UNITED NATIONS UNIVERSITY
Fisheries Training Programme
PO Box 1390, Skulagata 4
121 Reykjavik, Iceland.

Final Project 2008

GILLNET SELECTIVITY: A CASE STUDY IN ICELANDIC LAKE AND MARINE ENVIRONMENTS WITH REFERENCE TO CAMBODIAN FISHERIES

Makkhen Kheng
Battambang Fisheries Administration Cantonment
Fisheries Administration
Phnom Phen, Cambodia. P.O. Box 582.
Khenmak@yahoo.com

Supervisor:
Ólafur A. Ingólfsson
Marine Research Institute
olafur@hafro.is

ABSTRACT

This study demonstrates the selectivity of different mesh sizes and mesh types for different marine and fresh water fisheries. Three species of fish were chosen for this study: cod (*Gadus morhua*) and saithe (*Pollachius virens*) from marine fisheries and brown trout (*Salmo trutta*), from the inland fisheries. The selection model is expanded by application of relative length (i.e. the ratio of fish length to the mesh size) to obtain the curve for gillnet selectivity. Four kinds of functions are fitted to the data: normal fixed spread, normal, gamma and log-normal with proportional spread. Each fish species was best fitted to a different model: the gamma model gave the best fit to the cod data, the normal model for saithe and log-normal model for trout. The study shows how catches change with different mesh sizes and mesh types of gillnets and it shows how selective gillnets are. A study like this can serve as a tool for choosing the right mesh size to avoid juvenile fish as well as to maximize and control catches of the targeted fish by the right choice of gillnets.

TABLE OF CONTENTS

Deleted:
Deleted:
Deleted:
Deleted:
Deleted:
Deleted
Deleted
Deleted:
Deleted:
Deleted:
Deleted:
Deleted:
Deleted:
Deleted:
Deleted:
Deleted:
Deleted:
Deleted:
Deleted:
Deleted:
Deleted:
Deleted:
Deleted:

LIST OF TABLES

Table 1: Fishing scheme of 6 monofilament and 6 multifilament gillnets (mesh size in inches) 16
Table 2: The models used in the selection calculations. All are of unit height as relative fishing intensity is modeled separately (Millar and Fryer, 1999). 17
Table 3: Numbers and weight of marine fish caught with gillnets of varying mesh sizes and mesh types from the 56 stations in 2007 (catches are pooled for the stations and standardized as catch per two gillnets). 18
Table 4: Log-linear fit to cod data caught by monofilament gillnets. 18
Table 5: Mean length and standard deviation of cod length from monofilament gillnets. 18
Table 6: Log-linear fit to cod data caught by multifilament gillnets. 19
Table 7: Mean length and standard deviation of cod length from multifilament gillnets............ 20
Table 8: Log-linear fit to saithe data caught by monofilament gillnets. 21
Table 9: Mean length and standard deviation for saithe length with monofilament gillnet. 21
Table 10: Log-linear fit to saithe data caught by multifilament gillnets..................................... 22
Table 11: Mean length and standard deviation for saithe length with multifilament gillnets. 22
Table 12: Number of trout caught in Baulárvallavatn lake in eight different mesh sizes 24
Table 13: Log-linear fit to trout caught in Baulárvallavatn lake. 24
Table 14: Number of trout caught in Hraunsfjarðarvatn lake in ten different mesh sizes. 26
Table 15: Log-linear fit trout caught in Hraunsfjarðarvatn lake. 26

Deleted:

LIST OF FIGURES

1 INTRODUCTION

Gillnets are fishing gear that have been used for centuries. A gillnet is a wall of netting vertically hanging in the water. The net is kept vertical by floats on top and weights at the bottom and mainly used by small to intermediate sized boats. Gillnetting probably began with early fishermen using canoes and cedar fiber nets. They probably attached stones to the bottom of the nets as weights, and pieces of wood to the top to use as floats. Each net would be suspended either from shore or between two boats (Anon., 2008 b). Modern gillnets are used in both inland and marine fisheries; the design of the net depends upon the target species. Gillnet fishing is based on the fish swimming into the net, which they are not able to see, and becoming entangled by the gills (Anon., 2008 c). Gillnets are the most popular fishing gear used for subsistence fishing in Cambodia and their use is mainly limited to this sector. The majority of fish for subsistence purposes is caught by gillnets (Lamberts, 2001). Gillnet fishing makes up a substantial part of the inland fisheries, and they are therefore important to food security and to the national economy.

Limited information is available on the practice and selectivity of gillnet fishing in Tonle Sap lake and in other inland waters of Cambodia. In 2000, the government of Cambodia initiated a fishery reform by releasing 56 percent of leased lots to the fishing communities, aiming at reducing conflicts and sharing more resources with the poor fishers. Some community fisheries were established by the government and whereas others were created by non-governmental organizations (NGO) or other projects. As a means of improving the conditions of the communities many agreements and regulations were developed as a policy to manage the fisheries resources such as: community fisheries sub-decree, the community fisheries by-law rule and regulation, the community fisheries boundary demarcation and map, and the communities fisheries area management plan (CFAMP). The appropriate number, length and size of the fishing gear was debated and limited in some of these documents, but the limitation of the fishing gear used in communities fishing areas lacked criteria and was not based on experiments at all. Gillnet selectivity studies are important to assist the community fisheries in determining the most suitable fishing gears.

The aim of this study is to assist community fisheries to establish sustainable gillnet fisheries in their fishing grounds. To accomplish this aim, gillnet selectivity was estimated with the focus on general methods to calculate the length distribution and selection by using gillnet series of different mesh sizes and mesh types. The knowledge and experience gained from this study will serve as a guide to design an experiment based on the same method for estimating gillnet selectivity in the home country. The results of the current study will be a call to the community fisheries for a standardization of gillnets by length and mesh size for sustainable utilization of fisheries resources.

2 LITERATURE REVIEW

2.1 Fisheries in Cambodia

Figure 1: Cambodia and its water body map (TSEMP, Anon., 2008 a)

Cambodia covers 181,035 km^2 within the tropical region in Southeast Asia between Lao PDR, Vietnam, Thailand and the Gulf of Thailand. It is divided into four principal agro-ecological zones: plains, coastal, plateau/mountain and Tonle Sap Great Lake. The Tonle Sap is the largest freshwater lake in Southeast Asia. It forms a natural floodplain reservoir in the depression of the Cambodian Plain and is drained by the Tonle Sap River into the Mekong River near Phnom Penh (Anon., 2007 a).

Fisheries constitute one of the most important sectors, playing an important role in the daily food production and contributing to the national economy. The freshwater fisheries are one of the most productive in this region due to the presence of large flood plains around the Great Lake and along the Tonle Sap and the Mekong Rivers. The marine fishery and aquaculture are small compared to the inland fisheries. Cambodia has a coastline of 435 km. The marine fishing grounds are located on the eastern coast of the Gulf of Thailand (Anon., 2008 d).

2.2 Gillnet fishing gear in Cambodia

Cambodian fishermen usually use different gillnets depending on the season and the location of fishing ground. Two types of gillnets are normally used: fixed gillnets and drift gillnets. The fixed gillnets are used in flooded forest areas or near the edge of the river and the drift gillnets are used across the stream to catch migrating fish. Gillnets are made of mono- or multifilament nylon, although multifilament is being used less and less. Smaller meshed nets are mostly monofilament, while larger meshed nets can still be multifilament. Usually the fisher buys the materials and assembles the net at home. Most nets have a bottom line. Metal rings are used as weights and sizes vary (Deap *et al.*, 2003). Gillnets are divided into three groups by species selectivity and length distribution:

- Mesh size group <50 mm: mesh sizes 40-45 mm; length of net 50-1000 m; depth 1.8-3.5 m. Hanging ratio varies from 0.43-0.55. The nets are set at the surface and used year round in most provinces. The catch consists mainly of Riel (*Henicorhynchus* spp.), Khnawng Veng (*Dangila lineata* and *cuvieri*), Kros (*Osteochilus hasselti*), Sraka Kdam (*Cyclocheilichthys apogon*), Chrakaing (*Puntioplites* spp.), but there are another 9 species frequently captured as well.
- Mesh size group 50-70 mm: most common is 60 mm; length of net 100-700 m; depth 1.5-1.8 m. hanging ratio recorded is 0.44. The nets are set mostly at the surface and in mid water. They are used year round in most provinces. The catch consists mainly of Chhkok (*Cyclocheilichthys enoplos*), Kantrang Preng (*Parambassis wolffi*), Chhlang (*Mystus*

nemurus), and Chrakaing (*Puntioplites* spp.). There are another 5 species frequently captured as well.

- Mesh size group >70 mm: mesh sizes vary from 80-90 mm; length of net 60-1200 m; depth 1.2-4 m. The nets are set mostly at the surface and less often at the bottom. They are used most of the year, but there are no reports for April and May. The catch consists mainly of Chhkok (*Cyclocheilichthys enoplos*), Krum (*Osteochilus melanopleurus*), Kaek (*Morulius chrysophekadion*), Khlang Hai (*Belodontichthys dinema*), Pruol (*Cirrhinus microlepis*), and Chhpin (*Barbodes gonionotus*), and there are another 5 species frequently captured as well (Deap *et al.*, 2003)

The use of gillnets as family fishing gear is limited to lengths of less than 10 m by law (Anon., 1987). Such a length is not realistic and most people will use greater lengths. Proposals have been made to ban the use of the smallest and the largest mesh sized nets in view of the negative effects on fingerlings and the brood stock of a number of valuable species. Nets and seines with mesh size less than 15 mm and bigger than 150 mm are already prohibited (Anon., 2007 b).

2.3 Fisheries management in Cambodia

The Cambodian fisheries sector is managed by the Fisheries Administration (FiA) within the Ministry of Agriculture, Forestry and Fisheries (MAFF). The FiA has jurisdiction over marine fisheries and over all bodies of inland waters up to the average highest water levels during the period of annual inundation, i.e. the flood plains. Consequently, the FiA is responsible for management of hundreds of thousands of hectares of seasonally flooded lands and extensive coastal mangrove forests. When the level of the Mekong river is high the flow of the Tonle Sap river reverses: water is pushed into the lake, raising its level by up to 10 meters and increasing its area from 2,500-3,000 Km^2 in the dry season to 10,000-16,000 Km^2 in the rainy season.

Inland fisheries: The inland fishery includes the water bodies that extend from the marine water to the inland border of the Kingdom of Cambodia. The inland fishery is divided into:

- The concession fishing lot allocated for investment or hiring for fishing.
- Fisheries conservation area, defined as habitats of protected aquatic flora and fauna. There are 13 fish sanctuaries (8 situated in the Great Lake) throughout the country (So and Buoy, 2005).
- Inundated forest area including forest zone, where there is important aquatic animal habitat for feeding, spawning, breeding and protected inundated area.
- Family scale fishing area reserved for people or traditional community fishing.
- The open access area, which is not otherwise classified.
- Fishing area for aquaculture development.
- Flooded plain in wet season.

2.3.1 Fisheries management based on seasons

The open seasons of fishing are from 1st October to 31st of May for areas to the north of the quarter bras parallel (Chaktomuk junction) and from 1st November to 30th of June for areas to the south of the quarter bras parallel.

2.3.2 Fisheries management based on fishing gears

The fisheries management system is based on the categorization by operation size—large/commercial-scale, middle-scale and family-scale—as determined by the MAFF proclamation. The criteria for classification of each fishing gear are based on the size of the gear, the method of fishing and the catch capacity of the gear.

Cambodians use a variety of gears of all sizes, many of which were developed to suit local conditions. Many gears and methods reflect the accumulated knowledge of generations of Cambodian fishers. The largest gears, such as "dais" bag net and bamboo fence/barrages with traps, are considered non-selective and target migrating fish in shoals (So and Buoy, 2005).

Most smaller, traditional gears are specialized for fishing particular habitats in a particular way to catch a few target species. The diversity of gears parallels the diversity of fish—more than 150 types of gears are known from Cambodia (Deap *et al.*, 2003). Fresh water fishing methods of Cambodia are divided into three groups.

Large-scale or commercial fishing "the fishing lots": Access is usually regulated by the government (FiA/MAFF) through an auction-like process. The fishing lots are operated for 2–4 years. The auctions grant private lot owners exclusive rights over a particular fishing grounds or anchor positions for large-scale fishing gear. The lot owners are also charged with the task of protecting natural habitats within the lot boundaries, although law enforcement remains the responsibility of the FiA. There are two types of large-scale fishing gear used in Cambodia, namely dais (i.e. bag net) and bamboo fence/barrage with trap.

Licensed or middle-scale fishing: It is currently operated under a system of licensing, whereby access is granted to those who could afford to purchase a license enabling them to use larger fishing gear. However, as there are no limits to the number of licenses that are issued, the system cannot be considered as a tool to properly manage the resources. Its gear includes, gillnet (length more than 10m and mesh size 15 to 150 mm), seine net, Lop Nor (arrow-shaped trap), drag net, surface trawling, giant cast net, etc.

Family or small-scale fishing: It is not licensed and family gear can be used throughout the year and in almost all water bodies, except in protected areas (e.g. fish sanctuaries) and in the fishing lots during the open season. The family gears can be used inside the fishing lots in areas designated as "set aside" for people during open season and throughout the lots during the closed season. Its gear includes cast nets, dip-nets and small gillnets, less than 10 meters long, small bamboo traps, long-line and single hook-line, etc. (Anon., 1987 and Anon., 2007b).

In October 2000 the government of Cambodia announced a major change in fisheries management policy where small scale fisheries was promoted through establishment of community fisheries, 56 percent of the total area was reallocated from fishing lot concession to open access. The establishment of community fisheries based on legal basis and the framework laid out in the Royal Decree on Community Fisheries and the Sub-decree on the establishment of community fisheries from 2005. These legislations (decree and sub-decree) provided the basis for a co-management system through community fisheries. The Fisheries Administration (FiA) has a key role in fostering and facilitating the community efforts in resources management and livelihood development (Suy, 2007).

2.4 Fish behavior

According to the case study on floodplain gillnets fisheries in Tonle Sap (1996-1997); eight economically important species were selected for a detailed study of the relationship between the fish and the different habitats (Lamberts, 2001). The selected species were:

- **Trey pruol *(Cirrhinus microlepis)***: An important species found in large rivers in the lowland floodplains of Thailand, Cambodia, and Vietnam. This family is the most developed one in Cambodia in terms of numbers of genera, species and number of individuals attained size up to 65 cm. Believed to spawn from June to September in the northern Mekong rapids from Sambor to the Khone falls. The fish move with the Mekong floods and re-enter the Tonle Sap mainly for feeding in the rich feeding grounds of the inundated areas. When the water recedes (December to March), they leave the Tonle Sap lake and channel in waves and migrate up the Mekong. The age of sexual maturation and first spawning is in the third or forth year. Caught with seines, gillnets, traps, and hook and line.

- **Trey srawka kdam *(Cyclocheilichthys apogon)***: a widely distributed, common mid-water species in the Mekong, with size up to 15 cm. Occurs in canals, ditches, and generally in habitats with slowly moving or standing water. Typically found near the surface, branches, and tree roots where it browses for small plankton and crustaceans. During the high water season, it moves into flooded forest and the floodplain. Known to breed late in the high water season from September to October as water levels peak and begin to decline. Often found in impoundment and seems to prosper there. Taken with seines, cast-nets, set-nets, and traps.
- **Trey chhkok *(Cyclocheilichthys enoplos)***: Found at mid water to the bottom level of rivers, common in the Mekong, attaining size up to 74 cm, commonly 45 cm. Started spawning in the rainy season, probably on floodplains or inundated riparian forest. Return to rivers from October to December with the catch decreasing steadily as the fishing season progresses in the Tonle Sap. The main spawning season of the group of anadromously migrating fish for breeding in the Mekong from May to July. Not found in impoundments. Young feed on zooplankton and adults on insect larvae, crustaceans, and fish. Taken with seines, cast-nets, gillnets, set-nets, and traps.
- **Trey reil *(Henicorhynchus siamensis)***: Found often in great abundance at mid water to bottom depths in large and small rivers in the Mekong and Chao Phraya basins, with size up to 20 cm. Annual tropic migrations to the floodplain in the wet season. Return to the rivers as water levels begin to fall in October with number increasing through December and then slowly declining. Feeds on algae, periphyton and phytoplankton. This is the most important fish in the annual dai (set-net) fishery on the Tonle Sap. Caught with seines, cast-nets, set-net and traps.
- **Trey krum *(Osteochilus melanopleurus)***: Found at mid water to the bottom depths in rivers, streams, canals, and swamps throughout Cambodia, with size up to 24 cm. Large individuals are also in impoundments. Moves into seasonally flooded habitats that supply its preferred diet of mostly periphyton as well as leafy plants such as aquatic macrophytes

and inundated land plants. Feeds also on phytoplankton, filamentous algae, and bottom algae. Begins to return to the rivers in October, with numbers steadily increasing until January, when they begin to decline again. Abundant in the catches of the *dai* fisheries in the Tonle Sap. Caught with seines, cast-nets and traps.

- **Trey slak russey *(Paralaubuca typus)***: Found at shallow depths in large rivers. A schooling species that is usually harvested in a large numbers throughout its range. Attaining size up to 18 cm. Moves into the flooded area late in the flood cycle when water levels are high, and only leaves the inundated area when the water levels have already considerably declined. *Paralaubuca typus* are feeding mainly on plankton and crustaceans, but occasionally on grains, seeds and flying insects. The diverse diet permits the species to thrive in several kinds of habitats in the inundated area, spawning at the beginning of the rains (May-June), the fish reaching full maturity when 13 to 15 cm long. Its greatest abundance in the lower Mekong coincides with the peak fishing season of December. Taken by seines, cast-nets, set-nets, weirs, and traps.
- **Trey kawmphleanh phluk *(Trichogaster microlepis)***: Found in shallow sluggish or standing water habitats with a lot of aquatic vegetation from Thailand to Vietnam and common in the Tonle Sap and makes up a significant part of the fisheries in the lake, with size up to 15 cm. The species of the *Trichogaster* genus blow masses of glutinous bubbles to form floating nests in which they deposit their eggs. The use of a nest to deposit the eggs in keeps the eggs and the newly hatched fry concentrated in a protected locality. Feeds on zooplankton, crustaceans, and aquatic insects. Caught with seines and cast-nets.
- **Trey kawmphleanh samrai *(Trichogaster trichopterus)***: Found in shallow sluggish or standing water habitats with a lot of aquatic vegetation from Thailand to Indonesia. Occurs in seasonally flooded forests throughout the middle and lower Mekong and Tonle Sap. Reaches a maximum length of 15 cm, commonly 12.5 cm. Feeds on zooplankton, crustaceans, and insect larvae. Caught with seines cast-nets, set-nets, and traps.

These eight important species will be the subject of the planned survey in Cambodia. The experiment will be conducted in one of the community fishing areas using a series of different mesh size gillnets in accordance with the fish species and specific locations. The fish species data obtained from an experiment will be utilized for the assessment of fish length distribution and gillnet mesh size selectivity. This study could be helpful in standardizing the length and mesh size of gillnets in accordance with the above species.

2.5 Gillnet selectivity

The meshes of a gill net are uniform in size and shape, hence highly selective for a particular size of fish. Fish which are smaller than the mesh of the net are able to pass through unhindered, while those too large to push their heads through the meshes as far as their gills are unlikely to become firmly wedged and may escape. This gives selectivity towards medium sized fishes, (Puente, 1997). The probability of a fish being caught when it comes in contact with a gillnet is largely dependent upon fish size. Gillnets are, therefore, size selective" (Potter and Pawson, 1991). A specific mesh size catches fish in a certain length category and is often most effective within a narrow length group. In addition, gillnets may discriminate among species according to fish morphology, for example body form and the presence of spines. Gillnets are also restricted to certain habitats, which will also influence the species selectivity of this gear. The body length distributions of fish in the different gillnet mesh sizes are the simplest way to express and compare selectivity of gillnets of different mesh sizes.

For management purposes it is preferable to calculate the gill net selection curve, which is an expression of the probability of capturing a certain size group of fish in a specific gillnet mesh size (Næsje *et al.*, 2004). The gillnet selection curve has (unlike trawl selection) a descending slope on the right hand side. Small fish can pass through the meshes as was the case for trawl net, but large fish may avoid being caught in gillnets because their heads are so large that they cannot be gilled (Sparre and Venema, 1998).

Gillnet selection is known to depend on a variety of other factors than mesh size, such as net construction, visibility and elasticity of the net, net material, shape and behavior of the fish, and method of fishing. Selectivity is affected by elasticity and flexibility of the net twines, meshes of a more elastic twine can be stretched to catch a large struggling fish but a small fish may be too weak to stretch the twine. Nets of thinner twine are less visible and are easy to stretch and more flexible, therefore they should tangle more fish and catch larger fish, as long as the twine is not broken by those larger fish. A lower hanging ratio is likely to increase the proportion of fish that are tangled. Selectivity can be affected by the way a net is fished, as different fish may occupy different habitats and the sizes caught may depend on the location and depth of fishing (Hamley, 1975; Fernö and Losen, 1994).

There are four main ways of fish getting caught by gillnet (Figure 2):

- **Snagged:** The fish is attached to the netting at the head region.(A)
- **Gilled:** The fish is meshed immediately behind the gill cover.(B)
- **Wedged:** The fish is meshed around the body somewhere behind the gill cover. Wedging is hardly distinguishable from gilling when the maximal girth is found at a position close to the gill cover.(C)
- **Entangled:** The fish is wrapped into the netting, held by pockets of netting or attached to the net by teeth, fins, spines or other projections. Fish that are already caught by other catch processes may

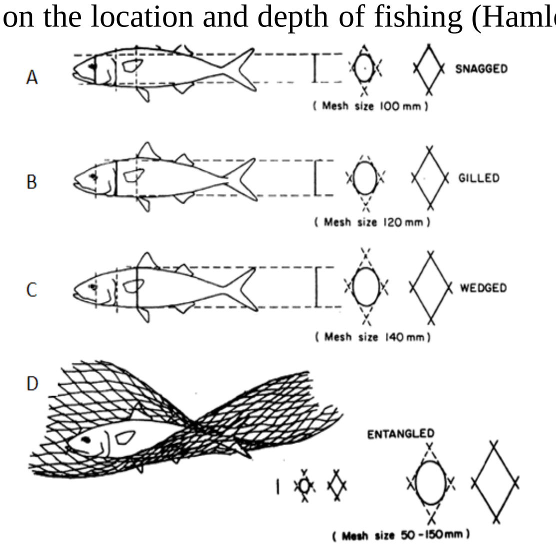

Figure 2: Four different ways of fish getting caught by gillnet (Karlsen and Bjarnason, 1986).

subsequently be wrapped into the netting while struggling to free themselves. When recording catch processes, care should be given to classify such catches by the primary catch process (D) (Potter and Pawson, 1991; Hovgård and Lassen, 2000; Karlsen and Bjarnason, 1986).

The gillnet is a passive fishing gear and it can be used in any location that an active gear—such as a trawl, drag net, purse seine, etc.—cannot be used, especially in inland fisheries. Besides using gillnets to estimate fish length distribution and size selectivity, gillnets have been used by many researchers to collect fish samples to assess stock abundance of fish populations. For example, gillnets are commonly used by Water Framework Directive of Fisheries of Ireland to get fish samples from many reservoirs for assessing fish stock population and also used by FISHCU (Fish Ecology Unit) to monitor fish stock of reservoirs in the Czech Republic as well as in other European countries.

2.6 Selectivity estimation

Hovgård and Lassen, (2000) demonstrated two main methods of estimating selectivity—direct and indirect method—based on whether information on the length distribution of fish available to the gear exists or not. The direct method requires an external estimate of the fish abundance per size class, i.e. that N_l (number of fish available) is known. The indirect method does not require such information, i.e. that N_l is unknown. In most cases, N_l is unknown and hence the indirect method is most often used.

Indirect estimates can be classified into two groups: i) using Type B curves as intermediaries where Type B curves (selectivity of different mesh sizes to one length mesh-class of fish) are plotted first and used to determine Type A curves (selectivity of one mesh size to different sizes of fish) and ii) fitting a predetermined distribution, using a prior model of selectivity curves. Here, Type A curves are estimated algebraically from catch data (Hamley, 1975; Miller 1999).
A useful assumption for describing gillnet selectivity is the principle of geometric similarity (Baranov, 1948) which states that gillnet selectivity is only dependent on the size of the fish relative to the mesh size. The principle states that selectivity is the same when the relationship between fish size and mesh size (z/m) is the same. This provides a convenient simplification of the selection process.

Selection curves of fishing gears can be sigmoid, bell-shaped, and two-peaked. Gillnet selection curves are either bell-shaped or two-peaked, where the latter formulation is useful when the catch are taken by two distinct catch processes (Figure 3). The two-peaked selection curves are typically represented by the sum of two bell-shaped distributions (Hovgård and Lassen, 2000). A typical gillnet selection curve is bell-shaped, falling to zero on both sides of a maximum. It is described by its mode, width, height and shape. The mode corresponds to the optimum length of fish caught, the width to the selection range, the height describes how efficiently the mesh catches fish of the optimum length, and the shape varies according to several characteristics of net and fish (Hamley, 1975).

For gillnet and longline selectivity, Millar and Holst (1997) demonstrated that the model reduces to a log-linear model for a number of uni-modal selection curves (normal scale, normal location, log normal and gamma). These models observe the principle of geometric similarity, i.e. gillnet selectivity estimation is based on the assumption that the selectivity curves for all mesh sizes have the same shape and size. Accordingly, the retention curve spread is proportional to mesh size. Goodness of fit is evaluated by comparing deviance residual plots, with the lowest deviance corresponding to the best fitting model (Millar and Holst 1997; Karakulak and Erk 2008).

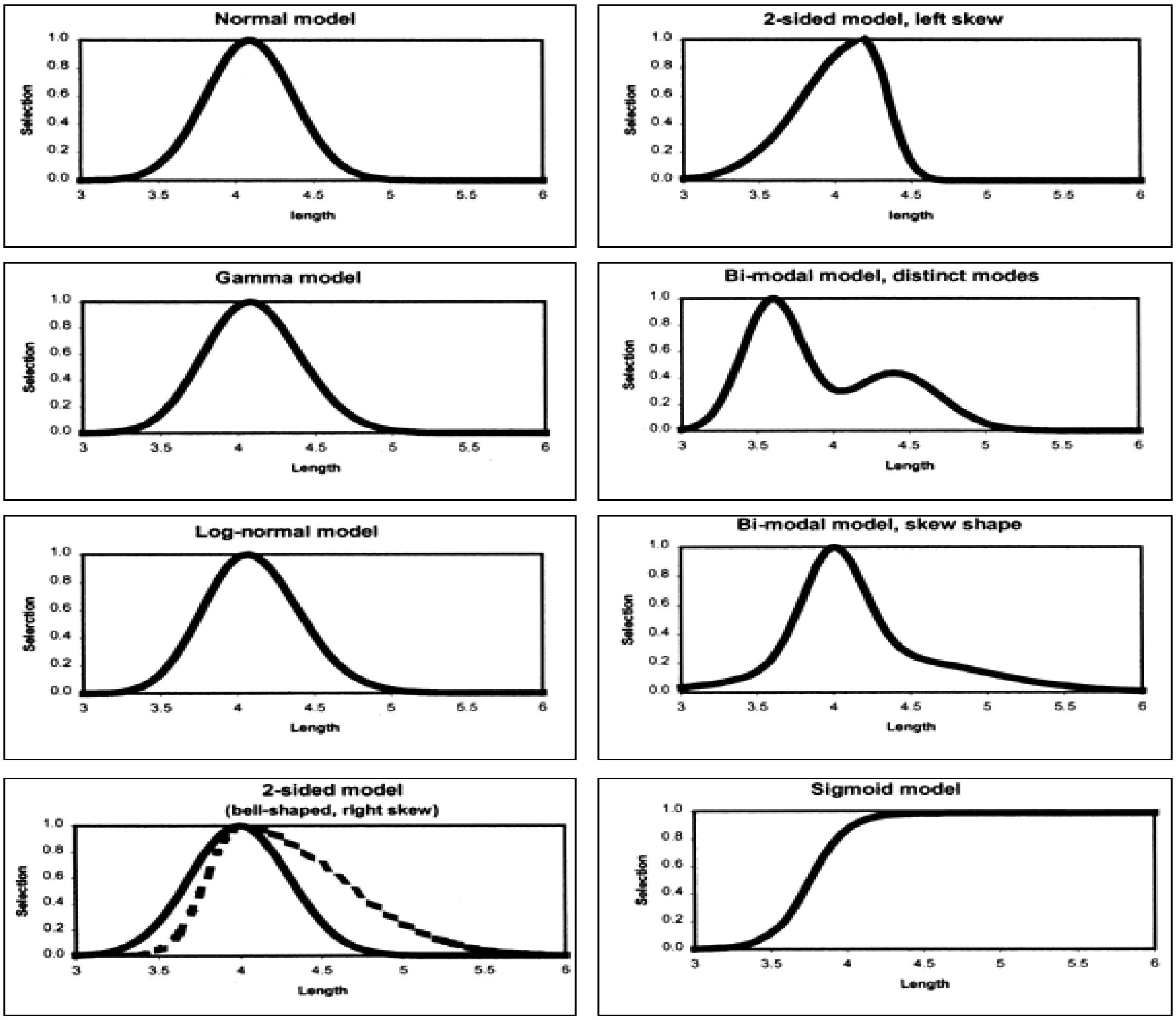

Figure 3: Examples of the potential shapes of the selection curve

3 MATERIALS AND METHODS

This study is based on gillnet records data collected from coastal waters south of Iceland and inland waters on the Snæfellsnes peninsula, west Iceland (Figure 7). Three important fish species are studied, Atlantic cod and saithe from the marine environment and brown trout from fresh water.

3.1 Species studies

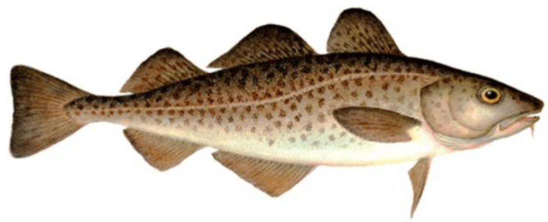

Figure 4: Atlantic cod

Atlantic cod: The Atlantic cod (Figure 4) is a demersal fish, but may become pelagic when feeding or spawning. The presence of cod usually depends on prey distribution rather than on temperature. It lives in water of a wide range of salinity, from nearly fresh to full oceanic water, and in a range of temperatures from 0 to 20°C. Larger fish are found in colder waters in most areas (0-5° C). Cod is widely distributed in a variety of habitats from the shoreline to depths greater than 600 m, but is mostly found within the continental shelf areas from 50-200 m. The maximum range of temperature for spawning is from below 0°C to about 12ºC. The largest individual measured in Icelandic waters was 186 cm long and 17 years old. Common size is in the range of 45 to 85 cm in most fishing gear. Growth is variable, between years and areas. In general, three year old cod are about 1 kg and in the range of 30 to 40 cm long, while 10 year old cod are around 10 kg and measure about 100 cm. The cod spawns all around Iceland, but the most important spawning grounds are off the southwestern coast. Spawning takes place in late winter. After spawning, the cod migrates, spreading out over the continental shelf, but the highest abundance remains on the main feeding grounds off the northwest and southeast coasts where the warm Atlantic current meets cold Polar currents. In autumn the juveniles settle near the bottom where they must avoid predators, mostly larger cod. The most important rearing grounds for the juveniles are in the colder waters northwest, north and east of Iceland. The main food of the juveniles is various zooplankton species; the most important being copepods, krill and capelin larvae. When the cod grows larger and starts a demersal existence, the main food becomes various benthic invertebrates and fish (Cohen *et al.*, 1999; Anon., 2009 a).

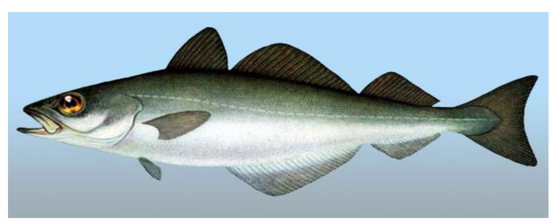

Figure 5: Saithe

Saithe: Saith or Pollock (figure 5) is found in the Northeastern Atlantic from Norway, the Faeroes and Iceland to the Bay of Biscay. Mostly close to shore down to at least 300 m depth over hard bottoms. Juveniles are pelagic and live near the coast up to 3 years, and then migrate to the open sea where they are found mostly between 40 and 100 m depth. Usually between 70 and 110 cm long in catches, but the largest individual caught in Icelandic waters measured 132 cm. It is found all around Iceland. Spawning takes place along the south and southwest coasts, from January to March—earlier than other codfishes. In mid June the juveniles are very common in shallow waters all around Iceland. The saithe reaches sexual maturity at the age of 5 or 6 years. Young saithe in inshore waters feed on planktonic organisms, including copepods and euphausiids. Small saithe may also feed on larval and juvenile fish, including herring, cod and sandeel. Adults feed almost entirely on pelagic and demersal fish such as herring, Norway pout, haddock and sandeel. Caught with bottom or pelagic trawls, longlines and gillnets (Cohen *et al.*, 1999; Anon., 2009 a; Anon., 2009 b).

Figure 6: Brown trout

Brown trout: Is found in a wide variety of freshwater habitats from brooks and rivers to large lakes and reservoirs. Common size is 35 to 50 cm for the freshwater stock. It occurs all over Iceland. Brown trout is an anadromous fish, which can remain at sea for several years where they grow to sizes much larger than stream-resident brown trout, much like their relative the Atlantic salmon (*Salmo salar*). Brown trout spawn from October to December in running waters ranging in size from large streams to small tributaries. Lake-dwelling brown trout migrate back to tributary streams in order to spawn. The female builds a saucer-shaped redd, or nest, in the gravel substrate of a stream. After the eggs are fertilized the female covers them with fine gravel, the fry hatch the following spring and feed on the larval and adult forms of aquatic and terrestrial insects. Larger brown trout feed on other fish (Kraft *et al.*, 2006; Anon., 2009 a).

3.2 Study areas and experimental setup

Atlantic cod and saithe: The study area south of the Reykjanes peninsula included 56 stations (Figure 7) sampled in April 2007. Twelve polyamide gillnets, of which six were monofilament and six were multifilament, with a combination of four different mesh sizes 6” (inches) 7”, 8” and 9” (equal to 152, 178, 202, 228 mm) from knot to knot, were tied together to form one panel. Each of the twelve nets with four mesh sizes were 50 m in length. The 6” nets were 60 meshes in depth and the 7”, 8” and 9” nets were 50 meshes in depth. The diameters of twine were 0.7 mm to 0.85 mm for monofilament and 1.5/8 to 1.5/12 for multifilament. The hanging ratio of gillnets was 0.5 and equal for all nets. Gillnets were set in the research area in the afternoon and collected the next morning after at least 12 hours soak time. As the number of gillnets (Table 1) was unequal (two 6” and 7” monofilament and one 8” and 9” monofilament, one 6 and 7” multifilament and two 8” and 9” multifilament), fish numbers were extrapolated to simulate equal fishing effort. The vessel used for this study data was Marta Ágústsdóttir GK-14, a 40.5 m long gillnetter.

Table 1: Fishing scheme of 6 monofilament and 6 multifilament gillnets (mesh size in inches)

Net no	1	2	3	4	5	6	7	8	9	10	11	12
Mesh size	6”	7”	8”	9”	6”	7”	8”	9”	9”	8”	7”	6”
Type	Mono	Mono	Multi	Multi	Mono	Mono	Multi	Multi	Mono	Mono	Multi	Multi

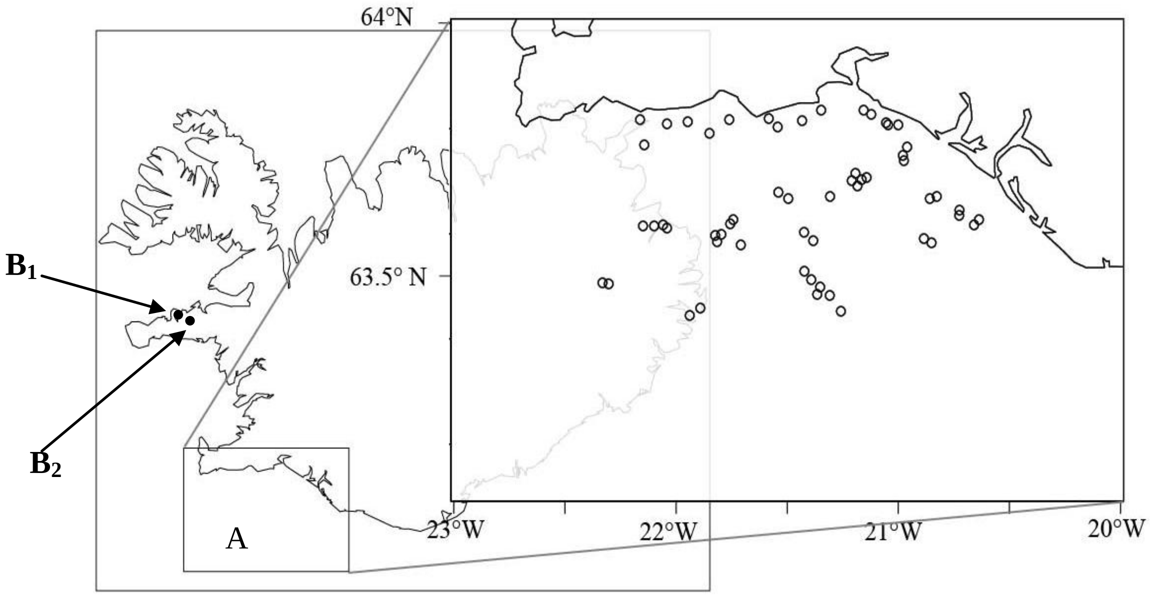

Figure 7: Map of the gillnet survey area (A) and the freshwater lakes sampled, B_1 Location of lake Hraunsfjarðarvatn, B_2 Location of lake Baulárvallavatn.

Brown trout: The study was conducted in two different lakes, Hraunsfjarðarvatn and Baulárvallavatn in September 2008. Lake Hraunsfjarðarvatn and Lake Baulárvallavatn are located on the Snæfellsnes peninsula in the western part of Iceland, (Figure 7, location B_1 and B_2). Hraunsfjarðarvatn covers an area of 2.5 km^2 and is 84 m deep at its deepest point. The lake lies at 207 m above sea level. From the lake the Vatnaá River runs to Baulárvallavatn and lake Baulárvallavatn covers about 1.6 km^2 and has a maximum depth of 47 m. It is situated at 193 m above sea level.

Ten monofilament nylon gillnet series were used, each with ten different mesh sizes, 12, 16.5, 18.5, 21.5, 25, 30, 35, 40, 46 and 50 mm. The nets were tied together to be 30 m total in length and1.5m in depth. For the 12-25 mm mesh size the twine diameters was 0.17 mm, for the 30-46 mm it was 0.2 mm and for the 50 mm mesh it was 0.24 mm. The hanging ratio was 0.5 for all mesh sizes.

3.3 Statistical analysis

The selection pattern calculation is based on the measurement of the length of the fish. Analysis was done by fitting a normal curve to the size distributions and the selectivity of the gillnet series was calculated. Four different type selection curves were fitted to the catch of all mesh sizes: Normal with fixed spread and Normal, Gamma and Log-normal models with proportional spread (Table 2), following analysis suggested by Millar and Holst (1997). Each selection curve was fitted under the assumption that the meshes are equal in efficiency and effort. In cases where unequal numbers of mesh sizes were used, numbers of fish were extrapolated accordingly.

The normal curve was fitted to the size distribution of fish by minimizing the residual sum of squares. The fitting of the size distribution: $s(l) = e^{\left(\frac{-1(l-\mu)^2}{2\sigma^2}\right)}$ was conducted by the Solver add-in program in MS-Excel where s(*l*) is size distribution, *l* is length of fish, μ is modal point and σ is standard deviation.

Table 2: The models used in the selection calculations. All are of unit height as relative fishing intensity is modeled separately (Millar and Fryer, 1999).

Model	Selection	Variables
Normal fixed spread	$Sel(k,\sigma) = \exp\left(-\frac{(L - k \cdot m_j)^2}{2\sigma^2}\right)$	- *L*: length of fish - *m*: mesh size - *k, k_1 and k_2*: parameters to be estimated - $k \cdot m = \mu$ (modal point) - $k_1 \cdot m = \mu$ (modal point) - $k_2 \cdot m_2 = \sigma^2$ (variance)
Normal spread α m_j	$Sel(k_1,k_2) = \exp\left(-\frac{(L - k_1 \cdot m_j)^2}{2k_2 \cdot m_j^2}\right)$	
Gamma spread α m_j	$Sel(\alpha,k) = \left(\frac{L}{(\alpha-1)k \cdot m_j}\right)^{\alpha-1} \exp\left(\alpha - 1 - \frac{L}{k \cdot m_j}\right)$	
Lognormal spread α m_j	$Sel(\mu,\sigma) = \frac{1}{\mathrm{L}} \exp\left(\mu_1 + \log\left(\frac{m_j}{m_1}\right) - \frac{\sigma^2}{2} - \frac{\left(\log(L) - \mu_1 - \log\left(\frac{m_j}{m_1}\right)\right)^2}{2\sigma^2}\right)$	

The calculation and modeling is carried out using the programming package R (R Development Core Team, 2008) and Microsoft excel.

The length-weight relationship for cod and saithe was used to calculate catch weights (Table 3). The length-weight relationship is established by calculating the least squares and fitting a curve through the data points of each species using the equation $w = q L^b$, where w is the weight and L is fish length. The equation describes a relationship between length and weight. The constants q and b used here for both species are commonly used for cod in the Marine Research Institute in Iceland, $q = 10^{-5}$ and b = 3 (Haraldur Einarsson pers. comm.).

4 RESULTS

Log-linear models were fitted to the gillnet data (normal fixed spread, normal gamma and log-normal with proportional spread). The best fit selectivity curves are shown, where best fit is based on lowest deviance (Millar and Holst, 1997; Karakulak and Erk, 2008). A different model best fit each of the three fish species with proportional spread: the gamma model fit cod data, the normal model fit the saithe data and log-normal model fit the trout data. Note that mesh size in mm was used for calculation, but mesh size is presented in inches in the tables and figures.

Table 3: Numbers and weight of marine fish caught with gillnets of varying mesh sizes and mesh types from the 56 stations in 2007 (catches are pooled for the stations and standardized as catch per two gillnets).

Fish species	Mesh types	Number & Weight	Mesh Sizes 6"	7"	8"	9"	Total	Length Ranges
Cod	Monofilament	No. Catches	4134	4574	3342	1784	13834	45-123 cm
		Weight (Kg)	23,949	30,593	25,272	15,073	94,886	
	Multifilament	No. Catches	3292	3420	3794	2233	12739	40-130 cm
		Weight (Kg)	19,772	23,486	28,386	18,333	89,978	
Saithe	Monofilament	No. Catches	1113	688	540	420	2761	65-120 cm
		Weight (Kg)	7,067	5,469	4,332	2,837	19,704	
	Multifilament	No. Catches	880	628	378	362	2248	48-121cm
		Weight (Kg)	5,251	4,369	3,352	2,795	15,767	

4.1 Cod caught by monofilament gillnets

The length of cod ranged from 45 to 123 cm in the monofilament gillnets. The 6, 7, 8, and 9" gillnets caught: 4134, 4574, 1671 and 892, respectively (raised n=13834). The mean length increases with mesh size (Figure 8, Table 5). The gamma retention curve gave the best fit. According to the model, the modal length for the selection model is 76 cm for the smallest size and increases by αk =0.5 cm for every cm increase in mesh size (Figure 9, Table 4).

Table 4: Log-linear fit to cod data caught by monofilament gillnets.

Model	Parameters	Mode (mesh1)	Std (mesh1)	Model deviance	D.o.f
Gamma Spread	α = 46.86 k = 0.011	76.02	11.35	1768.07	196

Table 5: Mean length and standard deviation of cod length from monofilament gillnets.

Mesh Types	Monofilament			
Mesh Sizes	6"	7"	8"	9"
Mean	82.56	87.02	90.67	93.78
Standard deviation	8.12	6.16	6.30	8.54
Mean norm dist	81.83	86.93	90.72	94.57
Std. norm dist	8.36	5.28	5.41	6.39
Mode Selectivity Model	76.0	88.5	101	114

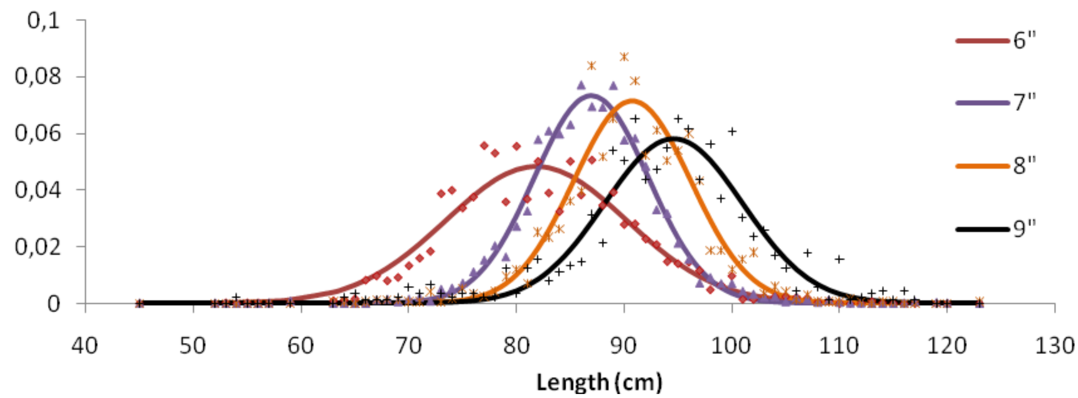

Figure 8: Size distribution curves for cod for all mesh sizes of monofilament gillnets.

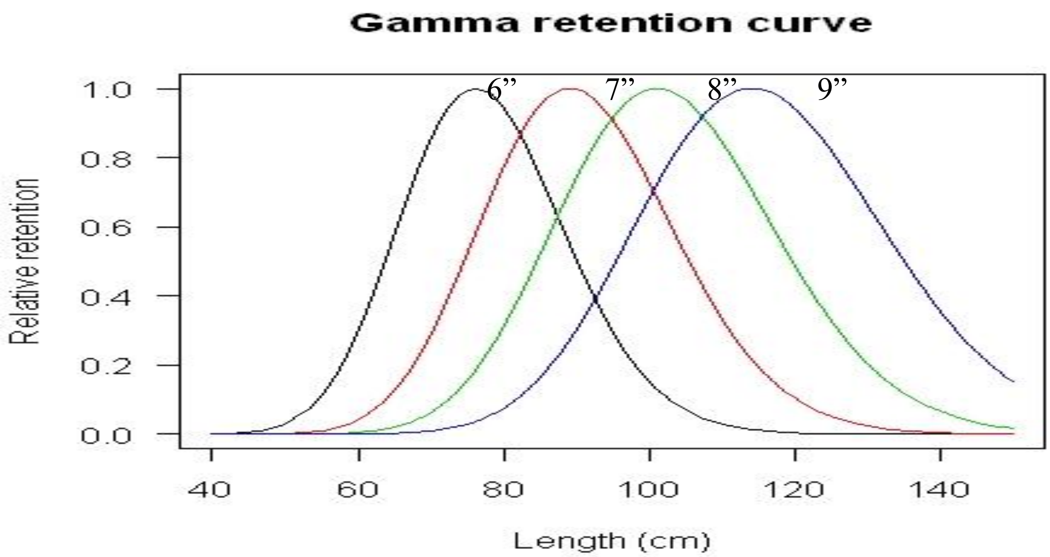

Figure 9: Estimated selection curves from gamma model for cod monofilament gillnets.

4.2 Cod caught by multifilament gillnets

The length of cod ranged from 40 to 130 cm in the multifilament gillnets. The 6, 7, 8 and 9" gillnet caught: 1646, 1710, 3794 and 2233 fish respectively (raised n=12739). The mean length increases with mesh size (Figure 10, Table 7). The gamma retention curve gave the best fit. According to the model, the modal length for the selection model is 74.3 cm for the smallest size and increases by αk =0.5 cm for every cm increase in mesh size (Figure 11, Table 6).

Table 6: Log-linear fit to cod data caught by multifilament gillnets.

Model	Parameters	Mode (mesh1)	Std (mesh1)	Model deviance	D.o.f
Gamma Spread	α = 31.88 k = 0.016	74.31	13.59	1654.45	214

Table 7: Mean length and standard deviation of cod length from multifilament gillnets.

Mesh Types	Cod Multifilament			
Mesh Sizes	6"	7"	8"	9"
Mean	83.43	87.69	90.21	92.85
Standard deviation	8.89	6.82	7.18	8.52
Mean norm dist	83.13	87.31	90.26	93.30
Std. norm dist	9.03	5.91	5.73	6.32
Mode Selectivity Model	74.31	86.53	98.75	111.5

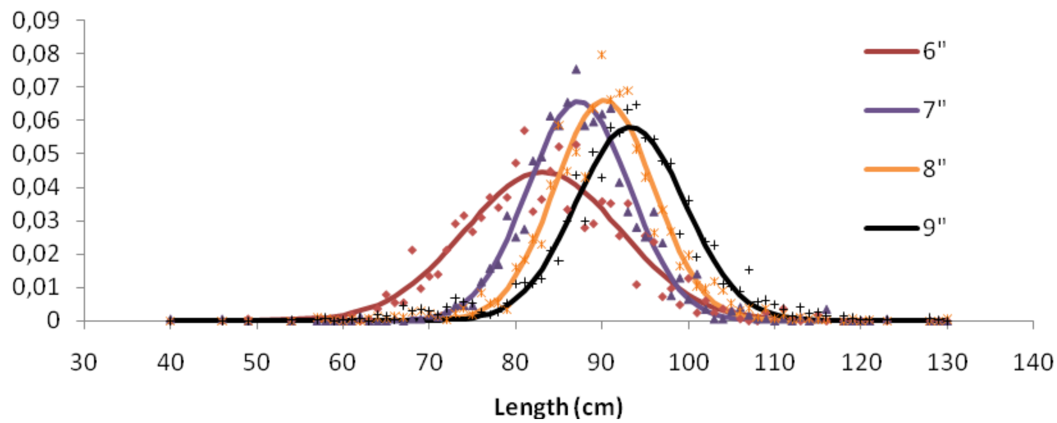

Figure 10: Size distribution curves for cod for all mesh sizes of multifilament gillnets.

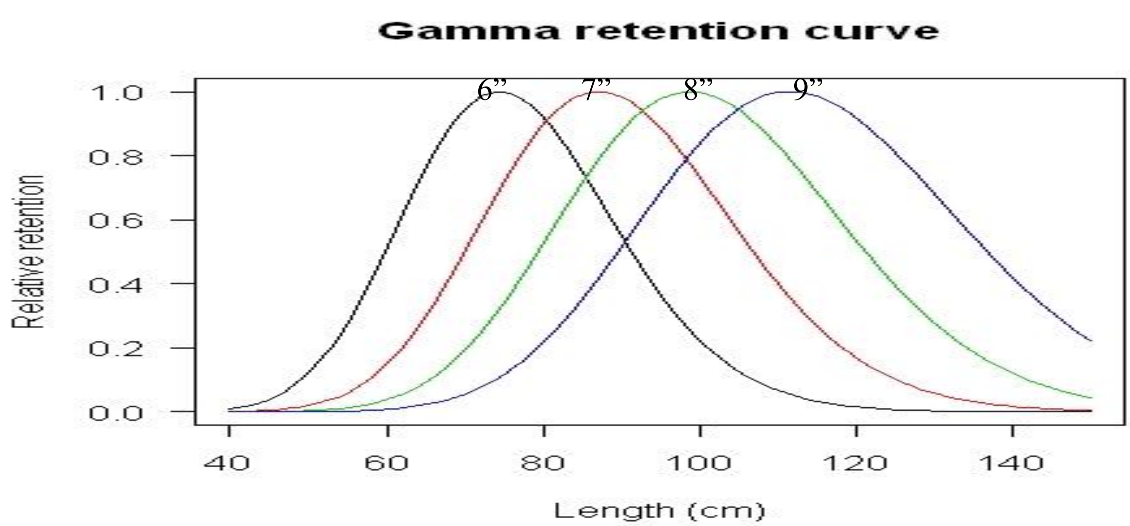

Figure 11: Estimated selection curves from gamma model for cod multifilament gillnets.

4.3 Saithe caught by monofilament gillnets

The length of saithe ranged from 65 to 120 cm in the monofilament gillnets. The 6, 7, 8 and 9" gillnets caught: 1113, 688, 270 and 210 fish respectively (raised n=2761). The mean length is approximately equal and highest in mesh sizes 7" and 8", but 6-7 cm lower on both sides (6" and

9”) (Figure 12, Table 9). The normal retention curve gave the best fit. According to the model, the modal length for the selection model is 90.9 cm for the smallest size and increase by k_1 =0.6 cm for every centimeter increase in mesh size (Figure 13, Table 8).

Table 8: Log-linear fit to saithe data caught by monofilament gillnets.

Model	Parameters	Mode (mesh1)	Std (mesh1)	Model deviance	D.o.f
Normal Proportion spread	k_1 = 0.60 k_2 = 0.02	90.87	21.14	1325.54	163

Table 9: Mean length and standard deviation for saithe length with monofilament gillnet.

Mesh Types	Saithe Monofilament			
Mesh Sizes	6”	7”	8”	9”
Mean	85.25	92.01	91.56	86.22
Standard deviation	7.71	7.60	11.24	11.38
Mean norm dist	84.82	92.30	92.85	82.81
Std. norm dist	7.88	6.58	11.43	13.44
Mode Selectivity Model	90.87	106.4	120.8	136.3

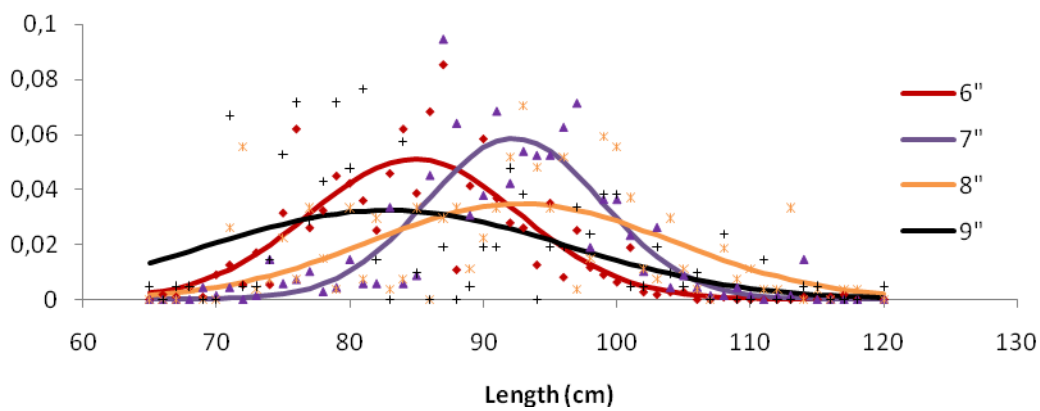

Figure 12: Size distribution curves for saithe for all mesh sizes of monofilament gillnets.

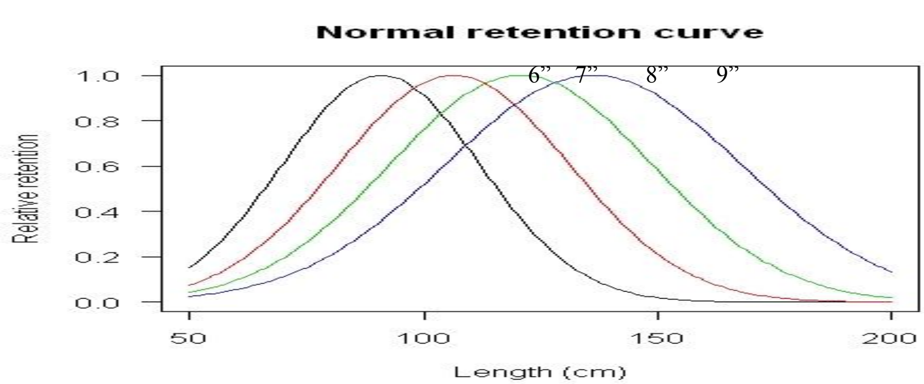

Figure 13: Estimated selection curves from normal model for saithe monofilament gillnets.

4.4 Saithe caught by multifilament gillnets

The length of saithe ranged from 48 to 121 cm in the multifilament gillnets. The 6, 7, 8 and 9” gillnets caught 440, 314, 378 and 362 fish respectively (raised n=2248). The mean length is highest in 8” mesh sizes, but decreases with distance in both directions (Figure 14, Table 11). The normal retention curve gave the best fit. According to the model, the modal length for the selection model is 83.5 cm for the smallest mesh size and increases by k_1=0.55 cm for every cm increase in mesh size (Figure 15, Table 10).

Table 10: Log-linear fit to saithe data caught by multifilament gillnets.

Model	Parameters	Mode (mesh1)	Std (mesh1)	Model deviance	D.o.f
Normal Proportions spread	k_1 = 0.55 k_2 = 0.011	83.45	15.64	1128.30	163

Table 11: Mean length and standard deviation for saithe length with multifilament gillnets.

Mesh Types	Saithe Monofilament			
Mesh Sizes	6”	7”	8”	9”
Mean	83.35	87.54	95.15	90.21
Standard deviation	8.36	9.67	9.55	11.87
Mean norm dist	82.00	86.23	97.76	90.29
Std. norm dist	8.76	9.63	6.53	15.54
Mode Selectivity Model	83.45	97.73	110.9	125.2

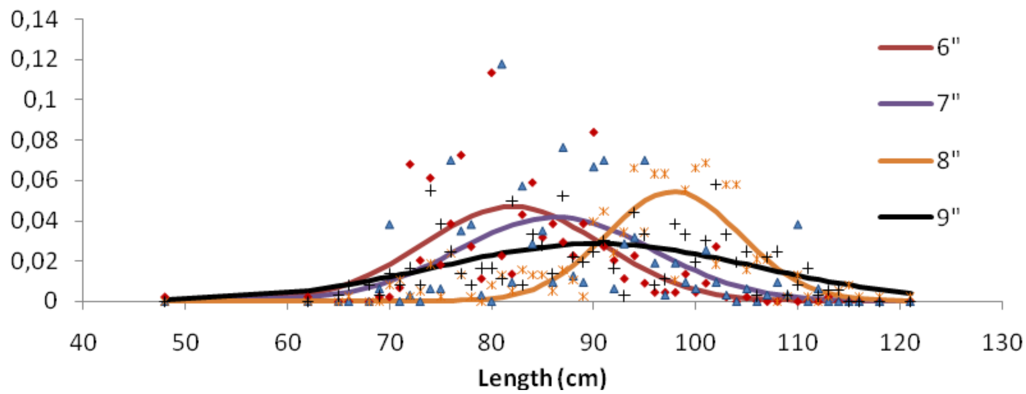

Figure 14: Size distribution curves for saithe for all mesh sizes of multifilament gillnets.

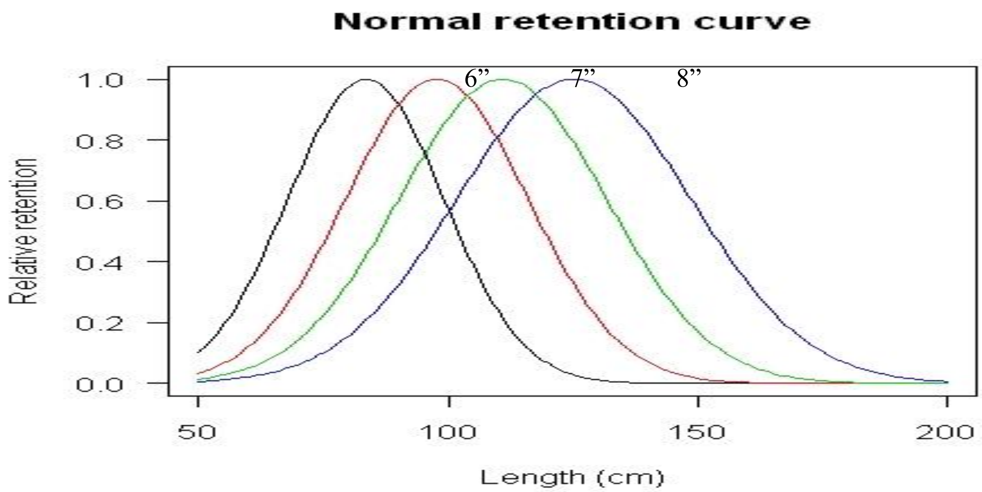

Figure 15: Estimated selection curves from normal spread model for saithe multifilament gillnets.

4.5 Trout caught from Baulárvallavatn lake

The length of trout from Baulárvallavatn lake ranged from 11 to 47 cm (n=96). The highest catch was in the 16.5 mm mesh size (Table 12). The log-normal retention curve gave the best fit (lowest deviance). The modal length for the selection model is 20.4 cm for the smallest size and increased by 1.2 cm for every centimeter increase in mesh size (Figure 16, Table 13). The modal point for each mesh size is $m = \exp(\mu-\sigma^2)\cdot m_j/m_1$, where m_j is the corresponding mesh size, and m_1 is the smallest mesh size.

Table 12: Number of trout caught in Baulárvallavatn lake in eight different mesh sizes

Fork length	Mesh size (mm)								Total	Total
(cm)	16.5	18.5	21.5	25	30	35	40	46	Fish	Weight
11				1					1	14
13	1				1				2	46
14	1								1	30
15	5					1			6	210
16	5	1				2			8	350
17	1	4							5	248
18	3								3	174
19		1	1	1					3	216
20			1						1	76
21	1		3						4	346
22				2					2	214
24		1	1	3					5	1056
25	1		1		1				3	482
26		1							1	180
27			1		2				3	624
28				1	1				2	490
29				1					1	248
30			2			1			3	852
31				1	2				3	1030
32			1	1	1				3	1088
33		1					1		2	868
34				1		2	1		4	1490
35	1			2	1				4	1565
36	1		1	1					3	1632
37	1	1		1	1	1	1		6	3692
38					1			2	3	1906
39	1			1			1	1	4	2846
40							2	1	3	2264
41					1	1			2	1566
42				1				2	3	2716
43	1								1	1016
47				1					1	1330
Total fish	23	10	12	19	12	8	6	6	96	
Weight(g)	4164	1712	2406	7566	4021	2644	3788	4564		30,865

Table 13: Log-linear fit to trout caught in Baulárvallavatn lake.

Model	Parameters	Mode (mesh1)	Std (mesh1)	Model deviance	D.o.f
Log-Normal Proportional spread	$\mu = 3.172$ $\sigma = 0.399$	20.35	10.71	205.72	222

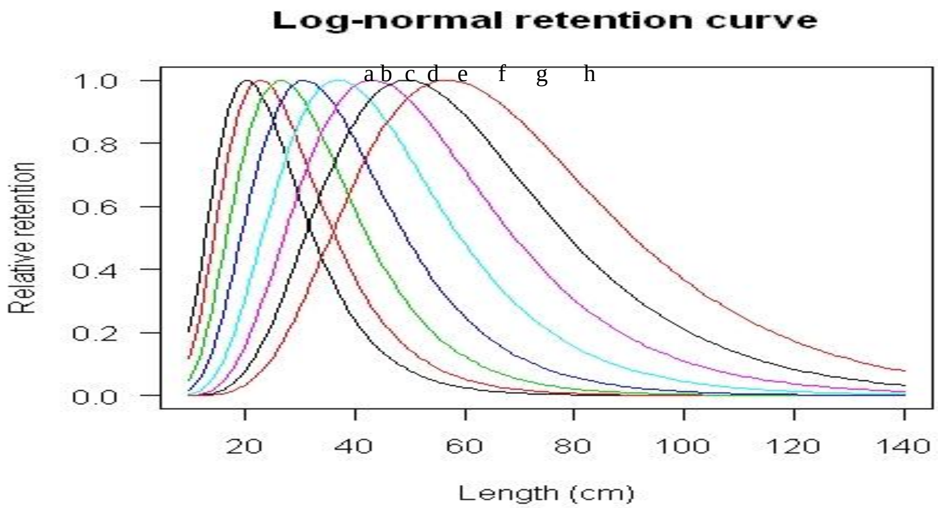

Figure 16: Estimated selection curves fit log-normal model for trout in Baulárvallavatn lake (a=16.5, b=18.5, c=21.5, d= 25, e= 30, f=35, g=40, h=46 mm)

Trout caught from Hraunsfjarðarvatn lake

The length of trout caught from Hraunsfjarðarvatn lake ranges from 12 to 46 cm (n=141). The 21.5 mm mesh size provided the best catch (Table 14). The log-normal retention curve gave best fit and the modal length for the selection model is 12.7 cm for the smallest size and increases by 1.1 cm for every cm increase in mesh size (Figure 17, Table 15)

Table 14: Number of trout caught in Hraunsfjarðarvatn lake in ten different mesh sizes.

Fork length	Mesh size (mm)										Total	Total
(cm)	12	16.5	18.5	21.5	25	30	35	40	46	50	Fish	Weight
12	1										1	18
13		1									1	28
14		3									3	82
15		5	1								6	216
16		3									3	132
17		8	5	1							14	724
18		2	2	1							5	318
19		2	4	8		1	3				18	1308
20	1	2	1	4			1				9	764
21		1		6	1		2				10	936
22				6	2						8	884
23				3							4	538
24				3	3		2				7	1020
25				4	1	1					6	1002
26				2	1	1					4	680
27				2	1						3	570
28				2		2	1				5	1130
29				1	1						2	271
30				1		1				1	3	876
31				2							2	630
32				1	1	1					3	1074
33				1		1	2				4	1588
34			2	1			1	1			5	2242
35				1			1				2	1032
36			1				1				2	1056
37				2							2	1094
38		1				1					2	1284
39								1	1		2	1496
42						1		1			2	1818
43										2	2	1910
45									1		1	1012
Total	2	28	16	52	11	10	14	3	2	3	141	
Weight(g)				885	168			209				27733
	116	1966	2244	4	9	3508	3274	0	1788	2204		

Table 15: Log-linear fit trout caught in Hraunsfjarðarvatn lake.

Model	Parameters	Mode (mesh1)	Std (mesh1)	Model deviance	D.o.f
Log-Normal Proportional spread	$\mu = 2.6125$ $\sigma = 0.266$	12.7	3.82	250.68	277

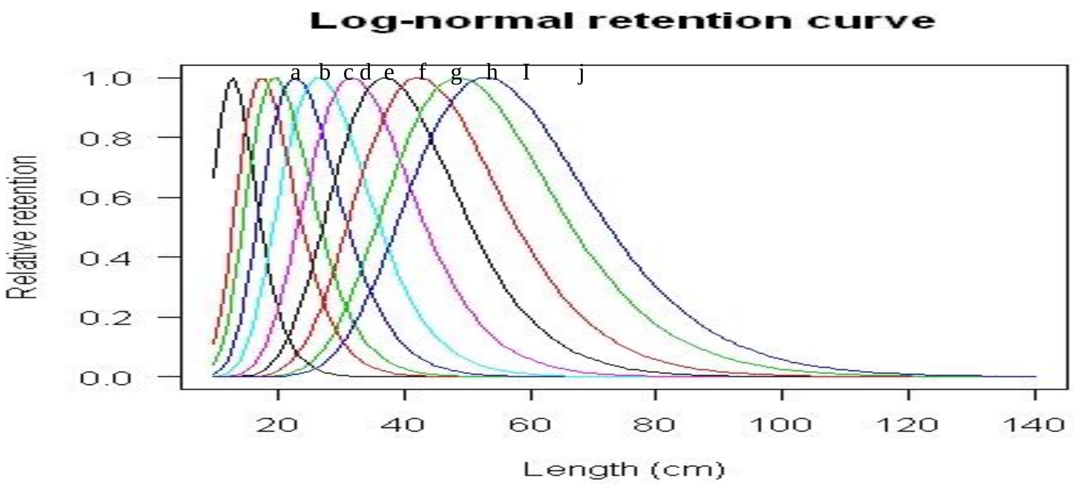

Figure 17: Estimated selection curves fit log-normal model for trout in Hraunsfjarðarvatn Lake (a=12, b=16.5, c=18.5, d=21.5, e= 25, f= 30, g=35, h=40, i=46, g=50 mm).

5 DISCUSSION

This study demonstrates the selectivity of various mesh sizes for diverse marine and freshwater fisheries, based on catch data for the marine species cod and saithe and the freshwater brown trout in Iceland. The study shows how catches vary with different mesh sizes and mesh types of gillnets and it also shows how selective gillnets are. A study like this can serve as a tool for choosing the right mesh size for avoiding juvenile fish as well as maximizing and controlling catches of the targeted fish by the right choice of gillnets.

In this study, both the length distribution of caught fish and the relative selectivity curve are shown. While the catches reflect the length distribution of fish in the area, the selectivity curves are estimates of retention probabilities for given mesh sizes and fish sizes. If the size distribution of fish in the area were uniform, i.e. equal number of fish of all size classes, there should be no differenc between the size distributions of catches in gillnets and the selectivity curves. As a result, the size distribution in the area can be estimated when size distributions in gillnets and retention probability are known.

The size distribution of catch ($s(l)_{catch}$) is the product of the stock ($s(l)_{stock}$) and selection ($r(l)$) (Hovgård and Lassen, 2000). From algebraic conversion we can then approximate: ($s(l)_{stock}$)= ($s(l)_{catch}$)/ ($r(l)$).

The joined retention probability of all gillnets can be estimated: $r(l)_{total} = \frac{\sum_{i=1}^{n} r_i(l)}{n}$, n is numbers of gillnets.

Figure 18 demonstrates how the size distribution of the cod in the study area can be estimated by using data from the monofilament gillnet. For estimating fish abundance, information on gear encounter probabilities would be needed. This interpretation however, can serve as a visual aid to select appropriate mesh sizes.

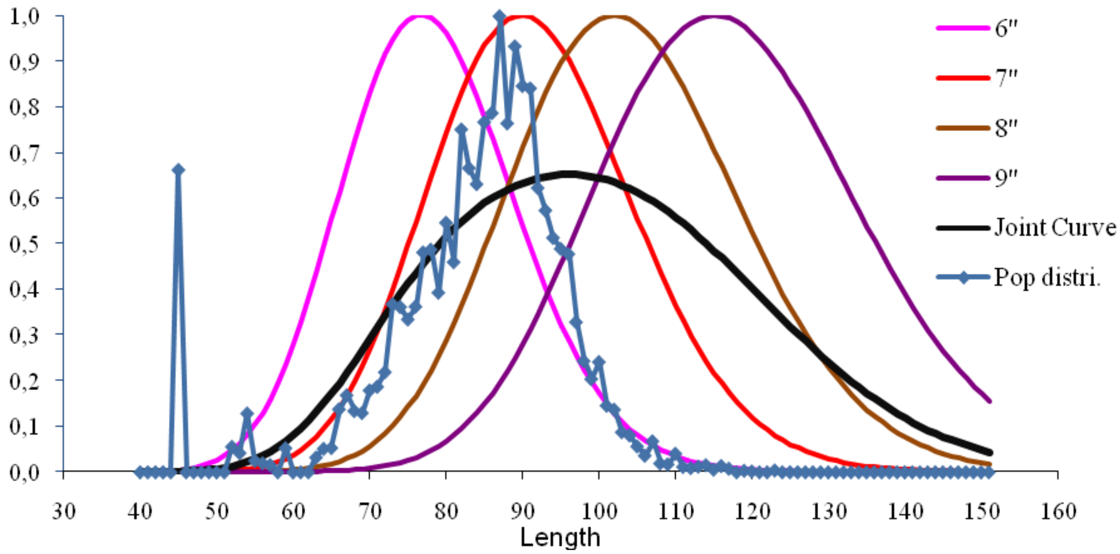

Figure 18: The relative size distribution for cod, individual selection curves and the joint retention curve (black) for monofilament gillnets

The catchability of the cod decreased with increasing mesh size. The 6" and 7" mesh size caught more fish in both number and weight (Table 3). Monofilament gillnets catch more fish in the small mesh sizes, but for larger mesh sizes (8" and 9") multifilament gillnets appear to catch more cod than monofilament.

Different variances showing a wider selection range for multifilament suggest that fish may (at least partly) be caught in different ways in the two types of gillnets; smaller fish are perhaps more commonly entangled or the fine multifilament nets grasp the teeth and/or mouth.

Mean length of cod increased with mesh size and varies from 82.6 to 93.8 cm for monofilament gillnets and from 83.4 to 92.9 cm for multifilament gillnets of 6" to 9" mesh sizes (Table 5 and 7). The difference in mean lengths of cod is thus marginal but the efficiency of monofilament gillnets was considerably higher than multifilament gillnets (Table 3).

According to the gamma model used to fit cod (monofilament), the modal length for 6" gillnet selection is 76 cm, or less than the mode of the length distribution of catches (~82 cm). For 7" gillnets modal values for the selection curve are about equal to the modal points of catches. For 8 and 9" mesh sizes, the modal values for the selection curves are higher than for the length distribution, (Table 5 and 7). This is a result of (relatively) few fish in the optimum selection range for 6, 8 and 9" gillnets.

The catches of saithe decreased with increasing mesh size. In both monofilament and multifilament gillnets the catch rates decreased in number of fish from 1113 to 420 for monofilament and from 880 to 362 for multifilament (Table 3). The variation of distributions for 8" and 9" mesh sizes of monofilament is higher than for the 6" and 7" (Table 9, Figure 12). Thus they seem to catch a wider range of fish. The same pattern can be seen for the 9" mesh size of multifilament (Figure 14). This may be a result of more small fish being entangled or wedged in the big mesh size or it could be that the fish were not big enough to be caught by the big mesh sizes.

The mean length of saithe in all mesh sizes varied considerably. For monofilament the mean length for 6” mesh size is 85 cm, increasing to 92 cm for 8” and decreasing again to 86 cm for 9” mesh size. For multifilament gillnets, the mode of the length distribution for 6” gillnet is 83 cm - the same as the mode of the selectivity model. For 7, 8 and 9” the mode of selectivity model are higher. It’s probable that the 9” mesh size is too big to catch saithe in that area.

For the normal proportion spread model, the selection mode values are higher than the mean length distribution of catch in all mesh sizes, mesh type and even higher with the 9” mesh size (Table 9 and 11). This demonstrated that the catchability of fish decreases with increasing mesh size and only a small number of fish are caught by 8 and 9” mesh size gillnets. In addition, it is noticeable that the size distribution of saithe in gillnets is ill-behaved compared to that of cod. This suggests that the species may be caught differently, i.e. a relatively high number of saithe may be snagged or entangled rather than gilled or wedged.

This study has shown that monofilament gillnets catch, in most cases, more cod and saithe than multifilament gillnets. This is probably because of high friction of multifilament gillnets or more flexibility, elasticity and less visibility of monofilament gillnets. An experiment on Baltic cod suggests that an increase in the number of filaments in a multifilament twine from four to six decreases catch numbers by about a third (Hovgård *et al.*, 1999). Hamley (1975) suggested that nets made of thinner twine are less visible, easy to stretch, and more flexible; therefore, they should tangle more fish and catch large fish. Hovgård (1996 a) reported that the fishing power of a net increases when the ratio between twine diameter and mesh size decreases and suggested that thin twines fish better than thicker ones.

By comparing the modal length in the length distribution with the modal length of selectivity estimation and calculating the relationship between length and weight, this study demonstrated that the 7” mesh size gillnets get the best catch for cod and 6” mesh size for saithe in both mesh type gillnets and also show that fishing with the monofilament mesh results in higher catches. For saithe with 6” mesh size monofilament gillnet the modes of model selection are higher than the modal length of length distribution. Hence, the monofilament gillnet with 5” or 5.5” could be suggested for further study and to make comparisons of the estimated mean selective length with the minimum legal landing length of a given fish species.

In Lake Baulárvallavatn the smallest and the biggest mesh size didn’t catch any fish and only a small number of fish were caught by these mesh sizes in Hraunsfjarðarvatn. The total catch was 96 specimens from Lake Baulárvallavatn and 141 from Lake Hraunsfjarðarvatn. There are only a few fish caught by each mesh size in the range so the modal length distribution couldn’t be calculated with confidence. For the selection model the modal selection of trout caught from Lake Baulárvallavatn in the 16.5 cm gillnet is 20.4 cm and higher than the modal length of trout caught from Lake Hraunsfjarðarvatn that have a modal length around 17.5 mm. This suggests the condition of the trout populations are either different or the difference may be due to inaccuracy in estimates because of low catches. The condition factor ($K= w * 100/L^3$) is, on average, slightly higher for the fish from Baulárvallavatn. The relationship between length and weight shows that 25 mm mesh gillnets caught the most trout by weight in Lake Baulárvallavatn and 21.5 mm mesh size gillnet in Lake Hraunsfjarðarvatn. The results probably reflect difference in local size distributions.

Application

Results from a study like this can be used to select the most efficient gillnet, to select the right gillnet to avoid catches of juvenile fish or to select a mixture of mesh sizes to target more than one species. If average catches of fish per meter of gillnet over some period of time is known, such knowledge can be used for controlling effort in terms of mesh sizes and lengths of net. As an example, we can setup an artificial example where a fisherman is allowed to catch 2.000 Kg of cod and 1000 Kg of saithe over a given period in an effort-controlled fishery. We assume the cod and saithe are occupying the same areas and our catch results reflect average circumstances. To round off, let us say we caught 4.000 kg cod and 1.000 kg saithe in 1.000 m of 6" gillnet or 4 and 1 kg m^{-1} respectively. 500 m of gillnet is thus sufficient to fill his quota for cod. If the fisherman will be allowed to fish with 500 m of 6" gillnet he will catch only 50% of his allowed saithe catches. If the fisherman on the other hand uses 7" gillnet he needs less effort (about 400 m of 7" gillnet) to catch the same amount of cod, but then he catches just over 30% of his allowed saithe catch. If the fisherman uses smaller mesh sizes (say 5"), the criteria may be met but he may end up using a lot of effort to do so. The only feasible way out of this dilemma appears to be to use mixed mesh sizes, 6, 7 or 8" for the cod and less than 6" to catch the saithe (assuming the saithe catches will be more than or the same as those with 6" gillnet but cod catches will decline). With even more species involved, fisheries management inevitably becomes more and more difficult and some compromises are likely to be needed. This example, however, shows that information on selectivity and catching efficiency is a fundamental necessity in fisheries management. In addition to that, knowledge of size selectivity can be useful in fisheries management for:

- Estimation of incidental mortality (i.e. mortality of discards and escapes)
- Yield per recruit analysis.
- Age and length based population models
- Estimation of population length frequencies.
  (Millar and Fryer, 1999)

Gillnets are commonly used to estimate the size distribution and selectivity by many scientists. Gillnets are highly selective gears, the use of an appropriate mesh size gillnet makes it possible to catch a desirable narrow size range of fish. Besides using gillnets for selectivity studies, gillnets are also used as a tool to access the fish stock abundance in many water bodies, especially in inland fisheries, i.e. lakes, rivers or reservoirs.

The Water Framework Directive (WFD) is a part of a substantial restructuring of EU water policy and legislation. This institution has developed various methodologies to collect specimens from different locations to estimate stock assessment of fish populations. In this line, gillnet is one of the most used fishing gears in their research. There are three different methodologies that are prescribed by the WFD depending on the different water bodies (river, lake, and estuary).

Electronic fishing and many forms of netting (gill netting, fyke netting, seine netting and beam trawl) are the principal methods of stock assessment being used to monitor fish in rivers. The standard method for sampling fish in lakes features monofilament multi-mesh, survey gill nets (benthic and surface), and large-mesh braided multifilament gill nets and fyke nets. The standard method for sampling fish in estuaries includes the use of seine nets, beam trawls and fyke nets (Anon., 2009 c).

Gillnets are also used in monitoring the fish stocks of Czech Reservoirs. The nets are set randomly in different locations and at different levels of the water in the reservoirs, i.e. bottom water, mid-water, surface, along the shore and in the middle of the reservoirs; the mesh sizes of the nets are varied. In addition to using gillnets to sample the fish population, seine nets and drag nets are also used (Anon., 2009 d).

The data obtained from the gillnet series in this study is suitable for selectivity calculations, for assessing fish size distribution and for estimating the optimum length of fish selectivity in each mesh size of gillnet. To estimate fish stock abundances, more information would be needed on the spatial and temporal distribution of the target species, as well as on the biology and age distribution of the stocks.

Gillnet study in Cambodia

In view of the results of the present study, an experiment of gillnet selection will be conducted in one of the community fisheries in Cambodia. It is my hope that the results will assist the community fisheries to make an educated choice for standardizing gillnet fishing.

The gear to be used for the experimental gillnet fishing will be monofilament nylon. There are many species of fish and their length distributions vary from approximately 10 to more than 50 cm and the species differ in morphology. The mesh size of gillnets to be used for the study will be 20, 30, 40, 50, 60, 70, 80, 90 and 100 mm with 0.5 hanging ratio. These nets will have a length of 20 m each and depth will vary from 1.5 to 2.5 m depending on the area of operation. Sets of these gillnets as mentioned above will be assembled, with random order of mesh sizes, forming a series of 180 meters long panels.

The sampling will take place in flooded forest during the flooding season in August or September depending on the water level of the lake, during this season the water from Mekong river starts to rise and the migratory fish move from the central part of the great lake or from the conservation area to the flooded forest to feed and spawn. During this period there is a closed season for the large and middle scale fishing gears. These fishing gears are prohibited in that particular area, only small scale fishing gears are allowed to be used. Three panels of gillnet series will be set in different places in the community fishing ground and the catch data will be combined and analyzed. The nets will be set in the evening and lifted the following day during 7:00 to 9:00. The catches from each net will be recorded separately, all fish will be separated to species and the weight and length of all fish will be measured. Samples of fish caught by fishermen with other fishing gears i.e. traps, hooks and lines, cast nets, drift nets etc. will be collected and selection investigated based on the length distributions.

The data will be investigated to analyze length distribution, size selection, species selection, fishing power and the relationship of the length and weight of each fish species, to the mesh sizes in which they were captured. The length and mesh sizes of gillnets will be suggested depending on the management plan of the community fisheries.

ACKNOWLEDGEMENTS

This study was part of and financed by the United Nations University Fisheries Training Program. I am grateful to Tumi Tomasson and Thor Asgeirsson for taking part in the program and for their constructive criticism. I am thankful to Dr. Ólafur A. Ingólfsson for supervising and help and his patience as well. My thanks and appreciation to the MRI group involved in data-collecting for providing the data. My thanks to Mr. Einar Hreinsson for providing a lecture regarding fishing technology. My thanks to Mr. Peter Weiss director of the University of Westfjords. I express my sincere gratitude to Mr. Konrad Thorisson for his valuable comment and suggestion on the report. I'm also thankful to my colleagues, all members of Marine Research Institute and all members of the UNU Fishing Training Program for the contribution in this study.

LIST OF REFERENCES

Anon., 1987. People's Republic of Cambodia, *Law on fisheries.*

Anon., 2007 a. *The Tonle Sap Initiative, Future Solutions*, < **Error! Hyperlink reference not valid.**> [10-12-2008].

Anon., 2007 b. Kingdom of Cambodia 2007, *Law on fisheries*.

Anon., 2008 a. *View Map-Tonle Sap Environment Management Project*, < http://www.adb.org/ projects/ tonle_sap/background.asp> [10-12-2008].

Anon., 2008 b. Gillnet article on Wikipedia website, < http://en.wikipedia.org/wiki/Gillnet# History >, [10-12-2008].

Anon., 2008 c. Information centre for Icelandic Ministry of Fisheries and Agriculture, *Fishing gears, gillnets* <http://www.fisheries.is/the-fisheries/fishing-gear/gillnets>,[01 -12-2008].

Anon., 2008 d. Cambodia Fishery and Aquaculture Country Profile, fishery sector structure, Overall fishery sector. <http://www.fao.org /fishery/countrysector/FI-CP_KH/en>,[10-12-2008].

Anon., 2009 a. Information centre of the Icelandic, Ministry of fisheries and agriculture, fish species, cod, saithe and trout. <**Error! Hyperlink reference not valid.** [10-02-2009].

Anon., 2009 b. International Council Exploration of the sea, saithe behavior. <**Error! Hyperlink reference not valid.**marineworld/ fishmap/ices/pdf/saithe.pdf>, [10-01-2009].

Anon., 2009 c. *Sampling Fish for the Water Framework Directive*, Central and Regional Fisheries Boards. Fisheries of Ireland < http://www.wfdfish.ie/?page_id=3>, [14-02-2009].

Anon. 2009 d. FISHECU - Specialists for fisheries surveys of large inland waters. Institute of Hydrobiology, Biology Centre of the AS CR, v.v.i. http://www.hbu.cas.cz/fishecu/. [14-02-2009].

Baranov, F. I., 1948. *Theory and assessment of fishing gear*. Chap. 7. Theory of fishing with gillnets. Pishchepromizdat, Moscow (Translated from Russian by the Ontario Department of Lands and Forests. Maplc. Ont.).

Cohen, D.M.; Inada.T.; Iwamoto, T.; Scialabba**, N.**1990, *FAO species catalogue. Vol. 10. Gadiform fishes of the world (Order Gadiformes). An annotated and illustrated catalogue of cods, hakes, grenadiers and other gadiform fishes known to date***.** FAO Fisheries Synopsis**.** No. 125, Vol. 10. Rome, 442 p.

Deap, L., P. Degen and N. Van Zaling, 2003. *Fishing gears of Cambodia Mekong*. Inland fisheries Research and Development Institute of Cambodia (IFReDI), Phnom Penh. Cambodia Fisheries Thecniqucal paper Series, Volume IV.

Fernö, A. and Olsen, S. 1994. *Marine fish behaviour in capture and abundance estimation*. Institude of Marine Research, Department of Marine Resources, Fish Capture Division, PO Box 1870, N-5024, Bergen, Norway.

Hamley, J.M., 1975. *Review of gillnet selectivity*. Journal of Fisheries Research Board of Canada 32: 1943-1969.

Hap Navy amd Bhattarai Madhusudan, 2006: *Economic Assessment of Small-Scale Inland Fisheries and Wetland Livelihoods in Cambodia.* Paper prepared for presentation at .International Riversymposium, Brisbane, Australia.

Holst, R., Madsen, N., Moth-Poulsen, T., Fonseca, P. and Campos, A. 1998: *Manual for GillNet Selectivity*. European Commission, 43 p.

Hovgård, H. 1996a. *A two step approach to estimating selectivity and fishing power of research gillnets used in Greenland waters*. *Canadian Journal of fisheries and Aquatic Science* 53-1007-1013.

Hovgård, H., Lassen, H., Madsen, N., Poulsen, T. and Wileman, D. 1999. *Gillnet Selectivity for North sea Atlantic Cod (Gadus morhua)*: Model Ambiguity and Data Quality are related. Canadian Journal of fisheries and Aquatic Science.56: 1307-1316.

Hovgård, H.; Lassen, H. 2000: *Manual on estimation of selectivity for gillnet and longline gears in abundance surveys*. FAO Fisheries Technical Paper. No. 397. Rome, FAO. 84p.

Karakulak, F.S. and Erk, H. 2008. *Gillnet and trammel net selectivity in the northren Aegean Sea, Turkey*. Faculty of Fisheries, Istanbul University. Ordu St. No. 200, 34470 Laleli, Istanbul, Turkey. ISSN: 0214-8358.

Karlsen, L. And Bjarnasson, B.A. 1986, *Small-scall fishing with driftnets.* FAO Fish. Techneical paper. (284): 64p.

Kraft, C.E, D.M. Carlson, and M. Carlson .2006 *Inland, Fisheries of New York* (online) ,Version 4.0 Department of Natural Resources, Cornell University, and the New York State, Department of Environment Conservation. <http://pond.dnr.cornell.edu/nyfish/Salmonidae/brown_trout.html>, [12-12-2008].

Lamberts, D. 2001. *Tonle Sap fisheries: a case study on floodplain gillnet fisheries in Siem Reap, Cambodia*. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand. RAP Publication 2001/11, 133 p.

Millar, R.B. and Fryer, R.J. 1999: *Estimating the size-selection curves of towed gears, traps, nets and hooks*. Reviews in Fish Biology and Fisheries 9: 89-116.

Millar, R.B., 1999. *Untangling the confution surrounding the estimation of gillnet selectivity*. Journal of Marine Science, 55: 1328–1337

Millar, R.B., and Holst, R. 1997. *Estimation of gillnet and hook selectivity using log-linear models*. ICES Journal of Marine Science, 54: 471–477.

Næsje, T.F., Hay, C.J., Nickanor, N., Koekemoer, J.H., Strand, R., and Thorstad, E.B. 2004. *Fish populations, gill net catches and gill net selectivity in the Kwando River, Namibia*. – NINA, Project Report 27. 64p.

R Development Core Team, 2008. The R project for statistical computing. R-2.8.0, modified on 20-10-2008. < http://www.r-project.org/>, [02-12-2008].

Potter E.C.E. and Pawson, 1991: *Gill Netting*. Fisheries Laboratory at Lowestoft. Lab, Leafl, MAFF Direct Fish. Res, Lowestoft, (69). 34p.

Puente, E. 1997. *Incidental impacts of gill nets*. Report to the European Commission, No. 94/095,152. <http://en.wikipedia.org/wiki/Gillnet>, [10-12-2008].

Rainboth W. J. 1996. FAO species identification field guide for fishery purpose. *Fishes of the Cambodia Mekong.*Rome, FAO. 265 p. 27 color plates.

So Nam and Buoy Roitana, 2005, *A Review of Inland Fisheries Management in Cambodia.* Asian Productivity Organization (APO) and the International Seminar on Inland Fisheries Management 21-26 September 2005, New Delhi, India.

Sparre, P. and Venema, S.C. 1998: *Introduction to Tropical Fish Stock Assessment - Part 1: Manual*. FAO Fisheries Technical Paper No 306.1 Rev.2. Rome, FAO.407p

Suy Sereywath 2007, *small scale fishereis of Cambodia*, RFPN for Cambodia, <http://rsn-ssf.net/ download/ uploads/SSF%20Cambodia.pdf>, [01-12-2008].