The United Nations University
FISHERIES TRAINING PROGRAMME

P.O. Box 1390, Skulagata 4
120 Reykjavik, Iceland

Final Project 2006

SMALL SCALE LONGLINE FISHING TECHNIQUE FOR THE ARTISANAL FISHERMEN IN MAURITIUS

Devanand Bolaky
Ministry of Agro Industry and Fisheries
The Fisheries Training & Extension Centre (FiTEC)
Pointe Aux Sables
Mauritius
Tel: +(230) 234 7209, +(230) 234 6858
Fax: +(230) 234 6967
Email: fitec@mail.gov.mu

Supervisors
Einar Hreinsson, eihreins@hafro.is
Olafur Arnar Ingolfsson, olafur@hafro.is

ABSTRACT

This study considers small scale longline fishing techniques in Mauritius using boats less than 14 m long. The project identifies requirements in terms of choice of boat, equipment and fishing gear. This study is based on a literature review, collection and evaluation of data from the Mauritius fisheries, and collection of technical data regarding longline gears and boats. The characteristics of four different alternative boats and their operations with regard to longline gears to catching pelagic species were worked out. A tool for technical and economic evaluation of boat and gear options was developed. In this study, it is shown how this tool can be used to evaluate practical options for introducing deep sea longline fishing to the artisanal fishermen in Mauritius. The findings of this project can also be used in developing training curriculum for fishermen in the same context

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1 INTRODUCTION

The longline capture technique has been known to fishing nations throughout the world since ancient times. Longline fishing has developed through the years from handline fishing. The trend from handlines to fishing with rods and poles and onwards to longline fishing was mainly governed by fishing conditions, habitat and the prey itself (Von Brandt 1972). Using handlines, the hunter has an eye on the fishing instrument whereas longlines are not monitored. A longline is defined as a passive gear and mainly based on fish attraction by means of bait, which serves as a source of smell and taste stimuli, to lure the fish to the gear and stimulate it to ingest the baited hook (Bjordal and Løkkeborg 1996). Longline gear can be of remarkable length and can be set at the seabed targeting demersal species, or above the bottom, targeting pelagic or semi pelagic species. A drifting longline, set to drift freely, is not limited to a fixed location and can operate over large water bodies. “The drift line searches for the fish” is a fishing slogan. Longline for tuna is said to have been invented by the Japanese more than 250 years ago (Von Brandt 1972). It has developed from small scale artisanal fishing to modern mechanised longline operations.

2 PURPOSE OF THIS STUDY

The target group in this project is the artisanal fishermen of Mauritius operating inside the lagoons, in the vicinity of the outer reef area, and those fishing around the fish aggregating devices (FADs) placed in the high seas. Fresh fish production in 2004 has decreased compared to that of 2003 (Anon 2004b). On the other hand, catch around FADs was higher than in other fisheries. However, FADs are productive only during peak season of tuna migrations. Fishermen fishing around the FADs want to go further in extending their capabilities in the high seas. Some efforts have been made by artisanal fishermen to enter deep sea longline fishing but so far without success.

Considering the tuna and tuna like resources which could be exploited in the adjacent waters, the development of the pelagic longline fishery appears more feasible than purse, since purse seining is a capital intensive venture and more farfetched for the artisanal fishermen. Longlining is practiced globally in many fisheries and much information and current practices can be gathered. The demand for fresh fish continues to increase in the world with a potential increase in prices as well. Under these circumstances, small sized longliners may be more economical and efficient than large sized longliners in catching tuna for the fresh fish market in Mauritius.

Longline fishing is a domain into which artisanal fishermen could venture. However, without access to essential capital, information, counselling and guidance, these fishermen may not be able to engage in longline fishing. The aim of this project is to develop tools to assist the artisanal fishermen to identify the needs regarding longline fishing for tuna and swordfish in the local context of Mauritius and investigate ways in which the choice of boat and fishing equipments could be considered. In addition, collected background information could be used to support training courses and workshops in longline fishing for the targeted group. The tools may help fishermen, officials and bankers approach the task of exploiting tuna and associated species. The main focus is on small scale vessels for tuna longlining. The outcome is expected to provide both basic and specific knowledge regarding the:

- Introduction of longline fishing using small scale boats.
- Evaluation of technical and economical parameters of boats and gears.
- Organisation of courses and developing teaching materials for local fishermen.
- Organisation of experimental fishing on existing research boats.

3 THE FISHERMEN COMMUNITY IN MAURITIUS

The fishermen community in Mauritius consists of 2,300 registered artisanal fishers operating mainly inside the lagoon and in the vicinity of the outer reef. The gears used are basket traps, hooks and lines, harpoons, large nets and gill nets (Appendix 7). Catch per fishermen per day is estimated to be about 4 kg. Implementation of a buy-back scheme is going on for the reduction of net fishing by paying compensation to net owners and fishers. The gillnet fishermen also receive compensations when gillnet fishing is prohibited (Anon 2004b).

3.1 Boats

There are about 2,300 registered artisanal fishing boats, and there of 1,900 are active in fishing powered with outboard engines (Table 1) (Anon 2004b). Some 150 fishing boats with inboard motors are also operating. The engine capacity of the motors used by the artisanal fishermen ranges from 8 to 25 Hp. The boats are 10- 24 feet (3 – 9 m) long and made of wood or fibreglass.

Table 1: Total number of registered boats in Mauritius.

District	Artisanal Fishing	Pleasure Boat	Sport fishing	Semi industrial boat	Others	Total
Port Louis	162	89	0	0	0	251
Pamplemousses	325	600	3	0	0	928
Riv.Du Rempart	417	272	1	0	55	745
Flacq	395	237	2	0	28	662
Grand port	554	434	2	0	46	1,036
Savanne	106	53	0	1	0	160
Black river	367	499	3	0	0	869
Total	**2,326**	**2,184**	**11**	**1**	**129**	**4,651**

3.2 Fishermen training

Being aware of the importance of the economic and social aspect of the artisanal fishery, the Government of Mauritius has taken steps to encourage off-lagoon fishery by developing the use of FADs in the open sea. In 1984, Mauritius obtained financial and technical assistance from the French Government. A mobile training school (Formation Itinerante de Peche) was launched to train artisanal fishers in fishing techniques to improve their knowledge and skills to fish in the outer lagoons.

Recently the Fisheries Training and Extension Centre, which is situated at Pointe aux Sables has been set up through a grant from the Government of Japan. It is destined to cater to the training needs of artisanal fishers both in Mauritius and Rodrigues and for fishers in the region.

3.3 Fish aggregating devices

A fishery for pelagic species around FADs was developed in 1984. FADs were placed in the high seas. These FADs are placed between 2-12 nm from the coast of Mauritius (Figure 1). Artisanal fishers were trained to fish around them by the Formation Itinerante de Peche. In the 1990s, the catch rate around FADs was 20 kg/fisherman/day (Venkatasami and Mamode 1995). Presently, the catch rate is estimated to be about 30 kg/fisherman/day. An increase in albacore tuna landings (*Thunnus alalunga*), commonly known as Thon Germon, is notable due to the increasing use of vertical longlines aimed at this species (Venkatasami and Mamode 1995).

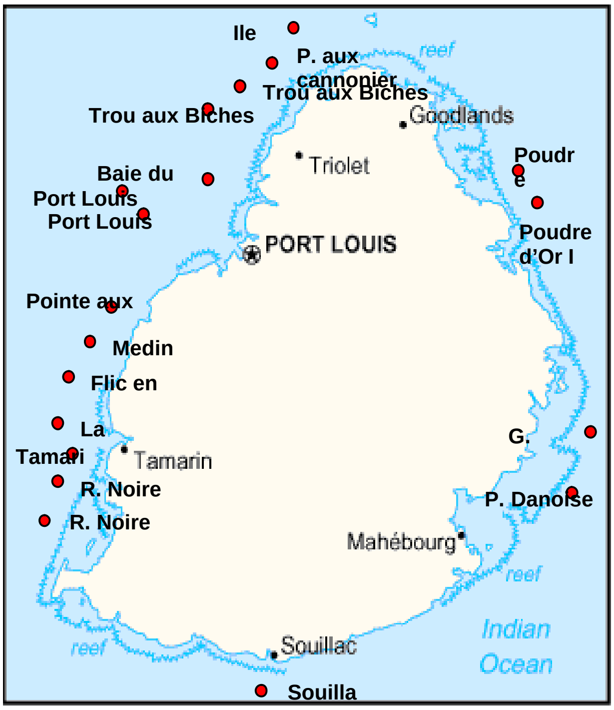


Figure 1: FADs around Mauritius.

3.4 Financial incentives put in place for the fishermen community

Loan schemes have been established and are constantly revised in collaboration with the Development Bank of Mauritius to encourage fishers to move from the heavily exploited lagoon to outer reef areas.

The different loan schemes are as follows (Anon 2004b):

- Loan ceiling of Rs 200,000 (Rs = Mauritius rupees, approx. $6,000)* with respect to small scale fishers for the purchase of boats, outboard motors, fishing and safety equipment;
- The loan ceiling available to groups of fishers is Rs 3 million (approx. $90,000)* for the development of semi industrial fishing;
- A Loan Guarantee Fund of Rs 10 million (approx. $300,000)* was set up to enable fishers to obtain loans for the development of the semi-industrial fishery;

- A special loan scheme amounting to Rs 5 million (approx. $150,000)* was put in place for the setting up of fish and sea food processing plants, including cold room facilities.
- A loan amounting to Rs 50 million (approx. $1,500,000)* for the purchase of fishing vessels was made available.

*Note approximate currency rate taken is Rs 33.31 for 1 US $ (10.01.2007)

There is an organisation which is a parastatal body called the Fishermen Welfare Fund under the aegis of the Ministry of Agro-Industry and Fisheries which promotes the wellbeing of registered fishermen and their families by managing several schemes introduced by the government. These schemes, e.g. scholarships for children, sick allowance, interim assistance to families of fishermen in distress, financial assistance for the repairs of damaged boats and outboard motors and compensation for accidental death at sea, contribute to the welfare of the community.

3.5 The artisanal fishery

The artisanal coastal fishers in Mauritius, Rodrigues and the outer islands exploit the lagoons and outer lagoon coastal grounds. The fishery is essentially a multispecies one, comprising *Lethrinus* spp., *Mugil* spp., *Siganus* spp., *Naso* spp., *Scarus* spp., *Epinephelus* spp. and *Parapenaeus* spp. as the main species. *Penaeid* shrimps, oysters and octopus are also fished to a lesser extent. The artisanal fishery is the main source of fresh fish supply for the local market. This fishery uses traditional means and methods of fishing. The fishing devices used are mostly hooks and lines, basket traps, large nets, gill nets, canard nets, cast nets, shrimp nets and harpoons (FAO 2000).

4 LONGLINE FISHING IN THE SOUTH WEST INDIAN OCEAN

Longlines contribute to the catch much more significantly in the Indian Ocean than in other oceans. The Japanese, Taiwanese and Korean longline fisheries and small artisanal fisheries (baitboats, trawls and gillnets) of coastal nations, e.g. the Maldives and Sri Lanka, were the major fisheries in the Indian Ocean until the early 1980s. Japanese longline catches were predominant, around 20,000 tonnes of tuna per year. The longline catches then increased, due to increases in the number of longline fishing vessels of Taiwan, the Republic of Korea, and Indonesia, and reached almost 260,000 tonnes by 1993. However, the development of the purse-seine fishery was even faster, and its catches have exceeded the longline catches since the early 1980s. The catches of the purse-seine fishery targeting skipjack and yellowfin, introduced in the western Indian Ocean by France and Spain in the mid-1980s, together exceeded 350,000 tonnes in 1995. Baitboat catches have increased gradually since the mid-1980s, due to the increase of catch by the Maldives (Anon 2004a).

4.1 The Mauritian longline fishing activities

Three foreign owned vessels operating under the Mauritian flag were actively engaged in the longline fishery in 2004. They undertook 10 fishing trips, unloading a total of 1,117 tonnes. The species composition of the landings is shown in Figure 2. Most of the catch was composed of swordfish (60.4%), the target species of the vessels. The catch per unit effort was 1.2 kg per hook. The fishing area was spread between latitudes 19º S and 34º S and longitudes 41º E and 100º E (Anon 2004b).

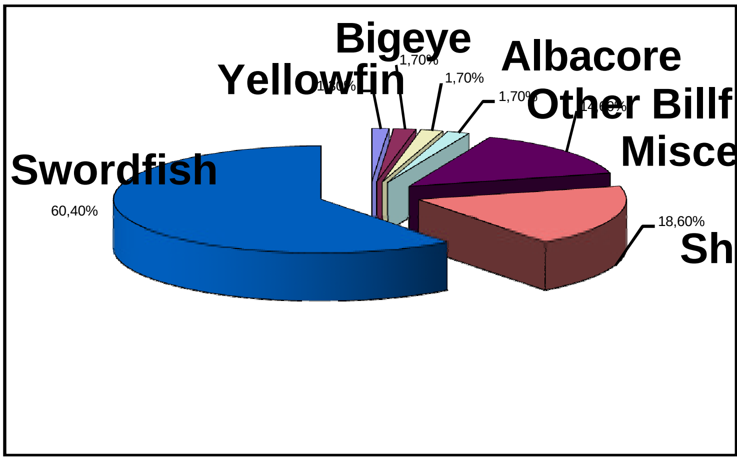


Figure 2: Catch composition of Mauritian Longliners (Anon 2004b).

The fishing area of the licensed longliners was spread widely in the Western Indian Ocean between 8º N and 33º S and 40º E and 107º E as depicted in Figure 3 (Anon 2004b).

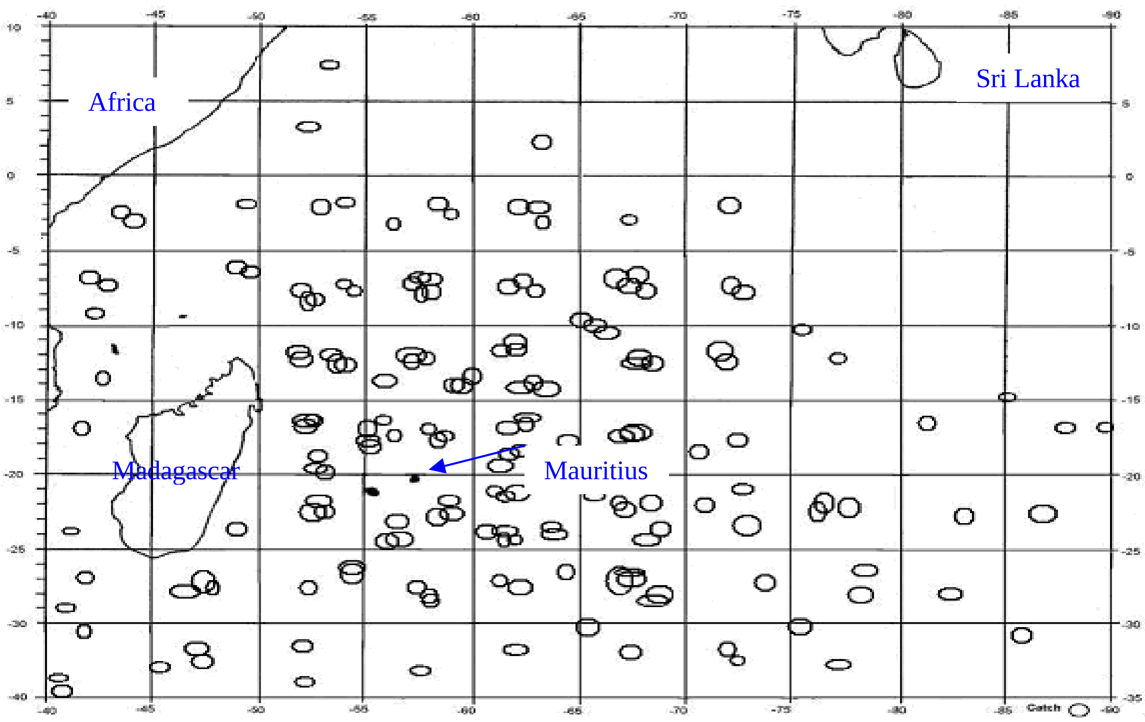


Figure 3: Fishing area of longliners in the Western Indian Ocean (Anon 2004b).

4.2 Tuna longliners transhipment

A total of 14,255 tonnes of tuna and tuna-like species was transhipped in 2004 at Port Louis by licensed and non-licensed longliners, which effected calls in the port of Mauritius. Albacore tuna constituted 32.5% of the total quantity transhipped Table 2 (Anon 2004b). Under the Fishing Agreement with the European Union, 37 licences were issued to longliners in 2004. Six licences were issued to Japanese longline fishing vessels under a Fishing Agreement with the Federation of Japan Tuna Fisheries Co-operative Associations (JTFCA) (Anon 2004b). In addition, 138 licences were issued to individual foreign vessels. Extensions of licences were granted to 121 vessels during that same period. The species composition of the fish transhipped is shown in Table 2.

Table 2: Species composition of fish transhipped in Mauritius.

Year		ALB	YFT	BE	SPJK	SWF	BF	MAR	SAIL	SHK	Misc.	Total
2000	Tonnes	12846	835	780	33	355	-	238	22	-	474	15583
	%	82.4	5.4	5.0	0.2	2.3	-	1.5	0.1	-	3.0	100
2001	Tonnes	13595	898	880	-	274	-	319	25	-	336	16327
	%	83.3	5.5	5.4	-	1.7	-	1.95	0.2	-	2.1	100
2002	Tonnes	13584	2505	528	-	228	-	267	20	-	315	17447
	%	77.9	14.4	3.0	-	1.3	-	1.5	0.1	-	1.8	100
2003	Tonnes	6225	1280	415	25	2126	34	187	59	1657	456	12464
	%	50	10.3	3.3	0.2	17	0.3	1.5	0.5	13.3	3.7	100
2004	Tonnes	4633	4110	1361	3.4	1595	0.4	172	5.6	2022	352	14255
	%	32.5	28.83	9.55	0.024	11.2	0.003	1.2	0.04	14.18	2.471	100

ALB=Albacore, YFT=Yellowfin, BE=Bigeye, SPJK=Skipjack, SWF=Swordfish, BF=Bluefin, MAR=Marlin, SAIL=Sailfish, SHK=Shark

4.3 Swordfish fishery

Five local vessels were involved in the fishery in 2004. The vessels effected 70 trips and landed 97.2 tonnes of fish. Swordfish constituted 53.3% of the catch. The fishing area was spread around Mauritius, between the latitudes 14º S and 25º S and longitudes 51º E and 65º E. The catch composition of the local vessels from 2000 to 2004 is shown in Table 3 (Anon 2004b) and the percentages for 2004 are presented in Figure 4 (Anon 2004b).

Table 3: Catch composition of the local swordfish fishing vessels (kg*)*.

Year	Swordfish	Yellowfin	Bigeye	Albacore	Marlin	Shark	Misc.	Total
2000	10 021	2 368	945	2 375	805	-	5 398	21 912
2001	33 919	24 061	5 098	17 754	2 483	-	4 042	87 357
2002	26 248	5 288	2 152	7 242	1 162	220	4 108	46 492
2003	35 123	21 395	2 190	14 003	2 413	228	3 986	79 338
2004	51 844	12 597	4 412	19 864	2 236	538	5 876	97 187

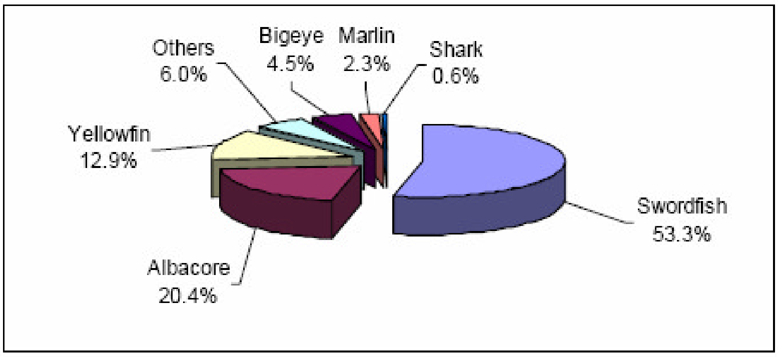


Figure 4: Species composition on swordfish vessels.

4.4 Locating and catching pelagic species

The information below is mainly taken from the manual "Horizontal Longline Fishing Methods and Techniques" (Beverly *et al*. 2003).

When a longline is used in a traditional non-selective way, its hooks are distributed throughout a 100 m deep water layer. The upper ones tend to catch yellowfin tuna, albacore, swordfish and marlins, while the lower ones that reach depths where the water is cooler and contains less oxygen would catch species such as bigeye tuna (Table 4).

Scientists have determined from studies the preferred habitats of the main species caught with longlines. Most tunas make wide vertical diurnal movements. The depth of the habitat is quite variable depending on the water temperature, species and size of fish. It is impossible to generalise where those species are available. Besides, the hooks set in the deeper zone still have chances to hit the fish near the surface, while the line is being set or hauled. As a matter of fact, when the line is moving, it has even better chances to catch fish (Beverly *et al*. 2003). In general, longlines targeting yellowfin are set in relatively shallow waters, near the thermocline, for albacore in the temperate waters, also near the thermocline. Swordfish lines are also set shallow waters but during the night. Bluefin lines depend on the time and area (and size of the target fish) but also in the intermediate depth. Bigeye lines are set the deepest (FAO 2006c).

The main targeted species of pelagic longline fishing are tunas, while other species including sharks can also be an important component of the catch. The catch can be divided into three distinct categories: target, by-product and by-catch. Tunas are by far the most important targeted species for horizontal longlining. The highest value species are bluefin tuna, bigeye tuna, yellowfin tuna, and albacore tuna, respectively. Some billfish are also targeted, with broadbill swordfish being the most important, followed by striped marlin (Table 4). Beverly *et al*. (2003) outline the main parameters for locating and catching these target species. (Note: these general parameters will vary with hemisphere, locality, season, moon phase, and local conditions.)

Table 4: Some parameters for locating and catching target species.

Species	Capture depth	Best baits	Set/ haul times
Albacore tuna	50 – 600 m, thermocline	saury, pilchard, sardine	0400 – 0800 1400 – 1800
Yellowfin tuna	50 – 250 m, mixed and intermediate layer	saury, bigeye scad milkfish, squid	0400 – 0800 1400 – 1800
Swordfish	50 – 250 m, mixed and intermediate layer	*Illex* spp. Squid, lightsticks	1800 – 2000 0600 – 0800
Bigeye tuna	50 – 600 m, thermocline	saury, bigeye scad pilchard, squid	0400 – 0800 1400 – 1800

5 BASIC DESIGN OF DRIFTLINES

As indicated by the name of the gear, the main part of it is a long mainline to which shorter branchlines with baited hooks are attached. A longline consists of sections of line. A basket of longline gear is the amount of mainline and branchlines in between two floats (Figure 5). For tuna and swordfish a basket may contain from 4 to 40 branchlines. Typically, a basket gear has small baskets of between five and 15 branchlines, while monofilament gears have baskets of between 15 and 40 branchlines. A branchline is a single line, sometimes made up of several materials joined together with a snap at one end and a hook at the other (Figure 6).

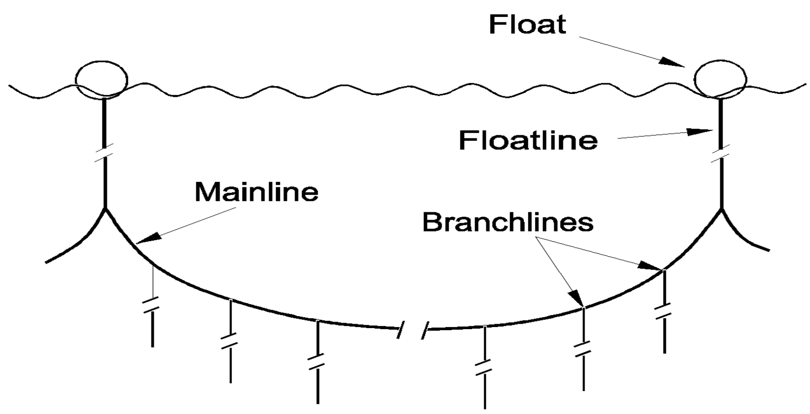


Figure 5: A longline set.

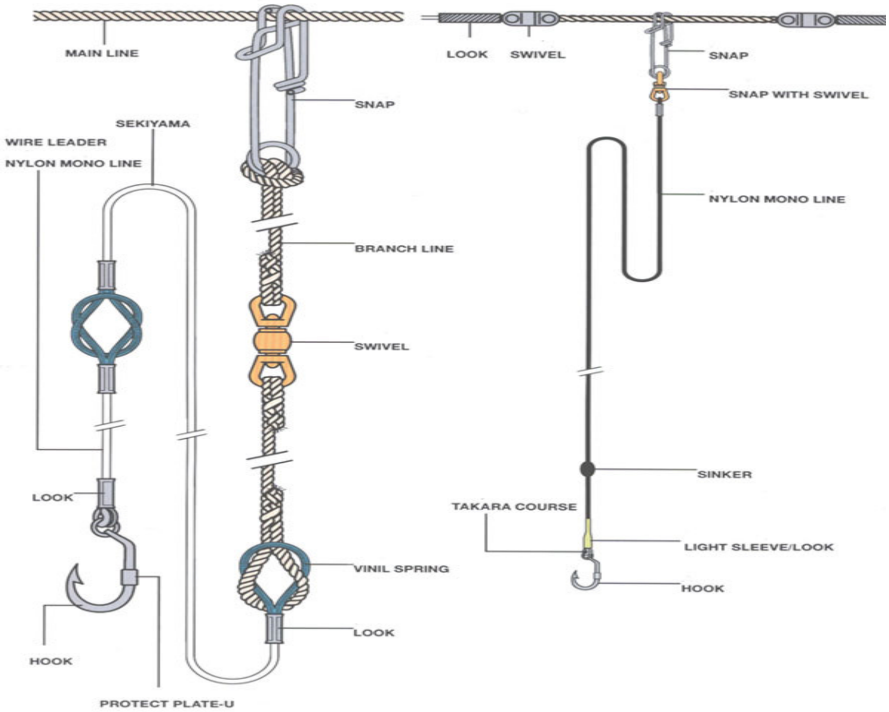


Figure 6: Branchline details.

5.1 Hooks

Branchlines can be rigged with three different types of hook: Japanese tuna hook with ring, tuna circle hook, or big-game hook (Figure 7). Japanese tuna hooks come in sizes ranging from 3.4 to 4.0 *sun* (*sun* = 3.3 cm) but 3.6 is the most popular, (Beverly 2006). Tuna circle hooks come in a range of sizes, with the sizes 14/0 to 16/0 the most popular for pelagic longlining. Big-game hooks (also called ‘J’ hooks), are the most popular hooks when fishing for swordfish. Sizes are usually 8/0 or 9/0. All of these hook types are available in either galvanised steel or stainless steel. Stainless steel hooks last longer than galvanised hooks but are more expensive.

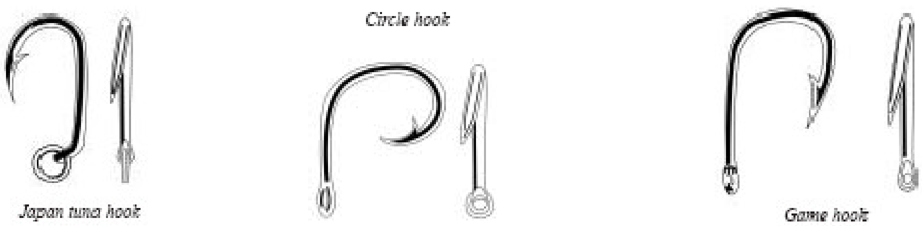


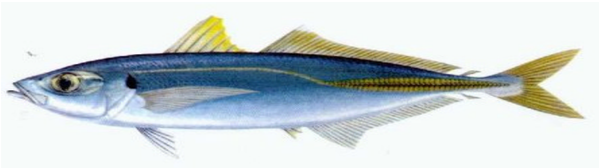
Figure 7: Hooks used for tuna and swordfish (Beverly *et al.* 2003).

5.2 Bait

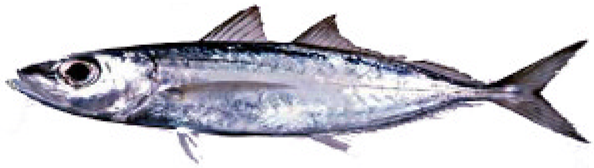
Bait used for longline fishing is usually frozen whole finfish such as sardines, saury, or mackerel scad (Figure 8). Frozen whole squid is often used for tuna longlining but is more important as bait for swordfish. Live milkfish is also used for tuna longlining, particularly by Taiwanese boats. Table 5 and Figure 8 show some of the most common longline baits in English, French, Japanese and Latin. Many longline operations have adopted the Japanese names for bait species.

Table 5: English, French and Japanese and scientific names for the main bait species.

English	French	Japanese	Scientific
Bigeye scad	Selar coulisou	Me ajii	*Selar spp.*
Blue pilchard, Australian pilchard	Pilchard d'autralie	Iwashi	*Sardinops neopilchardus*
Club mackerel	Maquereau espagnol	Saba	*Scomber japonicus*
Mackerel scad	Comete	Muro aji	*Decapterus spp.*
Milkfish	Chanos	Sabahii	*Chanos chanos*
Sardine, Japanese pilchard	Pilchard du japon	Ma iwashi	*Sardinops melanostictus*
Saury	Balaou du pacifique	Sanma	*Colobis sairi*
Squid	Encornet, calmar	Ika	*Ilex spp.*

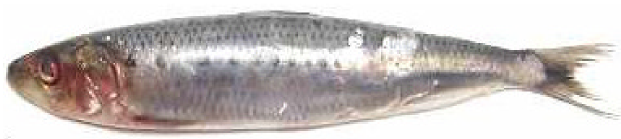


Mackerel Scad

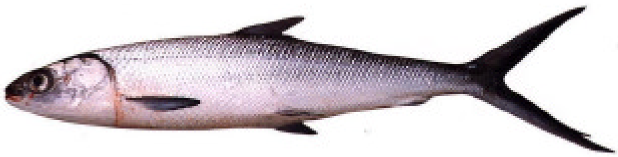


Bigeye scad

Mackerel

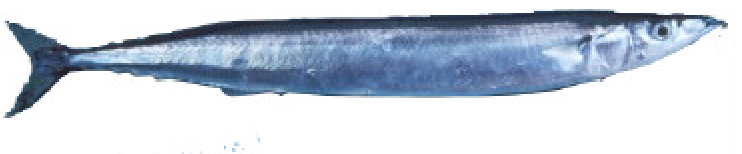


Sardines and pilchards



Milkfish

Squid



Saury or sanma

Figure 8: Common bait fishes used in longline fishing.

5.3 Targeting the gear and depth of set

The depth of the set is important. If a line setter is not used, but the line is allowed to run freely then the length of the mainline that goes out is equal to the distance the boat travels during setting. This is called towing the line. A towed line will generally only be as deep as the floatlines. There will be some sag between floats but not nearly as much as when a line setter is used (Figure 10). There are, however, ways of achieving a deeper set without the use of a line setter. The gear can be set deeper if longer floatlines are used or if more branchlines are put into each basket. For example, a longline with 30 m floatlines and baskets with 20 branchlines will be deeper than a longline with 30 m floatlines and baskets with 10 branchlines, even though the floatlines are the same length (Figure 9).

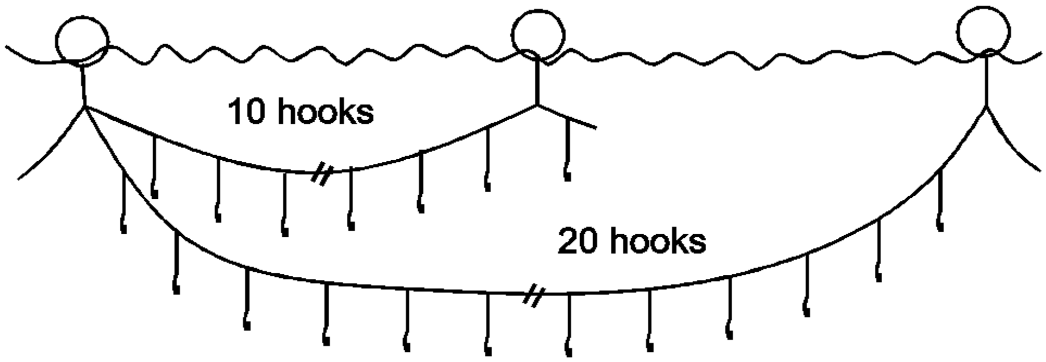


Figure 9: Floatline distance.

Another way to achieve a deeper set is to attach weights to baskets near the middle branchline. There is a risk, however, that too much weight may cause the line to collapse. When a line collapses, the branchlines sink and the floats come together. In the case of increasing basket size or adding weights, floats should be doubled (two floats to a floatline). The best way to regulate the depth of the set and to achieve a deep set is to use a line setter (Figure 10). A line setter throws out the mainline at a greater speed than the boat is travelling. That way, there will be a curve or sag in the basket, between the floatlines. The branchlines will not be at a uniform depth but most will be at a depth greater than the length of the floatlines (Beverly 2006).

Line Setter: Hydraulic winch fitted with a main spool through which the fishing line runs at controlled speed during setting operation

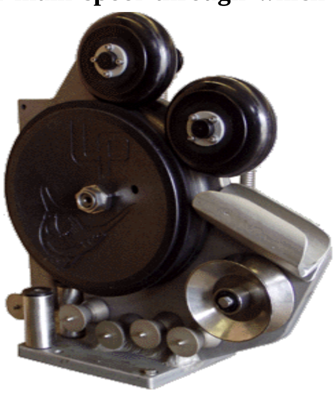


Figure 10: Line setter (monofilament gear) (Source: http://www.lindgren-pitman.com/).

5.3.1 Calculating the depth of the mainline

A horizontal longline sinks in a series of catenary curves (Figure 11), each suspended between two floats (one basket of gear). A catenary curve is the natural curve formed by a line or cable suspended between two points (e.g. telephone lines between telephone poles). On a longline the deepest hooks are found in the middle of the basket. The curve, or sag, of the line is a function of the speed of the boat, the number of branchlines per basket, and the rate at which the line setter deploys the line. The length of the floatlines and the length of the branchlines also determine depth of the line but these dimensions do not change so can be added on after calculating the depth of the catenary curve. However, the true depth will be less than the calculated depth because of currents pushing the floats together, pulling them apart, or pushing up or sideways on the mainline (Beverly 2006).

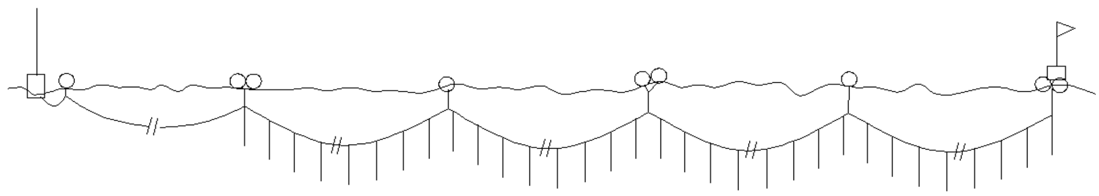


Figure 11: Catenary curves in longline.

5.3.2 Theoretical depth of the mainline

To calculate the theoretical depth of the mainline, the speed of the boat and the speed of the line being ejected by the line setter should be known. The ratio of these two speeds is called the sagging ratio, or SR, and is a dimensionless number (a number without length, weight or time). SR can also be expressed as the ratio of the distance the boat travels to the length of line ejected by the line setter during the same period. For example, if the speed of the boat is 6 knots and the speed of the line being ejected by the line setter is 8 knots, then the SR is 6 ÷ 8 = 0.75. The same ratio could be derived by comparing the distance that the boat travels between two floats (900 m for our example) to the length of line between the two floats (1200 m) — 900 ÷ 1200 = 0.75. Once the SR is determined, the depth of the deepest hook on the line can be determined (Beverly 2006).

5.3.3 Speed of the boat

To know the speed of the boat, you need only to look at the electronic instruments in the wheelhouse such as the GPS or a speed log. Alternately, the speed can be calculated using chart work and the formula, Speed = Distance ÷ Time, or it can be determined by comparing the engine tachometer with the known boat speed.

5.3.4 Speed of the line

There are several techniques to determine the speed of the line being ejected by the line setter. If a hand held tachometer is available it can be used to determine the speed, in revolutions per minute (RPM), of the large drive wheel of the line setter. The diameter of the wheel is measured and multiplied by 3.14 to obtain the circumference (c = dia x p). A piece of line can also be wrapped around the drive wheel and measured to give the circumference. As the line passes directly over the drive wheel, the amount of line ejected in metres per minute is equal to the circumference of the drive wheel in metres times the RPM. To find the speed of the line in nautical miles per hour you need to divide this number by 31 (there are 1852 m/nm, 1852 ÷ 60 = 31 h.m/nm.m, or 31m/min). Alternately, the line can be ejected from the line setter for one minute exactly while the boat is not moving. The line is then measured as it is pulled back aboard the boat. They divide this number by 31 to get the line speed (Beverly *et al*. 2003).

5.3.5 Information on fishing grounds

The decision where to fish is generally based on previous fishing trips, or from information from other fishing boats. Some information may be available from remote sensors like satellite images, surface temperatures, colour and light. These are accessible through the Internet for commercial subscribers. Fishermen at sea can observe the sea parameters such as a temperature front, current convergences, eddies and upwelling as they indicate anomalies which help to locate fish schools. Anomalies like the concentration of planktons may be detected by echo sounders. Marine birds provide indications of small fish concentration which is preyed upon by larger fish. The best source of information about how, when, and where to catch tuna or swordfish is by talking to other longline fishermen (Beverly *et al.* 2003).

5.3.6 The surface layer of the sea and thermocline

The surface layer is that portion of the water column where the temperature of the water remains fairly constant, or decreases gradually with depth. It extends from the surface down to the thermocline (Figure 12). The surface layer can be divided into the mixed layer and the intermediate layer. The mixed layer occurs from the surface down to where the temperature is 1ºC below the surface temperature (Beverly *et al*. 2003). It is mixed by a combination of wind, waves and convection (warm water rises as cooler water sinks). In the intermediate layer, from the bottom of the mixed layer to the top of the thermocline, the temperature drops gradually with depth. The thermocline is that place in the water column where temperature decreases sharply over a relatively small depth range. In a temperature profile showing temperature against depth, the thermocline shows up as a bend in the graph.

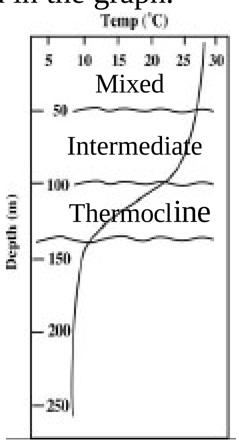


Figure 12: Thermocline (tropical pacific) (Source: Beverly *et al.* 2003).

The 20°C isotherm is usually used to define the thermocline. Yellowfin tuna and broadbill swordfish are associated with the surface layer, and particularly with the mixed layer. To target these fish, the longline should be set so that the hooks fish within the mixed layer. Bigeye tuna and albacore tuna are usually associated with the thermocline (Beverly *et al*. 2003). (Note these parameters vary between oceans, seasons and local conditions)

5.4 Swordfish fishing with longline

Swordfish differ from tuna in many aspects and can attain lengths up to 5 m and weigh up to 500 kg. They are nocturnal feeders, and prey mostly on small fishes and squids. Their flesh is a high value product.

5.4.1 Gear and boat

In Reunion Island the vessels use a system of drifting longline using a main spool (Poisson and Taquet 2000). The main line is a monofilament nylon 3.5 or 4 mm in diameter, stored on a large Hydraulic-powered reel, storing from 20 to 80 km of line. The branchlines with hooks (size 8/0 or 9/0) are 15-20 m long and 2 mm in diameter (Figure 13). These are attached to the mainline with snaps (Figure 13). The depth of fishing is controlled by branchline and floatline lengths, the distance between buoys, the number of hooks between two floats and the speed of the boat during setting. Weights can also be added to control the line depth in strong currents. In addition, larger floats are used to separate the various sections composed of 60 to 100 hooks. Between 300 and 2500 hooks are used during each set. The buoys at the end of the longline are equipped with a strobe light and a radio direction finder system in retrieval (Poisson and Taquet 2000).

Squid is used as bait and a light stick is placed 1 m above the hook. Light sticks increase efficiency in catching swordfish either by attracting swordfish prey or the swordfish itself (Poisson and Taquet 2000). The longliners set about 6-10 hooks between floats and attach generally one light stick for every three branchlines. This whole operation requires three crewmen on deck for baiting the hooks and clipping buoys and branchlines on the mainline and one at the helm. The longline is set in 3 to 6 hours cruising down wind. The line is hauled after sunrise. The duration of the haul depends on the catch and sea conditions. Depending upon the capacity of the boat and fishing ground location about 500 to 1200 hooks can be shot at a time.

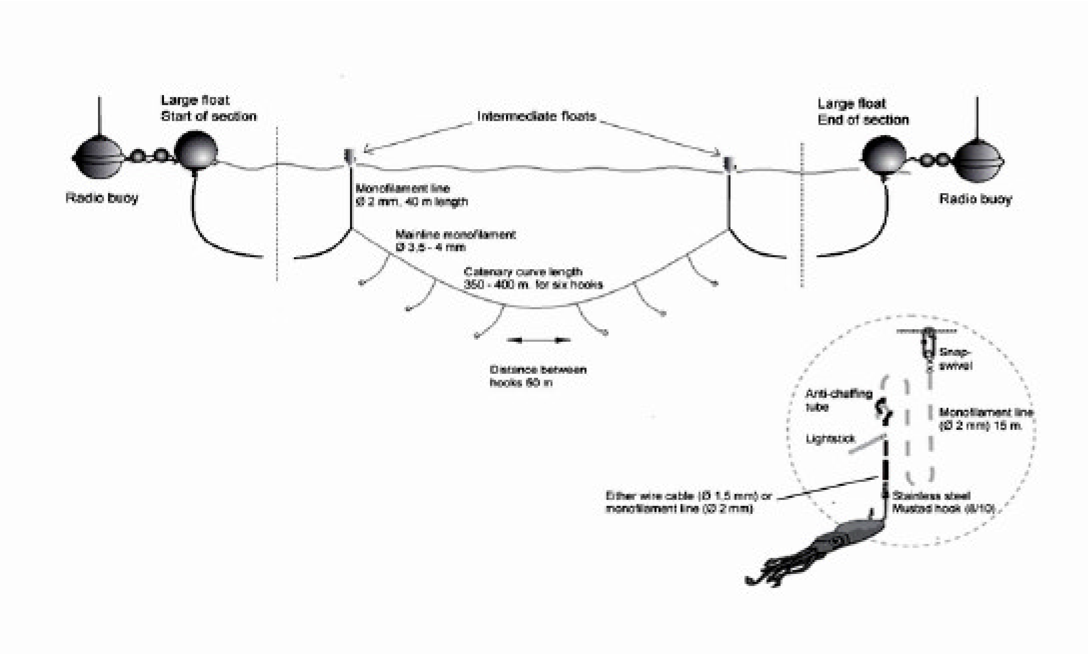


Figure 13: Diagram of a horizontal longline used for swordfish fish (redrawn from Poisson and Taquet 2000).

Boats ranging from 12 to 18 m are suitable for exploiting the swordfish with the semi-industrial longline fishing technique. Navigation, communication and fishing equipment should be available. A hydraulic-operated spool (Figure 14) for hauling and storing the main line is advantageous. The boats should have hold capacity and autonomy of 3 to 8 days with a crew of 4 to 6 persons.

Figure 14: Hydraulic spool 28” x 36” (Source: Lingren-Pitman Inc http://www.lindgren-pitman.com/)

A manually operated reel (Figure 15) can also be used for storing monofilament mainline but on small boats where a short longline of about 5 nm is used. The reel is operated by one or two crew for both setting and hauling.

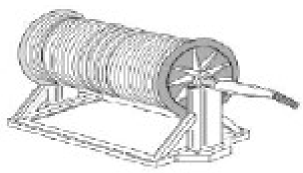


Figure 15: Manually operated reel (Beverly *et al.* 2003).

5.5 By-catch

Theoretically, longline fisheries focus on one or a few target species. However, longlines do not discriminate between species or sizes, and thus they end up hooking large numbers of animals unintentionally (by-catch). The gear is responsible for the unintended deaths of other fish and animals, such as seabirds, sea turtles, and marine mammals. These non-targeted species can be of commercial value and retained for sale. In these circumstances species like marlin, sailfish, skipjack tuna, dorado, wahoo and sharks are caught. Unwanted fish are discarded because they lack commercial value. These species include pelagic rays, sea turtles and marine birds. The catch of seabirds and sea turtles by longliners has become an environmental issue as in some places the animals are protected. In longlining it has been noticed that predation by larger fish such as sharks and toothed whales takes place. It is inevitable to encounter by-catch problems even though some scaring methods or using setting funnels (Bjordal and Løkkeborg 1996) to avoid birds have been put into practice. Setting the line deep can help avoid shark encounters and other by-catch (Beverly 2005). The by-catch varies according to target species. In tuna and swordfish longlining the catch could be composed of the following (Figure 16):

Tunas	*Thunnus spp.*
Dolphin fish	*Coryphaena hippurus*
Sailfish	*Isthiophorus platypterus*
Marlin	*Makaira spp.*
Shark	*Carcharhinus and Isurus spp*
Wahoo	*Acanthocybium solandri*
Skipjack	*Katsowanus pelamis*

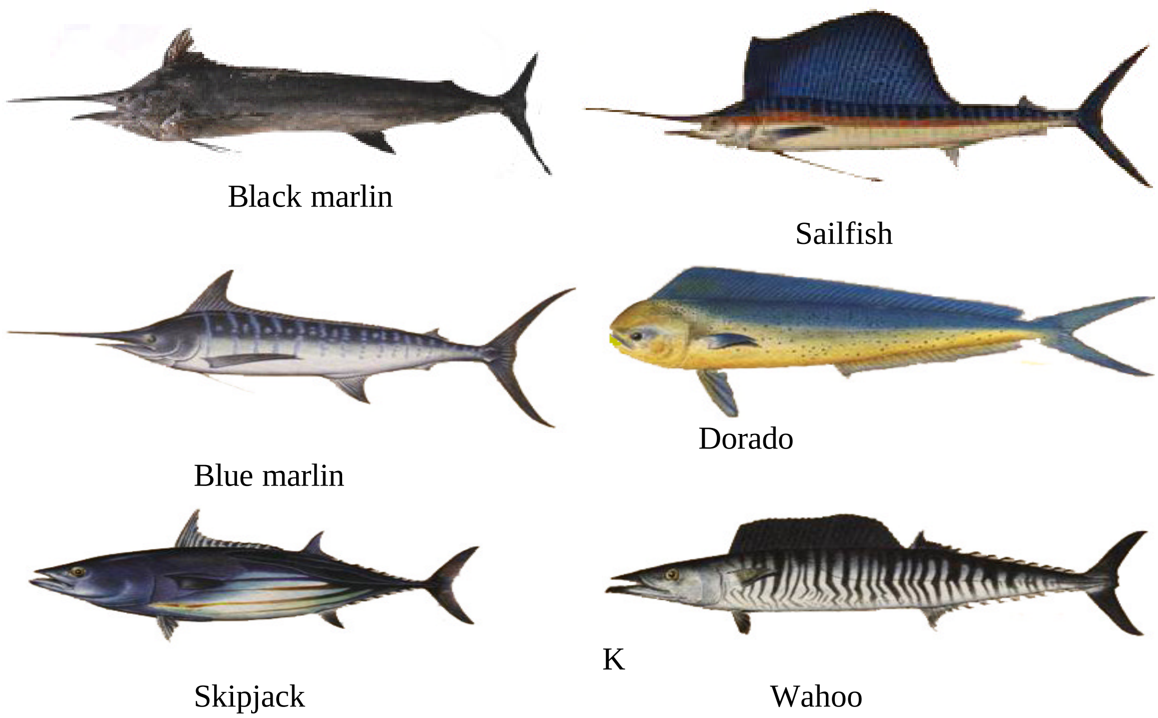


Figure 16: Types of by-catch fish in longline (Source: Beverly *et al.* 2003).

5.5.1 Shark interactions in the pelagic longline fishing

A large quantity of pelagic sharks is taken as by-catch in pelagic longline fishing in the tuna and swordfish fisheries. Since most fish will take a baited hook, it is difficult to be selective with this gear. Together with sharks there are other species living in the same habitat which are caught including skates, rays, turtles and other chondrichthyan fishes (Gilman 2006). The shark when caught can be retained as non-targeted or incidental catch which has raised concern globally about the sustainability of their exploitation. Longline gears have a more destructive impact on sharks than on other species. In addition to depredation of sharks, which is very disturbing, another side effect is the complete removal of hooked fish and bait from the gear which eventually results in damaged and lost of gear. Therefore it is important that fishermen choose hooks which are more selective by using knowledge of fish behaviour e.g. choosing bait, lures and hook sizes known to catch their target species (Skrobe 2003, Gilman 2006).

There are some ways avoiding shark interaction that are practiced by fishermen. The most common method is to change fishing position from high shark interaction and low catch rate of target species. It is also wise to avoid reputed shark infested areas identified by other fishing vessels. Some skippers prefer to set the gear deeper than usual to reduce shark capture and depredation. Some new methods and strategies have been tried but the results have not yet been conclusive.

These practices include:

- Release of refrain from chummed fishing reduces shark detection of baited hooks.
- Deep setting with line setter (Figure 17) and altering soak and haul timings (Beverly *et al.* 2003).
- Use of artificial baits and avoiding certain types of baits to reduce attractiveness of baited hooks.
- Avoiding some types of hooks and wire leaders to reduce shark capture and retention.
- Use of chemical deterrents.
- Magnetic and electrical shark deterrents (Michael 2006).

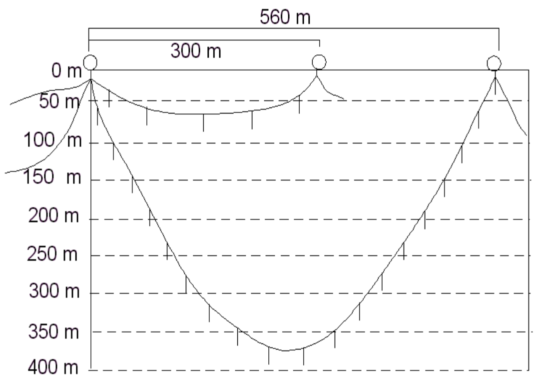


Figure 17: Deep set vs. shallow set longline (Source: Beverly *et al.* 2003)

6 SMALL BOATS FOR LONGLINING

6.1 Introduction

Longline boats exist in different sizes with different deck layouts. They can be made from steel, aluminium, fibreglass or wood, and equipped with a variety of machinery and fishing equipments. In most cases the characteristics of the boat should be defined by analysing the necessary trip length (trip endurance). It is important to take into account the sea conditions, resource availability, technical expertise of prospective crew members and land based infrastructures. Some critical parameters such as depth of the boat for fish hold capacity, beam and length for deck space are important. Since most artisanal fishermen in Mauritius are familiar with fibreglass boats, this study focuses on such boats.

In the light of the above, a report on Marine Fisheries Development Tuna Longliners (Gulbrandsen 1998) is taken as a reference to build up a framework for defining longline boats for the Mauritian context.

6.2 Some theoretical aspects of boat design

In this chapter some important aspects of boat design will be discussed, built on a study manual by Ragnarsson (2006). The most important ones are the main dimensions, displacement, light-ship weight, deadweight, cubic number and capacity. In addition, engine power, resistance, fuel consumption and stability are taken into account.

6.2.1 Main dimensions

The main dimensions or principal particulars (Figure 18) are the following:

(i) The length overall (L_{oa}) is the length in metres from stem to stern.

(ii) The length between perpendiculars (L_{pp}) is the length in metres between the aft and fore perpendicular. Aft perpendicular (AP) often through rudder shaft and fore perpendicular (FP) through the intersection of the designed (construction) waterline (CWL) and the foreside of the stem.

(iii) Beam moulded (B_m) is the maximum breadth of the midship section (⊗) in metres with thickness of shell for GRP boats. The midship section is the perpendicular, located halfway between aft and fore perpendicular.

(iv) Moulded depth to main deck (D_m) is the height in metres from the base line to the deck.

(v) Draught (or draft) moulded (T) is the height from the base line at midship (⊗) to the designed waterline.

In designing a vessel, the cubic number (CUNO) is an essential parameter to configure many characteristics of the boat. In this report the multiple of L_{oa}, B_m and

D_m is being used. For example the fish hold can be calculated approximately from the CUNO.

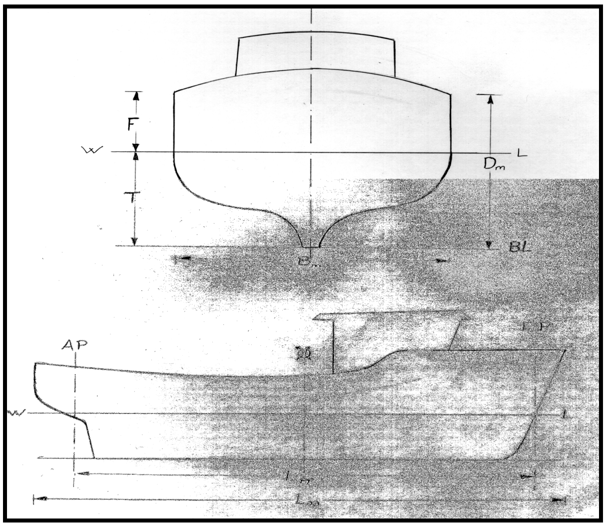


Figure 18: The main dimensions of a boat.

6.2.2 Volume of displacement

The volume of the underwater portion of a vessel is calculated according to the body lines (Figure 19) and mathematical methods, nowadays mainly done by computerised programs. The result is known as the volume of displacement of the vessel up to the waterline at which it is floating.

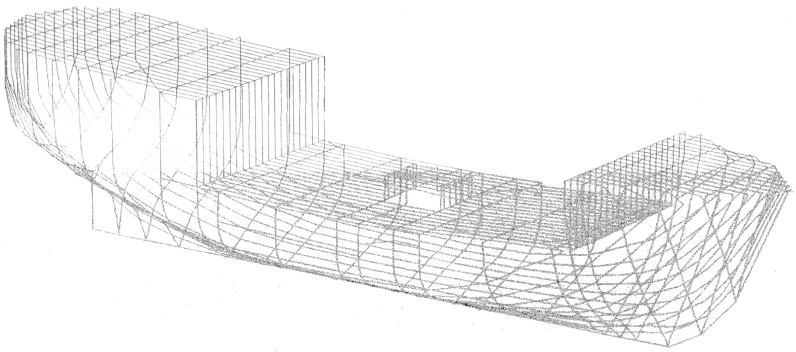


Figure 19: Body lines of a boat and calculations by a computer.

Volume of displacement is denoted with the symbol:

∇ = volume of displacement (m^3)

7.2.4 Displacement of a vessel

The displacement of a vessel in tonnes will be:

Δ = displacement = $\rho \cdot \nabla$ (tonnes)

The common value for the specific weight (ρ = specific weight, tonnes/m^3) of the seawater is 1.025 tonnes/m^3, the sea of the Atlantic Ocean. From the above formula one can see that the draught of a vessel that is floating is lesser in seawater than freshwater. The maximum displacement, which is at the deepest waterline, is a very important parameter for describing a vessel. This refers to the so-called summer loadline for bigger vessels.

6.2.3 Light-ship weight and deadweight:

The light-ship weight (LSW) is the weight of an empty ship, i.e. the weight of a fully outfitted vessel, prepared to sail, without fuel oil, water etc. (no deadweight items onboard). It is important that the weight is estimated at an early stage in the design of a ship. The light-ship weight of a boat is often divided into three main categories:

- Hull
- Outfit
- Machinery (wet)

The deadweight (DW) of a boat is the difference between the displacement and light-ship weight according to the following formula:

$$DW = \Delta - LSW$$

The main components of deadweight are as follows:

- Fuel oil
- Fresh water
- Special outfit (fishing gear)
- Cargo in holds (bait, ice, fish)
- Crew
- Provisions
- Others

The maximum displacement of a ship is the displacement to the deepest waterline (maximum draught). Then the following will be valid:

$$\Delta_{max} = LSW + DW_{max}$$

6.2.4 Stability

Stability is a key factor in vessel design. To ensure good stability the gravity point (G) must always be beneath the so-called transverse metacentre point (M). For instance the Icelandic Maritime Administration (IMA) insists on a minimum GM of 0.35 m for small fishing for all conditions. To satisfy this it is important to have the catch in the hold, minimise the overweight on deck, and ensure a minimum breadth/depth ratio of the boat. According to stability theory, the M-point will move upwards in second potens of the beam, which shows us the importance of the beam.

The fundamentals of stability (Source IMA)

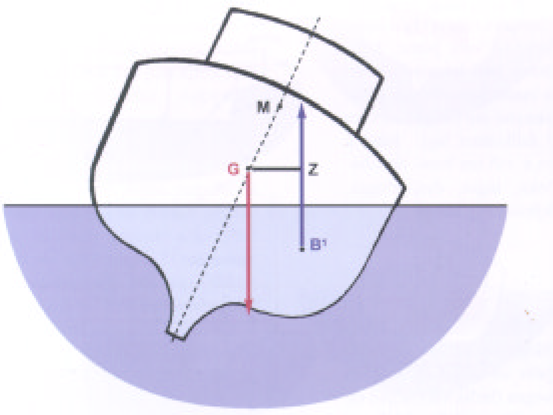


Figure 20: The main points regarding stability at the healing stage of a boat.

Note: The gravity point G, the metacentre point M, the buoyancy point at healing B1, (moving from centre line to the healing side). The righting lever is the difference between gravity force and buoyancy force denoted as GZ.

6.2.5 Resistance and propulsion

The resistance of a ship at a given speed is the force required to tow the ship at that speed in smooth water, assuming no interference from the towing ship. If the hull has no appendages, this is called the bare-hull resistance. The power necessary to overcome this resistance is called the towrope or effective horsepower (ehp or P_e) and is given by:

$$P_e = \frac{R_t \text{ x } v}{75} \quad \text{hp}$$

Where

R_t = total resistance (kg)
v = speed (m/sec)
1 hp = 75 kgm/sec

If we choose to give the effective power in kilowatts we have in mind that:

1 hp = 0.736 kW

This total water resistance is made up of a number of different components, which are due to a variety of causes and which interact with one another. It is customary to consider the total water resistance as being made up of three main components:

1) The frictional resistance, due to the motion of the hull through a viscous fluid.

2) The wave-making resistance, due to the energy that must be supplied continuously by the ship to the wave system created on the surface of the water. The speed-length ratio (V/vL) is related to wave making resistance. The calculated service speed in my case is built on an empirical figure of that ratio and the length of boat.

3) Eddy resistance, due to the energy carried away by eddies shed from the hull or appendages. Local eddying will occur behind appendages such as bossing, shafts and shaft struts, and from stern frames and rudders if these items are not properly streamlined and aligned with the flow. Also, if the aft end of the ship is too blunt, the water may be unable to follow the curvature and will break away from the hull, again giving rise to eddies and separation resistance.

The resistance under 2 and 3 are commonly taken together under the name *residuary resistance*.

Propulsion is dealing with the power to overcome the resistance and the devices. To describe a propeller, many so-called propeller parameters are used, among the most important are:

Number of blades, Z
Propeller diameter, D (mm)
Blade area (blade area ratio), m^2
Revolutions, N, n (rpm, rps)
Pitch, H (pitch ratio H/D)
Fixed and controllable pitch

One type of drive is the so-called outboard drive, but for the case here inboard drive will be used and fixed pitch propeller.

In Iceland two types of small boats have been in use in the last decades, i.e. slow-speed displacement boats and fast-going planning boats, even some boats between (half-planning boats). The figures below give some idea of these types and dimensions.

Small boats in Iceland (Skipaskrain 2006):

Figure 21: Single deck GRP fishing boat (displacement boat for gillnetting).

Note: Built in 1987, 9.7 GRT, length overall 10.5 m, equipped with a Ford 85 kW (115 hp) main engine.

Figure 22: Single deck GRP high-speed fishing boat for longlining.

Note: Built in 2000, 6. GRT, length overall 9.9 m, equipped with a Volvo Penta 197 kW (267 hp) main engine.

6.2.6 Fuel consumption

The following will describe the method of calculating fuel consumption for a boat. Having some knowledge of the need of horsepower, or %-load, and also the specific fuel consumption in grams per horsepower-hour (or specific fuel consumption in grams per kilowatt-hour), density of the fuel, the formula is:

$$Hp \text{ x } \frac{g}{Hp\text{-}h} \text{ x } \frac{1}{g/l} = l/h$$

If power is in kW we get:

$$kW \text{ x } \frac{g}{kW\text{-}h} \text{ x } \frac{1}{g/l} = l/h$$

Where 1 hp = 0.736 kW

Having information on time splitting of the fishing trip into operations, and power need for each operation, it is easy to calculate the total fuel consumption for the fishing trip.

6.3 Main factors in the design of a tuna longline boat

6.3.1 Appropriate boat sizes

Four different alternatives of longline boats have been framed in Table 6. The main size of the boats is at first expressed in CUNO calculated by the following formula:

Cubic number = CUNO = Length overall x Beam moulded x Depth moulded.

Alt. 1: CUNO = 38 m^3, Length overall = 9.83 m, Beam moulded = 3.08 m, Depth moulded =1.31 m with a 61 kW engine. Fishing with 667 hooks and using a hydraulic hauler. Trip endurance = 3.75 days.

Alt. 2: CUNO = 60 m^3, Length overall = 11.44 m, Beam moulded = 3.59 m, Depth moulded = 1.53 m with a 70 kW engine. Fishing with 800 hooks and using a hydraulic drum. Trip endurance = 5 days.

Alt. 3: CUNO = 89 m^3, Length overall = 13.05 m, Beam moulded = 4.09 m, Depth moulded = 1.74 m with an 83 kW engine. The boat will be fishing with 1200 hooks, using a hydraulic spool and line setter. Trip endurance = 5 days.

Alt. 4: CUNO = 111 m^3, Length overall = 14.05 m, Beam moulded = 4.40 m, Depth moulded = 1.87 m with a 93 kW engine. The boat will be fishing with 1200 hooks using a hydraulic spool, line setter and radio direction finder. Trip endurance = 6.25 days.

The main factors upon which the various alternative boats were built and calculated are described in Table 6.

In Appendix 1 a general arrangement of an Icelandic boat is given to have an idea of the size of the boat for Alt 4.

Table 6: Sea trip planning for the four alternative boat sizes.

BOAT CHARACTERISTICS

	Item	Unit	Calculation	Alt 1	Alt 2	Alt 3	Alt 4
a	Sea days per trip	day	b/0.8	3.75	5	5	6.25
b	Fishing days per trip	day		**3**	**4**	**4**	**5**
c	Number of hooks	hk		**667**	**800**	**1200**	**1200**
d	Catch rate, kg/1000hook	kg	**0.5 kg/hk**	**500**	**500**	**500**	**500**
e	Catch	kg	**b** x **c** x **d** / 1000	1001	1600	2400	3000
f	Bait	kg	**e** x 0.32	400	600	800	1000
g	Ice	kg	**e** x 2.5	2501	4000	6000	7500
h	Fuel + water etc.	kg	**(f** + **g**)*0.7	2031	3220	4760	5950
i	Fish hold volume	m³	(**f** + **g**) x 1.8/1000	5.23	8.28	12.24	15.3
j	Boat CUNO	m³	**i** x 7.2	38	60	89	111
k	Boat length over all (LOA)	m	³√**j** / 0.04	9.83	11.44	13.05	14.05
k1	Breadth moulded	m	**k** / 3.19	3.08	3.59	4.09	4.40
k2	Depth moulded	m	**k** /7.54	1.31	1.52	1.74	1.87
l	Displacement light boat	kg	**j** x 100	3800	6000	8900	11100
m	Full load	kg	**f** + **g** + **h**	4932	7820	11560	14450
n	Displacement service	kg	**l** + 0.75 x **m**	7500	11865	17570	21938
o	Installed engine power	hp	60 + (3 x **n** / 1000)	83	96	113	126
p	Installed engine power	Kw	**o** x 0.736	61	70	83	93
q	Fuel / trip	litre	[(**a-b**) x 24 x 0.75 x **o** x 0.205] + [**b** x 24 x 0.35 x **o** x 0.205]	655	1011	1192	1664
r	Fuel tank capacity	litre	**q** x 1.7	1113	1719	2027	2828
s	Number of crew	men		**3**	**3**	**4**	**4**
t	Water tank capacity	litre	**s** x 14lt x 14 days	590	590	790	790
u	Service speed	knot	2.08 **vk** x 0.9	6.2	6.7	7.1	7.4
u1	Sailing distance (2 way)	nm	(**a-b**) x 24 x **u**	111.4	160.2	171.1	221.9
v	Sea days / year	day	175+(0.22x **j)**	184	189	195	200
w	Trips / year	no.	**v** / **a**	50	38	39	32
y	Fishing days / year	day	**b** x **w**	150	152	156	160
z	Catch / year	kg	**e** x **w**	**50025**	**60800**	**93600**	**96000**

6.3.2 Fishing trip endurance

The sailing distance (u1 in Table 6) from Mauritius to fishing grounds resulted in a minimum of 50 and maximum of 100 nm. A speed of 7.5 knots could be established in the longest endurance (Alt 4). In addition to that, the total time to a fishing ground both ways is 27 hours of direct sailing. Accordingly the sailing time is about 20% and fishing time 80% of total sea trip. This percentage of time splitting will be used for all the alternatives.

In Table 6 the fishing days are used for computing the total number of sea days in the fishing trip.

6.3.3 Number of hooks and catch rates

The number of hooks (667, 800 and 1200) that can be operated per fishing day together with the catch rate and number of sea days, have a significant effect on the boat size needed. The number of hooks in the smallest boat (Alt 1) has been adjusted in order to obtain a minimum vessel size for this fishing. The total catch amount is the number of fishing days per trip x the number of hooks per day x the estimated catch per hook. It has been subsequently increased in other alternatives. In order to consider other factors in the design of a boat an average catch rate of 0.5 kg per hook is taken (Beverly 1996, Gulbrandsen 1998).

6.3.4 Fishing gear and equipment

There has been a rapid development in longline fishing over the years and nowadays the mainline and branchline is of a monofilament type which has proven to be more efficient and adaptable to various conditions. The mainline can be divided into small spools. These can be manually handled and stored in continuous bundles to occupy less space. Due to space constraints, this method is not practical in smaller boats. Storing the line on a reel (Figures 14 and 15) is more convenient for ease of handling and reduced deck space. A hydraulic powered reel with both setting and hauling systems for the line can be fitted where no separate line hauler is required. The line is led over several blocks up to the drum. This system is used in modern longline fishing. Using a line setter allows more control over the curvature of the mainline in the water between the buoys. In longer sets, radio direction finders using beeper buoys are attached to the extremities of the mainline. Since the price of such equipment is considerable, it should be cost effective when selecting them for small boats. A boat suitable for longer trips (Alt 4) could target more valuable species like swordfish for a better return on investment.

6.3.5 Bait and ice

The requirement of bait is taken to be a function of expected catch size; the coefficient factor of 0.32 kg bait per kg of catch is taken (Gulbrandsen 1998). Bait consumption per hook is high. The cost and availability of good bait is usually a constraint. Some bait fish such as milkfish can be cultured to supply the longline boats.

The ice consumption is based on the assumption that a boat will have sufficient insulation. Since the operational area will be in tropical waters, the consumption is taken to be 2.5 kg ice/kg fish caught.

The stowage rate of a crushed block of ice is normally 1.5 m^3/1000 kg of ice, but for calculation of fish hold volume a figure of 1.8 m^3/1000 kg of ice is used taking into account that it is not possible to fill the side bins in the fish hold completely (Gulbrandsen 1998). Some of the boats can be equipped with an inboard ice machine, and it has been proven that the cost of this investment can bring returns. Hence, the fish hold volume in cubic metres is based on the sum of bait and ice in tonnes times 1.8.

6.3.6 Fuel and fresh water

During sailing the engine of the boat is assumed to work at 75% of nominal installed power, whereas for fishing, i.e. setting and hauling, it will work at about 35 - 40% load (Emil Ragnarsson Naval Arch, pers. com.; Gulbrandsen 1998). Specific fuel consumption for a diesel engine in the smaller boats (high rpm) an estimate of 0.205 l/hp hr at the above loads.

To calculate the fuel consumption for sailing we take the number of sailing days per trip (on average 20% of the total time at sea) x 24 hours x 75% load x installed hp x specific fuel consumption. The consumption for fishing days is obtained by taking the fishing days (80% of the total time at sea) x 24 hours x 35% load x installed hp x specific fuel consumption. Eventually the total fuel consumption will be the sum of the fuel consumption during steaming and fishing.

Sufficient fresh water should be carried including contingency requirements. Therefore the drinking water requirement is taken as 2 l/man/day and 12 l/man/day for washing (Gulbrandsen 1998). The total water requirement is thus 14 l/man/day. For calculation purposes the contingency of one week is taken in addition to actual requirements. Space for the water tank has to be considered and eventually accounted for in the full load and displacement of the boat.

The weight of fuel, water etc. is taken to be 70% of the total weight of bait and ice together, built on data from Gulbrandsen (1998), in calculating displacement.

6.3.7 Boat size and dimension

The cubic number (CUNO) is based on the fish hold volume which is defined in 7.3.5, therefore CUNO is fish hold volume x 7.2 (Gulbrandsen 1998). The CUNO is used to calculate the length overall and light-ship weight of the boat.

The light-ship weight in kg (LSW) is defined as the CUNO x 100. The maximum expected deadweight (DW max) of the boat is the sum of the weight of bait, ice, fuel and water etc. The average deadweight for service is taken as 75% of the maximum deadweight. The displacement in service will be LSW + 0.75 x DW max.

According to Gulbrandsen (1998) the length overall is calculated by the following formula:

$$L_{oa} = (CUNO/0.04)^{1/3}$$

The other dimension such as breadth and depth of the boat has been computed from the Icelandic deck boat data (IMA 2006). From a database of 461 boats a coefficient for the ratio of Loa/Bm and Loa/Dm was calculated in order to estimate the breadth and depth. These results give the following ratios:

Loa/Bm = 3.19

Loa/Dm = 7.52

In Appendix 2 a sample of the Icelandic deck boat data used for calculation is shown.

6.3.8 Engine

The engine power will be based on the following formula:

Engine (hp) = 60 + 3 x (displacement service/1000)

Regarding the size of installed engine power to accommodate the minimum power requirement for a fishing boat was taken to be 60 hp in Table 6 according to the Gulbrandsen formula.

6.3.9 Service speed and sailing distance

The service speed will be based on the following formula:

Service speed (knots) = 2.08 x $(L_{oa} \times 0.9)^{1/2}$

In the formula the ratio of length of waterline to length overall is taken as 0.9.

In Table 6 the sailing distance has been computed from sailing time and calculated service speed which resulted to be in the operational distance range (50 – 100 nm) from Mauritius.

6.3.10 The fishing effort over year

To estimate the sea days per year the following formula is used (Gulbrandsen 1998).

Sea days per year = 175 + (0.22 x CUNO)

In the Mauritian context a minimum number of 175 days is chosen accounting for bad weather conditions and other constraints.

7 EVALUATION OF GEAR AND BOAT

7.1 Fishing equipment and gear

Due to the different dimensions of the boats framed in Table 6, the fishing gears required on each boat will vary depending upon various factors. The deck space requirement for some fishing equipment such as a spool with hydraulic system will need power and deck accommodation. The number of hooks that the boats will be able to operate per day to target different fish will determine the type equipment needed. Therefore, the fishing equipment and gear needed in each case have been estimated according to their respective characteristics defined in Table 6. A list of fishing equipment and gear needed in the four alternative boats has been made and the price estimated for each of the alternatives is shown in Table 7.

7.1.1 Alternative boat 1

The boat described in Alt 1 is the smallest one equipped with a hydraulic hauler only and the main line could be stored on several hand-driven drums. Some 667 hooks are used as a primary factor in the price evaluation of other associated implements. The amount of mainline and branchlines is estimated to be about 34 km and 14 km respectively. For easy location of mainline, radar reflectors are used.

7.1.2 Alternative boat 2

In this alternative the number of hooks used is 800. Having a longer beam this type of boat can accommodate a hydraulic powered reel both for hauls and storage of line hence no separate line hauler is required. The amount of mainline and branchlines is estimated to be about 40 km and 16 km respectively

7.1.3 Alternative boats 3 and 4

These two boats are both shooting 1200 hooks but with different numbers of fishing days hence the equipment and gear costs are similar. The mainline and branchlines used in these cases are 60 km and 24 km in length respectively. The additional cost of equipment in Alt 4 is for a set of beeper buoys which help locate lines in case of break up. A line setter is used in both alternatives for targeting particular species. The highest gear cost involves purchase of a hydraulic reel system and monofilament lines.

7.1.4 Price of fishing equipment and gear

Boats	Alt 1	Alt 2	Alt 3	Alt 4
Fishing equipment*	170,000	480,000	780,000	780,000
Fishing gear*	466,360	832,050	1,314,700	1,314,700

*Estimated prices worked out by the Fisheries Training Centre in Mauritius

Table 7: Estimated quantity and cost of fishing equipment and gear (Rupees).

Fishing Equipment	**Alt 1**	**Alt 2**	**Alt 3**	**Alt 4**		**Alt 1**	**Alt 2**	**Alt 3**	**Alt 4**
Item	**Qty**	**Qty**	**Qty**	**Qty**	**Unit price**	**Price**	**Price**	**Price**	**Price**
Hydraulic hauler	1	0	0	0	150,000	150,000	0	0	0
Hydraulic spool (monofil.)	0	1	1	1	460,000	0	460,000	460,000	460,000
Storage reel for buoy line	1	1	2	2	20,000	20,000	20,000	40,000	40,000
Hydraulic line setter	0	0	1	1	165,000	0	0	165,000	165,000
Radio buoys	0	0	2	2	57,500	0	0	115,000	115,000
TOTAL						170,000	480,000	780,000	780,000
Fishing gear									
Radar reflectors	2	2	2	2	1,000	2,000	2,000	2,000	2,000
Line(monofil. 3-3.6 mm Ø) km	34	40	60	60	4,120	140,080	164,800	247,200	247,200
Line(monofil. 2 mm Ø) km	14	16	24	24	3,200	44,800	51,200	76,800	76,800
Hooks(9/0 eagle claw)	667	800	1200	1200	40	26,680	32,000	48,000	48,000
Storage hook box	1	1	2	2	2,400	2,400	2,400	4,800	4,800
Floats plastic	140	160	280	280	250	35,000	40,000	70,000	70,000
Floats inflatable	20	30	40	40	200	4,000	6,000	8,000	8,000
Flashing lights	4	4	4	4	1,250	5,000	5,000	5,000	5,000
Light sticks	1000	1500	2000	2000	13	12,500	18,750	25,000	25,000
Snap swivels	700	900	1500	1500	30	21,000	27,000	45,000	45,000
Knives	3	3	3	3	300	900	900	900	900
Hacksaw	1	1	1	1	1,000	1,000	1,000	1,000	1,000
Gaffs	2	2	2	2	500	1,000	1,000	1,000	1,000
TOTAL						296,360	352,050	534,700	534,700
Grand Total						466,360	832,050	1,314,700	1,314,700

Estimated prices worked out by the Fisheries Training Centre in Mauritius.

7.2 Cost of fishing operation

In the Pacific the boat and the crew have two sets of books and two accounts. The reason for this is that there are two types of costs involved: operating costs and fixed costs which are considered as two sets of expenses (Beverly 2006). Usually the costs of running the fishing operation are shared between the boat owner and crew sometimes in a pre-arranged manner. On the other hand, fixed costs are solely the responsibility of the boat owner. The cost and revenue for the four alternative boats has been estimated using information from Tables 6 and 7 with estimated prices to show the use of Table 8 as a tool for economic evaluation.

7.2.1 Investment

The boat price is estimated according to cubic number (j) (Table 6) and engine according to horse power (o) (Table 6). Real quotations for new boats or market prices of used boats are to be used when this tool is used for real cases. The cost of fishing equipment and gear is from the total estimated price from Table 7. The minimum electronic equipment required to sail a boat was evaluated at the same price as the cost of the fishing equipment for all the alternatives.

7.2.2 Income

The income is generated from the price obtained for the total yearly catch (z) Table 6. An estimated price of the catch was taken to be Rs 45/kg considering the catch composition percentage transhipped in Mauritius (Table 2). The price that can be obtained for the fish is a crucial element and it is necessary to examination more closely realistic prices in both local and overseas markets. Export of tuna and tuna related species will affect the outcome considerably.

7.2.3 Fixed costs

The fixed costs such as depreciation and insurance for the boat and gear are estimated in the same way as in the Gulbrandsen report. The boat depreciation is spread over twelve years, 1.8% for insurance coverage of the total vessel cost and 5% insurance coverage for the fishing gears.

7.2.4 Operating costs

The operating costs include items such as fuel, bait ice, food and miscellaneous expenses (Table 6). Actual current prices from the Mauritian context are used to get the total yearly trip operating costs.

7.2.5 Crew share

The proceeds obtained after deducting the trip operating costs from the total revenue are distributed in predetermined shares agreed upon between the crew and the owner-operator of the boat. In this case the crew share is taken to be 30% but can of course vary depending upon the owner and crew agreements.

7.2.6 Repairs

During the annual operation of the boats expenditures such as routine repairs to the boat, engine and fishing gears have been taken into account in accordance with Gulbrandsen (1998). Hull and equipment at 3%, engine at 10% and fishing gears at 30% amounts to the total repairs.

7.2.7 Total variable costs and yearly costs

Lastly the total variable costs are obtained by adding the operating costs, crew share and variable costs. The total yearly costs will be the fixed costs (13) together with total variable costs (28) as shown in Table 8. The profit is obtained by deducting the total yearly costs from the revenues (8- 28). Finally the rate of return could be evaluated by the percentage of profit over the total investment.

Table 8: A tool for economic evaluation of the four alternative boats (Rupees).

	Investment		**Alt 1**	**Alt 2**	**Alt 3**	**Alt 4**
1	Vessel	**j** x Rs 48,000	1,824,000	2,880,000	4,272,000	5,328,000
2	Engine	**o** x Rs 20,000	1,650,000	1,911,900	2,254,200	2,516,280
3	Fishing equipment	from table 7	170,000	480,000	665,000	780,000
4	Electronic		170,000	170,000	170,000	170,000
5	Total vessel cost		3,814,000	5,441,900	7,361,200	8,794,280
6	Fishing gear	from table 7	296,360	352,050	534,700	534,700
7	TOTAL INVESTMENT		**4,110,360**	**5,793,950**	**7,895,900**	**9,328,980**
8	REVENUE	Average price Rs 45 x **z**	**2,251,125**	**2,736,000**	**4,212,000**	**4,320,000**
9	**Fixed cost**					
10	Depreciation	**5** / 15 years	254,267	362,794	490,747	586,286
11	Insurance, vessel	**5** x 1.8 %	68,652	97,954	132,502	158,297
12	Insurance, fishing gear	**6** x 3 %	8,891	10,562	16,041	16,041
13	TOTAL FIXED COST		331,810	471,310	639,290	760,624
14	**Operating cost**					
15	Fuel	**q** x **w** x Rs 26.50	867,231	1,018,282	1,232,187	1,410,712
16	Bait	**f** x **w** x Rs 30	600,000	684,000	936,000	960,000
17	Ice	**g** x **w** x Rs 4	500,250	608,000	936,000	960,000
18	Food	**v** x **s** x Rs 150	82,800	85,050	117,000	120,000
19	Other	**z** x Rs 2	100,050	121,600	187,200	192,000
20	TRIP OPERATING COST		2,150,331	2,516,932	3,408,387	3,642,712
21	CREW SHARE	(**8** - **20**) x 30 %	30,238	65,720	241,084	203,186
22	**Repairs**					
23	Hull and equipment	(**3** + **4** + **5**) x 3 %	64,920	105,900	153,210	188,340
24	Engine	**2** x 10 %	165,000	191,190	225,420	251,628
25	Fishing gear	**6** x 30 %	88,908	105,615	160,410	160,410
26	TOTAL REPAIRS		318,828	402,705	539,040	600,378
27	TOTAL VARIABLE COST	(**20** + **21** + **26**)	2,499,397	2,985,358	4,188,511	4,446,276
28	TOTAL YEARLY COST	(**13** + **27**)	2,831,207	3,456,667	4,827,800	5,206,901
29	PROFIT	(**8** - **28**)	**-580,082**	**-720,667**	**-615,800**	**-886,901**
30	ACCT. RATE OF RETURN	(**29** / **7**) %	-14	-13	-8	-10

7.2.8 Demonstrating the evaluation tool

An example of the boat alternative 4 which is gone for some six days at sea including five fishing days is taken to demonstrate the influence of fish price increase on the overall positive rate of return as shown in Table 9. Let's say that this boat is targeting swordfish which is a high value fish having a higher price on the export market. The price is estimated at Rs 80/kg to attain a minimum positive rate of return (Table 9). In the present condition the bait is imported, using locally caught bait at lower prices could influence the return. The price of a suitable second hand boat can also reduce initial costs of investment at the start of the fishing venture. The catch rate (0.5 kg/hook) is an average taken from both the Sri Lankan and Pacific region. An increase in actual catch rates for example from 0.5 to 0.6kg/hook makes the income 20% higher. The depreciation of the total vessel costs is also spread over 15 years considering the longer lifetime of fibreglass boats.

Table 9: An example of operating costs and crew payments.

	Investment		
1	Vessel	**j** x Rs 48,000	5,328,000
2	Engine	**o** x Rs 20,000	2,516,280
3	Fishing equipment	from Table 7	780,000
4	Electronic		170,000
5	Total vessel cost		8,794,280
6	Fishing gear	from Table 7	534,700
7	TOTAL INVESTMENT		**9,328,980**
8	REVENUE	Average price Rs 80 x **z**	**7,680,000**
9	Fixed cost		
10	Depreciation	**5** / 15 years	586,286
11	Insurance, vessel	**5** x 1.8 %	158,297
12	Insurance, fishing gear	**6** x 3 %	16,041
13	TOTAL FIXED COST		760,624
14	Operating cost		
15	Fuel	**q** x **w** x Rs 26.50	1,410,712
16	Bait	**f** x **w** x Rs 30	960,000
17	Ice	**g** x **w** x Rs 4	960,000
18	Food	**v** x **s** x Rs 150	120,000
19	Other	**z** x Rs 2	192,000
20	TRIP OPERATING COST		3,642,712
21	CREW SHARE	(**8** - **20**) x 30 %	1,211,186
22	Repairs		
23	Hull and equipment	(**3** + **4** + **5**) x 3 %	188,340
24	Engine	**2** x 10 %	251,628
25	Fishing gear	**6** x 30 %	160,410
26	TOTAL REPAIRS		600,378
27	TOTAL VARIABLE COST	(**20** + **21** + **26**)	5,454,276
28	TOTAL YEARLY COST	(**13** + **27**)	6,214,901
29	PROFIT	(**8** - **28**)	**1,465,099**
30	ACCT. RATE OF RETURN	(**29** / **7**) %	16

8 DISCUSSION AND CONCLUSIONS

Four different alternative boats for longline fishing were framed in order to suit the Mauritian context considering size, capacity and endurance of design. The fishing equipment required in each alternative varied accordingly, from traditional methods to modern technology like hydraulic longline reels. The catch of smaller boats (Alts 1 and 2) was 50-60 tonnes annually and of larger boats (Alts 2 and 3) was 93-96 tonnes annually which seems not to vary much respectively. The number of hooks (667, 800, 1200) used in the alternatives is just to get the approximate catch for each condition of boats. The sailing distance from the coast to high seas in smaller boat is about 50 nm and 100 nm miles in larger boats. The minimum horse power requirement limit on the small boats was taken as 60 hp which is required in the propulsion forces and other power requirements.

It is to be noted that the conditioning of the parameters and factors involved in the fishing operation remains in the hands of the owner operator and the crew. These would be subject to changes and alterations if put into real conditions. The tool structured in this report could be used by artisanal fishermen to have an overview of the intricate adjustments that can be made to put the mechanism together for the success of a fishing enterprise in longline fishing.

A shift from traditional methods to modern technology with larger boats will entail more costs for gear and equipment, and therefore more valuable species like swordfish and big eye tuna should be targeted. Factors such as value addition ashore in fish processing can increase returns considerably to promote longline fishing. The land based facilities to secure landings, berthing facilities, ice making machines, storage, and other utility services need to be provided to support offshore fishing

This study was limited to the initial gear application and boat issues. The information collected and the findings could be used to assist fishermen, governmental and financial institutes to evaluate options of boat and gear investments in the Mauritius context. In addition, this project could be used as a contribution to education and training activities for the artisanal fishermen of Mauritius.

ACKNOWLEDGEMENTS

First of all my special thanks go to Dr Tumi Tomasson, the Director of the United Nation University - Fisheries Training Programme in Iceland, the Deputy Programme Director, Mr Thor Asgeirsson, and Programme Officer, Mrs Sigridur Kr. Ingvarsdottir, for giving me the opportunity to participate in this programme with their constant support and guidance during the course. There has also been a great deal of participation of the resource persons from the Marine Research Institute and various other organisations to whom I am thankful for their lectures and educational tours during the UNU-FTP course. I would also like to thank my supervisors Mr Einar Hreinsson and Mr Olafur Arnar Ingolfsson for their continuous support during my project work and Mr Emil Ragnarsson (Naval Arch.) for his valuable advice and guidance. During my stay in Iceland I came across many kind and helpful persons who in one way or another shouldered me, therefore my thanks and appreciation go to:

1. Mr. Peter Weiss (Director) University Centre of the West Fjords
2. Larus Palmason (Lecturer) Sudurnes College
3. Pall Reynisson (Lecturer) Marine Research Institute
4. Sigurdur Jonsson (Naval Arch.) Borea Adventures Co. Ltd
5. All fellows of UNU –FTP 2006

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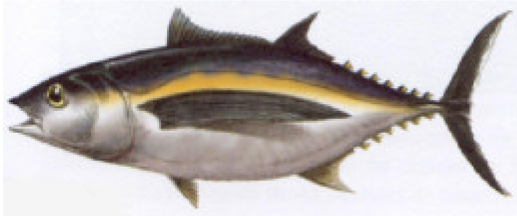
Appendix 1 : General arrangement of an Icelandic boat

Appendix 2 : Sample of Icelandic deck boat data
(used for the calculation of a coefficient for the ratio of Loa/Bm and Loa/Dm).

No.	Year of build	Gross tonnage	LOA	Beam	Depth	CUNO	Loa/Bm	Loa/Dm
1	2001	8.39	9.48	3.07	1.14	33.18	3.09	8.32
2	2001	5.99	9.5	2.57	1.19	29.05	3.70	7.98
3	2001	5.99	9.5	2.57	1.19	29.05	3.70	7.98
4	2001	5.88	9	3.16	1.13	32.14	2.85	7.96
5	2001	4.63	7.71	2.54	0.91	17.82	3.04	8.47
6	2001	5.92	9.49	2.97	1.22	34.39	3.20	7.78
7	2001	9.25	10	2.99	1.15	34.39	3.34	8.70
8	2001	11.56	10.8	3.48	1.35	50.74	3.10	8.00
9	2001	5.97	9.13	2.9	1.14	30.18	3.15	8.01
10	2001	4.55	8.62	2.48	0.92	19.67	3.48	9.37
11	2001	5.92	8.73	2.54	1.05	23.28	3.44	8.31
12	2001	5.89	9.46	2.97	1.22	34.28	3.19	7.75
13	2001	5.19	8.86	2.64	1.09	25.50	3.36	8.13
14	2001	8.38	9.54	2.99	1.23	35.09	3.19	7.76
15	2002	9.18	9.97	2.99	1.12	33.39	3.33	8.90
16	2002	2.86	6.82	2.56	1.25	21.82	2.66	5.46
17	2002	5.86	9.5	2.54	1.19	28.71	3.74	7.98
18	2002	3.49	7.89	2.54	1.19	23.85	3.11	6.63
19	2002	5.99	8.73	2.57	1.19	26.70	3.40	7.34
20	2002	10.91	9.94	3.57	1.35	47.91	2.78	7.36
21	2002	9.25	10	2.99	1.13	33.79	3.34	8.85
22	2002	13.33	11.07	3.51	1.54	59.84	3.15	7.19
23	2002	2.97	6.22	2.49	1.1	17.04	2.50	5.65
24	2002	12.30	10.48	3.62	1.4	53.11	2.90	7.49
25	2002	5.99	9.51	2.57	1.19	29.08	3.70	7.99
26	2002	13.22	11.22	3.43	1.28	49.26	3.27	8.77
27	2002	9.26	10	3	1.12	33.60	3.33	8.93
28	2002	14.62	11.35	3.68	1.45	60.56	3.08	7.83
29	2003	13.84	11.27	3.56	1.31	52.56	3.17	8.60
30	2003	3.68	8.34	2.4	1.09	21.82	3.48	7.65
31	2003	4.09	7.87	2.56	1.19	23.98	3.07	6.61
32	2003	4.73	8.71	2.54	1.19	26.33	3.43	7.32
33	2003	14.44	11.22	3.74	1.44	60.43	3.00	7.79
34	2003	5.98	8.74	2.56	1.19	26.63	3.41	7.34
35	2003	3.68	7.94	2.63	1.16	24.22	3.02	6.84
36	2003	14.50	11.25	3.73	1.45	60.85	3.02	7.76
37	2003	14.90	11.51	3.64	1.35	56.56	3.16	8.53
38	2003	4.08	7.95	2.57	1.19	24.31	3.09	6.68
39	2003	14.71	11.41	3.67	1.46	61.14	3.11	7.82
40	2003	14.54	11.24	3.74	1.44	60.53	3.01	7.81
41	2003	3.02	6.87	2.72	1.37	25.60	2.53	5.01
42	2003	5.86	9.45	2.99	1.24	35.04	3.16	7.62
43	2003	3.02	6.88	2.72	1.53	28.63	2.53	4.50
44	2003	13.90	11.34	3.55	1.31	52.74	3.19	8.66
45	2003	14.87	11.55	3.66	1.34	56.65	3.16	8.62

Appendix 3 : Albacore (habitat and biology)

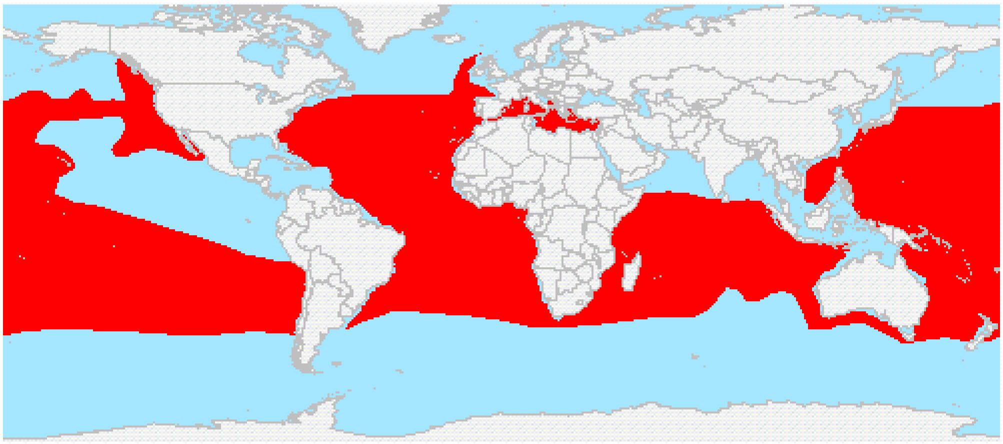
Thunnus alalunga



Scomber alalunqa Bonnaterre, 1788, Tableau Encyclopédique et Méthodique, Ichthyologie:139 (Sardinia)
En - Albacore; Fr - German; Sp - Atún blanco.

Geographical Distribution
Cosmopolitan in tropical and temperate waters of all oceans including the Mediterranean Sea, extending north to 45 to 50°N and south to 30 to 40°S, but not at the surface between 10°N and 10°S.

Habitat and Biology
An epi- and mesopelagic, oceanic species, abundant in surface waters of 15.6° to 19.4°C; deeper swimming, large albacore are found in waters of 13.5° to 25.2°C; temperatures as low as 9.5°C may be tolerated for short periods. In the Atlantic, the larger size classes (80 to 125 cm) are associated with cooler water bodies, while smaller individuals tend to occur in warmer strata. According to data presently available, the opposite occurs in the northeastern Pacific. Albacore tend to concentrate along thermal discontinuities (oceanic fronts such as the Transition Zone in the north Pacific and the Kuroshio Front east of Japan) where large catches are made. The Transition Zones are preferred to cooler upwelling waters which are richer in forage organisms but poorer in oxygen content. Minimun oxygen requirements are probably similar to those of yellowfin tuna, that is about 2 ml/l. Albacore migrate within water masses rather than across temperature and oxygen boundaries.



Distribution of Albacore tuna
(http://www.fao.org/figis/servlet/species?fid=2496)

Size
Maximum fork length is 127 em. In the Pacific surface fishery (pole-and-line, and troll fishery), smaller sizes (modes between 55 to 80 cm fork length) predominate, while longline fisheries take bigger fish (modes about 95 to 115 cm); in the Indian Ocean, common sizes range from 40 to 100 cm fork length (Silas & Pillai, 1982), while males up to 109 cm and females up to 106 cm are not exceptional in the Atlantic. In the Pacific, maturity may be attained at about 90 cm fork length in females and at about 97 cm in males; in the Atlantic it is reached at about 94 cm in both sexes.

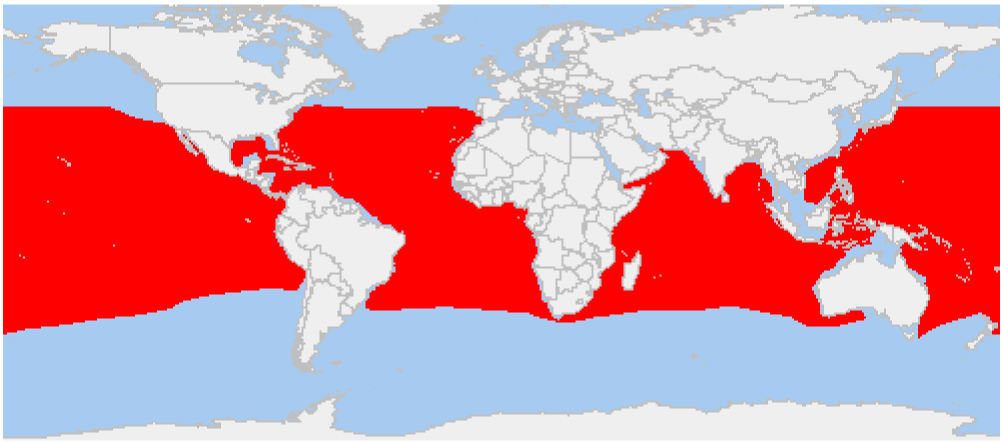
Appendix 4 : Yellowfin tuna (habitat and biology)

Thunnus albacares

En - Yellowfin tuna; Fr - Albacore; Sp - Rabil.

Geographical Distribution
Worldwide in tropical and subtropical seas, but absent from the Mediterranean Sea.

Habitat and Biology
Epipelagic, oceanic, above and below the thermocline. The thermal boundaries of occurrence are roughly 18° and 31°C. Vertical distribution appears to be influenced by the thermal structure of the water column, as is shown by the close correlation between the vulnerability of the fish to purse seine capture, the depth of the mixed layer, and the strength of the temperature gradient within the thermocline. Yellowfin tuna are essentially confined to the upper 100 m of the water column in areas with marked oxyclines, since oxygen concentrations less than 2 ml/l encountered below the thermocline and strong thermocline gradients tend to exclude their presence in waters below the discontinuity layer.



Distribution of yellowfin tuna
(http://www.fao.org/figis/servlet/species?fid=2497)
Schooling occurs more commonly in near-surface waters, primarily by size, either in monospecific or multispecies groups, in some areas, i.e. eastern Pacific, larger fish (greater than 8.5 cm fork length) frequently school with porpoises. Association with floating debris and other objects is also observed. Although the distribution of yellowfin tuna in the Pacific is nearly continuous, lack of evidence for long-ranging east-west or north-south migrations of adults suggests that there may not be much exchange between the yellowfin tuna from the eastern and the central Pacific, nor between those from the western and the central Pacific. This hints at the existence of subpopulations.
Spawning occurs throughout the year in the core areas of distribution, but peaks are always observed in the northern and southern summer months respectively. Joseph (1968) gives a relationship between size and fecundity of yellowfin tuna in the eastern Pacific.

Size
Maximum fork length is over 200 cm. Common to 150 cm fork length.

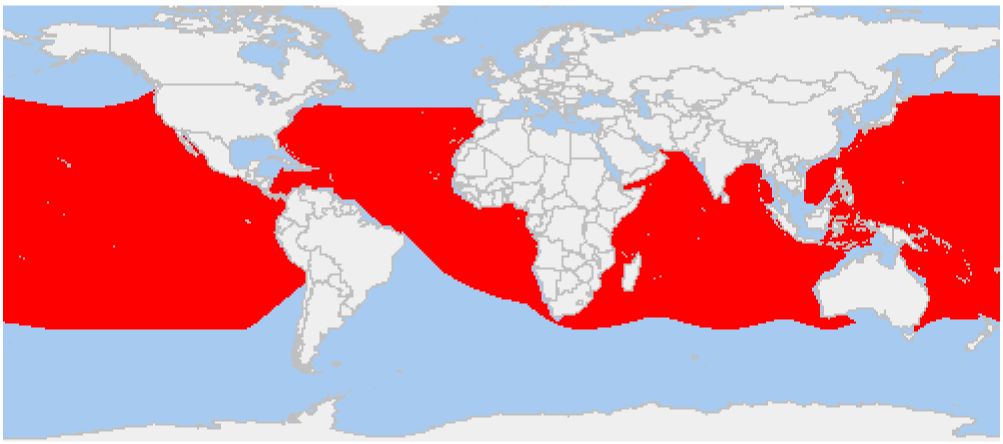
Appendix 5 : Bigeye tuna (habitat and biology)

Thunnus obesus

Thynnus obesus Lowe,
1839,Proc.Zool.Soc.London, 7:78 (Madeira).
En - Bigeye tuna; Fr - Thon obèse; Sp - Patudo.

Geographical Distribution
Worldwide in tropical and subtropical waters of the Atlantic, Indian and Pacific oceans, but absent from the Mediterranean.

Habitat and Biology
Epipelagic and mesopelagic in oceanic water occurring from the surface to about 250 m depth. Temperature and thermocline depth seem to be the main environmental factors governing the vertical and horizontal distribution of bigeye tuna: Water temperatures in which the species has bean found range from 13° to 29°C, but the optimum range lies between 17° and 22°C. This coincides with the temperature range of the permanent thermocline. In fact, in the tropical western and central Pacific, major concentrations of T. obesus are associated with the thermocline rather than with the surface phytoplankton maximum. For this reason, variation in occurrence of the species is closely related to seasonal and climatic changes in surface temperature and thermocline.



Distribution of Big eye tuna
(http://www.fao.org/figis/servlet/species?fid=2498)

Juveniles and small adults of bigeye tuna school at the surface in mono-species groups or together with yellowfin tuna and/or skipjack. Schools may be associated with floating objects. In the eastern Pacific some spawning is recorded between 10°N and 10°S throughout the year, with a peak from April through September in the northern hemisphere and between January and March in the southern hemisphere. Kume (1967) found a correlation between the occurrence of sexually inactive bigeye tuna and a decrease of surface temperature below 23° or 24°C. The food spectrum of bigeye tuna covers a variety of fish species, cephalopods and crustaceans, thus not diverging significantly from that of other similar-sized tunas. Feeding occurs in daytime as well as at night. The main predators are large billfish and toothed whales.

Size

Maximum fork length over 200 cm; common to 180 cm (corresponding to an age of at least 3 years). The all-tackle angling record for the Pacific is a 197.3 kg fish from off Cabo Blanco, Peru in 1957. This fish was 236 cm long but it was not specified whether this pertained to fork length or total length. For the Atlantic, the all-tackle angling record is a 170.3 kg fish with a fork length of 206 cm taken off Ocean City, Maryland, USA in 1977. Maturity seems to be attained at 100 to 130 cm fork length in the eastern Pacific and in the Indian Ocean, and at about 130 cm in the central Pacific.
(www.fao.org/docrep/field/255095.htm)

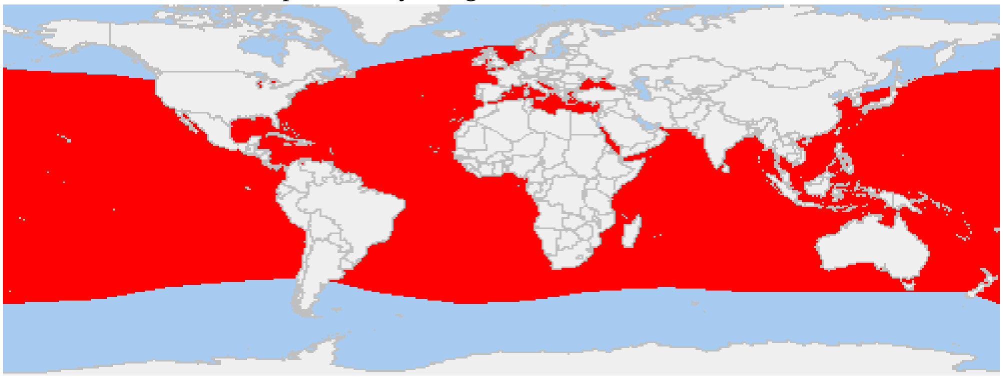
Appendix 6 : Swordfish (habitat and biology)

Xiphias gladius

English language common names include swordfish, broadbill, broadbill swordfish, and sword fish.

Geographical Distribution

The swordfish is found in oceanic regions worldwide, including the Atlantic, Pacific, and Indian Oceans. It is found in tropical, temperate, and sometimes cold waters, with a latitudinal range of approximately 60°N to 45°S. The swordfish is a highly migratory species, generally moving to warmer waters in the winter and cooler waters in the summer. It is often present in frontal zones, areas where ocean currents collide and productivity is high.



Distribution of Swordfish

(http://www.fao.org/figis/servlet/species?fid=2503)

Habitat and biology

Generally an oceanic species, the swordfish is primarily a midwater fish at depths of 650-1970 feet (200-600 m) and water temperatures of 64 to 71°F (18-22°C). Although mainly a warm-water species, the swordfish has the widest temperature tolerance of any billfish, and can be found in waters from 41-80°F (5-27°C). The swordfish is commonly observed in surface waters, although it is believed to swim to depths of 2,100 feet (650 m) or greater, where the water temperature may be just above freezing. One adaptation which allows for swimming in such cold water is the presence of a "brain heater," a large bundle of tissue associated with one of the eye muscles, which insulates and warms the brain. Blood is supplied to the tissue through a specialized vascular heat exchanger, similar to the counter current exchange found in some tunas. This helps prevent rapid cooling and damage to the brain as a result of extreme vertical movements.

Size, Age, and Growth

Swordfish reach a maximum size of 177 in. (455 cm) total length and a maximum weight of 1,400 lbs. (650 kg), although the individuals commercially taken are usually 47 to 75 in. (120-190 cm) long in the Pacific. Females are larger than males of the same age, and nearly all specimens over 300 lbs. (140 kg) are female. Pacific swordfish grow to be the largest, while western Atlantic adults grow to 700 lbs. (320 kg) and Mediterranean adults are rarely over 500 lbs. (230 kg). Swordfish reach sexual maturity at 5-6 years of age, with a maximum lifespan of at least 9 years.

Food Habits

As opportunistic predators, swordfish feed at the surface as well as the bottom of their depth range (>2,100 ft (650 m)) as evidenced by stomach contents. They feed mostly upon pelagic fishes, and occasionally squids and other cephalopods. At lower depths they feed upon demersal fishes. The sword is apparently used in obtaining prey, as squid and cuttlefishes commonly exhibit slashes to the body when taken from swordfish stomachs. A recent study found the majority of large fish prey had been slashed, while small prey items had been consumed whole. Larval swordfish feed on zooplankton including other fish larvae Juveniles eat squid, fishes, and pelagic crustaceans. (http://www.flmnh.ufl.edu/fish/Gallery/Descript/Swordfish/Swordfish.html)

Appendix 7 : The artisanal net fishery

Nets operated by fishers in the coastal fisheries of Mauritius include large nets, gill nets, pocket nets, canard nets and shrimp nets. The various nets are defined in the Fisheries and Marine Resources Act, 1998, namely:

- A large net means a net which (i) does not exceed 500 m in length and 2.5 m in width; and (ii) is made up of square meshes measuring not less than 9 cm when stretched diagonally;

- A gill net means a net which (i) is set for catching fish; (ii) does not exceed 250 m in length and 2.5 m in width; and (iii) is made up of square meshes measuring not less than 11 cm when stretched diagonally;

- A pocket net means a net (i) not exceeding 15 m in length and 12 m in width; (ii) with 2 arms not exceeding 10 m each; (iii) which is made up of square meshes not less than 9 cm when stretched diagonally; and (iv) which is used in conjunction with a large net;

- A canard net means a net (i) which is used in conjunction with a large net for catching mullets; (ii) which does not exceed 100 m in length and 5 m in width; (iii) which is made by several layers of nets fitted with poles to maintain the whole net afloat on the surface of the water; and (iv) the meshes of any of the layers measure not less than 9 cm when stretched diagonally;

- A shrimp net means a net in the form of a bag not exceeding 2 m^2 which (i) is used for catching shrimps; (ii) is fitted with a loop measuring not more than 50 cm diametrically or diagonally; or (iii) is mounted on 2 handles and fitted with weights.