

Shrimp by-catch reduction using a short funnel net, in the Gulf of Tehuantepec, South Pacific, Mexico

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Abstract: Reduction of the by-catch in shrimp fishery is an important goal worldwide. In order to compare by-catch using the conventional trawling net and a newly designed short funnel net, nine cruises were carried out by the commercial fleet operating in the Gulf of Tehuantepec, Mexico. A total of 480 trawls were done (mean duration: 85 min). The experimental trawls using the modified net produced a 21.13-28.86 % by-catch reduction (confidence interval 95 %), a 3 % increase of shrimp catch, and a significant reduction on net recovery time. *Rev. Biol. Trop.* 55 (3-4): 889-897. Epub 2007 December, 28.

Key words: Shrimp trawling, by-catch, new net design.

Shrimp trawling fishery in the México started in 1927 (Ferreira 1965, Igartua 1992) and development in fishing techniques and gear structure has not been constant. At the beginning and until the decade of 1950, ships were equipped with wing and "corua" trawling nets (Sarmiento and Gil 1995). Later, former trawl nets were replaced by new American designs, mainly because these were simpler and easier to handle, and a substantial increase of their fishing efficiency was observed.

Some years later, Ercoli (1989) developed a selective device denominated DISELA, in order to reduce incidental catch of hake in the prawn fishery in Argentina; the device was incorporated in a 180 feet net size of mouth. Results of those experimental cruises indicated that when installed to the net, the excluder produced a 70 % escape of hake, and although an 18 % loss of prawn was observed, the device did not affect the size composition of the prawn catch. Afterwards, Conolly (1992) in

Brazil modified the shape of the traditional net by reducing the original length from 20.1 m to 11.25 m, to compare the differences of shrimp accompanying fauna (SAF) of both trawl nets within the commercial fleet. More recently, Sarmiento (1993) proposed a double shrimp net of 11.43 cm (4½") mesh size, these overlapped nets conformed a 5.71 cm (2¼") mesh size. Later on, various attempts regarding trawling system improvement for shrimp capture were carried out by countries like Canada and United States among others, while scarce technical innovations were done in Mexico.

In spite of the improvements developed until now, the incidental catch of non-target species is one of the most worrying problems that shrimp fishing faces, it is particularly important in tropical areas where shrimp by-catches are high and an important amount is discarded.

Because of the importance of a sustainable use of marine resources, a traditional trawl and a modified trawl were tested in the Gulf

of Tehuantepec, Mexico, in order to assess efficiency on by-catch reduction in shrimp trawling; cruises were carried out during commercial and shrimp ban seasons.

MATERIALS AND METHODS

Study area description: The Gulf of Tehuantepec is the most important fishing area in Mexico's southern Pacific and corresponds to the traditional shrimp fishing grounds for Oaxaca and Chiapas commercial fleets with a continental shelf of approximately 5 988 km² (Sepúlveda & Soto 1987). The Gulf extends from Punta Chipehua, 8 km West from Salina Cruz Port, in Oaxaca State, to Puerto Madero, Chiapas (16°00' – 14° 42' N, 95°25' – 92° 30'W).

The Gulf's geological origin is based on the tectonic activity generated by the interaction between the Cocos and Caribbean plates. Geologically, it is conformed by detritus of terrigenous material from metamorphic and plutonic rocks that are continuously eroded, and have the ocean as final destiny (Carranza-Edwards *et al.* 1998). The marine floor texture distribution of silts are composed principally by muddy sands, sandy-muds and muds (Carranza-

Edwards 1987). The most important lithologic groups on the coastal zone are silts and sedimentary rocks of different ages, intermediate and basic volcanic rocks, plutonic and metamorphic rocks (Padilla and Sánchez 1983).

The Gulf of Tehuantepec is influenced by northern winds, as well as tropical storms, quasi-biannual Pacific oscillation and in a higher degree by "El Niño" phenomenon (Hurd 1929). According to Köppen (modified by Garcia 1981), the region type corresponds to a humid warm climate (Monreal-Gomez and Salas de León 1998), with summer rainy season and presence of midsummer isotherm, and an annual temperature that corresponds to the Ganges type (Anonymous 1988).

Fleet characteristics: The experimental cruises were carried out onboard commercial trawlers of the shrimp fleet that operates in the Gulf of Tehuantepec, having as disembarking ports Salina Cruz in Oaxaca State and Puerto Madero in Chiapas. Technical characteristics of ships used for the experimental cruises are listed in Table 1.

Description of fishing gears: Modification of fishing gears were applied for two trawl net

TABLE 1
Characteristics of shrimp fleet experimental units

Vessel	Year	L (m)	W (m)	D(m)	Hp*	GTR*	NTR*	Hull material
F/V 1	1982	20.26	6.60	3.60	375	123.24	73.24	Steel
F/V 2	1974	21.60	6.00	3.26	365	93.82	28.96	Steel
F/V 3	1964	21.00	5.40	4.20	170	96.01	62.28	Steel
F/V 4	1980	21.00	6.00	3.35	365	115.64	62.95	Steel
F/V 5	1976	21.00	6.79	3.35	365	96.96	62.08	Steel
F/V 6	1966	21.30	6.16	3.10	370	113.34	84.73	Steel
F/V 7	1971	19.80	5.41	3.60	380	65.00	32.50	Steel
F/V 8	1974	21.60	6.00	3.26	375	93.82	28.96	Steel
F/V 9	1972	22.87	6.10	3.45	380	100.01	65.37	Steel

*(L= Length; W= Width D= Draft; Hp= Horse power; GTR=Gross Tonnage Record; NTR = Net Tonnage Record)

Note. By mandate of the Federal Law for Transparency and Access to Government Public Information, names of fishing vessels participating in any research conducted under government endorsement are confidential.

designs: Volador (Flyer) type, which is used by 70 % of the fleet operating in the Gulf of Tehuantepec (Sarmiento-Náfate and Gil-López 1998) and the Cholo type, which was only used in one cruise. Netting materials used to built both trawls were polyamide (PA) multifilament dye and treated, twine #18 and diameter of 1.6 mm, mesh size 4.44 cm (1¾") and 5.08 cm (2"); whereas the codend was made of the same PA and 3.81 cm (1½") mesh size.

Net was modified by making all bars tapping along lateral edges of upper and lower panels, in order to reduce the length of the funnel on approximately 49 % of the normal length. The reduction was determined by the net size, and by the array of the sections (regarding dimensions of side panels, as well as upper and lower panels length). These characteristics may vary from one net to another, although upper panel may have the same length. Changes in the Volador net were made inside, upper and lower panels, resulting in a general decrease of length funnel, particularly in the last section before the codend.

The whole trawling system was rigged according to skipper's skill and experience. Characteristics of experimental nets used in the cruises regarding type, size and mesh size, are listed in Table 2. Modifications were based on the concept of fish behavior. Fish will escape using its lateral muscles, that would enable

them to slip from the original 11.43 cm (4 1/2") mesh. Nevertheless, as the target species, shrimp will be caught, since there is a significant difference on fish and shrimp locomotion patterns. In this study is also assumed that shrimp by-catch obtained by the conventional net represents the unit, this means, it will be the unit of measure between the conventional and modified nets, and therefore, the difference found is given in these terms.

Experimental cruises: The cruises took place both during fishing and shrimp ban seasons of 1998 and 1999. Paired trawls were done on outrigger traditional trawlers; the modified experimental net was placed at starboard and control net at port side, as shown in Fig. 1 (to avoid bias, nets were switched after a number of sets). Catch obtained from each net was separated by a wooden gate to enable an adequate classification and quantification of the catch. Trawl sets were done within a range of 10.92-69.2 m depth along the fishing grounds of the Gulf of Tehuantepec. Trawling time varied from 32 up to 360 min, with an average of 85 min (mode of 60 min). For each trawl set, initial and final geographical data position (GPS Magellan DLX 5000) was registered, as well as total fishing time and depth (videosounder Furuno FVC 668).

Data analysis: Catch volumes were compared using frequency histograms and descriptive statistics, which provided reliable assessment to identify the most adequate analysis for the information to be processed. Variance Analysis Test was applied to shrimp and by-catch to establish if catches of both nets were statistically different with a significance level of 0.05, under the following hypothesis:

Ho = Differences between shrimp and by-catch in traditional and modified nets are originated randomly.

Ha = Differences between shrimp and by-catch in traditional and modified nets are derived from modifications made to the experimental net.

TABLE 2
Net characteristics by type for experimental trials

Vessel	Net type	Net size (m)	Mesh size (mm)
F/V 1	Volador	24.4 (80')	44.45
F/V 2	Volador	24.4 (80')	44.45
F/V 3	Volador	22.9 (75')	44.45
F/V 4	Volador	24.4 (80')	44.45
F/V 5	Volador	24.4 (80')	44.45
F/V 6	Volador	24.4 (80')	44.45
F/V 7	Volador	22.9 (75')	44.45
F/V 8	Volador	24.4 (80')	44.45
F/V 9	Volador	24.4 (80')	44.45

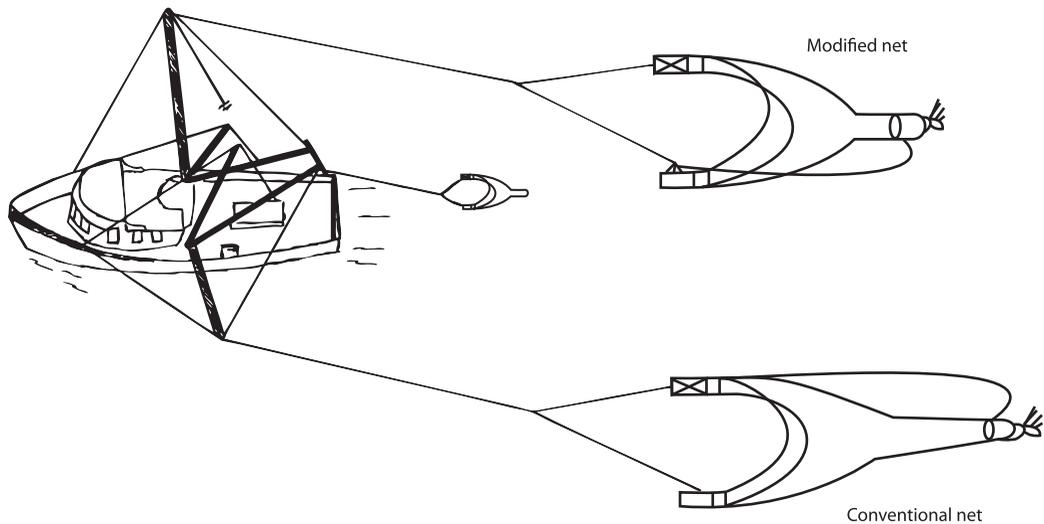


Fig. 1. Rigging of trawling nets in the experimental cruises.

RESULTS

Statistical tests were applied to shrimp catches and by-catch data, in order to determine significant statistical differences between conventional and modified fishing gears (short tunnel net). The analysis of variance of by-catch data from both conventional and modified nets, is significant ($F=11.94$, $p<0.05$), indicating that the modification of the fishing gear reduces substantially the by-catch of diverse species and for different sizes. Nevertheless, in spite of the different values obtained, no statistical differences were observed from shrimp catch results ($F=0.0005$, $p<0.05$).

A total of 480 paired trawl sets were made during nine experimental cruises, using both conventional and modified nets. Total trawling time was equivalent to 483.4 h.

Total catch was 95 213.8 kg, 3.31 % correspond to shrimp and 96.69 % to by-catch. Total by-catch from both nets were 92 061 kg, from which 55.75 % (51 315 kg) was for the conventional net and 44.25 % (40 746 kg) for the experimental net. This resulted in a 21 % of by-catch reduction for the modified net.

As for by-catch composition of each net, Table 3 shows the incidence of species with a

description of their commercial importance. In the list it is evident the absence of barracuda, silver corvina and the guitarfish on the modified net; whereas crabs, snails and shells, scorpionfish and devil ray don't appear when using the conventional net.

Shrimp by-catch composition: Shrimp by-catch species composition in the Gulf of Tehuantepec is diverse, some organisms being abundant. The catch composition during the study period reached up to 30 species of which 78 % were fish, 6.5 % rays, 6.5 % crabs, 6.5 % mollusks, 3 % other organisms (species of fish for this frequency was very low) and a 3 % composed mainly of plant material. From the total of species obtained as by-catch, only 10 % were considered as fine commercial species, which are used for consumption onboard; second class fish is used for commercial purposes.

The most important by-catch species in terms of abundance was the sheepshead (*P. axillaris*) with an average frequency value of 22 % in the conventional net and 20 % in the modified net (Tables 4 and 5). The blue crab was another important species, representing 7 % and 13.6 % of the catch by conventional and modified nets, respectively. The term "others"

TABLE 3
Species abundance in control trawls for Conventional (CN) and Modified (MN) nets during the study

Common name	Scientific name	CN	MN	Commercial sp.
Croaker	<i>Polydactilus approximans</i>	X	X	Yes
Silvery drum	<i>Larimus acclivis</i>	X	X	Yes
King fish	<i>Micropogon altipinnis</i>	X	X	No
Puffer	<i>Sphoreoides annulatus</i>	X	X	Yes
Spur drum	<i>Stellifer illecebrosus</i>	X	X	Yes
Silver butterflyfish	<i>Peprilus simillumus</i>	X	X	Yes
Chapeta	<i>Selene peruviana</i>	X	X	Yes
Sea catfish	<i>Arius seemani</i>	X	X	Yes
Shorthead lizardfish	<i>Synodus scituliceps</i>	X	X	No
Goatfish	<i>Pseudopeneus grandisquamis</i>	X	X	No
Armed snook	<i>Centropomus robalito</i>	X	X	Yes
Snapper	<i>Lujanus peru</i>	X	X	Yes
Crab	<i>Callinectes</i> spp.	X	X	Yes
Thoothed flounder	<i>Cyclopseta querna</i>	X	X	Yes
Lucero	<i>Diplectrum pacificum</i>	X	X	No
White mojarra	<i>Diapterus peruvianus</i>	X	X	Yes
Mojarra	<i>Eucinostomus entomelas</i>	X	X	No
Palmera	<i>Chloroscombrus orqueta</i>	X	X	No
Bobo	<i>Menticirrhus elongatus</i>	X	X	Yes
Ray	<i>Rhinoptera steindachneri</i>	X	X	Yes
Sheepshead	<i>Pomadasys axillaris</i>	X	X	No
Deepbody threadherring	<i>Ophistonema libertate</i>	X	X	No
Searobin	<i>Prionotus loxias</i>	X	X	No
Threadfish	<i>Chaetodipterus zonatus</i>	X	X	No
Barracuda	<i>Sphyrnaena ensis</i>	X		No
Silver drum	<i>Elattarchus archidium</i>	X		No
Guitarfish	No identified	X		No
Bluecrab	<i>Calappa convexa</i>		X	No
Snail & shells	Whitout name		X	No
Scorpionfish	<i>Scorpaena russula</i>		X	No
Devil ray	<i>Rhinobates glaucostigma</i>		X	No
Others	Whitout name	X	X	No
Waste	Whitout name	X	X	No

TABLE 4
By-catch composition by percentage of species using
the conventional net

Common name	Maximun %	Minimun %	Average %
Croaker	25.25	15.21	17.60
Silvery drum	5.10	1.50	3.90
King fish	7.60	3.00	4.40
Spur drum	10.50	3.40	6.30
Corvina	4.10	1.60	2.95
Silver butterfish	12.80	1.50	5.45
Chapeta	17.90	2.25	10.15
Sea catfish	6.30	1.50	4.40
Armed snook	8.10	0.75	4.10
Blue Crab	12.60	2.15	7.00
Toothed flounder	24.50	1.60	6.25
White mojarra	18.25	1.50	9.80
Mojarra	15.50	1.15	8.40
Mojarra charra	26.35	0.70	9.95
Bobo	2.55	2.00	2.30
Ray	17.30	1.00	8.90
Sheepshead	45.40	4.05	22.15
Sardine	3.00	1.70	2.40
Searobin	7.20	2.10	3.90
Threadfish	11.90	3.05	5.90
Snapper	11.35	2.15	6.75
Lucero	4.30	2.15	3.20
Puffer	4.25	0.80	2.50
Others	9.32	3.15	5.30
Waste	15.75	2.30	8.50
Barracuda	2.02	2.02	2.02
Guitarfish	4.32	4.32	4.32
Shortthead Lizardfish	6.38	6.38	6.38
Goatfish	7.75	7.75	7.75

TABLE 5
Estimated values of by-catch composition by percentage
of species using the modified net

Common name	Maximun %	Minimun %	Average %
Croaker	21.00	1.50	8.00
Silvery drum	7.00	1.20	4.00
King fish	10.00	4.00	6.65
Puffer	1.50	1.50	1.50
Blue crab	19.50	19.50	19.50
Snail and shells	2.25	2.25	2.25
Spur drum	4.10	3.00	3.50
Silver butterfish	2.25	2.25	2.25
Chapeta	18.50	3.00	10.10
Sea catfish	6.75	5.50	6.25
Shortthead Lizardfish	7.50	7.50	7.50
Goatfish	6.90	2.25	4.60
Armed snook	10.00	2.50	6.25
Devil ray	2.90	2.90	2.90
Snapper	6.90	5.20	6.10
Blue Crab	46.60	2.25	13.60
Toothed flounder	18.30	3.00	8.50
Lucero	1.50	1.50	1.50
Scorpionfish	11.70	11.70	11.60
Hite mojarra	20.00	2.90	11.05
Mojarra	16.70	3.60	8.25
Palmera	16.70	2.25	7.25
Bobo	8.40	2.15	5.30
Ray	23.00	0.75	11.30
Sheepshead	35.00	5.00	20.00
Sardine	4.30	1.50	2.90
Searobin	7.70	5.00	6.30
Threadfish	7.20	1.40	3.80
Others	9.20	2.00	4.80
Waste	4.50	2.00	3.50

in the species list, refers to species represented by a single specimen of small size, and included the following species: mullet, catarina, barracuda and tonguefish. Note that all the species referred in Tables 4 and 5 are the most usually obtained as by-catch fauna in shrimp fishery in the Gulf of Tehuantepec.

Data analysis indicated that both trawl nets catch the same species, however, their volumes varied. While the volume of chapeta, mojarra, sardine, silvery drum and snapper, was the same for both fishing nets, the volume of armed snook, bobo, crab, king fish, ray, searobin and toothed flounder, slightly increased with the modified net. Besides, the catch volume of croaker, goatfish, lucero, puffer, sea catfish, sheepshead, shorthead lizardfish, silver butterfly, spur drum, threadfish, white mojarra and others, was observed to be reduced when using the modified net (Tables 4 and 5).

By-catch with the conventional shrimp trawl: By-catch with the conventional shrimp trawl varied from 0 kg up to 1 200 kg per set, with a mean value of 106.9 kg (96.86 kg to 119.94 kg, with a confidence level of 95 %) and a median of 90 kg. The most frequent ranges observed were between 0-100 kg, that represented the 60.2 % of all trawls (289 trawls) carried out with this net; the second most frequent range found was 100-200 kg, with a 32.29 % of the total trawls (155 trawls). Table 4 also lists maximum, minimum and average values for the species captured with the conventional net. Values are given in percentages and they represent the proportion of the by-catch in general terms.

By-catch with the modified shrimp trawl (Short Funnel Net): By-catch with the modified net varied from 0 kg to 850 kg per set, with an average value of 84.8 kg (77.40 kg to 92.37 kg, with a confidence level of 95 %) and a median of 70 kg. The most frequent range was 0-100 kg representing 75.62 % of the total trawls (367 trawls). The second most frequent range observed was 100-200 kg, representing the 19.58 % of trawls (94 trawls). The

maximum, minimum and average values for the captured group of species with the modified net are detailed in Table 5.

By-catch reduction: A reduction from 15 % to 50 % of the by-catch component, was observed when using the modified fishing trawl at different depth strata. In this study, the largest number of trawls (50 % of total trawls), were carried out from 10 to 20 m deep, followed by those between 21 and 30 m.

Shrimp catch: Shrimps captured were mostly composed by white (*Litopenaeus vannamei*), brown (*Farfantepenaeus aztecus*), blue (*Litopenaeus stylirostris*) and red shrimp (*Farfantepenaeus brevisrostris*), with sizes from 80 mm to 220 mm of total length. The total catch of shrimp with both trawl nets was of 49 % and 51 % for the conventional and the modified gears respectively. In this study the shrimp volumes obtained with both nets were not statistically different by the ANOVA test applied; however, a slightly higher shrimp catch was observed with the modified net (3 %).

Regarding shrimp catches using the conventional net, they varied from 0 up to 26 kg, being the most frequent range 0 to 5 kg, with a value of 60 % (288 trawls), and the second ranged from 5 to 10 kg, with a value of 22.7 % (109 trawls). In the case of the modified net, catch variation ranged from 0 up to 26.2 kg, where the most frequent capture range was from 0 to 5 kg, representing the 62 % (299) of the total trawls; whereas the second range observed was between 5 and 10 kg, which represented 19.4 % (93) of the trawls.

DISCUSSION

In many world shrimp fisheries the under-utilized by-catch component represents almost 96 % of the total capture. Alternatives to reduce this accompanying fauna, are proposed in this paper and in previous studies (Sarmiento-Náfate and Gil-López 1998), such as the increase of mesh size from 3.81 cm (1 ½")

to 4.12 cm (1 5/8") in the codend, in order to allow the escape of juvenile fish caught during trawls. Among most fish groups, lateral muscles are used for movement, feeding, migration and escape; when caught in the net, the fish reaction results in a higher degree of movement when compared to shrimp (Okonski and Martini 1976). The behavior pattern described, becomes more evident in threatening circumstances, having more varied reactions, depending on the species, and even on the situation. With a trawling net, small fish have few escape possibilities, as the operation of the net is faster than its locomotion speed, being then captured in the net, whereas bigger fish may succeed in the escape process (Boddeke 1970). Taking this into consideration, one could conclude that reducing the size of the trawling shrimp net will cause a higher possibility of fish to escape, and reduce some of the by-catch fish species, as was observed in this study. Even though, a 3 % higher volume on shrimp catch was observed when using the modified net, more studies should be developed in order to confirm this result as to be completely related to the modification of the fishing gear. However, is very important to state that in terms of output, the modified gear won't cause a decrease of shrimp catch and therefore, it won't be an economical hazard to the activity; on the contrary, it may represent an increase of economic income as it is the target specie, and also a better shrimp quality.

From the results obtained, it is evident that the trawling fishing gears generate different effects due to the extraction of a varied number of fish and shellfish species that are, most of the time, discarded with the subsequent biodiversity disturbance. The new device decreased the by-catch component, and increased the shrimp one.

The modification of the fishing gear (short funnel trawl net) represented not only a by-catch reduction, but also may be interpreted as possible energy savings, since the less netting material used for the construction of the modified trawl (consequently less netting

working area), may generate a smaller trawling resistance, thus may cause a reduction in fuel consumption; however this objective was not directly quantified in this study. Nevertheless, there are obvious economic savings, since there is a reduction of netting materials for construction of the modified trawl, increased quality of shrimp and time decrease on trawl recovery and discharge of the catch.

As further information, authors of this study carried out some other tests in the trawling section of the capture system using a double rigged foot rope, and despite the observed results were not the expected, this alternative might be feasible, and the observed volumes of by-catch escape increased. Is possible that the use of double rigged foot rope in the fishing gear may favour by 60 % the by-catch escape, however, this possibility requires further research.

The principal conclusions of this study remark the importance on the reduction of the body of shrimp trawl nets, as a feasible alternative to reduce by-catch. Secondly, that an increase in the mesh size of the codend from 3.81 cm (1 1/2") to 4.12 cm (1 5/8"), allows juvenile fish to escape, without shrimp losses, and finally, the possibility to experience the double foot rope in shrimp trawling net, aiming to increase volumes of by-catch escapes.

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RESUMEN

La reducción de la fauna de acompañamiento del camarón (FAC) es uno de los temas de discusión más

importantes en la pesca mundial. Con la finalidad de contribuir en este t3pico, se dise1o y utiliz3 una red de arrastre variando la longitud del t3nel, y se compar3 su efecto con el de una red tradicional; durante 9 cruceros de la flota comercial en el Golfo de Tehuantepec, M3xico. Se realiz3 un total de 480 lances con promedio de 85 min cada uno. Los arrastres de la red modificada mostraron mejores resultados, con variaci3n entre 21.13 a 28.86 %, con un 95 % de confianza de reducci3n de FAC, un incremento de 3 % en la captura de camar3n, y una disminuci3n del tiempo de recuperaci3n, lo que sugiere un incremento en la eficiencia gracias al nuevo dise1o.

Palabras clave: arrastre de camar3n, captura incidental, dise1o de red, FAC.

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