An Assessment of the Catching Performance of Circle Hooks and J-hooks in the Demersal Longline Fishery in the Sultanate of Oman

By

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THIS WORK IS DEDICATED TO MY WIFE AND MY CHILDREN, ALMOHANED, METHAQ, AYSHAH, MARYEM, AND ZOLFA FOR THEIR ENDLESS ENCOURAGEMENT AND PATIENCE

Declaration of Originality

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Abstract

The objectives of this study were to evaluate performance in efficiency and selectivity of two hook types, namely, circle hooks and J-hooks used in demersal longline gear in Omani waters. To achieve these objectives, in December 2004 a longline experiment was conducted at three fishing locations at Masirah Island in the Sultanate of Oman. A total of 6 120 baited hooks (3 060 (no. 6) J-hooks and 3 060 (no. 6) circle hooks) were deployed over a 17-day period.

The results indicated that 90% and 89% of circle- and J-hooks respectively were retrieved. Of the total catch of 581 fish (924 kg), the circle hooks caught 63% by numbers and 51% by weight. It was found that the catch of both hook types were dominated by one family (Lethrinidiae) and one species (*Lethrinus microdon*), which accounted for 38% by weight and 48% by number of all total catch. The non-commercial species accounted for 12% by weight and 7.4 % by number of the total catch.

With particular reference to the total catch, where the commercial catch is significantly higher than the non-commercial catch, the effectiveness of the circle hook is significantly higher than that of the J-hook. In the absence of output control in the fishery (that is, total allowable catch limit), and given the equal soak time for both hook types, the implication of this finding is that the circle hooks are more efficient than J-hooks in harvesting commercial species. In other words, all else being equal, the use of circle hooks could minimize the costs of fishing effort. This finding is promising from both management and fishing operational perspectives as the use of circle hooks could be promoted in the fishery.

It was also found that about 90% of the commercial catch by circle hook was hooked in the corner of the mouth. However, the J-hook figure was less than 24%. This result clearly indicates that the use of circle hooks can minimize gut hooking and thereby minimize physical damage to fish caught. An important implication of this finding is that the fish caught by the circle hook would remain fresh due to less physical damage and could therefore be expected to command higher market prices for fishermen.

In terms of non-commercial catch, there was no significant difference between hook types. An implication of this finding is that the circle hook does not increase the number

of by-catch compared to the J-hook and thereby does not undermine the conservation of non-commercial species.

The market value of catch was calculated for all commercial species. The results indicate that the average price per kg for circle hook catch was higher because more highly valued species where caught with the circle hook. Based on these findings, it could be concluded that the performance of circle hooks in relation to catching efficiency and selectivity is comparatively better than that of its counterpart and the management authority could encourage their use fully in Omani waters.

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AC:	Aquaculture Center
AFMA:	Australian Fisheries Management Authority
ANOVA:	Analysis of Variance
ASMFC:	Atlantic States Marine Fisheries Commission
CPUE:	Catch Per Unit of Effort
EEZ:	Exclusive Economic Zone
FAO:	Food and Agriculture Organization of United Nations
FEF:	Fisheries Encouragement Fund
FMRI:	Florida Marine Research Institute
FQCC:	Fish Quality Control Center
FRP:	Fiberglass Reinforced Plastics
GDP:	Gross Domestic Product
GPS:	Global Positioning System
HP:	Horse Power
IPHC:	International Pacific Halibut Commission
LSD:	Less Significant Difference
MAF:	Ministry of Agriculture and Fisheries
MD:	Ministry of Development
MI:	Ministry of Information
MNE:	Ministry of National Economy
MSFC:	Marine Science and Fisheries Center
OER:	Oman Economic Review
PE:	Polyethylene
PES:	Polyester
PHT:	Post Hoc Test
R.O:	Rial Omani

RV:	Research Vessel
SPSS:	Statistical Package for the Social Sciences program
SQU:	Sultan Qaboos University
TL:	Total Length frequency
YFV:	Youth Fishing Vessels

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Longline Gear

Longline fishing to catch pelagic species such as tuna and swordfish, and demersal species such as cod, haddock, halibut, ling and snapper is widely practiced throughout the world. In Oman demersal longliners typically catch grouper (*Epinephelus sp., Cephalopholis sp.*), emperor *(Lethrinus sp.)*, snapper *(Lutjanus sp.)*, thicklip *(Plectorhinchus sp.)*, and sea bream *(Argyrops sp., Acanthopagrus sp.)* and longline fishing gear consists of a monofilament or multifilament mainline (sometimes called groundline) to which several hundred or more monofilament or multifilament branchlines (also called gangions and snoods) are attached, each carrying a baited hook.

The catching principle of longlining, using baited hooks, is based on attracting and retaining fish and the principle is widely used by both traditional and commercial fishermen all over the world. In Oman it is one of the most widely used fishing techniques. Longline gear can be deployed from virtually any size and type of vessel varied ranging from small canoes in rivers and estuarine waters to large modern fishing vessels in the high seas to depths of 800 m, and sometimes down to 2,500 m (Bjordal & Lokkeborg 1996; Sainsbury 1996, 1986). The major difference in fishing gear between these vessels is the length of the mainline and the number of hooks used (Siddeek 1999), and the degree of automation used to bait the hooks and deploy and haul in the longline. In Omani waters the demersal longline is typically set in depths from 16 m to 300 m.

Longline vessels may be classified by size (length overall or LOA), from small (8 – 15 m) to medium (15 – 25 m) and large (25 – 50 m) (Bjordal & Lokkeborg 1996) and in Oman, the longline vessel is usually classified by length and hull construction material. Small fishing boats, usually constructed from Fiberglass Reinforced Plastic (FRP) typically measure between 5 – 10 m and a medium boat, including FRP and timber Dhows and Hori's typically measures between 10 – 25 m. A sub set of the medium boat class is the so-called Youth Fishing Vessel (YFV), which measures between 12 – 30 m (MAF 2002).

Vessel size and the level of automation influences the amount of fishing gear that is operated in a daily fishing cycle, with small boats typically working a few hundred hooks while larger vessels with auto-line systems are capable of operating over 20,000 hooks (Farmery 1993). The amount of gear operated also depends on the seabed topography and distribution and density of fish (Bjordal & Lokkeborg 1996).

1.1.1 Longline (Mainline) Construction

The mainline is the basic constituent of longline gear. Branchlines, buoys and sinker lines are attached to it. The mainline is characterised by the material, material construction and size and it varies in length according to the fishing ground, scale of fishing operation and other conditions. In large-scale longline fishing, the length of the mainline can be up to 180 km (Sainsbury 1996, 1986). It is made of highly specific gravity materials such as hard twisted polyamide, polyvinyl chloride or polyvinyl alcohol. In the past, natural fibres were used but synthetic materials are now widely used because of their higher breaking strength and higher resistance to deterioration (Bjordal & Lokkeborg 1996).

The mainline can be either multifilament or monofilament, where the multifilament mainline consists of fibre filaments that are twisted to threads and strands to make rope. These mainlines are normally treated with coal tar or some other impregnating material to improve their handling properties and increase the life of the line (Hovgard & Lassen 2000). Breaking strength, resistance and inflexibility of the line are all important properties of the mainline. Inflexibility is related to the so-called coiling properties of the line because a prerequisite in effective handling of longline gear is that the mainline coils nicely with a low risk of tangling (Bjordal & Lokkeborg 1996). This multifilament line is usually very tightly twisted nylon, polyester, or polypropylene having a diameter between 4 to 11 mm (George 1993; Sainsbury 1996).

During the last 30 years however, monofilament mainlines have gained in popularity because their catching efficiency has been shown to be superior to that of multifilament lines (Bjordal & Lokkeborg 1996). In contrast to multifilament lines, monofilament lines have only one filament and it is made of polyamide. Because of their low breaking strength and poor resistance to chafing, monofilament mainlines can seldom be laid on the bottom except on smooth seabeds (Bjordal 1988).

Monofilament mainlines are usually used in pelagic or semi pelagic longline fishing and the filament is given a particular heat treatment in order to obtain good coiling and handling properties (Bjordal & Lokkeborg 1996). For example, Bjordal (1983a) found that catch rates of cod and haddock using monofilament were 10 - 20% higher than that for multifilament lines. Monofilament lines have a relatively small twine diameter, a smooth surface, and a non-absorbing surface area, and increased catching efficiency is thought to be a result of lower line visibility, more effective transmission of vibrations along the line from movements of hooked fish (Johannessen 1983), and lower absorption of smell stimuli from bait; hence fish are attracted more effectively to the baited hook (Bjordal & Lokkeborg 1996).

1.1.2 Branchline

The branchline is made from either multifilament or monofilament line. The advantages of using a monofilament branchline are that it is almost invisible, it stretches before breaking, and it has reasonably good durability (George 1993). The lower visibility of the monofilament branchlines results in higher catch rates. When the length of branchline is increased, the catch rate usually increases, but because longer branchlines tend to tangle easily, their length is limited to less than half the hook spacing (Bjordal & Lokkeborg 1996). The diameter of monofilament branchline ranges from 0.3 to 1 mm in thickness and from 0.5 m to several metres in length according to the type of fishery. The diameter of the multifilament branchline may be from 2 to 4 mm, and with a length ranging from 0.3 m to several metres (Bjordal & Lokkeborg 1996).

In order to keep the branchline from getting tangled its length must be less than half that distance between two consecutive branchline tie-points (George 1993; Bjordal & Lokkeborg 1996). The breaking strength of the branchline must be less than that of the mainline and at least equal to twice the largest weight of the anticipated fish to be caught (George 1993). The length of the branchline together with the length of the buoy line and the shape of the mainline catenary attained during operation determines the fishing depth of hooks. When a fish is hauled, the branchline tends to rotate around its own axis and around the mainline (Gil 2005), thus twisting and shortening of the branch line takes place. Due to this reduction in flexibility, the possibility of the fish breaking loose and getting lost is increased.

Comparative fishing trials have shown that length and material construction of the branchline has an effect on longline catch rates. Monofilament branchlines have a 10 - 20% higher catch rate for cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), and ling (*Molva molva*), compared with multifilament branchlines (Bjordal 1988; Bjordal & Lokkeborg 1996). Fishing trials have shown that the catch rates are generally improved by increasing branchline length (Bjordal & Lokkeborg 1996), however, the reasons for this are not fully understood. Branchline floats have been used as a method to prevent bait predation by bottom scavengers. Bjordal (1984) found that branchline floats of 5 and 8 g buoyancy reduced bait loss and improved catching efficiency.

1.2 Hook

The hook is the heart of the longline system. The hook consists of a shank, bend, point, barb and an eye (or ring) for attaching it to the branchline (Figure 1.1). Hook types vary greatly and about 50,000 types of hooks have been designed (Gil 2005) which can be classified into hooks for commercial and for sport fishing. The hook has two functions, firstly to catch the fish and secondly to retain it until it is safely landed on board the boat. The J-shaped hook was a commonly used hook which dominated demersal longline fisheries until the mid 1980s (Bjordal & Lokkeborg 1996). Circle hooks are now commonly used in longline fisheries. Cook & Suski (2003) and Prince et al. (2002) defined a circle hook as having a point that is perpendicular to the shank, whereas J-hooks are defined as having a point parallel to the shank (Figure 1.1). A California statute defines a circle hook as "a hook with a generally circular shape and a point which turns inwards, pointing directly back at the shank at a 90º angle" (cited in ASMFC 2003).

Circle hooks are not new. Excavations of graves from pre-Columbian Indians in Latin America have found hooks made from seashells that resemble modern circle hooks (ASMFC 2003). Early Japanese fishermen tied pieces of reindeer horn together in the shape of a circle hook, while a similar design has been found at Easter Island (Moore 2001). Pacific coast Native Americans also used hooks that fished similarly to modern circle hooks (Bowerman 1984; Stengel & Al-Harthy 2001). Modern commercial longline fishermen have been using circle hooks for many years (Moore 2001; Prince et al. 2002).

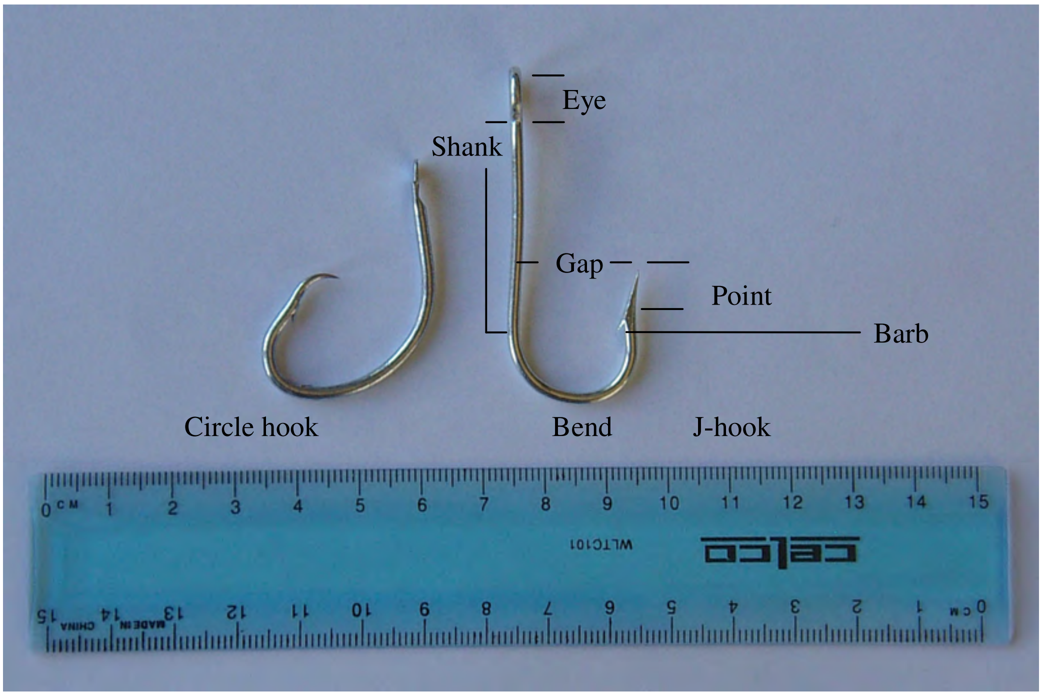


Figure 1.1 The circle hook and the J-hook structure.

1.2.1 Hook Design (Shape and Size)

The most important component of the longline fishing system is the fish hook. Today, fish hooks are mostly made from steel, with many being tin-plated, galvanised or even made from stainless steel to protect them from corrosion. They come in a wide variety of shapes and sizes which have evolved over time through the development of line fishing for different species throughout the world. There is a tremendous variety of hook shapes including the J-hook, circle hook, E-Z Baiter, Kirby, O'Shaughnessy, Wide Gap, hooks with eyes or rings, and hooks with flat shanks or swivels. The size of a hook is indicated by a number (Bjordal & Lokkeborg 1996), where the number either increases, (i.e. 1/0, 2/0, 3/0) or decreases (i.e. 1, 2, 3, see Figure 1.2), with size depending on the manufacturer.

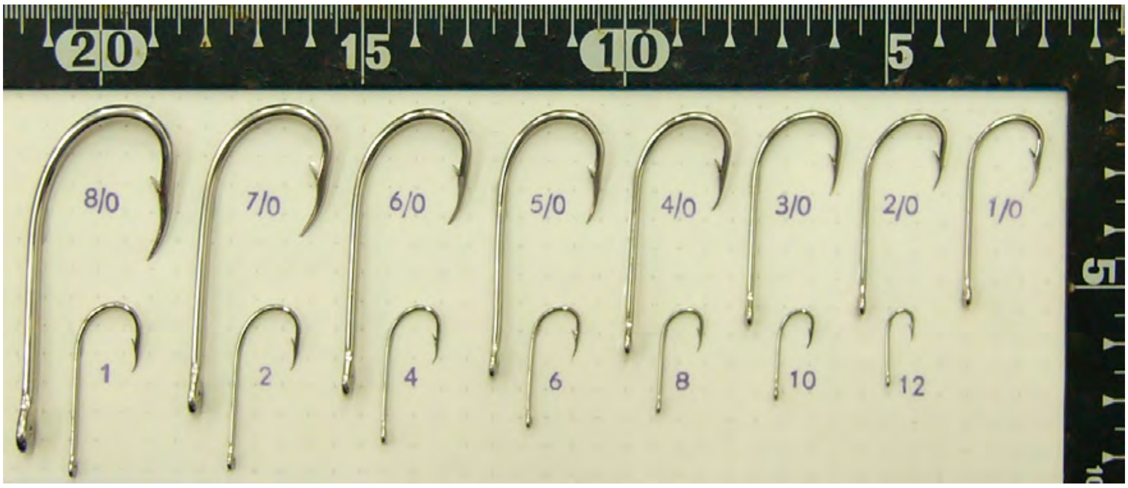


Figure 1.2 Hook size numbering (not to actual scale). Ruler scaling is in millimetres.

1.2.2 Hook Spacing

The variations in hook spacing for longline fishing are often related to the density of the target fish species. In pelagic longline fisheries branchline distances[1] are typically 10 to 50 m (Skud 1978), although Bjordal & Lokkeborg (1996) reported distances of 24 to 180 m in tuna fisheries. In demersal fisheries they are typically less than 3 m (Bjordal & Lokkeborg 1996; Hovgard & Lassen 2000). Skud (1978) found that hook spacing may have an effect on the catch per unit of effort (CPUE), with wider spacing between hooks resulting in larger individual fish being caught. A comprehensive study by the International Pacific Halibut Commission (IPHC) to investigate the effect of hook spacing on catching efficiency concluded that the catch per hook increases as hook spacing increases (Bjordal & Lokkeborg 1996; Skud & Hamley 1978). This difference in catch is related to "competition" between the hooks. With close spacing between hooks, several hooks vie for the capture of the same fish i.e. several hooks fall within the feeding range of each fish (Bjordal & Lokkeborg 1996).

1.2.3 Swivels

When branchlines made from monofilament material are attached to the mainline, there are some problems because they are slippery and stiff. To solve these problems, swivels are used to connect the branchlines to the mainline. Because swivels

[1] As the hook is attached to the branchline, branchline distance is a measure of hook distance or spacing.

prevent twisting and tangling, monofilament lines with a swivel give high catch rates. Comparative fishing trials conducted in the cod, haddock and ling fisheries in Norway have shown that the use of swivels improves catch rates by about 15% (Bjordal 1988; Bjordal & Lokkeborg 1996) and a two plane swivel increases catch rates by over 40% when compared with traditional longline gear using fixed branchlines (Gorman 1996b; Bjordal 1992). Swivel connected branchlines make the de-twisting work of fisherman easy. Swivels also allow for the possibility of using a monofilament branchline with a multifilament mainline (Bjordal & Lokkeborg 1996; George 1993).

1.3 Bait and Baiting

The principle of line fishing is to lure fish to bite the bait. Therefore, bait is one of the most important factors in line fishing. The catch rate depends to a large extent on bait type, quality and size (Bach et al. 2000). Experience accumulated over the years allows fishermen to use different types of bait and the type of bait chosen depends on the target species. There are a large variety of bait types used for longline fishing including mackerel, sardine, herring, shrimp, crab, squid, cuttlefish and octopus, and these are used whole or cut into pieces. Omani fishermen use mackerel, sardine, cuttlefish and squid as bait which may be fresh, frozen or salted. Bait must be suitable to the target species (Bjordal & Lokkeborg 1996) with quality one of the important factors, which affects the catch rate.

The ideal bait should both stay on the hook throughout the fishing period and effectively attract fish (Ekanayake 1999; Lokkeborg 1989). The process of attracting fish by bait is explained by Bjordal and Lokkeborg (1996). The fish are caught on longlines because the bait releases odours, including amino acids, which are dispersed by the water currents triggering the fish's foraging behaviour. Bait effectiveness therefore depends on the bait type, and the quality and quantity of odour released (Bjordal & Lokkeborg 1996; Lokkeborg 1989). Since the catching process using baited hooks is based on the foraging behaviour of fish (Lokkeborg 1989) and feeding stimulants (Carr 1982; Carr & Derby 1986), bait type is the most important gear parameter affecting species selectivity of longlines (Bjordal & Lokkeborg 1996).

In some longline fishing for tusk and ling, a combination of mackerel and squid bait is used. It has been shown that the catch rate for squid bait was 100% higher than the mackerel bait for ling but only 9% higher in catching tusk when the combination of mackerel and squid was 4:1 ratio. Another fishing experiment showed that mackerel and squid bait at 1:1 ratio caught 40% more tusk (*Brosme brosme*) than longlines baited with mackerel alone (Bjordal & Lokkeborg 1996).

When comparing several natural baits in fishing experiments, Martin and McCracken (1954) found squid to be the most effective for the capture of cod and hake, whereas mackerel appeared to be more effective for haddock. Bjordal (1983a, 1988) found that squid bait caught twice as many ling (*Molva molva*) as mackerel bait and 90% more tusk. Thorsteinsson and Bjornsson (1996) documented that squid bait was more effective than mackerel, but gave a similar catch in number for haddock and cod. They showed that squid and octopus bait are often superior to fish bait. Under-water observations have shown that squid and octopus bait are less easily removed from the hook than fish bait (He 1996; High 1980).

In addition to the attractiveness of the smell and taste stimuli, the efficiency of bait is determined by its physical strength and ability to remain on the hook throughout the soaking time (Bjordal & Lokkeborg 1996). In catching cod and haddock, mackerel has given a higher catch rate than squid in pelagic longlining. However, squid stays on the hook better than mackerel, and when catching cod and haddock in bottom longline fishing, fishermen often use squid or a combination of squid and mackerel as bait (Bjordal 1988). The bait loss is more important for hooks on the bottom, and squid may be more efficient for bottom longline fishing than mackerel even though mackerel may be more attractive to cod and haddock (Lokkeborg & Bjordal 1992).

The problem of low hooking efficiency in longline gear includes bait loss, low feeding motivation, escape from the hooks and hooking of non target species (Gorman 1996a). These problems are described by Bjordal 1988; Bjordal & Lokkeborg 1996; High 1980; Lokkeborg & Bjordal 1992 and Skud & Hamley 1978. Predators such as sea birds are the cause of bait loss during the setting of longlines while starfish, hagfish and sea lice (isopods and amphipods) are the cause during soaking. Often fish themselves (target and non-target species) succeed in removing bait without becoming hooked

(Bjordal 1988). Bait loss can therefore be influenced by the type of bait, soak time and fishing depth, and may vary from 20 - 100%.

The quantity of bait lost might be reduced by lifting the mainline and/or branchlines off the bottom so the bottom predators cannot access the bait. Sainsbury (1996) reported that rigging the longline gear so that the branchline, hook and bait are off the bottom helps keep bait away from unwanted scavengers. Other research (He 1996), found significantly lower bait loss when the line was lifted off the bottom. Bjordal (1983b) observed a similar reduction in bait loss when he lifted the hooks off the bottom by attaching small floats to individual hooks. Bait size is also an important factor affecting the fish size and catch rate.

The most pronounced effect of bait size on catch rate has been shown for haddock catch using semi pelagic longline. Mackerel bait weighing 10 g was shown to catch more than twice as many haddock as 30 g mackerel bait. Because bait in mid-water is more easily seen than bait on the seabed, the effects of bait size are more pronounced for pelagic or semi pelagic longline than for bottom longline. The bait size also affects the size of the fish caught because a fish's mouth size and ability to bite and handle the prey, means small fish prefer small size prey (Bjordal & Lokkeborg 1996). In Icelandic waters, the most common bait size is 30 g/hook and the bait type used is herring, squid, mackerel and saury from Brim Company.

Hooks are baited either by hand or mechanically by baiting machines. The best way to bait any hook, especially a circle hook, is to hold the bait still and rotate the hook into and through the bait (Figure 1.3). Because of their peculiar shape, a circle hook takes more time to bait than a J-hook (Bowerman 1984).

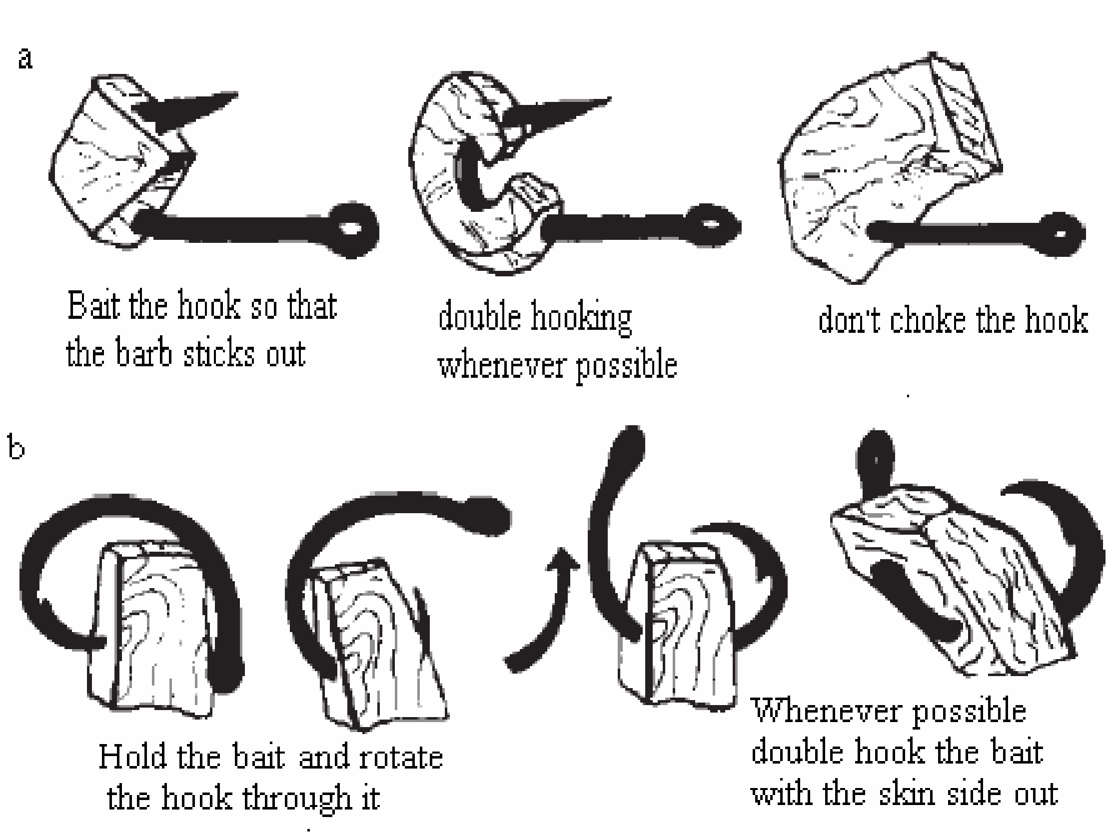


Figure 1.3 Diagram (a) presents the J-hook baiting technique and diagram (b) presents the circle hook baiting technique (source: Garry et al. 1999). (http://www.spc.int/coastfish/Fishing/Deep_E/DeepBottom2.pdf)

1.4 Mechanised Process

Since the early 1960s many studies been conducted on longline mechanisation especially in Canada, the Faroe Islands, Germany, Iceland, Ireland, Japan, Norway, Sweden, UK and USA (Bjordal & Lokkeborg 1996). The main focus of this research has been on automated baiting, hauling operation systems and line handling systems. These three systems are operated in a whole system. Two main systems have been quite successful. One is automated baiting (precise or random baiting) and the other is storage of the gear (rack or drum storage). In precise baiting, a piece of bait is put on each individual hook by a baiting machine, which cuts the whole bait fish to a certain size. Precise bait size is guaranteed to be comparable to hand baited bait size.

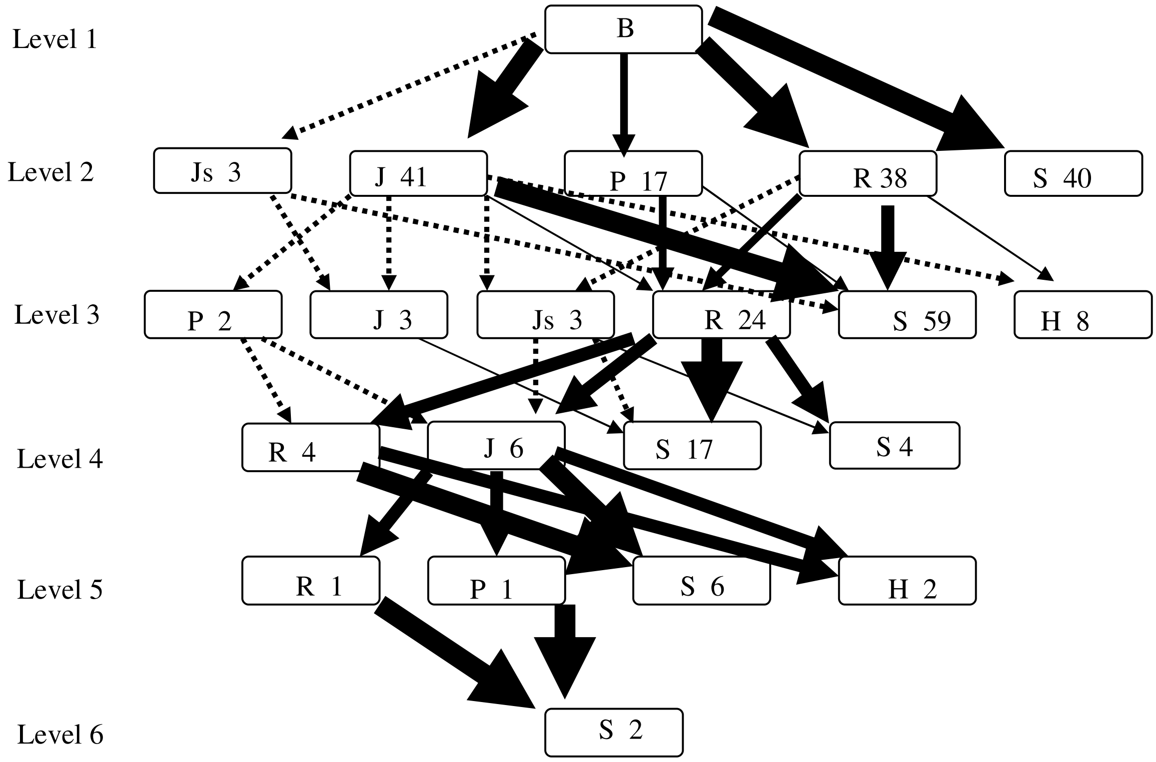
The auto longline system, a system operated by three fishermen, was developed by O. Mustad and Sons Ltd of Norway and is widely used in commercial fishing. When setting is done, one fisherman feeds bait fish onto the conveyor belt and the other checks that the hooks run smoothly off the rack and replaces empty racks with loaded ones. When the hook penetrates the bait, a piece of bait is cut by a mechanically driven knife and the baited hook is pulled out of the machine.

The captain controls the vessel and fishing operation and the work is done at a speed of up to six EZ baiter hooks per second with a hooking spacing (branch line spacing) of 1.3 m. The setting speed is usually from 6 -10 knots depending on the model of baiting machine used and spacing between hooks. Hauling is done by a powered line hauler which pulls the gear over a rail roller. When hauling, one fisherman gaffs and the other blades the fish and the line from the rail roller passes the de-hooker and the hook cleaner.

It then passes through the hauler to the twist remover and the hook separator. By using water jet flushing, twists in the branchlines are removed automatically by the twist remover, and the branchlines are cleaned. By using magnets the hook separator catches the hooks and guides them onto the rack. When the hooks and line arrive on the rack, repair work is done. In random baiting, the line is set through the container with the mixture of pre-cut bait and water and a piece of bait is snagged to a hook randomly when the hook passes through the bait mixture. In this case, the bait is securely fastened. Metal racks or rails are used for rack storage. The hooks are put onto the rack in sequence and branchlines and the mainline are suspended underneath. Drums are used either to store only the mainline when using detachable branchlines or to store the complete gear.

1.5 Hooking Process

When the longline gear has been set the fish may either accept or reject the baited hook. This hooking process depends on the visibility of the branchline and mainline gear, and the bait size and shape (Bjordal & Lokkeborg 1996). The behaviour of fish towards a baited hook has been studied in the laboratory (Ferno & Huse 1983) and in the field (Ferno et al. 1976; Ferno & Olsen 1994; He 1995; Lokkeborg et al. 1989) and these studies have lead to a description of a typical sequence of fish behaviour. Despite different hooking behaviour between species, the typical behaviour of cod may be used to illustrate the hooking process for longline gear (Figure 1.4).



Key:

- Complete bite (B); the fish sucks whole baited hook and closes its mouth
- Incomplete bite (Bi); the fish takes in only part of the bait or does not close its mouth completely around the baited hook
- Pulling (P); the fish swims slowly with stretched branchline with the baited hook in its mouth
- Chewing (C); the fish chews on the baited hook
- Jerk (J); the fish moves its head rapidly sideways with the bait and hook in its mouth
- Jerk series (Js); the fish performs several very fast jerks in succession from side to side with the baited hooks in its mouth
- Rush (R); the fish accelerates rapidly with the baited hook in its mouth
- Hook out of mouth (S); the hook with or without bait is spat or pulled out of the mouth.
- Hooking (H); the fish was considered hooked when the hook was retained in the mouth

Figure 1.4 Behaviour sequence (flow chart) for cod (*Gadus morhua L.*) taking a baited hook assuming each sequence starts with a bite (B), and ends either with the hook out of the mouth (S) or the fish hooked (H). The thickness of arrows indicates the reactive importance of the transition between the two behaviour patterns, and the dotted arrows indicate the infrequent transitions. Each level contains the corresponding behaviour pattern in each of the summed sequences. The numbers indicates the observed values for transitions from one behaviour pattern to another with behaviour sequences of the cod. The sequences B-P-J-Js-R-S thus have the B in level 1, the P in level 2, the J in level 3 etc (source: Ferno & Huse 1983).

Usually the fish probe the baited hook by biting the bait or touching the bait with their lips or barbel (Bjordal & Lokkeborg 1996). After biting the bait, the fish may make a rush or a series of jerks (i.e. rapid sideways movements of the head). The attacking sequence ends with the fish being hooked or the baited hook being ejected from the mouth. Hooking occurs when the rushing or jerking motion causes the hook point to penetrate the tissue of the mouth cavity. Normally, the hooked fish thrashes vigorously for a short period in an attempt to escape before exhausting itself (Ferno & Huse 1983; Lokkeborg et al. 1989).

Generally, fish do not handle stress, caused by the hooking process, very well. They tire quickly as they are unable to easily remove cortisol (i.e. stress hormone) or lactic acid in muscles (built up during the struggle), from their body. The curling of the body and tail (probably more likely in less active fish) is due to acid build up and osmoregulatory failure (Moyle & Cech 2000). At the time of hauling, many of the captured fish are exhausted and acid build up in the muscles causes the fish's body to curl up into an inflexible curve which then causes the fish to rotate as it is hauled. This can cause the branchline to become twisted and tangled with the mainline (Bjordal & Lokkeborg 1996; Lokkeborg 1993; Lokkeborg et al. 1989).

1.6 Hooking Location

There are a number of positive claims connected with circle hooks. Circle hooks are intended to hook on the exposed edge of a fish's mouth and thus decrease handling time and physical injury (Cooke & Suski 2004) and it is also intended to reduce gut hooking. Gut hooking is known to increase the risk of bleeding and damage to vital tissue (e.g heart) and thus increase mortality (Muoneke & Childress 1994). The circle hook increases survival because circle hooks predominantly catch in the jaw, whereas the J-hook catches more fish in the gut (Trumble et al. 2002). An investigation by Skomal et al. (2002) on the USA Atlantic coast compared the performance of the circle hook to the J-hook and found that the circle hook caused less physical damage than the J-hook. Falterman (2002) found that the circle hook had a higher frequency of jaw hooking and lower frequency of gut hooking than the J-hook. An experiment carried out by Falterman and Graves (2002) compared the circle hook and J-hook mortality rate and hooking efficiency in a pelagic longline industry. They found CPUE was higher and mortality rate lower for both target fish (yellowfin tuna) and bycatch (non target species) using circle hooks. In a study of the Gulf of Mexico pelagic longline fishery, Berkeley and Edwards (1997) noted a higher immediate mortality for billfish caught on the J-hook than the circle hook (cited by Lucy & Studholme 2002).

Grover et al. (2002) recommended that the circle hook be used to reduce the hook and release mortality in the California tuna fishery. McEachron et al. (1985) studied mixed marine trotline fisheries off Texas and Woll et al. (2001) studied Greenland halibut in the North Atlantic. Both reported that circle hooks had higher catch rates and higher levels of jaw hooking than J-hooks. Kaimmer and Trumble (1997) reported that high rates of jaw hooking were found with the circle hook (95%) relative to the J-hook (80%) in Pacific halibut. In a study of Chinook salmon from commercial trolling, Orsi et al. (1993) determined that the circle hook had higher jaw hooking but lower catch rates.

Studies by the Maryland Department of Natural Resources indicated significantly lower release mortality in striped bass when using non-offset circle hooks, as opposed to conventional J-hooks (Lukacovic 1999, 2000, 2001). An experiment conducted by Lukacovic & Uphoff (2002) investigated the influence on catch and release mortality of striped bass by hook location, fish size and seasons using the non-offset circle hook and J-hook. The researchers found that fish size, season and hook location were not independent of hook-and-release mortality. The circle hook may therefore be considered a gear modification designed to reduce fish mortality in commercial and recreational fisheries (Lukacovic & Uphoff 2002). Investigating the use of circle hooks as a management tool for marine and freshwater recreation fisheries, Cooke and Suski (2003) found that hooking mortality rates were reduced by 50% by using circle hooks when compared to J-hooks.

A report by Prince et al. (2002) indicated that circle hooks used in recreational fisheries had a 1.83 times higher hooking percentage compared to J-hooks. However, some studies have found that the effectiveness of a circle hook for reducing foul-hooking is compromised when the hook point is offset (i.e. the point of the hook is not in the same plane as the shank of the hook) (FMRI 2004). The design of the circle hook seems to clearly reduce the probability of a hook being caught in the gut or throat if swallowed. When the hook is ingested, the shape of the hook allows it to slide towards a fish's jaw as the line is hauled, typically hooking itself in the corner of the fish's mouth (FMRI 2004).

There are a number of factors that can affect hooking mortality including cumulative sublethal physiological disturbance, physical injury and bleeding (Muoneke & Childress 1994). Hook type plays little role in physiological disturbance except where hook type influences the difficulty of hook removal, leading to increased air exposure (Bacheler & Buckel 2004; Cooke et al. 2001). Compared to the circle hook, fishing mortality was consistently higher for J-hook caught fish in the majority of the studies. For example, in studies on red drum, the hooking mortality rate for the circle hook was 3% and for the J-hook was 7% (Thomas et al. 1997). In Maryland, striped bass have also shown reduced mortality rates when captured on circle hooks (0.8%) compared with those captured on J-hooks (9.1%) (Lukacovic 1999). An experiment conducted in North Carolina by Hand (2001) showed hooking mortality rates for striped bass were higher when captured on J-hook (18.2%) when compared with those captured on circle hook (5.9%).

There are also some engineering aspects of hook design that need to be considered. These relate to the lines of force acting through the point and eye of the hook in relation to how best the hook will penetrate the fish's mouth (Radcliffe 2005). For many temperate water species with relatively soft mouth structures the point should follow the line directly to the eye of the hook with a minimal angle of attack at the point (Figure 1.5).

Some tropical species are protected by very bony and heavily scaled structures which make it very difficult for a fish hook to penetrate the flesh (Radcliffe 2005). The wide gap hook with a very fine turned in point may be more successful in penetrating the inner mouth parts than a more conventional hook (Figure 1.5).

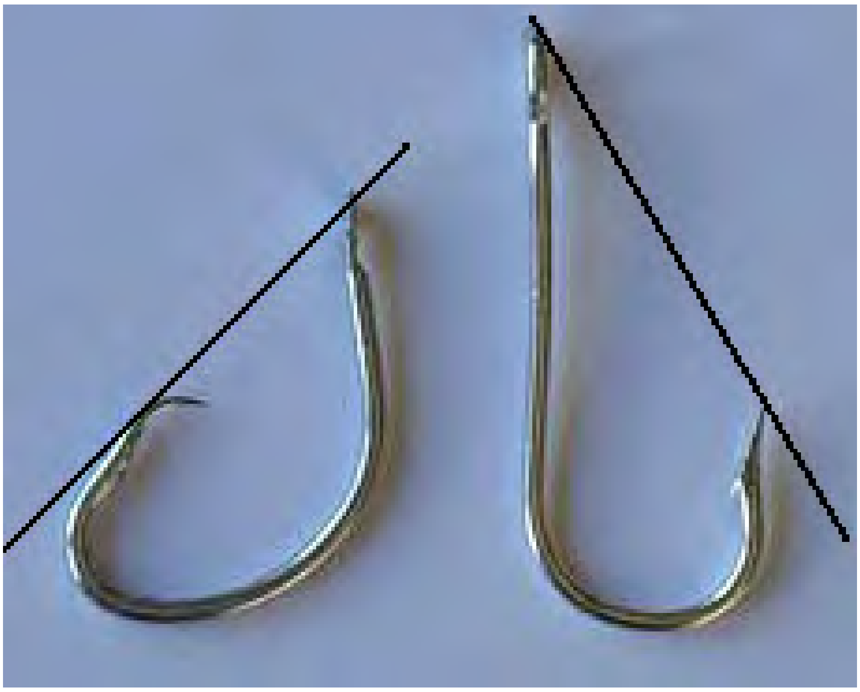


Figure 1.5 Lines of force between the hook point and the eye showing the angle at which the hook point will enter the fish's flesh, and hence the advantage of a wide gap hook. The circle hook with a turned in point is on the left.

In addition there are many articles published which indicate the benefits of the circle hook in locations including Australia (Bowerman 1984), North America (Manns 2002; Stange 1999), Africa (Bursik 1999; Van 1999) and central South America (Fogt 2000). Furthermore, many governments around the world encourage their fishermen and anglers to use the circle hook by producing catch and release educational material (for example, New South Wales Fisheries Unit, Australia; Maryland Department of Natural Resources, USA; Florida Sea Grant, USA; Fisheries and Ocean, Canada) (Cook & Suski 2004).

1.7 Catching Efficiency

Longline gear is one of the few fishing gears that have a definite saturation point, limited by the number of hooks that can be set and hauled during a day (Bjordal & Lokkeborg 1996). However, longline fishing appears to be a relatively inefficient fishing method, when compared with other fishing gear. The catching efficiency of a longline is defined as the proportion of target or commercial fish that are caught per unit number of baited hooks set. The daily catch (c) of a longline is therefore defined by the number of hooks that are set and hauled per day and can be expressed by the following equation (Bjordal & Lokkeborg 1996);

$$C = n * a_1 * (1 - a_2) * (1 - a_3) * (1 - a_4) * a_5 * w$$

where, n = number of hooks set and hauled per day, a_1 = proportion of hooks leaving the vessel with bait on, a_2 = proportion of hooks with bait loss caused by sea birds, a_3 = proportion of hooks with bait loss due to seabed scavengers, a_4 = proportion of hooks with bait loss due to small fish or non target species that eat the bait without being hooked, a_5 = catching (hooking and retention) probability of target fish, and w = average weight of target fish.

There are several factors that might influence catching efficiency including the size of the hook, which is measured by gap width, shank length and wire dimension (Garry et al. 1999). Bjordal and Lokkeborg (1996) reported that smaller hooks give higher catch rates than larger hooks because a fish more easily takes a smaller hook into its mouth. The smaller hook is also thinner and can therefore more easily penetrate the flesh. George (1993) reported that smaller hooks cost less, need less bait and give a higher yield. A second factor is the material of the hook (iron, stainless steel), which has to be strong enough not to be broken by large fish.

Another factor that can influence the hook catching efficiency is the shape of the point; e.g. with or without a barb. The barb has to be hard and sharp to penetrate the hard skin and bone of the fish (Garry et al. 1999). The shank and bend of a hook has to be solid and strong enough to withstand the fish's struggles, without snapping or straightening. Bjordal and Lokkeborg (1996) reported that the form of the eye (a loop or flat plate) and the finish of the hook (colour and coating) might also influence the hook catching efficiency.

The size of the hook may also affect the species composition of the longline catch. Research done by Skud (1978), Lokkeborg and Bjordal (1992) and Bjordal and Lokkeborg (1996) found that smaller hooks give higher catch rates than larger hooks. A smaller hook has been shown to be more effective for catching cod and haddock than larger hooks (Johannessen et al. 1993). A study of hook size (Koike et al. 1968; Koike & Kanda 1978) assumed that the hook has an optimum catching efficiency for a certain fish length, and the researchers obtained selection curves indicating that length increased with increasing hook size. Hamley and Skud (1978) found that some factors such as branchline length and hook spacing also influence the catch rate. Catch rates of longlines compared with different gear, like trawl net and gillnet, have been studied by, Clark et al. (2002), Hovgard and Right (1992) and Neilson et al. (1989). These studies confirmed that when compared to other fishing gear, the longline gear caught larger fish. The length frequency distribution of fish caught by the trawl was considerably smaller than those caught by longline gear (Neilson et al. 1989; Nomura 1991).

Catching efficiency is also influenced by bait size and type. Martian and McCracken (1954) found that bait size has a significant effect on catching efficiency, and longline experiments have demonstrated very different rates of effectiveness of squid, mackerel and herring for catching demersal fish. Johannessen (1983) showed that 10g baits caught more than twice as many haddock as 30g baits. Halliday and Kenchington (1993) concluded that since the power of attraction is directly related to the size of the bait, it is important in selectivity studies to use a standard bait size. The longline experiments have shown that bait size has a significant influence on catching efficiency and size selectivity for cod and haddock (Johannessen et al. 1993). Bait size may also have a species selective effect (Lokkeborg et al. 1989). Johannessen (1983) and Bjordal and Lokkeborg (1996) found that smaller baits gave significantly higher haddock catch rates than larger baits and that there is potential for size selective effects within the range of hook sizes that are relevant to commercial longline fisheries. Lokkeborg and Johannessen (1992) tested bottom longline gear with different bait such as mackerel and squid, and reported that squid bait gave a 100% higher catch rate for ling than the mackerel bait, but only 9% more for tusk.

Differences in feeding behaviour between large and small fish may affect the size selectivity in longline gear. Larger fish have a larger foraging area and a higher probability of encountering baited gear; therefore there is higher competition for the bait (Engas & Lokkeborg 1994). With lower density and a lower proportion of larger fish there is less competition for the bait and smaller fish may be more successful in taking the bait (Engas & Lokkeborg 1994). Environmental factors such as tide, current, light, moon phase and the nature of the sea bed, also influence catch rates of longlines (ICES 1977).

1.8 Catch Composition

In longline fisheries, the probability of catching a fish may decrease as successive fish are caught and fewer hooks remain available to hook and retain fish. On the other hand, caught fish may attract other fish to the gear, thus raising the probability of capture as successive fish are caught (Engas & Lokkeborg 1994). Lokkeborg and Bjordal (1992) conclude that fishing strategies relating to fish distribution, feeding range, competition, hook design, bait type and size are important to the selection process.

The catch composition of demersal species has been shown to be different for three varieties of coastal set-lines (Arimoto 1984) and also to be different between two floated lines; one with vertical and horizontal lines, and other with vertical lines only. The composition of pelagic species in longline catches is influenced by fishing depth (Bjordal & Lokkeborg 1996). A longline fishing experiment conducted by Sakagawa et al. (1987) found that yellowfin tuna (*Thunnus albacares*) and albacore tuna (*Thunnus alalunga*) are mostly caught in shallow water whereas in other fishing experiments done by Gong et al. (1989), bigeye tuna (*Thunnus obesus*) were mainly caught in deeper water. Differences in vertical longline distribution of tuna may be a reflection of preferences for different water temperatures (Bjordal & Lokkeborg 1996).

1.9 Selectivity

Despite the fact that longlines may attract and catch a large variety of fish species and sizes, this gear is considered to have only medium to good species and size selective properties (FAO 1998). The property of fishing gear to catch fish of a certain size and species from a given mixed population is called selectivity (Fridman 1986). Selectivity depends on the fishing method used and the design of the fishing gear. Longline gear has a level of gear saturation and catching capacity, defined as the daily catch in number of fish, which is limited upwards to the number of hooks operated per day. In Norwegian longlining the number of hooks used ranges from 3,000 to 40,000 hooks according to the vessel's size (Bjordal 1988), manning levels and degree of automation. Bjordal (1988) reported that the normal catch rates of Norwegian longliners, ranged from 10 – 30 fish per 100 hooks, with 5 – 10% of fish undersized. Bjordal and

Lokkeborg (1996) reported that longline selectivity was influenced by four main factors: the fish available on the fishing grounds; fish accessible within the range of the bait; odour plume (encountered fish responding to the bait odour) and the fish retained by the hook.

1.9.1 Species Selectivity

Many investigations have been done on the species and size selectivity of longline fisheries including Bertrand 1988, Ferno et al. 1986; Huse 1990; and Lokkeborg and Bjordal 1992. However, the species selectivity of longlines can clearly be affected by the type of bait used, as different species have been shown to have different bait preferences (FAO 1998). Differences in the species composition of catches taken by baits of various sizes have been reported (Lokkeborg et al. 1989; Johannessen et al. 1993). Bait preference studies have shown that species composition of the catches was significantly affected by the type of bait (Lokkeborg & Bjordal 1992). Carr and Derby (1986) found that feeding attractant and stimulants have been shown to be species specific. Competition for bait may also affect species selectivity.

Hook types have also been shown to influence the species selectivity when longlining (Lokkeborg 1991; Skeide et al. 1986). The shape of hooks can be designed to increase species catches by increasing the probability of penetrating the inside of the mouth (Huse & Ferno 1990). Species selectivity is also affected by the fishing strategy with respect to the fish distribution (Lokkeborg & Bjordal 1992). However, different fish show different habitat preference and the skipper will use his experience to fish for the target species. Habitat preference varies between different species, and the target species may be selected by setting the gear over particular areas or at specific depths (Lokkeborg & Bjordal 1992).

1.9.2 Size Selectivity

Most of the studies on size selectivity of hooks have focused on handline and longline fisheries. Investigations by Ralston (1982) and Bertrand (1988) in a handline fishery found no effect of hook size on size selectivity, while investigations by Erzini et al. (1996), Koike et al. (1968) and Otway and Craig (1993) found no effect of hook size on size selectivity in longline fisheries. In contrast, an experiment by Erzini et al. (1997)

in a Portuguese longline fishery examined the size selectivity of three J-hooks (no. 15, 13 and 11), and found that the catch rates of the smallest number 15 hook were greater than 30% in a significant number of longlines set, with total catches up to 60 kg per 1,200 hooks set. Prey size preferences may also play a role in size selectivity (Erzini et al. 1996; Ralston 1990; Werner 1974,). Including the effect of prey size preference implies that the selectivity curve should follow a bell shaped pattern (Hovgard & Lassen 2000).

Erzini et al. (1999) examined catch composition, catch rate and size selectivity of three longline fishing methods in the Algarve (southern Portugal) using four hook sizes (10, 9, 7 and 5) and found that the catch rates decreased with increased hook size for each species. They also concluded that the catch size distribution overlapped, with no differences in size selectivity.

1.10 Economic Benefit

Demersal longlining possesses several advantages that account for its popularity: low cost of initial capitalization (unless automated systems are used); low direct fishing related expenses; limited crew requirement; simple and efficient operation and proven catch record (Cai et al. 2005). Longlining has proven extremely effective for catching a large number of commercially valuable demersal species (He et al. 1997). The introduction of modern materials and new techniques into a basic bottom system can result in consistently larger catches, lower cost per unit effort and improved gear recovery.

The direct dependence between fish size and profitability in longline fishing is a strong incentive towards exploitation of larger fish. This means that the profit in longline fishing depends on a maximum return or pay back per invested hook, i.e. the bigger the fish caught on each hook the larger the profit (Ovetz 2005). Fishermen are paid by weight of profitable fish and generally obtain higher prices for larger fish. However, every small fish caught on the longline gear has a direct negative effect on profitability, as the catch weight decreases with an increasing proportion of small fish (Bjordal & Lokkeborg 1996) and fewer hooks are available to catch large fish. It is important to identify the differences between larger vessel auto line systems and the use and modification of hook-limited manually baited systems. The longer term success of highly mechanized, mega-hook, auto-baiting longline systems remains in doubt. By comparison, the majority of demersal longline vessels are under 30 m length, and they fish with fewer than 3,000 hooks (Gaw & Carl 1999). These smaller scale bottom fishing operations typically harvest higher valued species destined for fresh/ice world markets.

1.10.1 Fish Quality

Fish caught by longline gear are generally of a better quality than fish caught by trawl or gillnets, as each fish caught by a longline is hauled aboard separately and not forced into the codend or mesh (Bjordal & Lokkeborg 1992). Furthermore, fish caught by hook are often still alive and in good condition when brought on deck and it is possible to bleed or process individual fish immediately after capture, resulting in a higher quality product. This higher quality often leads to better prices for fish caught by longline fishing methods (Hareide 1995). Trawls may produce fish of high quality but large trawl catches and hauls of a long duration may lead to reduced quality. This reduction in quality may be due to the fish being exposed in the codend and there may be a long delay before parts of the catch are processed (Bjordal 1988).

Fish caught early in the soaking period of a gillnet operation may have been dead for hours with correspondingly reduced quality, while fish caught later might still be alive when brought on board (Bjordal & Lokkeborg 1992). Fish caught by gillnet may suffer bruising due to mesh compression, internal haemorrhage or even become moribund.

1.10.2 Fuel Conservation

Typically, longline fishing vessels use less fuel compared with demersal trawling vessels per kilogram of fish caught (Bjordal 1988). Bjorkum (1992 in Hareide 1995) showed that Norwegian deep sea longliners and demersal trawlers used about 0.4 and 0.8 litres of fuel respectively per kg fish caught. A similar study conducted by Endal (1979), showed that longliners used between 0.075 and 0.14 litres of fuel per kg of fish caught, while the corresponding value for trawling was 0.370 litres of fuel per kg fish. This indicates that longline fishing vessels are more fuel efficient than trawling vessels with the energy consumption of trawling about three times that of longlining.

1.11 Time Efficiency

Time efficiency is considered to be the number of hooks deployed per minute. The time of setting and hauling and duration of a set (soak time) are important factors in influencing the catch rate of longline fisheries (Bjordal & Lokkeborg 1996), and are based on the experience level of fishers. Time of setting is important in longline fishing due to the feeding motivation of fish during the day and the feeding periods of bait scavengers (Lokkeborg & Johannessen 1992). The time needed for hauling can drastically increase if the line breaks. The important parameters influencing hauling speed are depth, current, sea conditions, setting design, number of hooked fish and capture of big fishes (Tatone 2008). However, the lines are normally hauled at a speed of 1 to 3 knots for demersal longlining and 6 to 10 knots for pelagic tuna longlining (Bjordal & Lokkeborg 1996).

Wide variations in catch rates caused by differences between fishing sites and days, current conditions and setting time relative to feeding activity (Skud 1978; Ralston 1982) may mask soak time effects. Gear saturation is one of several other factors that affect the relationship between the soak time and the catching efficiency of the longlines. However, studies have shown that soaked bait loses its attractiveness after a while due to the reduction in the concentration of attractants, thereby, with time, it reduces its catch efficiency (Bjordal and Lokkeborg 1996; Lokkeborg and Bjordal 1992). The low catch efficiency of the lines deployed first could also be explained by predation of bait by benthic animals. The most common benthic scavengers are sealice, starfish, sea cucumber, sea urchins, crabs and other decapods crustaceans. These species are particularly active when the longline is first deployed during the night (Tatone 2008). Engas and Lokkeborg (1994) concluded that a change in attractant release rate, bait loss and fish density within the fished area produced lower catch efficiency over time. Accordingly, baited longline gear (automated system) should be the most effective during the first part of the fishing period, and the total catch would increase over time at a progressively lower rate. This implies that longline fishing with different soak times, with all bait soaked during the active period and for several hours, may not result in significant differences in catch rates. Thus, unless soak time is short (e.g. less than 6 hours), the catch results of longline surveys will not be significantly affected by these factors (Engas & Lokkeborg 1994).

1.12 Conservational Aspects of the Longline

Many investigations, for example Bjordal 1988, Hovgard and Riget 1992 and Millar 1992, have found that longline gear is a selective fishing gear and is less effective in catching undersize (i.e. juvenile) fish compared to demersal trawling. Similar comparative studies by Clarke et al. (2002) and Hareide (1995) found that longlining is a more size selective fishing method than demersal trawling. Longline gear also has good species selective properties through the selection of hook type, bait type and fishing depth and ground (Clarke et al. 2002). Demersal trawling, in comparison, often has a poor species selective property as shown by the large species range in the catch. However, longline gear might also catch small fish and length frequency distributions of longline and trawl catches might be similar when the proportion of small fish in the fishing area is high (Neilson et al. 1989).

1.12.1 Ghost Fishing

Ghost fishing is fishing mortality caused by fishing gear that continues to catch fish even after it has been lost. Lost gear will continue to fish until such time as deterioration renders it inoperative and this duration varies with the type of gear. Pots, traps and gillnets have the greatest potential for ghost fishing and for an extended duration, while longlines, trawls, jigging systems and wires may entangle individual animals but generally have a lesser impact (Carr & Harris 1994; cited in Al-Masroori 2002). Trawls, longlines and gillnets are incidentally lost when the gear gets stuck on the bottom and broken warps and lines occur. Additionally, when finishing at great depths and /or in strong tides, longlines and gillnets get lost because the marker buoys and floats are submerged by the drag from the buoy line (Bjordal 1988; Bjordal & Lokkeborg 1992). However, in cases of gear loss, the fish kill is limited to the amount of fish in the trawl and there is no further catching or killing of fish. Likewise, fish kill by lost longlines is limited to the initial number of fish caught.

However, gillnets and traps can remain intact and still catch marine life for well over a decade including target, non-target and even endangered / protected species such as marine turtles and sea birds (Laist 1995; cited in Al-Masroori 2002). Lost gillnet recovery programmes have shown that nets can continue to fish for up to ten years after being initially lost, and though the total unaccounted mortality due to gillnet ghost fishing has never been quantified, it might be significant in certain fisheries (Bjordal and Lokkeborg 1996).

1.12.2 Environmental Damage

Longline and gillnet fishing gear have relatively minor effects on the seabed compared to demersal trawling (Bjordal & Lokkeborg 1992). A study by Hareide (1995) has shown that demersal trawling with heavy ground gear and otter boards will inevitably have an effect on seabed conditions and benthic communities, while longline gear has very little impact on the seabed or benthic communities. The bottom substrate is left untouched with pelagic longline fishing while trawling, which often has severely damaging effects, can have repercussions on the balance of the whole ecosystem (AFMA 2005). As a result, trawls are accused of ruining benthic ecosystems with corresponding negative effects on biodiversity while on the other hand it is claimed that the harrowing effect actually increase fish production (Bjordal and Lokkeborg 1996). Trawl gear affects the environment in both direct and indirect ways. Direct effects include scraping and ploughing of the substrate, sediment resuspension, destruction of benthos, and dumping of processing waste. Indirect effects include post-fishing mortality and long-term trawl-induced changes to the benthos (Jones 1992). Towed gears such as beam trawls, otter trawls and shellfish dredges which are in contact with the seabed are known to have a major impact on the sea bottom, killing and injuring seabed (benthic) organisms and possibly causing loss of species diversity (Walting and Norse 1998). Physical disturbance of the seabed can also increase the amount of suspended sediment, and thus increase sediment transport, and alter the chemical equilibrium of the sediments. Demersal trawls (i.e. trawl gear towed so that it is close to, or in contact with, the seabed) constitute one of the most invasive methods of fishing. Nets, often with rollers, chains, and heavy wooden or steel doors (otter boards) to keep the mouth of the net open, are dragged across the seabed, scooping-up everything in their path (Collie et al. 2000). Since the 1980s, nets with heavy rollers that allow the trawls to roll or jump over rough terrain including boulders or coral reef heads, have been employed.

1.12.3 Seabirds

Although longline fishing is often regarded as an environmentally friendly fishing method with no destructive impact on bottom habitats, good selectivity and low fuel consumption, one disadvantage is the incidental catching and thus killing of seabirds which might occur, particularly during setting of the line (FAO 1999). The impact of this incidental catching of seabirds has recently given rise to some international concerns and actions have been initiated regionally and globally to reduce the problem.

Large numbers of seabirds being hooked on setting lines in certain longline fisheries. The major "problem" fisheries are the demersal fisheries of the Northeast Pacific, North Atlantic, Southern Ocean and the Atlantic coast of South America, and the tuna pelagic fisheries of cool temperate seas in the North Pacific and in the Southern Ocean (FAO 1999). However, data on the incidental catch of seabirds is lacking for a number of longline fisheries, including the Pacific coast of South America, the Mediterranean Sea and in tropical waters of all oceans. Of 61 seabirds species affected, 23 (38%) are considered threatened by the World Conservation Union (FAO 1999). Species most commonly taken are the albatross, petrels, shearwaters, gulls and skuas (Environment Australia 2000). Other groups of seabirds such as penguins, cormorants, gannets, and boobies have rarely been recorded as incidental catch from longlining.

Seabirds feed on baited hooks as the longline is deployed overboard, and hooked birds are dragged underwater and drown. The average death rate of albatross per 1,000 hooks deployed in Southern Oceans is 0.4 birds (Antarctic Ocean) (Robertson 2001; cited in year book Australia 2003). The number of hooks set annually is high, between 50 and 100 million in the world's southern oceans alone. The problem is twofold as seabirds also reduce the efficiency on longline operations when they feed on bait because fewer hooks are now available to catch fish. A number of methods have been tried to solve this problem such as scaring the birds with visual and acoustic stimuli and adding weight on the line to increase sinking speed (Bjordal & Lokkeborg 1996). One of the more effective methods has been the development of a bird scarer made from a line with pendants at certain intervals that is towed over the longline during setting. This device, developed to scare albatross way from the longline, when tested in the Norwegian longline fishery, has been proven to give a significant reduction in bait loss caused by birds. Another solution to this problem has been developed by the Japanese longline vessels and guides the longline beneath the sea behind the vessels so the baited hooks are unavailable to the birds. The line is set through the tunnel in the hull, constructed such that the line pays out under water. Yet another recent development system is the outboard funnel. The funnel is hinged to the stern of the vessel and during setting line it is swung (by means of hydraulic) into the setting position. To allow the gear set it has a longitudinal slot so that anchors can be dropped beside the funnel, with the anchor line sliding down through the slot. After the line has sunk out of range of the birds there is believed to be little bait loss until the line has reached its fishing depth (Bjordal & Lokkeborg 1996). Recently, tuna longline vessels have started using the Australian "ITO" Gyro bait setting machine which automates the process of throwing the baited hook and throws them at right angles to the ship's course so the hook falls clear of the turbulence of the ship's wake and quickly sinks (Gorman 1996a).

1.13 Background to the study

Fisheries have traditionally played a significant role in the social and economic development of the Sultanate of Oman. They have been an important source of nutritious food and the primary means of livelihood for thousands of fishermen and their dependents in virtually all communities along Oman's 1,700 km coastline.

Fisheries in Oman are categorized into two main groups; traditional and industrial (commercial) fisheries. The traditional fisheries target demersal, pelagic and semi-pelagic fish using a range of fishing gear and methods including traps, gillnets, handlines, trolling and longlines (Al-Abdessalam 1993; Siddeek et al. 1999). In the commercial fisheries, demersal trawling and pelagic longlining are used. Total fish landings from traditional and industrial fisheries have increased gradually from 94,893 mt (valued at R.O 25.04 million2) in 1985 to 138,485 mt (valued at R.O 62.86 million) in 2003 (Statistic Oman 2003). This increase in fish landings has been attributed to the growth in investment growth in fishing vessels and gear started in the 1980s and

2 1 Rial Omani (RO) equals AUD 3.3302

landings currently continue to increase due improved skills and ability of the fishers to explore newer fishing grounds and greater water depths (Al-Oufi 1999). There are about 29,330 active Omani fishermen and about 4,000 Omani workers engaged in associated industries such as packing, transporting and trading (OER 2000), additionally there is also an unquantified foreign labour force engaged in the associated industries.

Hook and line fishing is widely used by both traditional and industrial fishermen all over the world, and it is one of the most widely used fishing techniques in Oman. Currently, the traditional sector mostly uses handlines, although in some areas demersal and semi-pelagic longlines are being used. Demersal or bottom longline fishing is relatively new in Oman and knowledge of this fishing method is scant. Preliminary investigations have shown that bottom longlining has good potential in the inshore regions of Oman (Stengel & Harthy 2002).

Despite the socio-economic importance of traditional fisheries, there is a lack of published information on the catch composition, selectivity, efficiency, and economic performance of all fishing gear, including longline gear. Little is also known about the amount of longline gear currently in use in Oman since there is no legislation limiting the use of this gear nor a requirement for fishermen to document the type of gear used. Hence, there is a need to assess the efficiency and selectivity of demersal longline fishing and its impact on the environment to provide information that can be used for sustainable management of the fishery resources.

1.14 Objectives and Hypothesis

The main objectives of this study are;

1- To investigate the efficiency (catching and time) and gross economic benefit of two fishing hooks (J-hook and circle hook) in the Omani demersal longline fishery.

2- To evaluate the selectivity of the J-hook and the circle hook in the longline fishery.

The two hypotheses in this study are;

1- The efficiency (catching and time) and economic benefit of the circle hook is higher than that of the J-hook for fish species targeted by demersal longline fishing in Oman.

2- The size distribution range of demersal fish species captured by longlining using circle hooks is wider than that of J-hooks.

1.15 Procedure and Methods

Since its introduction (Moore 2001; Prince et al. 2002), circle-shaped hook has improved the efficiency of the long line fishing gear compared to the J-shaped hook, the most common one. Some initial research trials and experiences in Oman (Stengel & Al-Harthy 2001) prove this perception and recommend further research to compare its performance with the J-hook, specifically for size number 6.

A demersal longline fishing experiment was conducted in three fishing locations at Ra's Abu Rasas, south of Masirah Island, Oman from December 2 – 23, 2004, to evaluate the efficiency and selectivity of a J-hook and circle hook. This fishing location was chosen for the experiment on the basis of previous fishing experience, its productivity and local fishermen knowledge. Three locations were selected 2 to 4 nm apart with depths ranged between 10 to 50 m. A total of 6,120 hooks (3,060 J-hooks and 3,060 circle hooks) were deployed from a small fishing boat in depths ranging from 10 to 50 m over a period of 17 days (see section 3.1.1).

1.16 Aims and Significance of the Study

This study aimed to examine differences in the catch characteristics, ie hooking location and catch efficiency, of J-hook and circle hooks, with specific focus on spatial differences in commercial and non-commercial species caught by the two hook types. The Lethrinidae are a significant commercial species caught in the line fishing industry and this group was examined in more detail. This data was used to examine the spatial difference in the catch efficiency, as a function of time, for the two hook types and estimate the gross economic benefit for each hook type.

No single study has investigated the spatial differences in selectivity and efficiency of line fishing gear in Oman. Therefore, this study will contribute to the general scientific and technical knowledge of gear technology in wild harvest of fish in Oman. Specifically, it would improve the design and construction of the demersal longline and guide the fishery stockholders toward efficient and selective longlining practice. This therefore will improve resource utilization and environment protection toward ecologically sustainable development. In addition, the study would allow the future formulation of suitable recommendations for the Ministry of Fisheries Wealth for the sustainable management of the longline fishery in the long term, and provide a basis for further research and development in the fishery.

1.17 Construction of the study

Chapter 1 briefly describes the fisheries in Oman and provides a context for this study. It also provides a literature review that describes the design and operation of demersal longline fishing gear, including factors that affect longline efficiency and selectivity. It describes the circle hook and J-hook, and evaluates the effectiveness of these hooks in catching demersal fish species. Species and size selectivity of longlines, relative to other gear types such as demersal trawls and gill net's are also discussed and the environmental impact of demersal longline fishing is examined.

Chapter 2 provides an overview of the traditional and industrial fishing sectors in Oman, including an overview of the fisheries resources and types of fishing gears used in these sectors.

Chapter 3 describes the research strategy and methodology that was used to compare and evaluate the efficiency and selectivity of the circle hook and the J-hook. It also describes the process of gathering the necessary data and the data analysis methodology.

Chapter 4 presents the results of the study from three fishing locations. The data from the experiments were analysed using Chi-square, ANOVA, ANCOVA and Post Hoc Tests (PHT) with highest significant difference (HSD).

Chapter 5 discusses the results of the study and compares these results with others from the literature. Its also summarizes the study and highlights the implications for the traditional longline fishery of Oman. Finally, the chapter suggests a number of recommendations and offers directions for future research in this area.

CHAPTER 2

FISHERIES RESOURCES OF THE SULTANATE OF OMAN

2.1 Country Profile

The Sultanate of Oman is formed by the south-eastern corner of the Arabian Peninsula and is located between longitudes 51^{o} 50' and 59^{o} 40' E and latitudes 16^{o} 40' and 26^{o} 20' N. Oman has a total land area of 309,500 km^{2} (MI 2003), bordering the United Arab Emirates in the northwest, Saudi Arabia in the west, and Yemen in the southwest (Figure 2.1).

Figure 2.1 Sultanate of Oman including major areas and the sampling area (Masirah Island) (source: MNE 2004).

The coastline of Oman extends for a distance of 1,700 km, including all bays and islands, from Musandam (Strait of Hormuz) in the north to the border with Yemen in the south. There are many coastal habitats with a high diversity of animal and plant life (Al-Oufi 1999) and comparatively rich fishing grounds. The total population of Oman as reported in the general census of population, housing and establishment was 2,340,815 in 2003, of whom 76.1% were Omanis and the remainder expatriates (MNE 2004). Oman consists of three governorates: Muscat (the capital), Dhofar, Musandam; and five regions; Al-Batinah, Al-Sharqyiah, Al-Wusta, Al-Dakhiliah and Al-Dhaherah. Each region is further divided into wilayats (districts) governed by walis (local officials).

Before the discovery of oil, agriculture and fisheries dominated Oman's economy, with approximately 80% of the population depending on these two sectors for food, employment and trade (Al-Oufi 1999; Al-Oufi et al. 2000). In 2000, agriculture and fisheries supplied 65% of Omani's food requirements, and 69% of their animal feed requirements (MI 2004). In 2001, more than 100,000 Omanis were employed in the agricultural and fisheries sectors.

2.2 Fisheries of Oman

2.2.1 Introduction

Fishing has traditionally played a significant role in the social and economic development of Oman. It has been an important source of highly nutritious food and the primary means of livelihood for thousands of fishermen and their dependents in virtually all communities along Oman's coastline (MI 2004). It is also a major contributor to the nation's Gross Domestic Product (GDP) as well as to the development of other fish related industry sectors and tourism (World Book 1999). With an accessible Exclusive Economic Zone (EEZ) of 350,500 km^2, Oman is considered to be one of the most important and productive fishing countries in the Middle East.

2.2.2 Fisheries Income

The revenue from fisheries resources currently exceeds all Omani agricultural resources, and is second only to oil as a natural resource (Al-Oufi 2003). As such, the sector is considered to be one of Oman's most important, long-term renewable resources. Total fish landings have increased gradually from 94,893 mt (valued at R.O 25.04 million) in 1985 to 138,485 mt (valued at R.O 62.86 million) in 2003 (Figure 2.2) (MAF 2004). Prior to 1970, utilization of fisheries resources was limited to small traditional boats with outboard engines. Although these small vessels still comprise the majority of the fishing fleet, the use of larger, modern fishing vessels with inboard engines has increased substantially in recent decades. This increase has been attributed to greater investment in fishing vessels and gear.

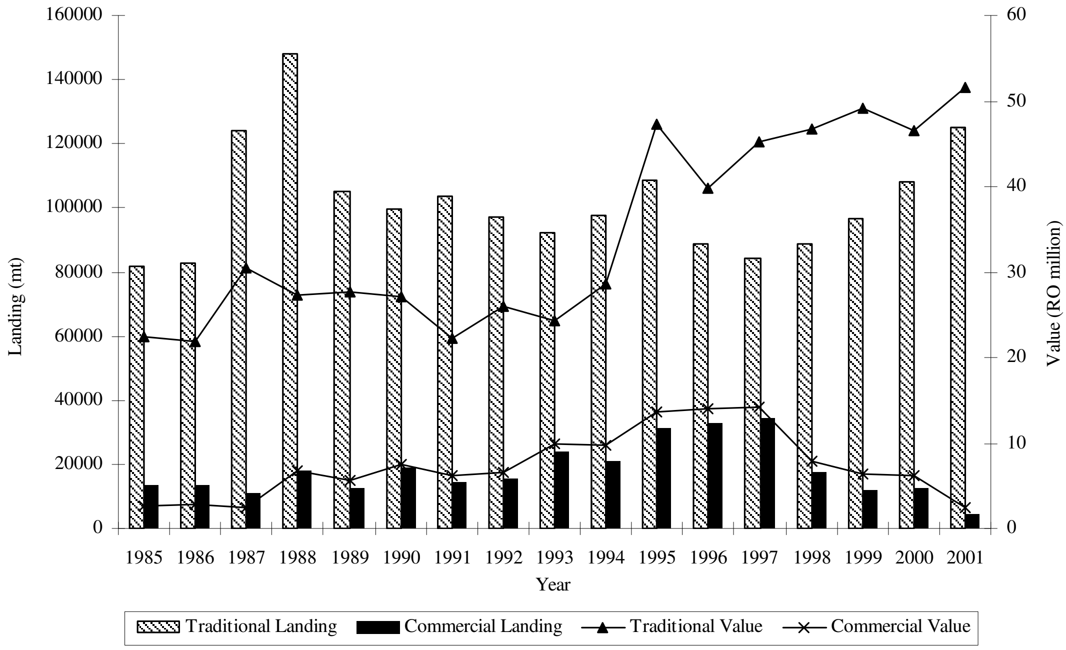


Figure 2.2 Traditional and commercial fish landing and monetary value from 1985 to 2001 (source: MAF 2004).

2.3 Fisheries Sectors

Omani fisheries are categorized into traditional and industrial (commercial) fisheries sectors. The traditional sector refers to groups of small-scale fishermen employing a variety of traditional fishing gear and vessels (Al-Masroori et al. 2004). The industrial sector refers to groups of fishermen working on larger vessels that operate on the high seas and in specifically designated fishing zones on the continental shelf.

The fisheries in Oman are also categorized by target species, grouped into five major divisions: large pelagics, small pelagics, demersal fishes, sharks and rays, and shellfish fisheries. The total landed catch in 2003 was estimated at 138,485 mt, with 85.8% derived from traditional landings and 14.2% from the industrial fisheries (MAF 2004). In 2003, of the total landings, approximately 50% was consumed domestically with the remainder being exported (MAF 2004). The value of the 2003 landings was RO 62.855 million (Table 2.1).

Table 2.1 2003 total of fish landed by weight and value in both traditional and industrial fisheries (source: MAF 2004).

Species	Total Landing (mt)	%	Total value (R.O million)	%
Large pelagic	34 116	24.6	17.644	28.1
Small pelagic	41 868	30.2	10. 059	16.0
Demersal	40 534	29.3	16. 984	27.0
Sharks and Rays	6 089	4.4	4. 284	6.8
Crustaceans	15 876	11.5	13. 884	22.1
Total landing	138 483	100.0	62. 855	100.0

2.3.1 Traditional Fisheries Sector

In 2003 there were an estimated 31,587 fishermen operating in the traditional sector utilizing 13,831 vessels ranging in size from 5 - 20 metres. The contribution of these fishermen to total fish landings averaged 84.7% between 1985 and 2003 (MAF 2004). The total catch landed by the traditional fishery sector in 2003 was estimated to be 118,877 mt, an increase of 3% over the previous year (Table 2.2). This was largely due to the catching of large pelagic fish such as yellowfin tuna, skipjack and other pelagic species. There was an increase of 10.5% from the previous year in total landed value of these species (MAF 2004).

Table 2.2 Contribution of the traditional fisheries sector to total fish landings (mt) and landing value (R.O million) between 1990 and 2003 (source: MAF 2004).

Year	Total Landing	Demersal fish		Total value	Demersal fish	
		landing	%		value	%
1990	99 798	23 403	23.45	34.62	27.12	78.34
1991	103 536	21 908	21.16	28.35	22.26	78.52
1992	37 046	23 395	63.15	32.63	26.01	79.71
1993	92 434	27 374	29.61	34.31	24.39	71.09
1994	97 535	28 404	29.12	38.27	28.67	74.92
1995	108 566	35 253	32.47	60.87	47.25	77.62
1996	88 514	33 450	37.79	53.82	39.85	74.04
1997	84 444	38 634	45.75	59.41	45.24	76.15
1998	88 557	32 713	36.94	54.42	46.66	85.74
1999	96 664	34 186	35.37	55.52	49.15	88.53
2000	108 019	33 294	30.82	52.77	46.57	88.25
2001	125 275	25 939	20.71	54.06	51.57	95.39
2002	115 308	47 150	40.89	61.15	47.55	77.76
2003	118 877	40 534	34.10	62.86	52.55	83.60
Average	97 469	31 831	34.38	48.79	39.63	80.69

2.3.1.1 Traditional Fishing Gear

Fishing gear in the traditional sector consists of bottom and surface gill nets (drift and set gill nets), metallic cages, traps or pots (wire mesh and plastic types), barrier traps, hand lines, bare hands, and knives. In addition there are demersal longlines, tuna longlines, trolling, beach seines, cast nets for shrimp and sardines, harpoons for cuttlefish and encircling nets (Al-Oufi & Palfreman 2000). Gill nets are widely used both inshore and offshore to catch sardines, mackerel, horse mackerel, tuna, kingfish, shark and other fishes. In the coastal waters, Omani fishermen use symmetric beach seines with a bag to catch sardines, anchovies, other small coastal pelagic fish and juveniles of many pelagic and demersal species. Encircling nets are used to catch small pelagic fish, including sardine and Indian mackerel, and some large pelagic species such as kingfish, in Muscat and Al-Batinah. Traps or pots are mainly used to catch crustaceans, molluscs and demersal fish (Al-Masroori 2002).

Line fishing is widely used by both traditional and industrial fishermen and it is one of the most widely used fishing techniques in Oman. Currently the traditional sector mostly uses handlines and trolled lures while demersal and semi-pelagic longlines are used in some areas of Oman. Longline fishing in Oman is categorized into traditional and industrial longlining. Traditional longlining, which is locally referred to as Al-Shakah, is used only by local fishermen in the coastal area at depths less than 200 m for catching demersal and pelagic fish such as snapper, sea bream, grouper, emperor, catfish, tuna and sharks (MAF 2002).

The demersal longline (called Al-Shakah) consists of a mainline, branchlines and hooks in between two floats. The mainline is usually several hundred metres in length, with a diameter commonly ranging from 0.5 to 1 cm and is made of various types of multifilament (cotton, nylon, polyester or polypropylene) and monofilament (polyamide, nylon) materials (Figure 2.3).

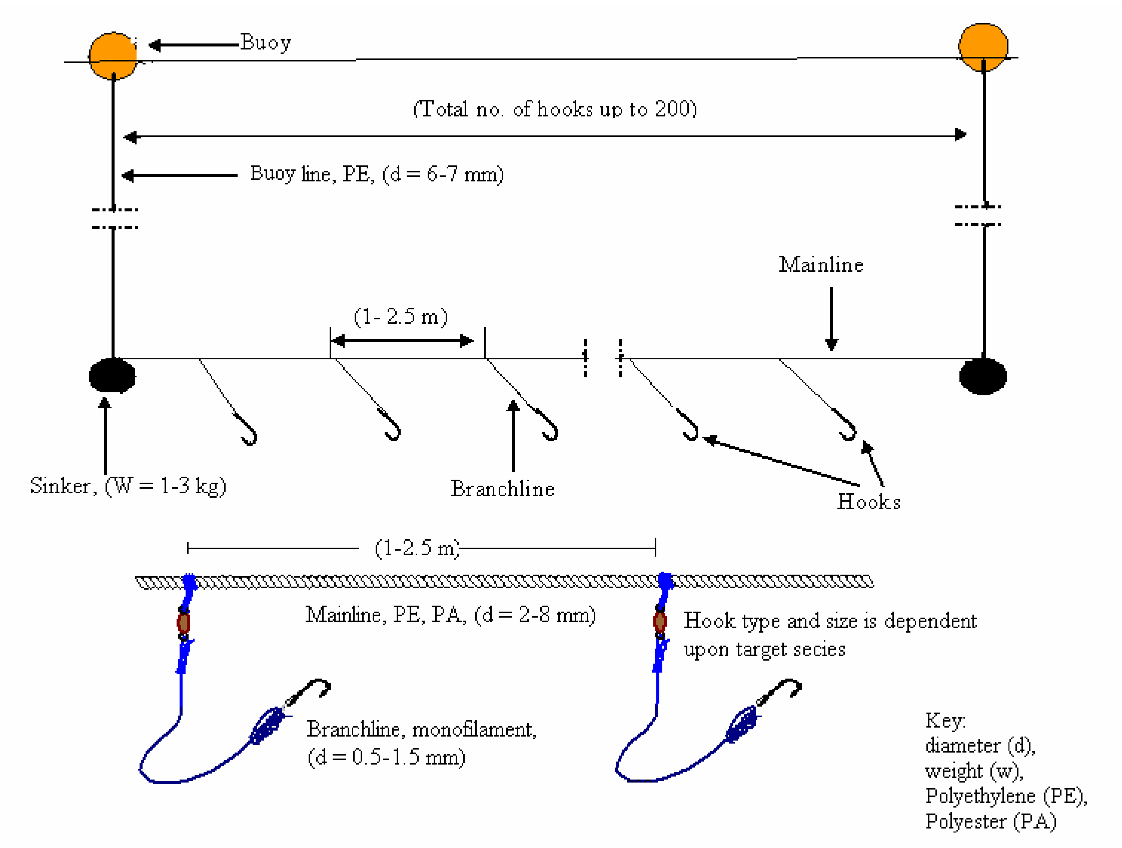


Figure 2.3 Traditional demersal longline for species as used in Oman.

A branchline is a single line made of polyamide monofilament with attachment points for the mainline at one end and a hook at the other. For reasons of cost, most fishermen use nylon for the branchlines. The monofilament branchline is normally connected to the mainline by swivels, or by tying the branchline directly to the mainline. The thickness of the branchline ranges from 0.03 to 0.1 cm in diameter with the length ranging from 0.5 cm to several metres (Figure 2.3).

The overall longline may consist of several sections of mainline (usually with 10 – 200 branchlines attached), and with each section arranged in a basket. A basket may be a polystyrene ice-box measuring 60 cm x 45 cm x 30 cm or a plastic basket with a diameter of 60 cm with foam rubber on the top for arranging the gear (Figure 2.4).

Figure 2.4 Traditional demersal longline basket (polystyrene, 60 cm x 45 cm x 30 cm).

The most common hooks used in Omani longline fisheries are the traditional J-hook and the circle hook. Until recently, the traditional J-hook was that most commonly used to harvest demersal and pelagic species but today, despite its higher cost (2 - 3 times higher) the circle hook is widely used, giving a significantly higher catch rate and fish quality compared with the traditional J-hook (Stengel & Al-Harthy 2001) A box of 100 Mustad size 6 common longline J-hook, costs approximately R.O. 3 (depending on the number and location of purchase) while the same quantity of equivalent sized number 6/0 circle hooks might cost from R.O. 6 to 9.

2.3.1.2 Traditional Fishing Vessels

The traditional fishing vessels include wooden or fiberglass dhows (launches), skiffs, hori, shashah, small aluminum boats, or FRP-fishing boats (Table 2.3).

Table 2.3 Number of fishermen and boats for all regions recorded in 2003 (source:MAF 2004).

Region	No. of fishermen	Number of boats					
		FRP (Fiberglass Reinforced Plastic)	Hori	Dhow	Aluminum	Shashah	Total
Musandam	3 366	1 158	217	111	28	0	1 514
Al-Batinah	10 298	3 465	182	36	84	986	4 753
Muscat	3 961	1 749	59	12	14	1	1 835
Al-Sharqiyah	7 110	1 922	283	296	79	0	2 580
Al-Wusta	3 269	1 390	58	38	23	0	1 509
Dohfar	3 583	1 484	10	32	114	0	1 640
Total	31 587	11 168	809	525	342	987	13 831

Dhows, powered by inboard diesel engines, are commonly used and may measure more than 11 m in length (Figure 2.5). In the past these vessels were used as cargo and passenger vessels, but today they are used as gill net fishing boats. Skiffs are constructed of either fiberglass or aluminum, and range in length from 4 to 8 metres. Horis are wooden vessels of between 3 to 10 metres while. Shashah, between 3 to 4 metres, are locally designed vessels made of palm fronds (Stengel & Al-Harthy 2002) (Figure 2.5) and all skiffs, horis and shashah are powered by outboard engines. FRP-fishing boats are widely used along the coast of Oman. The introduction of FRP (Fiberglass Reinforced Plastic) fishing boats in the 1970’s represented a considerable step towards improving the working conditions and productivity of coastal fishermen and are widely used along the Oman coast.

Figure 2.5 Traditional fishing vessels used in Oman (a. Dhows, b. Horis, c. FRP-fishing boat, and d. Shashah).

2.3.2 Industrial Fisheries Sector

The industrial sector comprises demersal trawling for a variety of fish species and pelagic longlining for tuna and other pelagic species. During the period 1985 - 2003 this sector was responsible for just over 15% of the total fish landings in Oman.. In 2003, 19,608 mt were landed with a total value of R.O. 10.3 million (Table 2.4) (MAF 2004). The fishing fleet is exclusively foreign with all 3,416 fishermen being of non-Omani origin. The catch is frozen at sea in whole, round form with 80% retained by the foreign boat-owners and trans-shipped to Korea or Japan and the remainder sold locally or exported to other Gulf countries, Jordan, or Europe.

Table 2.4 Total landings and monetary value of industrial trawling and longlining from 1995 to 2003 (source: MAF 2004).

Year	Commercial landing (mt)	Total value (RO. million)
1995	31 295	13.62
1996	33 101	13.97
1997	34 549	14.17
1998	17 608	7.76
1999	12 145	6.37
2000	12 402	6.20
2001	4 629	2.49
2002	27 360	13.60
2003	19 608	10.30

Each vessel has a trained observer allocated by the Ministry of Agriculture and Fisheries to monitor the vessel's activity and ensure accordance with Ministry rules and quotas. The Ministry of Agriculture and Fisheries is currently conducting a major project called 'Youth Vessels Project' to train Omani youth to replace the existing foreign employment (MAF 2005) (Figure 2.6).

Figure 2.6 Youth fishing vessel (left) and a foreign industrial fishing vessel in Oman.

In 2003, 35 industrial longliners landed 1,746 mt of fish in 2,780 fishing days. This was 8.9% of the total industrial landings and was valued at R.O 1.204 million. The highest catches recorded were for yellowfin tuna (85%; 1,483 mt) and shark (8%; 139 mt). Four fishing companies were responsible for these landings: the Protein Products

International Company landed 906 mt (51.9%), the Gulf of Oman Company landed 659 mt (37.6%), the Muran International Company landed 114 mt (6.5%), and Anais Trading landed 69 mt (4%).

In the same year, 20 industrial trawlers landed 17,862 mt in 2,596 fishing days (MAF 2004), with a value of R.O 9.096 million. Five fishing companies were responsible for these landings: the Oman Fish Company landed 13,526 mt (75.7%), the Protein Products International Company landed 2,850 mt (16%), the Oman Sea Company landed 890 mt (5%), the Gulf of Oman Company landed 589 mt (3.3%), and the Dhofar Fisheries Products Company landed 7 mt (0.04%) (MAF 2004).

2.3.2.1 Industrial Longline Fishing Gear

Industrial fishing by longliners began in Oman in 1989. The pelagic longline is mainly used to catch tuna and swordfish and it differs from demersal longlines in that it leaves the line drifting free in the sea. Pelagic longlines for tuna were traditionally made from a 6 mm hard lay tarred polyamide, which was made up of a series of lengths that were 50 m long with an eye spliced into each end (Nomura 1981). The sections were joined together with a double sheet bend leaving a 30 cm tail rope with the eye splice in it. The branch lines were then connected to these tail loops. The branch lines were traditionally made of a section of 6 mm polyamide (PA) twist spliced into a snood clip at one end and a swivel at the other (Nomura & Yamazaki 1977). This was followed by the sekiame, a length of wire that was served with a thin Polyamide twisted twine, followed by a short length of plane wire that was attached to the hook (Figure 2.7).

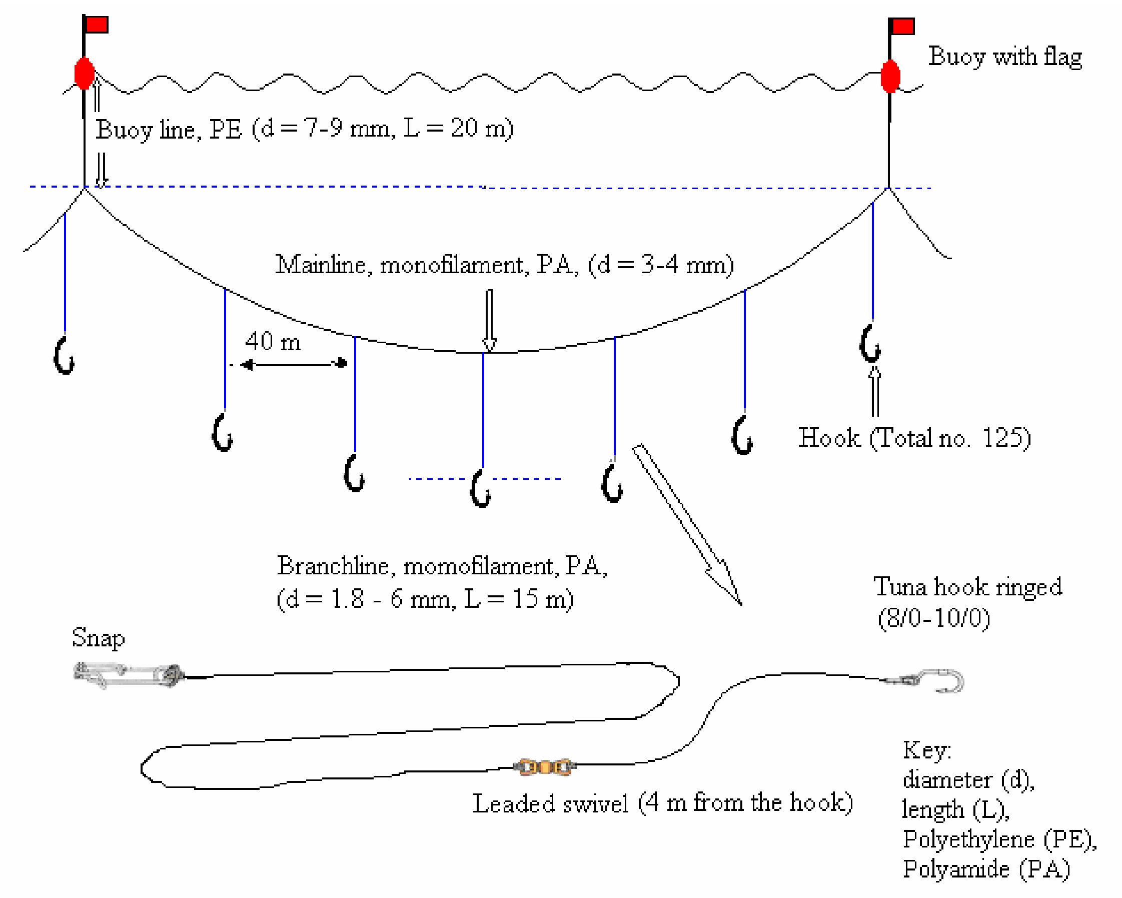


Figure 2.7 Pelagic longline gear and branchline rigs used by industrial fishing boats in Oman.

2.3.2.2 Industrial Fishing Vessels

In 2003, the industrial fishing fleet included 20 demersal trawlers and 35 longline vessels. Demersal industrial trawlers are licensed to operate along the continental shelf between latitude 21° 40' N, south of Masirah Island and longitude 55° 45' E, North of Halaniyat Island, at a distance of 10 nautical miles or more from the shore at depths exceeding 50 meters. Fishing operations are prohibited on the western side of Masirah Island and in marine areas around Ras Al-Had between longitudes 45° 00' and 55° 00' E. Only a single codend trawl is allowed in Oman with a minimum of 110 mm stretched mesh size to be used in the codend. In addition, following each fishing trip, trawlers must provide a catch report, which must include, by area and day, details of the species caught (MAF 1994). The demersal trawlers are either fiberglass or steel in structure, and range in length from 24 to 60 m. The number of longliners increased from an initial fleet of 18 to 184 vessels in 1994 (MAF 2004) and then declined to 35 vessels by 2003.

These are steel vessels that can range in length from 40 to 60 m, and they fish in the high seas at distances of more than 20 nautical miles offshore.

2.4 Fisheries Resources

There have only been a few surveys carried out in Oman to determine the potential yield of fish stocks. The Ministry of Agriculture and Fisheries and the Food and Agriculture Organization of the United Nations (FAO) conducted a fisheries resource assessment survey using the Research Vessel (RV) *Rastrelliger* during the period 15 November 1989 to 15 November 1990. The survey covered demersal fish resources, small pelagic fish resources and mesopelagic resources (lanternfish). It covered an area of 90,000 km² and all of the EEZ, at depths ranging from 15 to 200 m. The survey did not cover the large pelagic fish resources, sharks, crustaceans nor molluscs. This survey continued earlier work, including the surveys carried out in the period 1975-1976 and 1983-1984 by the RV *Dr. Fridtjof Nansen* and the Regional Fisheries Survey in the period 1976-1979 (Al-Abdessalam 1991 & 1993). There have been no subsequent research surveys.

The Rastrelliger survey of 1989-1990 estimated the biomass of small pelagics to be 252,000 mt (the *Fridtjof Nansen* survey estimated 600,000 mt) (Siebren 1976). The greatest abundance was found to be in the Masirah Island – Ra's al Madrakah region (189,000 mt), and a lesser abundance in Muscat – Ra's Al-Had (9,000 mt) (Gojsater & Tilseth 1983; Al-Abdessalam 1991, 1993). The four small pelagic species mainly found in the Omani EEZ were Indian oil sardine (*Sardinella longiceps*), Indian scad (*Decapterus russelli*), horse mackerel (*Trachurus indicus*) and bigeye scad (*Selar crumenophtalmus*) (Al-Abdessalam 1995). The *Rastrelliger* survey estimated the demersal biomass over the entire Omani continental shelf area to be 565,000 mt, about 36% higher than the previous estimate from the *Fridtjof Nansen* survey in 1983-84 (Gojsater & Tilseth 1983; Mohan 1994). Only 96,000 mt or 17% of this biomass was found in the Gulf of Oman, while 469,000 mt, the remaining 83%, was found in the Arabian Sea. The biomass of the mesopelagic fish (lantern fish) was estimated to be 890,000 mt, made up of 400,000 mt in the Gulf of Oman and 490, 000 mt in the Arabian Sea (OER 2000; Al-Abdessalam 1993).

A total of 156 demersal species and species groups belonging to more than 10 families were documented during the *Rastrelliger* survey. Around 51% of the demersal stocks were found in soft, trawlable grounds, whereas the remaining 49% were found in hard, untrawlable grounds (Randall 1995). From the potential yield estimate of 137,000 mt, only 73,000 mt have been categorized as commercial species based upon current market trends. The dominant commercially important families are emperor (Lethrinidae), seabream (Sparidae), grouper (Epinephelinae), snapper (Lutjanidae), sweetlips (Haemulidae), catfish (Ariidae) and ribbonfish (Coryphaenidae) (Randall 1995). The most abundant species in the non-commercial category were rays, lizardfishes, sea catfishes, gurnards, sharks and porcupine fishes, which accounted for about 36% of the total fish biomass.

2.5 Investment in Fisheries

Since 1970, the Government of Oman, fully realizing that an effective fisheries development program requires both a long-term commitment and substantial financing, has supported the construction of fisheries infrastructure required for the development of the industry (MAF 2001). Many changes have taken place and in contrast to their previous subsistence orientation, fisheries have become more market oriented (Al-Mukhaini 2005). In 1972 the Fisheries Department was formed and then relocated in 1974 to the Ministry of Agriculture and Fisheries (MAF). In 1976 the Fisheries Encouragement Fund (FEF) was established and managed by the MAF to upgrade the economic, social and technical standards of the traditional fishermen and to realize optimal utilization of fisheries. This had a significant impact on modernization of the traditional inshore fleet, where several thousand fishing vessels needed upgrading (OER 2000). Considering the importance of research in fisheries development, the Government established the Fisheries Research Fund (FRF) in 1991 to provide finance for fisheries research projects.

2.6 Fisheries Regulations

Activities of the fisheries sector are organized and governed by the Marine Fishing and Living Aquatic Resources Law, issued by Royal Decree No. 53/81, dated 30/5/1981, and the Executive Regulations of the Law, issued in accordance with

Ministerial Decisions No. 3/82 and 4/94 (MAF 1994). The Law has six sections, covering definition and terminology, handling, marketing and processing, violation and penalties and general provisions. The Executive Regulations deal with Marine Fishing Licences, Licence Fees, Protection and Development of Living Aquatic Resources, Regulation of Fishing, Preservation, Transport and Marketing of Living Aquatic Resources, General Provisions and Penalties (MAF 1994). Other relevant legislation includes Quality Control Regulations of Omani Exported Fish, issued in accordance with Ministerial Decision No. 136/98. Also, Ministerial Decision No. 121/98, concerns conditions and specifications of Industrial Fishing Vessels Equipped for Preservation and Handling of Fish Products, in addition to other ministerial decisions issued from time to time (MAF 1994). There are currently no regulatory concerns about the longline fishery in Oman.

2.7 Fisheries Research

MAF and Sultan Qaboos University (SQU) carry out most of the fisheries research through several centers including the Marine Science and Fisheries Centre (MSFC), the Fish Quality Control Center (FQCC), and the Aquaculture Center (AC). The research program of the MSFC has been designed to provide data and information necessary for decision making regarding development and management of local marine resources. As such, the MSFC carries out fisheries research projects and programs covering many areas, including fisheries resources assessments and surveys, marine biology and environmental studies, food technology, and aquaculture. In 1991, a Fisheries Research Fund (FRF) was established to further develop fisheries research by providing finance for fisheries research projects.

CHAPTER 3

METHODOLOGY

3.1 Materials and Methods

3.1.1 Study Location

The longline fishing experiment was carried out south of Masirah Island from December 2 – 23, 2004 (Figure 3.1). The fishing ground known as Ra's Abu Rasas, was chosen for the experiment on the basis of geographical proximity to and my familiarity with the selected location which is essential for successful deployment and the gear,. An onboard fish finder and GPS (Global Positioning System) were used on a small fiberglass reinforced plastic fishing boat to locate the precise fishing locations within Ra's Abu Rasas for deployment of fishing gear. Three locations were selected 2 to 4 nm apart. The depth of each location ranged between 10 to 50 m, and the seabed was characterised by patches of rocks, sand and coral. The locations were selected based on productivity of the fishing ground, local fishermen knowledge, and previous fishing experience. Other variables such as depth, distance between locations, and proximity were also considered in selection. Given their close proximity and similar seabed characteristics, it was assumed that the three locations were similar with respect to the fish communities.

Each location was given a number from one to three (Figure 3.1) and every day a location was randomly selected by making a blind choice from a small bowl containing three different locations slips (Table 3.1). For all three locations the same fishing gear was engaged throughout the study period. In this manner the potential for localised fish depletion was minimised.

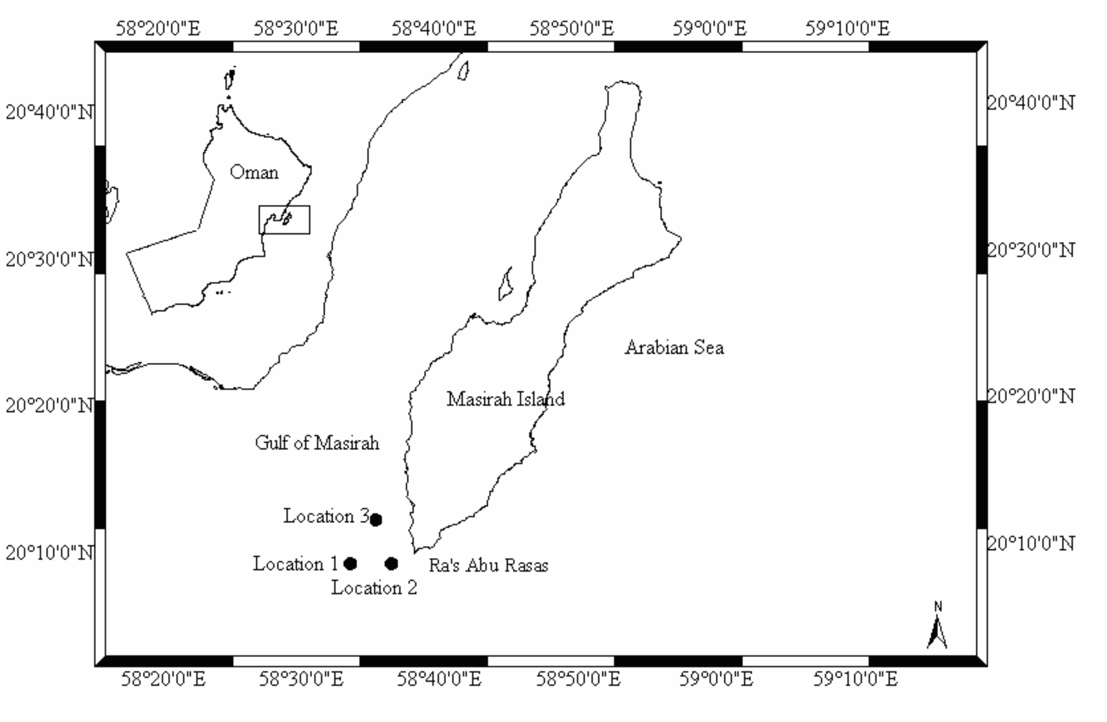


Figure 3.1 Experimental area showing the three locations of the bottom longline trials.

Table 3.1 Randomly selected schedule for deploying the longline gear between the three fishing locations.

Day	Fishing Location
1	1
2	1
3	3
4	1
5	3
6	2
7	2
8	2
9	2
10	3
11	1
12	3
13	1
14	3
15	1
16	2
17	1

3.1.2 Research Boat

The experiments were conducted onboard a small FPR fishing boat, measuring 9 m long x 2.5 m wide x 0.8 m draft, propelled by two 60 HP outboard Marina engines.

3.1.3 Fishing Gear Design

A total of six demersal longlines were used daily in this study. Each longline consisted of a 124 m polyester (PES) multifilament mainline with a diameter of 0.4 cm (Figure 3.2). Sixty monofilament branchlines were connected to each mainline via a number 2/0 swivel to prevent the fish rotating and tangling the branchline and mainline (Figure 3.3). The length of each branchline was 80 cm with a 0.1 cm diameter. Each branchline was attached to the mainline 2 m apart; hence, hook spacing was also 2 m.

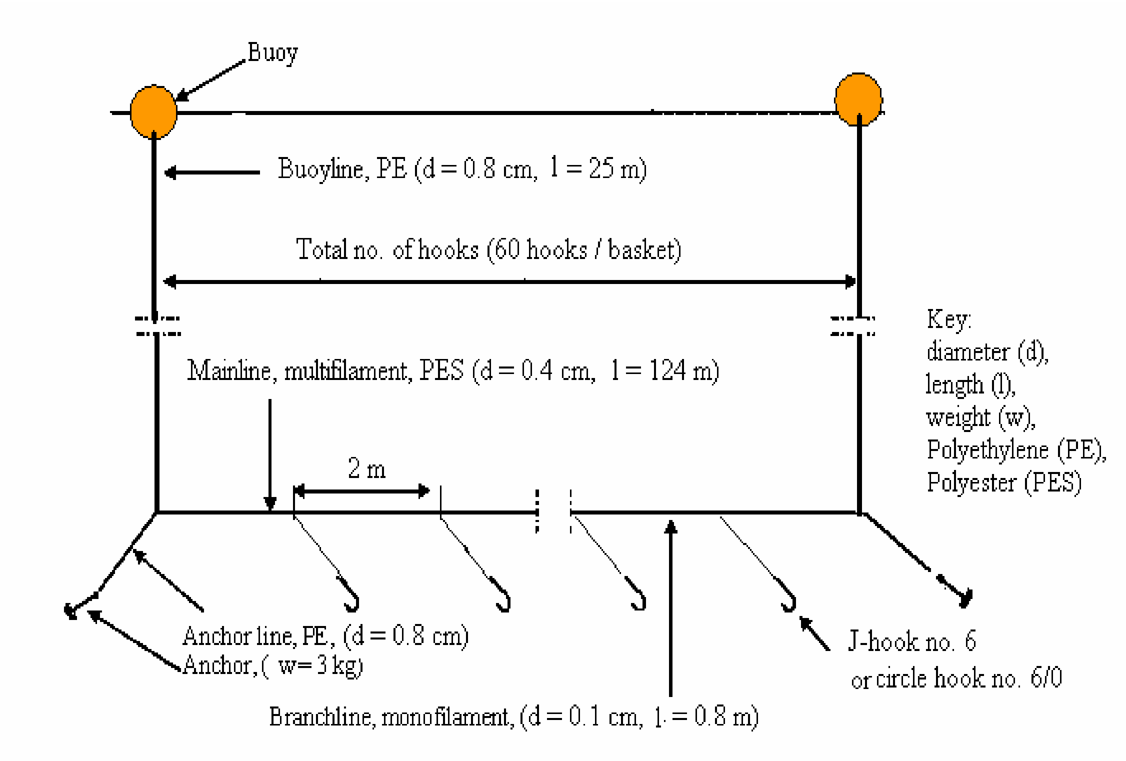


Figure 3.2 Construction of the experiment demersal longline (one basket).

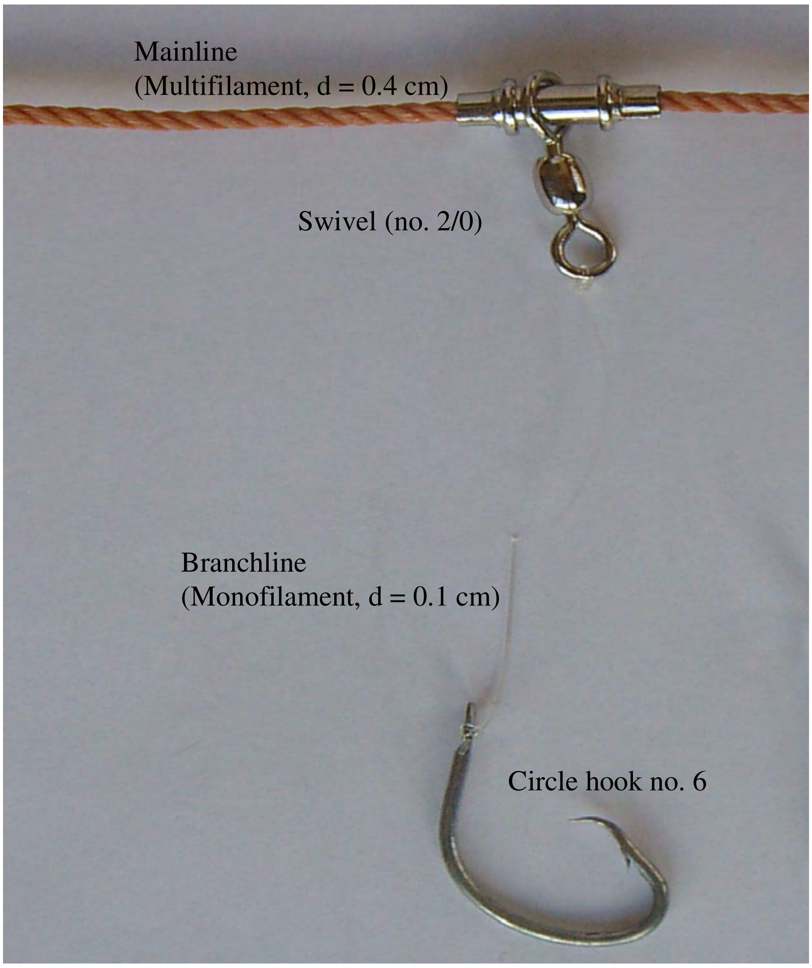


Figure 3.3 Branchline of the experiment demersal –longline.

At the end of each branchline was either a circle hook or a J-hook, thus a total of 60 hooks per basket were used in this study. The researcher used the same hooks that traditional Omani fishermen use to catch demersal fish, that is, the J-hook size no. 6 (Mustad, Ref: 2335DT, Key brand, made in Norway) and the circle hook size no. 6/0 (Mustu Hooks, Maruto fish hook works, Quality No. 350, Superior Steel, Eagle Wave brand, made in Japan) (Figure 3.4).

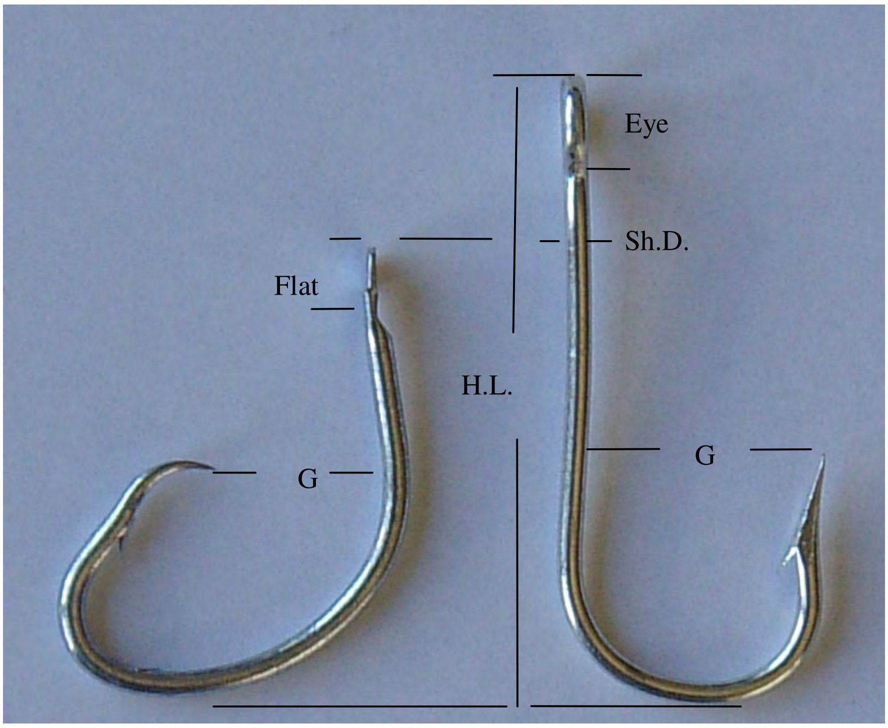


Figure 3.4 The anatomy of the circle hook and J-hook (Hook length (H.L.), Shank diameter (Sh.D.), Gap (G).

The dimensions of the J-hook were 5.3 cm in length with a 1.9 cm wide gap. To help identify which specific hook caught the fish, numbered tapes were inserted in every 10th hook. Dimension of the circle hook were 3.5 cm in length with a 1.4 cm wide gap (Table 3.2). A 25 m polyethylene (PE) buoy line with a diameter of 0.8 cm was used . Around 3 kg of weight was used as a sinker at each end of the mainline.

Table 3.2 Circle hook and J-hook comparison of dimension.

Dimension (cm)	Circle hook	J-hook
Hook Length (H.L.)	3.5	5.3
Shank Diameter (Sh.D.)	0.2	0.2
Gap (G)	1.4	1.9
Shank termination	Flat	Eye

Each longline was stored in, and deployed from, a circular plastic basket 55 cm in diameter and with a depth of 22 cm (Figure 3.5).

Figure 3.5 Demersal longline basket (55 cm x 22 cm) with hooks baited.

3.1.4 Gear Setting

A total of 3,060 J- hooks and 3,060 circle hooks were deployed over 17 days. Each morning, 180 J-hooks and 180 circle hooks were deployed from six baskets in the selected location. Each of the six baskets was given a number from one to six. For ease of identification, the baskets holding the circle hooks were numbered B.C.2, B.C.4 and B.C.6 whereas the baskets holding the J-hooks were numbered B.J.1, B.J.3 and B.J.5. Each day of the study, the researcher wrote the number of the baskets on pieces of paper and placed them in a small bowl and each piece of paper was randomly selected from the bowl. The first basket selected was the first basket deployed. In this manner the bias in favour of one hook design over the other was avoided.

3.1.5 Bait and Baiting

Frozen cuttlefish (*Sepia spp.*) was used as bait in this study. The frozen cuttlefish was bought from the Oman Fisheries Company, Masirah branch. The frozen baits were thawed before preparation and cut into small pieces each weighing about 10g (Figure 3.6). Each evening the crew baited the hooks for the following day's fishing experiment, and the baited longline was then refrigerated overnight.

Figure 3.6 Cuttlefish bait (10 g per piece).

3.1.6 Deploying and Hauling

The longline set was deployed and hauled by hand in a single continuous line in the direction of the prevailing tides. In this way it was assumed that the bait-plume from one longline would not influence the attractiveness of any adjacent longline within the same fishing location.

3.1.7 Operation Time

Using the small fishing boat, the researchers sailed early in the morning, and returned in the afternoon. The experiments were usually conducted between 07:25 am and 12:00 pm, which is the common operation time for coastal fishing boats in Masirah Island waters. The demersal longlines were set in the morning and the soak times for all experiments were similar, i.e. two hours, a common soak time for the coastal boats in Omani waters. The times of deployment and hauling of the longline gear are shown in Table 3.3.

Table 3.3 Schedule for deployment and hauling of each basket.

Basket number	Deployment time	Hauling time
1	07:25	09:35
2	07:35	10:00
3	07:45	10:30
4	08:55	11:00
5	08:05	10:30
6	08:15	12:00

3.2 Data Recording

All data was recorded onto data sheets and entered into a computer (Appendix 3.1). When a longline was hauled, each caught fish was recorded in terms of weight (kg), total length (cm), species (common, scientific and family name) and hook location. Information on hook status (e.g. hooks missing, damaged), gear condition (e.g. mainline and branchline loss or damaged) and bait condition (loss, return) was also recorded for each set. Hooking locations were designated using the following terminology: corner of the mouth, jaw (upper and lower), gill, gut, eye and body (Figure 3.7). Additional information was also recorded giving the fishing location (longitude, latitude, depth, and bottom characteristic); weather conditions; operation time (deployment time - start and finish), hauling time (start and time);, number of tests and the day.

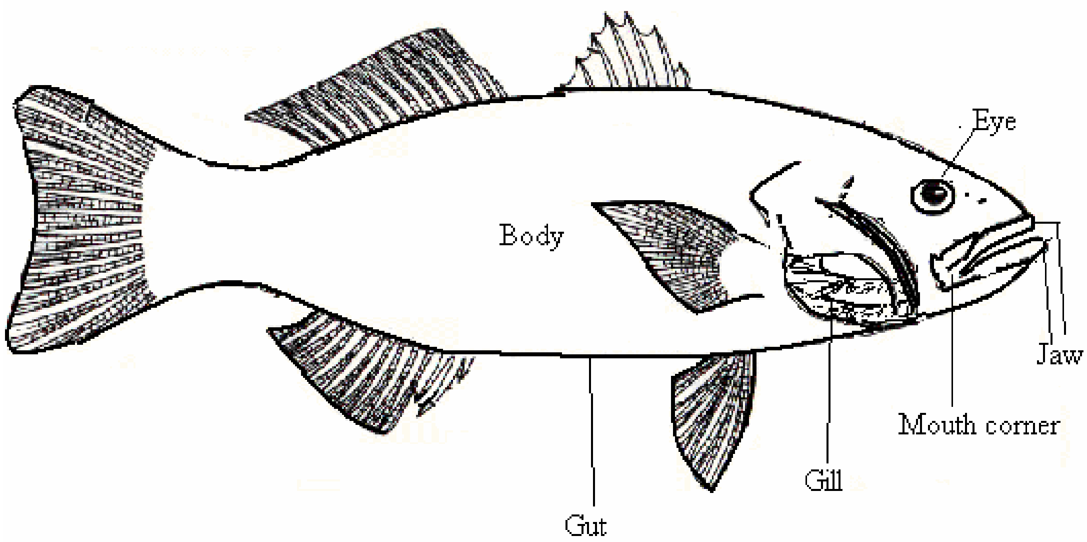


Figure 3.7 Hook locations reported in this study.

3.3 Data Analysis

Data from the experiments was processed using Microsoft Excel and the Statistical Package for the Social Sciences (SPSS) program. The catch was assessed and species identified using Randall (1995) and Al-Abdessalaam (1998). Catch weight and length by the two types of hook from the three locations were analysed by two way analyses of variance (ANOVA) and analyses of covariance (ANCOVA). Data, from the J-hooks and circle hooks from the three locations, was grouped and total catches were standardized to daily catch per unit of effort (CPUE), defined as the number of fish caught per 100 hooks retrieved (no. of fish / 100 hooks retrieved).

Chi-square distribution was used to compare expected and observed catch frequencies e.g. number of fish caught by the two types of hooks from the three locations. The chi-square goodness of fit procedure was used to examine the null hypothesis that there were no differences in catch numbers, hooking location, and hook status between the two hooks. For comparisons of data with more than 2 samples, such as data from the three locations, analysis of covariance (ANCOVA) and the Tukey's Post Hoc Test (PHT) with highest significant difference (HSD) was used.

The value of the commercial fishes caught (as sourced from the Fisheries Statistic Book 2004) was used to calculate the economic benefit of each hook type.

CHAPTER 4

RESULTS

4.1 Hook Status

A total of 6,120 baited hooks (3,060 J-hooks and 3,060 circle hooks) were deployed in this study, but due to gear loss or damage 90% of the circle hooks and 89% of the J-hooks were retrieved (Figure 4.1).

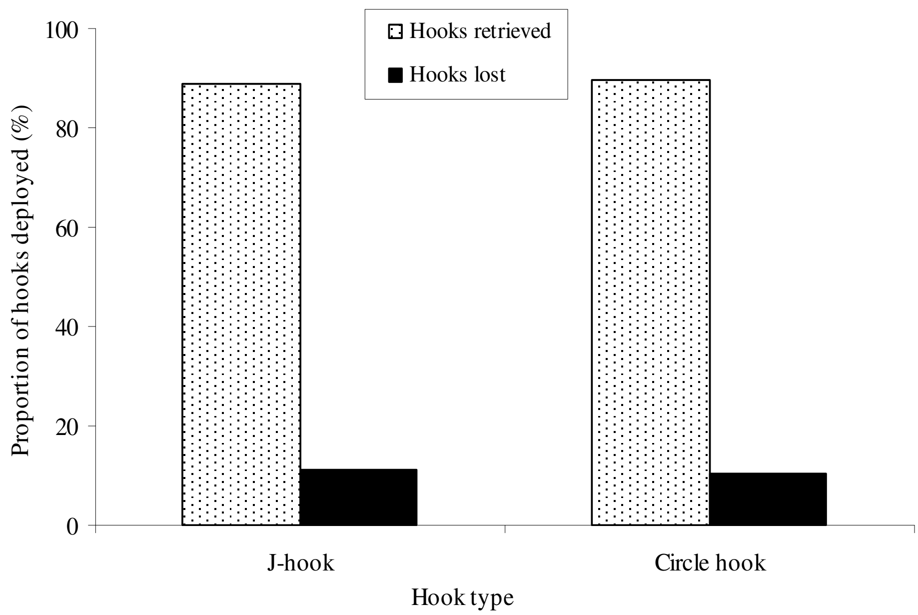


Figure 4.1 The proportion of deployed hooks that were retrieved or lost by hook type.

There was a significant difference in hook status by hook types (χ^2 = 123.698, df 2, P < 0.001), with more circle hooks were retrieved with fish than expected and there was less retrieval than expected of circle hooks with bait attached (Figure 4.2). Compared to the circle hook, there was an almost twofold increase in the proportion of J-hooks that were retrieved with bait attached. Approximately 13% of retrieved circle hooks had hooked fish while less than 8% of the J-hooks had hooked fish (fish attached and landed). The results also indicated that almost 76% of circle hooks were retrieved empty (without bait) whereas 72% of J-hooks were retrieved without bait.

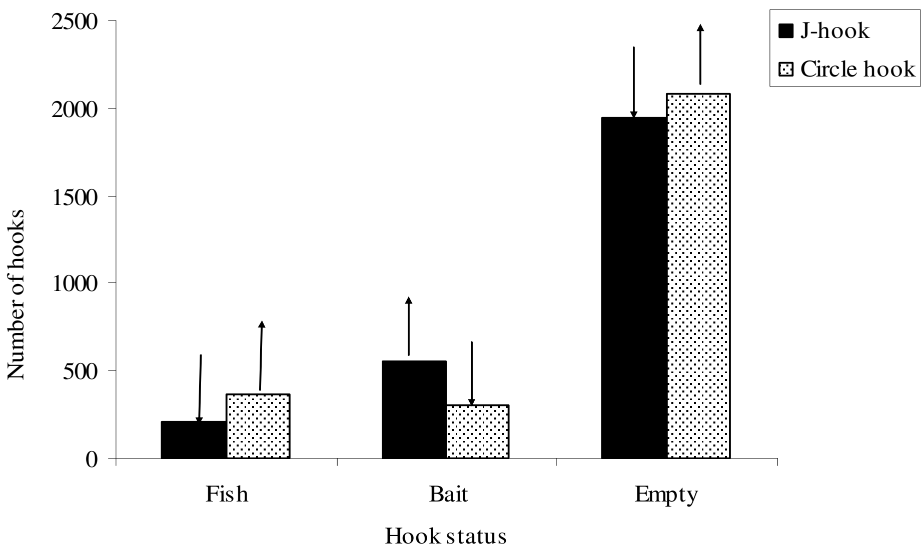


Figure 4.2 Hook status by hook type. Hook status describes a retrieved hook either with fish (commercial and non-commercial) attached, only bait attached or empty (bait removed). The arrows indicate the outcome of Chi-square analysis of hook status where the observed number of hook was less (down arrow) or more (up arrow) than expected.

Across all three fishing locations an equal number of circle and J-hooks were randomly deployed each day. Over the duration of the study 41.2% of the total number of hooks were deployed at location 1 and 29.4% were deployed at each of locations 2 and 3 (Table 4.1).

Table 4.1 Status of retrieved hooks by location. * Hooks retrieved include any that are retrieved from the longline irrespective of hook status, i.e. hooks with fish and hooks with or without bait.

	Location 1				Location 2				Location 3			
Hook status	J-hook		Circle hook		J-hook		Circle hook		J-hook		Circle hook	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Fish	93	8.4	157	13.9	46	5.7	93	11.4	74	9.1	118	14.8
Bait	130	11.8	48	4.2	304	37.9	224	27.4	124	15.2	26	3.3
Empty	882	79.8	928	81.9	452	56.4	501	61.2	616	75.7	652	81.9
*Hook retrieved	1105	100.0	1133	100.0	802	100.0	818	100.0	814	100.0	796	100.0

Differences in the frequency of hooks in each hook status (empty, bait only, or fish) was evident among the fishing locations (χ^2 = 502.376, df 4, P < 0.001). The spatial difference was because more than expected hooks in location 2 were retrieved with bait attached, irrespective of hook type (Figure 4.3). The proportion of retrieved hooks with bait attached was more for both hook types in location 2 and the proportion of empty hooks was less for both hook types at this location. This was due to circle hooks being retrieved with at least 50% more of the hooks with fish attached (χ^2 = 123.698, df 2, P < 0.001). The greatest proportion of retrieved hooks with fish attached (14.8%) was recorded in location 3 using the circle hook.

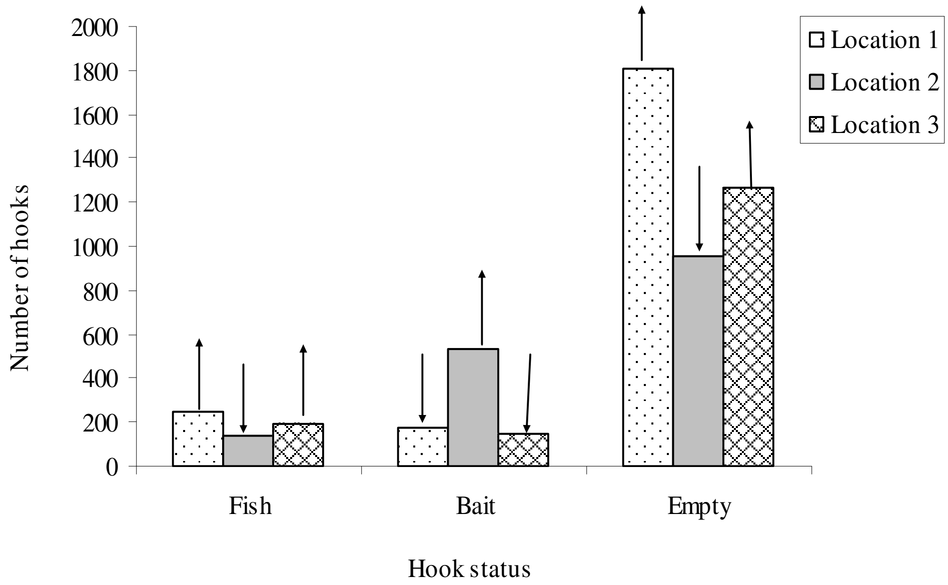


Figure 4.3 Hook status of both hook type by fishing location. Hook status describes a retrieved hook either with fish (commercial and non-commercial) attached, only bait attached or empty (bait removed). The arrows indicate the outcome of Chi-square analysis of hook status where the observed number of hook was less (down arrow) or more (up arrow) than expected.

Of the total number of hooks deployed, approximately 10% of the gear from both hook types was lost. About 5% of the total loss was assigned to missing sections of the mainline, while 24% was due to broken branchlines and the remainder was due to hooks missing. Losses in hooks was dependent on the hook type (χ^2 = 29.471, df 2, P < 0.001) but losses in hooks were similar among the three fishing locations (χ^2 = 4.363, df 4, P = 0.359) (Figure 4.4). More circle hooks (52% lost) than J-hooks (48%) were lost and longlines with J-hooks had greater losses of branchlines and the whole or part of mainline.

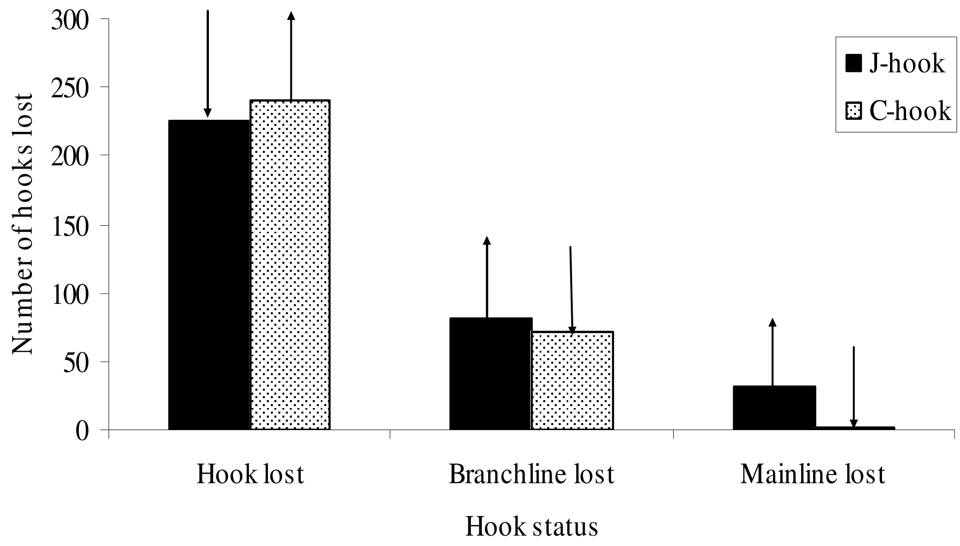


Figure 4.4 Hook lost status by hook type. The arrows indicate the outcome of Chi-square analysis of hook lost status where the observed number of hook was less (down arrow) or more (up arrow) than expected.

4.2 Catch Composition

The catch consisted of 11 families (seven commercial and four non-commercial) (Table 4.2). Circle hooks caught nine families whereas the J-hook caught all 11 families. The two families that were not captured by the circle hook were the commercially important Ariidae (*Arius bilineatus*) and the non-commercial family Stegostomatidae (*Stegostoma varium*). Catches by both hook types were dominated by one family Lethrinidiae; the threes species *Lethrinus microdon*, *Lethrinus nebulosus* and *Lethrinus lentjan* together accounted for 53% and 62% of the total commercial catch by weight and number respectively.

There were total of 18 (14 commercial and 4 non-commercial) species in the catch. Circle hook caught a total of 15 species, whereas the J-hook caught 16 species. Three of the species caught by the J-hook were absent from circle hook catches. These were the commercial species, *Arius bilineatus* and *Rhabdosargus sarba,* and a non-commercial species, *Stegostoma varium.* On the other hand, two species, the commercial

Lutjanus coeruleolineatus and *Epinephelus diacanthus,* were caught by circle hooks but not by J-hooks (Table 4.2). Catches of both hook types were dominated by *Lethrinus microdon*, which accounted for 38% and 48% of the total catch by weight and number respectively.

Table 4.2 Catch composition by hook type.

	Family name	Scientific name	Common name	Fish number	
Commercial species				J-hook	Circle hook
1	ARIIDAE	*Arius bilineatus*	Roundsnot sea catfish	3	0
2	HAEMULIDAE	*Plectorhinchus pictus*	Trout thicklip	13	22
3	HAEMULIDAE	*Plectorhinchus gibbosus*	Dusky thicklip	1	5
4	HEMIGALEIDAE	*Paragaleus sp.*	Arabian weasel shark	44	4
5	LETHRINIDAE	*Lethrinus microdon*	Spangled emperor	68	188
6	LETHRINIDAE	*Lethrinus nebulosus*	Smalltooth emperor	16	23
7	LETHRINIDAE	*Lethrinus lentjan*	Redspot emperor	26	38
8	LUTJANIDAE	*Lutjanus coeruleolineatus*	Bluelined snapper	0	13
9	LUTJANIDAE	*Lutjanus russelli*	Russell's snapper	1	3
10	SERRANIDAE	*Epinephelus stoliczkae*	Epaulet grouper	8	8
11	SERRANIDAE	*Epinephelus areolatus*	Areolate grouper	1	8
12	SERRANIDAE	*Epinephelus diacanthus*	Spinycheek grouper	0	1
13	SPARIDAE	*Argyrops spinifer*	King soldier bream	13	30
14	SPARIDAE	*Rhabdosargus sarba*	Gold striped seabream	1	0
Non-commercial species					
1	BALISTIDAE	*Sufflamen frarnatus*	Bridled triggerfish	7	9
2	DIODONTIDAE	*Diodon hystrix*	Porcupine fish	2	2
3	MURAENIDAE	*Siderea flavocula*	Palenose moray	6	14
4	STEGOSTOMATIDAE	*Stegostoma varium*	Zebra shark	3	0

4.3 Hooking Location of the Total Catch

Of the total catch of commercial and non-commercial fish by both hook types, 65% of the fish were hooked in the corner of the mouth, 19% were hooked in the jaw, 11% were hooked in the gill and 5% were hooked in the gut. During the experiment only one fish was hooked in the eye and two fish were hooked through the body. All three of these fish were caught by a J-hook.

There was a significant difference in hooking location for the total catch between hook types (χ^2 = 291.338, df 3, P < 0.001), with more than expected fish being hooked in the corner of the mouth by the circle hook and more than expected fish caught in the jaw, gill, and gut by the J-hook (Figure 4.5). Almost 90% of the total catch caught by the circle hook was hooked in the corner of the mouth, but only 21% were hooked in this position by J-hooks. There was little difference in the proportion of fish hooked in the jaw and gill using the J-hook; 38% and 29% respectively.

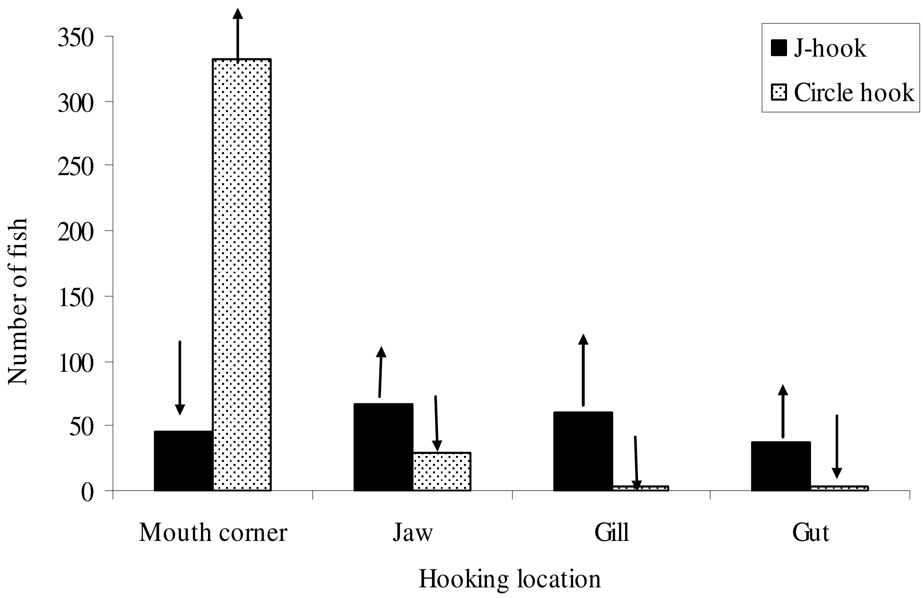


Figure 4.5 The observed number of fish caught in each hooking location by hook type. The arrows indicate the outcome of Chi-square analysis where the observed number of fish was less (down arrow) or more (up arrow) than expected.

There was a significant difference (χ^2 = 15.708, df 6, P = 0.015) in hooking location for the total catch fishing location, with a greater number of fish being hooked in the gill by both hook types at location 1 and a greater than expected number being hooked in the jaw at location 2 (Figure 5.6). In all three fishing locations at least 87% of the total catch using the circle hook was retained in the corner of the mouth, but when using the J-hook, no more than 37% of the catch was retained in this position. In location 3, almost 60% of the catch using the J-hook was retained in the jaw, but less than half of this proportion was retained in this position in location 1. Similarly, at location 1 almost 40% of the catch using the J-hook were retained in the gill, but less than half of this proportion were retained in this position in location 2. At location 1, using the J-hook, around 13% of the catch was hooked in the gut.

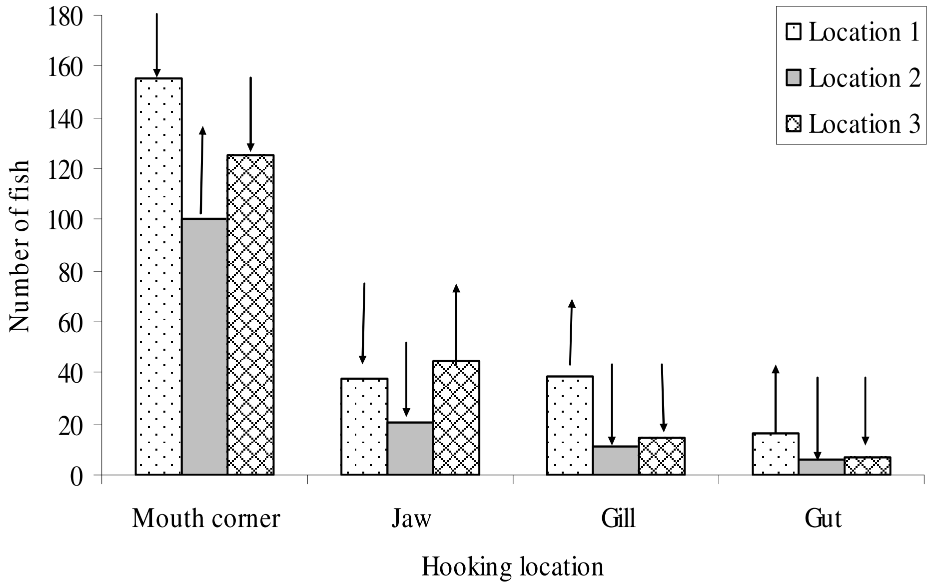


Figure 4.6 The hooking location of the total catch by fishing location. The arrows indicate the outcome of Chi-square analysis where the observed number of fish was less (down arrow) or more (up arrow) than expected.

4.3.1 Hooking Location of the Commercial Catch

There was a significant difference ($\chi^2 = 248.49$, df 3, $P < 0.001$) in the hooking location of commercial species by hook type, with a greater than expected number of commercial fish hooked in the corner of the mouth by the circle hook and a greater than expected number of fish caught in the jaw, gill and gut by the J-hook (Figure 4.7). Almost 90% of the commercial catch using the circle hook was hooked in the corner of the mouth, but less than 24% were hooked in this position by the J-hook.

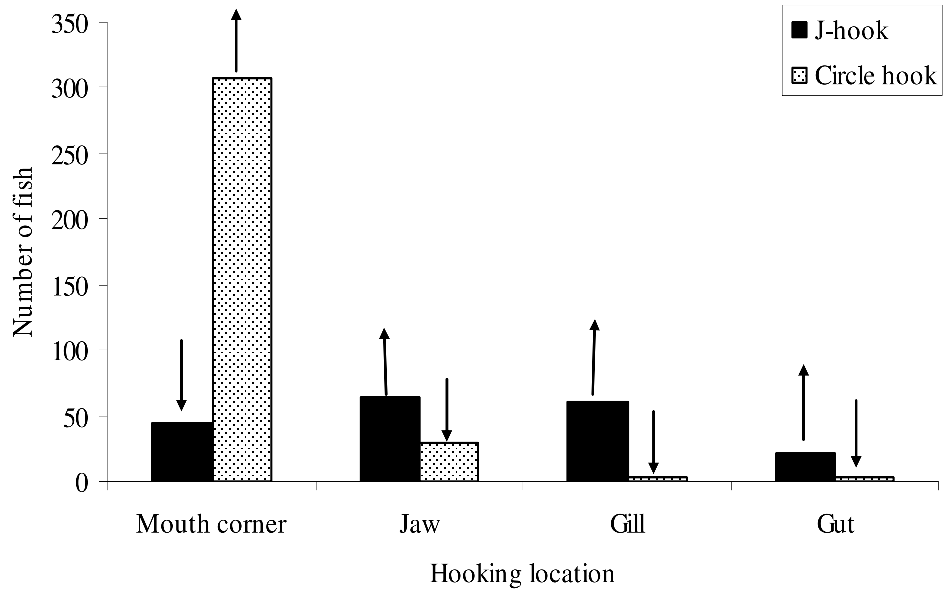


Figure 4.7 The hooking location of the commercial catch by hook type. The arrows indicate hooking location where the observed numbers were less (down arrow) or more (up arrow) than expected.

There was no significant difference (χ^2 = 12.05, df 6, P = 0.061) in hooking location for commercial catch as by fishing locations. Almost two-thirds of the total commercial catch from both hook types were hooked in the corner of the mouth, 18% were hooked in the jaw, 12% were hooked in the gill and 5% were hooked in the gut. Less than 1% (only 3 fish) of the commercial catch were hooked in the eye and body using the J-hook, and only at location 1.

4.3.2 Hooking Location of the Non-commercial Catch

There was a significant difference in the hooking location of non-commercial species by hook type (χ^2 = 43.00, df 3, P < 0.001) with a greater than expected number of non-commercial fish being hooked in the corner of the mouth by the circle hook and a greater than expected number of fish were caught in the jaw by the J-hook (Figure 4.8).

There was no significant difference in hooking location (χ^2 = 9.46, df 6, P = 0.149) of non-commercial catch by fishing locations. All of the non-commercial catch caught by the circle hook were hooked in the corner of the mouth, whereas almost all of the non-commercial catch (89%) caught by the J-hook were hooked in the jaw.

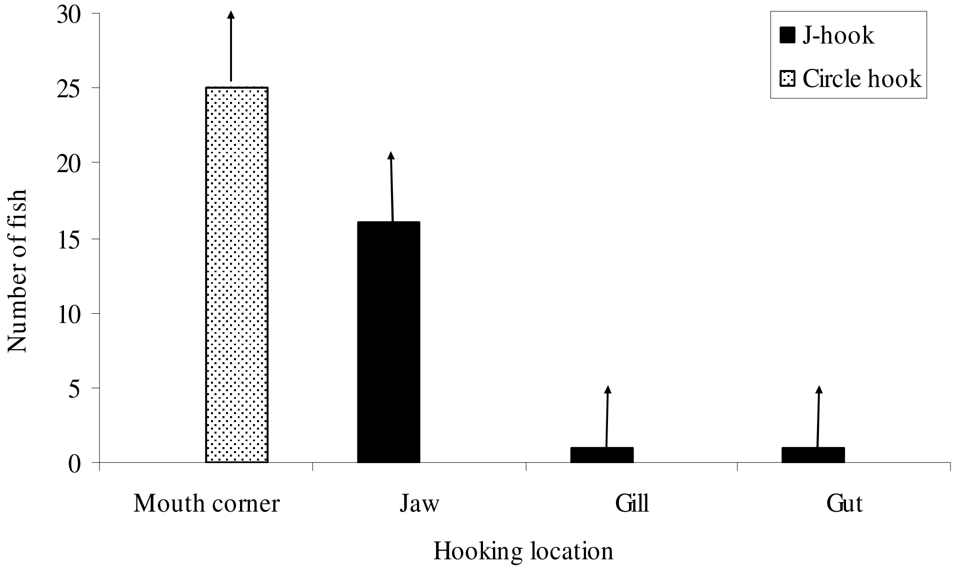


Figure 4.8 The hooking location of the total non-commercial catch by hook type. The arrows indicate hooking location where the observed numbers were less (down arrow) or more (up arrow) than expected.

4.3.3 Hooking Location of the Dominant Family (Lethrinidae)

There was a significant difference in hooking location of the Lethrinidae catch between hook types (χ^2 = 153.896, df 3, $P < 0.001$), with a greater number of Lethrinidae catch being hooked in the corner of the mouth by the circle hook and a greater than expected number being hooked in the gut by the J-hook (Figure 4.9). Over 97% of the total catch of Lethrinidae caught by the circle hook were hooked in the corner of the mouth, but only 29% were hooked in this same position by the J-hook. Of the total catch of Lethrinidae, by both hook types, around 71% were hooked in the corner of the mouth, 11% were hooked in the jaw, 13% were hooked in the gill and less than 5% were hooked in the gut.

A significant difference (χ^2 = 16.318, df 6, $P = 0.012$) was also found in hooking location for the Lethrinidae catch by fishing location, with the higher number of fish hooked in the gut by both hook types at location 1 and a higher than expected number hooked in the corner of the mouth at location 3 (Figure 4.10).

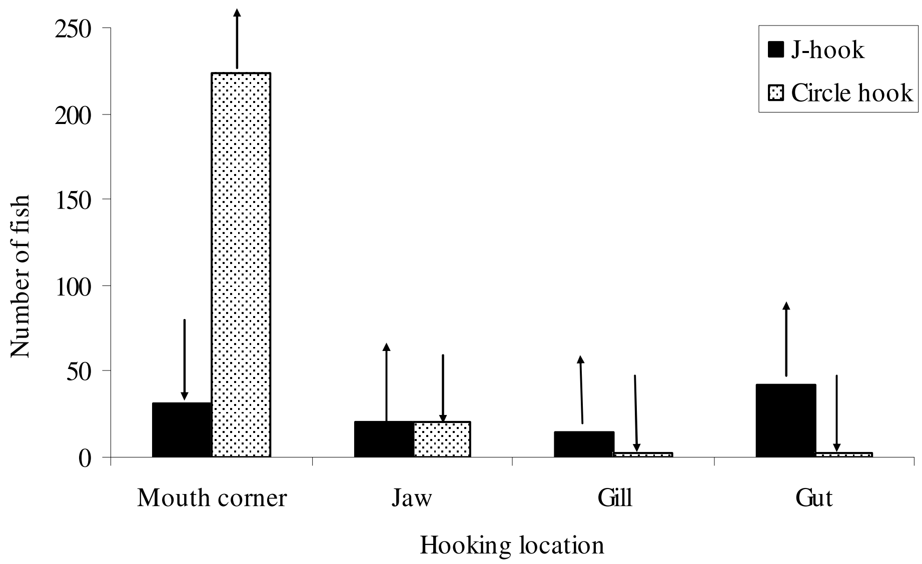


Figure 4.9 The hooking location of the Lethrinidae by hook type. The arrows indicate hooking location where the observed numbers were less (down arrow) or more (up arrow) than expected.

In location 1, almost 47% of the catch using this hook was retained in the gill, but in location 2 less than 17% of this proportion was retained in this position.

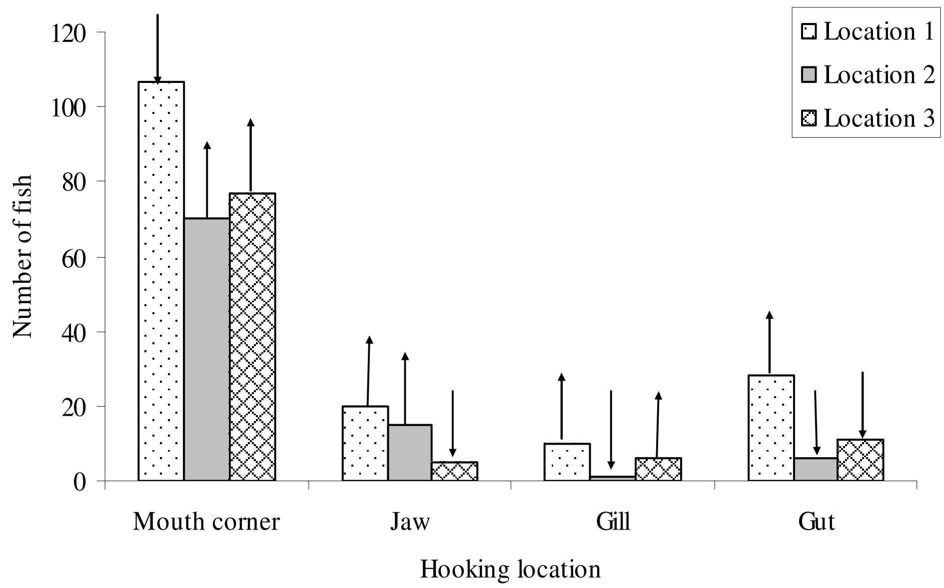


Figure 4.10 The hooking location of the Lethrinidae by fishing location. The arrows indicate hooking location where the observed numbers were less (down arrow) or more (up arrow) than expected.

4.3.4 Hooking Location of the Dominant Species (*Lethrinus microdon)*

There was significant difference ($\chi^2 = 89.807$, df 3, $P < 0.001$) in the hooking location for *Lethrinus microdon* by hook type, with a greater than expected number of fish being hooked in the corner of the mouth by the circle hook whereas a greater than expected number of fish were caught in the jaw, gill and gut by the J-hook hook (Figure 4.11). Of the total catch of *L. microdon,* by both hook types, around 73% were hooked in the corner of the mouth, 13% were hooked in the jaw, 9% were hooked in the gill and less than 5% were hooked in the gut.

Almost 87% of the *L. microdon* catch caught by the circle hook was hooked in the corner of the mouth, whereas the J-hook hooked less than 31% in this position. For the *L. microdon* catch, by fishing location, no significant difference ($\chi^2 = 9.54$, df 6, P = 0.145) was found in this pattern.

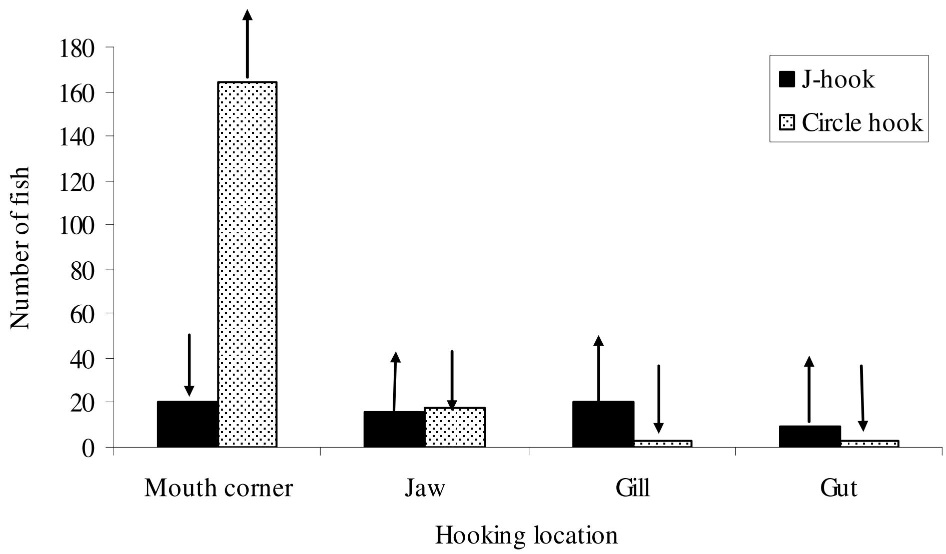


Figure 4.11 The hooking location of the *Lethrinus microdon* by hook type. The arrows indicate hooking location where the observed numbers were less (down arrow) or more (up arrow) than expected.

4.4 Catching Efficiency of the Total Catch

The catching efficiency (+/- standard error) for the circle hook and the J-hook was 17.1 +/- 2.0 kg and 16.7 +/- 3.0 kg per 100 hooks retrieved, respectively. There was no significant difference in the mean catching efficiency of the total catch between hook type (ANOVA: F = 0.001, df 1, 96, P = 0.976). Also, the difference in mean catching efficiency between hook type and location was not significant (ANOVA: $F_{(hook\ type*locations)}$ = 0.002, df 2, P = 0.998).

However, there was a significant difference in the mean catching efficiency for the total catch between the three fishing locations (ANOVA: F = 4.367, df 2, 96, P = 0.015). Furthermore, the Tukey's Post Hoc Test showed that this difference was significant between locations 1 and 2 (P = 0.013) (Figure 4.12). However, there were no differences noted in the mean catching efficiency of the total catch between location 2 and 3.

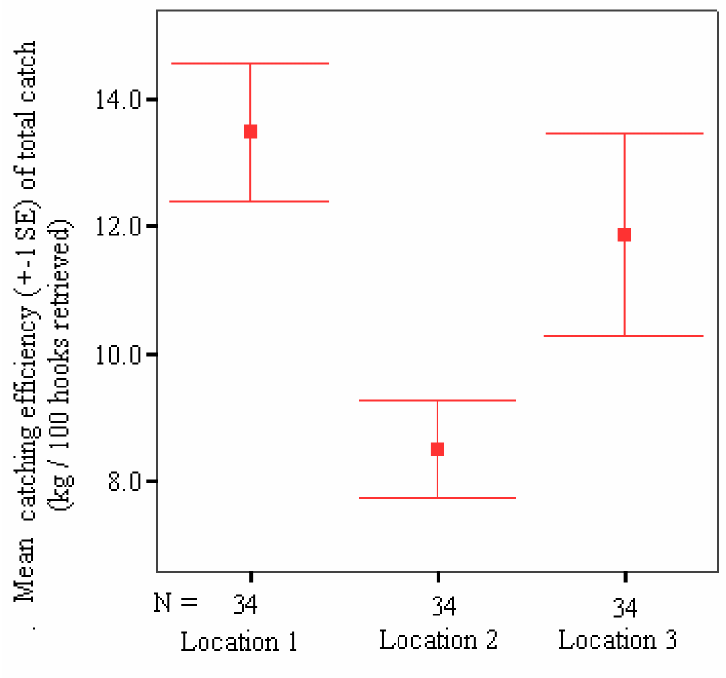


Figure 4.12 The average catching efficiency (+/-se) of the total catch of both hook type by fishing locations.

4.4.1 Total Catch in Weight and Numbers

A total of 581 fish were caught by the J-hook and circle hook with a combined total weight of 924.3 kg. The circle hook caught 50.7% of the total catch weight and 63% of the total catch number (Table 4.3). There was a significant difference in the total catch weight by hook type (ANCOVA: $F = 16.312$, df 1, 574, $P < 0.001$). The average catch per day was not affected by the difference in fishing days among the locations (ANCOVA: $F = 0.181$, df 1, 574, $P = 0.670$), and the difference in average catch per day between hook type and location was not significant (ANCOVA: $F_{(hook\ type*location)} = 0.278$, df 2, $P = 0.757$).

There was no significant difference (ANCOVA: $F = 0.694$, df 2, 574, $P = 0.500$) in the total catch mean weight by fishing locations. Based on the results presented in Table 4.3, the total catch weight for both hook types was higher only at location 1; the catch from the circle and J-hook was 38.7% and 40.5% of the total combined catch respectively.

Table 4.3 Total combined catch weight and number (+/- se) at each fishing location by hook type.

Location	Hook type	Number of fish	Wt. (kg)	Wt. (%)	Av. Wt.	SE
1	J-hook	93	184.4	40.5	2.0	0.35
	Circle hook	157	181.5	38.7	1.2	0.08
2	J-hook	46	97.9	21.5	2.1	0.17
	Circle hook	93	134.4	28.7	1.4	0.13
3	J-hook	74	173.4	38.1	2.3	0.52
	Circle hook	118	152.6	32.6	1.3	0.09
Total	J-hook	213	455.7	100.0	2.1	0.23
	Circle hook	368	468.5	100.0	1.3	0.10

4.4.2 Length Frequency Distribution of the Total Catch

There was a significant difference in length frequency distribution of the total catch between the two hook types ($\chi^2 = 67.229$, df 4, $P < 0.001$), with fish > 60 cm more likely to be caught using the J-hook than the circle hook and the circle hook more likely to have caught more small fish (Figure 4.13). For both hook types 58% of the combined catch of commercial and non-commercial species in all three fishing locations measured between 31 - 60 cm, with 25% less than 31 cm and 17% greater than 60 cm.

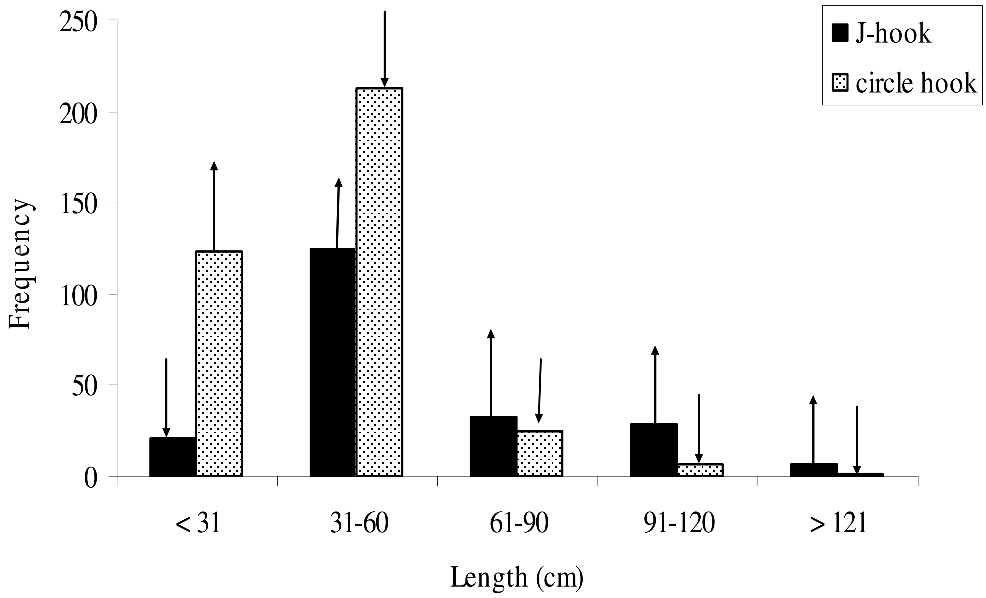


Figure 4.13 Length frequency distribution of the total catch by hook type. The arrows indicate length frequency where the observed numbers were less (down arrow) or more (up arrow) than expected.

However, there was a significant difference ($\chi^2 = 32.240$, df 8, $P < 0.001$) in length frequency distributions for the total catch among the fishing locations, with more small fish (<31 cm) caught by both hook types at location 1 and more than expected large fish (>91 cm) caught at location 2 (Figure 4.14). The length frequency distribution of the total catch shows that only at location 2 did both hook types catch more than expected fish in the 31 - 60 cm size class.

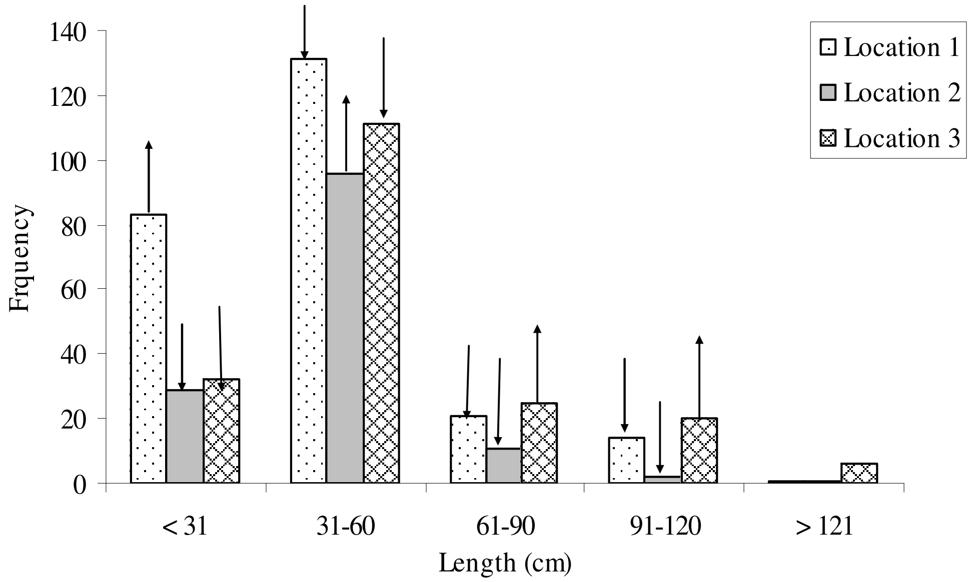


Figure 4.14 Length frequency distributions for the total catch by fishing location. The arrows indicate length frequency where the observed numbers were less (down arrow) or more (up arrow) than expected.

4.5 Catching Efficiency of the Commercial Catch

There was no significant difference in the mean catching efficiency of total commercial catch by hook type (ANOVA: F = 0.001, df 1, 96, P = 0.975). Also, the difference in mean catching efficiency between hook type and location was not significant (ANOVA: $F_{(hook\ type*locations)} = 0.004$, df 2, P = 0.996).

However, there was a significant difference in the mean catching efficacy for the total commercial catch between the three fishing locations (ANOVA: F = 8.004, df 2, 96, P = 0.001). Furthermore, the Tukey's Post Hoc Test showed that this difference was significant between locations 1 and 2 (P = 0.001) and location 1 and 3 (P = 0.007) (Figure 4.15). However, there were no differences noted in mean catch between location 2 and 3.

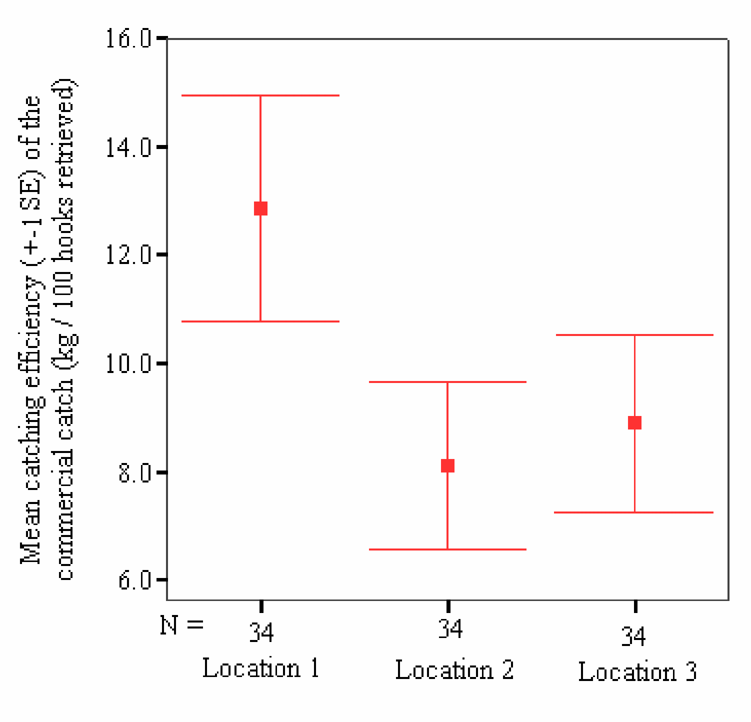


Figure 4.15 Average catching efficiency per 100 hooks (+/- se) retrieved for the total commercial catch by fishing location.

4.5.1 Commercial Catch in Weight and Numbers

The commercial catch comprised 88% by weight and 92.6% by number of the total catch. There was a significant difference in catch weight by hook type (ANCOVA: F = 8.800, df 1, 531, P = 0.003). The circle hook caught 94.7% by weight and 93.2% by number of the total combined catch (commercial and non-commercial) (Table 4.4). The difference in the number of fishing days among the locations did not affect the average catch per day (ANCOVA: F = 1.644, df 1, 531, P = 0.200). The difference in average total commercial catch per day between the two hook types was the same at all locations (ANCOVA: $F_{\text{(hook type*location)}}$ = 2.395, df 2, P = 0.092).

There was no significant difference (ANCOVA: F = 2.646, df 1, 531, P = 0.072) in the total commercial catch weight by fishing locations. The circle hook caught 54.5% by weight and 63.8% by number, of the total combined commercial catch (Table 4.4).

Table 4.4 Total commercial catch weight and number (+/- se) at each fishing location by hook type.

Location	Hook type	Number of fish	Wt. (kg)	Wt. (%)	Av. Wt.	SE
1	J-hook	88	179.4	48.4	2.0	0.34
	Circle hook	144	169.5	38.2	1.2	0.08
2	J-hook	42	93.7	25.3	2.2	0.18
	Circle hook	86	127.2	28.7	1.5	0.14
3	J-hook	65	97.7	26.3	1.5	0.10
	Circle hook	113	147.1	33.1	1.3	0.09
Total	J-hook	195	370.8	100.0	1.9	0.16
	Circle hook	343	443.8	100.0	1.3	0.06

4.5.2 Length Frequency Distribution of the Commercial Catch

In all three fishing locations and for both hook types, 60% of the commercial catch measured between 61 - 60 cm, 26% were < 31 cm and 14% were > 60 cm. Between hook types the length frequency distributions of the commercial catch were significantly different ($\chi^2 = 70.880$, df 4, $P < 0.001$) (Figure 4.16). Circle hooks caught more than expected fish in the 31 - 60 cm size class. Fish > 61 cm were more likely to be caught using the J-hook than the circle hook and the circle hook caught more of the smaller fish.

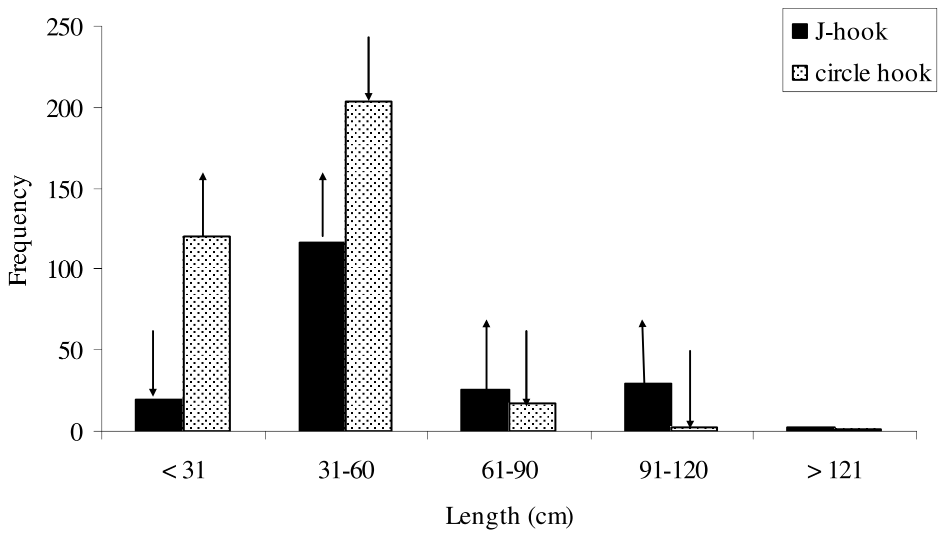


Figure 4.16 Length frequency of the commercial catch by hook type. The arrows indicate length frequency where the observed numbers were less (down arrow) or more (up arrow) than expected.

There was a significant difference (χ^2 = 23.421, df 8, P = 0.003) in size frequency distributions for the total commercial catch by fishing location, with more small fish (< 31 cm) caught by both hook types at location 1 and more than expected number of large fish (> 61 cm) caught at location 3 (Figure 4.17). The length frequency distribution of the total commercial catch indicated that both hook types caught more than expected fish in 31-60 cm size class at location 2 only.

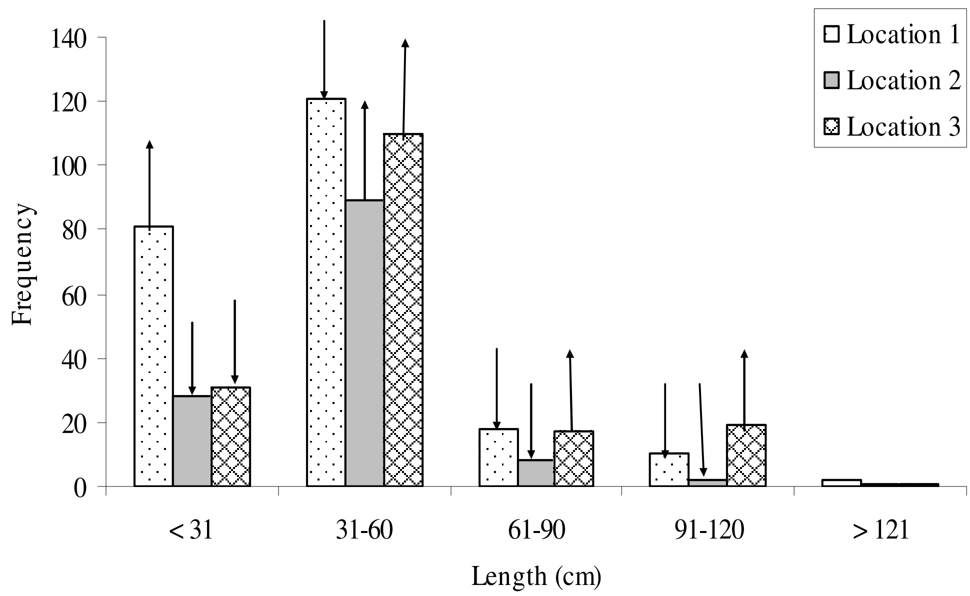


Figure 4.17 Length frequency distributions of the commercial catch by fishing location. The arrows indicate length frequency where the observed numbers were less (down arrow) or more (up arrow) than expected.

4.6 Catching Efficiency of the Non-commercial Catch

There was no significant difference in the catching efficiency between the two hook types (ANOVA: F = 0.000, df 1, 42, P = 0.991). Also, the difference in average catching efficiency between hook type and location was not significant (ANOVA: $F_{(hook\ type*locations)}$ = 0.000, df 2, P = 0.991). However, there was a significant difference (ANOVA: F = 3.498, df 2, 42, P = 0.039) in the catching efficiency for the non-commercial catch by fishing locations. Furthermore, the Tukey's Post Hoc Test showed that this difference was not significant between the three fishing locations.

4.6.1 Non-commercial Catch in Weight and Numbers

There was no significant difference between the two hook types in the average weight of the total catch (ANCOVA: F = 2.008, df 1, 36, P = 0.165). The average catch weight of the total non-commercial catch caught by the circle hook and the J-hook was 1.0 +/- 0.04 kg and 4.7 +/- 2.0 kg, respectively (Table 4.5). The average catch per day was not affected by fishing days across the locations (ANCOVA: F = 0.123, df 1, 36, P = 0.728). The difference in average total non-commercial catch per day between the two hook types was the same at all locations (ANCOVA: $F_{(\text{hook type*location})}$ = 1.362, df 2, P = 0.269).

There was no significant difference (ANCOVA: F = 1.961, df 2, 36, P = 0.156) in the average total non-commercial catch weight by hook type. Based on the results presented in Table 4.5, the total non-commercial catch weight and number for the circle hook, compared to the J-hook catch, was higher at locations 1 and 2. The circle hook caught 22.5% by weight and 58.1% by number of the total combined non-commercial catch.

Table 4.5 Total non-commercial catch weight and number (+/- se) at each fishing location by hook type.

Location	Hook type	Number of fish	Wt. (kg)	Wt. (%)	Av. Wt.	SE
1	J-hook	5	5.0	5.9	1.0	0.00
	Circle hook	13	12.0	48.6	0.9	0.07
2	J-hook	4	4.2	4.9	1.1	0.05
	Circle hook	7	7.2	29.1	1.0	0.03
3	J-hook	9	75.7	89.2	8.4	3.85
	Circle hook	5	5.5	22.3	1.1	0.10
Total	J-hook	18	84.9	100.0	4.7	2.00
	Circle hook	25	24.7	100.0	1.0	0.04

4.6.2 Length Frequency Distribution of the Non-commercial Catch

For both hook types, of the non-commercial catch in the all fishing locations, 42% were 31 – 60 cm in length, 49% were > 61 cm, and 9% measured < 31 cm. Between the hook types there was no significant difference in the length frequency distribution of the non-commercial catch (χ^2 = 6.793, df 4, P = 0.147) (Figure 4.18).

However, for the non-commercial catch, there was a significant difference ($\chi^2 = 19.362$, df 8, $P = 0.013$) in length frequency distribution among fishing locations, with more than the expected number of fish in 31 - 60 cm size class caught by both hook type at locations 1 and 2, and more than expected fish in the 61 - 90 cm size class caught at location 3.

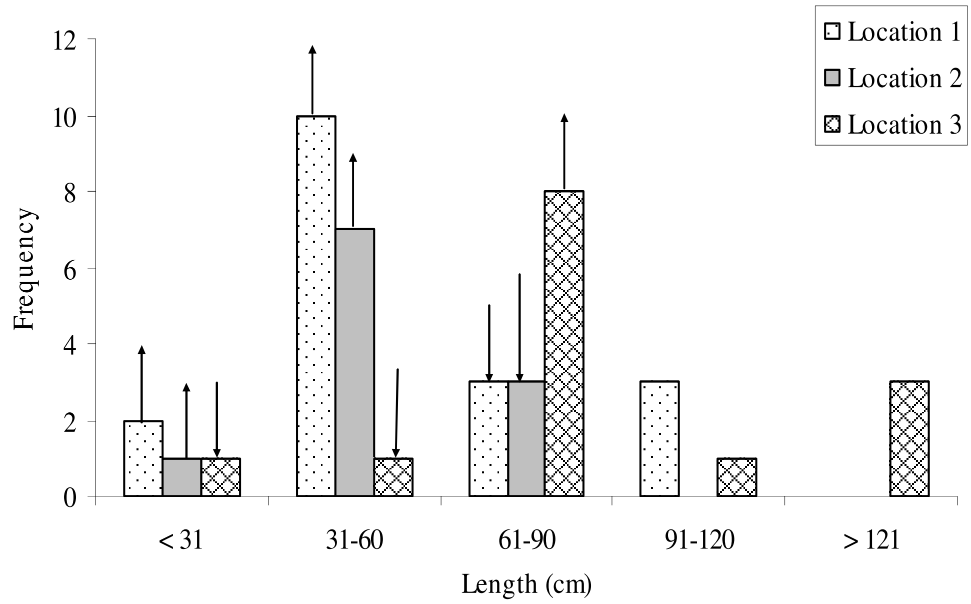


Figure 4.18 Length frequency distributions for the non-commercial catch by fishing location. The arrows indicate length frequency where the observed numbers were less (down arrow) or more (up arrow) than expected.

4.7 Catching Efficiency of the Dominant Family (LETHRINIDAE)

There was no significant difference (ANOVA: $F = 0.001$, df 1, 96, $P = 0.982$) in the catching efficiency of the lethrinidae by hook type. Also, the difference in average catching efficiency between hook type and location was not significant (ANOVA: $F_{(hook\ type*locations)} = 0.001$, df 2, $P = 0.999$).

However, there was no significant difference in catching efficiency of the Lethrinidae catch among the three fishing locations (ANOVA: $F = 2.366$, df 2, 96, $P = 0.099$). Furthermore, the Tukey's Post Hoc Test showed that this difference was not significant between locations.

4.7.1 Catch Weight and Numbers of Lethrinidae

There was a significant difference in the average total catch weight of Lethrinidae by hook type (ANCOVA: $F = 12.931$, df 1, 352, $P < 0.001$). The circle hooks caught on average 36.3% by weight and 46.3% by number of the total combined catch (Table 4.6). The Lethrinidae catch accounted for 59.6% by weight and 66.7% by number of the total combined catch (commercial and non-commercial).

Table 4.6 Total catch weight and number (+/- se) of Lethrinidae at each fishing location by hook type.

Location	Hook type	Number of fish	Wt. (kg)	Wt. (%)	Av. Wt.	SE
1	J-hook	59	103.9	54.7	1.8	0.16
	Circle hook	108	110.4	37.4	1.0	0.09
2	J-hook	25	53.0	27.9	2.1	0.25
	Circle hook	68	93.8	31.8	1.4	0.16
3	J-hook	26	33.2	17.5	1.3	0.15
	Circle hook	73	91.2	30.9	1.2	0.12
Total	J-hook	110	190.1	100.0	1.7	0.10
	Circle hook	249	295.4	100.0	1.2	0.07

The average catch per day was not affected by the difference in fishing days among the locations (ANCOVA: $F = 3.327$, df 1, 352, $P = 0.069$). Also, the difference in average total catch of Lethrinidae per day between the two hook types was the same at all locations (ANCOVA: $F_{\text{(hook type*location)}} = 2.676$, df 2, $P = 0.070$).

However, there was a significant difference (ANCOVA: $F = 3.271$, df 2, 352, $P = 0.039$) in the average catch weight of Lethrinidae among the fishing locations. Furthermore, the Post Hoc Test showed that this average difference was not significant between locations.

4.7.2 Length Frequency Distribution of Lethrinidae

In all three locations and for both hook types, 63% of the total catch of Lethrinidae were 31 - 60 cm, 30% were < 31 cm, and only 7% were > 61 cm in length. Between the hook types the length frequency distribution of Lethrinidae was significantly different ($\chi^2 = 22.783$, df 2, $P < 0.001$), with fewer small fish (< 31 cm) caught by the J-hook and the circle hook caught more than expected Lethrinidae 31 - 60 cm. Of Lethrinidae > 61 cm, both hook types caught similar numbers (Figure 4.19).

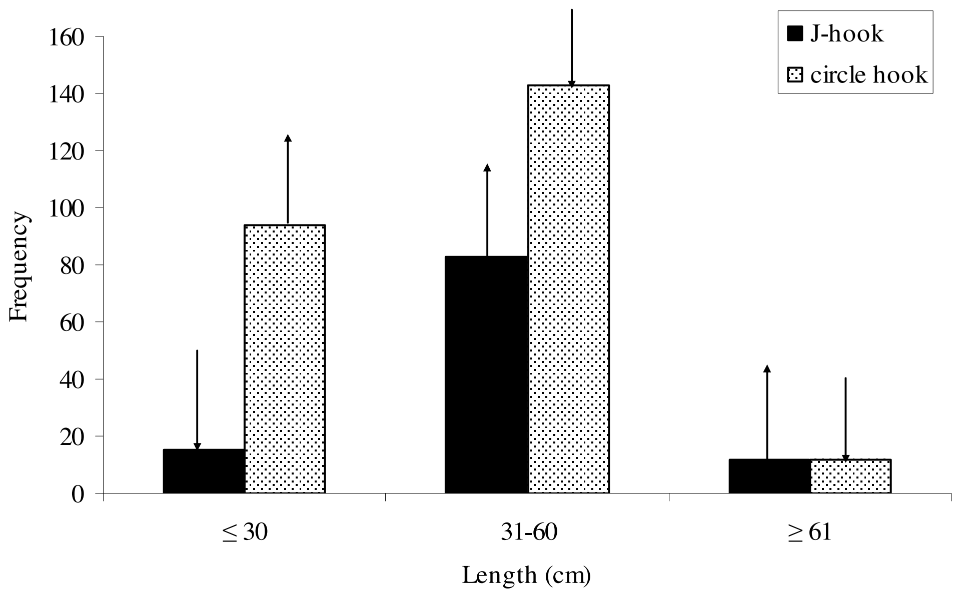


Figure 4.19 The observed number of the J-hook and circle hooks in each size class of Lethrinidae. The arrows indicate length frequency where the observed numbers were less (down arrow) or more (up arrow) than expected.

There was a significant difference (χ^2 = 19.270, df 4, P = 0.001) in the length frequency distribution by fishing location, with more small fish (< 31 cm) caught by both hook types at location 1 and more than expected number of large fish (> 61 cm) caught at the same fishing location (Figure 4.20). The length frequency distribution of the Lethrinidae indicated that at location 1, both hooks caught less than the expected number of fish in the range 31 – 60 cm in length.

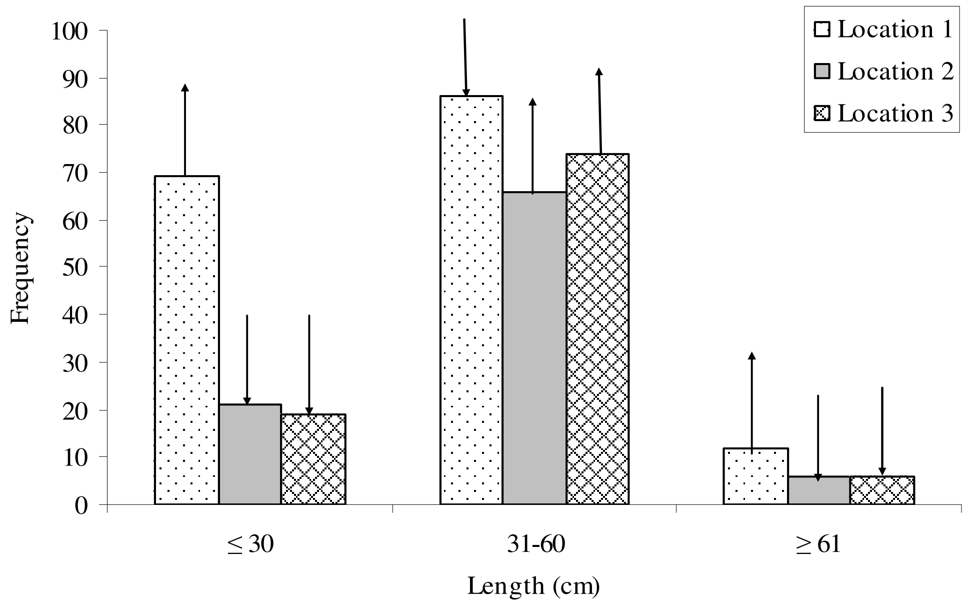


Figure 4.20 Length frequency distributions for the Lethrinidae catch by fishing location. The arrows indicate length frequency where the observed numbers were less (down arrow) or more (up arrow) than expected.

4.8 Catching Efficiency of Dominant Species (*Lethrinus microdon*)

The catching efficiency between hook type was not significantly different (ANOVA: F = 0.000, df 1, 96, P = 0.996). Also the difference in average catching efficiency between hook type and location was not significant (ANOVA: $F_{(hook\ type*location)}$ = 0.002, df 2, P = 0.998). The catching efficiency (+/- standard error) for *Lethrinus microdon* using both hook types at all fishing locations was 5.6 kg +/- 0.6 per 100 hooks retrieved.

Furthermore, for the *Lethrinus microdon* catch, no significant difference noted in the catching efficiency among the fishing locations (ANOVA: F = 1.036, df 2, 96, P = 0.359). However, the Tukey's Post Hoc Test showed that this difference was not significant between locations.

4.8.1 Catch Weight and Numbers of *Lethrinus microdon*

There was a significant difference in the average total catch weight of *Lethrinus microdon* by hook type (ANCOVA: F = 6.917, df 1, 249, P = 0.009). *Lethrinus microdon* catch accounted for 33.2% by weight and 44.1% by number of the total combined catch (commercial and non-commercial). The circle hook caught on average 21.7% by weight and 32.4% by total of the total combined catch (Table 4.7). The average catch per day was not affected by the difference in fishing days across the locations (ANCOVA: F = 0.002, df 1, 249, P = 0.964). The difference in average total catch of *Lethrinus microdon* per day between the two hook types was the same at all locations (ANCOVA: $F_{(hook\ type*location)} = 2.217$, df 2, P = 0.111).

By fishing location, there was no significant difference (ANCOVA: F = 0.994, df 2, 249, P = 0.372) in the average catch weight of *L. microdon*. Based on the results presented in Table 4.7, by using the circle hook the catch weight and number of *L. microdon* was greater than when the J-hook was used at all three locations. The circle hook caught 65.3% of the total weight and 73.4% of the total number of *L. microdon*.

Table 4.7 Total catch weight and number (+/- se) of *Lethrinus microdon* at each fishing location by hook type.

Location	Hook type	Number of fish	Wt. (kg)	Wt. (%)	Av. Wt.	SE
1	J-hook	34	55.2	51.9	1.6	0.17
	Circle hook	80	71.0	35.4	0.9	0.09
2	J-hook	20	34.5	32.4	1.7	0.21
	Circle hook	58	68.2	34.0	1.2	0.15
3	J-hook	14	16.7	15.7	1.2	0.17
	Circle hook	50	61.3	30.6	1.2	0.15
Total	J-hook	68	106.4	100.0	1.6	0.11
	Circle hook	188	200.5	100.0	1.1	0.07

4.8.2 Length Frequency Distribution of *Lethrinus microdon*

For both hook types, 64% of the total catch of *Lethrinus microdon* in all three locations measured 31 - 60 cm, 32% were < 31 cm and only 4% were > 61 cm. Between the hook types the length frequency distribution of *Lethrinus microdon* was significantly different ($\chi^2 = 23.720$, df 2, P < 0.001) (Figure 4.21). The length frequency distribution showed that the circle hook caught less than the expected number of fish in the range of 31 to 60 cm. Fish > 61 cm were more likely to be caught using the J-hook than the circle hook and the circle hook caught more small fish.

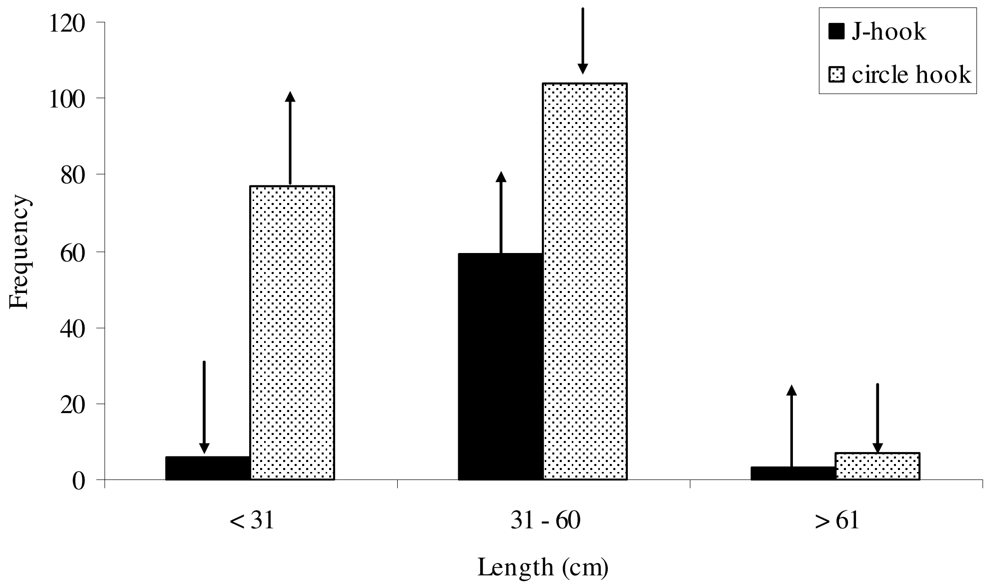


Figure 4.21 The observed number of *Lethrinus microdon* caught using J-hook and circle hooks in each length class. The arrows indicate length frequency where the observed numbers were less (down arrow) or more (up arrow) than expected.

There was a significant difference (χ^2 = 20.583, df 4, P < 0.001) in the length frequency distribution by fishing location, with most small fish (< 31 cm) caught by both hook types at location 1 and a higher than expected number of large fish (61 cm) being caught at location 3 (Figure 4.22). The length frequency distribution showed that both hook types caught a higher than expected number of fish in the length range 31 to 60 cm at locations 1 and 2.

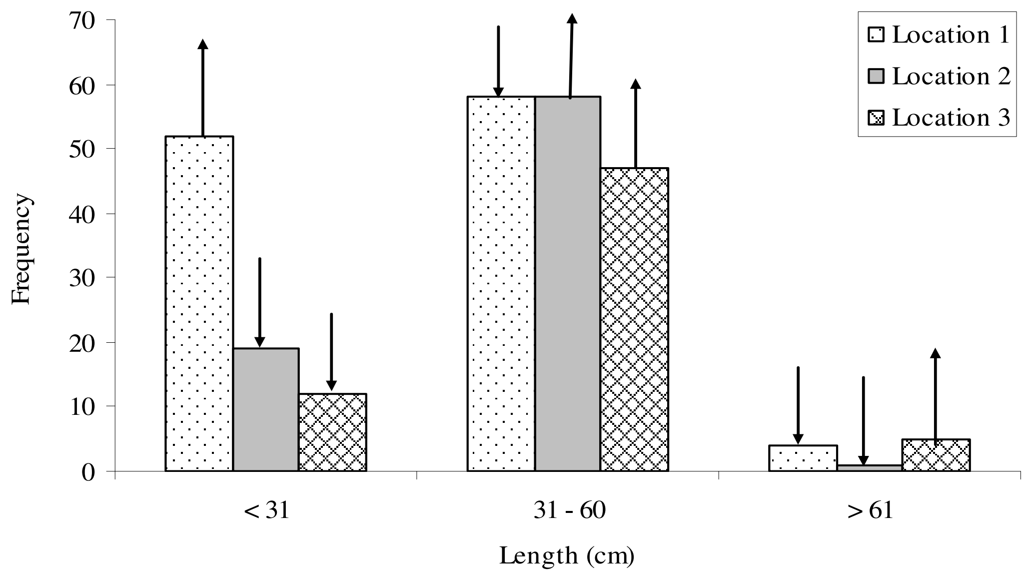


Figure 4.22 Length frequency distributions for the *Lethrinus microdon* at each fishing location. The arrows indicate length frequency where the observed numbers were less (down arrow) or more (up arrow) than expected.

4.9 Gross Economic Benefit of the Commercial Catch

Since there are no regulations for undersize demersal fish in Oman all of the catch was considered commercially valuable. The total catch value of the commercial catch from both hook types, not including the protected species *Paragaleus sp.* (Ducrocq 2004), was [1]R.O. 354 or 0.50 R.O/kg (Table 4.8). Of the value of the total catch circle hooks caught 62%.

However, for the total commercial catch -not including the *Paragaleus sp.*-, there was a significant difference ($\chi^2 = 7.501$, df 2, $P = 0.024$) in the total catch value by hook type (Figure 4.23). When using the circle hook, the total catch value at all three fishing locations was higher than that of the J-hook.

[1] 1 Rail Omani (R.O.) equals AU$ 3.5091 (19 December 2005)

Table 4.8 Total catch value of commercial species caught using the J-hook and the circle hook by location, not including *Paragaleus sp.*.

Species	Av. Price	Location 1				Location 2				Location 3				Total			
		J-hook		circle hook		J-hook		circle hook		J-hook		circle hook		J-hook		circle hook	
	RO	Wt.(kg)	value (R.O)	Wt.(kg)	value (R.O)	Wt.(kg)	value (R.O)	Wt.(kg)	value (R.O)	Wt.(kg)	value (R.O)	Wt.(kg)	value (R.O)	Wt.(kg)	value (R.O)	Wt.(kg)	value (R.O)
L. microdon	0.49	55.2	27.0	71.0	34.8	34.5	16.9	68.2	33.4	16.7	8.2	61.3	30.0	106.4	52.1	200.5	98.2
L. nebulosus	0.49	27.5	13.5	16.7	8.2	18.5	9.1	24.0	11.8	6.5	3.2	22.7	11.1	52.5	25.7	63.4	31.1
P. pictus	0.55	9.0	5.0	22.0	12.1	19.0	10.5	13.1	7.2	8.5	4.7	20.2	11.1	36.5	20.1	55.3	30.4
A. spinifer	0.5	11.5	5.8	14.8	7.4	10.5	5.3	18.0	9.0	7.5	3.8	19.7	9.9	29.5	14.8	52.5	26.3
L. lentjan	0.49	21.3	10.4	22.8	11.1	0.0	0.0	1.6	0.8	10.0	4.9	7.2	3.5	31.3	15.3	31.5	15.4
P. gibbosus	0.55	0.0	0.0	6.0	3.3	3.5	1.9	0.0	0.0	0.0	0.0	8.0	4.4	3.5	1.9	14.0	7.7
A. bilineatus	0.13	4.5	0.6	0.0	0.0	0.0	0.0	0.0	0.0	7.5	1.0	0.0	0.0	12.0	1.6	0.0	0.0
E. stoliczkae	0.59	1.5	0.9	1.1	0.6	0.7	0.4	0.2	0.1	1.3	0.8	2.4	1.4	3.5	2.1	3.7	2.2
E. areolatus	0.59	0.5	0.3	6.1	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.3	6.1	3.6
L. coeruleolineatus	0.67	0.0	0.0	2.5	1.7	0.0	0.0	2.0	1.3	0.0	0.0	2.0	1.3	0.0	0.0	6.5	4.4
R. sarba	0.50	1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.5	0.0	0.0
L. russelli	0.67	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.2	0.2	0.1	0.3	0.2	0.3	0.2
E. diacanthus	0.59	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1
Total		132.0	64.0	163.2	82.9	86.7	44.0	127.2	63.7	58.3	26.8	143.7	72.8	277.0	134.6	434.0	219.6
Price per kg		0.48		0.51		0.51		0.50		0.46		0.51		0.49		0.51	

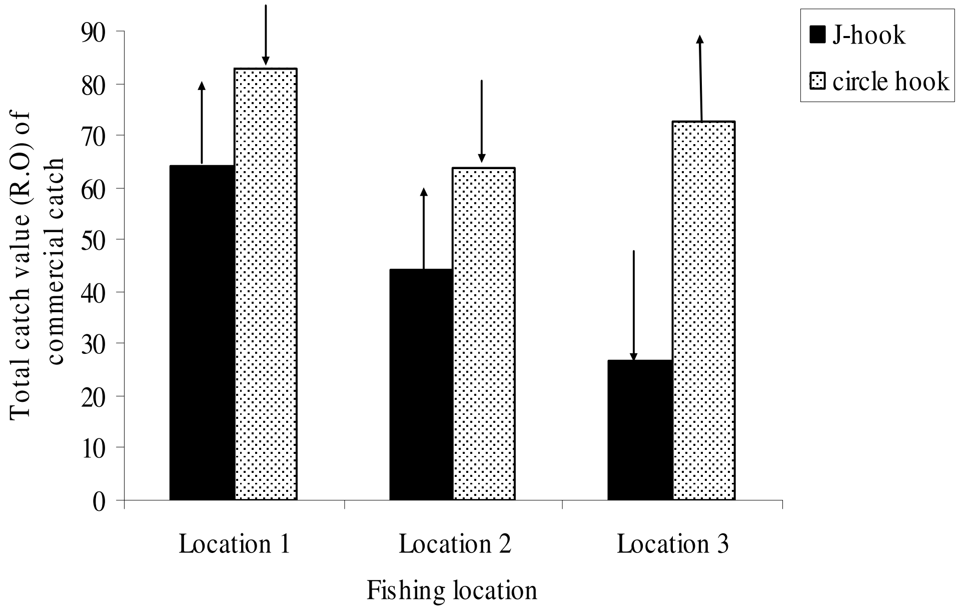


Figure 4.23 Total catch value (R.O.) of all commercially valuable species by hook types at each fishing locations, not including *Paragaleus sp.* The arrows indicate catch value where the observed values were less (down arrow) or more (up arrow) than expected.

4.9.1 Gross Economic Benefit of Lethrinidae

The total catch value of Lethrinidae from both hook types was R.O. 237.9 or 0.49 R.O/kg (Table 4.8). By hook type the value of the catch of Lethrinidae was significantly greater at all three locations ($\chi^2 = 8.032$, df 2, $P = 0.018$). At locations 2 and 3 the catch value for the circle hook was greater than that of the J-hook (Figure 4.24). The total value of the catch taken by the circle hook was 61%, however on a value per kg basis there was little difference between hook types (Table 4.8).

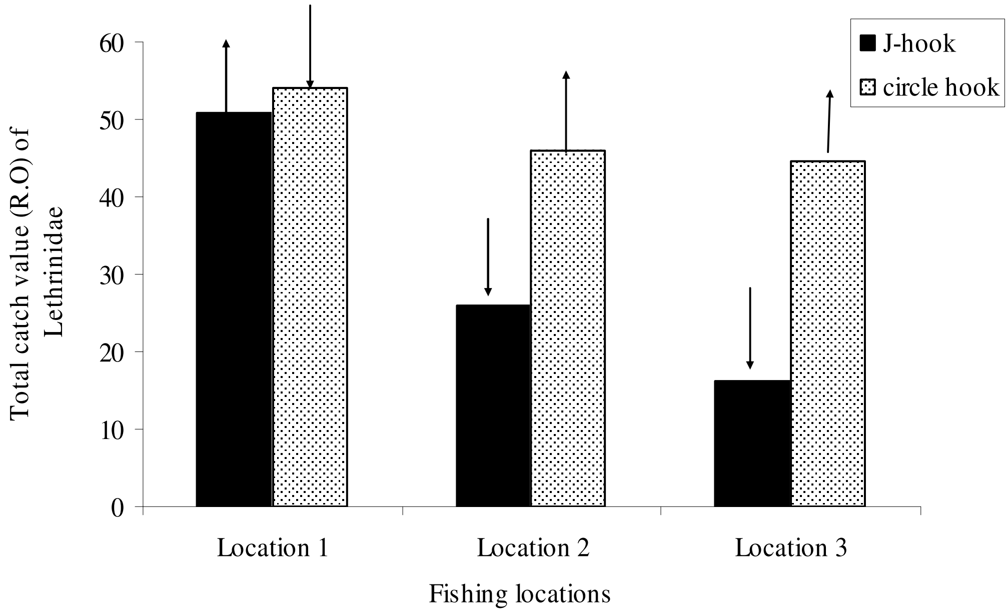


Figure 4.24 Total catch value (R.O.) of Lethrinidae for both hook types by fishing locations. The arrows indicate catch value where the observed values were less (down arrow) or more (up arrow) than expected.

4.9.2 Gross Economic Benefit of *Lethrinus microdon*

Lethrinus microdon was by far the most dominant commercially valuable species caught by both hook types with a total catch value of R.O 135.4 (Table 4.8). There was no significant difference across all three locations in the catch value of *Lethrinus microdon* by hook type ($\chi^2 = 5.186$, df 1, $P = 0.075$) (Figure 4.25). The total catch of *L. microdon* from the circle hook accounted for 65% of the total catch value of this species. By location, the total catch value of this species, caught by the circle hook, was higher at all three locations.

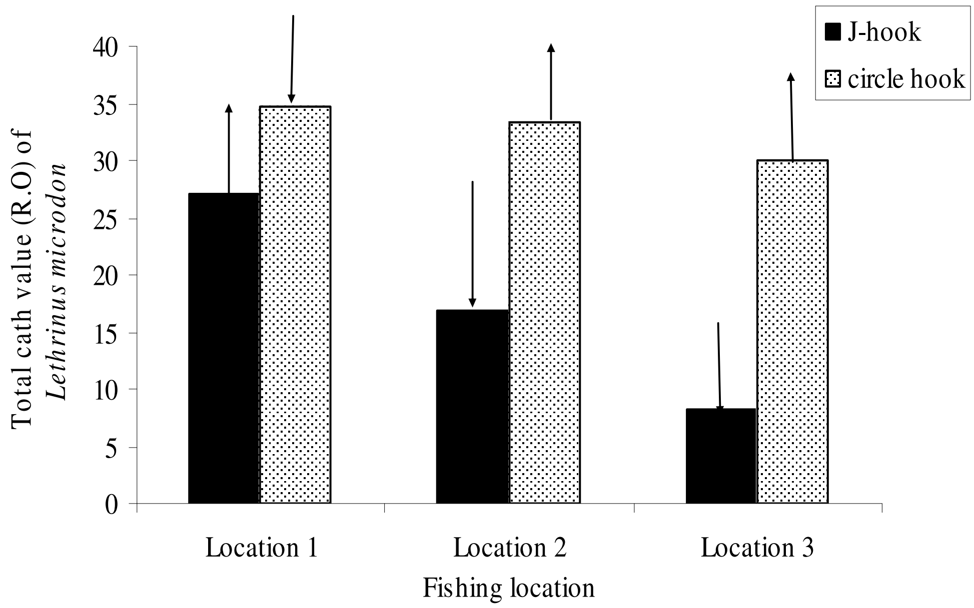


Figure 4.25 Total catch value (R.O.) of *Lethrinus microdon* for both hook types by fishing locations. The arrows indicate catch value where the observed values were less (down arrow) or more (up arrow) than expected.

4.10 Time Efficiency

4.10.1 Setting and Hauling times

There was no significant difference in the time required to set a longline for either hook type (ANOVA: F = 0.397, df 1, 32, P = 0.533) or between fishing locations (ANOVA: F = 0.629, df 2, 48, P = 0.537). For both hook types at each location, the average setting time (+/- standard error) was 6.8 +/- 0.2 minutes.

There was no significant difference in the time required to haul a longline of either hook type (ANOVA: F = 2.269, df 1, 32, P = 0.141) or between fishing locations (ANOVA: F = 0.632, df 2, 48, P = 0.536). For both hook types at each location the average hauling time (+/- standard error) was 14.3 +/- 0.4 minutes.

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 Hook Status

The results presented in Chapter 5 clearly demonstrate the superiority of the circle hook over the J-hook, in relation to the numbers of fish caught. Of the total hooks retrieved, less than 8% of the J-hooks had hooked fish (fish attached and landed) compared to 13% of the circle hooks. With particular reference to the total catch, where the commercial catch is significantly higher than the non-commercial catch, the effectiveness of the circle hook is significantly higher than that of the J-hook. As there is no output control (that is, total allowable catch limit) in the fishery and given the equal soak time for both hook types, the implication of this finding is that the circle hooks are more efficient than J-hooks in harvesting commercial species. In other words, all else being equal, the use of circle hooks could minimize the costs of fishing effort. These results mirror those of Bjordal (1987) for a longline fishery catching tusk and ling and studies by Skeide et al. (1986) for catching cod and haddock. Research conducted by the International Pacific Halibut Commission has shown that the catch rate of the circle hook may be 2.2 times higher than that of the J-hook.

The results also show that 76% and 72% of the circle hooks and the J-hook respectively were retrieved empty (without bait). The problem of bait loss has been described by several authors including Skud & Hamley 1978; Skud 1978b; High 1980; Bjordal 1988; Bjordal & Lokkeborg 1996; and Lokkeborg & Bjordal 1992 who found that depending on bait type, soak time and fishing depth, bait loss may range from 20 – 100%. According to Lokkeborg (1987), bait loss might be as high as 70% with respect to fishing ground, time of day and season. Bait loss occurs during the setting of longlines, by bait predators such as sea birds, fish and sea lice (isopods and amphipods) and during soaking time by starfish or by the fish (target and non-target species) which succeed in removing the bait without becoming hooked (Bjordal 1988). As field level observation does not provide any indication of bait loss to seabirds, turtles or sea mammals, it is possible that small fish or crustaceans could have eaten the bait without being hooked.

The proportion of retrieved J-hooks with bait still attached was almost double the proportion of circle hooks with bait. This suggests that the baited J-hook may have been less attractive to fish, perhaps because the shank of the hook is longer and more exposed. It could also be a result of the lack of experience of the crews in correctly baiting circle hooks, which may have resulted in poorer bait retention on the hook. Nevertheless, J-hooks had better bait retention than circle hooks in this experiment.

During the experiment both hook types were lost on occasion either because of missing mainline section or missing branchlines or due to missing hooks only. Compared to the J-hook, the circle hook had a relatively low proportion of gear loss. It is possible that more J-hooks were lost because of the shape and design of this hook. In contrast to the circle hook, the J-hook has an exposed point which may increase its potential for fouling on rocks and coral. The second reason for losing branchlines and hooks might relate to the characteristics of fishing locations. In this experiment, the three fishing locations used are all in an area known as Ra's Abu Rasa's, an area characterised by patchy regions of coral reefs and rocks. The third reason might be related to the sea conditions, which were unpredictable and fluctuated between calm and rough and this resulted in high current tension on the gear which increased the snagging rate beyond that caused by operating in the reef region.

5.2 Catch Composition

Although this study was conducted after the monsoon season, generally regarded as a good fishing season on Masirah Island, the numbers of commercial and non-commercial fish caught by both hook types at all three fishing locations were relatively low compared to the catch rate from normal commercial fishing operations. The reasons for this low catch rate could be related to several factors including environmental factors such as wind, current, temperature and depth, and geographical factors, being the fishing locale. During the experimental period, the weather frequently fluctuated between calm and rough and this may have had a direct affect on the catch and effort. Patchy bottoms within the fishing locations could possible be another reason for catching less fish Stengel & Al-Harthy (2001) reported that the only fishing gear that can be used at Ra's

Abu Rasa's is longline gear, due to the rocky, patchy, sandy and coralline sea bed structure. Biological factors (e.g. species diversity, fish habitat preference); engineering factors (e.g. fishing gear constructions); and human factors (e.g. skill and experience of the skipper and crew) could all be other reasons for this lower catch rate (Bjordal & Lokkeborg 1996).

The results also indicate that only a few species were caught by one hook type but not by the other hook type. Three species of fish, the commercial species *Arius bilineatus* and *Rhabdosargus sarba,* and a non-commercial species *Stegostoma varium* were caught by the J-hook but not by the circle hook. On the other hand, two species were caught by the circle hook but not by the J-hook. These were the commercial species *Lutjanus coeruleolineatus* and *Epinephelus diacanthus*. These results support the findings of Peeling (1985) and Forster (1973) that the circle hook was more effective than the J-hook for capturing some species over others, although the opposite is true for different species. One possible explanation for these results could relate to differences in species feeding habitats.

Another possible explanation for this result might relate to the behaviour of fish toward baited hooks and it may be that the two species caught by the circle hook were not aggressive enough toward the baited hook. The behaviour of a fish responding to a baited hook is similar to the behaviour of foraging fish (Lokkeborg 1989) and the bait size is probably an important factor affecting the size of fish caught by longline. Fish behavioural studies with longline have shown that cod and haddock exhibit a differing behaviour toward baited hooks; haddock tend to nibble at the bait, thus reducing its size, while cod tend to completely ingest the bait with one bite. Haddock often repeat the attack if ingestion and hooking fails whilst usually cod do not (Lokkeborg et al. 1989).

Another explanation could relate to the engineering aspects of hook shape and design for capturing some species and the kind of species that are caught. This could relate to the lines of force acting through the point and eye of the hook in relation to how best the hook will penetrate the fish's mouth. Radcliff (2005) claimed that for many temperate water species with relatively soft mouth structures the point of the hook should follow a line directly to the eye of the hook, with a minimal angle of attack at the point. Some tropical species are protected by very bony and heavily scaled structures which make it very difficult for a fish hook to penetrate the flesh, and this may explain the reason why the circle hook caught 155 fish more than the J-hook. On the other hand, there were also some species not captured by the circle hook such as *Arius bilineatus* and *Stegostoma varium*, and this might be related to the shape of the hook which has a straight shank which makes it easy for the J-hook to penetrate the wide bony mouth of these species.

5.3 Hooking Location of the Total Catch

Between the circle hook and the J-hook, there were pronounced differences in hooking location. Circle hooks cause less hooking damage than the J-hooks because circle hooks predominantly catch in the corner of the mouth and jaw, while the J-hooks catch more in the throat, gills and gut (Grover et al. 2002). In this study, the vast majority (98%) of the fish caught by the circle hook were hooked in the corner of the mouth and jaw. In contrast, of the fish caught with the J-hook, only 59% were hooked in the corner of the mouth and jaw. On the other hand, the circle hook had substantially fewer fish with gill and gut hooking (1% and 0.8% respectively) compared to the J-hook (29% and 11% respectively), while eye and body hooking were rarely observed for either hook. These results clearly indicate that the use of circle hooks can minimize gut hooking in demersal longline fisheries. Numerous other studies have found similar results for a wide variety of species including striped bass (Lukacovic & Uphoff 2002), Atlantic bluefin tuna (Skomal et al. 2002), Chinook salmon (Grover et al. 2002) and Billfish (Prince et al. 2002).

5.3.1 Hooking Location of the Commercial Catch

The difference in hooking location between the two hook types was also evident in the commercial species. There is a relationship between hooking location and survival of commercial and non-commercial species (Lukacovic & Uphoff 2002). In this study, those fish that were hooked in the mouth and jaw were hauled onboard alive, whereas those hooked in the gut were more than likely dead when hauled onboard. Fish that were hooked in the corner of the mouth and jaw exhibited higher rates of survival than those that were hooked in the gut. In this study, almost 90% of the commercial catch caught using the circle hook was hooked in the corner of the mouth but less than 24% were hooked in this position by the J-hook. The implication of this finding is that the fish caught by the circle hook remain fresh and may command a better market price due to their less physical damage. This finding is also consistent with findings from studies of recreational fisheries (Lukacovic & Uphoff 2002; Grover et al. 2002; Skomal et al. 2002).

5.3.2 Hooking Location of the Non-commercial Catch

All of the non-commercial catch caught by the circle hook were hooked in the corner of the mouth, whereas almost all of the non-commercial catch (89%) caught by the J-hook were hooked in the gut. The statistical test indicated that by hook type, there is a significant difference in the hooking location, with a greater than expected number of non-commercial fish being hooked in the corner of the mouth by the circle hook and a greater than expected number of fish caught in the jaw by the J-hook.

5.3.3 Hooking Location of the Dominant Family (Lethrinidae)

Like the overall catch, the hooking location of the dominant family, Lethrinidae, differed between hook types. In this study, over 89% of lethrinidae taken on the circle hooks were hooked the corner of the mouth, compared with 29% of those taken on the J-hooks. These results suggest that use of the circle hooks could increase the survival of Lethrinidae as there was clearly a relationship between hooking location and survival of Lethrinidae.

5.3.4 Hooking Location of the Dominant Species (*Lethrinus microdon)*

The study also shows that nearly 87% of *lethrinus micro*don caught on the circle hooks were consistently hooked in the cornet of the mouth whereas the J-hooks hooked in the corner of the mouth for about 50% the cases. Similar results demonstrating a very high frequency of hooking in the corner of the mouth have been noted for recreational species, including Billfishes, taken on the circle hook (Prince et al. 2002). The type of hook also affects the species composition of longline catches. This is because fish caught by baited hook are hooked either in the mouth cavity or in the alimentary tract if the hook is swallowed. Some species are hooked more often in the mouth than others (Bjordal & Lokkeborg 1996). Behaviour studies and longline fishing experiments have shown how hooks can be designed to penetrate the tissue of the mouth cavity more efficiency than the J-hook shape. When compared with the J-hook, the circle hook has proven to be superior in catching species such as halibut and hake in the jaw.

5.4 Catching Efficiency of the Total Catch

The catching efficiency of total combined catch (commercial and non-commercial) for both hook types was 16.9 kg per 100 hooks retrieved. This value was considerably higher than those reported by Pajot & Weerasooriya (1980) in Sri Lanka (4.6 kg per100 hooks) and by Kihedu et al. (2001) in Tanzania (5.8 kg per 100 hooks). However, the results indicate that in the difference in catching efficiency between the circle hook (17.1 kg / 100 hooks retrieved) and the J-hook (16.7 kg / 100 hooks retrieved) was not significant.

5.4.1 Total Catch in Weight and Numbers

The total catch weight of the combined catch (commercial and non-commercial) caught by circle hook was relatively higher compared to that of the J-hook. The analysis of variance assumed no significant difference in total catch number among the two hook types, but significant differences were observed in the total catch weight. The circle hook caught 51% of the total catch by weight. The implication of this finding is that, all things being equal, the higher catch weight offers higher revenue for fishermen. Therefore, the results from this study suggest that fishers should use circle hooks as these are more profitable than J-hooks.

These results are consistent with those of Hoey (1996) who reported an increased catch rate for circle hooks relative to J-hooks on observed pelagic longlines sets in the Gulf of Mexico. In that study, J-hooks caught an average 25.5 fish per set and circle hooks caught 32.9 fish per set. A similar increased catching rate for circle hooks has also been reported in the Pacific halibut fishery. At 174 fixed survey stations that were fished twice, once with circle hooks and once with J-hooks, results indicated that circle hooks caught 2.3 times more legal-sized halibut (by weight) than J-hooks (Bjordal & Lokkeborg 1996).

5.4.2 Length Frequency of the Catch

The relative length frequency varied considerably between the J-hook and the circle hook, and across the three locations. The results indicate that the circle hook caught a significantly higher number of fish (over 91%) at a length frequency less than 61 cm compared to the J-hook, whereas J-hooks caught more fish within a length range over 61 cm (almost 30%) compared to the circle hook. One possible explanation for this result might be related to the shape of the circle hook used in this study. Since the size of both hooks was standard (number 6), the circle hook shape was different from the J-hook shape. The shank length and gap of the circle hook was short and circular compared to the J-hook which was straight with a wide gap. Another explanation could be related to the engineering aspects of hook shape and design for capturing some species and the kind of species caught. These are related to the lines of force acting through the point and eye of the hook in relation to how best the hook will penetrate the fish's mouth (Radcliff 2005). This may explain the reason why the circle hook caught 290 fish more than the J-hook within the length range of less than 61 cm.

5.5 Catching Efficiency of the Commercial Catch

The results also indicated that the catching efficiency for the commercial catch of the circle hook was higher than that the J-hook (16.3 kg / 100 circle hooks retrieved versus 13.6 kg / 100 J-hooks). The analysis of variance test indicated a significant difference in catching efficiency of the total commercial catch between the two hooks. The results clearly demonstrate that the circle hook is a more efficient gear than the J-hook. This finding is promising from both a management as well as a fishing operational perspective in promoting the use of circle hooks. This is because of the fact that both management authority and the fishing industry are continuously looking to maximise the net benefits from fisheries. These results confirm the results of other studies (Skeide et al. 1986; Bjordal & Lokkeborg 1996; Erzini et al. 1999; Bjordal 1987; Bacheler & Buckel 2004; Prince et al. 2002; Bertrand 1988; Ralston 1990; Jones 2005; Ekanayake 1999), which found that the circle hook was superior in its catch rate. Many investigations have shown that the circle hook when compared to the J-hook, is clearly superior in catching efficiency (Forster 1973; Quinn et al. 1985; Skeide et al. 1986).

Innovative hook designs such as the circle hook have been shown to improve catch rates over the J-hook in the order of 50 – 100% for halibut (Bjordal 1988). In the North American longline fisheries, the circle hook has been proven to give significantly better catch rates, especially for halibut and other species (Peeling & Rodgers 1985). There are several factors that can influence the catch rate, including species, catch composition, and size selectivity of longline gear. For example, the bait and size of the bait, hook spacing and gear construction will all influence the attractiveness of the baited hook and the retention of hooked fish until they are landed. These factors were standardized during the present study, so that the observed differences could be related to hook type only.

5.5.1 Commercial Catch in Weight and Numbers

By weight and numbers, circle hooks caught a higher commercial catch compared to that of the J-hook. The commercial catch of the circle hook was 94.7% and 93.2% of the total weight and numbers, respectively of all fish caught by the circle hook. The results also indicated that the circle hook is more efficient in catching commercial species. These findings are consistent with the studies of Peeling (1985) and Forster (1973) that showed circle hooks were more effective than J-hooks in catching halibut and other species. Compared with the J-hook, the circle hook is reported to give a 50 – 100% increase in the catch rate of halibut. These results are consistent with those of the US National Marine Fisheries Service and International Pacific Halibut Commission, which in 1984 reported that the J-hook caught on average 17 fish per 100 hooks deployed and the circle hook 27 fish per 100 hooks deployed (Bowerman 1984).

The greater total catch weight of commercial species using the J-hook compared with the circle hooks, but no difference in total catch number, can be explained by the capacity of J-hooks to catch larger fish. There is evidence that larger fish are more easily caught with a J-hook than with a circle hook (Peeling 1985; Forster 1973). This would allow the use of minimum size limits as a management tool as use of J-hooks would facilitate a reduction in catches of smaller fish.

5.5.2 Length Frequency of the Commercial Catch

The results show that compared to the J-hook, the circle hook caught a considerably higher number of commercial fish i.e. over 94% at a length frequency of less than 61 cm. However, the J-hook caught larger fish, over 39% at a length range over 61 cm. This result might be related to the design and shape of the J-hook when compared to the design of the circle hook or another explanation for this difference might be found in the feeding behaviour between large and small fish. Fish feeding in a habitat with a mixture of natural prey of different sizes will often show a preference for certain prey size. Smaller fish generally prefer prey below a certain size, determined by such factors as their mouth size and their ability to capture and handle the prey (Bjordal & Lokkeborg 1996). Therefore, bait size is likely to be an important factor affecting the size of fish caught by baited hooks.

5.6 Catching Efficiency of the Non-commercial Catch

The catching efficiency of the circle hook and the J-hook of the total non-commercial catch were 1.9 +/- 0.4 kg and 6.6 +/- 4 kg per 100 hooks retrieved, respectively. It was found that in terms of non-commercial catch, there was no significant difference between hook types. The management implication of this finding is that the circle hook does not increase the number of by-catch compared to the J-hook and thereby it does not undermine the conservation of non-commercial species.

The statistical test results indicate that there was no significant difference between hook type in relation to the total catch weight and number of non-commercial catch.

For both hook types 42% of the non-commercial catch in the all fishing locations measured between 31 – 60 cm, with 49% greater than 61 cm and 9% less than 31 cm. Between the hook types there was no significant difference in the length frequency distribution of the non-commercial catch.

5.7 Catching efficiency of the Dominant Family (Lethrinidae)

The diversity of families caught in this study was relatively low between the J-hook and the circle hook. There are many factors such as habitat preference, fishing ground and bait odour plume that can influence the distribution of families, (Bjordal & Lokkeborg 1996). It is fundamentally important in longline gear selectivity studies to use a standard bait since the power of attraction is directly related to bait size (Bjordal & Lokkeborg 1996). In this study, cuttlefish bait was used since the second objective of the study was to evaluate the selectivity of two types of hooks. However, the effect of bait size was not investigated in this study. All other gear characteristics and fishing strategies were in accordance with normal commercial longline fishing procedures in Oman. The results indicate that the most dominant family was Lethrinidae. The J-hook has been shown to be more effective for catching larger individuals of this family than the circle hook, although the circle hook catches more smaller fish and a greater weight overall. A significant difference in catch weight of Lethrinidae was observed between the two hook types and location.

5.8 Catching efficiency of the Dominant Species (*Lethrinus microdon)*

The most dominant species caught by both hooks at the three locations was *Lethrinus microdon.* Even though a significant difference in catch weight was observed between the two hook types, no significant difference occurred across the fishing locations. Although the circle hook is an efficient gear for catching large numbers of this species, the J-hook is a selective gear for catching larger sized *L. microdon*.

A possible explanation for these results could relate to the design of the circle hook and J-hook used in this experiment. The 5.3 cm shank length of the J-hook was straight and long compared to the circle hook that was circular and short and only 3.5 cm in length. In addition, the gap of the J-hook was wider by 1.9 cm than that of the circle hook. The wide gap hook, with a very fine turned-in point, may be more successful in penetrating the inner mouth parts of the catch than a more conventional J-hook.

5.9 Gross Economic Benefit

The catch value was calculated for all commercial species without *Paragaleus sp.* because it is treated as a protected species (Ducrocq 2004). The results indicated that the total catch value of the commercial catch using the circle hook was higher than that of the catch using the J-hook. The average price per kg was also higher for the catch of the circle hook because more highly valued species where caught with this hook. This finding reinforced the fact that, all things being equal, the circle hook has the potential of generating higher economic benefits to fishers.

5.10 Time Efficiency

Hauling of the longline gear was by far a more time consuming task than setting the gear due to the time required to remove the fish from the hook or to untangle or remove fishing gear from rocks or coral. The average hauling time per basket for both hook types was around 14.3 minutes compared with an average setting time of 7.1 minutes. Although the average setting and hauling time for the J-hook was less than that of the circle hook the results from the statistical test indicate that there was no significant difference in relation to setting and hauling times between the two hooks.

Despite the fact that the soaking time was standardized at two hours per basket for both hooks, it was sometimes difficult to differentiate between the baskets, and it took a long time to haul in. The reason for this was related to the bad weather conditions on some fishing days, the number of fish caught in the gear, the time spent to remove the fish from the hook and tangling of the gear on rocks or on coral reefs.

On the other hand, there is fishing time which is not directly related to catching such as time spent steaming to and from the fishing grounds, preparing the fishing gear including baiting the hooks, deploying and handling the gear, handling the catch after it has been caught and time lost to bad weather. In this study, there was a difference in time taken baiting the two different types of hooks, with the circle hook taking more baiting time than the J-hook. However, one basket of the circle hook took around 11 to 20 minutes to be baited, whereas it took around 8 to 16 minutes for the J-hook (Pers. obs.). The reason for this was related to the peculiar shape of the circle hook, making it more difficult to bait than the J-hook.

5.11 Conclusion

Fisheries have traditionally played a significant role in the social and economic development of the Sultanate of Oman. Notwithstanding the major socio-economic importance of small-scale fisheries in Oman, many aspects regarding fisheries have not been studied comprehensively. In particular there is a lack of information on size selectivity of longline gear, catch composition, catching and time efficiency, and gross economic benefit. Little is known about the amount of longline gear in use, since there is no legislation limiting hook and line gear. The objectives of this study were to evaluate the efficiency (catching and time), selectivity, and gross economic benefit, of two hooks types.

Longlining is a simple traditional fishing method which is used world wide and it is considered to be one of the cleanest, most fuel efficient and environmentally friendly catching methods. Longlines are selective fishing gear which by using the right hook size can avoid catching undersized fish (i.e. juveniles), thereby enhancing catch quality. Longline gear is used for catching a large number of commercially valuable demersal species, semi-pelagic and pelagic species (Chapter 2).

The revenue from fisheries resources in Oman exceeds revenue generated from all other agricultural resources and among the natural resources it is second only to the proceeds obtained from oil and natural gas. Although fisheries resources are renewable, maximum benefits can only be realized when they are properly managed and protected from over-exploitation. Fishing gear used in Oman consists of trawls, gill nets, traps, hand lines, and longlines (Chapter 3).

To achieve the objectives of this study, for 17 days in December 2004 a demersal longline fishing experiment was conducted in three fishing locations at Ra's Abu Rasas south of Masirah Island in Oman using 6,120 hooks (i.e. 3,060 J-hooks and 3,060 circle hooks) deployed from a small fishing boat in depths ranging from 10 to 50 m (Chapter 4). The most important findings of this study are:

1. The number of circle hooks retrieved (i.e. empty hooks, with fish or with bait) was higher and as the number of circle hooks lost was lower than the J-hook.

2. Although the circle hook resulted in significantly more fish being caught in the corner of the mouth and jaw, the J-hook had significantly higher gill and gut capturing.

3. As there was no output control (that is, total allowable catch limit) in the fishery and given the equal soak time for both hook types, the implication of

this finding is that the circle hooks are more efficient than J-hooks in harvesting commercial species. In other words, all things being equal, the use of circle hooks could minimize the costs of fishing effort.

4. The J-hook caught 11 families whereas the circle hook caught 9 families. Classified by species, the J-hook caught a total of 16 species, whereas the circle hook caught 15 species.

5. Circle hooks can minimize gut hooking in demersal longline fisheries.

6. Circle hooks caught a greater proportion of fish < 31 cm than did J-hooks, whereas J-hooks caught a greater proportion of fish > 60 cm total length.

7. The results demonstrate that the catching efficiency (i.e. total weight of all commercial fish caught) by the circle hook was relatively, but not significantly, higher than the J-hook.

8. The fish caught by the circle hook weighted more than those fish caught by the J-hook. This may result in a higher price being obtained in the market as the higher catch weight generates higher economic benefits for fisher.

9. The circle hook is economically more profitable – the weight of the total catch was greater and could be sold for a higher total price than the catch from J-hooks.

10. Circle hooks were more time consuming to operate than J-hooks, relative to setting and hauling time.

Species selectivity of longline fishing gear selectivity depends on feeding motivation of different species, hooking probability of different species, competition among species, and bait size. To allow this study to quantify species selectively, only as a function of hook type and location, the potential effects of hook size, fishing strategy, and bait size were standardized across the hook types and locations. The circle hook caught more commercial species with a higher economic value than did the J-hook. The main factors influencing the setting and hauling time for longline gear include: hook shape and design, number of fish caught in the gear, time spent removing fish from the hooks, tangling or sticking of the gear on the seabed and weather conditions at the time of fishing (Chapter 6). Finally, the circle hook is selective and an efficient gear which can be used successfully in Omani waters.

5.12 Recommendations

Some suggestions for further studies of longline fishing in Oman fisheries are mentioned in this study. The following are the main suggestions and recommendations that need to be a priority for further studies of longline fisheries:

1. Studies should also be carried out to test the efficiency and selectivity of semi-pelagic, pelagic and vertical longline gear in the Oman EEZ.

2. Whereas in this study only the J-hook and the circle hook number 6 were used, further studies are necessary using different hook sizes and shapes. In particular a larger circle hook should be tested in an attempt to increase the average length of the catch and reduce catches of small fish.

3. As cuttlefish and squid are considered the best bait for demersal longlining, further studies on different bait (such as mackerel, sardine and ribbonfish) and bait size, would be useful to evaluate their efficiency and selectivity on longline gear.

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Appendices

Appendix 3.1: Data collecting sheet.

Date:			Long:		Trail No.	Sea condition:		
Location No:			Lat:		1 2 3 4 5 6	Sea bottom:		
Setting T. S:			Hauling T.S:		Current (kt):	Depth:		
Setting T.F:			Hauling T.F:		Wind force:			
Hook No.	Fish caught	Bait on	Branchline lost	Hook lost	* Hooking location	Fish Name	Weight	Length
	Y/N	Y/N	Y/N	Y / N			(kg)	(cm)
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
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.								
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58								
59								
60								

*Hooking location: Jaw (J), Gut (Gu), Eye (E), Gill (G), Mouth corner (Mc), ?Body (B)