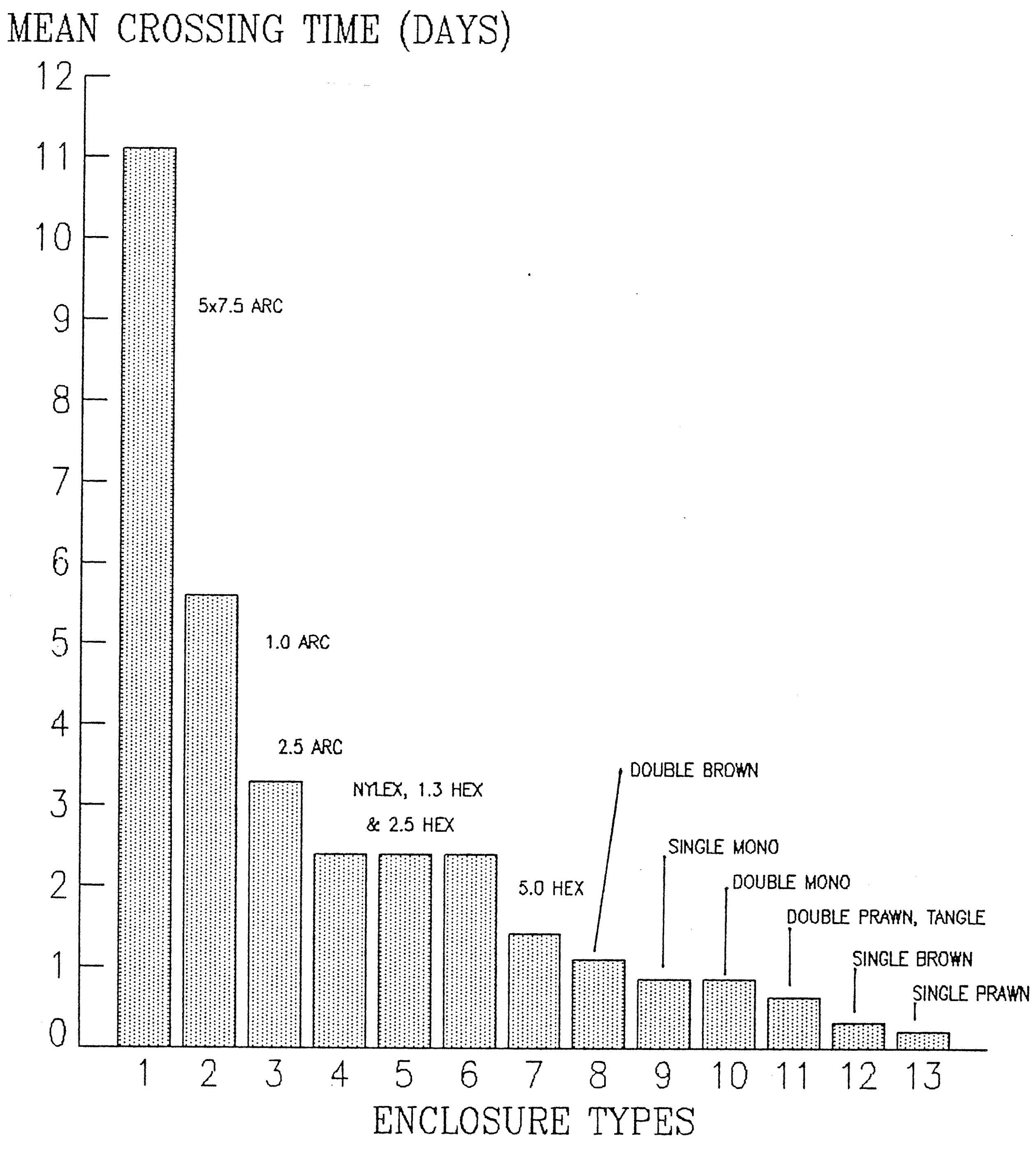


FIG. 1. GROSS EFFECTIVENESS
OF THE 13 ENCLOSURES
% OF DEFEATED ATTEMPTS
100
90
80
70
1 2 3 4 5 6 7 8 9 10 11 12 13
ENCLOSURE TYPE
LEGEND
1 NYLEX
2 SINGLE MONO
3 SINGLE BROWN
4 DOUBLE BROWN
5 SINGLE PRAWN
6 1.3cm HEX
7 DOUBLE MONO
8 2.5cm HEX
9 1 x 1cm ARC
10 2.5 x 2.5cm ARC
11 5cm HEX
12 5 x 7.5cm ARC
13 DOUBLE PRAWN
+ TANGLE

FIG. 2. RETENTION TIMES OF STARFISH BY ENCLOSURES



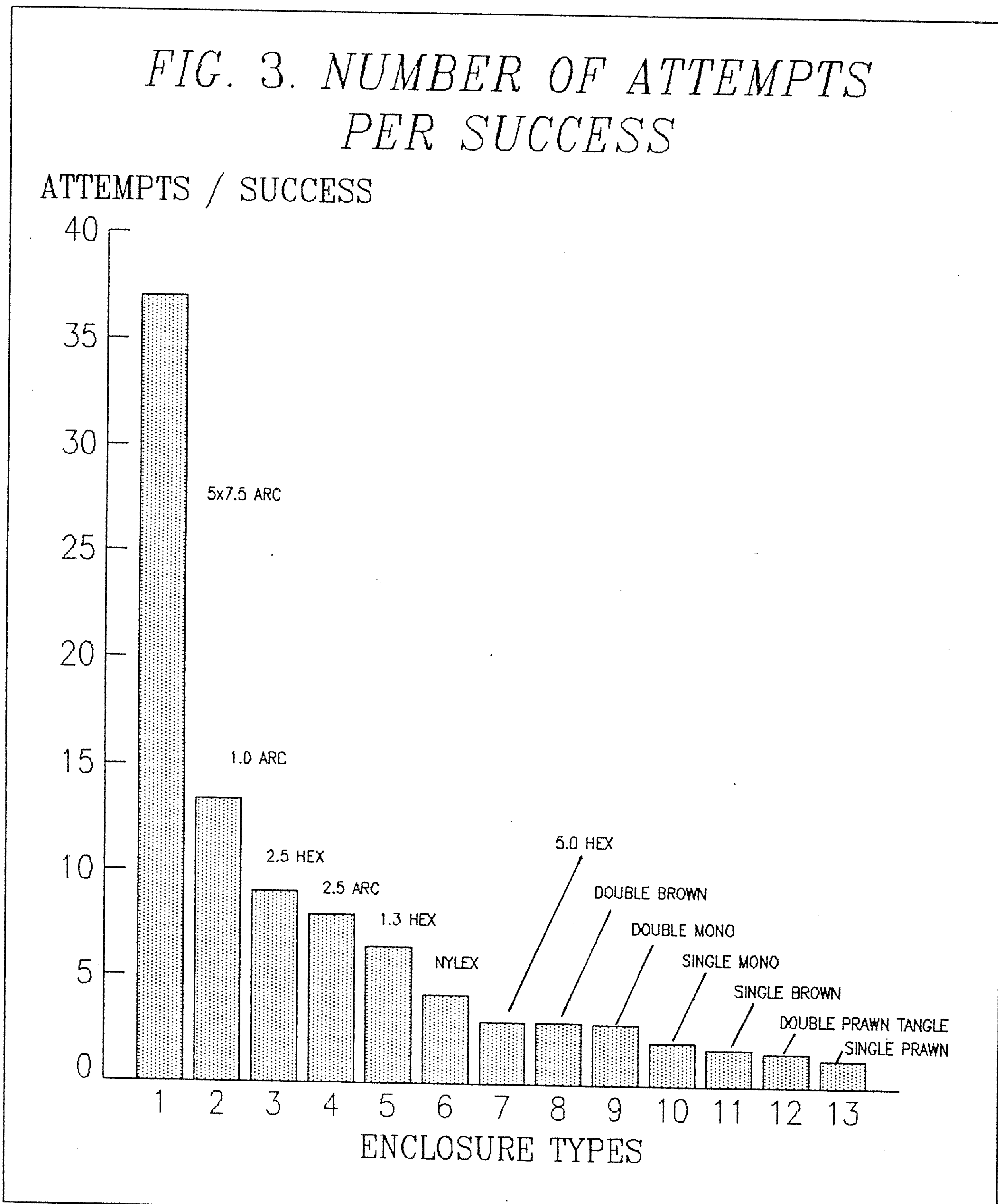


FIG. 3. NUMBER OF ATTEMPTS PER SUCCESS
ATTEMPTS / SUCCESS
40
35
30
25
20
15
10
5
0
5x7.5 ARC
1.0 ARC
2.5 HEX
2.5 ARC
1.3 HEX
NYLEX
5.0 HEX
DOUBLE BROWN
DOUBLE MONO
SINGLE MONO
SINGLE BROWN
DOUBLE PRAWN TANGLE
SINGLE PRAWN
1 2 3 4 5 6 7 8 9 10 11 12 13
ENCLOSURE TYPES

FIG. 4.1. CONTRIBUTION OF STRUCTURAL ELEMENTS TO EFFECTIVENESS

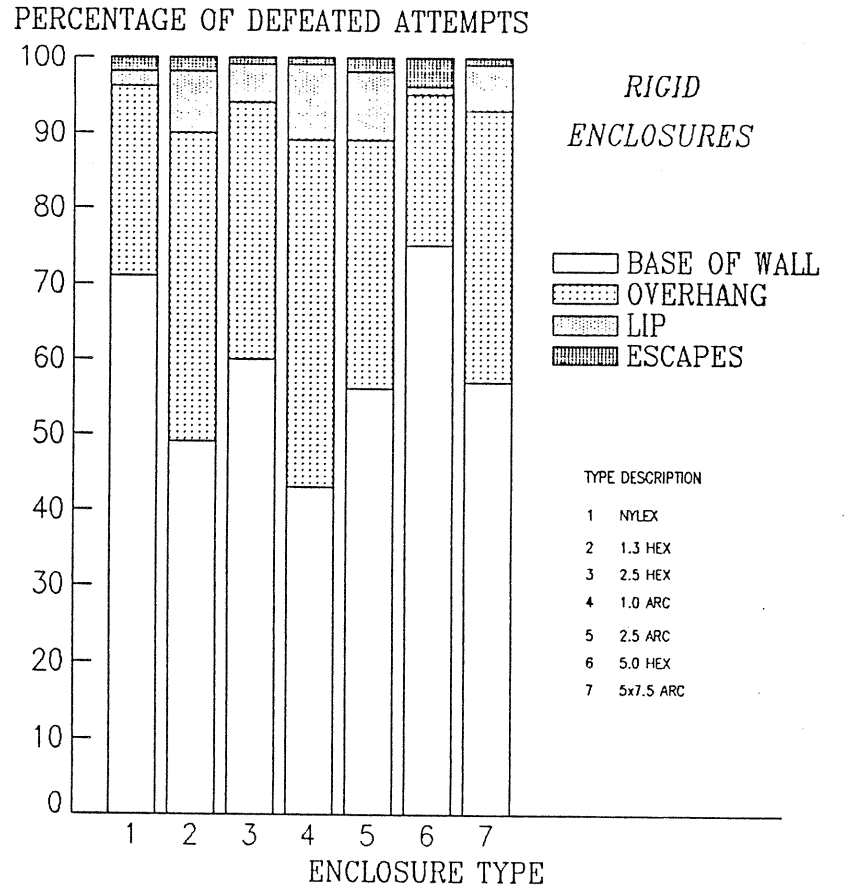
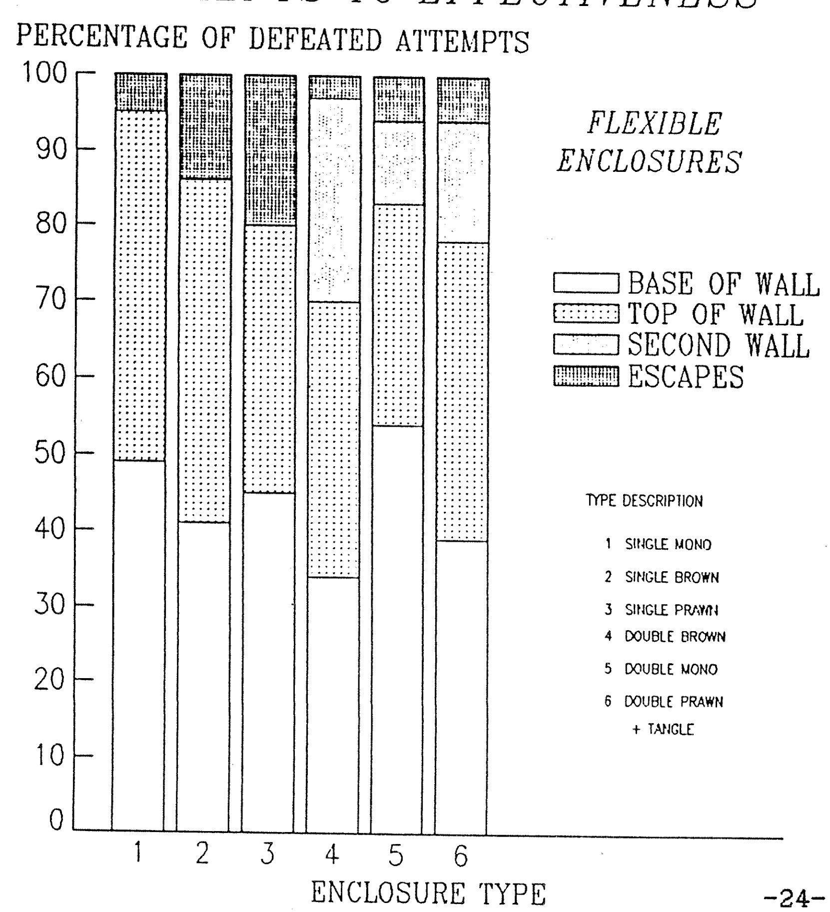


FIG. 4.2. CONTRIBUTION OF STRUCTURAL ELEMENTS TO EFFECTIVENESS



DISCUSSION

Assessment of the effectiveness and feasiblity of fences as barriers to starfish movement has considered a number of criteria; a) the effectiveness of the fence as a barrier to starfish movement, b) the amount of bycatch killed or restricted from ranging freely by the fence, c) the durability of the fence, d) the aesthetic appearance of a fence in a popular tourist area and e) the cost-effectiveness of the construction and maintenence of the fence. The results of this project are discussed according to these criteria.

EFFECTIVENESS OF THE FENCES AS BARRIERS TO STARFISH MOVEMENT

It appears from the results that the most important factors influencing the escape rates and strategies were; a) the interrelationships between the size of the starfish and the hole size and gauge of the various materials, b) the flexures and overhang elements of fence design and c) the rigidity of the fence and its materials.

The soft netting materials were less effective than the rigid mesh materials. The single walled monofilament enclosure (cage B) was the most successful of the soft materials. This enclosure was lightly bouyed and constructed of fine gauge, flexible material. The single walled prawn netting enclosure was very ineffective. It was supported by many bouys and constructed of a less pliable, coarse gauge multistrand material, which suggests that the greater rigidity of this enclosure provided more purchase for starfish to climb than the monofilament enclosure. These conclusions are supported by observations of starfish escapes from each of these enclosures. On many occassions starfish which escaped from the monofilament did so in the corners which were supported firmly by steel posts. Figure 2. shows that the crossing time for the monofilament was 1.1 days whilst that of the multifilament was c. 0.25 days. Clearly having to climb a less rigid enclosure slowed down their rate of movement.

Rigidity of materials was a minor consideration for the hard materials, as all of these provided enough support for starfish to climb.

The interrelationship of starfish size, mesh hole size and gauge of the material appeared to be very significant for the hard walled enclosures, and to a lesser extent for the soft netting enclosures. Large mesh sizes provided the lowest surface area available for adhesion. However, larger meshes permitted starfish to climb through the wall. Starfish up to c.35cm in diameter were observed to escape through the 5cm hexagonal mesh. Conversely smaller sized holes prevented starfish from climbing through the fence but offered greater surface area for starfish to cling to. Casual observations suggest that small starfish are less able to squeeze through small holes. The proportionally greater amount of skeletal elements in small starfish (Kettle and Lucas, in press) may contribute to reduced flexibilty.

Figure 4 highlights the significance of the flexures, demonstrating that 60% of the starfish observed had climbed no further than the base of the wall. About 30% had climbed no further than the start of the overhang. These results appear to indicate that the skirt/wall and wall/overhang flexures affect starfish behaviour. On encountering these obstacles, many starfish either stop moving or turn and follow the discontinuities in the orientation of the surface. Analysis of the 6 hour continuous observation data (Table 4) supports this conclusion. Of 31 starfish observed moving inside the enclosures, 24 either stopped or turned and followed a flexure. Figure 4 also suggests, that in the absence of an overhang, as many as 40% of the starfish would have made it to the top of the wall and escaped rather than the c.1% that were recorded. The recurved surface of the overhang was designed so that when negotiating the wall, the starfish climbing onto the overhang would risk loosing their grip and fall. During the period of continuous observation, 3 out of 5 animals that climbed onto the overhang fell. Clearly the overhang contributes greatly to the effectiveness of an otherwise simple vertical wall. In their natural environment starfish are often seen moving or resting on the undersides of plate corals and other surfaces. However these surfaces are solid and offer a large surface area for the starfish to cling to. The observed effect of the overhang is likely to be attributable to the smaller surface area that meshes offer a starfish to adhere upon.

Assessment of the 5cm x 7.5cm steel ARC mesh cage is somewhat anomolous as it did not contain juvenile starfish for the entire monitoring period. Juveniles (diameter range 6cm to 15cm) were placed in this cage before monitoring began, but they walked through the mesh before the first observation period. It was deemed unfeasible to continue to look at the responses of juveniles in this cage, and thus the assessment of this cage as represented by the graphs is artificially enhanced. Recalculation of the adults-only crossing time for the 1cm x 1cm mesh yielded a value of 13.1 days. This is superior to the result obtained for the 5cm x 7.5cm mesh. However it was deemed necessary to appraise the fences for all starfish larger than c.10cm. It has been observed in the field that small starfish are comparitively sedentary. They remain within a small feeding range until subadulthood (10-15 cm) at which time they change their feeding behaviour (Zann et. al., in press, Bell and Kettle, manuscript in prep.)

Considering these three factors the most successful barrier was the 1cm x 1cm ARC mesh enclosure. The small size of the mesh prevented small starfish from escaping through the wall whilst the overhang prevented starfish from climbing over.

ASSUMPTIONS AND CONSTRAINTS

In assessing the effectiveness of the enclosures, several assumptions about starfish behaviour were made.

The first assumption was that the starfish used for the trials were healthy and normal and were not adversely affected during their collection or confinement. Starfish collected were handled carefully and kept in water whilst being transported to the cages. There may have been a response to this handling and on occasions when individuals were moved to facilitate counts of clumped starfish in the cages, but this was likely to have resulted in greater activity, not less (Kettle, pers. obs.).

The second assumption was that starfish behave the same within the cages as they would when they encounter a large scale continuous fence.

It is important to note several other factors which may have affected starfish behaviour.

The enclosures were situated on open sand and starfish were given no cover under which to hide. This was deliberate, as *Acanthaster* on open areas of sand have shown the potential to move quickly until they find cover (DeVantier and Kettle, unpub. report to GBRMPA). Thus movement rates may have been increased as starfish attempted to locate cover.

The chances for starfish encountering a wall whilst moving were increased by the enclosures being small and square. Often starfish which encountered a corner would stop and congregate in them, possibly sensing the corners as areas affording greater cover. In a large scale application, especially if care were taken to prevent corners, starfish might continue to move along a barrier and ultimately move past the protected area.

BY-CATCH

Though the amounts of by-catch accidently caught or impeded by the enclosures was quite small the significance of it must be carefully considered, especially if any larger scaled fencing project was proposed. The high possibilities of by-catch by netting materials would certainly make them unsuitable for any large scale fences. Apart from the original animals caught in these materials, the problem becomes progressively worse as predators attempt to take struggling fish from the nets and either become entangled themselves or tear large holes in the them. Zann (pers. comm.) found this to be a major problem after deploying large lengths of gill net in an attempt to delimit a control area during the Grub Reef *Acanthaster* control program. However, due to the relatively small time period in which the net enclosures were trialled during this project, the problem was not great. In addition the constant presence of divers monitoring the nets enabled many fish caught in the nets to be quickly removed. It is significant to note that all of the fish that became entangled were trapped in the monofilament nets and that all of these were trapped in the first two days. This is probably due to the fact that the monofilaments, which were originally difficult for fish to discern, were fouled with fine coralline sediments and algae and thus became more visible to fish and were avoided.

No animals ever became entangled in the mesh of the hard enclosures. The potential of the hard mesh materials to act as a trap for other animals was mostly due to the fact that the materials were constructed to form enclosures, completely surrounding animals unfortunate enough to enter them. Animals encountering a long fence would either retreat or swim along it or over it and would not be 'trapped.'

ECOLOGICAL IMPLICATIONS

Fences would not affect reproduction or recruitment within enclosed areas of the reef as the great majority of reefal organisms have external fertilization and a planktonic larval dispersal period. The only animals that may suffer in an enclosed area of reef are large, benthic brooders who's young are large enough to be excluded by the fence. For example bailer shells have live young that would be unable to fit through 1cm x 1cm mesh.

Other animals may be restricted by the fence, particularly large crawling animals such as holothurians, gastropods and other starfish. Epibenthic fishes such as Lizard fish, Soles and Flatheads may also be restricted.

Steel fences will rust away in a few years but plastic materials have a much slower degradation rate. In the event of a cyclone or storm dispersing the materials unretrievably throughout the environment, the steel fences may prove to be more desirable than plastic materials.

DEGRADATION AND FOULING

Degradation and fouling rates of the steel and plastic mesh enclosures only, are being monitored and this will continue until March, 1987. All of the 6 netting enclosures were dismantled and removed because of their potential to trap fish and as they were deemed to be inefficient and impractical for any larger scale fence constructions.

Within the first 2 to 3 days of monitoring the enclosures it was noted that all materials became lightly fouled with fine sediments and filamentous algae. There was no discernable difference in the rates at which this occurred. Six of the hard materials were galvanized steel, whilst the seventh was polyethylene plastic. Though it is expected that the galvanized steel will rust, the film of fouling may afford the steel some protection against corrosion, and may be important in determining the durability of the construction. If fouling accumulates excessively it may reduce the hole size of the mesh, increasing the surface area and enabling starfish to scale the barrier more readily. Communications with manufacturers and people who have used these materials in marine applications suggest that a durability of about one year could be expected for the chicken wire and longer than this for the weld-mesh. The crimped staples which were used to fasten the enclosures were not galvanized and may rust more quickly than the mesh. The support posts, constructed of 10mm round rod should have a life expectancy of a few years even though they are not galvanised.

Other sources of possible physical damage to a large scale fence would include storms, cyclones and fouling with boat anchors. The destructive potentials of these are difficult to predict. It is conceivable that damage done by boat anchors may be the most significant, especially given the continous nature of the fence material. An anchor caught in the fence and lifted to the surface or dragged free would destroy many metres of fencing, and is unlikely to be reported. Given that many starfish are likely to be moving along the fence large numbers may enter through the hole in a short period of time. As such some way must be found to minimise the chances of anchor damage and to monitor the fence for damage.

AESTHETICS

Reef users most likely to adopt fences to control *Acanthaster* are tourist operators. As these operations utilize coral viewing areas the fence must not detract aesthetically from the spectacle of the coral. Fences should be constructed on the sand between the bases of bommies, but far enough away from them so as not impinge upon the view from glass bottom boats and semi-submersible viewing craft. Even divers and swimmers would remain unaware of the fence if its layout is routed away from regularly used diving and snorkelling sites.

COST EFFICIENCY

Cost per metre for each of the enclosure types are given in Table 1. These values include costs for posts, chain for weighting, net floats and staples. These figures show the most effectiveness enclosures (i.e 1cm x 1cm and 5cm x 7.5cm weldmesh enclosures) to be comparitively more expensive than many of the less effective materials. Clearly it is undesirable to sacrifice effectiveness for cost when an enterprise depends upon the attraction of live coral. Assessments of the cost efficiency figures of any large scale fencing program cannot be made from this study alone. Material costs could be estimated accurately, but the huge labour contingent needed to construct an *Acanthaster* impervious fence, would constitute the greatest expense in any such operation. However use of large, willing labour resources such as the Australian Army and Navy may be viable as they have been involved in scientific and civic projects in the past with great success.

CONCLUSIONS AND RECOMMENDATIONS

1. Fences appear to be useful for limiting *Acanthaster* movement. The presence of any vertical mesh wall could be expected to deter many starfish.
2. Of the materials tested the 1cm x 1cm ARC mesh was the most effective cage at limiting starfish escapes. The presence of a downturned overhang on this and other hard enclosures significantly enhanced the retention of starfish.

3. The variety of materials was quite small. Indications from this exercise suggest that other materials and designs may be even more effective at limiting starfish movement.

   eg. Composite fences of different sized meshes may exclude more juveniles.

   A composite hard mesh wall with overhang and lip, which included 30cm of flexible netting added to the edge of the lip may increase the effectiveness of the lip.

   It may be possible to design a flexible net with an overhang.

4. The steel posts should be 2m long rather than 1.5m, as shorter lengths are driven too far into the sand. Posts should be made from 12mm deform bar rather than 10mm round, as this would enhance their rigidity in the sand.

5. Materials should be prefabricated without joins or gaps.

6. Fences would need to be patrolled for damage and maintained regularly.

7. Where possible the fences should be constructed without corners.

8. Materials with a limited lifespan are desirable in case of irretrievable dispersal by a storm or cyclone.

9. Use of fences should be included as part of an overall crown-of-thorns management strategy.

ACKNOWLEDGEMENTS

We are grateful to Doug Tarca for making available to us the facilities of REEF LINK Pty Ltd, and funding the costs of all enclosure materials. This project was made possible with funding and equipment from the Great Barrier Reef Marine Park Authority. We wish to thank Cocky Watkins and Jan Kenworthy from the M.V. HERO for their assistance, and Cathy Bone, Libby Evans, Rob McCauley, Tony McKenna, Scotty Miller-Smith, Will Oxley, Julia Shand, Shirley Sorokin, Leon Zann and Rene Galzin for their many hours spent in underwater assistance. We would also like to thank the technical and administrative staff at the School of Biological Sciences, JCU.

FOOTNOTE: DIVING PRACTICES.

At "OCEANS '86" recent dive medicine findings were presented to indicate that divers can be bent by long periods in water less than ten metres deep. Whilst few guidelines can be found for this sort of diving it is critical that divers constructing large scale fences be aware of the potential dangers.

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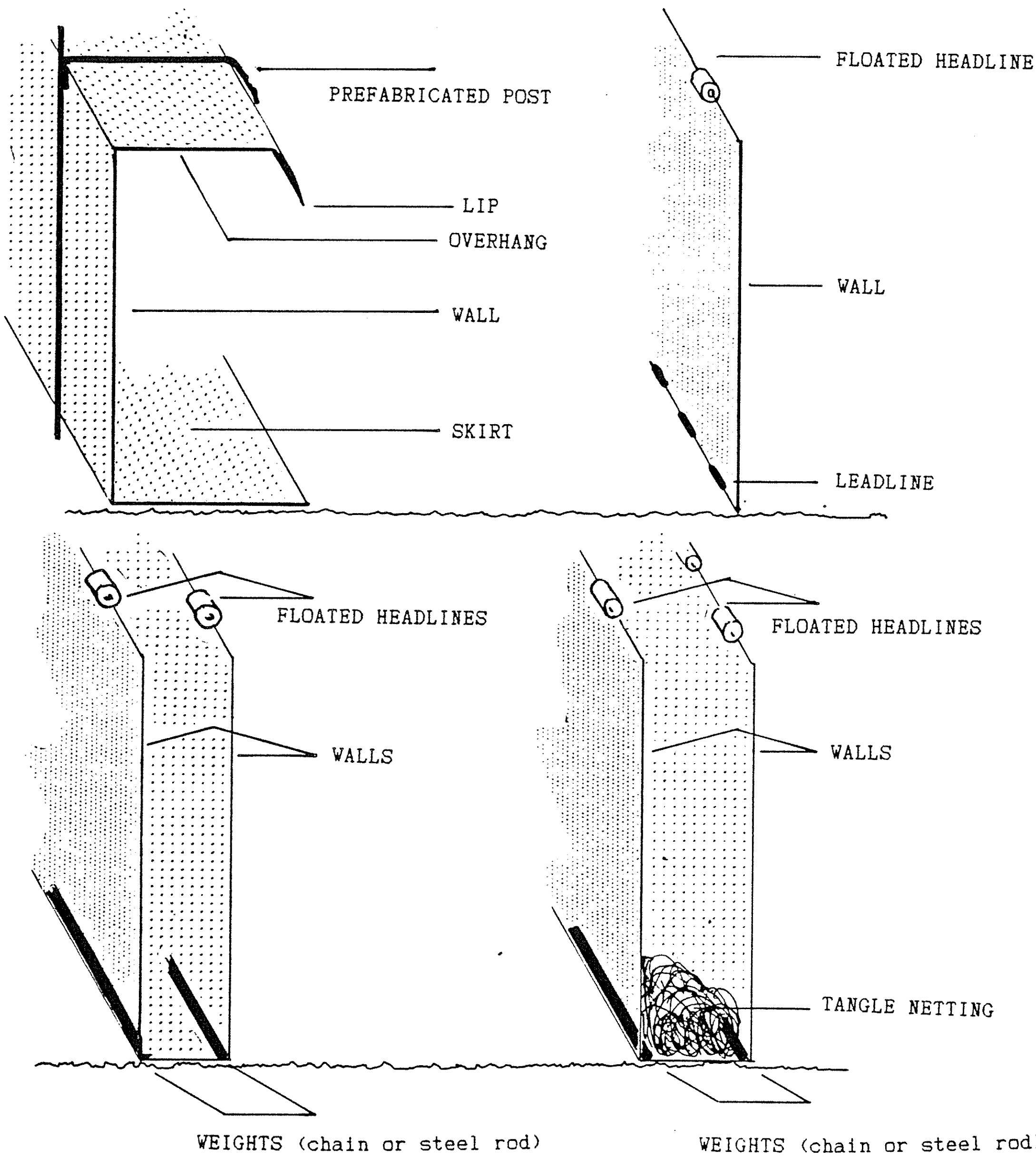
Appendix A. Schematic diagrams of the fence designs.

A.1. Overhanging rigid mesh enclosure

A.2. Single-walled flexible enclosure.

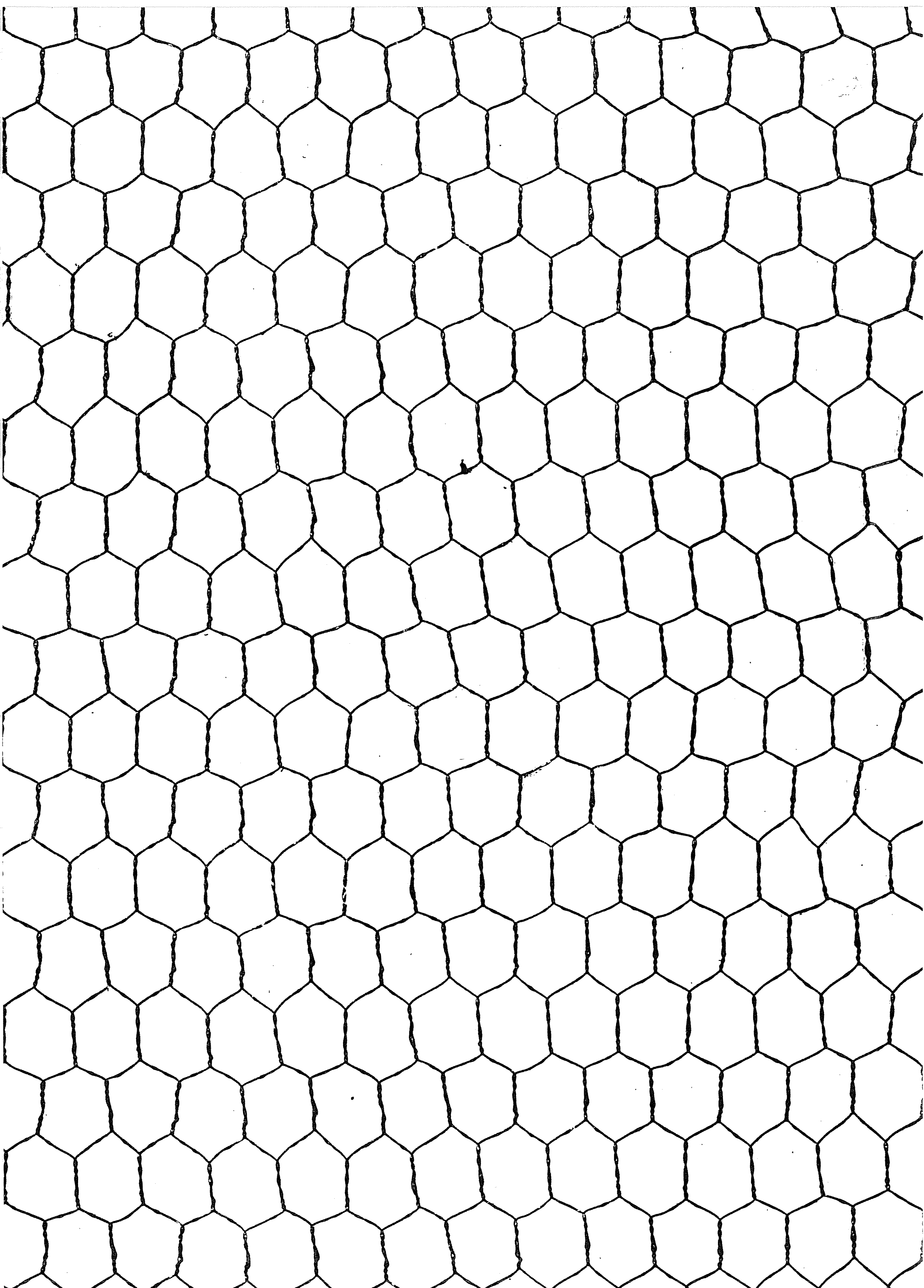


A.3. Double-walled flexible enclosure.

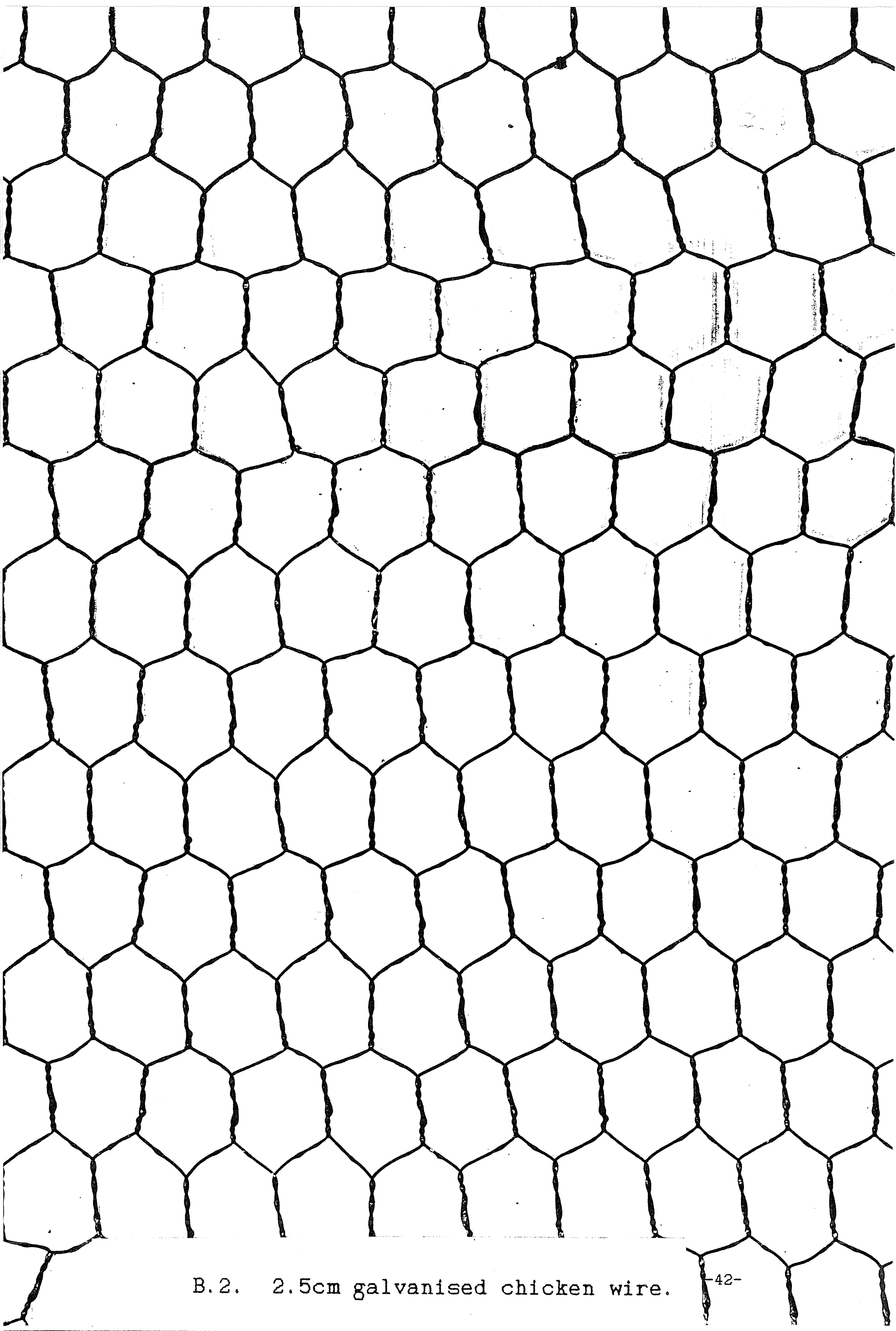
A.4. Double-walled flexible enclosure with tangle net.

APPENDIX B

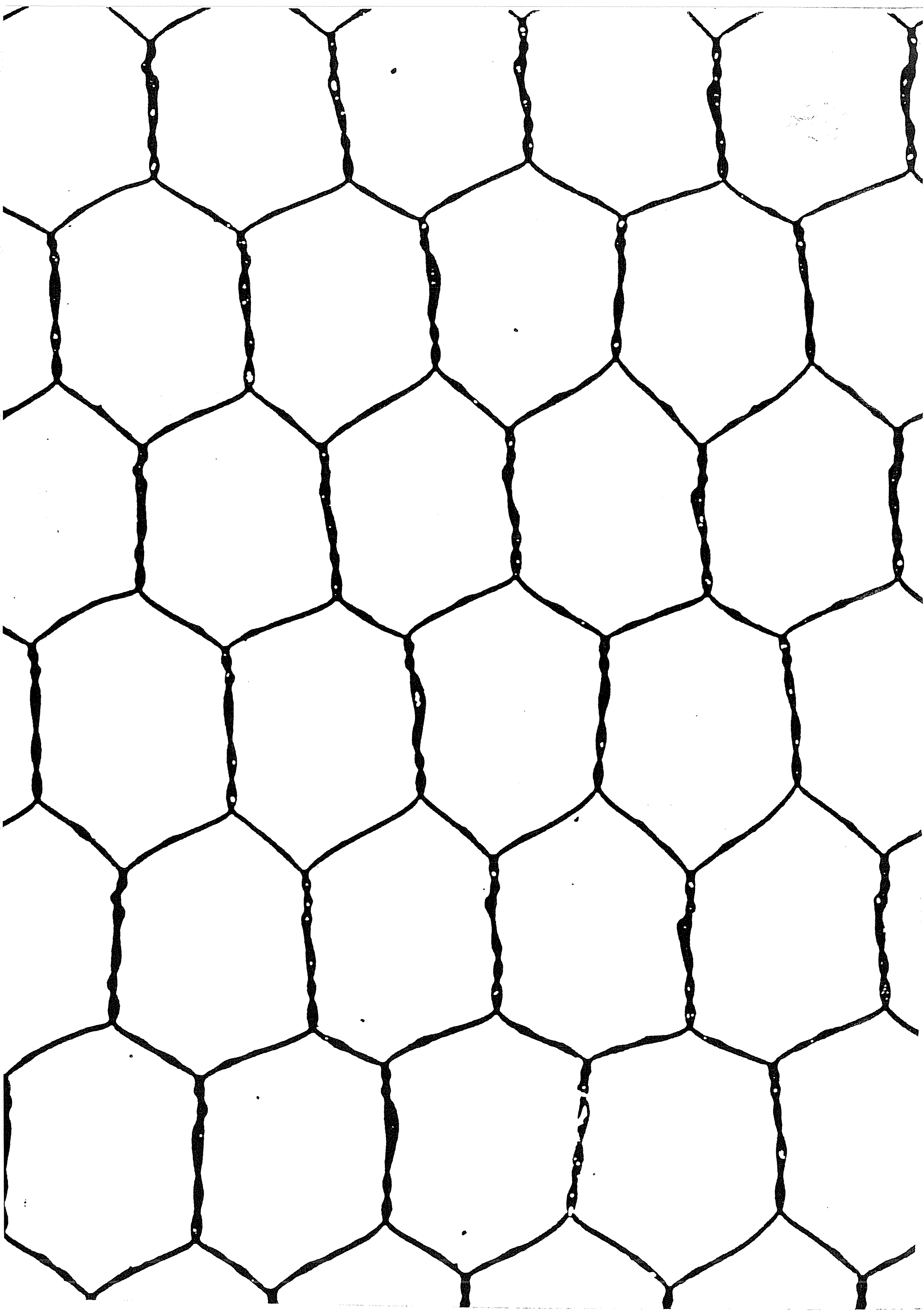
Photocopies of the ten materials used for enclosures.



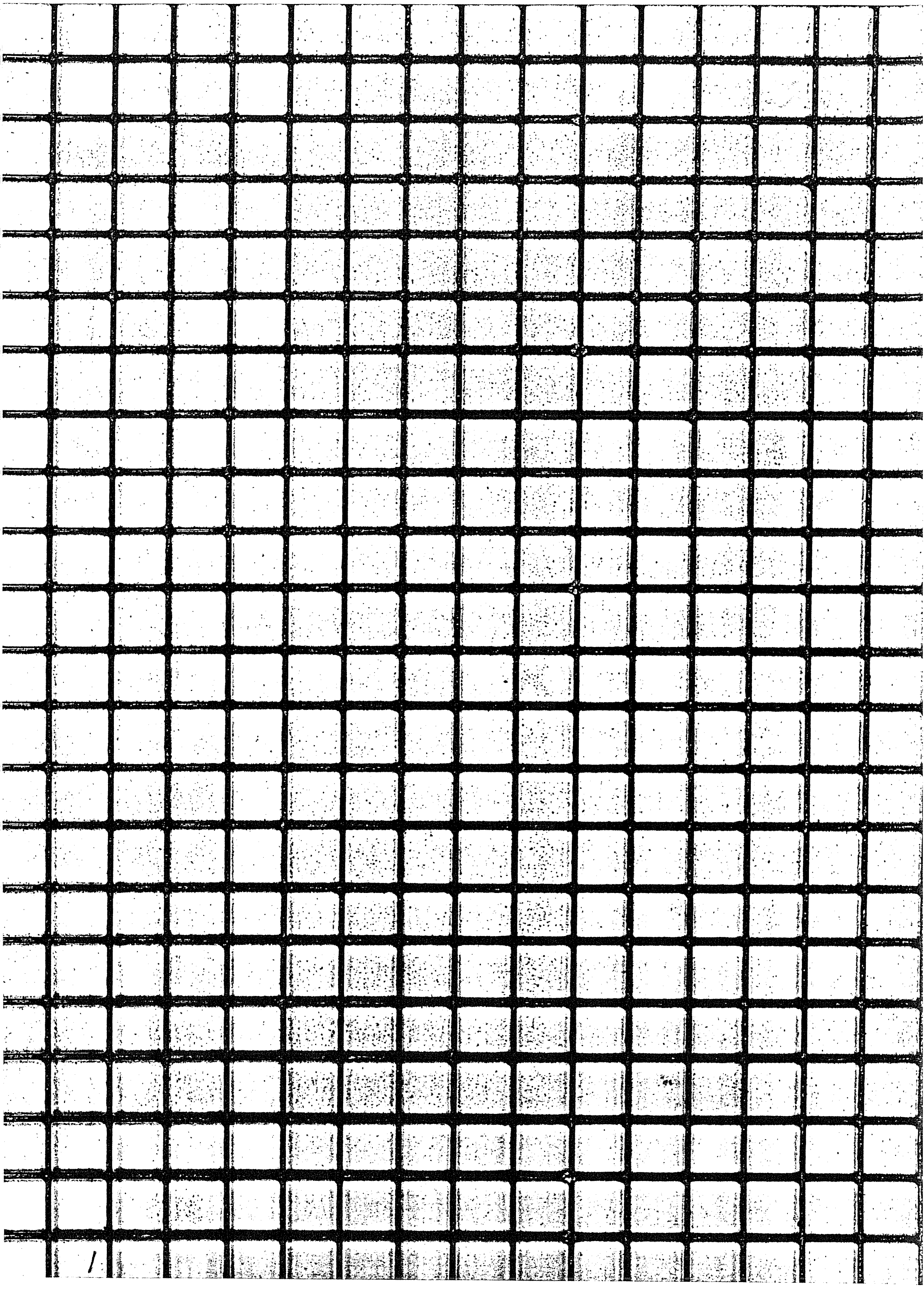
B.1. 1.3cm galvanised chicken wire.



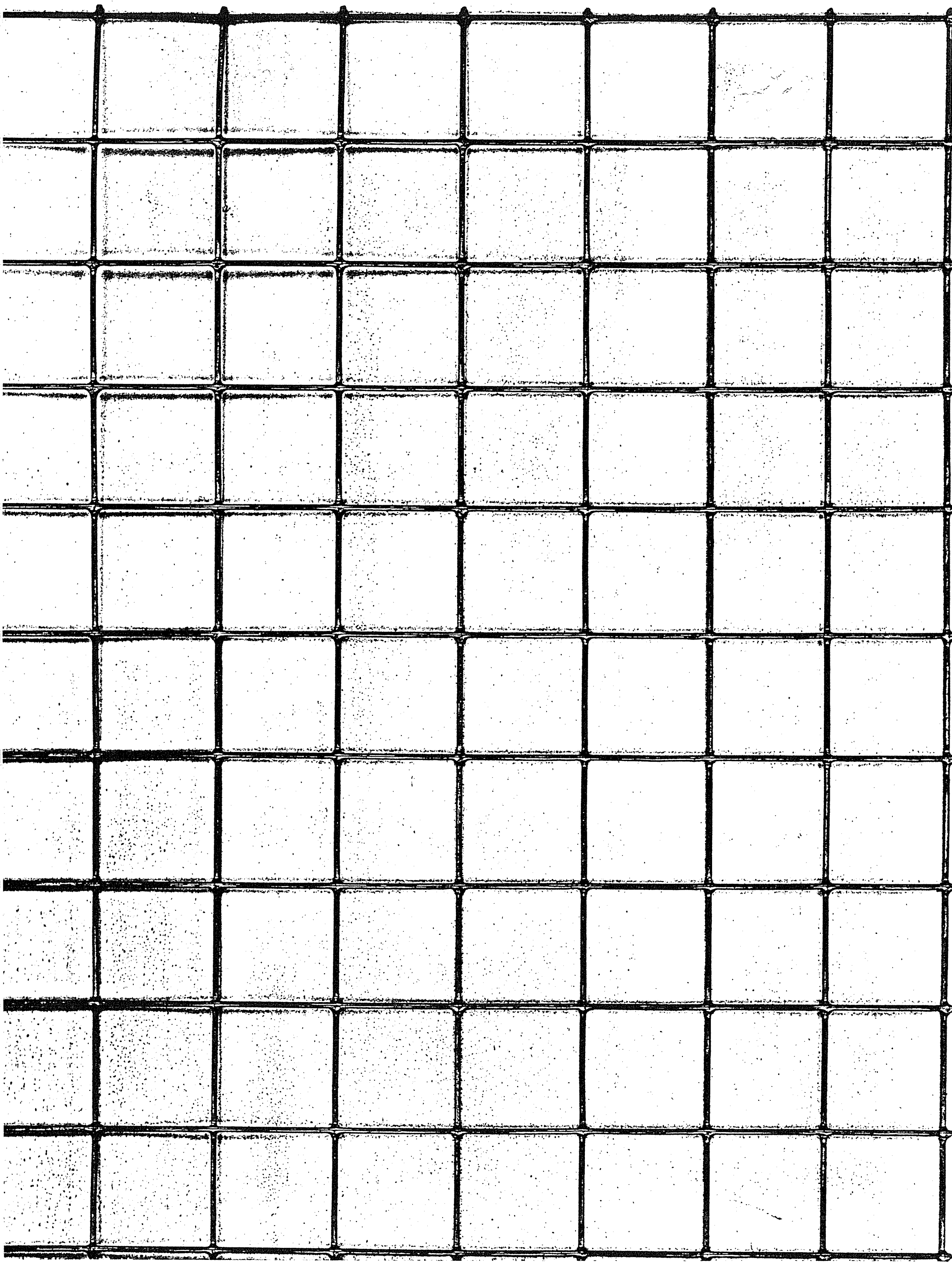
B.2. 2.5cm galvanised chicken wire.



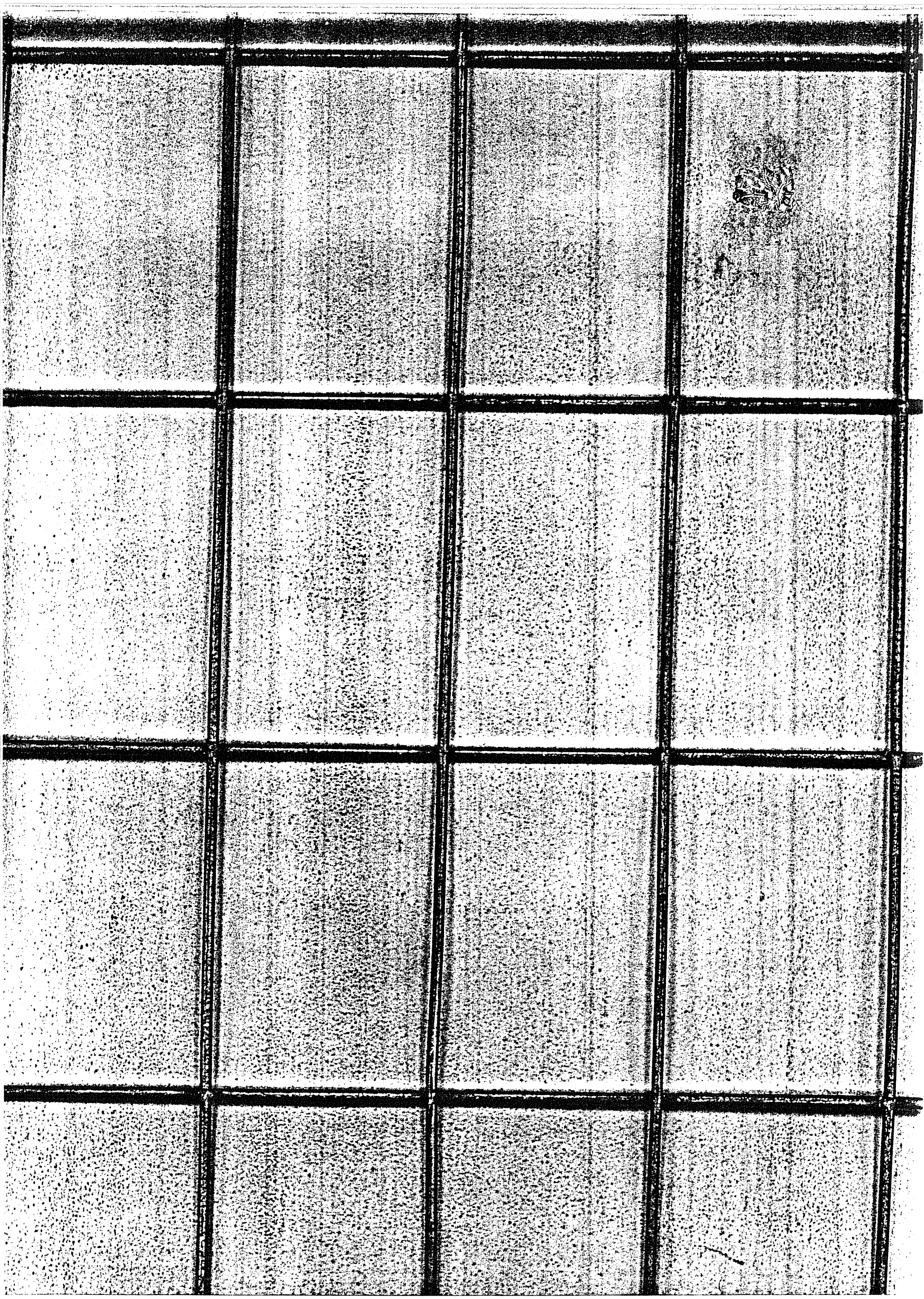
B.3. 5.0cm galvanised chicken wire.



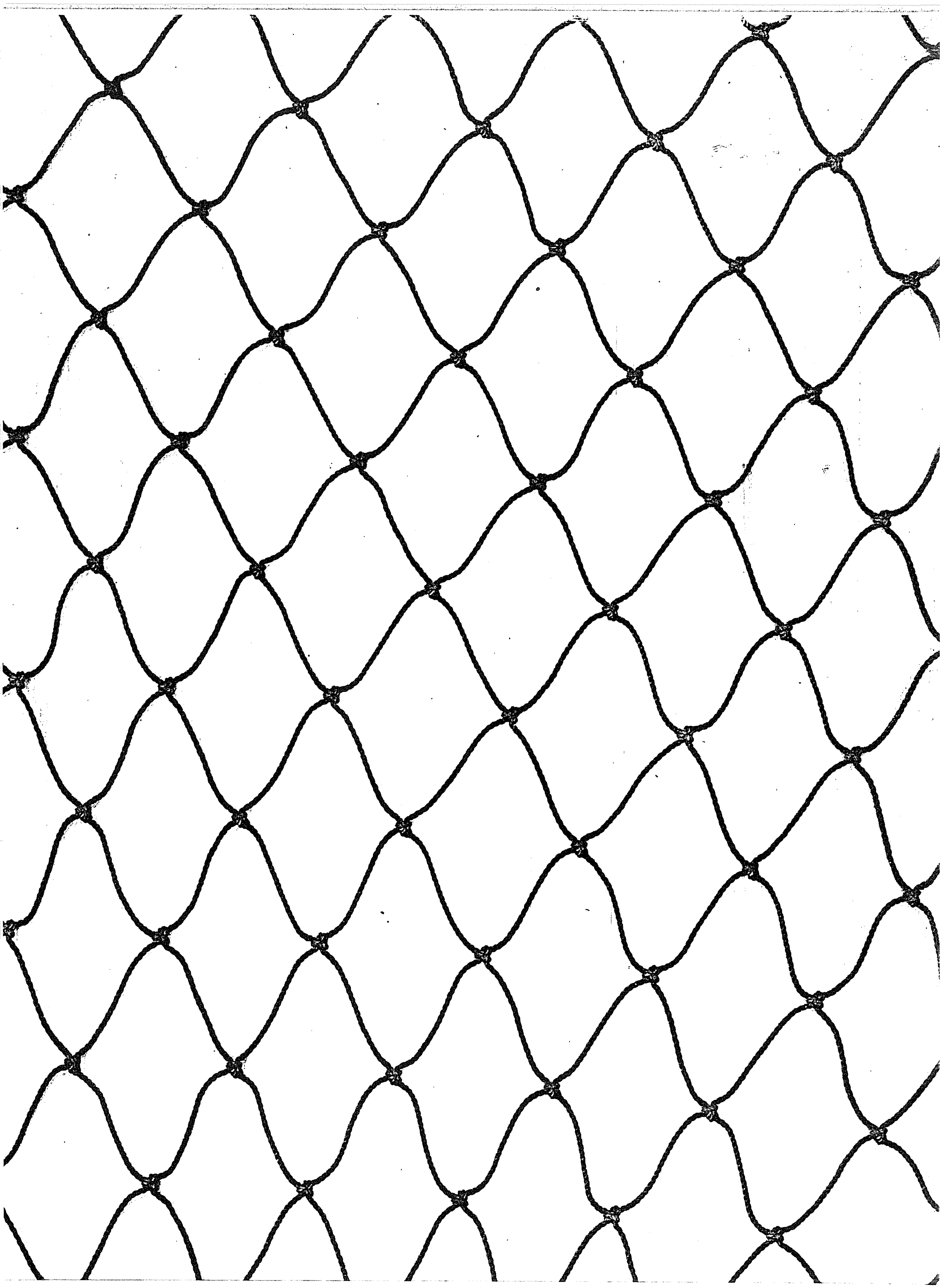
B.4. 1cm x 1cm galvanised ARC mesh.



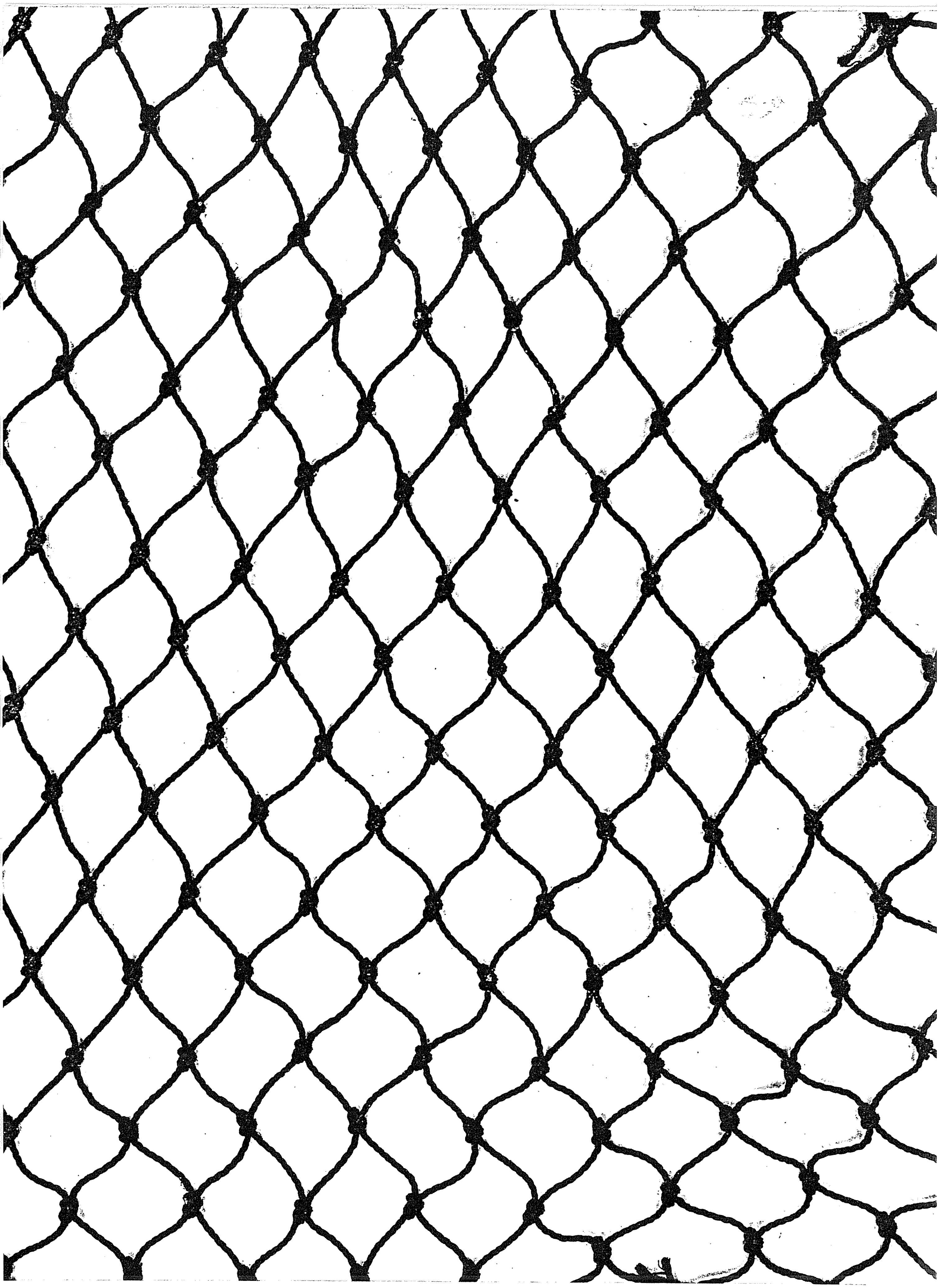
B.5. 2.5cm x 2.5cm galvanised ARC mesh.



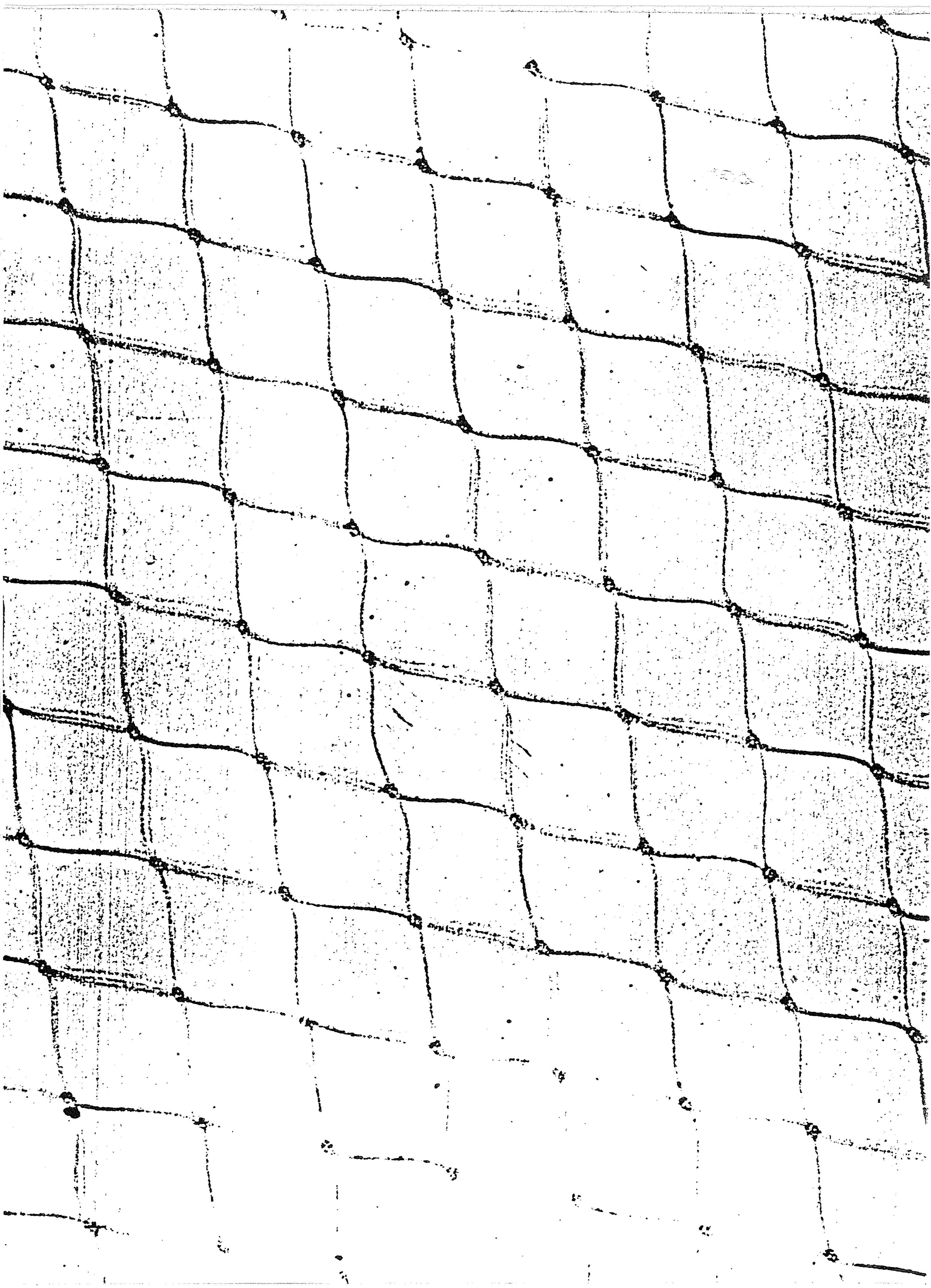
B.6. 5.0cm x 7.5cm galvanised ARC mesh.



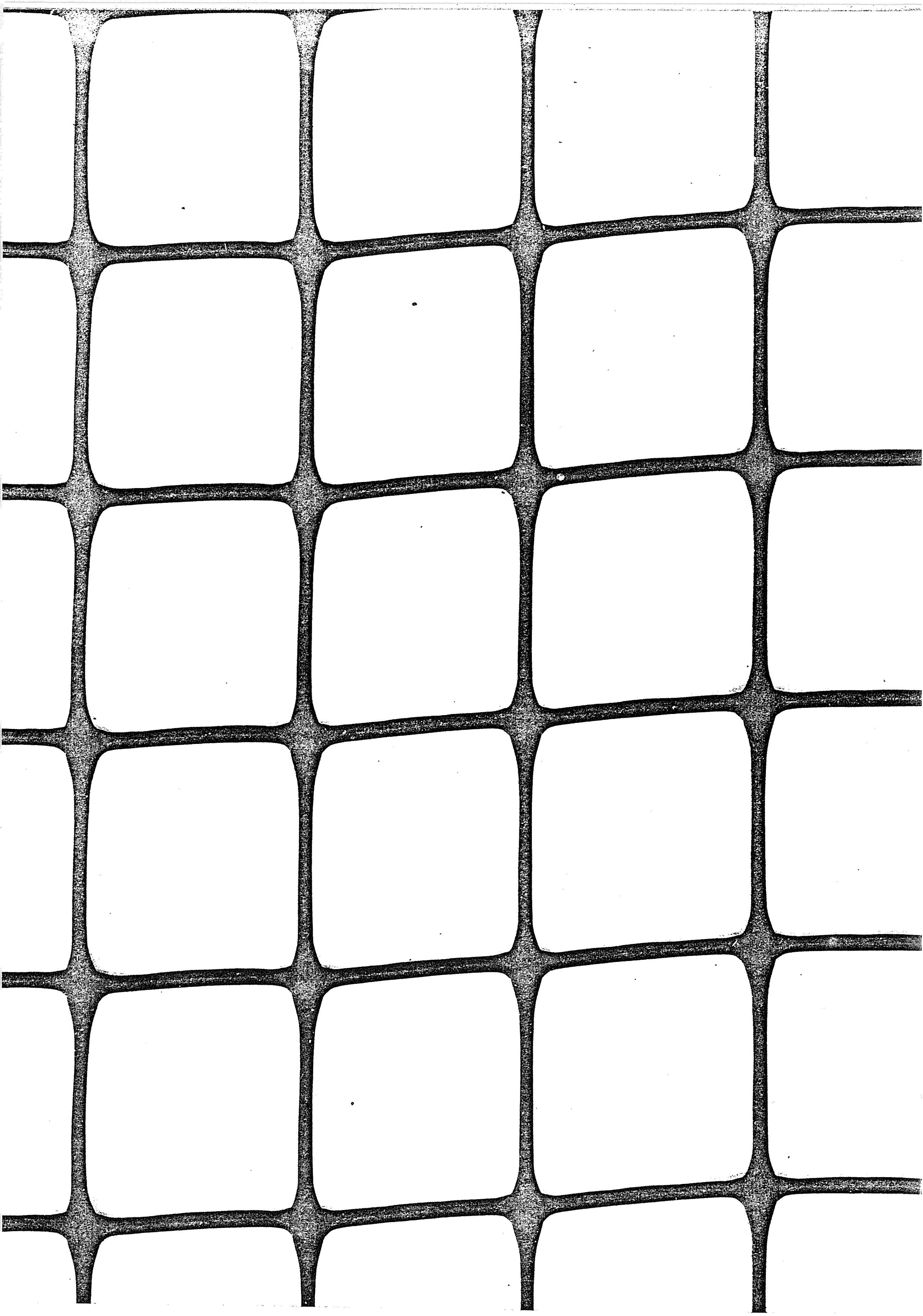
B.7. 58mm (2¼ inch) stretch 18 ply terylene multifilament (brown) gill netting.



B.8. 37mm (1½ inch) stretch 24 ply nylon multifilament (blue) prawn netting.



B.9. 58mm (2¼ inch) stretch monofilament gill netting.



B.10. 48mm NYLEX (plastic) "Instant Trellis".

APPENDIX C

BEHAVIOURAL OBSERVATIONS OVER THE CONTINOUS SIX HOUR PERIOD

CAGE	DIAM.(mm).	DETAILS OF ANIMAL.
I	180	up wall, along top, down, off
	180	diag, up, along top, diag, down, along skirt
	180	up wall, along top, down wall
	180	up in corner, along top, diag. down
	120	up in corner, down, off
	220	up, along at top
	400	diag, up, onto overhang, to lip, ½ body over and tried to attach arms, unable, rev, dir, and retreated, moved along o'hang, tried lip again, successful escape
A	350	on wall, down, off
	300	½ on wall, along, back to skirt
	300	½ on wall, off
E	180	up to top, turn along, down
	360	up, over, success, (v, quickly)
H	250	up in corner, stop
	180	onto skirt, reached wall, rev., off skirt
	150	up wall, reached o'hang but rev., diag, down, off
	200	up wall, onto o'hang, fell, up again, onto o'hang, rev., fell tryingto get back to wall
	250	around top, diag, down, to corner, off
	180	up wall, onto o'hang, fell
	350	onto o'hang, to lip, successful escape
	350	around top, down corner, off
	400	up in corner, onto o'hang, stop
F	220	on o'hang, turbulence from diver, fell
	220	up to top, around top, diag. down,off
	300	around top, down wall, off
	200	around middle of wall, up peg, diag. down wall, fell
	200	onto skirt, stop at wall
	350	onto skirt, slowed at wall, stop at wall
	220	diag, down, off
	300	up corner, along top, down
	250	up wall, along top, down corner

APPENDIX D

Daily summaries for each barrier.

DAY: SUNDAY 21/9/86

	CAGE												
	A	B	C	D	E	F	G	H	I	J	K	L	M
numb. in cage	7	7	5	5	4	7	6	7	10	9	4	4	4
numb. obs.	164	171	119	121	87	171	138	164	238	212	92	98	92
encounters	152	139	115	114	83	146	119	160	225	190	92	98	88
moving on wall	19	14	24	16	18	28	14	38	35	33	10	23	9
escapes	8	5	14	4	16	7	9	5	3	3	4	0	1
efficiency	95	96	88	95	81	94	92	96	99	98	96	100	99
crossing time	0.9	1.4	0.4	1.3	0.2	1.0	0.7	1.4	3.3	3.0	1.0	∞	4.0
attempts/success	2.4	2.8	1.7	4.0	1.1	3.4	1.6	7.6	8.3	11.0	2.5	∞	9.0

DAY: MONDAY 22/9/86

	CAGE												
	A	B	C	D	E	F	G	H	I	J	K	L	M
numb. in cage	11	10	6	8	6	10	8	10	13	10	4	5	7
numb. obs.	258	240	156	202	152	237	205	238	322	238	104	123	179
encounters	247	209	140	173	129	205	192	236	286	224	98	122	175
moving on wall	8	15	27	16	37	19	24	18	18	6	10	7	5
escapes	2	10	15	7	27	4	12	2	5	3	6	1	3
efficiency	99	95	89	96	79	98	94	99	98	99	94	99	98
crossing time	5.5	1.0	0.4	1.1	0.2	2.5	0.7	5.0	2.6	3.3	0.7	5.0	2.3
attempts/success	4.0	1.5	1.8	2.3	1.4	4.8	2.0	9.0	3.6	2.0	1.7	7.0	1.7

DAY: TUESDAY 23/9/86

	CAGE												
	A	B	C	D	E	F	G	H	I	J	K	L	M
numb. in cage	10	9	5	9	4	10	5	10	14	9	5	5	8
numb. obs.	234	221	116	219	103	235	124	229	333	217	120	119	203
encounters	226	197	115	209	96	225	119	227	297	207	110	119	202
moving on wall	33	32	31	21	24	26	17	40	38	32	19	21	14
escapes	3	14	13	6	19	1	5	2	1	2	4	0	12
efficiency	99	93	89	97	80	99	96	99	99	99	96	100	94
crossing time	3.3	0.6	0.4	1.5	0.2	10	1.0	5.0	14	4.5	1.3	∞	0.7
attempts/success	11	2.3	2.4	3.5	1.3	26	3.4	20	38	16	4.8	∞	1.2

DAY: WEDNESDAY 24/9/86

	CAGE												
	A	B	C	D	E	F	G	H	I	J	K	L	M
numb. in cage	10	7	4	12	3	10	5	8	14	8	5	5	9
numb. obs.	242	166	92	286	79	240	48	192	332	198	120	120	214
encounters	237	143	85	272	77	231	112	191	308	183	102	115	213
moving on wall	10	11	27	12	14	10	6	22	10	3	1	0	20
escapes	2	7	23	6	14	2	5	5	0	1	1	0	17
efficiency	99	95	73	98	82	99	96	97	99	98	99	-	92
crossing time	5.0	1.0	0.2	2.0	0.2	5.0	1.0	1.6	-	8.0	5.0	5.0	0.5
attempts/success	5.0	1.6	1.2	2.0	0.2	5.0	1.0	4.4	-	3.0	1.0	-	1.2

DAY: THURSDAY 25/9/86

	CAGE												
	A	B	C	D	E	F	G	H	I	J	K	L	M
numb. in cage	12	3	4	11	3	10	5	9	15	8	5	5	7
numb. obs.	106	30	32	101	28	89	45	81	134	72	45	45	62
encounters	100	30	30	95	25	87	44	80	130	68	44	45	60
moving on wall	5	12	16	26	16	24	24	27	33	22	7	23	15
escapes	3	4	6	6	7	1	6	1	0	1	1	1	6
efficiency	97	87	80	94	72	99	84	99	100	98	98	98	90
crossing time	4.0	0.7	0.7	1.8	0.4	10	0.8	9.0	15	8.0	5.0	5.0	1.2
attempts/success	1.7	3.0	2.3	4.3	2.3	24	4.0	27	-	22	7.0	23	2.5