Thesis for the Degree of Master of Fisheries Science

Stock assessment and fisheries management of scalloped hammerhead shark (*Sphyna lewini*) in the coast of Central America in Eastern Pacific Ocean

by

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KOICA-PKNU International Graduate Program of Fisheries Science

The Graduate School

Pukyong National University

February 2012

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중미 동부태평양 연안 홍살귀상어 (*Sphyrna lewini*)의 자원평가 및 어업관리

Advisor: Prof. Chang Ik Zhang

by

Salvador Cokkom Siu Navarro

A thesis submitted in partial fulfillment of the requirements for the degree
of Master of Fisheries Science
in KOICA-PKNU International Graduate Program of Fisheries Science,
The Graduate School,
Pukyong National University
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February 24, 2012

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Abstract

Artisanal fisheries in Central America are fishing hammerhead shark as a target and/or non-target species with gillnets. Scalloped hammerhead sharks (*Sphyrna lewini*) migrates along the warm current waters as large schooling and seasonally aggregates at seamounts. In this study, a total of 4,677 samples of body lengths were collected from commercial fisheries in eleven ports and villages along the coast of Central America Pacific Ocean and analyzed from April to November 2009. The sizes ranged from 30 cm to 275 cm in length and more than 55 cm in height. The growth parameters were estimated to be K = 0.15/year, t_0 = -0.57 year, L_∞ = 366 cm. the estimates of total mortality (Z) was 0.919 /year, natural mortality (M) was 0.450/year, fishing mortality (F) was 0.469/year, and t_c was 0.408 years. Biomass of *S. lewini* was estimated to be 54,230 mt in 2009 by the length based cohort analysis. The biological reference points for *S. lewini* were calculated that $F_{35\%}$ and $F_{40\%}$ were 0.267/year and 0.228/year, respectively. The acceptable biological catch (ABC) was estimated to be 4,782 mt when F_{ABC} was 0.115/year. This study is the first stock assessment for *S. lewini* carried out on the Central American region, which will provide more information on the population dynamics to assess the stock status and develop sustainable management plans for this species in future.

1. INTRODUCTION

Sharks, rays and chimeras, belong to the class Chondrichthyes where are 368 recognized species. The first sharks recorded to be appeared in the oceans between 400 and 350 million years. Moreover the Chondrichthyes are a high protein sources and economically important fisheries resources to coastal communities, particularly in Central America. Sharks generally have a late sexual maturity and relatively few progeny productivity than fishes. These biological characteristics have caused that they are considered as endangered species as fishing efforts have been increasing nowadays (RWGS, 2011).

The conservation and management of sharks' fisheries are affected by the lack of accurate data on catch, effort, discards, and trade data, as well as limited information on the biological parameters of many species and their identification (FAO, 2010-2011). In Central America there are two main problems in applying a management plan: 1) limited information of biological parameters and 2) the statistics report where the capture of sharks is registered as a whole, without distinction as species, both problems make it difficult for stock assessment and consequently a good fisheries management. Few efforts to improve statistical records in Central America, such as Costa Rica where their statistics about sharks are has registered into three major groups, i.e. Tresher sharks, Silkys sharks and Hammerhead sharks.

Many species of sharks utilize coastal estuarine environments as nursery grounds. It is thought that these areas offer the young more abundant food resources and better protection from predators than would be afforded to them in the pelagic environment (Lowe, 2002).

In some estuaries, juvenile sharks may represent the most abundant top-level predators in these marine ecosystems (Lowe, 2002). Neonates and juveniles spend the first part of their life within the nursery; these habitats are usually shallow, coastal areas that are geographically separated from adult feeding grounds (Duncan and Holland, 2006).

In Central America the *S. lewini* is common in the inshore gillnet and offshore longline fisheries in artisanal and industrial fisheries. Given its life-history characteristics, the *S. lewini* is expected to have very low resilience to exploitation and fisheries for the species should be managed with great caution (Maguire et al., 2006).

Many studies have been conducted about biological data of this shark around the world, but there is a lack of information about the status of biomass. The aim of this study is designing a management plan for this species to promote responsible fishing of this species in Central America, applying a new method to determine the biomass from minimal biological data (length).

If we increased knowledge and the dynamic development of fisheries, we can maintain a nutritional, economic and social contribution in long term and promote to the protection of fishes and human develop at the same time.

1.1 BACKGROUND

Chondrichthyans occupy a wide range of habitats, including freshwater riverine and lake systems, inshore estuaries and lagoons, coastal waters, the open sea, and the deep ocean. Historically considered of low economic value to large scale fisheries and therefore neglected by fishery management agencies, today many of these fishes have become the target of directed commercial and recreational fisheries around the world, and are increasingly taken in the bycatch of fisheries targeting other species (Camhi et al., 1998).

Sharks Fisheries have declined globally due to over- and unregulated fishing. As with many collapsed and unmonitored coastal fisheries, information is difficult to estimated (Lam et al., 2010).

In America there is a renewed effort towards management and conservation of sharks, in the framework of the International Action Plan Sharks led by FAO in 2008, in Manta, Ecuador, which sought to identify areas of action and cooperation to address this problem.

As part of the meeting held by *The Organization of Fisheries and Aquaculture Sector of Central America* (OFASCA) in November 2008, with

Central American countries, which also included representatives of IATTC, formed the Regional Working Group on Sharks (RWGS), one of the achievements made during the meeting was planning and development of a Pilot Regional Monitoring Landings of Sharks, Rays and Sharks Neonatal (PRMLS), based on harmonization of the use of methodologies and the use of regional formats for collecting information.

The PRMLS in Central America was conducted from April to November 2009 with a total of 5,532 specimens sampled. Within the database it had recorded a total of 37 species of elasmobranches; including 7 of them are of commercial importance.

Artisanal fisheries in Central America are very diverse and characterized by: 1) the use of different types of fishing gear, 2) fishing many stocks species of small sizes, 3) with the participation of full-time fishermen and part-time, and 4) the presence of numerous, often isolated, landing sites and a variety of marketing channels. A rough estimate indicates that there are about 19,559 artisanal vessels, with about 118,400 fishermen operating in the region, only in the area of the Pacific Ocean, in total are 135,400 fishermen and 61,725 vessels in both areas (Atlantic and Pacific ocean) (OFASCA, 2010). In many parts of the activities of small-scale fisheries also provide important means of generating income for the rural poor, including those who fish only occasionally and are not officially recognized as fishermen (subsistence fishing) (FAO, 2006) (APPENDIX A).

1.2 RESEARCH CONDUCTED OF *SPHYRNA LEWINI* (GRIFFITH AND SMITH, 1834)

There are several studies on age, growth and population, conducted mainly in the Atlantic Ocean, which are summarized in the Table 1.

Table 1. Research conducted on biological parameters and of *S. lewini* (CITES, 2010)

Parameters	Results	References
Growth coefficient *K* (von Bertalanffy) (year^{-1})	0.13 (Male, Western North Altantic.)	Piercy and others, (2007)
	0.09 (Female, Western North Altantic)	Chen and others (1990)
	0.13 (Male, Eastern pacific)	Tolentino and Mendoza (2001)
	0.15 (Female, Eastern pacific)	Tolentino and Mendoza (2008)
	0.22 (Male, Western pacific)	
	0.25 (Female, Western pacific)	
Maturity Length (Fork length, cm)	131 (Male, Western North Altantic)	Piercy
	180-200 (Female, Western North Altantic.)	(verbal communication)
	152 (Male, Western pacific)	Tolentino and Mendoza (2001)
	161 (Female, Western pacific)	Chen and others (1988)

	108-123 (Male, Australia septentrional) 154 (Female, Australia septentrional) 138-154 (Male, Western South Altantic) 184 (Female, Western South Altantic) 135 (Male, Indo-Pacific) 175-179 cm FL (Female, Indo-Pacific)	Stevens & Lyle (1989) Hazin and others (2001) White and others (2008)
Age of maturity	6 years (Male, Western North Altantic) 15-17 years (Female, Western North Altantic.)	Piercy (verbal communication)
Observed Longevity	30,5 years(Western North Altantic) 12,5 years (Eastern pacific) 14 years (Western pacific)	Piercy and others (2007) Tolentino & Mendoza (2001) Chen and others (1990)
Gestation period	8-12 Month (Global)	Piercy (comunicación personal) Chen and others (1988) Hazin and others (2001) White and others (2008)
Reproductive periodicity	2 years	Piercy (verbal communication) Chen and others (1988) Hazin and others (2001) White and others (2008)
Number of offspring (average)	Normal range =12-41	Piercy (interview)
Generation time	23 (Western North Altantic..) 14 (Western North Altantic..)	Chen and others (1988) Hazin and others (2001)

	25-26 (Indo-Pacific)	White and others (2008)
	20 years	Cortés and others (2008)
rate of population growth (r)	0,09 yrs-1	Cortés and others (2009)

Abundance analysis was carried out using CPUE as a measure unit, which provides an overview of the increase or decrease in abundance of *S. lewini* but gives no information about their population. Limited research has conducted in the Pacific Ocean, much less in the area of Latin America (Table 2).

Table 2. Research conducted on CPUE and the tendency to increase or decrease in the populations of *S. lewini* (CITES, 2010)

Year	Ocean placed	Data	Trends	Reference
1972-2003	Atlantic Ocean NOc.	Fishery independent survey (CPUE)	Decrease 98%*	Myers and others(2007)
1992-2003	Atlantic Ocean NOc.	Log of commercial pelagic (CPUE)	Decrease 89%*	Baum and others (2003)
1992-2005	Atlantic Ocean NOc.	Observer Program commercial pelagic longline (CPUE)	Decrease 76%*	Baum and others (2003)
1983-1984 y 1991-1995	Atlantic Ocean NOc.	Fishery independent survey (CPUE)	Decrease 66%	Ulrich (1996)
1994-2005	Atlantic Ocean NOc.	Observer Program commercial gill net (CPUE)	Decrease 25%*	Carlson and others (2005)

1994-2005	Atlantic Ocean NOc.	Observer program longline shark fishing trade (CPUE)	Increase 56%*	Hayes and others (2009)
1995-2005	Atlantic Ocean NOc.	Fishery independent survey (CPUE)	Decrease 44%*	Ingram and others (2005)
1981-2005	Atlantic Ocean NOc.	Population Assessment (capture biologycal cycle, CPUE)	Decrease 72%*	Jiao and others (2008)
1981-2005	Atlantic Ocean NOc.	Population Assessment (capture biologycal cycle, CPUE)	Decrease 83%*	Hayes and others (2009)
1898-1922, 1950-2006, 1978-1999, 1827-2000	Mediterranean Sea	Sightings, traps, longlines (CPUE)	Decrease 99%*	Ferretti and others (2008)
1993-2001	Atlantic Ocean NOc.	Landing	Decrease 60-90%	Vooren and others (2005)
1978-2007	Atlantic Ocean SOc.	Observer Program commercial pelagic longline (CPUE)	-	Carvalho (verbal communication)
1992-2004	Eastern Pacific Ocean	Sighting	Decrease 71%*	Myers and others (2007)
2004-2006	Eastern Pacific Ocean	Landing	Decrease 51%	Martínez-Ortiz and others (2007)
1963-2007	Western Pacific Ocean	Mesh size (CPUE)	Decrease 85%	De Jong and Simpfendorfer (2009)
1978-2003	Western Pacific Ocean	Mesh size (CPUE)	Decrease 64%*	Dudley and Simpfendorfer (2006)
1997-1998 and 2004-2005	Eastern Pacific Ocean	Catch (CPUE)	Decrease 50-75%	Heupel and McAuley (2007)

1.3 SHARKS FISHERIES IN CENTRAL AMERICA

Sharks, rays and chimaeras are grouped within the Chondrichthyes, a class that includes all cartilaginous fish, also called elasmobranchs (sharks and batoids) and holocéfalos (chimeras). These species also are an evolutionarily successful group, with almost 1,200 living species, very well adapted to a wide variety of habitats such an evolutionary success that have remained virtually unchanged for nearly 400 million years (Compagno et al., 2005; Garcia Nuñez, 2008) (APPENDIX B).

Chondrichthyans have biological characteristics unique and are located mainly in the highest level of the food chain of the marine ecosystem. Sharks have slow growth, longevity, maturation age, and low fertility in most species, therefore their abundance is relatively small compared with other groups. These features, coupled with the high fishing effort which are subject to worldwide and sum based on historical information available, we do assume that these species may be more vulnerable to fishing pressure and other resources that can be exploited (Bonfil , 1994).

At present, the levels in the fishery catch of sharks worldwide represent a situation which has aroused great scientific interest, increased their catches and the high vulnerability of their populations, of general concern, which has led to bodies such as FAO to develop the Action Plan for the Conservation and Management of Sharks (IPOA - Sharks) (FAO, 2001), within the framework of the Code of Conduct for Responsible Fisheries, encouraging countries to develop their own plans National Action. The guiding principle of the IPOA - Sharks, requires states to contribute to the mortality of a fish species or stock should participate in its conservation and management (RWGS, 2011).

In many parts of the world, the shark is considered an important source of protein, offers employment and economic benefits to those involved in the fishery, marketing and consumption. One of the most serious problems that one has for the evaluation of the fishery for this resource are the statistics records, because they are not accurate due to the high degree of organization required and monitoring costs involved in a structured, organized and disciplined.

Shark fisheries in Central America are mainly based on pelagic species, but also caught along the coast. 29 species are in this region, at least, eight of them correspond to pelagic individuals, five are coastal pelagic and 16 are coastal. The most abundant in the catches of both artisanal and industrial vessels correspond to pelagic species and coastal pelagic-wide distribution, also common in other fisheries such as those occurring in Mexico, South America and islands of the Eastern Tropical Pacific Ocean. This is not surprising given that many sharks, especially pelagic species, are typically straddling and highly migratory fish. *C. falciformis*, *P. glauca* and *S. lewini* appear in the landings of all countries and probably gather together the largest volumes in these fisheries (Porras, 1996). In Central America the catch of sharks was 10,663 mt in 2009 (Fig.1).

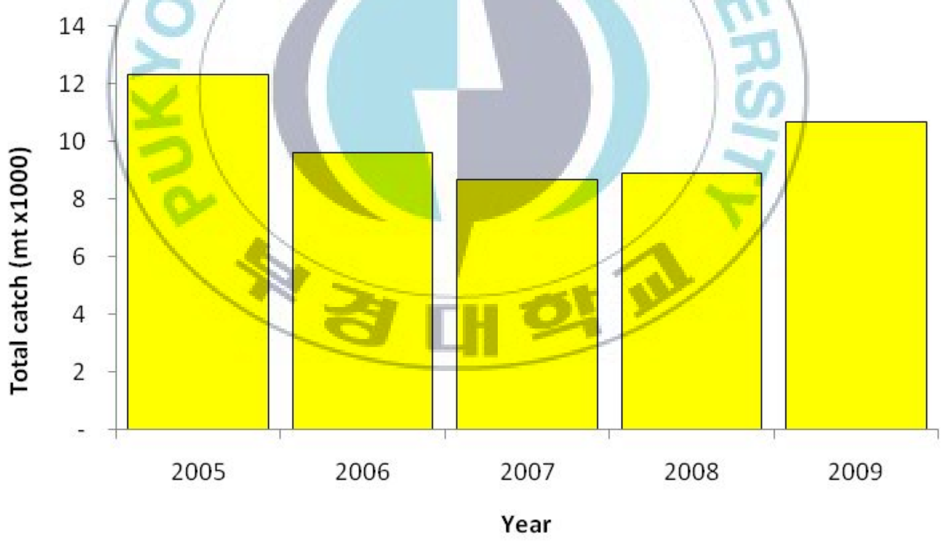

Fig. 1. Total catch of sharks by year in Central America from 2005-2009 (FAO, 2011).

The *S. lewini* is circumglobal, residing in coastal warm temperate and tropical seas (Compagno, 1995). This species, and perhaps all hammerhead sharks (Sphyrnidae), have geomagnetic orientation and navigation abilities, possibly enhanced by their unique laterally expanded head (Klimley, 1993; Duncan et al., 2006) (APPENDIX B).

Using information of each country about the representation of this species within the shark fishery, it was estimated that the *S. lewini* represents 51% of the total catch of sharks, mainly because it is mainly caught neonates. With this data, was estimated the annual catch of this species from 2005 to 2009, estimating an average of 5,438 mt in 2009 (Fig. 2).

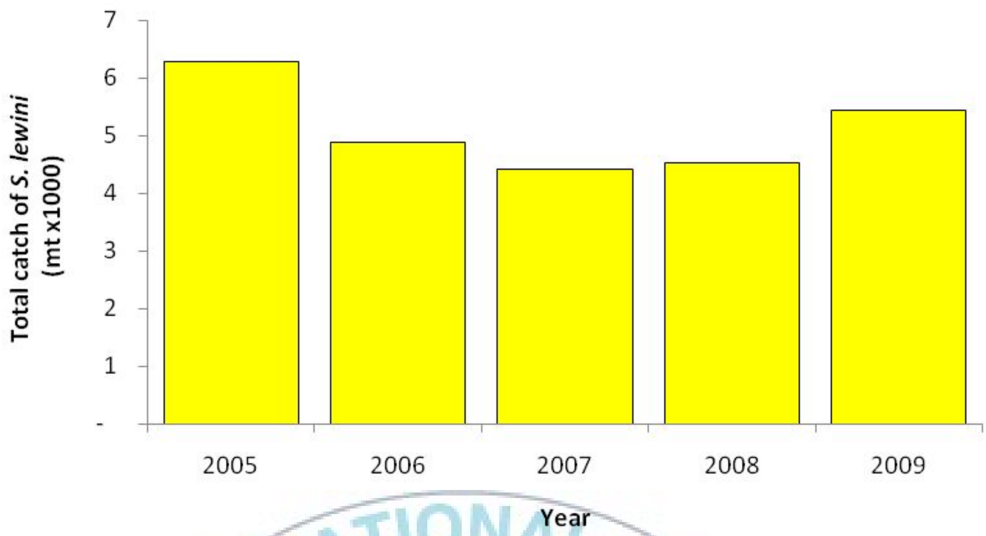

Fig. 2. Ratio of total catches of *S. lewini* by year in Central America from 2005-2009 (FAO, 2011)

Owing to its abundance, the species is common in inshore artisanal and small-scale commercial fisheries, as well as offshore operations. It is caught with pelagic long lines, fixed bottom long line, fixed bottom nets, and even bottom and pelagic trawls. Given its life-history characteristics, the *S. lewini* is expected to have very low resilience to exploitation and fisheries for the species should be managed with great caution (Maguire et al., 2006).

2. DATA AND METHODS

2.1 RESEARCH AREA

2.1.1 FISHING VILLAGES AND FISHING PORTS

Central America is a large geographical region that extends from the southern border of Mexico in North America to the northern border of Colombia, South America. Marine and coastal systems in the region support a complex interaction of different ecosystems, with an enormous biodiversity and are among the most productive in the world, provide breeding places for the reproduction of commercial species, generate tourism revenue and play a protective role (APPENDIX C).

In the follow Table 3 showed the summary of characteristic of fishing communities and fishing ports used in this research to monitor shark landings (Fig. 3).

It is clear that Honduras did not report details of the studied fishing villages on the Pacific Coast, specifically the Gulf of Fonseca, the descriptions of the fishing village was taken from nonpublic report and was describe apart.

In Honduras, the information listed was compiled from unpublished technical reports by the General Direction of Fisheries and Aquaculture of

Honduras (GDFAH/DIGEPESCA). Fishing villages studied were Cedeño, Guapinol, Punta Novillo and Boca de Rio Viejo. Fishing activities be do from boats into the Gulf of Fonseca using small boats called "pangas", which are built with fiberglass or wood. The fiberglass boats have a hull de 18 to 24 feet in length (from 5.40 m to 7.20 m), which represent 43.3% of the total fleet of all fishing communities that belong to Honduras in the Gulf. Only in the communities studied, a total of 104 active vessels of 613 registered in the offices of fishing with these characteristics. The number of vessels is the number of vessels active, what mean that does not match the number of boats that go out every day to fish in the Gulf. The fishermen involved various types of fishing gear, but the most important are gillnets (84%).

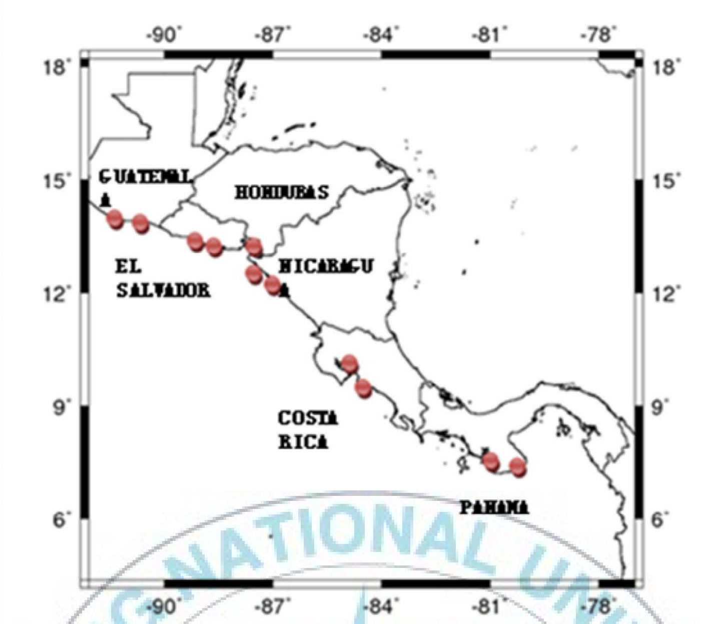

Fig. 3. Distribution of the fishing villages in each country of Central America that monitored from April to November 2009

Table 3. Summary of characteristics of target fishing port in Central America

Country	Landing area	Province or Department	Number of Vessels*	Engine Hp	No. Fisher men	Fisher men/vessel	Fishing gears	Type of Hooks	Quantity of Hooks	Mesh size of Gillnets	Quantities of Guillnets	Target Fisheries
GUATEMALA	Puerto de San Jose	Escuintla	200	40 - 75 Hp	751	3	Gillnets and Longlines	C/0 13; C/0 14	350 to 450 Hooks	1.3, 1.5 and 2,5 inches	8 gillnets of 1000 m. of long	Shark, dolphinfish, snaper, tunas, sea catfish, shrimp, etc.
	Puerto de Tulate	Municipio de San Andrés Villa Seca, departamento de Retalhuleu	50	40-48 Hp	100	2	Gillnets and Longlines	C 6; C 7 semi-eaglehook	300 to 350 hooks	2.5 inches	5 to 7 Gillnets of 1000 m of long	Snaper, sea catfish, shrimp, rays, etc.
EL SALVADOR	San Luis La Herradura	La Paz	200	25 -75 Hp	117	2 to 3	Gillnets and Longlines	C/0 (15, 16, 17, 18) and J (6)	80 - 363 hooks	2.5 to 3 inches	5 to 7 gillnets of 350 to 400 m. of long	Sharks, dolphinfish, mackerel, hammerhead shark, billfish
	Puerto El Triunfo	Usulután	150	15 -75 Hp	28	2	Gillnets and Longlines	C/0 (15, 16) and J (6)	230 - 240 hooks	2.5 to 3 inches	3 to 6 gillnets of 300 to 350 m. of long	sea catfish, meckerel, sharks
NICARAGUA	Puerto Corinto	Chinandega	88	40-75 Hp	276	3 to 4	Gillnets and Longlines	C/0 (15, 16) - J (6) y J (7)	180-3000 hooks	4 inches	3 to 6 of 200 to 300 m. of long	shark, dolphinfish, snapper, mackerel, sea catfish, bass, croakers, grunts, shrimp, berogata, mullet, halibut, lobster

	Masachapa	Managua	91	40-75 Hp	241	3 to 5	Gillnets and Longlines	C/0(15, 16)- J (6) and J (7)	200-1600 hooks	4 inches	4 to 8 of 200 to 300 m. of long	shark, dolphinfish, snapper, mackerel, sea catfish, bass, croakers, grunts, shrimp, berogata, mullet, halibut, lobster
COSTA RICA	Tárcoles	Puntarenas	17	15-60 Hp	40	2	Gillnets and Longlines	J(6) and J(7)	1200 hooks	3 inches	500 m. of long	croakers, sea bass, shrimp, snapper, grouper,conger and shark
	Quepos	Quepos	58	25-115 Hp			Gillnets and Longlines	C/0 (11,12,15 ,16,18); J (7, 8, 9, 11)	200-3600 hooks	3.5 inches	300 to 600 m. of long	eel, tuna, black tuna, barracuda, kingcroaker,grouper, catfish, croaker, mackerel, lobster, sole,mackerel, snapper, snook, sheepshead
PANAMA	Búcaro (Los Santos)	Los Santos	22	40 Hp			Gillnets and handlines		1-1000 hooks	3.5 - 14 inches	200-1000 m. of long	Sheriff, kingcroaker, Sole, snapper, snook, corvine
	Puerto Mutis (Veraguas)	Veraguas	14				Gillnets, Longline and Handline		1-8 hooks	3-3.5 inches	200-1000 m. of long	Sheriff, kingcroaker, Sole, snapper, snook, corvine

* All vessels was constructed using Fiberglass

2.2 DATA

Data were registered a total of 4,677 samples of *S. lewini* from April to November in 2009, distributed in 2,217 females, 2,208 males and 262 was unsexed, likewise were extracted 3,251 and 3,286 samples from the database to analyze the weight-length relationship and biomass, respectively. Sampled individuals belonged to commercial catches made by artisanal vessels using gill nets, long line and hand line, from the Pacific coast of Central America from Guatemala to Panama. In each country were identified the main artisanal ports (Table 4).

Sampling was conducted intensively for eight days per month between the third and fourth week, recording all catch.

Table 4. Fishing localities by country and sampling month

Country	Fishing localities	Sampling month
Guatemala	Buena Vista, Puerto de San José and Sipacate	2009: April May, June, July.
El Salvador	San Luis La Herradura and Puerto El Triunfo	2009: April, May, June, July, August.
Honduras (Gulf of Fonseca)	Cedeño, Guapinol, Punta Novillo and Boca de Rio Viejo	2009: April, September, Octuber.
Nicaragua	Corinto and Masachapa	2009: April, May, June, July.
Costa Rica	Puntarenas, Tarcoles and Quepos	2009: April, May, June, July.
Panamá	Búcaro, Mensabé (Azuero), Puerto Mutis and Punta Remedios	2009: May, June, July, November.

To register information a form was created specifically for this study (RWGS, 2011) which was divided into three parts:

I. Vessel data as date of sampling, type of engine, fuel used, and total catch weight, distance, direction or latitude and longitude.

II. Details Fishing Gear: Longline, gillnet, hand line or trawlnet.

III. Biological data: scientific name, length (total, fork and stem), sex, weight (total, fork and trail).

The emergence of this species depends when the adult sharks of this species typically migrate to nurseries for birthing (and possibly mating) during the rainy season (Branstetter 1990, cited for Duncan et al., 2006) from April to November (Escobar et al., 2006), and the effort is focused on this type of shark because it is carried with small vessels with small radius of operation (inshore fishing) (Fig. 4).

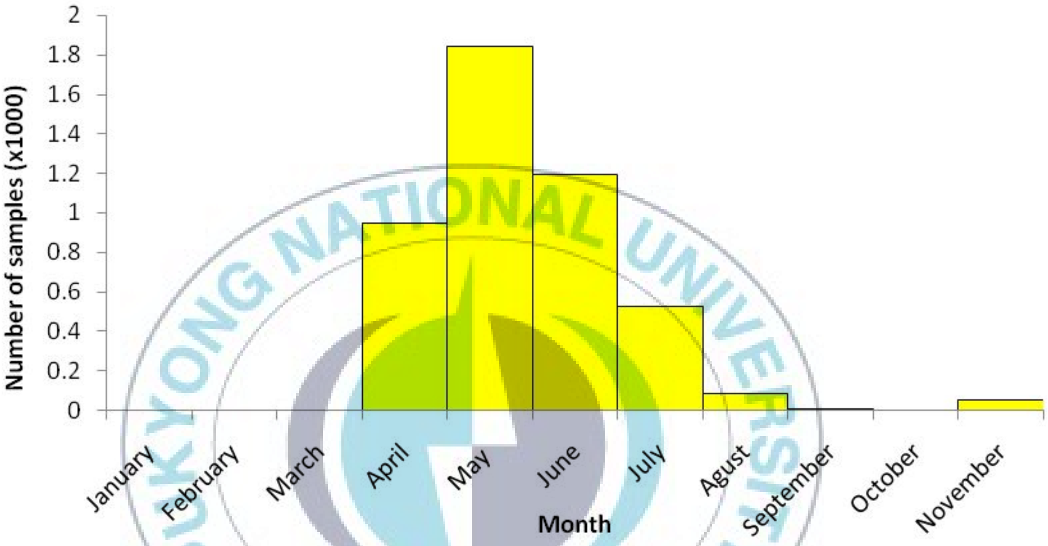

Fig. 4. Monthly change in catchof the *S. lewini* fishing from April to November 2009 in the data base of Central America.

A total of 26 species of sharks and rays were registered, 6 of them were the major species: *C. falciformis, C. limbatus, Dasyatis longus, N. velox, P. glauca* and *S. lewini*. These species were captured with different fishing gears used by artisanal fishermen.

Table 5. List of sharks and rays sampled captured in Central America in 2009

Scientific name	Common name	Number of Catch
Aetobatus narinari	Spotted eagle ray	12
Carcharhinus falciformis	Silky shark	224
Carcharhinus leucas	Bull shark	10
Carcharhinus limbatus	Blacktip shark	58
Carcharhinus porosus	Smalltail shark	6
Dasyatis brevis	Whiptail stingray	16
Dasyatis longus	Longtail stingray	93
Ginglymostoma cirratum	Nurse shark	1
Mustelus lunulatus	Sicklefin smooth-hound	1
Nasolamia velox	Whitenose shark	83
Rhinobatos leucorhynchus	Whitesnout guitarfish	16
Rhizoprionodon longurio	Pacific sharpnose shark	34
Sphyrna corona	Scalloped bonnethead	12
Sphyrna lewini	Scalloped hammerhead	4,677
Sphyrna tiburo	Bonnethead	1
Sphyrna zigaena	Smooth hammerhead	10
Urotrygon rogersi	Rogers' round ray	6
Galeocerdo cuvier	Tiger shark	2
Mustelus dorsalis	Sharptooth smooth-hound	1
Mustelus henlei	Brown smooth-hound	10
Prionace glauca	Blue shark	113
Rhinoptera steindachneri	Pacific cownose ray	1
Sphyrna mokarran	Great hammerhead	2
Torpedo spp	Pacific electric shark	60
Alopias pelagicus	Pelagic thresher	14
Alopias superciliosus	Bigeye thresher	9
Total catch		**5,472**

In this period 383 artisanal vessels were monitored, which caught approximately 4,677 *S. lewini* (Tabe 5). These vessels are mainly built with fiberglass and used outboard engines, with a fishing activity no more than 3 days or 72 hours (Table 6).

Table 6. Number of artisanal vessel registered by country in 2009 in Central America

Countries	Code	2009
Costa Rica	CR	41
El Salvador	ESA	133
Guatemala	GUA	36
Honduras	HON	28
Nicaragua	NIC	66
Panama	PAN	79
Total		**383**

The main gears are gillnet, longline and hand line. In Central America the most common fishing gear used to catch *S.lewini* is gillnet, due to its low effort required to operated and low cost for maintenance (Fig. 5).

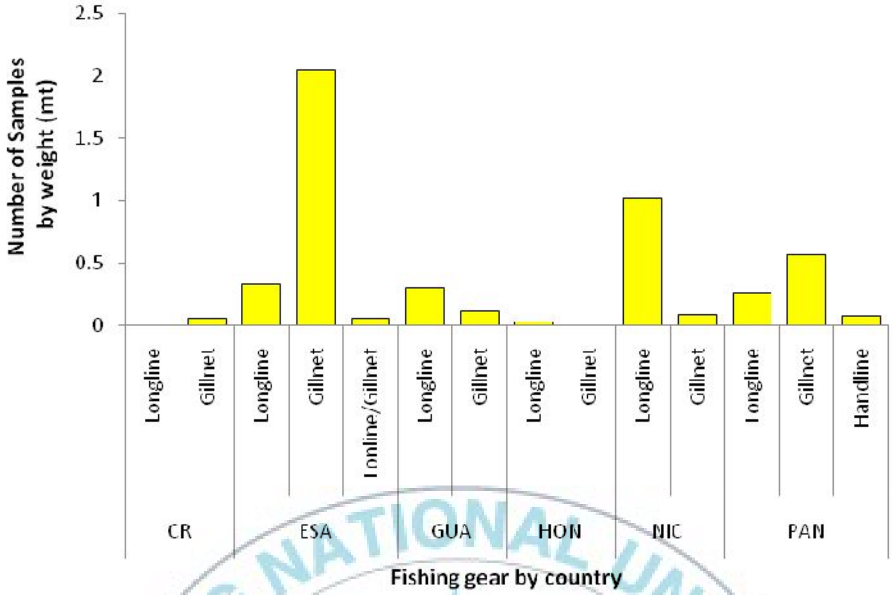

Fig. 5. Number of samples by fishing gear by country of *S. lewini* from April-November in 2009 in the data base of Central America.

For the analysis of data focused on the coastal artisanal fishery using gillnets as the main fishing gear with a mesh size from 2.57 to 14 inches, where the 58.3% of the total catch was captured with mesh size 2 and 6 inches. In El Salvador was also registered the use mixed of mesh size, bringing within the vessel three types of gillnets (Fig. 6).

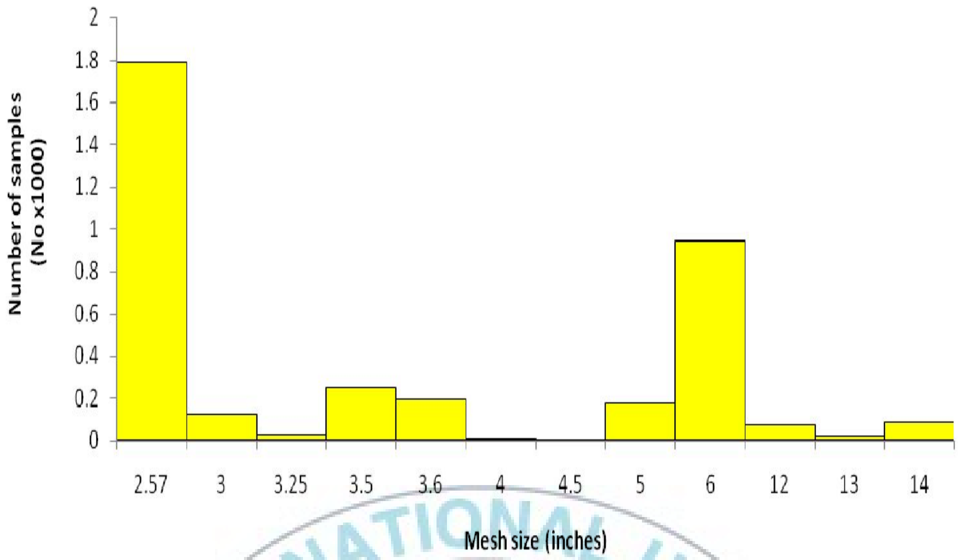

Fig 6. Type of mesh size of gillnet registered in the fishing activities from April to November in 2009, Central America.

The activity of artisanal fisheries was conducted near to the coast, in rare cases these were directed to the open sea, as seen in the figure below, which details the fishing areas in each country, being the fishing ground of fishermen for *S. lewini*: Bahia Jiquilisco (El Salvador), Bahia Corinto (Nicaragua), and Gulf of Panama (Panama) (Fig. 7).

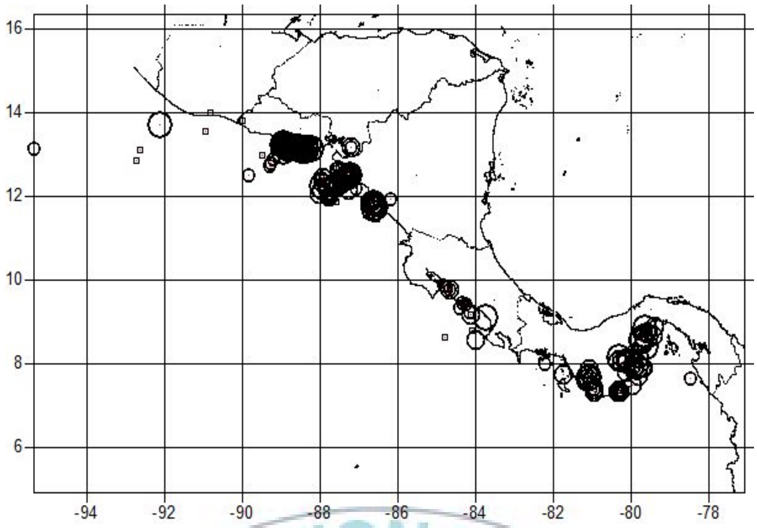

Fig. 7. Geographic distribution of catch of *S. lewini* in the coastal Eastern Pacific Ocean.

2.3 METHODS

2.3.1 BIOLOGICAL PARAMETERS

2.3.1.1 WEIGHT AND LENGTH RELATIONSHIP

By estimating the equation of the weight and length relationship ($W = \alpha L^{\beta}$) can be determined whether growth in these species are isometric or allometric, the above is based on the value of the slope (β) estimated, it is considered that when the value of β is close to three the growth is isometric and when moving away from this value is allometric (Tresierra and

Culquichicón, 1993). The relationship between total weight and total length was analyzed for both sexes without subtracting the weight of viscera and embryos. For the analysis of weight-length parameters α and β were analyzed for both sexes in order to compare with data from other investigations.

2.3.1.2 GROWTH PARAMETERS

The growth parameters were estimated using the software FISAT II, using an individual growth model described by von Bertalanffy (1938), were ordered the database with the total number of catch by the body length for the 8 months of monitoring and were used nonparametric methods as ELEFAN I (Electronic Length Frequency Analysis) and Shepherd model (1987) known as SLCA (Shepherd's Length Composition Analysis). With this analysis was estimated the growth coefficient (K). To compare which methods are the most available was applied the Goodness of fit index (Rn), which according to the theory of Rn model, comparing the results of both analysis the most valid will be the most closer to 1.

According Sparre and Venema (1997), the asymptotic length (L_∞) is interpreted as the average size of a old fish, and the asymptotic length can also be the largest size of fish reported during the investigation, in the case of this study, L_∞ was estimated using the most large sample estimated in Central America in the last seven years.

To estimate the age of fish when the size is zero ***(t_0)*** was used the equation of Pauly (1983), introducing the values of K and L_∞, estimated through FISAT II with the above methods. The equation is:

$$Log\,(-t_0) = -0.3922 - 0.2752 \cdot Log(L_\infty) - 1.038 \cdot Log(K)$$

Where L_∞ is the asymptotic length and K is the growth coefficient.

Subsequently estimate the growth parameters, apply the von Bertalanffy equation, which is expressed as follows:

$$L_t = L_\infty\left(1 - e^{-k(t-t_0)}\right)$$

Where, L_t is the body length at age t, L_∞ the asymptotic length, t_o is the age of fish when the size is zero and K is the growth coefficient.

2.3.1.3 MORTALITY

a. Natural Mortality

The method used to calculate natural mortality was through the equation proposed by Zhang and Megrey (2006). This method is expressed as a function of the growth coefficient (*K*), the power parameter of the weight and length relationship (β), the age of fish when the size is zero (t_0), and the critical age (t_{mb}).

$$M = \frac{\beta K}{e^{K(t_{mb}-t_0)} - 1}$$

Where $t_{mb} = C_i \cdot t_{max}$. Here t_{max} is the maximum age observed in the population (Beverton and Holt, 1959; Alagaraja, 1984; Zhang and Megrey, 2006), and C_i is the constant for specific ecological groups, demersal species (0.440), pelagic species (0.302) and overall mean (0.393), in this study, it used C_i= 0.302 to estimate natural mortality.

b. Fishing Mortality

The method used to calculate fishing mortality was through the equation proposed by Zhang and Megrey (2010). This method is expressed as a function of the biomass by length (B_{l_i}) to biomass ($B_{l_{i+\Delta t}}$), the natural mortality (*M*), the time needed to grow from length-class l_i (Δt_{l_i}), and weight by length (G_{l_i}):

$$F_{l_i} = \frac{\log_e\left(\frac{B_{l_i}}{B_{l_{i+\Delta t}}}\right) - M \times \Delta t_{l_i} + G_{l_i}}{\Delta t_{l_i}}$$

and was estimated the weighted by fishing mortality following the equation:

$$Weighted\ F_{l_i} = \frac{\sum B_{l_i} F_{l_i}}{\sum B_{l_i}}$$

c. Total Mortality

The total mortality (Z) was estimate by the sum of natural mortality (*M*) and fishing mortality (*F*).

$$Z = M + F$$

2.3.2 BIOMASS

To estimate the biomass was used the total catch of target species. By this estimation was used the ratio of the number of *S. lewini* in present research, versus the whole captured of sharks registered in FAO in 2009.

Analysis of biomass was estimated by applying a new method called "A simple biomass-based length-cohort analysis for estimating biomass" created by Zhang and Megrey (2010), which uses the size composition and catch data, for the fish stock. This method produces estimates of the population in terms of numbers.

For the application of this method is needed for the following information:

1. One year of length composition data for the catch;
2. Weight of catch for each length-class (l_i);
3. Estimate of Natural mortality (M)
4. von Bertalanffy Growth parameters (K, t_0, and L_∞);
5. Allometric parameters relating length to weight (α and β)

According to Zhang and Megrey (2010) are the six steps required to implement the method to estimate the biomass LCA:

Step 1 involves calculation of weight from length for each length-class (l_i) using the allometric weight equation.

$$W_{l_i} = \alpha \times l_i^{\beta}$$

Step 2 is the calculation of the instantaneous rate of growth per length-class (G_{l_i}) using the follow equation.

$$G_{l_i} = log_e\left(\frac{W_{l_i+\Delta l}}{W_{l_i}}\right)$$

Where, l_i is length-class, $l_i + \Delta l_i$ represent the time needed to grow from length class l_i to length class $l_i + \Delta l_i$.

Step 3 Δt is the time needed to grow from length class l_i to length class $l_i + \Delta l_i$, calculated for each length-class (l_i).

$$\Delta t_{l_i} = \frac{1}{K} log_e\left(\frac{L_\infty - l_i}{L_\infty - l_{i+\Delta l}}\right)$$

Step 4 population biomass in the longest length-class (l_i) is estimated based on the biomass-based catch equation and the estimate of F_T.

$$B_{l_i} = C_{l_i} \times \frac{(M + F_T) \times \Delta t_{l_i} - G_{l_i}}{F_T \times \Delta t_{l_i}}$$

Where, F_T is assumed to be equal to 0.5M for a lightly exploited stock, M for a moderately exploited stock, or 2M for a heavily exploited stock. In the present study was considered the fishery of *S. lewini* as a heavily exploited stock, and C_{l_i} means the total catch of weight by length-class (l_i). In this study, total catch of weight in 2009 was 5,438 mt.

Step 5 involves progressing from the longest length-class to the smallest length-class (l_i) to calculate B_{l_i} using the follow equation.

$$B_{l_i} = B_{l_i+\Delta l}\, exp\left[\frac{M}{K} log_e\left(\frac{L_\infty - l_i}{L_\infty - l_{i+\Delta l}}\right) - G_{l_i}\right] + C_{l_i}\, exp\left[\frac{M}{2K} log_e\left(\frac{L_\infty - l_i}{L_\infty - l_{i+\Delta l}}\right) - \frac{G_{l_i}}{2}\right]$$

2.3.3 YIELD PER RECRUIT ANALYSIS

The simple yield per recruit model, presents the sustainable yield of a fish population as a function of age of first catch, assuming knife-sharp selection and fishing mortality rate. The weight-length-relation is assumed to be close to 3 (cubic relation) and the natural mortality rate is in most cases close to the natural individual growth coefficient. Was used Beverton and Holt method (1957) by estimating the yield per recruitment; this is given by the following equations:

$$\frac{Y}{R} = F \cdot exp[-M(t_c - t_r)]W_\infty \sum_{n=0}^{3} \frac{U_n exp[-nK(t_c - t_0)]}{F + M + nK}$$

Where, K is growth coefficient, t_0 is the age of fish when the size is zero, t_c is age of first capture, t_r is the recruitment age, W_∞ is the asymptotic weight, F is the fishing mortality, M is the natural mortality and U_0=1, U_1= -3, U_2=3, U_3= -1.

To estimate the age at first capture (t_c) was used the dominant samples by age, following the next equation:

$$t_c = \frac{t_a \cdot P_a + t_b \cdot P_b}{P_a + P_b}$$

Where, t_a is the minimum age, t_b is the age of dominant group, P_a is the proportion of minimum age and P_b is the proportion of dominant group.

2.3.4 ACCEPTABLE BIOLOGICAL CATCH (ABC)

For many fish populations, there is insufficient information available to determine optimal harvesting policies. When the catchability increased suddenly, can also increase yields and non-equilibrium state of the fishery will result in its collapse. In this case the most appropriate management decision would be to set an only one quota usually easier to determine and control the variable effort limitations (Freon and Yanéz, 1995).

Much attention has therefore been given in the literature to determining biological reference points (BRPs) that can be readily calculated from available information. The BPRs are usually fishing mortalities (F) or abundance levels (thresholds) and may be specified either as a target for optimal harvesting or a danger zone to be avoided (Leaman, 1993 cited by Quinn and Deriso, 1999).

One of major limitations of BRPs based on yield per recruit such as F_{max} is that the effects on the spawning population are essentially ignored. As a worst case scenario, suppose that infinite fishing pressure were applied at critical age *t* but that fish matured at ages older than *t*. The maximum yield per recruit would be taken, but at the expense of rendering the population extinct. The class of BRPs coming out of this approach is denoted $F_{x\%}$, where is generally in the range of 20%-40%. Reference fishing mortality ($F_{x\%}$) result in a spawning stock biomass or egg production per recruit that is x% of that with no fishing (Quinn and Deriso, 1999).

For this research was carried out the analysis of fishing mortality by 40%, because this percentage defines acceptable biological catch levels. Likewise Quinn and Szarzi (1993), quote by Quinn and Deriso (1999) suggested that fishing mortalities between $F_{30\%}$ and $F_{45\%}$ in terms of spawning abundance instead of spawning biomass would result in sustainable harvests. The information used to estimate the $F_{x\%}$ was: length class, weight at length relationship, maturity rate, selectivity at length and mortality at length (Zhang, 2010).

$$F_{x\%} = \frac{\sum_{i=i}^{i\lambda} B_i' \cdot m_i \cdot e^{G_i - (M + F_{40\%} \cdot S_i)\left(\frac{1}{K} ln\left(\frac{(L_\infty - l_i)}{(L_\infty - l_{i+1})}\right)\right)}}{\sum_{i=i}^{i\lambda} B_i \cdot m_i \cdot e^{G_i - M\left(\frac{1}{K} ln\left(\frac{(L_\infty - l_i)}{(L_\infty - l_{i+1})}\right)\right)}}$$

Where, m_i is the maturity rate by length i, M is natural mortality, S_i is selectivity at length i, B_i' number of population at length i, K is growth coefficient of von Bertalanffy parameter, L_∞ is asymptotic length, G_i is the instantaneous rate of growth per length-class i.

If F=0, $B_i = B_{i-1} \cdot e^{G_{i-1} - M \cdot \Delta_{i-1}} = B_{i-1} \cdot e^{G_{i-1} - M\left(\frac{1}{K} ln\left(\frac{(L_\infty - l_i)}{(L_\infty - L_{i+1})}\right)\right)}$

If F =x%, $B_i^{'} = B_{i-1}^{'} \cdot e^{G_i - (M + F_{40\%} \cdot S_{i-1})\left(\frac{1}{K} ln\left(\frac{(L_\infty - l_i)}{(L_\infty - L_{i+1})}\right)\right)}$

In this study to estimate ABC, x% means 40%

$$G_i = ln\left(\frac{W_{i+1}}{W_i}\right)$$

$F_{40\%}$ of the level of biomass ($B_{40\%}$) was estimated by the equation:

$$B_{40\%} = B_c \times \frac{\frac{SB}{R}|_{F_{40\%}}}{\frac{SB}{R}|_{F_c}}$$

Where, B_c is the current biomass, $\frac{SB}{R}|_{F_{40\%}}$ is the spawning biomass per recruit with $F_{40\%}$, and $\frac{SB}{R}|_{F_c}$ is the spawning biomass per recruit with current F.

Subsequently this information was analyzed with Acceptable Biological Catch (ABC), which provides an acceptable level of capture of a species or species group. To estimate ABC this species was considered than demersal species, for two reasons: 1) the most sharks, include the *S. lewini*, not follows the common behavior of pelagic species (high number of eggs per seasons) producing a low number of neonates per birthing, around 15 to 31 neonates each two years (Compagno, 1984), 2) the habitat of this shark before maturity is in the turbid and deeper waters (Alejo-Plata et *al.*, 2007). This method is applied depending on the amount of information we have, making this method five tiers.

Table 7. Method to determine ABC of *S. lewini* in Central America (MOMAF, 2000)

Tier 1 Information available: Reliable estimates of annual B and F, B_{MSY}, F_{MSY}, $F_{X\%}$, M and environmental factor.
1a) Stock status: $B/B_{MSY} > 1$ $F_{ABC} = F_{MSY}$ 1b) Stock status: $\alpha < B/B_{MSY} \leq 1$ $F_{ABC} = F_{MSY} \times (B/B_{MSY} - \alpha)/(1-\alpha)$ 1c) Stock status: $B/B_{MSY} \leq \alpha$: $F_{ABC}=0$
Tier 2 Information available: Reliable estimates B, $B_{X\%}$ and $F_{X\%}$. 2a) Stock status: $B/B_{40\%} > 1$ $F_{ABC} = F_{40\%}$ 2b) Stock status: $\alpha < B/B_{40\%} \leq 1$ $F_{ABC} = F_{40\%} \times (B/B_{40\%} - \alpha)/(1-\alpha)$

2c) Stock status: $B/B_{40\%} \le \alpha$: $F_{ABC}=0$
Tier 3 Information available: Reliable estimates B and $F_{0.1}$ $F_{ABC}= F_{0.1}$
Tier 4 Information available: Time-series catch and effort data. 4a) Stock status: $CPUE/CPUE_{MSY} > 1$ ABC=MSY 4b) Stock status: $\alpha < CPUE/CPUE_{MSY} \le 1$ $ABC=MSY \times (CPUE/CPUE_{MSY} - \alpha)/(1- \alpha)$ 4c) Stock status: $CPUE/CPUE_{MSY} \le \alpha$: ABC =0
Tier 5 Information available: Reliable catch history. $ABC=M \times Y_{AM}$ (arithmetic mean catch over an appropriate time period), $0.5 \le P \le 1.0$
i) Equation used to determine ABC in tiers 1-3: $ABC= \frac{BF_{ABC}}{M+F_{ABC}}\left(1-e^{-(M+F_{ABC})}\right)$ Where B_i: *Biomass at age i M: instantaneous coefficient of actual mortality,* F_{ABC}: *instantaneous coefficient of fishing mortality for ABC determined by the data available and the stock status, r: recruit age,* t_L: *maximum fishing age.* ii) For tiers 1, 2 and 4, α is set at a default value of 0.05.

According this research, to estimate ABC was applied the 2b in tier 2 that described the information available in the current result (B, $B_{X\%}$ and $F_{x\%}$).

For complete the analysis was conducted the Spawning biomass per recruit (SBPR) that mean the biomass of recruit will provide in the future.

When F= 0, the spawning biomass per recruit (SB/R) is,

$$\frac{SB}{R} = \sum_{t=t_r}^{t_\lambda} m_t \cdot e^{-M(t_c-t_r)} \cdot e^{-(M+F)(t-t_c)} \cdot W_\infty\left(1 - e^{-K(t-t_0)}\right)$$

Where m_t is the maturity rate by time t, K is growth coefficient, $t_0$is the age of fish when the size is zero, $t_c$is age of first capture, t_r is the recruitment age, W_∞ is the asymptotic weight, F is the fishing mortality, M is the natural mortality.

3. RESULT

In order to standardize methodologies for reporting catches in shark fisheries, the RWGS worked during the fishing season of 2009, earning a total of approximately 5,532 samples, where 4,677 of these samples were *S. lewini*. The information of the data during eight month were provided by El Salvador, Panama, Guatemala, Nicaragua and Costa Rica, only Honduras reported 3 month of data, depending on the fishing activities of the respective fishing villages and climatic conditions of the evaluation period.

3.1 BIOLOGICAL PARAMETERS

From April to November were registered 4,146 samples of the total catch (Fig. 8), the distribution of most caught sizes was 46.5 cm to 56.5 cm and the size more captured was 55.3 cm. The numbers of samples of greatest weight and length were registered off the coast of Nicaragua (n = 39), but the most size that was caught in coastal Central America are neonates (newborns).

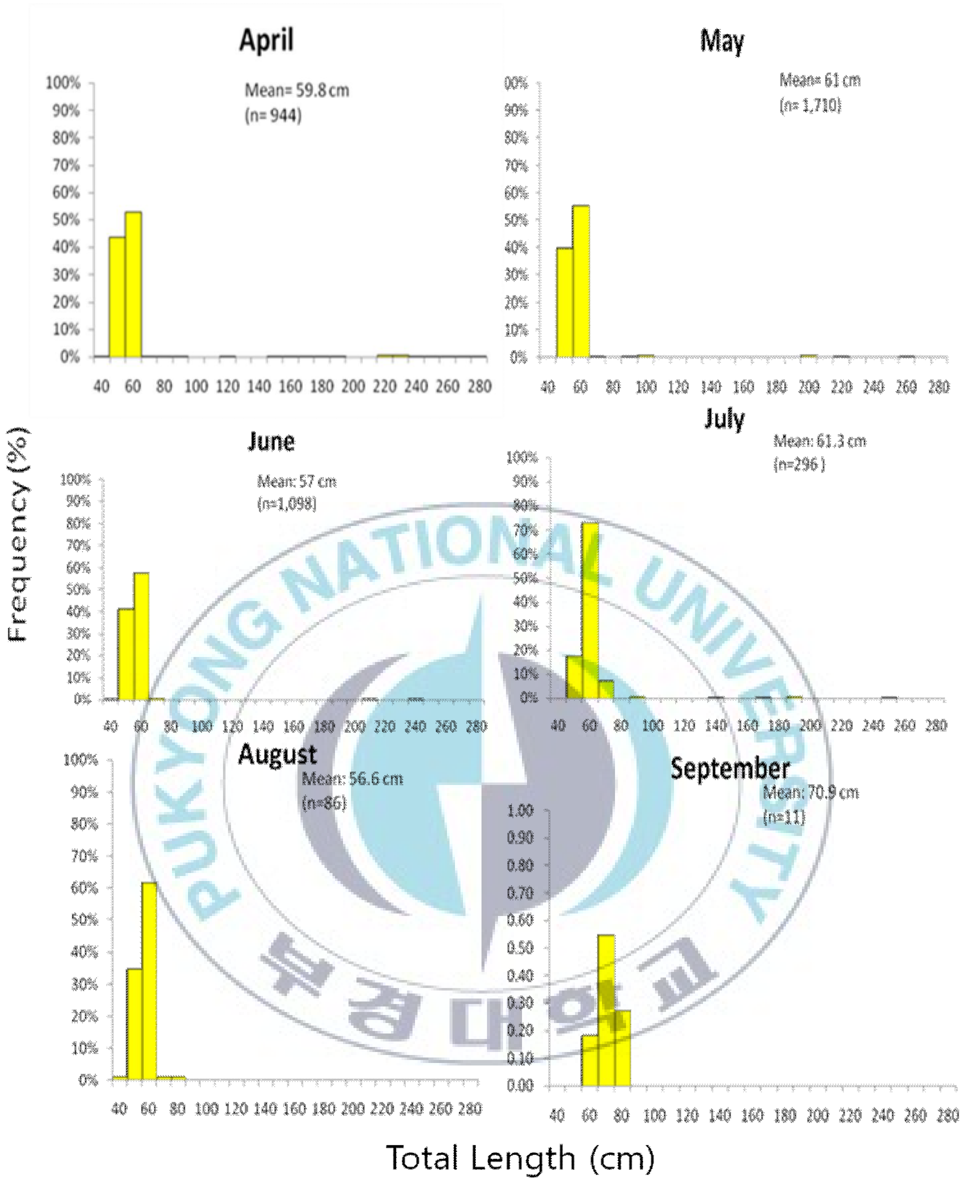

Fig. 8. Frequency per total length from April to September of *S. lewini* in 2009, in the coastal Pacific Ocean of Central America.

3.1.1 WEIGHT AND LENGTH RELATIONSHIP

In making the relationship between body length and body weight, they presented the following functions (for both sexes) (Fig. 9).

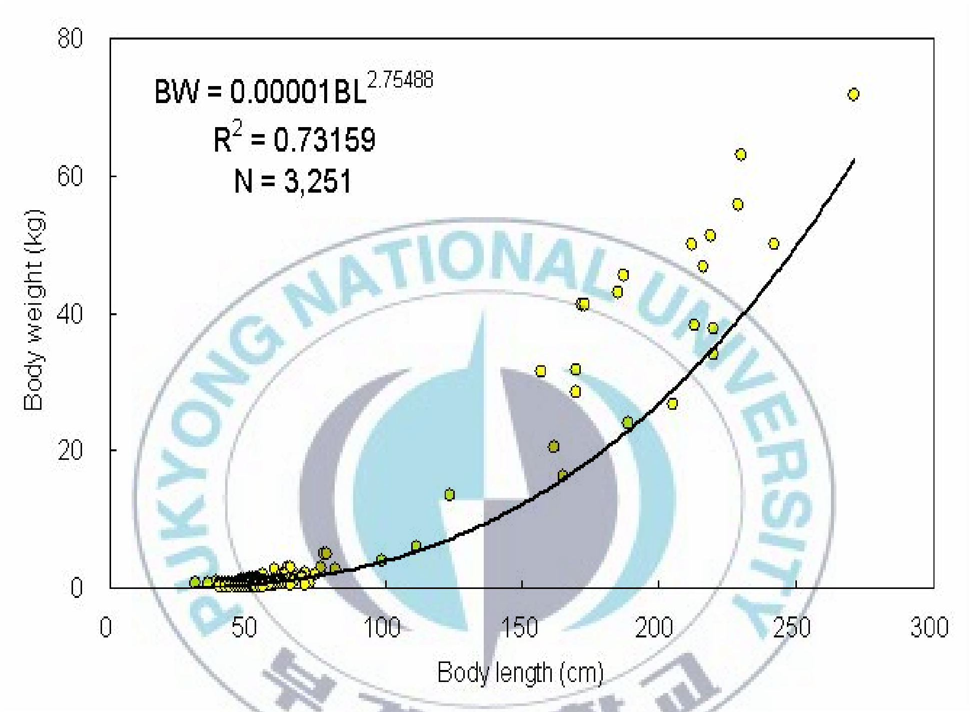

Fig. 9. Curvilinear relationship of total weight (W_t) with the total length (L_t).

The β value that estimated was very similar to those reported by other research in the Pacific Ocean (Anislado-Tolentino and Robinson-Mendoza, 2001; Chen et al., 1990). In the database was not recorded a full size distribution, most of the samples taken were neonates and juveniles (Table 8).

Table 8. Summary of the weight-length relationship parameters made on *S. lewini*

Author	Area	Sex	α	β	No. of samples
Chen et al (1990)	Northeasterm of Taiwan	Female	2.82x10^-6	3.129	276
		Male	1.35x10^-6	3.252	49
		Both	2.085x10^-6	3.191	325
Anislado-Tolentino&Robinson-Mendoza (2001)	Central Pacific of Mexico	Female	2x10^-5	2.800	50
		Male	1.05x10^-5	2.870	51
		Both	1.525x10^-5	2.840	101
Anislado-Tolentino&Robinson-Mendoza (2008)	Southerm Coast of Sinaloa, Mexico	Female	4.03x10^-6	3.000	44
		Male	4.30x10^-6	3.000	65
		Both	4.20x10^-6	3.000	109
This study	Eastern Pacific Ocean of Central America	Both	1x10^-5	2.755	3,251

The sex ratio was 50% for males with a range of sizes from 31 cm to 274 cm in length and 50% for females were with a range of sizes from 31 cm to 275 cm. For both sexes the most common months were April through June. The gender distribution was very homogeneous, without differences in the population, but is different when were analyzed by length, where had more adults males than adult females (Table 9).

Table 9. Percentage of sex ratio of *S. lewini* from Central America in 2009.

Length range (cm)	Number of Female	Number of Male	Female (%)	Male (%)
30	0	0	0	0
50	828	795	20.0	19.2
70	1187	1212	28.6	29.2
90	13	4	0.3	0.1
110	10	6	0.2	0.1
130	3	2	0.1	0.0
150	1	5	0.0	0.1
170	4	2	0.1	0.0
190	6	9	0.1	0.2
210	2	15	0.0	0.4
230	5	15	0.1	0.4
250	3	7	0.1	0.2
270	5	3	0.1	0.1
290	2	2	0.0	0.0
Total	2069	2077	49.9	50.1

3.1.2 GROWTH PARAMETERS

The estimated growth coefficient, was performed using two indirect methods through the statistical software FISAT II, model ELEFAN I and model nonparametric Shepherd's (SLCA) (Table 10).

Table 10. Growth parameters of *S. lewini* estimated by indirect means.

Methods/Parameters	***K* *(/year)***
ELEFAN I (A)	0.13
SLCA (B)	0.15

The analysis done by both indirect methods were plotted to know which one is most appropriate methods to use, the analysis of goodness of fit index was applied to evaluate the function K, when *Rn* was 1.00, and know which of the two nonparametric methods was suitable for use in the equation of von Bertalanffy. In this case the nonparametric Shepherd's method was the best represents of growth coefficient with *Rn* equal 1.00, while the method ELEFAN I was with a *Rn* of 0.40. (Fig. 10).

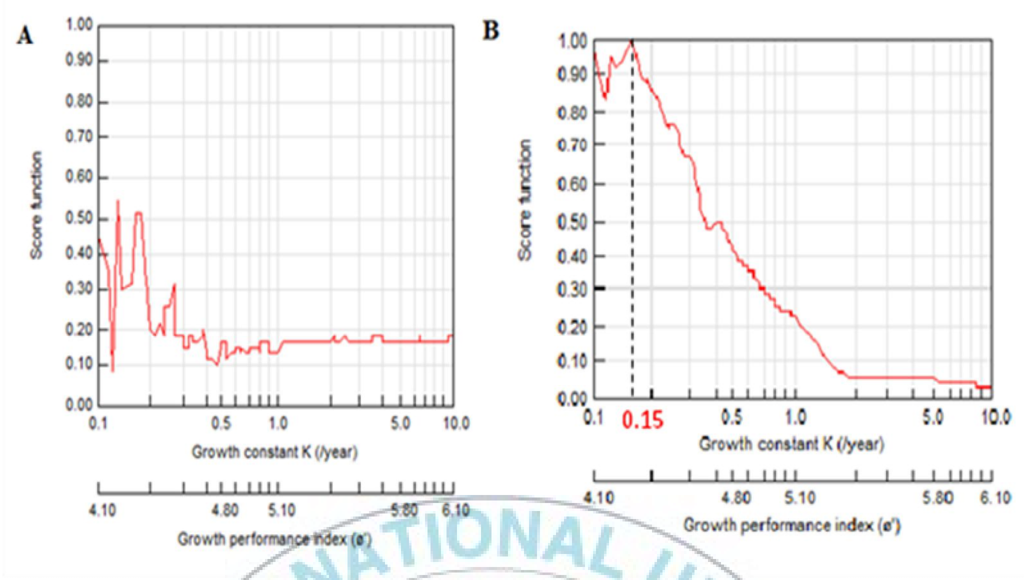

Fig. 10. Goodness of fit index for the two indirect methods: ELEFAN 1 (A) and Shepherd's (B) to determine the growth parameter (K) most appropriate for the species of *S.lewini*, Central America.

The growth coefficients indicate that it is a slow growing organism according Sparre and Venema (1997). After estimated the growth parameters, was calculated the size of fish at any age; using the equation of von Bertalanffy (1938), which generated a growth curve presented in Fig. 11, this figure show as organisms grow compared to the values of growth coefficient (K), asymptotic length (L_∞) and age of the fish at zero length (t_o) describe above.

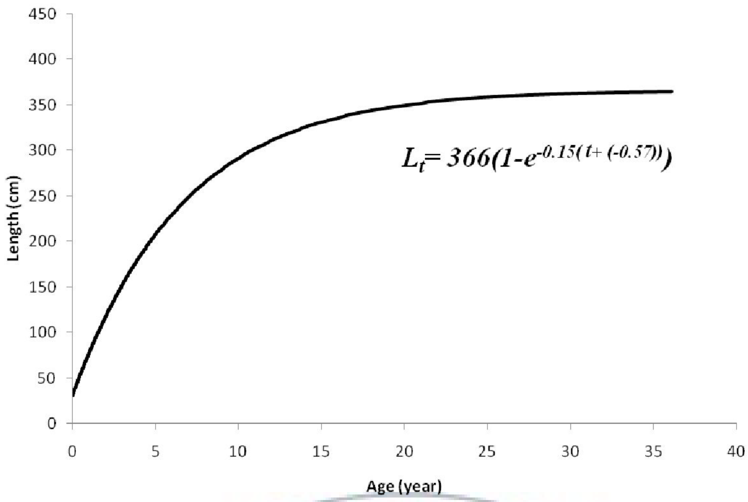

Fig 11. Growth curve for *S.lewini*, collected from the coastal artisanal fishery in Central America in 2009.

The parameter of adjusting was estimated through the equation of Pauly (1983), resulting in t_o equal -0.57 year. This parameters were compared the results of previous studies on growth of this species, where the results of this investigation are similar to previous studies (Table 11).

Table 11. Researches about growth parameters of *S. lewini* on Pacific Ocean

Author	Area	Sex	L_∞ (cm)	*K* *(/year)*	t_o *(year)*
Chen et al. (1990)	Northeasterm of Taiwan	Female	319	0.249	-0.413
		Male	321	0.222	-0.746
		Both	320	0.236	-0.5795
Anislado-Tolentino and Robinson-Mendoza (2001)	Central Pacific of Mexico	Female	353	0.153	-0.633
		Male	336	0.131	-1.091
		Both	345	0.142	-0.862
Anislado-Tolentino and Robinson-Mendoza (2008)	Southerm Coast of Sinaloa, Mexico	Female	376	0.1	-1.16
		Male	364	0.123	-1.18
		Both	370	0.1115	-1.17
This study	**Eastern Pacific Ocean of Central America**	**Both**	**366**	**0.15**	**-0.57**

3.1.3 MORTALITY

To estimate the natural mortality was used the model propose for Zhang and Megrey (2006), and the result was M=0.450 /year, the fishing mortality result was F= 0.469/year using the model of Zhang and Megrey (2010), and for total mortality coefficient (Z) was 0.919/year. All this result appears on the Table 12.

Table 12. Summary of total mortality, natural mortality and fisheries mortality estimated by three methods for the species *S. lewini* of coastal Pacific Ocean of Central America in 2009

Model/parameters	M (/year)	F (/year)	Z (/year)
Zhang & Megrey (2006)	0.450	-	-
Zhang & Megrey (2010)	-	0.469	-
Total mortality (Z = F +M)	-	-	0.919

3.2 BIOMASS

Taking as growth parameters $K = 0.15/year$, $t_o = -0.57year$, $L_\infty = 366$ cm, weight-length relationship ($a=0.00001$ and $\beta=2.75488$) and the data base of FAO about sharks caught in 2009 was used the method of Zhang and Megrey (2010), resulting in this analysis a biomass of 54,230 mt for the Central American region, clarifying that this biomass represents the artisanal fleet that using gill nets and longline and its operation is carried out near to the coast in 2009. The sizes range from 31 cm to 275 cm in total length. The main sizes taken were from 50 cm to 60 cm in body length with around 5,432 mt (Fig. 12).

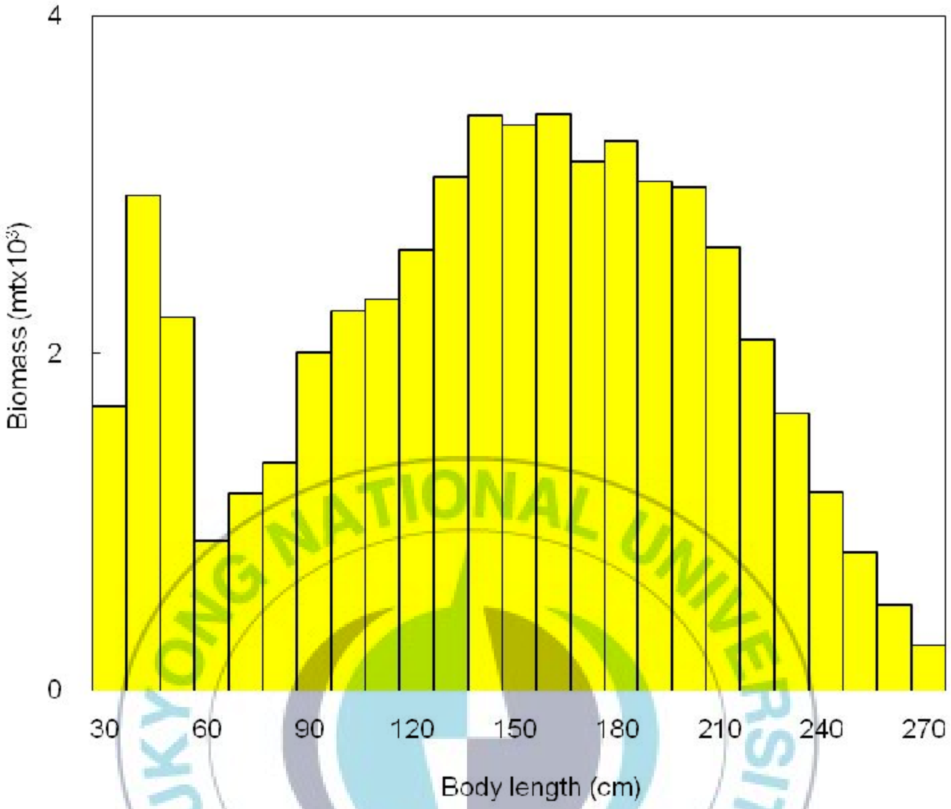

Fig. 12. Distributions of biomass by body length of *S. lewini* from Central America in 2009.

3.3 YIELD PER RECRUIT

A common purpose in fisheries management is pursuing a goal of maximum sustainable yield (MSY), which means nothing else than the application of the values of fishing mortality such that result in maximum yields possible long term. To induce different pressure on the exploited population, it is possible to determine the value of F that produces the maximum yield or capture. Were applied the Beverton and Holt (1957) model for diagnostic purposes, the yield per recruit was 1.345 kg with current F = 0.469 /year and current t_c= 0.408 year, around 50 cm of body length. Fixing t_c at the current level, maximum yield per recruit was 1.421 kg when used the maximum $F_{max}=0.304$/year, which resulted in a small increase of 0.076 kg for yield per recruit (Fig. 13a). Fixing F at the current level, maximum yield per recruit was 2.014kg using a $t_{cmax}=3.0$ *year*, about 150 of body length (Fig. 13b).

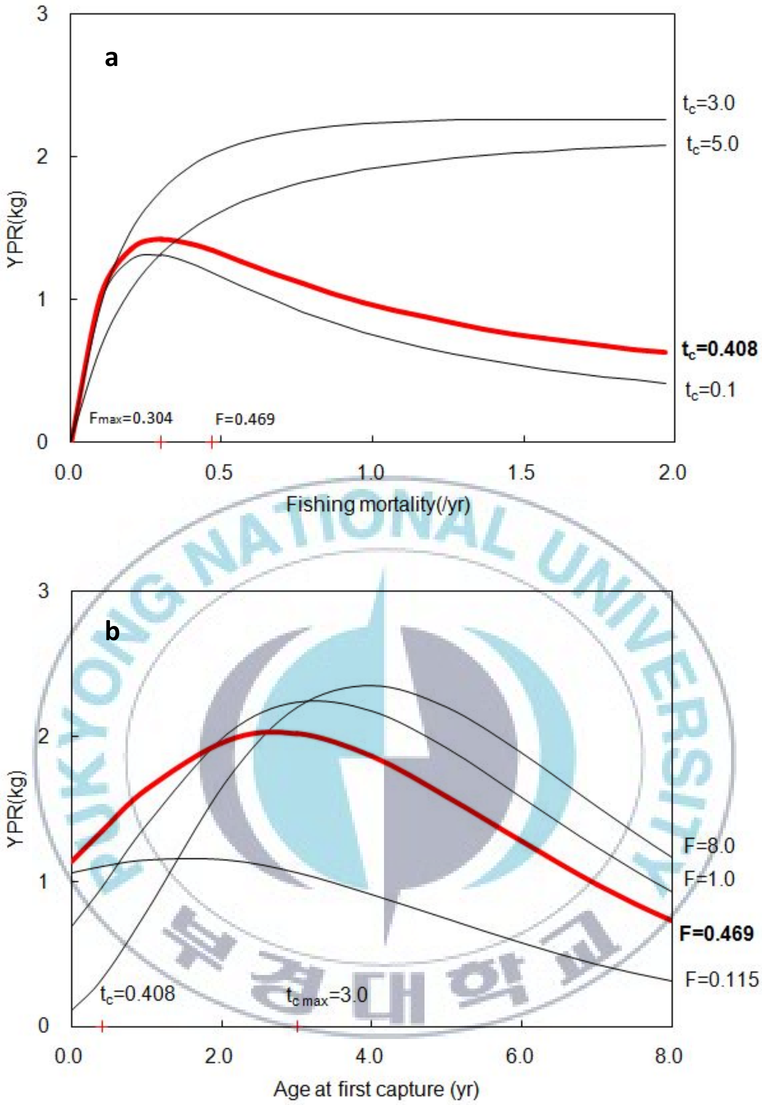

Fig. 13. Yield per recruit analysis of *S. lewini* from Central America in 2009.

The current yield per recruit the fishery is operating outside of the optimal yield per recruit (between AA' and BB'), that mean the species was operating in overfishing, and the age of first capture was less than first year of life, that causes a yield per recruit low of 1.345 kg per recruit. (Fig.14).

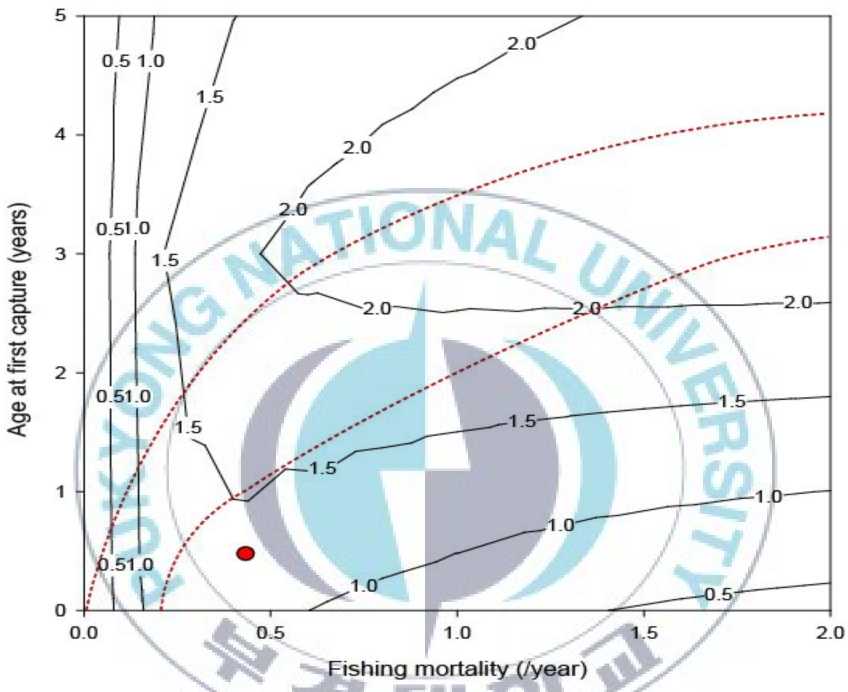

Fig. 14. Yield isopleths for *S. lewini* in the East Pacific coast of Central America. The red point represents the current state of fishing mortality (F) and age at first capture (t_c) with a current yield per recruit. Where AA' represents the maximum yield per recruit line at a given t_c and BB' indicates the maximum yield per recruit line at a given F.

3.4 ACCEPTABLE BIOLOGICAL CATCH

A method for estimating acceptable biological catch (ABC) is proposed for dealing with the large difference in the quality and quantity of information and data available (Zhang and Lee, 2001). The ABC was estimated in 4,782 mt with F_{ABC} =0.115/year, given spawning biomass of 21 kg per recruit, using the current fishing mortality of 0.469/year, given spawning biomass was 7.9 kg per recruit. The values of $F_{35\%}$ and $F_{40\%}$ were 0.267/year and 0.228/year, given SBPR about 12 kg and 15 kg, respectively (Fig. 15). The result of $F_{40\%}$ give an increased of biomass ($B_{40\%}$) of 102,358 mt, increasing the double that currently exists (54,230 mt). Currently the SBPR is about 20%, if apply the F_{ABC} the SBPR will increase to 60%.

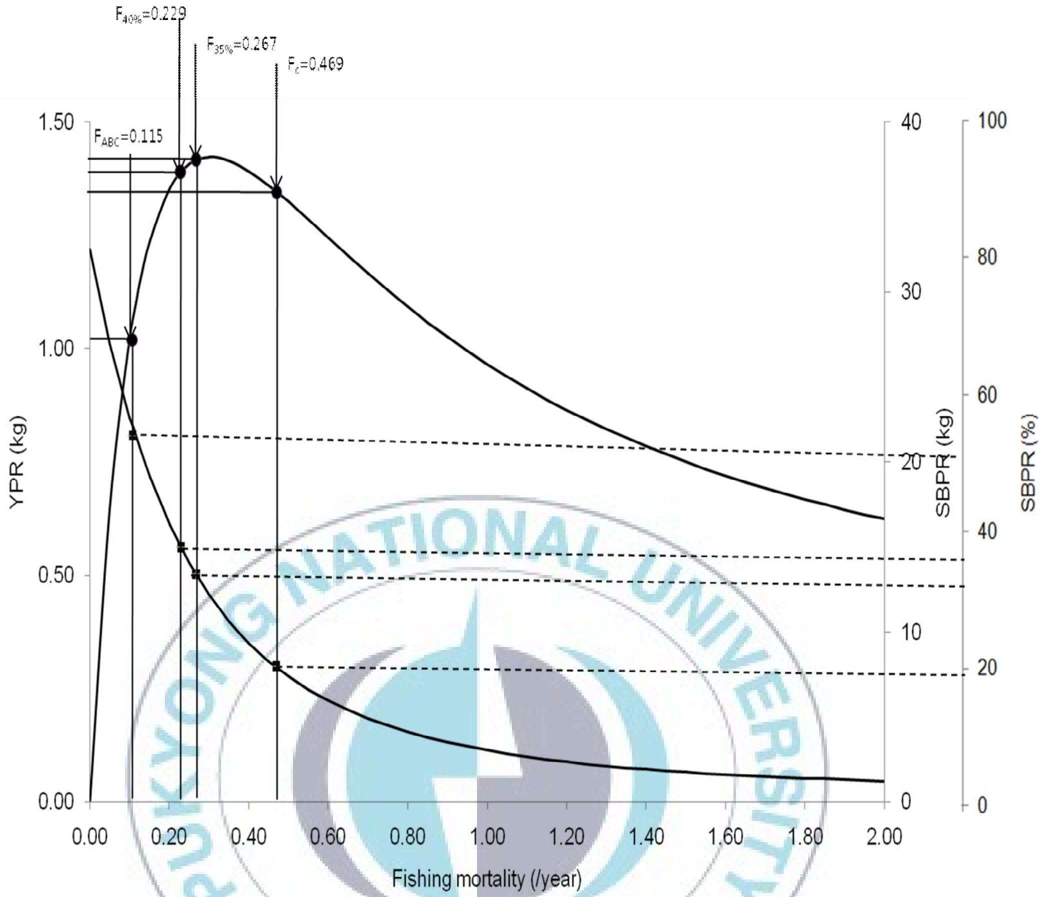

Fig. 15. Estimates of biological reference point (F_{ABC}, $F_{35\%}$, *and* $F_{40\%}$) and current F, with current t_c 0.408/year for *S. lewini*.

The acceptable biological catch was distributed by type of fishing gear by country, to establish better management controls and focus on which fishery should focus on management plans. One of the gear that needs to control are gill nets, especially in El Salvador, which for 2009 was capturing 11% more than the ABC permits, unlike other countries that have a difference of 1 % or 2% (table 13).

Table 13: Proportion of acceptable biological catch of *S. lewini* by fishing gear for 2009 in Central America

Catch by fishing gear / Country	Catch 2009 (mt)				ABC (mt)				Total of ABC
	LL	G	LL/G	HL	LL	G	LL/G	HL	
Panama	**17.94** (3.62%)	**490.35** (10.11%)		**92.09** (100%)	**15.77**	**431.15**		**80.97**	**527.89**
Costa Rica	**4.78** (0.97%)	**141.13** (2.91%)			**4.21**	**124.09**			**128.3**
Guatemala	**10.76** (2.17%)	**100.46** (2.07%)			**9.46**	**88.33**			**97.79**
Nicaragua	**333.68** (67.4%)	**263.12** (5.43%)			**293.39**	**231.35**			**524.74**
El Salvador	**112.42** (22.70%)	**3,847.47** (79.35%)	**2.39** (100%)		**98.85**	**3,382.96**	**2.1**		**3,483.91**
Honduras	**15.55** (3.14%)	**5.98** (0.12%)			**13.67**	**5.26**			**18.93**
Total	**495.14** (100%)	**4,848.51** (100%)	**2.39** (100%)	**92.09** (100%)	**435.36**	**4,263.15**	**2.1**	**80.97**	**4,782**

LL: Longline, G: Gillnet, LL/G: Longline/Gillnet, HL: Handline

4. DISCUSSION

For centuries fishermen have conducted sustainable fisheries for sharks in coastal waters, and some still do. During recent decades an increase in effort and yield of shark catches, as well as an expansion of the areas fished has taken place (FAO, 2010-2011).

S. lewini are large, semi-coastal and viviparous that utilize near shore nurseries throughout their circumtropical range also the *S. lewini* has a close dependence on the movement of warm currents to penetrate into bays and estuaries to mate and birth (Compagno 1984; Chen *et al.* 1988; Branstetter 1990). The behavior in this species of shark in the Pacifica coast of Central American has the same characteristics described by other researchers (Ixquiac 2009; Alejo-Plata *et al.* 2007; Pacheco and Siu, 2005), which confirm the approach of large schools off during the rainy season. Castro (1993) falls into three areas the distribution of these sharks from their life history: 1) feeding areas for adults, 2) breeding grounds and 3) rearing areas. This would explain the reason why are caught the most mature females of this species in advanced stages of gestation. Likewise the low catch of adult females is attributable, according to Branstetter (1987), the adult sexual segregation and female preference for deeper areas, which are located far from the coastal fishing areas.

For the region of the Pacific Ocean from Central America have potential rearing areas of *S. lewini*, to the following areas: Jaltepeque Estuary and Jiquilisco Bay (El Salvador), Aposentillo Bay and Corinto Bay (Nicaragua) and around the Peninsula in Los Santos and the Gulf of Panama (Panama).

In Central America there are a total of 118,400 fishermen, only in the Pacific Ocean, where Nicaragua and El Salvador account for 50% of the total population (OFASCA, 2010). In addition about 60% of fishermen use gill nets as the main gear, confirming the findings in this study where gillnets are the main fishing gear to catch this species (78%).

Because of the behavior of the *S. lewini* to travel in large schools during the day (Klimley, 1993) and its anatomical shape of the head, are very susceptible to capture by gillnets, mainly the young are easily caught (Maguire, 2006). Coastal fisheries in Central America used gillnets as main fishing gear, a smaller percentage longline and hand line, catching about 22,213 mt of sharks in 2009, where only for *S. lewini* were captured around

5,438 mt. The use of gillnets increases the chances of capture of this species, mainly due to the anatomy of the head that makes entangle the shark in the mesh.

The distribution of this species on the coast of Central America, are mostly neonates and juveniles, makes the management proposals are difficult to implement, because it interacts with fisheries. This behavior has been reported in different countries of the Mesoamerican region (Mexico to Panama) (Ixquiac, 2009, Alejo-Plata and Others, 2007, Anislado-Tolentino and Robinson-Mendoza, 2001, Anislado-Tolentino and Others, 2008), where the landings of coastal fisheries have, mostly, *S. lewini* in neonate and juvenile stage, therefore the analysis of the stock assessments are often not very accurate.

With this background, this species are a fragile resource, which cannot withstand high fishing pressure, so it is worth noting the importance of conducting research on the delimitation of areas of no fishing and breeding, and as mentioned Alejo-Plata et al. (2007) offer protection to the migration routes of this species.

According to the research of Branstetter (1990), where classified the growth coefficient (K) in the von Bertalanffy growth equation as: a)between 0.05/year to 0.1/year corresponds to a slow growing species; b)between 0.1/year to 0.2/year indicates a moderate growing species; and, c) between 0.2 year to 0.5 year corresponds to a fast growing species, the present research found at the classification b), which described as moderate growth, (K=0.15/year, for both sexes). This result was compared with other studies in the Pacific Ocean to confirm this classification Anislado-Tolentino and Robinson-Mendoza (2001) K=0.142/year^{-} and K=0.111/year (2008) for both sexes, the values differ significantly to Chen et *al* K=0.223/year, maybe the Pacific Ocean area of Taiwan resource does not provide enough prey for this species or the climate condition affect on their growth.

The analysis of weight and length relationship differs from other studies in the Pacific Ocean, and is only similar to those estimated by Anislado-Tolentino and Robinson-Mendoza (2001), which defines the growth of the shark as allometric growth (β= 2.80) while the current study estimates allometric growth of β= 2.755, with R^2 =0.73. This may, according to Chen et al 1990; Anislado-Tolentino and Robinson-Mendoza (2008), be due to factors like the number of samples estimated in each study, response mechanisms fishing effort applied to each area of study, oceanography, climate, may affect these parameters.

This research is the first to offer an overview of the fish stock population in Central America of *S. lewini*, many investigations around the world describe only the abundance of this species in the fishery (CPUE) (Anilsado-Tolentino and Robinson-Mendoza, 2001 and IUCN, 2010). The analysis of the biomass was estimated for the year 2009, which was 54,230 mt, with a current catch of 5,438 mt (FAO, 2011).

According to the yield-per-recruit analysis, the current yield per recruit was about 1.345 kg with F= 0.469/year with t_c =0.408 year is out of the optimal range, between AA' and BB', this result is lower because the sharks are being caught too young, less than one year or 50 cm of body length. Duncan et *al.* (2006) mentioned that recent evidence indicates that juvenile *S. lewini* reside within nursery habitats for extended periods of time, at least one year post parturition. The management for this species must therefore include all phases of population and also to the three regional nurseries of Central America. The fishing effort in the nursery habitat has negative effects on the biomass of *S. lewini* with an acceptable biological catch of 4,782 mt, as demonstrated in this study. A decrease in fishing effort in these areas has to be the first step to management, protecting their habitat to avoid affecting the dynamics of the stock-recruit.

The SBPR was about 20% with the current fishing mortality, it is recommended to decision makers decrease the fishing mortality at levels straight $F_{40\%}$ to obtain a SBPR about 38%, if the SBPR not increase at the time, will be necessary use the F_{ABC}, Achieving up to 40% increase over the current SBPR. The current capture is higher than of ABC, around 12% more than which can be fished, being gillnets the main fishing gear to catch this species, being El Salvador the country that must urgently implement management actions to reduce 11% of over-fishing, mainly juveniles. Thus are needed for urgent management of *S. lewini* before collapse this fishery.

Data from this study indicated that a significant number of juvenile *S. lewini* remain in the Pacific Ocean of Central America less than one year, and that they aggregate in the deep, turbid areas as bay or estuaries. The young *S. lewini* are more vulnerable to anthropogenic disturbance, like fisheries. In case of juvenile scalloped hammerheads sharks, expanded head shape and obligate ram ventilation make them particularly vulnerable to common nearshore activities such as gillnetting. Moreover, gillnet fishing gear does not discriminate between an adult and neonates of *S. lewini*. This fishing gear being used most often by artisanal fishermen in Central America. The capture of neonates is causing a considerable reduction of the spawning biomass, which in the near future would cause the collapse of this fishery and the rebuilding will be difficult. One of the measures that would help to reduce fishing mortality would be protect the breeding areas, creating closed seasons, reducing the use of gillnets and set restrictions on trade in this species during birth season.

In summary, to prevent the collapse of this fishery is necessary to carry out two urgent measures: 1) reduce the current catch levels, proposed in the ABC and 2) control the length of the sizes, mainly because there is growth overfishing. If the fishing mortality reduces at level of $F_{40\%}$, the biomass will be increases at 50% more than the current biomass, but if this measure no enough to increase the stock, will be necessary reduce the fishing mortality at level of F_{ABC}. The proposed measures that would help carry out the two measures described above are: closed seasons, no-fishing areas, reducing the use of gillnets and control or restrictions in trade of this species during the fishing season could reduce the decline of this population.

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6. APPENDIX

6.1 APPENDIX A

6.1.1 FISHERIES IN CENTRAL AMERICA

Artisanal fisheries in Central America are very diverse and characterized by: 1) the use of different types of fishing gear, 2) fishing many stocks species of small sizes, 3) with the participation of full-time fishermen and part-time, and 4) the presence of numerous, often isolated, landing sites and a variety of marketing channels. A rough estimate indicates that there are about 19,559 artisanal vessels, with about 118,400 fishermen operating in the region, only in the area of the Pacific Ocean, in total are 135,400 fishermen and 61,725 vessels in both areas (Atlantic and Pacific ocean) (OFASCA, 2010). In many parts of the activities of small-scale fisheries also provide important means of generating income for the rural poor, including those who fish only occasionally and are not officially recognized as fishermen (subsistence fishing) (FAO, 2006).

Detailed below general information about each of the countries where the study was conducted on small-scale fisheries this information was provided for FAO in 2006.

a. Guatemala

Guatemala has a coastline of 300 km in the Pacific Ocean and 100 km in the side of the Atlantic. The marine fishing activities is carried out on the continental shelves of the Pacific and Atlantic, 14,700 km^2 and 2,100 km^2 respectively, and all the waters of the Pacific (92,000 km^2) and part of the Atlantic Ocean (31,000 km^2). The Atlantic Ocean is carried out small-scale fisheries and artisanal fisheries as such, do not allow commercial fishing within the Bay of Amatique. In the Pacific Ocean is made small-scale and industrial fishing, while in inland waters (lakes, ponds and rivers) predominantly subsistence fishing (110,000 hectares).

Agriculture is a major economic sector in Guatemala, which contributes 22.5% to Gross domestic product (GDP). However, the fisheries sector has a very small share of 0.4%, with an annual production of about 30,000 mt in 1999 - 2000 (including almost 20,000 mt of tuna and 7,000 mt of freshwater fish), the country is a producer of fish in Central America average. Most of the marine catch is estimated from the Pacific Ocean and 60% is landed by the artisanal fleet.

b. El Salvador

El Salvador has a coastline of approximately 321 km along the Pacific Ocean. Marine resources are exploited in a continental shelf of 29,000 km^2 and 88,000 km^2 of exclusive economic zone (EEZ). The country with a total annual production of about 28,000 mt is one of the smaller producers in Central America. The fisheries sector contributes 0.3% of GDP in the country and its contribution comes mainly from the shrimp fishery. About 49% of production is estimated from the marine fishery industry, 39% of the artisanal marine fishery, 9% of inland fisheries and the remainder (4%) comes from aquaculture.

c. Honduras

Honduras has 162 km of coastline along the Pacific Ocean and 683 km of coastline on the Caribbean Sea. Coastal resources include 5,000 km^2 of continental shelf in the Pacific and 53,500 km^2 of continental shelf in the Caribbean Sea. Honduras with an annual production of about 30,000 mt is a producer of fish in Central America average. The fishing industry contributes 2% to GDP of Honduras. Most of the catch is estimated from the Caribbean Sea, with an important industrial catch located near the Bay Islands and is important artisanal fishery along all coasts of the Caribbean and Pacific.

d. Nicaragua

The Republic of Nicaragua is located in the central part of Central America and is bordered by Honduras to the north and Costa Rica to the south. It has a coastline of 410 km in the Pacific Ocean and 530 km in the Caribbean Sea. Coastal resources are captured in a continental shelf of 77,000 km^2 and 304,000 km^2 of exclusive economic zone, with an annual production of about 18,000-20,000 mt. It is one of the countries considered in the category of minor producers of fish in Central America. The fisheries sector contributes 1.5% to the GDP of Nicaragua. Shrimp aquaculture is one of the most important sub-sector, accounting for 40% of total production. About 24% of fish production comes from the Pacific coast and 33% of the Caribbean, while the remainder (about 1%) comes from inland waters. The fishing in the Pacific coast is the most important segment of the sector, with 35% of production, followed by fishing from the Atlantic coast (29%), the industrial fishery in the Pacific (29 %) and industrial fisheries in the Atlantic (7%).

e. Costa Rica

Costa Rica has a coastline of 1,016 km along the Pacific Ocean, with two major gulfs (Gulf of Nicoya and the Gulf of Dulce) and 212 km of coastline along the Caribbean Sea. The exclusive economic zone (EEZ) is 560,000 km^2 in the Pacific and 24,000 km^2 in the Caribbean. With an annual production of about 21,000 mt (not including 25,000 mt of tuna caught outside the EEZ) is a producer of fish in Central America average. The fisheries sector contributes between 0.5 to 1% of GDP of Costa Rica. Most of the catch is estimated from the Pacific Ocean and 77% the artisanal fleet.

f. Panama

Panama has a 700.6 km of coastline on the Pacific Ocean and a 287.7 km along the Caribbean Sea. Coastal resources within its exclusive economic zone (EEZ) are 319,118 km^2 and a continental shelf of 250,900 km^2. It is the second largest producer of fish in Central America with a production of about 240,000 mt (including catches of foreign vessels registered in Panama). The fisheries sector contributes 2.76% to GDP of Panama. Most of the local catch is estimated from the Pacific Ocean and 70% is landed by the industrial fleet.

6.2 APPENDIX B

6.2.1 BIOLOGY AND FISHERY OF *S. LEWINI*

Sharks, rays and chimaeras are grouped within the Chondrichthyes, a class that includes all cartilaginous fish, also called elasmobranchs (sharks and batoids) and holocéfalos (chimeras). These species also are an evolutionarily successful group, with almost 1,200 living species, very well adapted to a wide variety of habitats such an evolutionary success that have remained virtually unchanged for nearly 400 million years (Compagno et al., 2005; Garcia Nuñez, 2008).

Sharks are important biological resources from the viewpoint of ecological and economic (fisheries, food and tourism). These cartilaginous fish belonging to the class Chondrichthyes and taxonomically subdivided into two subclasses: Elasmobranchii (sharks and rays) and Holocephalii (chimeras) (Bonfil, 1994).

There are eight orders of sharks, listed below the most primitive to more modern:

- Hexanquiformes: Composed of two families and five species. Examples of this order are the cow shark (*Notorynchus cepedianus*) and sharks Canabota (*Hexanchus griseus*).
- Squaliformes: Composed of 3 families and 82 species. Some examples are the pygmy shark (*Europtomicrus bispinatus*) and marinated pork (*Oxynotus centrin*).
- Pristoforiformes: These are the sharks saw, with a toothy and elongated tube that used to cut the fish then eat.
- Esquatiniformes: Sharks angel or angels.
- Heterodontiformes: These include the horned suno (*Heterodontus Francisci*).
- Orectolobiformes: Including the carpet sharks and the largest of all fish, the whale shark.
- Carchariniformes: It has 197 known species. Includes the hammerhead shark (***Sphyrna lewini***), tiger shark (*Galeocerdo cuvier*) and the gray shark (*Carcharhinus amblyrhynchos*).
- Lamniformes: They have seven families and 16 species known. Include the mako shark (*Isurus oxyrinchus*) sharks duente

(*Mitsukurina owstoni*) and the great white shark (*Carcharodon carcharias*).

6.2.2 BIOLOGY AND DISTRIBUTION

S. lewini is distinguished from other hammerhead sharks by a notch located centrally in front of the margin of the head rather arched (Castro, 1983). The head extends laterally, resembling a hammer, hence the common name "hammerhead." This species grows from 3 to 4 meters long, compared to other species in this family that do not reach more than 1.5 meters, the head shape is important in identifying, (1) although it is worth noting that the contour the head can vary slightly depending on the age of the fish and pelvic fins with straight rear margins (2) (Fig. 1) (Lopez and Bussing, 1993).

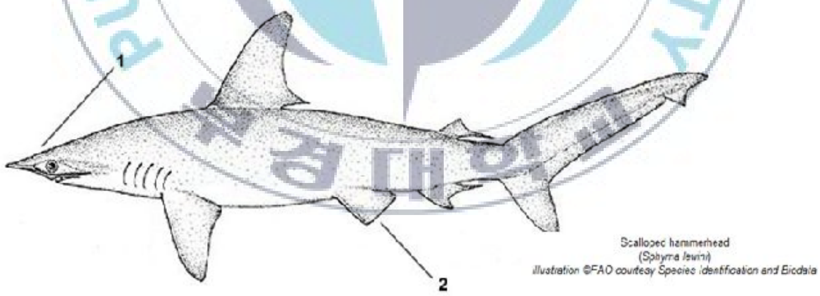

Fig. 1. Illustration of *Sphyrna lewini*, notch located centrally in front of the margin of the head (1) rather arched and pelvic fins (2) with straight rear margins (Compagno, 1984).

In the family of hammerheads presents several species with each other because of variations in the head. The great hammerhead (*S. mokarran*) is distinguished by a head in a "T" with a nearly straight front edge and a jagged mark in the center. The smooth hammerhead (*S. zygaena*) has a large head, flat and unmarked. The shark "bonnethead" (S. *tiburo*) is more easily identified by its shovel-shaped head. Another distinctive feature of *S. mokarran* is curved rear margin of pelvic fin, while S. hammerheads have straight trailing edges.

The *S. lewini* is circumglobal, residing in coastal warm temperate and tropical seas (Compagno, 1995). This species, and perhaps all hammerhead sharks (Sphyrnidae), have geomagnetic orientation and navigation abilities, possibly enhanced by their unique laterally expanded head (Klimley, 1993; Duncan et al., 2006). The *S. lewini, S mokarran* and *S. zygaena* are larger, ocean-going, and more widely distributed, but only the first is abundant along continental margins and around med oceanic island in tropical waters (Fig. 2) (Compagno, 1984).

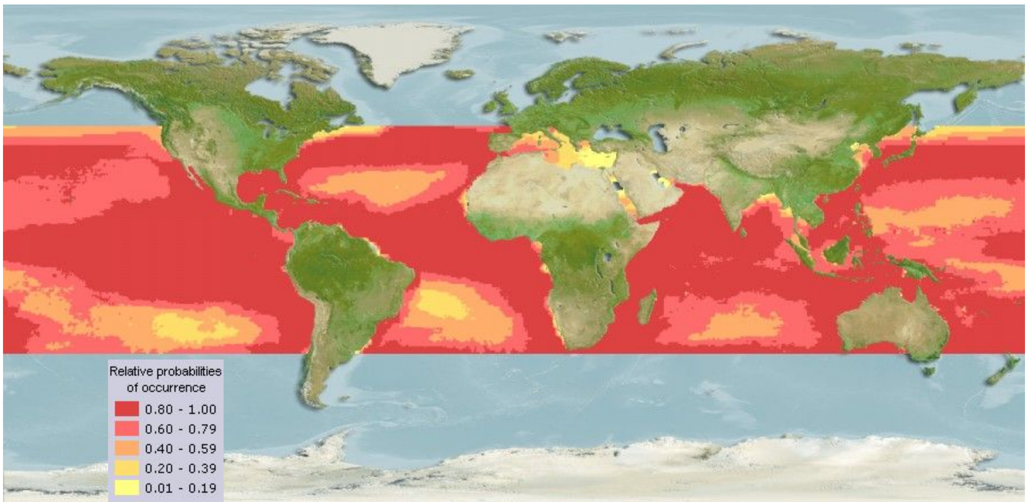

Fig. 2. Map showing the distribution of *S. lewini* (www.Fishbase.org).

However, studies on migration routes suggest that different populations exist in very close area between them. For the hammerhead shark off the coast of Florida, has found that sharks tagged in the region of Tampa Bay do not leave that area. However, tagged sharks in the Florida Bay migrate north without mixing with the Tampa Bay (Kohler et al., 1998, quoted by, 2008).

For the present study was taken to the Central American countries as one region and the sharks caught in it belong to the same population, this supported by studies conducted in *phylopatry* of *S. lewini*, which would explain the unexpected degree of population structure found in sharks, including some widely distributed, highly vagile species. Tagging data indicate that long distance forays are rare (Kohler & Turner, 2001 quote by Duncan et. al., 2006). Even if they are not loyal to specific nurseries, reproduction in many species is strongly affiliated with sheltered, coastal habitat (Duncan et. al., 2006).

6.2.3 TAXONOMIC STATUS

For the classification of *Sphyrna lewini* (Griffith and Smith, 1834) in the taxonomic categories used that proposed by Compagno (1984), which is presented below:

Domain: Eukaryota

Kingdom: Animalia

Phylum: Chordata

Subphylum: Vertebrata

Superclass: Gnathostomata

Grade: Chondrichthiomorphi

Class: Chondrichthyes

Subclass: Elasmobranchii

Superorder: Galeomorphii

Order: Carchariniformes

Family: Sphyrnidae (Linnaeus, 1758)

Genus: *Sphyrna*

Species: *lewini* (Griffith and Smith, 1834)

Scientific synonyms: *Cestracionleeuwenii* (Day, 1865), *Zygaenaerythraea* (Klunzinger, 1871), *estracionoceánica* (Garman, 1913), *Sphyrnadiplana* (Springer, 1941).

6.3 APPENDIX C

6.3.1 BIOGEOGRAPHIC AND OCEANOGRAPHIC DIVISION IN THE PACIFIC OCEAN OF CENTRAL AMERICA

Central America is a large geographical region that extends from the southern border of Mexico in North America to the northern border of Colombia, South America. Physiographic region extends from the Isthmus of Tehuantepec, Mexico, to the Gulf of Uraba, Colombia. The region, administratively and politically, is organized into the following seven independent nations: Belize, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica and Panama (Fig. 3).

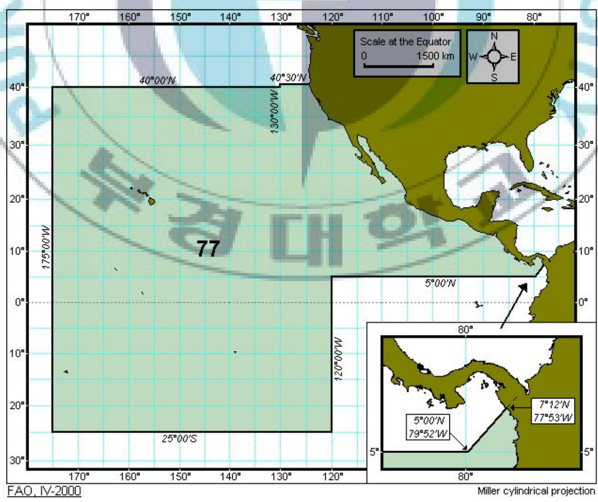

Fig. 3. Boundaries of the Eastern Central Pacific (Major Fishing Area 77) (FAO, 2011).

Central America has two seasons: dry (November to April) and rainy season (May to October), within the latter rainy season is affected by the Caribbean hurricane season (June to November). Frequent tropical storms and hurricanes increase the flow of local rivers, affecting some areas with flooding (Escobar et *al*., 2006).

a. Oceanography

The coastal zone of the region is 6.242 km long and includes about 14 million square miles of Exclusive Economic Zone (EEZ) (FAO, 2006).

North East Pacific (NEP) comprises the coastal and marine and freshwater environments related to them (Fig. 4), contained in 45 States / Departments and / or Provinces to the Pacific waterfront eight riparian countries (Colombia, Costa Rica, El Salvador, Guatemala, Honduras, México, Nicaragua and Panamá) (Escobar et *al*., 2006).

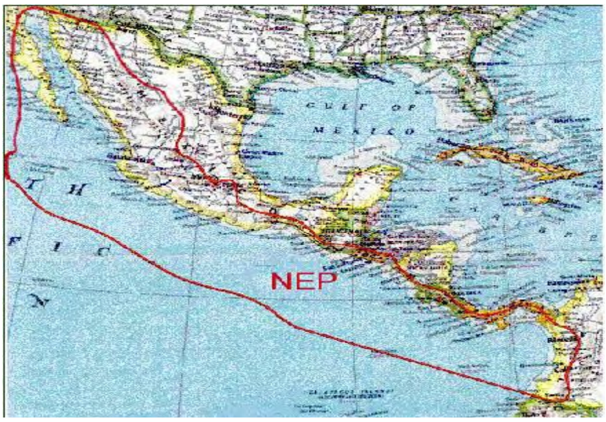

Fig. 4. Delimitation map Nolrd East Pacific (NEP), source of Action Plan by Protect and Sustainable Development of coast and marine areas of North East Pacific, 2006 (Escobar et *al*., 2006).

The costs of the NEP are colliding with the bordering mountain ranges and narrow coastal plain, which in some sections is reduced markedly, as does the continental shelf (Croom et *al*., 1995, quote for Escobar et *al*., 2006).

According to the research literature by Escobar et al. (2006) the continental shelf in America, described below: a) Guatemala, the continental shelf between zero and 200 m deep, covering an area in the Pacific Ocean: 14.700 km^2;

b) El Salvador there is some developments off the coast of central and eastern which extends 80 km from the coastline to depths of 200 m;

c) Nicaragua's platform presents significant reductions, where the slope is between 200 m and 500 m;

d) Costa Rica off the peninsulas of Nicoya and Osa, with peaks of 60 km in the Bahia de Coronado, and

e) Panama has a claim to the continental shelf in 500 m.

The coastal zone of the region is 6,242 km of long and includes about 14 million square nautical miles of Exclusive Economic Zone (EEZ) (FAO, 2006).

b. Biogeographic Area

Marine and coastal systems in the region support a complex interaction of different ecosystems, with an enormous biodiversity and are among the most productive in the world, provide breeding places for the reproduction of commercial species, generate tourism revenue and play a protective role.

According to CAIS (2001), 44% of the Central American coast is composed of agricultural systems, indicating the change through the years, of coastal systems for crop or livestock systems. In addition, the Pacific coast of Central America has 400,900 hectares of mangroves, which account for

71% of all mangrove forests in Central America, where countries with largest area of mangroves: Panama (52%), Honduras (11%) and Nicaragua (11%), other countries have about 9% each of the mangrove cover in the Central Pacific.