AN ASSESSMENT OF ICELANDIC FLATFISH STOCKS

by

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Abstract

Multispecies, multispatial assessment is provided for megrim, witch flounder, American plaice, dab, lemon sole, and plaice in Icelandic waters. Information used as input are logbook records on individual sets from the Danish seine fleet, biological samples mostly from port of landing, and information on individual tows from annual trawl surveys since 1985. Results are compared to commercial CPUE from the English trawler fleet that used to operate in Icelandic waters. Where data allowed the stocks were analysed with a delay difference model, cohort analysis, yield per recruit, and catch curve analysis. These models treated each species as a single stock. The condition of the flatfish stocks vary. All models indicate that the megrim stock is declining to a very low level. Megrim is however historically the smallest of the flatfish stocks and is almost exclusively caught as bycatch. Because of this, ways to protect the stock are few. The current catches of the witch flounder are close to estimated maximum sustainable yield. Some signs however indicate that the stock might be overexploited. The American plaice and dab stocks seem to be in good condition and trawl surveys do not show any decline with time. Uncertainties are large for these species and their real size can therefore not be evaluated. Using the same logic, no specific total allowed catch could be recommended. The lemon sole stock seems to be declining in most areas, how much and from what level is however difficult to judge since the models contradict each other. Information used here for the lemon sole might not be sufficient for stock evaluation. No specific TAC could therefore be advised, but on precautionary grounds, since some models estimate the stock to be on a very low level, all direct target fisheries should be limited. The plaice stock has been declining on most of the major grounds for about a decade. The stock is now at a very low level and all fishery should be reduced considerably.

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1 GENERAL INTRODUCTION

Fisheries are critical to the culture and economy of Iceland. Fisheries resources range from anadromous Atlantic salmon to a variety of pelagic and groundfish species. With the development of improved fishing technologies and conflicts with foreign fishing interests during this century, there has been much concern about the risks of overfishing and a long term decline in productivity. These concerns have driven considerable investment in information gathering, stock assessment, and design of regulatory policies. Much of this investment has been directed to a relative few major fish stocks, particularly cod, and there is a clear need for a multispecies perspective that addresses protection and future impacts of fishing on some of the less important stocks.

This thesis aims to provide information on the stock status (biomass) of several flatfish species that have received relatively little scientific attention in the past, and also the effects the fisheries are having on the stocks. The models used to analyse the data are traditional single species fisheries models and two multispatial, multispecies models. Information used to assess the stocks are samples on catch composition and size at age from port of landing, and logbook records on catches and position of individual sets, from the fleet that is targeting the flatfishes. Information from trawl survey is used as an index of the stock biomass to tune the models.

1.1 Iceland and the surrounding ocean

Iceland is the second largest island in Europe. It lies close to the Arctic Circle in the northern part of the North Atlantic. The maritime boundaries border Greenland in the west and northwest, Jan Mayen (Norwegian) in the north and the Faeroe Islands in the southeast. The total area of the 200-mile exclusive economic zone (EEZ) is 758 000 km^2, of which 111 000 km^2 is continental shelf less than 200 m deep, where most of the fishing is conducted (fig. 1).

The three major surface current systems that influence Icelandic waters are the warm and saline Irminger current, an offshoot from the Gulf Stream, flowing from the south, the colder and less saline East Greenland current from the north-west, and the East Iceland current from the north (Stefánsson 1962). The Irminger current flows clockwise around Iceland, but is mixed on the way with the colder waters. The Irminger current and its mixing with the colder currents are the main reason for the relatively high productivity in Icelandic waters. The Irminger current keeps the waters south and west of Iceland relatively warm and stable both inter and intra-annually. These waters generally have high species diversity and many of those species are not found in the colder waters. The colder waters north of Iceland experience greater changes in temperature and salinity, both between seasons and years, depending on the relative strength of the Irminger current and the colder currents. There are not many species inhabiting these waters permanently, but they are important rearing grounds for some species and some stocks go through on feeding or spawning migrations. Further north, the waters get even colder, but also less fluctuating. There are relatively high species diversity again, but few commercially important ones.

The most important fishery resources in Icelandic waters are medium to long lived demersal species typified by the cod (*Gadus morhua*) (see also Valtysson 1998). Other large species such as haddock (*Melanogrammus aeglifinus*), saithe (*Pollachius virens*), lings (*Molva* spp.), redfishes (*Sebastes* spp.), and wolfishes (*Anarhichas* spp.) are also common. The main pelagic species and the main prey for many of the piscivorous species is the capelin (*Mallotus villosus*). Most of the juvenile and adult capelin live in the cold waters north of Iceland. It spawns once during its lifetime, mainly in the warmer waters at the south coast of Iceland. It is particularly during these spawning migrations that the capelin becomes important food for other species, including some flatfishes. Other common pelagic or benthopelagic species in Icelandic waters are the herring (*Clupea harengus*) and sandeels (Ammodytidae).

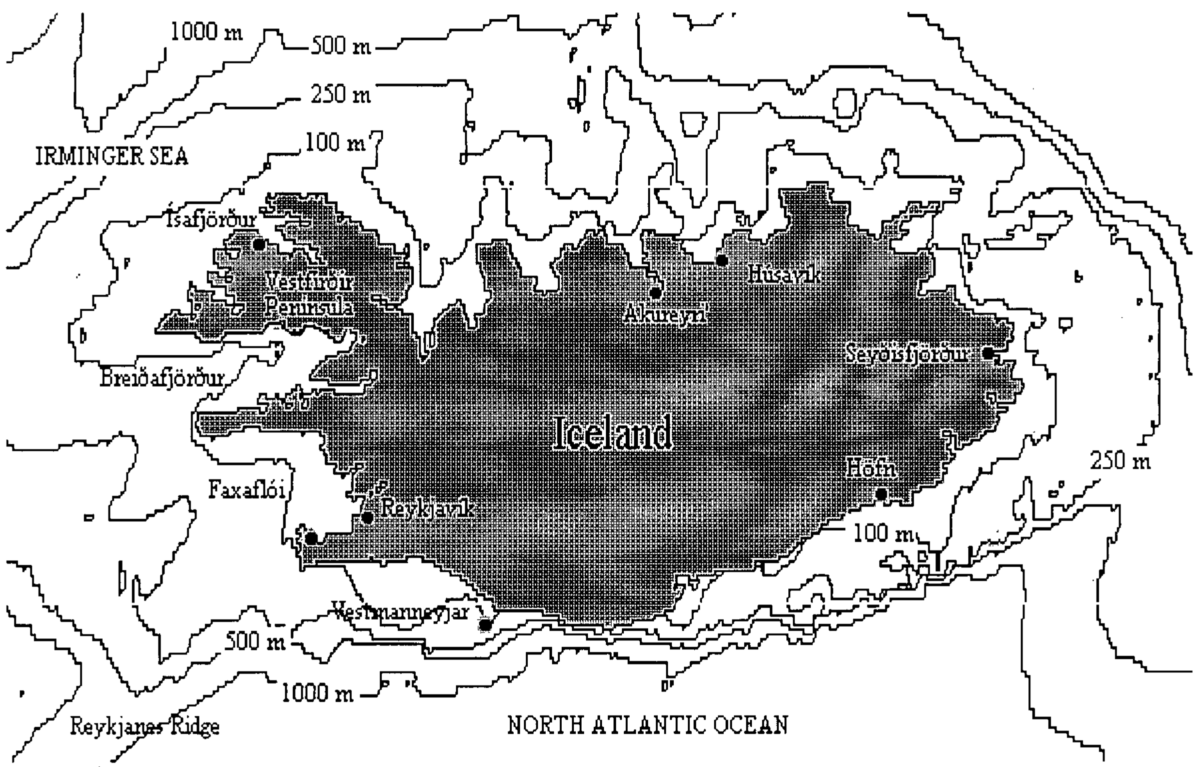

Figure 1: Iceland and the surrounding waters, 100, 250, 500 and 1 000 m depth contour lines, major towns and some geographical features shown

1.2 Fisheries in Icelandic waters

Few other independent countries in the world depend as much on fisheries as Iceland. The fisheries have to be well run since there are few other resources or industries to fall back on if something goes wrong. Although it might not always have worked well, good fisheries management has therefore always been one of the main agendas of the government in Iceland. The main problem has however always been to figure out how many fish there are and how much fishing the stocks can take.

In Iceland, cod is "the fish". Cod has always been the most important resource from the ocean, and until the end of last century, the fisheries in Icelandic waters were almost exclusively targeting it. The locals mostly conducted these early fisheries with hand-lines or long-lines, on small open rowing boats, but larger decked vessels were used by foreign fleets. Small-scale beach seine fisheries were conducted for plaice and dab by Icelanders in previous centuries (Kristjánsson 1986) as well as a limited Danish seine fishery by Danish boats late last century (Tåning 1929). These were however on a very low scale and most probably did not have any effect on the stocks.

The starting point for the real large-scale fisheries for flatfishes was in 1891 when the first English steam trawler was reported in Icelandic waters (Thor 1992). The next decade their number increased rapidly to more than 100. Originally, these trawlers were mainly targeting plaice, and haddock. There are even many reports of the foreign boats only retaining these species but discarding large quantities of cod, much to the displeasure of Icelandic fishers. Before World War I (W.W.I), there were indications that plaice was already being overfished since the average weight in catches and catch per unit effort (CPUE) declined rapidly (Tåning 1929). The percentage of plaice in total catches also declined from 10% in 1906 to 2% in 1916 (Thor 1992). This decrease in catches of plaice was not associated with an increase in catches of other species. Possibly because of this decline, the foreign fleets aimed their attention at cod, which was much more abundant and probably more robust to the fishing. Flatfishes were however always more valuable per weight and foreign fleets continued to take considerable amounts of them.

Since the first trawlers came to Icelandic waters, the fisheries off Iceland have gone through big changes. Icelanders themselves acquired their first trawler in 1905 (Þorleifsson 1974) and the total number and tonnage of the boats has been almost continuously increasing this century. Furthermore, the technology of the fishing fleets has improved rapidly with more effective fishing vessels, echosounders, improved fishing gear, radar, and GPS. Various management methods have been tried to control the fishery and protect the stocks which were being fished harder and harder (fig. 2). The EEZ was extended in steps, culminating in the total exclusion of foreign fleets in 1975. Controlling the expanding Icelandic fleet has however proved more difficult. Trip limits, area closures and increasing mesh size have all been tried at some time or are still in use. These alone did not manage to protect the main stocks. The current main system of individual transferable quotas (ITQs) has however given good results for cod (still the most important fish stock), haddock, capelin, herring, and shrimp (*Pandalus borealis*). There are however some species that are not doing as well or there are great uncertainties about, this applies to some of the flatfish species.

With the exception of plaice (*Pleuronectes platessa*) and halibut (*Hippoglossus hippoglossus*), Icelanders have not caught flatfishes in large numbers during this century, even after they acquired trawlers. Other species were more easily caught, more abundant and furthermore there was little tradition in Iceland to eat flatfishes. After the foreign fleets were expelled from Icelandic waters, there was a 15-year period where flatfish fisheries were minimal. Real large-scale Icelandic fisheries however started in the early 1980's. This was probably because the total allowable catch (TAC) on other species had decreased or was restricted, which in turn meant that fishers were increasingly targeting species which were ignored before. For example flatfish catches, excluding Greenland halibut (or Greenland turbot, *Reinhardtius hippoglossoides*), were 5 200 tons in 1981 or 0.7 % of total groundfish catch but are now about 25 000 tons or 5.6 % of total groundfish catch.

Except for the lemon sole (*Glyptocephalus cynoglossus*) and the halibut, which are much less abundant, the plaice is the most valuable flatfish species per weight in Icelandic waters. Catches of plaice therefore started to increase first of the flatfish species, in 1982. The dab (*Limanda limanda*) is of low value, but since it is very abundant, lives in shallow easily accessible waters, and is frequently caught with the more valuable plaice, its catches increased rapidly soon afterwards, in 1984. The order of the other species is then directly related to value per weight. Catches of lemon sole increased in 1985, witch flounder (*Glyptocephalus cynoglossus*) in 1986, megrim (*Lepidorhombus whiffiagonis*) in 1987 and finally American plaice (*Hippoglossoides platessoides*) in 1988. This pattern is comparable to the current world-wide trend in fishing down the trophic levels of the marine food webs (Pauly et al. 1998). Although the flatfish fishery is not going down a trophic level, the driving force is the same. The most valuable species are taken first. When the fishery for them is restricted or the stocks decline the fishers turn their attention to lower value species.

Currently, the catches of flatfishes in Icelandic waters are around 10 000 t/y of plaice, 5 000 t/y of dab and American plaice, 1 000 t/y of lemon sole and witch flounder and less than 500 t/y of megrim. Except for megrim and lemon sole, these catches are considerably higher than the annual catches by all fleets before the expulsion of the foreign fleets (Hjörleifsson et al. 1998a). Roughly half of the catches of plaice, megrim and lemon sole are by Danish seiners, the rest is by demersal fish and lobster trawlers, the other flatfish species are mostly caught by Danish seiners (table 1).

Originally there were no restrictions on catches of flatfish, but as the catches increased, they have been assigned their own TACs. First the plaice in 1991, then the witch flounder in 1996, and in 1997 the dab and the American plaice. The lemon sole and the megrim do not have a TAC, since they are mostly bycatch of other fisheries. All species in Iceland are theoretically included in the ITQ system but the TAC is unrestricted for some species of minor importance. The problem with the flatfish species is that there is still very little known about these stocks and some of the TACs are just set on precautionary grounds as the sustainable yield is uncertain.

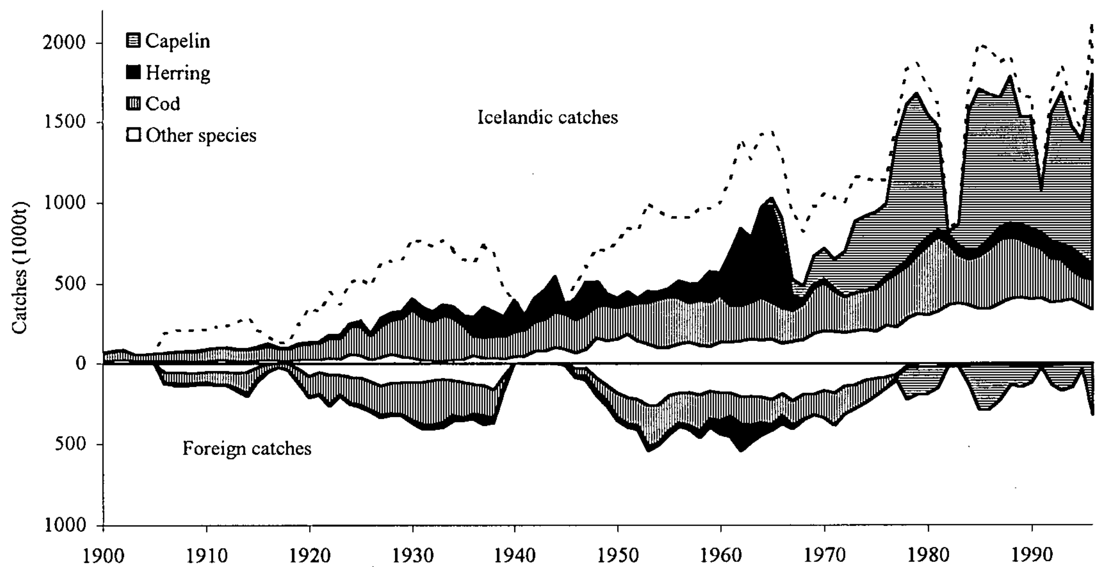

Figure 2: Catches in Icelandic waters according to species groups and fleets, broken line is all catches combined

Table 1: Percentage of total species catches caught by Danish seine since 1982, catches by Danish seine boats were low prior to that.

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Megrim	0	3	0	0	21	79	68	69	44	44	72	55	52	53	42	36
Witch	0	44	0	19	94	96	98	98	91	84	83	77	71	75	63	63
Am. pl.	-	-	-	100	-	90	99	100	95	98	95	97	90	86	90	88
Dab	-	-	-	100	90	99	100	95	98	95	97	99	98	95	98	98
Lemon	12	33	0	8	26	36	47	55	37	46	40	45	9	52	71	57
Plaice	42	40	51	40	44	38	52	57	56	56	50	58	76	77	77	67

1.3 The Danish seine

The Danish seine is the main fishing gear used to catch flatfish in Icelandic waters. In appearance, it resembles a trawl with its wings, belly, and codend. It is operated quite differently though, particularly as trawl doors (otter boards) are not used to keep the Danish seine open. The Danish seine is operated with a set of warps (towing-lines, drag-lines), one on each side, usually kept on large drums. The procedure of Danish seining (fly dragging) is first to set out the end of a warp on a buoy, usually the starboard warp. While the warp is set out the boat sails in a half circle. The wing of the seine is then set out, followed by the net bag and the other wing, followed by the backboard warp when the boat heads back to the buoy. The track of the boat during this procedure forms either a circular, pear shaped, or triangular pattern. Once the buoy has been taken aboard, the towing lines made equal and fastened, the boat starts to pull the gear at a certain speed. During towing the warps are gradually pulled together, herding the fish in front of the seine. As the warps are pulled together the seine moves over the bottom, capturing the herded fish. Once the warps have come together, they are hauled in on the warping drums and the seine is taken aboard using a power block.

The Danish seine has certain disadvantages over trawls (Dickson 1959). It cannot work on as rough grounds as otter trawls, it demands relatively calm weathers and low currents, it is difficult to use during the night or in fog, the workload of the fishers is higher and can also bee more dangerous than trawling. Finally, it demands better navigational skills since when it is set out it cannot be moved to another ground except by hauling it in first. The advantages of the Danish seine are however that it does not need much power to operate (low fuel consumption per catch), it is much cheaper and less bulky than a trawl and can therefore be used on much smaller boats. If good navigational equipments are available and the grounds are well known the seine can be used efficiently (for example on very rough grounds with small patches of good grounds, trawlers cannot operate there but Danish seiners can). Finally, the tows are quite efficient in herding the fish toward the codend, especially flatfish (Þorsteinsson 1990).

During almost all of this century it has been hotly debated in Iceland if the Danish seine is damaging to the bottom (Friðriksson 1932, Jónsson 1964, Sigurðsson 1978, Þorsteinsson 1994). Studies however do not support this (Þorsteinsson 1990). Because of this debate, Danish seining was however severely restricted in many areas for long period. When the EEZ was extended to 12 miles, all trawling (including the Icelandic trawlers) and Danish seining was banned within this zone with few exceptions. Restrictions of Danish seining were gradually lifted, but not so for trawling. Today, Danish seining is allowed on most waters around Iceland, although some of the grounds are only open seasonally. The minimum allowed mesh size is 135 mm, except in Faxaflói Bay where it is 155 mm and on certain grounds where the witch flounder is targeted where it is 120 mm. About 140 boats all around Iceland conduct fisheries with Danish seine, some of them however use other gear in other seasons.

1.4 The flatfishes

Eleven flatfish species (order heterosomata) have been found in Icelandic waters (Jónsson 1992). Five of them are not included in this assessment. The turbot (*Psetta maxima*) is rare, and is not considered to spawn in Icelandic waters, the brill (*Scophthalmus rhombus*) has only once been recorded in Icelandic waters. The Norwegian topknot (*Phrynorhombus norvegius*) is probably common in Icelandic waters but is much too small to be of commercial interest. The Greenland halibut is currently the most valuable flatfish in Icelandic waters, but it is a deep-water species, mainly found in the cold waters west, north and east of Iceland, very different areas than the other flatfish species. It is also primarily caught with deep-water trawl, never with Danish seine. The Atlantic halibut is however frequently caught with Danish seine although it is only a small part of the total catch. It is now considered to be in a serious decline but is not included here for several reasons; firstly because of the relatively low percentage of the total catch caught with Danish seine, secondly because of the extensive migration patterns and different areas that different age classes inhabit, but the Danish seines operate in shallow waters and therefore only catch very young fish, thirdly because catches are mainly from young fish, before growth deflection making it impossible to fit the Ford-Brody growth parameters necessary for the delay difference model.

The other species are witch flounder, American plaice, megrim, dab, lemon sole and plaice, they are roughly similar in shape and size, and share similar ranges. Generally, the dab is caught in the shallowest waters or between 0 to 40 m. Then the plaice between 20 and 60 m, the lemon sole between 40 and 60 m, the witch flounder and American plaice between 60 and 100 m, and the megrim in deepest waters between 100 and 140 m (Hjörleifsson 1998). There are also differences in the bottom types they prefer. The extremes are the witch flounder primarily found over mud bottoms and the lemon sole that prefers hard bottoms (Rae 1965). The other species generally prefer soft bottom, but may be found over various other bottom types. Results from annual trawl surveys since 1985 indicate that all these species, except dab and American plaice, are declining in abundance (Pálsson et al. 1997). Further discussion on the life history and catches of each species is in the chapter on stock synthesis.

2 METHODS

The main methods used to assess the stocks are based on two models originally developed for the groundfish fishery in British Columbia (B.C.), Canada (Walters and Bonfil 1998). The Fishmap program plots CPUE for individual tows on a map, and estimates minimum biomass for the area fished and adjacent areas. The effort spatial dynamics model (Effmod) uses historical catches and stock size indices with population dynamics data to get estimates of total biomass, through the delay different model. Best parameter estimates are based on Bayes posterior probability calculations. The data used for these assessments is from the Marine Research Institute in Iceland and mainly consists of logbook records from boats using Danish seines, from aged samples from the fishery and from annual trawl surveys.

Other models are used where the information allows so. The witch, the plaice, and the dab have enough time series of aged samples to do cohort analysis. The witch flounder, plaice, megrim and lemon sole have a consistent downward trend in trawl surveys, that makes it possible to estimate biomass with a single stock delay difference model. All of the species have enough information to estimate exploitation rate (with catch curve analysis), maximum sustainable yield (MSY) and spawning stock size at equilibrium for a range of exploitation rates.

2.1 Data

The data for this study comes from the Marine Research Institute (MRI) in Iceland and consists of three databases. Firstly, a database on length and/or weight at age from port of landing. Secondly, logbooks from the Danish seine fleet on the location, timing and catches of individual sets. Thirdly, a database on the catches per tow in annual trawl surveys from 1985 to 1997. Information to supplement this, such as information on catch by other fleets than the Danish seine, information on age at maturity, and on the CPUE of the English trawler fleet, were acquired from literature.

Database on length or weight at age: Biological samples (otoliths for ageing, and length and/or weight measurements) from port of landing are collected regularly for all the species, but the plaice and the witch flounder are the only species with more than 5 years of data (table 2, see also summary of age distribution and weight at age in appendix B). The information on weight at age and age composition of catches used to run cohort and catch curve analyses was primarily from the Danish seine fleet. In cases when sample-size from Danish seine fleet was small, samples from other fleets were also used. Only samples from the waters south and west of Iceland were used since these are the major fishing grounds. Samples from other areas were however few or none, depending on the species. Table 2 shows the data that was used. The average weight/length of youngest age classes in the samples from the Danish seine fleet were biased upward because of gear selectivity, samples from research vessels or lobster trawls with finer mesh size were therefore used to get biological data to estimate natural mortality. Samples from all seasons were pooled together, and possible effects of seasonal differences in growth were ignored

Logbooks from the Danish seine fleet: Information on CPUE and catch from individual tows are available in logbook records from the Danish seine fleet since 1979 (about 370 000 tows, table 3). The information recorded in the logbooks are; latitude and longitude (degrees and minutes), statistical area, timing, and the catch of each species per set. Sometimes tow-length and depth are also recorded. In the records before 1991 the latitude and longitude was often not recorded only the statistical area. Logbook turn inns were not very good until after 1990, when new fishery regulations were introduced and it made compulsory to turn in the logbooks. CPUE trend until 1990 may be biased because of this. Note however that catch reports only gives location and timing of individual tows, but government officials at port of landing always record total catch per trip. Because of the discrepancy in logbook records before and after 1991, the logbook records from before 1991 were usually not used directly in the assessment.

Table 2: Total number of samples used (normal font) and individuals measured (*italic font*) from fishing fleet. LT = lobster trawl, DS = Danish seine, BT = bottom trawl, ST = survey trawl, BeT = beam trawl

	Gear	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Megrim	LT										1	1	
											93	*98*	
Witch flounder	DS	3	2	7	4	3	2	3	3	6	5	8	5
		336	*197*	*674*	*374*	*291*	*187*	*292*	*296*	*589*	*481*	*782*	*469*
	BT												1
													99
	LT			10							10	8	7
				1190							*1112*	*895*	*1176*
	BeT									1			
										96			
American plaice	DS								2		3	6	
									185		*281*	*674*	
	LT										10	7	6
											1047	*730*	*570*
	ST									2			
										189			
Dab	DS								6	6	19	21	17
									592	*589*	*1867*	*2061*	*1748*
Lemon sole	DS											1	
												98	
	BT										1		
											96		
	LT										3	1	
											384	*121*	
Plaice	DS			2	3		5	2	3	6	31	26	32
				207	*287*		*515*	*198*	*295*	*593*	*3104*	*2607*	*3191*

Table 3: Ratio (%) of catches reported in logbooks from the Danish seine fleet and total catches by the same fleet recorded at port of landing. Difference between these can sometimes be explained by the fact that the weights from logbooks are estimated by each skipper after each set, but the total weigh of catches per trip are from official scales at port of landing. When the difference is large it can only be explained by failure to turn in the logbooks.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Megrim	0	0	0	0	0	0	0	0	0	0	25	49	135	33	17	19	4
Witch	0	0	0	0	0	0	55	71	42	22	65	73	86	93	85	77	47
Am. pl.	0	0	0	0	0	0	0	36	68	39	61	55	58	85	77	81	67
Dab	0	0	79	70	58	73	23	34	57	21	58	57	81	93	95	94	66
Lemon	5	65	1	90	4	6	3	53	29	10	38	71	55	56	51	36	41
Plaice	60	46	38	25	29	30	19	32	45	49	76	73	92	89	92	76	60

Catch per tow in annual trawl surveys: An annual late winter survey, covering about 550 fixed stations has been conducted in Icelandic waters since 1985 (Palsson et al. 1989, Pálsson et al. 1997). The aim of this survey was primarily to provide a biomass index of the cod, independent of the CPUE from the commercial fleet. The survey area covers the shelf to the 500 m depth contour, since below this depth few groundfish species of commercial interest exist. Information from the survey does thus provide valuable information on many species besides the cod. The survey is conducted with five commercial fishing vessels of similar size and design, since many stations need to be covered in a short period (2 to 3 weeks). The fishing gear is standardised, both between years and among vessels. The minimum mesh size in groundfish trawl fisheries in Icelandic waters is 155 mm (Danish seine mesh size is usually 135 mm). To get good estimates of year classes not yet in the commercial fishery, a 40 mm cover is in the codend. The trawl also has a heavy groundrope to prevent fish from being able to escape under the fishing line. Although the survey trawl is not optimised for flatfish catches, the heavy groundrope increases the catchability of flatfishes, that often escape under trawls (Walsh and Hickey 1993).

The tow stations are the same for all the years, but originally they were chosen semi-randomly. The continental shelf around Iceland was split up into roughly 100 statistical squares of half-degree latitude and one degree longitude. The numbers of tows in each square were assigned proportional to estimated cod density (from commercial catches and previous surveys). Half of the tows in each statistical square were chosen by commercial skippers and half of them chosen randomly by fishery scientists at the Marine Research Institute (MRI).

Trawling is done 24 hours a day. The skipper chooses the order of tows at each locality; individual tows might thus be done during the night in one year, but during the day the other. Results for American plaice in trawl survey do not indicate any difference in catchability between day and night (Palsson et al. 1989). Other results indicate that flatfishes are more easily caught during the night (Walsh and Hickey 1993, Bowering 1979). The possible effects of diurnal variation in catchability are not taken into account by this study.

In addition to position, depth, speed, and distance towed, a record is kept on meteorological and hydrographic conditions. All fish species caught are recorded and counted, species of commercial importance are measured for length, and otoliths are sampled from some species for age determination. Abundance indexes are thus available for most Icelandic groundfish species since 1985 (table 4). In this assessment, the trawl survey abundance index is assumed to be directly related to actual stock size.

Information on catches is from Hjörleifsson et al. (1998a) and anon (1998). Information from the fishery is supposed to be good, since there are multiple checks on the quantities of fish landed (Halliday and Pinhorn 1996). The only unknown factor is discards at sea, which are unknown and therefore impossible to put in the models.

Table 4: Indices from catchable stock by weight in groundfish survey 1985-96 (1 000 t). Numbers from 1998 were not used in this assessment since they were not available until very recently.

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Megrim	1.71	1.93	2.29	2.64	4.43	1.86	2.29	2.26	1.47	0.96	0.87	0.41	0.24	1.09
Witch	2.66	2.88	1.74	1.68	2.84	2.66	1.70	2.21	2.16	1.46	1.35	1.23	1.38	0.98
Am. pl.	10.80	13.00	12.90	11.19	9.58	11.95	12.40	12.38	12.26	13.64	12.23	14.14	14.65	15.14
Dab	3.39	9.89	3.99	3.87	2.05	2.67	2.73	1.86	1.83	2.83	2.47	3.53	4.07	1.56
Lemon	2.65	3.26	3.18	2.47	2.30	2.27	2.46	1.91	1.71	2.11	1.40	1.91	1.37	1.59
Plaice	36.87	22.95	17.97	14.77	9.99	10.31	12.62	10.30	9.02	7.25	4.79	5.28	3.80	3.95

2.2 Biological parameters

Various biological parameters are needed in the assessment models used here (table 5). Growth parameters needed for each species in this study are the intercept (α) and the slope (ρ) for the Ford-Brody growth equation:

$$w_{a+1} = \alpha + \rho w_a \qquad (1)$$

where w_a is weight at age a. For this equation, we also need the age of recruitment to the fishery (k_r) and weight at age of recruitment (w_{kr}). Also required are parameters for the von Bertalanffy growth equation

$$L_a = L_\infty\left(1 - e^{-k(a-t_0)}\right) \qquad (2)$$

where L_a is length at age a, L_∞ is the theoretical maximum length the species can reach, k is growth coefficient that measures the rate at which the L_∞ is reached, a is the age and t_0 is theoretical age at zero length. All the growth parameters were estimated from the database on length/weight at age, by finding the best fit to the observed weight or length at age. In some samples the weight was not recorded. In these cases the weight was estimated from length (L) by

$$w = a^{*}L^{b^{*}} \qquad (3)$$

where a* and b* are constants. These were calculated by finding the best fit to samples where both lengths and weights were recorded. Other parameters needed are natural mortality rate (M) and age of 50% sexual maturity.

Two versions of von Bertalanffy growth parameters (eq. 2) were calculated. The real biological growth rate, to use in natural mortality estimates, and the growth rate of the fishable part of the stock. In the later case, the size at age of the younger age classes was much higher than in the former case, because of gear selectivity. The real growth rate was estimated by fitting a curve to data from trawl surveys, or lobster trawls when trawl survey data was not available (by minimising the sum of squares between the observed data and the curve). The survey and lobster trawls use a very small mesh sizes compared to the Danish seine, and should adequately sample younger age classes. The growth rate of the fishable stock (apparent growth rate of only those fish that have recruited to sizes/areas where fishing occurs) was estimated from data from the Danish seine fleet. The parameters for these two growth versions proved to be very different. In the extreme case of the dab the data from the Danish seine feet did not show any growth with age. Ford-Brody curves were fitted to the data from the Danish seine fleet. For the von Bertalanffy parameters a separate curve was fitted to each sex, then the average for these was used. For the Ford-Brody parameters, combined data for both sexes was used. All the database was used to find the relationship between length and weight.

The age of recruitment was acquired from the literature (Steinarsson et al. 1996, Jónsson 1992). The weight at recruitment was estimated from the database and age of maturity was based on literature (Steinarson et al. 1996, Jónsson 1966, Jónsson 1992, Steinarsson et al. 1989) and unpublished information from the MRI.

Preliminary studies on plaice in Faxaflói Bay (Sigurdsson 1962) in the late 1950's estimated a total annual mortality of 19 %. This should be close to the natural mortality since catches were very low during this period. No further studies have been conducted on the natural mortality of flatfishes in Icelandic grounds. The value used by the MRI for the witch flounder and the plaice is 0.15, other species are not assessed. The flatfishes are different in many aspects and it would be unrealistic to assume the same M-value for all of them. Here the natural mortality rate (M) was first estimated by Pauly's M-formula (Pauly 1980)

$$M = T^{0.463} k^{0.6543} L_{\infty}^{-0.279} e^{-0.0152} \quad (4)$$

where the parameters from the von Bertalanffy growth equation (eq. 2) and temperature (T) were used. The temperature was assumed 5° C, based on near bottom temperatures in the waters south and west of Iceland (Pálsson et al. 1989), where most of the flatfish live. The M values from these estimates were however judged to be unrealistically high (besides the dab the average was around 0.3), and were scaled down so that the average was roughly 0.15, as used in stock assessment for these species in Iceland. The estimated values used here are as in table 5. Most values are between 0.12 and 0.175. The dab is an obvious exception, it has a natural mortality that is twice higher than other species. This is because the dab grows faster at a young age, the adults are smaller, and it matures earlier than other species, indicating a high mortality rate. The use of the Pauly M-formula was thus primarily to evaluate if growth patterns indicated significant differences in natural mortality rate, as was the case with the dab.

Relative price per weight is needed for Fishmap to estimate attraction weights of the grounds for prediction of changes in spatial distribution of fishing effort in Effmod. The value is the average in fish markets in Iceland in 1996 (measured in US dollars).

Table 5: Best estimates on growth and mortality parameters, age of recruitment and 50% maturity, and price per weight. The growth parameters from the real stock reflect the actual average growth of the species; the growth parameters from the fishable stock are however the average growth of the species as seen from catches from the commercial fleet.

	Megrim	Witch flounder	American plaice	Dab	Lemon sole	Plaice
L_{∞} (m), males, real stock	0.421	0.409	0.438	0.297	0.343	0.537
k, males, real stock	0.273	0.271	0.126	0.429	0.334	0.174
t_0 (years), males, real stock	0	1.774	0.198	0.828	0.500	-0.402
L_{∞} (m), females, real stock	0.630	0.438	0.452	0.340	0.359	0.537
k, females, real stock	0.143	0.277	0.159	0.379	0.413	0.174
t_0 (years), females, real stock	0	2.112	0.907	0.558	2.000	-0.402
L_{∞}, (m),total, fishable stock	0.525	0.472	0.437	0.293	0.347	0.474
k, total, fishable stock	0.208	0.228	0.156	0.892	0.293	0.243
t_0 (years), total, fishable stock	0	-1.038	0.280	1.857	0	0.010
α, total, fishable stock	0.1881	0.0842	0.0976	0.1945	0.1036	0.0799
ρ, total, fishable stock	0.9814	0.8333	0.9126	0.4462	0.7726	0.9785
Length- weight a	0.00295	0.000727	0.00232	0.00358	0.00590	0.0153
Length-weight b	3.245	3.598	3.362	3.352	3.168	2.946
W_{∞} (kg), total, fishable stock	1.127	0.513	0.978	0.351	0.452	1.320
W_k (kg), weight at recruitment	0.3726	0.2751	0.2885	0.2859	0.2921	0.4813
M, natural mortality	0.125	0.145	0.120	0.305	0.175	0.140
k_r (years), age of recruitment	8	7	8	5	7	5
Age of 50% maturity	7	5	4	3	4	4
Value per kg ($)	1.4	2.1	1.2	1.2	3.4	2.2

2.3 Fishmap

The Fishmap program is based on a grid map of the fishing area (i.e. Iceland in this study), where the ocean is split up into 2 nautical mile^2 squares. The data on catches of individual species for individual sets are plotted on the map to provide spatial distribution of CPUE (catch per set). Biomass is also estimated for each 2 nautical mile^2 block, by dividing the CPUE by swept area per set (nautical mile^2/set). A spatial averaging procedure is used to include CPUE information from surrounding squares in the estimate for each square, and to provide estimates for unfished squares immediately adjacent to fished ones. Summing these biomass estimates (B_{ij}, i = species, j = grounds) over each ground we get minimum biomass estimates for the whole area.

Some questions have to be answered and assumptions (table 6) made before this procedure can be used. Namely, estimating the area swept and the seasonality in CPUE. It would be best to combine observations for all times of year for the model. Catch however fluctuates regularly between seasons because of migration between or within grounds. In this case, information from all the year was used in the model and the possible effects of migration movements thus ignored. The last question concerns what collection of 2 nautical mile^2 blocks that were not fished (but were near fished areas), should CPUE estimates be provided by interpolating between, or extrapolating from, blocks that are actually fished. In this case we spatially weight the average of the CPUE in that block and in surrounding blocks within a 2 nautical mile radius;

$$y^*_b = \frac{\sum_n y_n w_n}{\sum_n w_n} \qquad (5)$$

where y^*_b is the weighted average of the CPUE in block b, y_n is CPUE in block b or surrounding blocks and w_n is the weight for each blocks, calculated as

$$w_n = 1/\left[\sigma^2{}_d d_{bn} + \frac{\sigma^2{}_0}{e_n}\right] \qquad (6)$$

where $\sigma^2{}_d$ is an index of variance within a block, e_n is effort in block n, $\sigma^2{}_0$ represents variance between blocks and d_{bn} is the distance (nautical miles) from the centre of block n to the centre of block b. In the B.C. model, these were assumed $\sigma^2{}_d = 100$ and $\sigma^2{}_0 = 1000$. The model of the B.C. fishery (Walters and Bonfil 1998) was found to be largely insensitive to the ratio of $\sigma^2{}_d$ and $\sigma^2{}_0$.

Regarding the area swept there is evidence that length of towing lines has been increasing for the last years (fig. 3). It is however difficult to say if this is because catch per set is declining and fishers are using longer towing lines, or if they are on average fishing in deeper grounds and therefore need longer tows. It is however noteworthy that there is no apparent increase in tow length for witch seines (120 mm). Other factors causing uncertainty are that not all boats report the length of the towing lines, and the ones that do, do not necessarily use all the tow length reported for each set. This is because they report what is available on the boat but not what is used. In face of this uncertainty and because of large number of logbook entries that do not report tow length, the data is not corrected for possible increase in area swept with time in the Fishmap analysis. All tows are considered equal effort units.

The question therefore is how much area each seine sweeps. The average diameter of each seine is 1.9 nautical miles, based on tow length in data. Part of the tow used does not reach the bottom; it is assumed that only 75% does. If each set is considered a circle the area swept is $(1.425/(2*\pi))^2*\pi \approx 0.15$ nautical mile^2, which is used in subsequent analyses.

The waters around Iceland was split into 16 grounds (fig. 4), based on distribution patterns of the flatfishes, the fishing grounds and depth. The grounds north and east of Iceland were split according to region. Few flatfish species inhabit these waters in large numbers, and the depth gradient is small compared to the waters south of Iceland (fig. 1). The grounds along the south and west were also split according to region, but then each region was split into inshore and offshore grounds based on the depth. Grounds 15 and 16 were not deemed reliable in assessment since tows were few and many of the might have been misreportings since these waters are generally to deep for the Danish seines. These grounds therefore functioned as trashcans for unreliable data and were not used in the assessments. Some tows were actually reported in the interior of Iceland, either misreporting or typing errors, these were not used.

The Fishmap analysis should be able to provide better predictions for flatfishes than other species like cod and redfishes. This is because the other species often school, spend more time in the water column and are often easily found by searching with acoustic methods. On the contrary, it is not possible to find flatfishes except by fishing, the actual effort is thus reflected in the number of sets by Danish seines. They are also reasonably dispersed over the bottom so that fishers will have to move around regularly. This means that the swept area concept used in Fishmap has more validity for flatfishes.

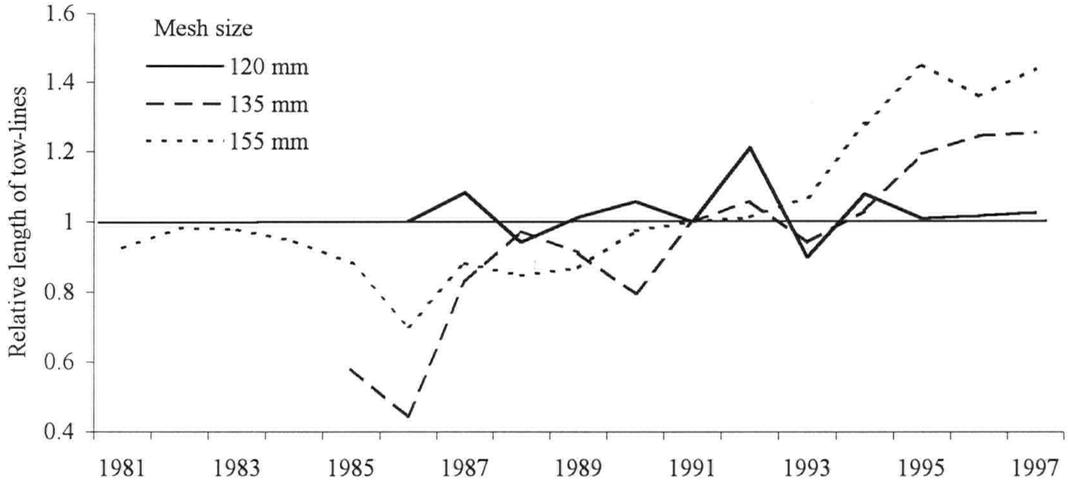

Figure 3: Relative average length of the tow lines from logbooks, the numbers are set so the length is 1 in 1991. The three lines represent different mesh sizes used, but mesh sizes vary among areas and seasons. The 135 mm mesh size is the default minimum mesh size, in Faxaflói Bay the minimum is 155 mm, and in some seasons in some areas the 120 mm mesh size is allowed to catch the witch flounder.

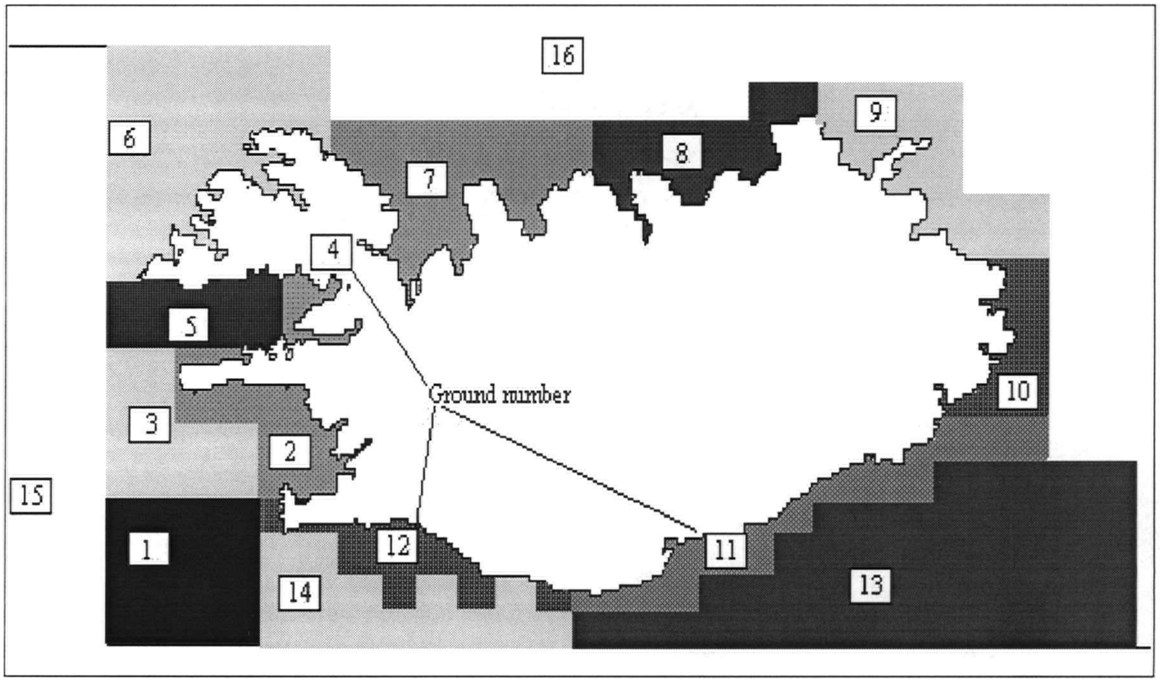

Figure 4: The grounds (gr.) around Iceland used in Fishmap and Effmod. Gr. 1 is Reykjanes Ridge, gr. 2 is inner Faxaflói bay, gr. 3 is outer Faxaflói Bay, gr. 4 is inner Breiðafjörður Bay, gr. 5 is outer Breiðafjörður Bay, gr. 6 is Vestfirðir Peninsula, gr. 7 is northwestern Iceland, gr. 8 is northern Iceland, gr. 9 is northeastern Iceland, gr. 10 is eastern Iceland, gr. 11 is shallow waters in southeastern Iceland, gr. 12 is shallow waters in southwestern Iceland, gr. 13 is intermediate depth in southeastern Iceland, gr. 14 is intermediate depth in southwestern Iceland, gr. 15 is deep waters south and west of Iceland, gr. 16 is deep waters north and east of Iceland.

Table 6: Models used, input and output of the models, how they are tuned and assumptions. All models assume the input data or parameters are correct and reflect the true state (survey index reflects biomass, samples from commercial fleet reflect actual stock composition and weight at age, M is correct etc.) and it is also assumed that the parameters do not change with time.

	Input	Output	Tuning	Assumptions
Fishmap	Catch by individual sets from fleet	Distribution of catches and effort, minimum biomass	None	Even and random distribution of fish and effort within each cell, swept area per set is constant, all fish within area swept caught, grounds are homogeneous, effort does not move or spread out within grounds between years.
Effmod	Effort by grounds, growth and recruitment parameters, M, age of recruitment	Biomass, MSY	Survey index, CPUE and catches	Recruitment a function of stock size, stock at B_0 in 1980, knife-edge recruitment, catchability constant for all age classes recruited to the fishery.
Delay difference model	Total catch, growth and recruitment parameters, M, age of recruitment	Biomass, exploitation rate, equilibrium yield	Survey index and CPUE	Recruitment a function of stock size, stock at B_0 in 1900, knife-edge recruitment, catchability constant for all age classes recruited to the fishery.
Cohort analysis	Catch and weight at age, M	Biomass, recruitment, vulnerability at age exploitation rate	Survey index	No fish alive at some age, no net immigration or emigration
Forwarded cohort analysis	Growth parameters, M. age of maturity	Equilibrium yield and spawning stock	None	Constant recruitment, growth and recruitment is some average from previous years
Yield per recruit	Growth parameters, M, age of maturity	Equilibrium yield and spawning stock per recruit	None	
Catch curve	Age proportions in catches, M	Exploitation rate	None	Constant recruitment, catchability constant for all age classes fully recruited to the fishery.

2.4 Effmod

This model provides two methods for analysis: (1) Multispatial simulation, modelling the effect of spatial effort movement in response to multispecies-multiground changes in abundance, and (2) single stock assessment for multiple species over multiple grounds. The difference delay model (Deriso 1980, Schnute 1985) is used to estimate the annual (t) biomass ($B_{ij,t+1}$) for each stock i for each ground j, given the survival rate ($s_{ij,t}$), growth (α, ρ), the biomass ($B_{ij,t}$) and number of fish ($N_{ij,t}$) the year before, recruitment ($R_{ij,t+1}$) and average weight of recruits (w_{kr});

$$B_{ij,t+1} = s_{ij,t}(\alpha_i N_{ij,t} + \rho_i B_{ij,t}) + w_{kr,i} R_{ij,t+1} \quad (7)$$

$$N_{ij,t+1} = s_{ij,t} N_{ij,t} + R_{ij,t+1} \quad (8)$$

The model assumes that recruitment to the fishery is knife-edge at age k_r, i.e. before that age none of the fish are vulnerable to the fishery, but all of them are equally vulnerable at and after age k_r. Further assumptions are that growth and mortality paramesters do not change with age. The growth parameters are from the Ford-Brody relationship (eq. 1). The survival rate ($s_{ij,t}$) varies with natural mortality rate (M_i) and fishing mortality rate ($F_{ij,t}$).

$$s_{ij,t} = e^{-M_i - F_{ij,t}} \qquad (9)$$

Fishing mortality rate is a function of $q_{ij}*e_{i,t}$, where $e_{i,t}$ is effort on ground i in year t and q_{ij} is catchability of species i on ground j.

Recruitment is modelled with the Shepherd (1982) stock-recruitment relationship as in Walters and Bonfil (1998)

$$R = \frac{a_R S}{(1 + a_R bS)^c} \qquad (10)$$

where S is spawning biomass (assumed to be the same as B in eq. 7), a_R is maximum number of age k_r recruits per unit spawning biomass, b is local recruitment carrying capacity parameter and c is the stock-recruitment curve shape parameter. Stock-recruitment parameters are not known for these species, but b can be estimated if a and c are assumed.

If unfished biomass (B_0) is assumed to be sustainable (and there are no catches), we can derive average unfished recruitment from eq. 7:

$$R_0 = \left(B_0 - s * \frac{B_0\left(\frac{\alpha}{w_0} + \rho\right)}{w_{kr}} \right) \qquad (11)$$

Where w_{kr} is body weight at age of recruitment and w_0 is average body weight in unfished stock, given by:

$$w_0 = \frac{s * \alpha + w_{kr} * (1 - s)}{1 - s * \rho} \qquad (12)$$

The main problem is to find out the stock-recruitment parameters (eq. 10). We assume here that the recruitment follows a Beverton and Holt profile, that is the c parameter is set to 1. Furthermore we assume that a_R is

$$a_R = \frac{KR_0}{B_0} \tag{13}$$

where K defines the initial slope of the stock-recruitment curve. High K values indicate a recruitment that is independent of stock size over a range of spawning stock sizes since the initial slope is steep, but a K value of 1 implies that recruitment is directly proportional to spawning stock. A value lower than 1 is not realistic since it implies that if the spawning stock declines the recruitment declines more, and the stock is bound for quick extinction. Studies indicate that K is usually between 5 and 10 for most species (Myers and Barrowman 1996, Myers and Mertz 1997). We take a conservative approach here and assume it to be 5.

Now the only parameter in equation 10 be found is b. The average unfished recruitment however implies one point in the stock-recruitment curve, from which we can derive b from equations 10 and 11 to give

$$b_{ij} = \frac{\left(\dfrac{w_{kr,i} a''_{ij}}{1 - \left(s_{ij,0} \dfrac{\alpha_i}{w_{0,i} + \rho_i} \right)} \right)^{\frac{1}{c_{ij}}} - 1}{B_{ij,0} a''_{ij}} \tag{14}$$

For effective calculation runs with the difference delay model, the initial biomass (B_0) has to be estimated. Estimating the parameter is done by fitting the model results to a survey and a CPUE time series, using progressively larger B_0 values until the model produces the best fit to the current survey index or CPUE estimate. Likelihood of B_0 under study is estimated with Bayesian statistical procedures (Walters and Ludwig 1994), giving a probability distribution for uncertain parameters. The likelihood value (L) for each run is calculated with;

$$L^{(y)} = \sum_{t=t''}^{t=t'} \frac{\ln\left(\frac{y_{ij,t}}{B_{ij,t}}\right) - \left(\sum_{t=t''}^{t=t'} \ln\left(\frac{y_{ij,t}}{B_{ij,t}}\right)\right)}{t'-t''} \qquad (15)$$

where $B_{ij,t}$ is biomass of species i on ground j in year t estimated by the model, $y_{ij,t}$ is biomass index of species i on ground j (survey or CPUE), t' is the first year we have information on y, and t" is the last. The years used for the trawl survey index were from 1985 to 1997, the years for the CPUE were from 1991 to 1997. The likelihood model assumes that the biomass indexes (y) is linearly related to actual biomass.

There are two likelihood functions in the overall probability value ($P(B_{ij,0}|y)$), where $B_{ij,0}$ is the unfished biomass and y represents the biomass index used. One is calculated from CPUE for the Danish seine fleet ($L^{(cpue)}$) and the other from trawl survey index ($L^{(survey)}$)

$$P(B_{ij,o} \mid y) = L^{(cpue)} L^{(survey)} \qquad (16)$$

The relative weight of these likelihood functions can be varied in the model and other biomass indexes, such as minimum biomass estimated from Fishmap, are possible to incorporate. In these analyses the Fishmap estimates were not used, except to set lower bounds on the likelihood distribution and the survey index was given more weight than the CPUE.

Two submodels were tested. Model one assumed the most likely B_0 where P (eq. 16) was maximised. Model two assumed B_0 as the value where the sum of the likelihood values, starting from the lowest B_0, was 20% of the total. This was done to get at least conservative estimates on B_0, because, in many cases, when there was no decline in survey or CPUE, the likelihood profile just reached an asymptote or an unrealistically high peak. However, when there was an obvious decline and the model gave a good fit, estimates from these two submodels gave very similar results.

Several problems arose over distribution of the effort and catches by grounds. Firstly, the length of the tows seems to be increasing with time. Secondly, logbook records from the Danish seine fleet were not accurate until 1991, since it was not mandatory until that time to turn them in except in the Faxaflói Bay (ground (gr.) 2). Thirdly the logbooks are only from the Danish seine fleet, but considerable catches of some flatfish species, most notably lemon sole and megrim, are from boats using other types of gear. Information on where other fleets are fishing is however not available for this study.

The total effort was corrected for the apparent increase in tow length with time (fig. 3), according to species (120 mm used for the witch flounder, 135 and 155 mm for other species) and areas (155 mm used in Faxaflói Bay and 135 mm in other areas). The correction was done by using the effort in 1991 as it was reported in the database, but corrected for the other years with the deviation from this. It is therefore assumed that the average of the reported tow lengths reflect the whole fleet and that they reflect the actual size used. About half of witch flounder catches are by boats that use more than 120 mm mesh size, and also about $^{1}/_{3}$ of American plaice catches are caught by the 120 mm gear. The effort was however not corrected for this.

The catch distribution of American plaice and dab used in Effmod was assumed to be directly proportional to the catch distribution in the logbooks, assuming that catch reports were randomly spread among the grounds and all of the catches were by Danish seine boats. This is likely since catches of these species were very low prior to 1990 and biased logbook records before that time will not affect these species much and because the majority of the catches have always been by the Danish seine fleet (table 1). Catch distribution from the Danish seine fleet of megrim after 1990, witch flounder after 1986, and lemon sole and plaice after 1987 were assumed to be directly related to logbook records. Prior to that time the catches were spread according to the average distribution in logbooks from 1991 to 1994 for megrim, 1987 and 1988 for witch flounder and 1988 to 1992 for lemon sole and plaice. Before 1988 catch reports for plaice in Faxaflói Bay were assumed to be complete. The catch in Faxaflói Bay was therefore subtracted from the total catch before it was distributed among the other grounds. The CPUE for each species per ground was assumed to be as in the logbooks, but corrected for increased tow-length with time. The effort of the Danish seine fleet by ground (fig. 5) was then the sum of all catches by species divided by the sum of CPUE by species. The total estimated effort was then similar as the reported effort by the Danish seine fleet (fig. 6). The divergence in the last years is because of the increase in tow length.

Distributing catches from the commercial trawler fleet is where most uncertainties lay, since logbook records from this fleet are not available here. We know that the trawlers are generally not fishing in the same grounds as the Danish seines since there are much more restrictions on where trawling is allowed. Trawling is generally banned within 12 miles from shore while Danish seining is not. We however now have estimates on how the Danish seine fleet is distributing its effort. We also know the catch distribution by fleets and the total effort of the trawler fleet (days at sea). The trawl effort was distributed so half of it was in ground 6, 13% in ground 14 and 7% in grounds 1, 3, 13, 15, 16. The other grounds are within 12 miles from shore so no trawler effort was assumed to be there. The total trawl effort per year was based on the reported number of days at sea for all Icelandic trawlers in Icelandic waters and corrected to the same level as Danish seine so that they used the same effort to catch the same amount. The CPUE from the Danish seine fleet was then used to estimate the catch of the trawler fleet by grounds, assuming that the CPUE for these fleets was the same for each ground. The main input into the Effmod was then the combined effort for these fleets and the CPUE from the Danish seine logbooks.

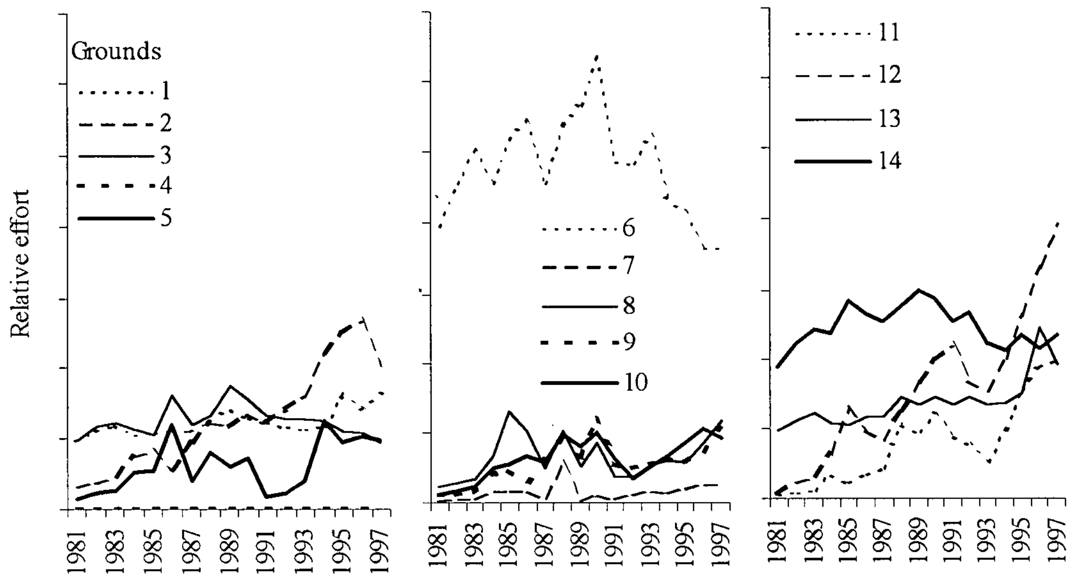

Figure 5: Relative effort by grounds as used in Effmod, the Y-axis scale is the same for all graphs.

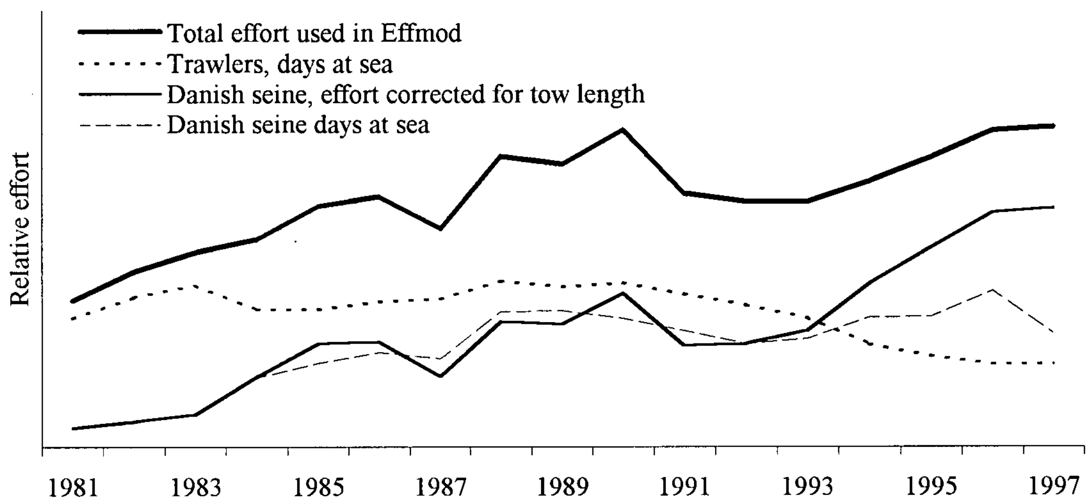

Figure 6: Total days at sea for the Icelandic trawler and Danish seine fleet, also effort corrected for increase in tow length and total effort used in Effmod. The total effort is the trawler effort plus the corrected effort by the Danish seine fleet.

2.5 Single stock delay difference model

The single stock delay difference (SSDD) model estimates annual biomass and uses the same equations as Effmod, except it does not split the species into stocks by grounds. Also as opposed to Effmod the most likely value of K (eq. 13), as well as B_0, is found. Finally, historical catches, but not effort, are used to drive the model. The survival rate ($s_{i,t}$) in this model is thus;

$$s_{i,t} = e^{-M} * (1 - \frac{C_{i,t-1}}{B_{i,t-1}}) \tag{17}$$

where $C_{i,t}$ is catches in year t and $B_{i,t}$ is biomass.

Survey indices (table 4) were used to tune the single stock model by changing unfished biomass (B_0) and K (eq. 13) until best fit is found. The likelihood values for each combination of B_0 and K are calculated with a Bayesian procedure (Walters and Ludwig 1994), where the likelihood (L) of the combination of K and unfished biomass is calculated with equation 15. The stock-recruitment curve was assumed to follow the Beverton and Holt profile. Note that since each species is assumed from a single stock, the j (for grounds) drops out of the equations.

In some cases the likelihood values were similar for a range of K values, in these cases a K value of 5 was used (i.e. if it fell within the range of likely values) in subsequent analysis. All the species were also assumed to show Beverton and Holt type of stock-recruitment relationship as in Effmod.

Estimated biomass (B_e) at equilibrium was derived from equations 7 and 10 to give

$$B_e = \frac{\left(\frac{\frac{s a_R \alpha}{1-s} + w_{kr} a_R}{1 - s\rho} \right)^{\frac{1}{c}} - 1}{a_R b} \tag{18}$$

Then we can estimate catch at equilibrium (C_e) as

$$C_e = U B_e e^{\frac{-M}{2}} \tag{19}$$

where U is exploitation rate.

2.6 Cohort analysis

The cohort analysis reconstructs the stock biomass from a known number of fish caught in each age class each year. The method adds up catches and assumed natural mortality for each cohort over time, where the number at age a at year t (N_{at}) is estimated from the following equation (Pope 1972):

$$N_{at} = \left(N_{a+1,t+1} e^{\frac{M}{2}} + C_{at} \right) e^{\frac{M}{2}} \qquad (20)$$

where ($N_{a+1,t+1}$) is the number in the cohort in the year t+1, M is natural mortality rate and C_{at} is the number caught in each cohort. The problem with this analysis is getting estimates on number of all age classes for the terminal year (A) and the numbers in the oldest age class for all years. The number in the oldest age class ($N_{a''t}$) was estimated as the catch of the cohort ($C_{a''t}$) divided by the fully vulnerable harvest rate (U_t) which is estimated from the following equation:

$$U_t = \frac{\sum_{a=a'}^{a=a''-1} C_{at}}{\sum_{a=a'}^{a=a''-1} N_{at}} \qquad (21)$$

where a' is age at which they are first fully vulnerable to the fishing gear. The relative vulnerability of age classes not fully vulnerable to the fishery (V_{at}) is an output of the model and is estimated by the following equation

$$V_{at} = \frac{C_{at}}{U_t * N_{at} * e^{\frac{-M}{2}}} \qquad (22)$$

Two main methods can be used to estimate numbers for the terminal year. Firstly recruitment can be estimated for the last years (e.g. use some recruitment function or the average for previous years) and then forwarded by subtracting catches and natural deaths. Secondly, relative vulnerability of each age class and fully vulnerable exploitation rate can be estimated for all the age classes in the last year. Then using equation 20, the size of each cohort is backtracked. The time span these cohort analysis covered were very short and datapoints with reliable recruitment estimates are thus few. The former method of forwarding average recruitment was therefore not used.

The vulnerability at age for the last year ($V_{at'}$) was described by the following equation

$$V_{at'} = \frac{1}{1+e^{(k_r*ð-ð*a)}} \tag{23}$$

where a is the age, k_r is the age of 50% vulnerability toward the gear and ð is the steepness of the slope through k_r. The value of ð was assumed based on the steepness of the slope in previous years. The most likely combination of k_r and terminal exploitation rate (U_{1997}) were found with Bayesian procedures (Walters and Ludwig 1994). These were obtained by fitting the estimated exploitable biomass (biomass of 5 years and older for dab and plaice and 7 years and older for witch flounder) to survey biomass indices (eq. 15). In addition to that the number of 5 year old plaice from the models was fitted to the recruitment indices from trawl surveys. The reason this was not done for the dab is because it has a very short time series. The reason it was not used for witch flounder is that it takes much longer to become fully recruited to the fishery (the recruitment of the dab and the plaice is closer to being knife-edge). The recruitment indices from trawl surveys are based on length distribution (Jónsson et al. 1995) and do thus probably cover many age classes when recruitment is not knife edge, which makes the index impossible to compare to certain age classes from cohort analysis.

To get estimates of MSY the model was forwarded for 50 years, using the following equation that is derived from equation 20:

$$N_{a+1,t+1} = \left(N_{at} e^{\frac{-M}{2}} - C_{at} \right) e^{\frac{-M}{2}} \tag{24}$$

Future catches of each cohort were similarly estimated from a equation derived from equation 22, where exploitation rate is varied and V_{at} used as in equation 23:

$$C_{at} = V_{at} U_t N_{at} e^{\frac{-M}{2}} \tag{25}$$

Weight at age used in forwarding the model was the average for each age class for all years with data, and recruitment used was the average for some previous years, 1993-1995 for dab, 1988-1992 for plaice and 1986-1992 for witch flounder.

Only three of the flatfish species have aged samples covering enough time for the cohort analysis to be used, these are plaice, witch flounder and dab. The age structure data from landings of plaice stretches back to 1987, to 1986 for witch flounder and to 1993 for dab (table 2). Samples were not available for plaice in 1990 so weight at age was estimated by the Von Bertalanffy equation (parameters as in table 5). The age composition for plaice that year was estimated to be the intermediate between the percentage of the cohort the previous year and the subsequent year.

The assumptions in this cohort analysis are that M is constant over time and age classes and age composition in catches are adequately described by the samples (table 6). The cohort analysis is also vulnerable to the ratio between fishing mortality and natural mortality. Preferably fishing mortality should be greater than natural mortality. All the species under consideration here have been fished intensively during the period of these analyses. Further assumptions in the forwarding procedure were that the weight at age was constant over time, vulnerability at age was the same as in 1997, and recruitment was constant. All these assumptions, especially for the forwarding analysis, mean that the results should be taken with extreme precaution.

2.7 Catch curve analysis

Catch curve analyses were done for all the flatfish species. In these the natural logarithm of the numbers at age for each year (pseudo-cohorts) was plotted, and a straight line fitted to the age classes that were considered to be fully recruited to the fishery (Beverton and Holt 1957). If all assumptions are met, then the slope of the line equals total mortality rate (Z). The natural mortality (M) (table 5) was then subtracted from this value to give fishing mortality (F). The exploitation rate is then 1-exp(-F). The first age class considered fully recruited to the fishery was either the most abundant age class or one year older than the most abundant. The age class was chosen that gave a steeper slope (higher Z). Old fish that were obvious outliers were excluded from the analysis.

The amount and type of samples available differed considerably between species. The usual number of fish aged in each sample is around 100, each of these were considered one sample and a catch curve fitted to each of them. In some cases only about 50 individuals or less were aged, these samples were combined with other samples from the same area and time so that the total number of fish measured in each sample was no less than 90. To fit a catch curve to each sample, but not to the average for all samples from each year, was done to get reasonable estimates on the variability within each year.

Generally, the data had to meet certain criteria to be used in this analysis. Data from waters north and east of Iceland was not used (gr. 7 to 10 in Fishmap), since it is not certain if the flatfishes inhibiting these waters are self sustaining populations or are caused by dispersion or larval drift from warmer waters. Catches in these waters are low and samples few or non-existent depending on species. Seasonal changes due to spawning migrations can also skew the data. Plaice samples from January to May were not used due to unusually high number of old individuals. This is probably because during this season the plaice is being targeted on spawning grounds where older individuals aggregate. Where sample size was high the analysis was only done on samples from Danish seine (dab and plaice) or

Danish seine and lobster trawl (witch flounder). All gears were used for other species but samples with less than 90 individuals measured were not used, but these were few.

The assumptions for this analysis (table 6) were that recruitment is either constant or at least that variation is low, and high and low abundance age classes cancel each other out when a line is fitted. The total mortality rate is assumed to be the same for all the age classes within each year. It is also assumed that the age composition of the samples reflect the age composition of the stock, i.e. the catchability should be the same for all age classes fully recruited to the fishery.

3 SPECIES SYNTHESIS

3.1 Abundance by grounds

Except for American plaice and dab, the highest estimated unfished flatfish biomass is in ground 9 (fig. 7), then in ground 6. The southern areas (gr. 12 to 14) also have high biomass, the western grounds (gr. 1 to 3 and 5) have intermediate level. Except for ground 4, the lowest unfished biomass is in northern grounds (7 and 8). The status of the species varies considerably among grounds.

The American plaice has by far the highest biomass estimate in ground 1, then the witchflounder. Neither of these stocks shows much decline, i.e. the current biomass is more than half unfished (table 7 and fig. 8). The plaice stock is the third most common, although it never seems to have been large. Nevertheless the stock is declining to low levels, and so is the megrim stock. The megrim stock is not high in these waters compared to other species but compared to megrim in other areas this stock is medium too large sized.

Ground 2 is very different to ground 1. Here the dab stock is by far the largest, followed by the plaice. Other stocks are very small in these waters. The dab stock seems to be in very good condition, but the plaice stock is at a low level. The American plaice is the largest stock in ground 3, followed by the witch flounder and plaice stocks. All the stocks in these waters seem to be in good condition except plaice. Ground 4 is estimated with low flatfish abundance, this might reflect very little fishing effort in the area. The only flatfish in these grounds are plaice and dab. The plaice stock has historically been the most abundant stock in ground 5, it is however at a very low level now, and currently the American plaice and dab stocks are estimated with higher biomass. Other species have always been rare in these waters. The plaice is the only significant flatfish stock in ground 6; it is at a low level currently.

The plaice and American plaice stocks are the most abundant in ground 7 and 8, followed by dab. Flatfish abundance is low in ground 7 and 8, where the situation is nevertheless very similar to previously described grounds. The American plaice and dab stocks do not show any decline, but plaice is at a low level. Plaice is the most abundant flatfish in ground 9, followed by American plaice. This ground is estimated to have the largest plaice stock in Icelandic waters, both historically and currently, and as opposed to all other grounds, the plaice stock in these waters shows a very small decline. The uncertainty is however very large and the results should be taken with precaution. The American plaice and plaice are the largest stocks in ground 10. The plaice stock is declining but not American plaice.

American plaice and dab are the most abundant species in ground 11, and neither is declining. Other stocks are not large historically or compared to other grounds, and are all declining to low levels. Dab and American plaice are also the most abundant species in ground 12. Plaice, witch flounder and lemon sole have however also been numerous historically. The plaice stock is however the only one of those that is currently at a low level. American plaice and plaice are the most abundant stocks in ground 13, followed by the lemon sole. None of these seems to be in bad condition. Witch flounder and megrim stocks that have historically not been large in this area are nevertheless in a bad situation. The American plaice is the most numerous stock in ground 14, followed by plaice, dab, and witch flounder, all historically at a similar level. The plaice, lemon sole and megrim stocks are at a low level in this ground.

The likelihood profile varies considerably among grounds and species (fig. 9). The American plaice and dab however generally have wide or asymptotic distribution profiles, implying that uncertainty about stock size is large. The profiles for the other species are narrower, but vary between grounds. The difference between observed and predicted catch by Effmod is also variable between species and grounds (fig. 10). For some cases, e.g. plaice in ground 2, 9, and 12, lemon sole in ground 2 and 12 and witch flounder in ground 11, the difference is quite small. Other cases such as plaice in ground 6, and dab and American plaice in many of the grounds do show large differences in the beginning of the period.

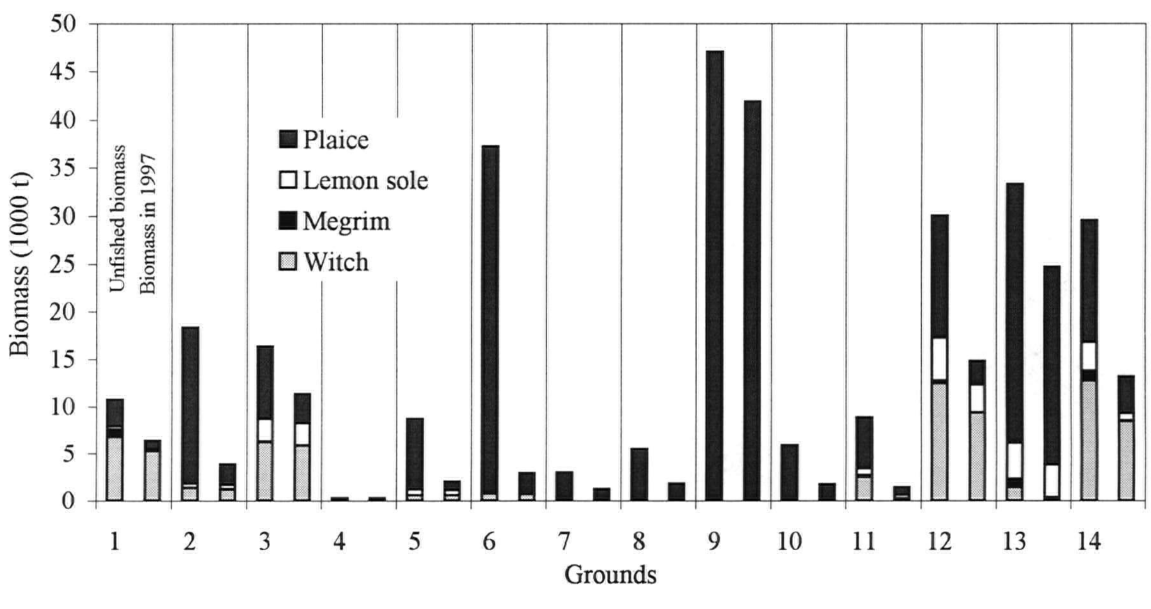

Figure 7: Biomass estimates from model 1 in effmod of plaice, lemon sole, megrim and witch flounder in the grounds around Iceland, the former column in each ground is unfished biomass, the later is biomass in 1997.

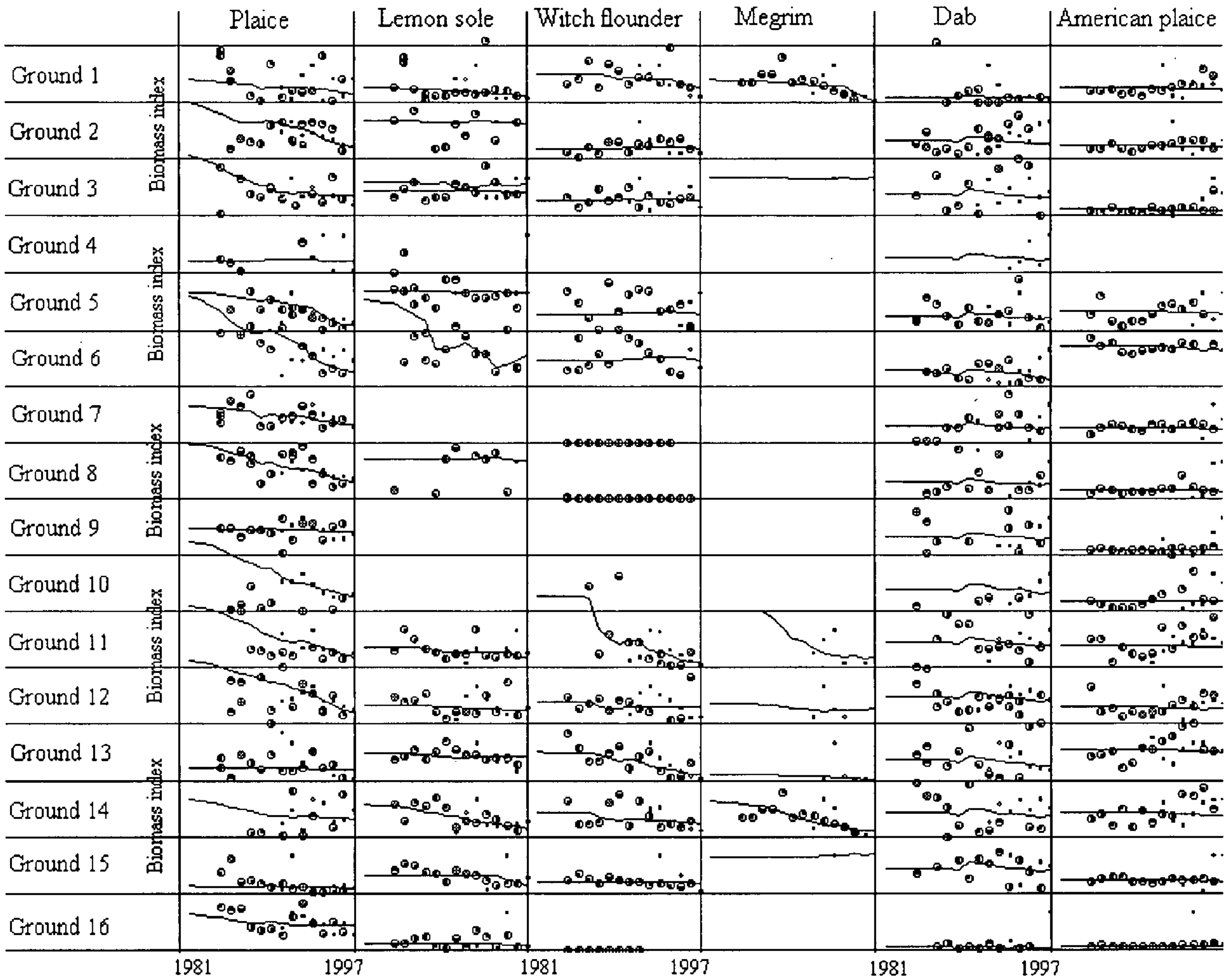

Figure 8: Results from Effmod model 1. Observed CPUE since 1991 (small circles), survey data since 1985 (large circles) and predicted relative biomass (line) from most probable unfished biomass estimate for each species on each ground. The x-axis for each graph is the time period from 1981 to 1997. Predicted CPUE represents most probably trend in biomass. The Y-axis of each plot is relative biomass, note that the scale on the y-axis is not comparable between species and grounds.

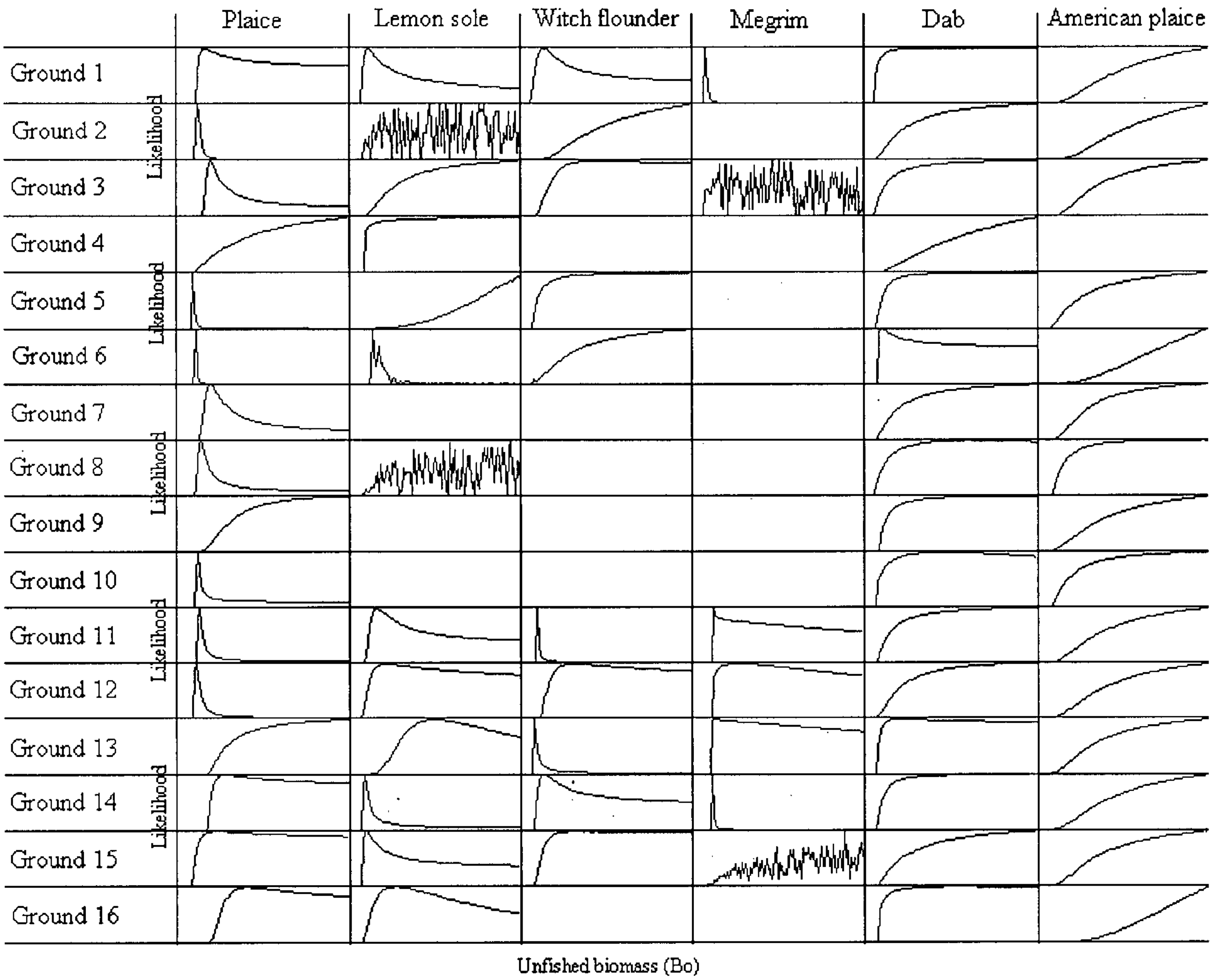

Figure 9: Bayes posterior profile for the unfished biomass for each species on each ground. The X-axis of each plot is the unfished biomass, ranging from 2 times to 200 times the mean reported catch for the stock in the area. The Y-axis of each plot is the relative probability of obtaining the observed CPUE for corresponding unfished biomass.

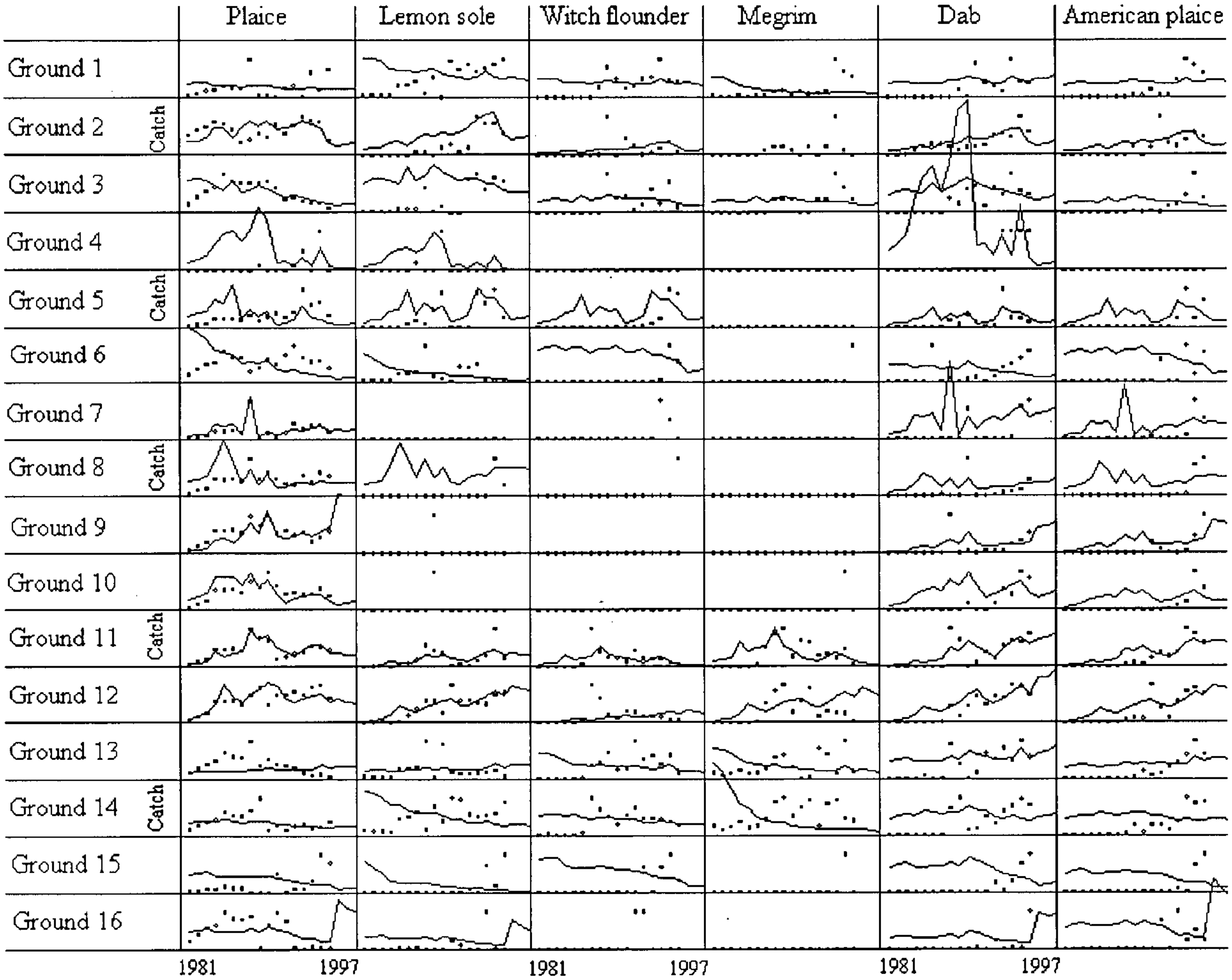

Figure 10: Results from Effmod model 1, observed catches (small circles), and predicted catches (line) since 1981 from most probable unfished biomass estimate for each species on each ground. The Y-axis of each plot is relative catches, note that the scale is different between species and grounds.

Table 7: Results from Effmod analysis. Current (1997) biomass estimates and percentage of current to unfished biomass (B_0) by species, grounds and models. Total unfished biomass (sum of all grounds) and MSY estimates by species and models

	Megrim		Witch flounder		American plaice		Dab		Lemon sole		Plaice	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Current biomass (t)												
Gr. 1	115	115	5223	1634	65344	20104	1730	153	164	66	894	326
Gr. 2	1	1	1228	574	2581	1146	229441	28458	424	68	2151	2151
Gr. 3	36	17	5883	927	27451	5150	3398	174	2295	302	3132	1751
Gr. 4	0	0	0	0	0	0	77	24	0	0	249	46
Gr. 5	0	0	589	28	1558	181	1191	162	581	457	820	820
Gr. 6	2	2	758	125	175	65	124	124	3	3	2184	2184
Gr. 7	0	0	1	1	1554	222	514	55	0	0	1211	448
Gr. 8	0	0	0	0	4901	325	1589	198	168	20	1663	819
Gr. 9	0	0	0	0	16114	3715	395	22	0	0	41879	13632
Gr. 10	0	0	0	0	3918	268	286	26	0	0	1775	925
Gr. 11	24	7	232	232	78817	18384	62310	4301	401	215	748	748
Gr. 12	14	14	9393	2348	36443	10107	34503	6174	2962	976	2409	975
Gr. 13	145	32	285	285	28699	9380	873	873	3412	1510	20850	7192
Gr. 14	95	95	8412	2922	46330	11773	13131	902	835	463	3807	1364
Gr. 15	15	5	24	8	378	62	912	103	9	5	416	50
Gr. 16	0	0	0	0	151	95	189	13	161	59	55	55
Total	448	287	32028	9085	314415	80977	350662	41763	11413	4143	84242	33486
Percentage of current to unfished biomass												
Gr. 1	15	15	77	50	95	86	90	44	51	30	31	14
Gr. 2	59	59	90	81	94	86	97	79	94	71	13	13
Gr. 3	80	64	94	70	95	80	97	62	96	77	41	27
Gr. 4							97	92			96	81
Gr. 5			93	39	95	71	93	66	96	94	11	11
Gr. 6	100	100	96	78	94	86	37	37	22	22	6	6
Gr. 7			100	100	95	73	96	73			40	19
Gr. 8			100	100	94	49	95	67	96	74	31	18
Gr. 9					95	80	94	45			89	73
Gr. 10	100	100			96	59	90	43			30	18
Gr. 11	12	4	9	9	95	81	97	67	55	40	14	14
Gr. 12	5	5	75	41	94	82	88	56	66	39	19	9
Gr. 13	16	4	20	20	84	64	37	37	88	76	77	51
Gr. 14	9	9	66	39	95	82	94	53	28	17	30	13
Gr. 15	94	84	80	57	95	77	97	78	36	23	78	29
Gr. 16			100	100	95	92	87	32	79	58	100	100
Total	14	9	71	40	94	80	95	70	70	46	45	24
Total unfished biomass (t)												
Total	3191	3051	45035	22603	335176	101790	368012	59442	16269	9089	188751	139792
Maximum sustainable yield (t)												
	69	66	1606	806	9074	2756	27234	4399	746	417	5656	4189

3.2 Megrim - *Lepidorhombus whiffiagonis* (Walbaum, 1792)

3.2.1 Introduction

The megrim is a medium to large sized and thin flatfish. It can reach up to 60 cm, but is usually between 40 and 50 cm. It is found in the warmer waters south and southwest of Iceland, on sand or mud bottoms (Sæmundson 1926, Jónsson 1992). In other waters, it is found in the northeastern Atlantic from northern Norway to the western Mediterranean Sea. It is usually in rather deep waters for a flatfish, from 40 to 400 m, but most common between 100 and 200 m. It probably spawns in spring in shallower waters and goes to deeper waters in the winter. The age of 50% maturity is around 5 years old for males and 7 to 8 years old for females (MRI, unpublished data). The megrim is the least known of flatfish species in Icelandic waters, and because of its small commercial importance, no attempt has ever been made to estimate the size of the stock and there is no TAC. A diet study indicates that the megrim feeds primarily on fish and shrimp and presumably, it is also semipelagic; which is rare among flatfishes (Steinarsson 1979).

The megrim was not caught in any numbers before this century, it was not until trawls and, much later, Danish seines became available that catches increased (fig. 11). Total catches were low prior to W.W.I. They increased after the war, droped rapidly again in 1940, due to World War II (W.W.II), and reached a peak of slightly over 700 tonnes in 1968 (Hjorleifsson et al. 1998). Foreign fleets, mainly Belgian and West German, have always dominated these cathes, Icelanders didn't generally consider the megrim worth "wasting" effort on. After 1970 foreign catches started to drop due to the extension of the Icelandic EEZ. The current catches of megrim by Icelanders are not as high as in the 1950's and 1960's, but there is cause for concern since stock and recruitment indices from trawl surveys indicate that the stock is in a steady decline (table 4, Jónsson et al. 1997). Most of the current fishery is along the south coast, with Danish seines or lobster trawls; In both cases the megrim is almost exclusively bycatch.

Most of the megrim catches are from early spring to early winter (fig. 12), the major exception is in shallow waters southeast of Iceland, where catches are high in March and April but virtually non-existent in other months. These large catches are reflected in the CPUE, which is high during these months but low in others. This could reflect an error in the data, since these values are solely because of high catch reported in 1993, but could also reflect some unusual conditions. On the other major grounds, the CPUE is highest during late summer and early winter (fig. 12), probably reflecting some seasonal movements. The CPUE of the megrim is highest in ground 1, 11, 12, 13, and 14 (fig. 13). The CPUE is declining with time in all the major grounds (not very obvious in ground 11 because of the scale of the graph), as the late summer peaks get almost constantly lower with time.

The total world catches of megrim have been increasing from 7 000 tonnes in 1950 to 32 000 t in 1981 but have since declined to 25 000 t in 1994. Most of these catches have been by Spanish and French boats, but since 1980, catches from the Ireland and the U.K. have been increasing. Compared to the catches by these nations Icelandic catches have been small, usually less than 1 % of total world catch.

3.2.2 Results

Fishmap: The megrim was not reported in logbooks from the Danish seine fleet until 1991 (fig. 14Figure 14). Most of the catches are concentrated along the south coast, but also, more recently, on the Reykjanes Ridge southwest of Iceland. Even if it is not taken into account that catch reports have been getting better with time it is possible to see on the graphs that the stock is declining. In 1992, the megrim was caught over a wide range along the southeast coast, but in 1997, only a few dots indicate the presence of the megrim. Minimum biomass estimates are low and indicate an increase from 1991 to 1993 (fig. 15), probably because of better catch reports (table 3), and a steady decline after that. All of the grounds show a similar pattern.

Effmod: Model 1 indicates that the megrim stock is around 450 t, model 2, however estimates it at around 290 t (table 7). The highest biomass is in deeper waters south and southwest of Iceland (gr. 1, 3, 13 and 14). Some quantities are also in ground 11 and 12, but the megrim is virtually absent from other areas. The biomass of megrim is far lower than for other flatfishes. The size of the megrim stock is very low in all the major grounds, or between 5 and 15 % of unfished (B_0). The likelihood profile is rather narrow for all the main grounds, except ground 3. This is reflected in similar biomass estimates between models, except for ground 13 where there is more than fourfold difference between the models. The MSY is only 60 to 70 t (table 7), much lower than current catches.

Other models: The likelihood distribution for different K and B_0 values shows a sharp peak for each K value (fig. 16), which sharpened as K values decreased. Low K values were more likely than high, but the difference was not as obvious as figure 16 indicates since the resolution in the graph is not fine enough to grab the narrow peaks. Very high K values were not likely since they would have implied that the stock should have been fished out of existence in the 1970's. Lower K values imply a higher B_0, i.e. the stock is large and unproductive, high K values imply smaller but more productive stock. A K value of 5 was used in subsequent analysis as in Effmod.

The SSDD model indicates that the megrim stock is only about 300 t, or 2% of the unfished biomass of 11 500 t (fig. 17). Although these biomass estimates are similar to Effmod, the status compared to unfished is much lower. Equilibrium MSY is estimated as being much higher or 275 tons per year (t/y) at an exploitation rate of 0.1 and a corresponding stock size of 40% of unfished (fig. 18). The reason for these differences is that the effort model assumes that the stock was at B_0 in the beginning of the simulation (1981), but the single stock model takes into account the previous foreign fishing for the megrim, which was higher than the current catches. According to the SSDD model the stock was therefore already at a low level, due to previous overfishing in the 1970's, when the Icelandic fishery started in the late 1980's. The current exploitation rate is close to 1 and has been increasing rapidly for the last years. The survey biomass index is very similar as the estimated biomass (survey index = 1.18 * biomass).

Catch curve analyses are based on only two samples (table 2), but indicate an exploitation rate of 0.33 in 1995 and 0.35 in 1996, lower than estimated by the single stock delay difference model for the same years, but higher than for the previous years. Analysis of yield per recruit for megrim showed that the curves reached an asymptote at 0.24 kg per recruit (fig. 19). At the current age of 50 % vulnerability (8), the spawning stock will go below 50% of unfished biomass at a long-term exploitation rate of 0.2 or more.

3.2.3 Discussion

The megrim stock seems to be in a dire situation. According to all the models and indices used, the stock is at a low level on all main grounds. The stock seems to be at such a low level that a moratorium on megrim fisheries seems justifiable. This is however almost impossible because the megrim is always a bycatch in fisheries for much more valuable species. According to Effmod, it would be very difficult to stop the current downward trend in stock size because the estimated MSY of about 65 t/y (table 7) is very difficult to enforce. Fisheries for other species would have to be severely restricted. The estimates from Effmod do not seem very realistic at first glance. The MSY estimated from Effmod is so low that the megrim should have been fished out of existence by the foreign fleet long ago when catches of more than 400 t/y were sustained for long periods. The SSDD model seems more realistic; it estimates a much higher MSY. According to that model the current stock size is at a very low level due to previous overfishing by foreign fleets. The downward trend is maintained by the current rather low Icelandic catches.

It should be kept in mind that megrim, in Icelandic waters, is at the northernmost edge of its distribution, and therefore probably living in a marginal habitat. It is therefore also quite possible that environmental conditions have a large influence on the stock size. It has been shown that in at least some species, including some flatfishes, the intrinsic rate of natural increase is positively related to temperature. Stocks in northern waters are generally much more vulnerable to high fishing mortality (Myers and Mertz 1997, Walsh 1994a). The period from the mid 1920's to the mid 1960's was a warm period in Icelandic waters with relatively high ocean temperatures (anon 1997b), after this the ocean has become colder and much more fluctuating. The catches of megrim were much higher during the warm period because of the foreign fleets. After 1970, coinciding with the cooling of the ocean, the catches declined to very low levels since foreign fleets had been expelled from Icelandic waters. Almost two decades followed with low reported catches before they increased again. If we assume that the reported catches are true (i.e. no discards), it is possible that the megrim recovered from the fishing, but to a much lower level, because of lower and more fluctuating ocean temperatures.

The MSY estimated from Effmod might thus be correct under current environmental conditions. It should also be kept in mind that the megrim now exclusively lives in the warmer waters south of Iceland, where these temperature fluctuations were not nearly as prominent as in the waters north of Iceland. It is therefore possible that the distribution of megrim was more widespread during warmer years, and some of the foreign fleets were actually fishing the megrim in more northern waters, where it is absent now. No quantitative analysis of the distribution of the megrim is available prior to the trawl survey. Sæmundsson (1926) mentions that the megrim was abundant in the waters south and southwest of Iceland and was found all the way to Vestfirðir Peninsula, an area where it is now not found (fig. 14). During the last decade, the environmental conditions have been improving. This happens at the same time that the catches of megrim have been increasing rapidly and the stock size index has been declining. This implies that the fishery is the cause of the current decline of the stock.

However, no matter how we look at the situation, the megrim stock is in serious trouble and more worryingly, the means to save the stock are few and difficult to enforce. One recommendation would be to severely restrict the effort on the deeper grounds south of Iceland (gr. 1, 13 and 14) where the megrim is the most abundant. This would however reduce catches of other flatfish species primarily the witch flounder and also on other species such as lobster or even cod, since megrim is also a frequent bycatch in other fishing gear than Danish seine. Another possibility would be to ban all landing of the megrim and thus force fishers to discard it. These are however desperate measures since discard mortality rate is unknown and the target species quite important for many communities. If the stock recovers better data and possibly better models will be available to estimate how much annual fishing the stock can sustain. Currently this stock does not need extensive modelling to describe its downfall, but extensive management measures to save it. It is however encouraging that megrim stocks in other waters seem to be in relatively healthy condition (anon 1994a). The megrim species is thus not in danger, and it might be able to make a comeback in Icelandic waters through dispersion from other areas, if a warmer period is ahead.

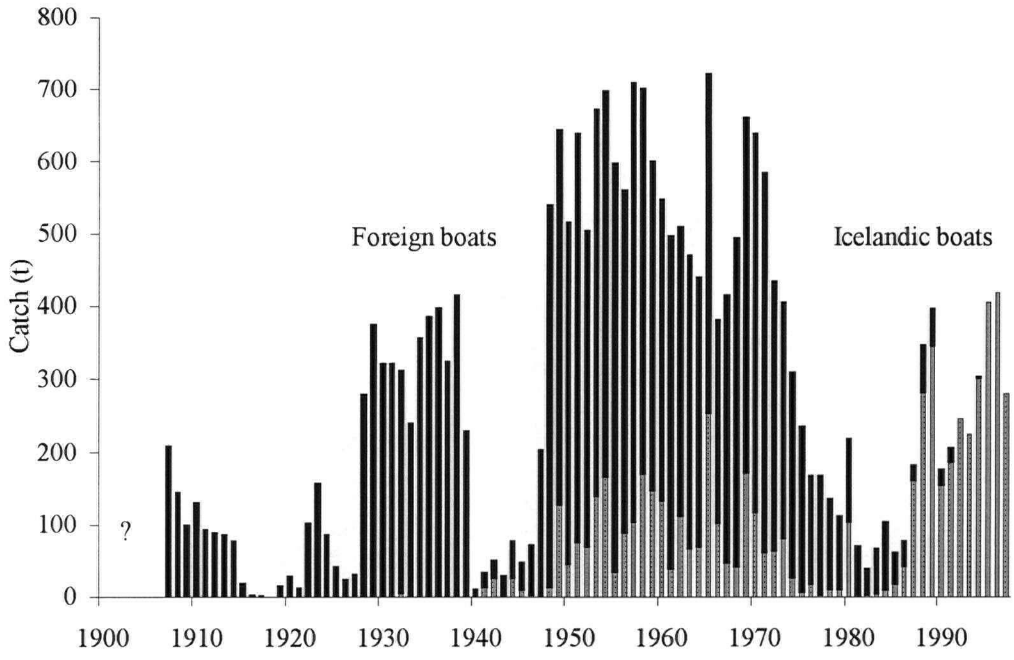

Figure 11: Megrim, historical catches since 1906, dark columns are foreign catches and light columns Icelandic catches

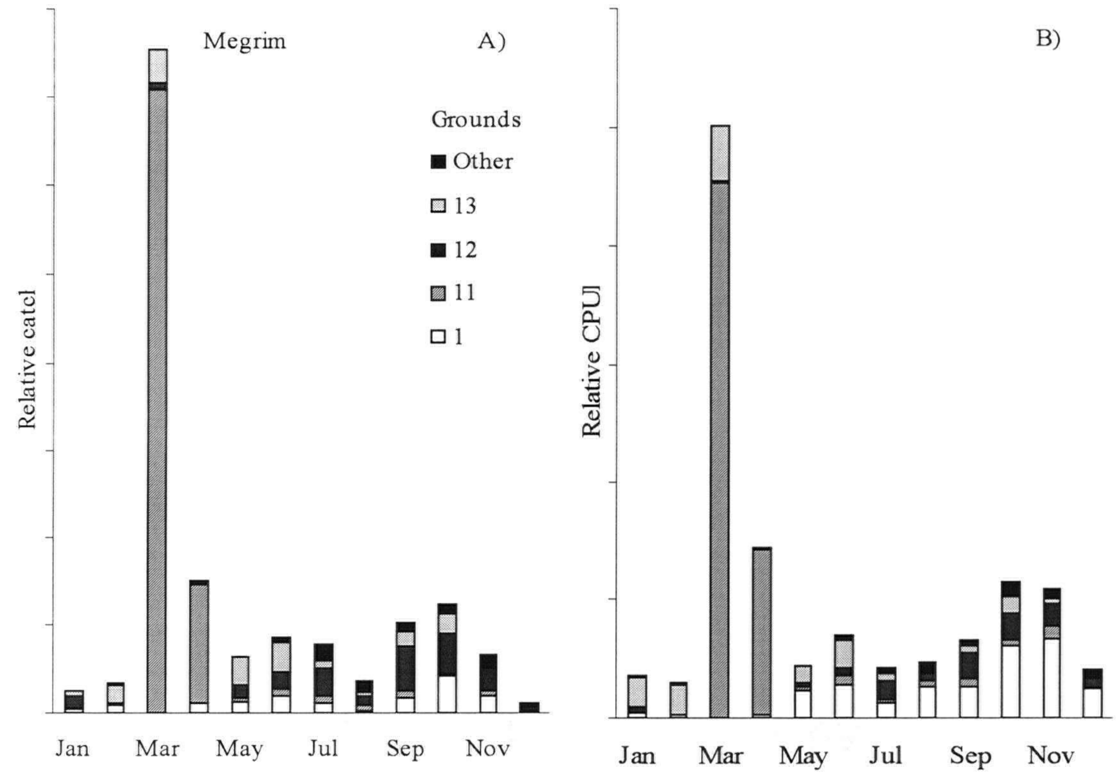

Figure 12: Megrim, average catch (a) and CPUE (b) per month on 4 of the major grounds, values are average since 1979. Catches in other grounds are sum of the average per ground and CPUE is average from all the grounds

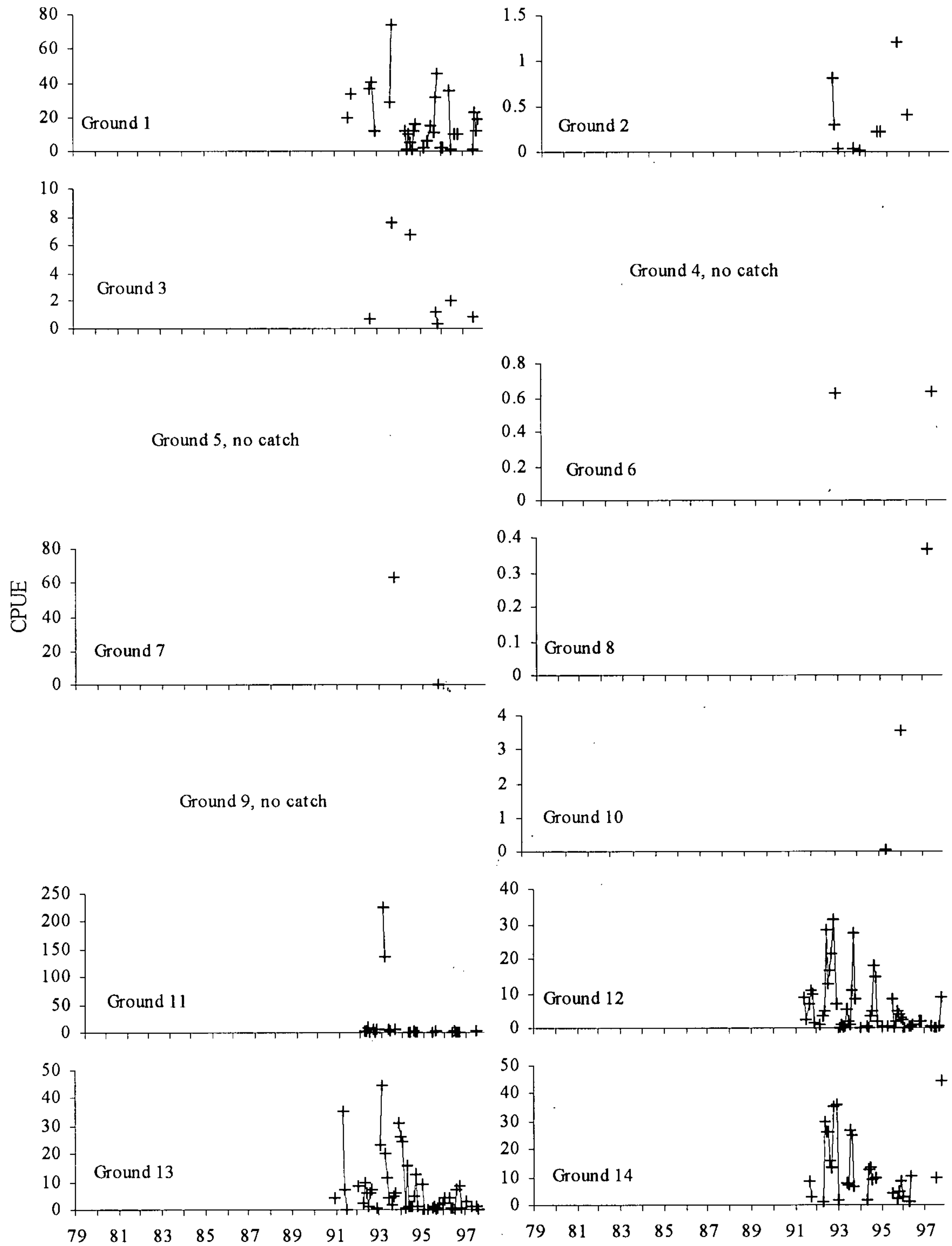

Figure 13: Megrim, CPUE per month by grounds since 1979

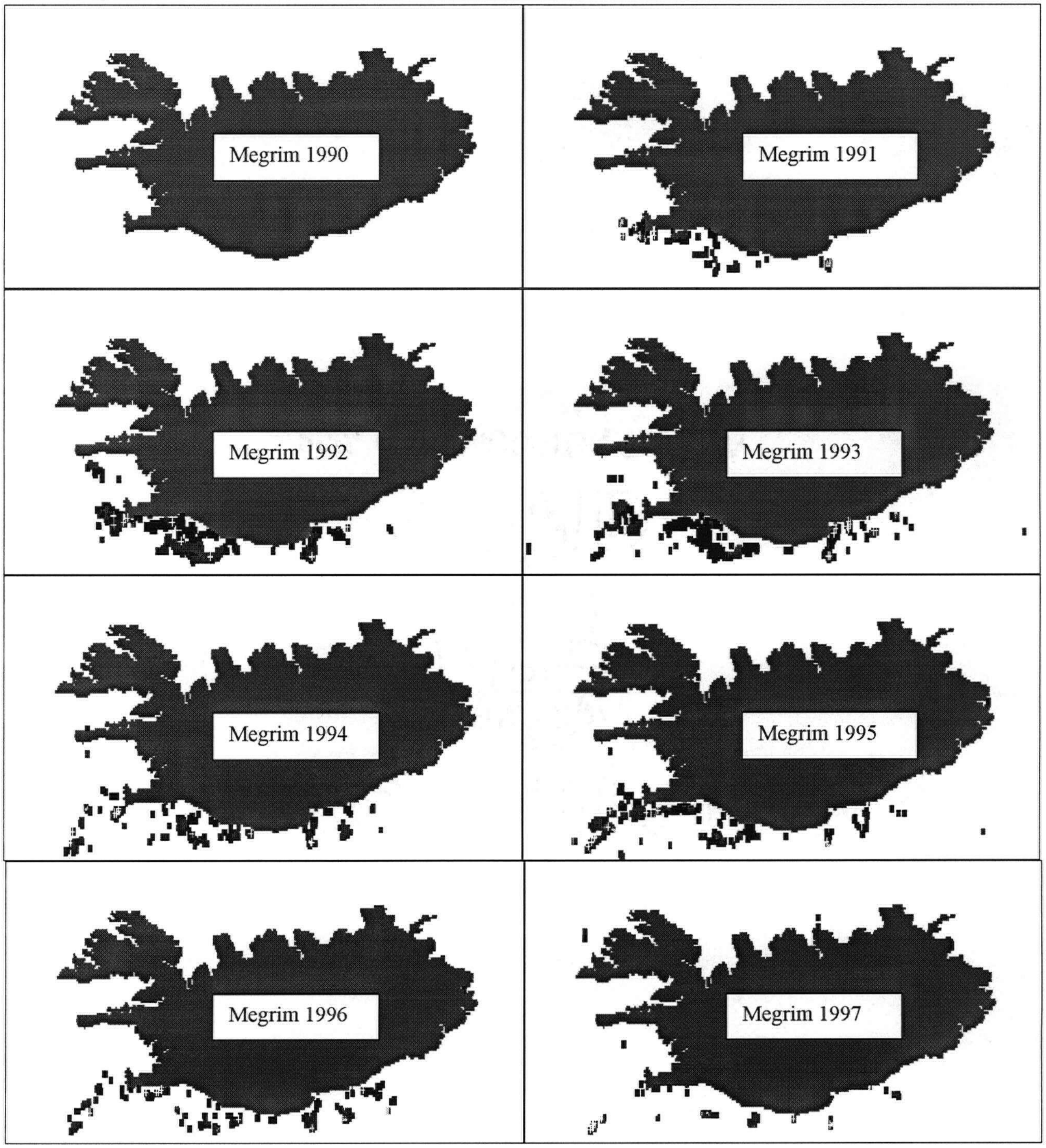

Figure 14: Megrim, distribution of catches from Danish seine fleet since 1988. Dark areas indicate low CPUE and light areas high; crosses are the cleanest sets, i.e. where the percentage of the species under consideration of the total catch is the highest

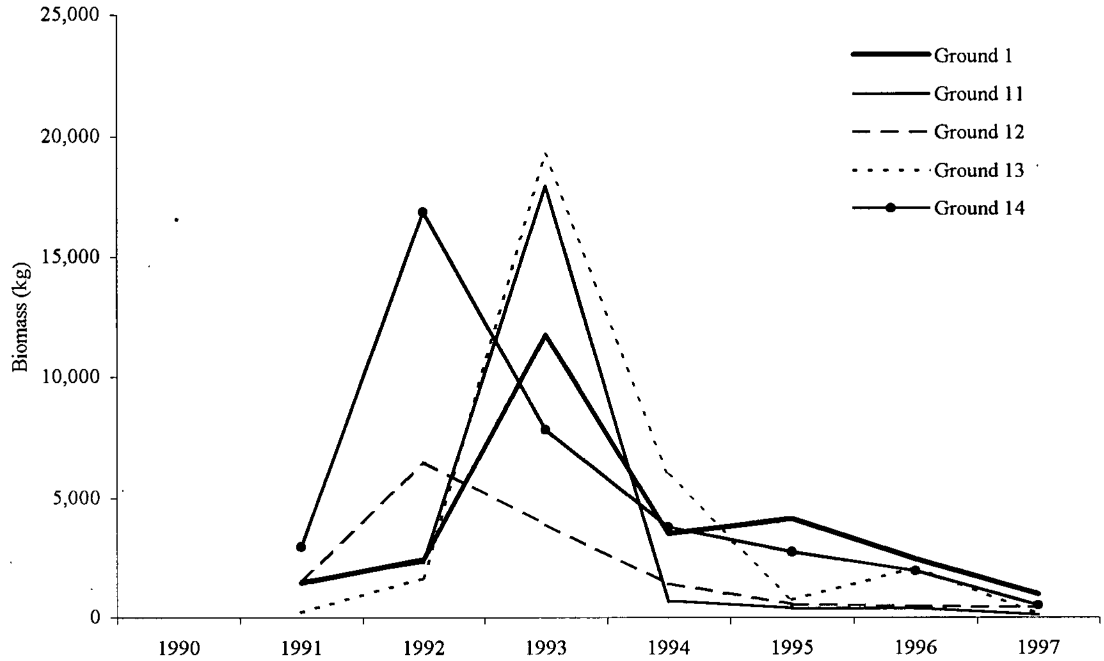

Figure 15: Megrim, estimated minimum biomass by 5 of the grounds with the highest biomass, Fishmap analysis.

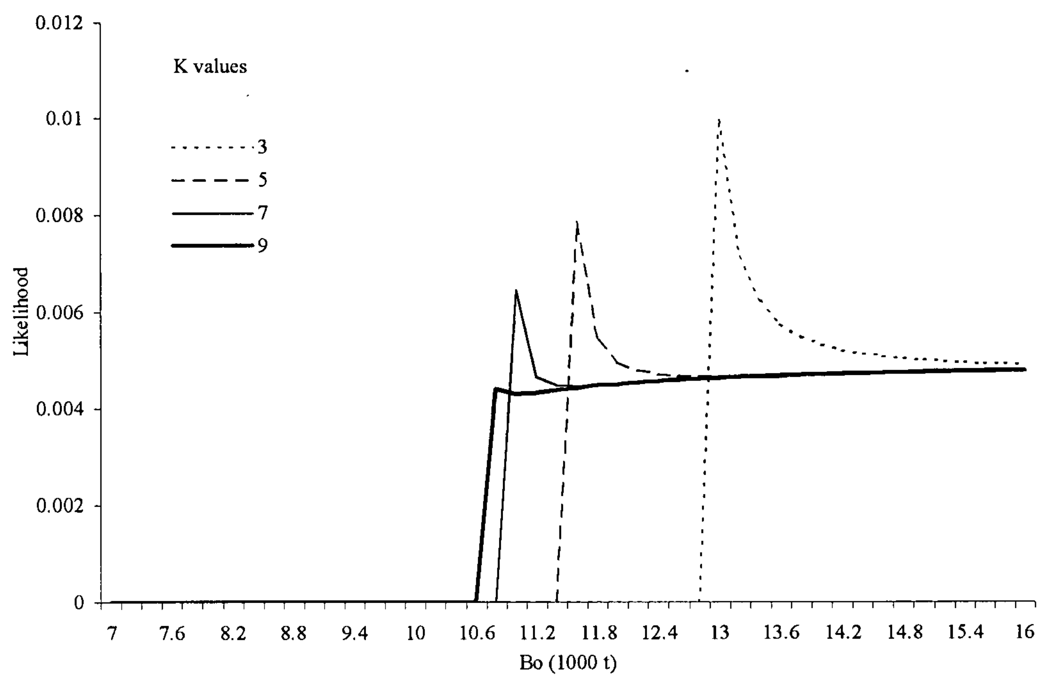

Figure 16: Megrim, likelihood profile with different stock recruitment "K" values and unfished biomass (B_0), single stock delay difference model.

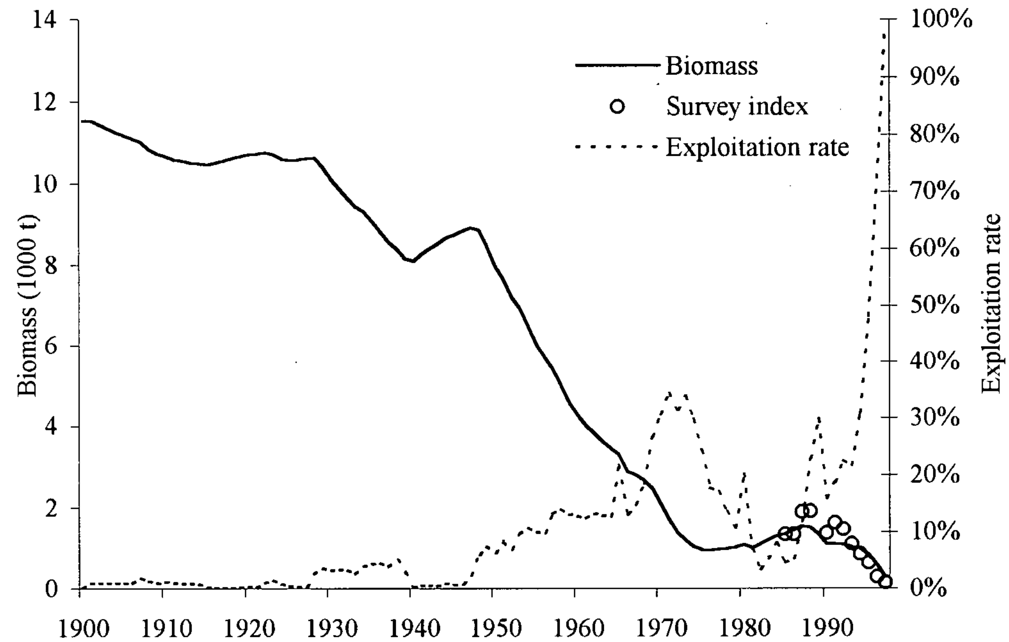

Figure 17: Megrim, estimated biomass of exploitable stock biomass (solid line), survey index (circles) and exploitation rate (broken line), single stock delay difference model.

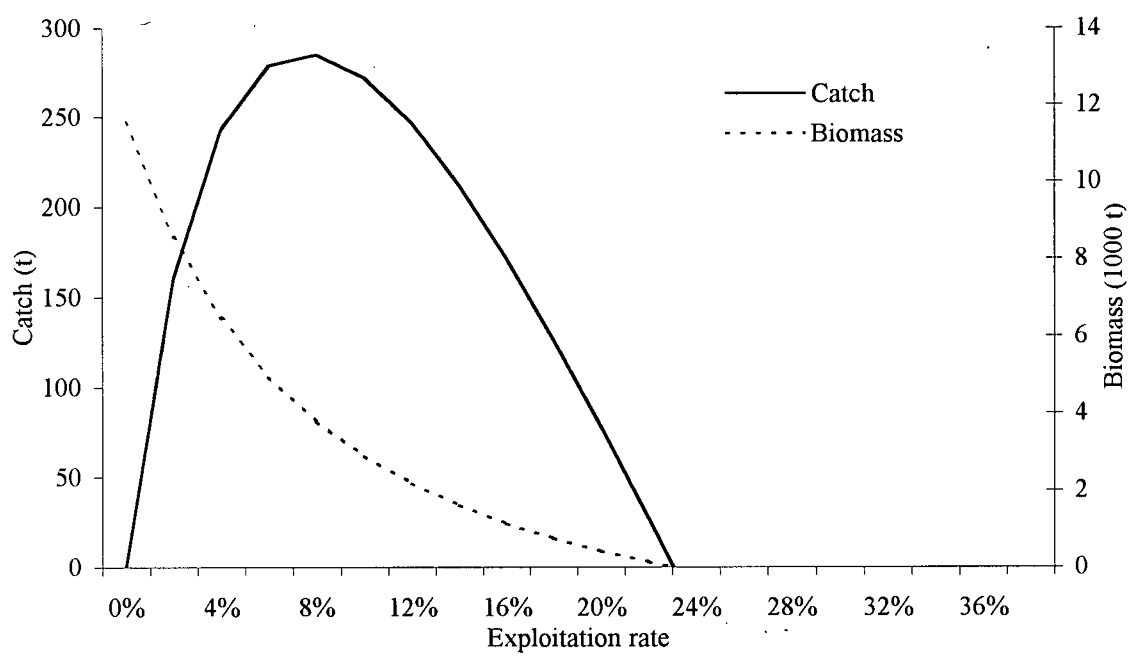

Figure 18: Megrim, biomass (broken line) and catches (solid line) at equilibrium, single stock delay difference model.

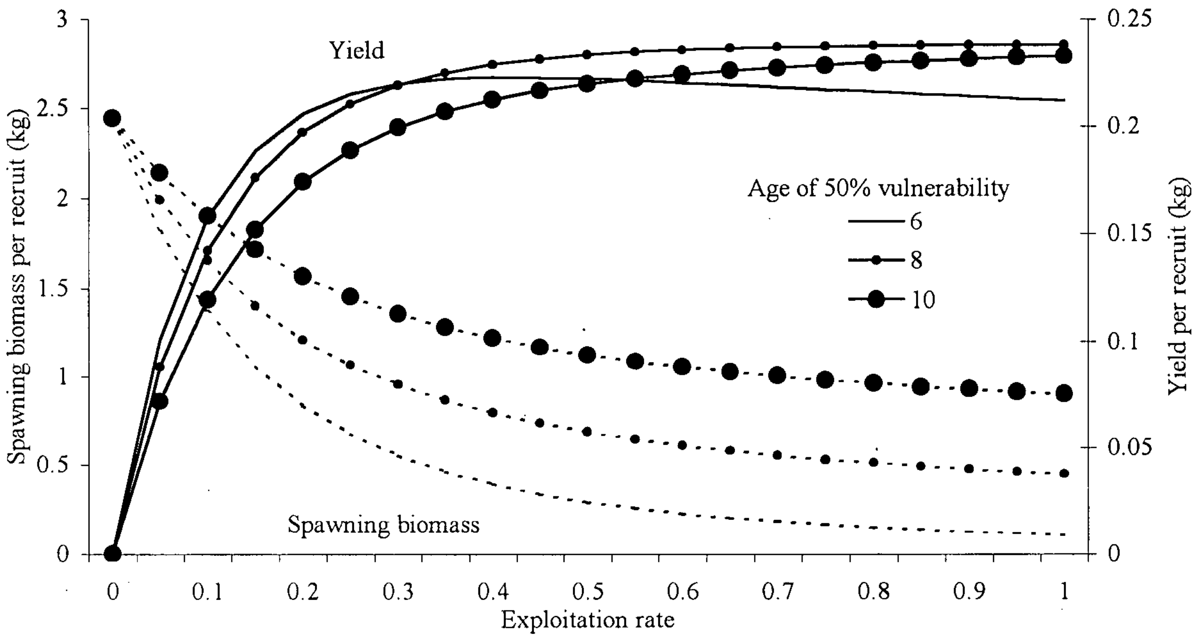

Figure 19: Megrim, Yield and spawning stock per recruit with different age of 50% vulnerability

3.3 Witch flounder - *Glyptocephalus cynoglossus* (Linnaeus, 1758)

3.3.1 Introduction

The witch is a medium sized, relatively long and thin flatfish. It can reach up to 63 cm in Icelandic waters but is most often 30 to 50 cm (Sæmundsson 1926, Jónsson 1992, Oddsson 1993). The world record is a 78 cm specimen caught in Canadian waters. It is slow growing and as with most other flatfishes the females grow larger. The witch can reach up to 14 years of age. The age of 50% maturity is 4 years for males and 5 years for females (Steinarsson et al. 1989). The witch is generally found on mud bottoms where it feeds predominantly on polychaets, but also other benthic invertebrates (Steinarsson 1979). It has a relative small mouth that limits its feeding range. The witch spawns along the south and southwest coast, from March to June, and some of the spawning grounds are now quite well known. It is found all around Iceland, but is most common along the south and southwest coast from about 50 to 300 m. It seldom goes shallower than 30 m and has been found as deep as 1 400 m. The witch flounder is also found in European waters from Murmansk in the north, to the Bay of Biscay in the south. In North American waters, it is found from Greenland and Labrador in the north, to Cape Cod in the south.

Until recently, foreign fleets have dominated catches of witch flounder off Iceland (fig. 20), mainly boats from England and Germany, and later by Scottish and Belgian boats. Catches were 300 to 800 t/y before W.W.I. There were virtually no catches during W.W.I, but after the war, catches increased slowly to around 1 200 t/y before W.W.II. Catches were low again during W.W.II, but increased sharply after the war, as the foreign fleets came back. Foreign catches then declined and remained at a level of around 500 t/y. During this period, Icelanders also started to catch the witch flounder. The catches, both by foreign and Icelandic fleets, then declined after 1960. The decline in foreign catches can be linked to the gradual extension of the Icelandic EEZ, but the decline in Icelandic catches is harder to explain. One explanation could be overfishing, but other is simply lack of interest. At the time this happened witch catches in North American waters rose sharply, which might have lowered its market value. Despite this, catches in Icelandic waters during this period (1905-1965) were never high, only fluctuating between 500 and 1 000 tonnes. After this there came a period when there were virtually no catches, foreign fleets were gone and Icelanders had enough cod. It is however possible that during this period the witch was discarded in some quantities (Steinarsson et al. 1989).

After the ITQ system was established and the effort for the most important groundfish species was reduced, fishermen started to look at alternative species, and the catch of witch flounders rose. This ascent was very fast in the beginning, from 32 t in 1985, to a peak of 4 566 in 1987. Catches then fell, and there were worries that the witch was being overfished (Steinarsson et al. 1989, Oddson, G.

1993). Catches however have stabilised since 1990 at around 1 200 tonnes annually. These catches are similar to early ones by foreign fleets. Most of the current catches is by the Danish seine fleet. Recently the percentage of the catch caught by lobster trawl has been increasing (table 1).

CPUE has been declining since 1987 and the average weight at age has been increasing lately possibly because of density dependent effects. There are no indicators of good recruitment and trawl surveys show that this stock seems to be in decline (table 4, Jónsson et al. 1997). Since 1990 the MRI has, based on the declining CPUE, been warning that the stock is overfished (anon 1990). In 1994 the MRI recommended a TAC of 1 500 t (anon 1994), this recommendation has however been reduced steadily to the current level of 1 100 t, which is now assumed to be the long-term sustainable yield (anon 1998). The catches have however always been higher than recommended and there were no effort restrictions until 1996 when the government set a TAC of 1 200 t as the MRI recommended.

Witch flounder catches are rather evenly spread over the year for the major grounds (fig. 21). The CPUE is however lower during the summer months, this could reflect both seasonal movements of the witch flounder and of the fleets. Special witch seines are allowed from September to April, the same months as CPUE is highest. Except in ground 5, the CPUE of witch flounder seems to be declining rapidly (fig. 22). The CPUE was generally high in 1987 and 1988, but fell after that.

Until this decade witch flounder catches were much higher in the western than in the eastern part of the North Atlantic. The majority of the catches was by Canadians, but also during the period from 1965 to 1976 the Soviet Union took considerable numbers. Since the late 1980's catches in American waters have been declining as opposed to increases in European waters. Since 1950 witch catches in European waters were 2 000 to 4 000 t/y, about half of the catches were taken by boats from the U.K., but also by other northern European nations including Iceland. In the 1980's Spanish catches increased rapidly and are now about half the total catch in European waters. Catches from other nations have also been increasing and have been about 10 000 t/y for the last decade, twice as high as in North American waters. Since 1987, Icelandic catches have been 6 to 12 % of the world total.

3.3.2 Results

Fishmap: The witch is most abundant along the south shore and on Reykjanes Ridge. Some quantities are also in the outer parts of Faxaflói Bay and Breiðafjörður Bay (fig. 23). There is no obvious trend discernible on the Fishmap figures except that catch is fairly stable in the southern grounds but has been increasing on the Reykjanes Ridge and Breiðafjörður Bay. Fishmap minimum biomass estimates indicate that biomass has been almost constantly declining since 1987, on most of the major grounds (fig. 24). Grounds with high original biomass however decline faster, so that in 1997 the biomass estimates in all the grounds are similar.

Effmod: The current biomass of witch flounder is estimated to be between 10 000 and 30 000 t depending on the model (table 7). The highest biomass is in the waters southwest of Iceland (gr. 1, 12 and 14), then the waters west of the country (gr. 2, 3 and 6). The witch is virtually absent from north and east Icelandic waters. The ratio of current to unfished biomass is variable between models. Areas 11 and 13, which are adjacent to each other, have the lowest ratio of current biomass to unfished. The ratio is around 45% for the southwestern areas (gr. 12, 14 and 1) but higher in others. The likelihood profile is variable between grounds (fig. 9). Grounds 11 and 13 have a narrow profile and consequently the difference between the models is small. Other grounds have less obvious maximum likelihood peaks or reach an asymptote. The sustainable yield ranges from 800 to 1 600 t/y depending on the model. These are in the same range as current catches.

Other models: The present biomass estimated by the SSDD model is around 13 000 t (fig. 25), in the same range as the Effmod estimates. The unfished biomass is also similar to the Effmod estimated 26 600 t. The stock seems to have had the chance to recover to unfished biomass in the period after foreign fishing stopped and before the Icelandic fisheries started. Equilibrium modeling indicates a sustainable catch of 1 300 t/y at an exploitation rate of 0.17 (fig. 26), which is similar to the present situation. The likelihood curves are not very narrow (fig. 27) but generally indicate an unfished biomass at around 25 000 t, except for very low K values. Most of the K values however had similar maximum likelihood levels. The trend in stock size was also similar over a range of K values. Since the survey index does not cover many years we do not have reasonable estimates on the spawning stock-recruitment relationship. In this analysis, the assumptions on the recruitment parameters are the same as in Effmod. The survey biomass index is only 10% of the estimated biomass.

The cohort analysis indicates that the exploitation rate in 1997 is 0.21 (fig. 28), higher than estimated from the SSDD model. As results, the exploitable biomass estimates are only half of that from the SSDD model. Cohort analysis estimates that the exploitable biomass has declined from 11 000 t in 1986 to 6 000 t in 1997; lower than estimates of other models. The age of 50% vulnerability has ranged from 6 to 9 (fig. 29), except in 1991 when it went down to 4 reflecting an abnormally high number of young fish in samples. It is currently at the age of 5 or 6 (6 used here) and declining. The average weight at age has been increasing lately so vulnerability at size might not have changed. Equilibrium yield analysis indicates a sustainable catch of 1 400 t/y at an exploitation rate of 0.3 or higher (fig. 30). The likelihood profile for a different age of 50% vulnerability and an exploitation rate for the last year is fairly well defined, usually peaking at around 20% exploitation rate (fig. 31). Catch curve analysis indicates an exploitation rate of 0.3 to 0.4 since 1986, similar but less fluctuating than in the cohort analysis (fig. 32). The variation is high and the downward trend in stock size is similar in all models but none indicates any significant danger.

3.3.3 Discussion

The witch flounder stock is at an intermediate level compared to other flatfishes. It is not in a severe condition, but the stock is declining. According to Effmod the stock is at a low level in the grounds southeast of Iceland (gr. 11 and 13), an intermediate level on the southwestern grounds (gr. 1, 12, and 14), but in good condition on the grounds west of Iceland (gr. 2 and 3). This might mean that the stock is in more serious trouble than the CPUE indicates. Grounds 11 and 13 can be considered fringe areas, because unfished biomass was not as high as in ground 1, 12, and 14. The decline in these grounds might thus mean that the range is declining because of the fishery. The fringe areas to the northwest (gr. 5 and 6) however do not show any serious decline. The average catch for the last decade is considerably higher than estimated MSY by Effmod model 2. The current TAC recommended by the MRI, of 1 100 t, is slightly lower than MSY estimates from the equilibrium models. According to these models, the spawning stock will increase slightly with catches of 1 000 t/y. If we believe these to be correct the catches should be allowed to be slightly higher than current level, but the effort should be restricted in the southeastern ground. If we believe model 2 in Effmod to be closer to the truth, the TAC should be reduced. The almost uninterrupted decline in the survey index does not necessarily mean that there is any danger ahead for the witch flounder stock, since a virgin (unfished) stock will decline to a lower level if it is fished. However the ability of the stock to compensate with higher recruitment per spawner (high K value) at low stock levels is uncertain (since the likelihood of K values was similar over a relatively wide range) and we still do not know where the stock size will level off. A precautionary approach should be taken and the current TAC should be reduced, until the current decline observed in the trawl survey levels off.

The problem is that an increasing proportion of total witch catches is reported from lobster boats. It is uncertain is this reflects a relative increase in catches or that they are now retaining witch flounder, instead of being discarded as in the past. They use fine mesh sizes and, therefore, catch much younger fishes. Where these catches are taken is not available here. If they are primarily taken in the southeastern grounds, they could be the main reason for the decline of the stock there, not the Danish seine fisheries. Additional measures to find out the effects of the lobster fisheries on the witch stock and how to reduce bycatch of witch in lobster trawl would therefore be necessary.

The witch stock in the western North Atlantic is currently at a low level. Previously, the stock seems to have been similar in size to the Icelandic stock (based on the cohort biomass estimates). The catches from this stock were however about twice as high as the Icelandic stock (anon 1997a). This is reassuring for the Icelandic stock since it implies a much lower exploitation rate.

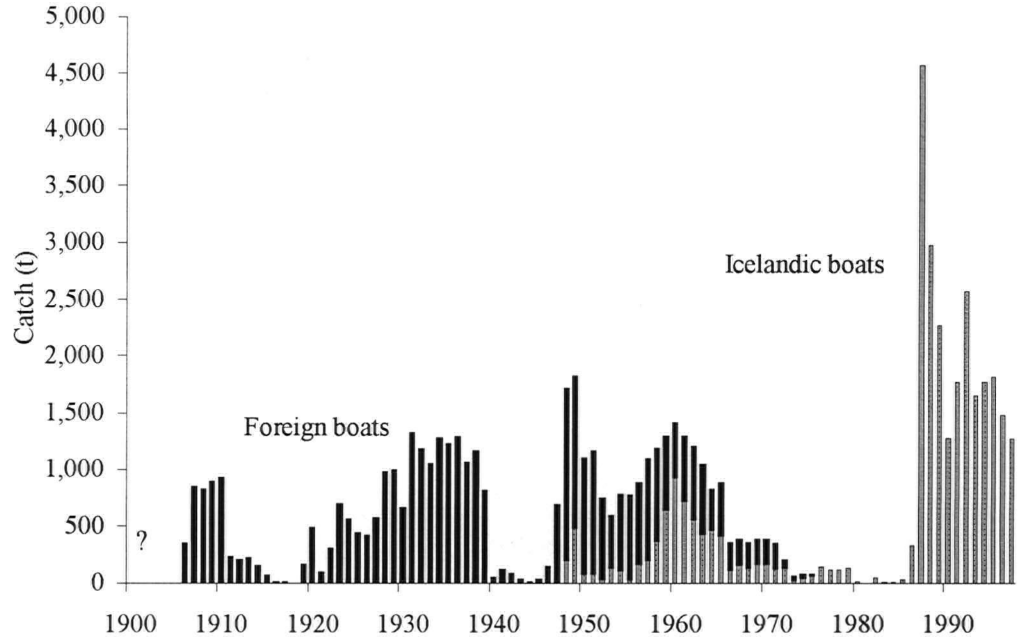

Figure 20: Witch flounder, historical catches since 1906, dark columns are foreign catches and light columns Icelandic catches

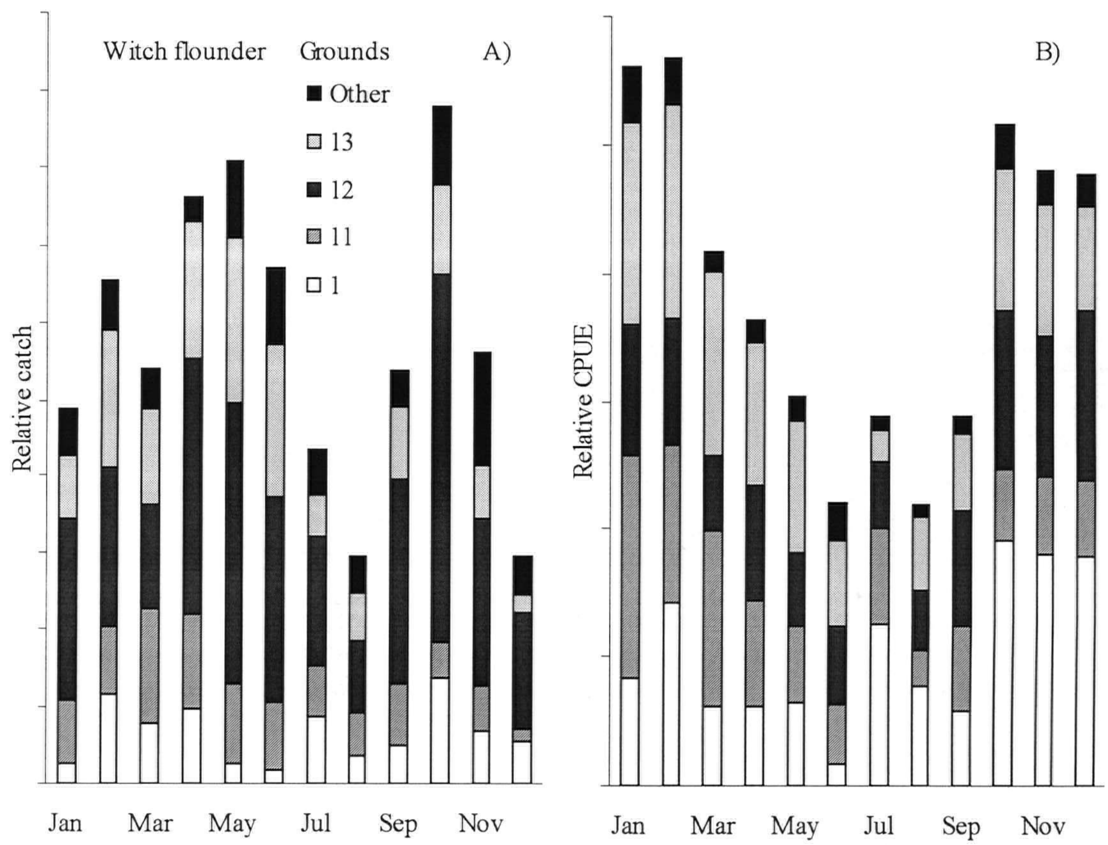

Figure 21: Witch flounder, average catch (a) and CPUE (b) per month on 4 of the major grounds, values are average since 1979. Catches in other grounds are sum of the average per ground and CPUE is average from all the grounds

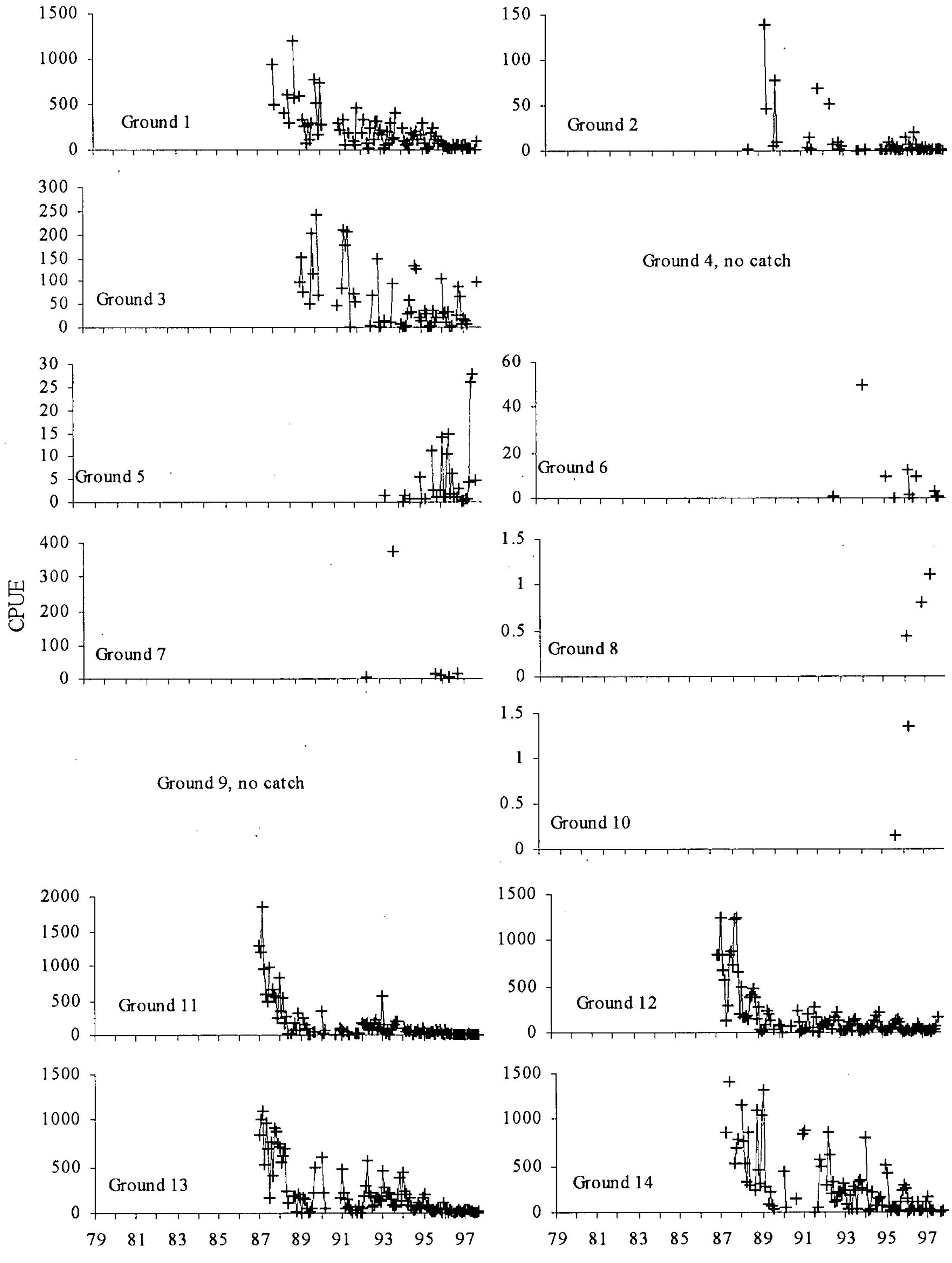

Figure 22: Witch flounder, CPUE per month by grounds since 1979

Figure 23: Witch flounder, distribution of catches from Danish seine fleet since 1990. Dark areas indicate low CPUE and light areas high; crosses are the cleanest sets, i.e. where the percentage of the species under consideration of the total catch is the highest

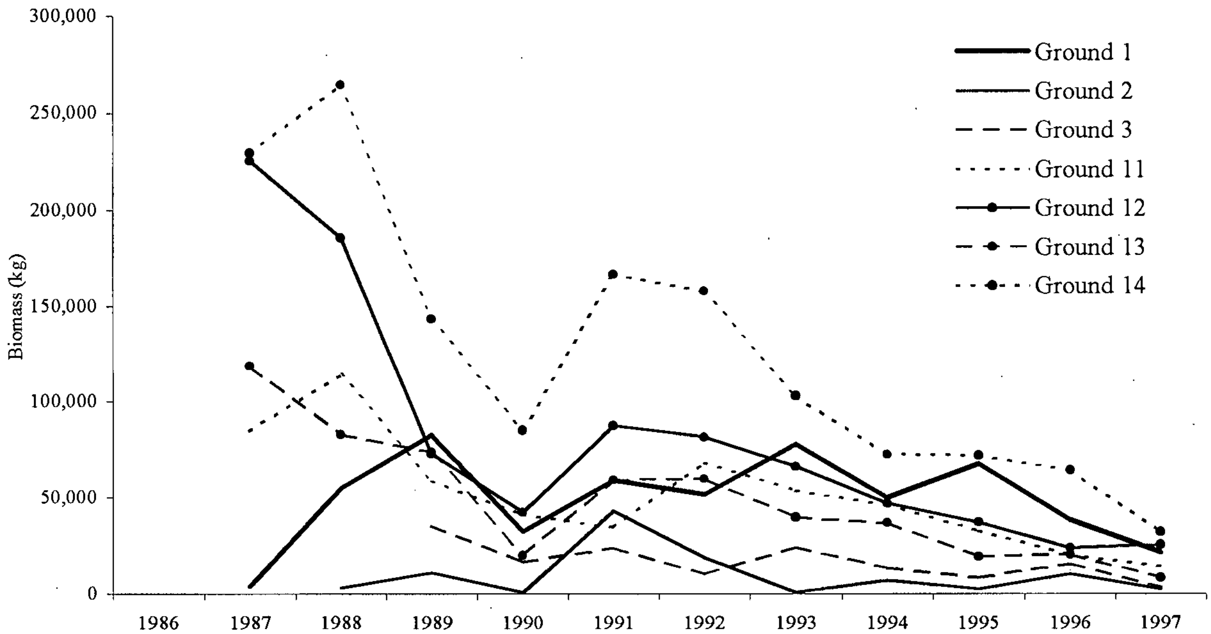

Figure 24: Witch flounder, estimated minimum biomass by 7 of the grounds with the highest biomass, Fishmap analysis.

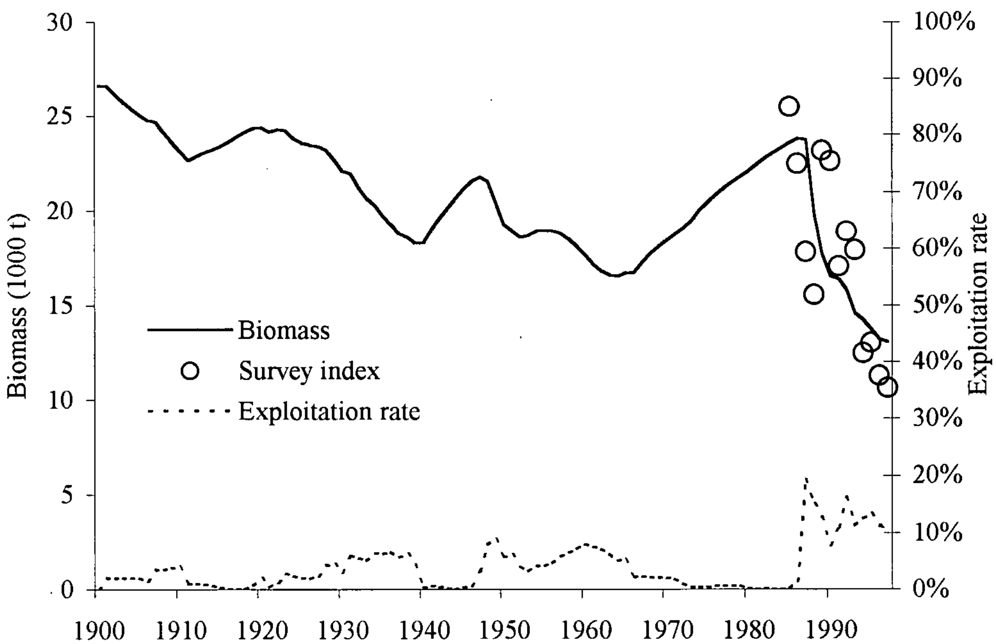

Figure 25: Witch flounder, estimated biomass of exploitable stock biomass (solid line), survey index (circles) and exploitation rate (broken line), single stock delay difference model.

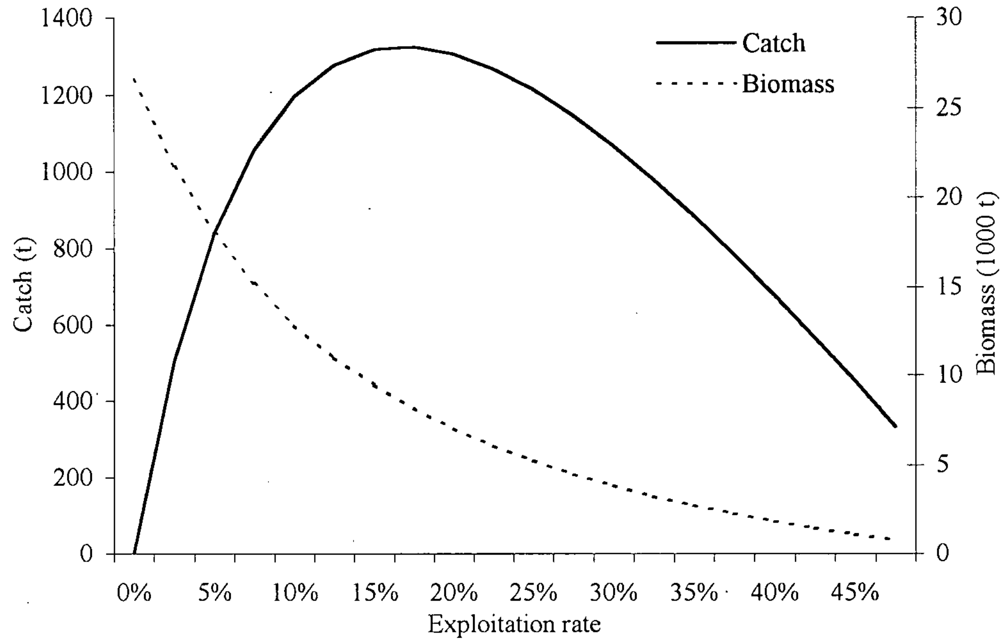

Figure 26: Witch flounder, biomass (broken line) and catches (solid line) at equilibrium, single stock delay difference model.

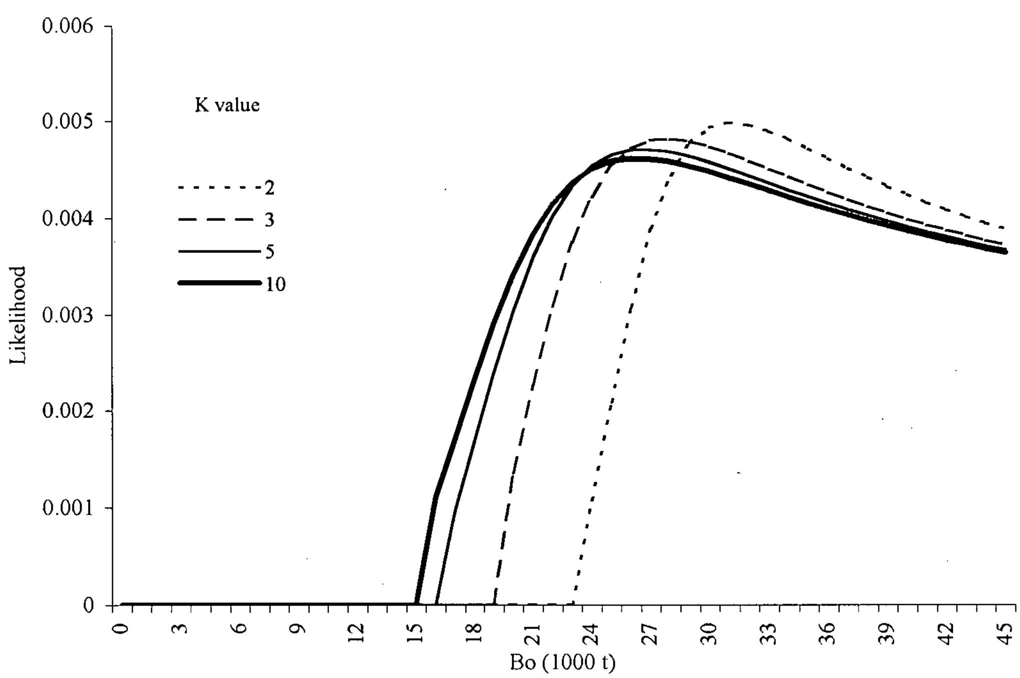

Figure 27: Witch flounder, likelihood profiles with different stock recruitment "K" values and unfished biomass (B_0), single stock delay difference model.

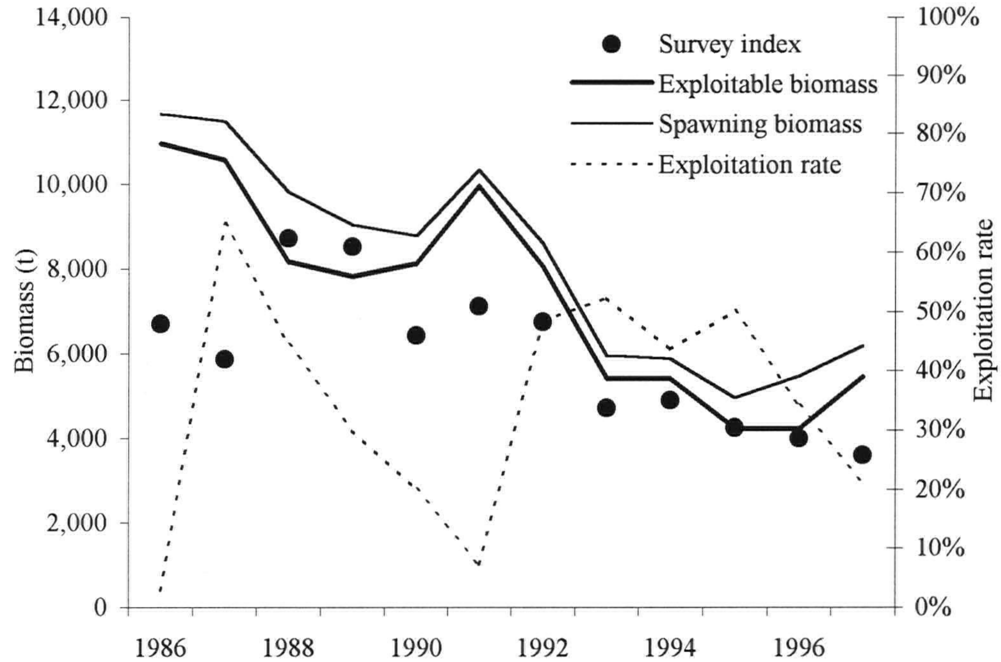

Figure 28: Witch flounder, estimated biomass of exploitable (thick line) and spawning stock (thin line), survey index (circles) and exploitation rate (broken line), cohort analysis.

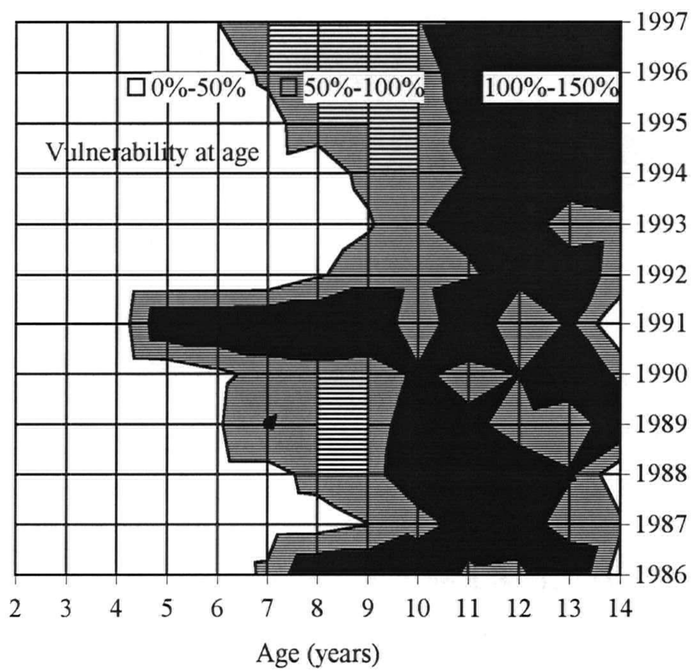

Figure 29: Witch flounder, vulnerability at age, cohort analysis

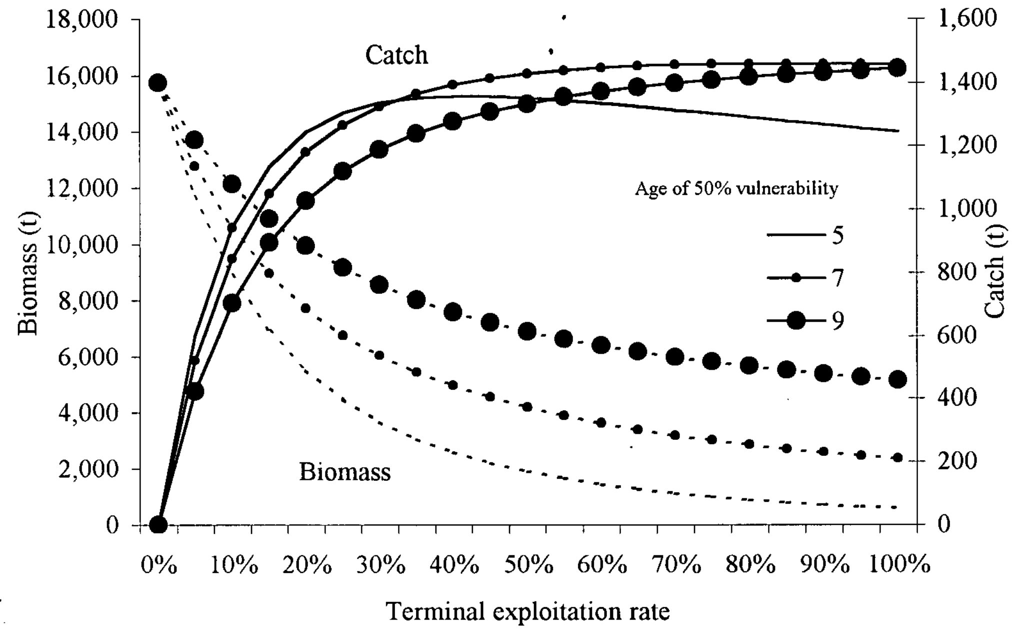

Figure 30: Witch flounder, biomass (broken line) and catches (solid line) at equilibrium, cohort analysis

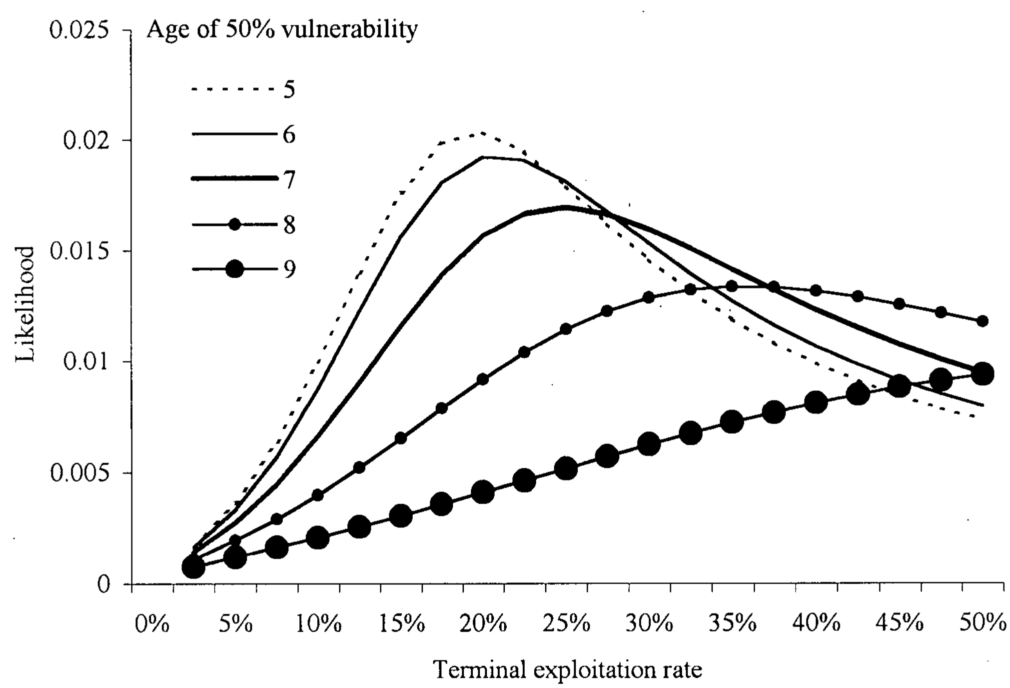

Figure 31: Witch flounder, likelihood profile for the terminal exploitation rate and different age of 50% vulnerability, cohort analysis

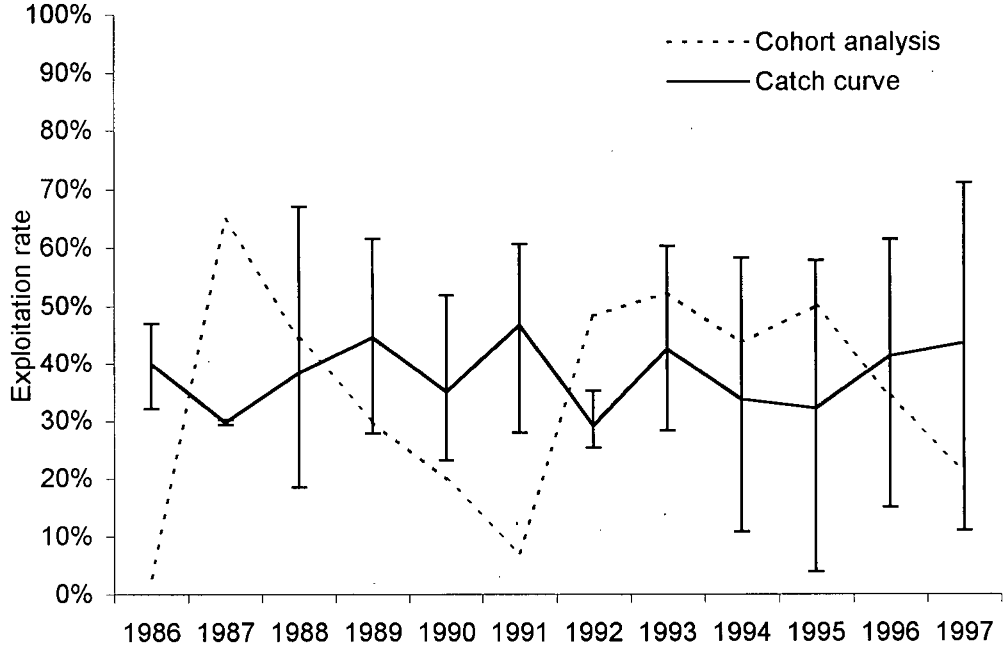

Figure 32: Witch flounder, estimated exploitation rate and standard deviation for catch curve analysis (solid line) and for cohort analysis (broken line).

3.4 American plaice - *Hippoglossoides platessoides* (Bloch, 1787)

3.4.1 Introduction

The American plaice, also called long rough dab in European waters, can reach up to 60 cm, but the usual size is between 15 and 30 cm for males, and between 20 and 40 cm for females. The growth rate is slow, but females grow faster and become much older and larger than the males, up to 19 years old. Half of the males reach sexual maturity by age 3, but females at age of 4 or 5 (MRI, unpublished data). The samples behind this information were taken in waters south of Iceland and the American plaice shows large variations in age of maturity by areas (Walsh 1994). It would therefore not be surprising if the age of maturity is higher in waters north of Iceland. The American plaice spawns all around the country in March to June (Sæmundsson 1929, Jónsson 1992). It has a broad feeding range, when small the it eats various benthic invertebrates, but as it grows other fish species such as capelin become important. Half of the food of individuals larger than 30 cm is various fishes, the rest mainly brittlestars (ophiuroidea) (Pálsson 1983, Pálsson 1997).

The American plaice is one of the most widely distributed and possibly the most numerous Icelandic groundfish. It is abundant all around Iceland at a depth range from 10 to 400 m, usually on mud bottoms but also on other bottom types. The distribution is even, and there are few places where large individuals are found in aggregations (Jónsson et al. 1995, Pálsson et al. 1997). There is no indicator of any large scale spawning/feeding migrations (Walsh 1994), except that it goes deeper in the winter (Sæmundsson 1926). It is abundant on both sides of the northern North Atlantic, from the Barents Sea to the English Channel in the east and from Greenland to Cape Cod in the west. The stock in the North Sea is considered the largest one, although in North American waters the American plaice is the most abundant flatfish species (Walsh 1994, Walsh 1994a). The American plaice in American waters is considered a subspecies (*H. p. platessoides*). It is larger than its European counterpart (*H. p. limandoides*) to which the American plaice stock in Iceland belongs (Jónsson 1992).

The American plaice does not really have any history of landings in Icelandic waters until after 1986. Only a few tonnes were reported earlier this century by boats from Belgium and Germany (fig. 33) (Hjörleifsson et al. 1998a). Because of its wide distribution the American plaice was however almost certainly discarded in large quantities since trawlers started to operate (Sæmundsson 1926), and when not discarded, might have been misreported as dab. Despite this, the American plaice stock has never shown any signs of overfishing. Since 1986, catches have been increasing rapidly to the current level of 6 000 t/y. This is both because the American plaice is now retained instead of being discarded as before and because of direct targeting by boats that have probably finished their quota for more valuable species. Usually more than 90% of the catches have been by Danish seines (table 1). The

CPUE in tows where American plaice is more than half of the catch has been declining from 1600 in 1991 to 1270 in 1992-1994, and to 720 in 1997 (anon 1998). The index of fishable stock from trawl surveys does not however show any downward trend (table 4) but the recruitment index has been increasing since the beginning of the surveys in 1985 (Jónsson et al. 1997). The recruitment index is based on length distribution, and since males are smaller than females, which the index is not corrected for, it should be taken with precaution. This stock is certainly not in danger, and the current TAC is set 5.000 tons, the same as in 1997, prior to that there was no TAC.

Most of the American plaice catches are large females, in late winter and spring (fig. 34), as reflected in the CPUE. This is because the American plaice is aggregating in spawning grounds at that time. The American plaice is of relatively low value and is therefore mostly fished when available in large quantities. It is difficult to discern any consistent trend in the CPUE with time (fig. 35). The CPUE originally increased in most of the grounds as fishers started targeting American plaice or stopped discarding it. A consistent decline in CPUE recently is only discernible in grounds 11 and 13, where catches are high.

World catches of American plaice since 1950 have followed a dome-shaped curve. They increased from little less than 20 000 t in 1950 to more than 120 000 t in 1968 and then slowly decline again to little less than 20 000 t in 1994. Canadians caught by far the largest share in the northwestern Atlantic. Catches in these waters were also high by the Soviet Union from 1965 to 1977, the USA from 1977 to 1987, and Spain and Portugal from 1985 to 1989. Until 1994 catches in the northeastern part of the Atlantic were very low or just a few thousand tonnes per year, mostly by boats from the USSR / Russia and recently from Iceland. In 1994 the catches from both sides of the Atlantic were roughly equal, 35 % of the total catch is taken by the USA, 20% by Iceland, Russia and Canada each, and 2.5 % by Spain and Portugal each.

3.4.2 Results

Fishmap: American plaice is caught all around Iceland, but the main grounds are along the south shore and on Reykjanes Ridge (fig. 36). Except for the northern and eastern grounds, the distribution of catches is similar to witch flounder. Catches are increasing rapidly making an apparent biomass increase. This trend is also obvious in estimates of minimum biomass by grounds. The biomass estimate in all the grounds is gradually increasing (fig. 37) because of increased effort and probably also less discarding.

Effmod: The current biomass estimates for American plaice are between 80 000 and 300 000 t (table 7), high compared to other flatfishes. This high biomass is consistent with estimates from trawl surveys (Jónsson et al. 1997). The models agree on the biomass distribution by grounds, the highest in grounds 1 and 11, then in grounds 12, 13 and 14, all with biomass of more than 10 000 t. The American plaice also has a wide distribution and is found in most other grounds.

The American plaice stock seems to be in a healthy condition on all grounds. Only model 2 estimates the stock to be slightly below 50% of unfished biomass in ground 8, otherwise the estimates are generally more than 75%. The likelihood distribution for all the grounds are wide or reach an asymptote (fig. 9) so these estimates have to be taken with precaution. The MSY is not as high as the biomass estimates might indicate, from 3 000 to 9 000 t/y. This is because the American plaice has a relatively low natural mortality rate and a slow growth rate compared to other flatfishes, especially dab.

Other models: It was not possible to do SSDD model estimates. No optimum K/Bo combination was found since there is no trend in the survey index. The likelihood curve just increased to an asymptote for all the K values, similar to the Effmod analysis. The American plaice does not have time series long enough to do a cohort analysis. The yield per recruit model indicates the highest Y/R as 0.136 kg at an exploitation rate of 0.45 (fig. 38), this however means that spawning stock has declined to 35% of unfished biomass. Catch curve analysis indicates a current exploitation rate of 0.4 (fig. 39), slightly increasing since 1994, but the variation is high.

3.4.3 Discussion

The American plaice is probably the species where quota recommendations are the most difficult because of uncertainties in stock size. Current landings of 5 000 to 6 000 t/y do not seem to have much effect on the stock. Estimated sustainable yield from Effmod model 2 indicates that the stock can not sustain catches at this rate for a long time. Biomass estimates by Effmod model 1 are very high, higher in fact than reported in any other American plaice stock (Walsh 1994a). Estimates from model 2 are also high but well within biomass ranges from other areas.

Because of its wide and scattered distribution, high abundance, low price, and absence of a downward trend in its survey index, it can be argued that a TAC on the American plaice is currently not necessary. The danger is however that if the fishery is unrestricted, fishers might go fish for American plaice but discard other species that need protection. This is one of the big drawbacks of individual quota systems. In a multispecies fishery all the species need a TAC. The TAC of each species should then not necessarily be linked to its own abundance, but also on the abundance of other species caught in the same area by the same gear. Another thing that might actually compensate for this is that if fishers have a quota on American plaice there will always a pressure to fill it, even if it is not too profitable. The effort aimed at American plaice might, in fact, decline if the fishery is unrestricted and bycatch of other species will therefore also decline. The American plaice does have a different general distribution than plaice and lemon sole, both of which are in need of protection. The distribution of the American plaice however overlaps megrim in many places, and the megrim stock is in a bad state.

Ultimately management advice on American plaice is going to be linked to megrim. Based on this analysis it is not possible to recommend any special TAC for American plaice, but the fishery should be restricted to deeper waters south of Iceland and on Reykjanes Ridge, to protect megrim.

Lessons from other areas show that American plaice can be overfished. In the North Sea where American plaice (long rough dab) is primarily a bycatch, the stock seems to be healthy (Heessen and Daan 1996). On the east coast of North America, where the American plaice is a target species, the situation is very different. The stock is currently overfished (Brodie and Bowering 1991, anon 1997a). This is unlikely to happen in Icelandic waters because of the generally smaller size at age of American plaice in Icelandic waters and therefore lower value. Also because of the lack of subsidies in Iceland which prevents unprofitable fisheries over the long run (Hannesson 1996). Continued monitoring of the Icelandic stock in surveys (especially the abundance of large females) is necessary so that the fishery can be restricted if signs of decline appear.

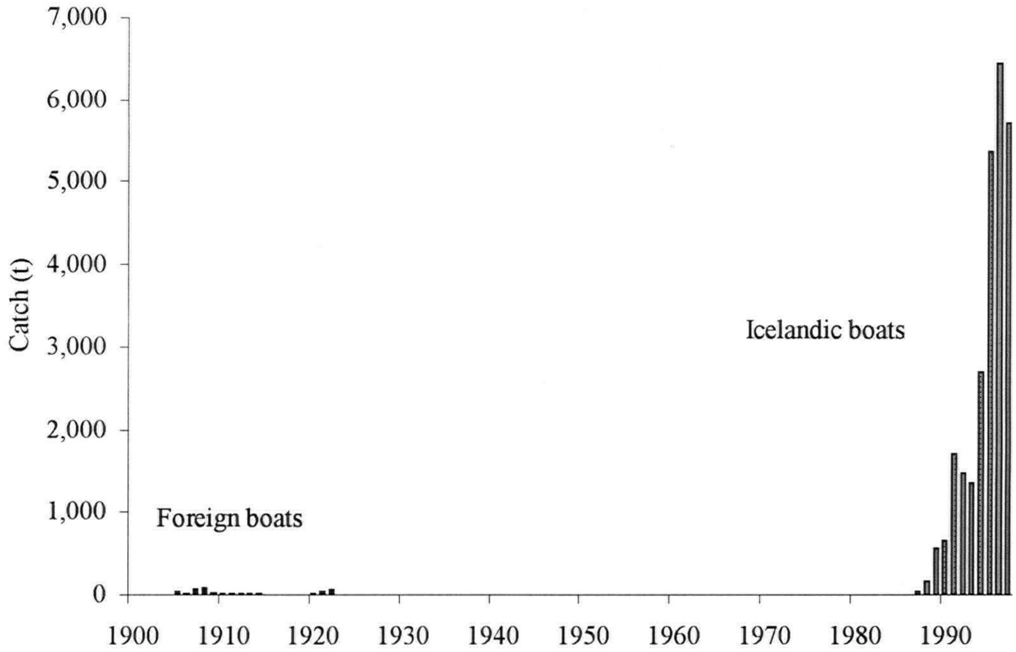

Figure 33: American plaice, historical catches since 1906, dark columns are foreign catches and light columns Icelandic catches

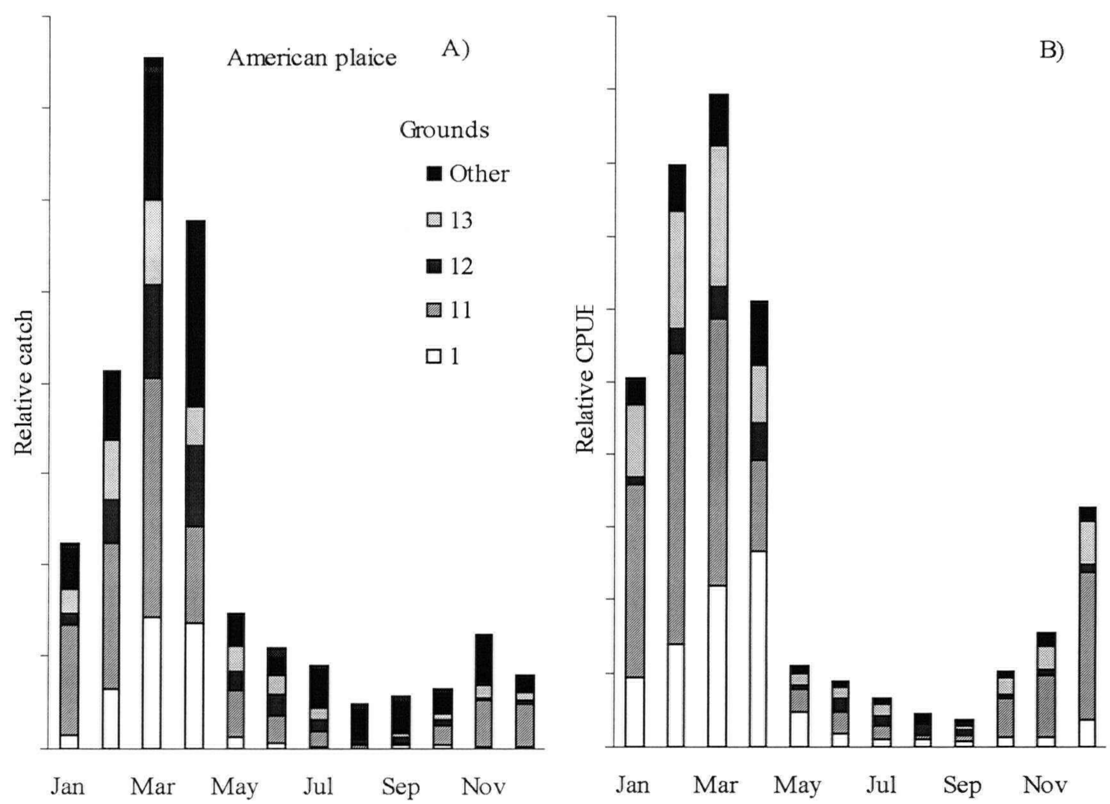

Figure 34: American plaice, average catch (a) and CPUE (b) per month on 4 of the major grounds, values are average since 1979. Catches in other grounds are sum of the average per ground and CPUE is average from all the grounds

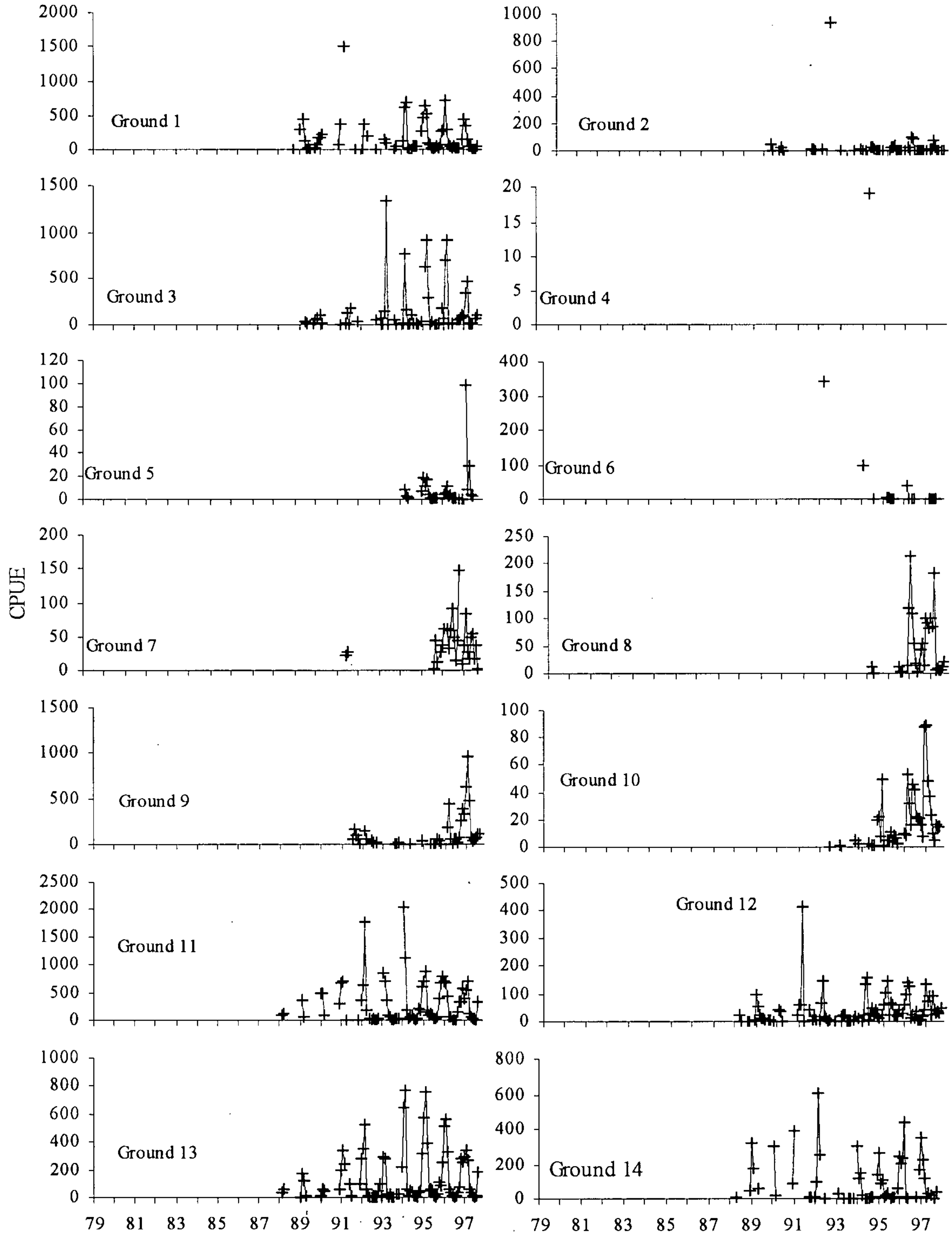

Figure 35: American plaice, CPUE per month by grounds since 1979

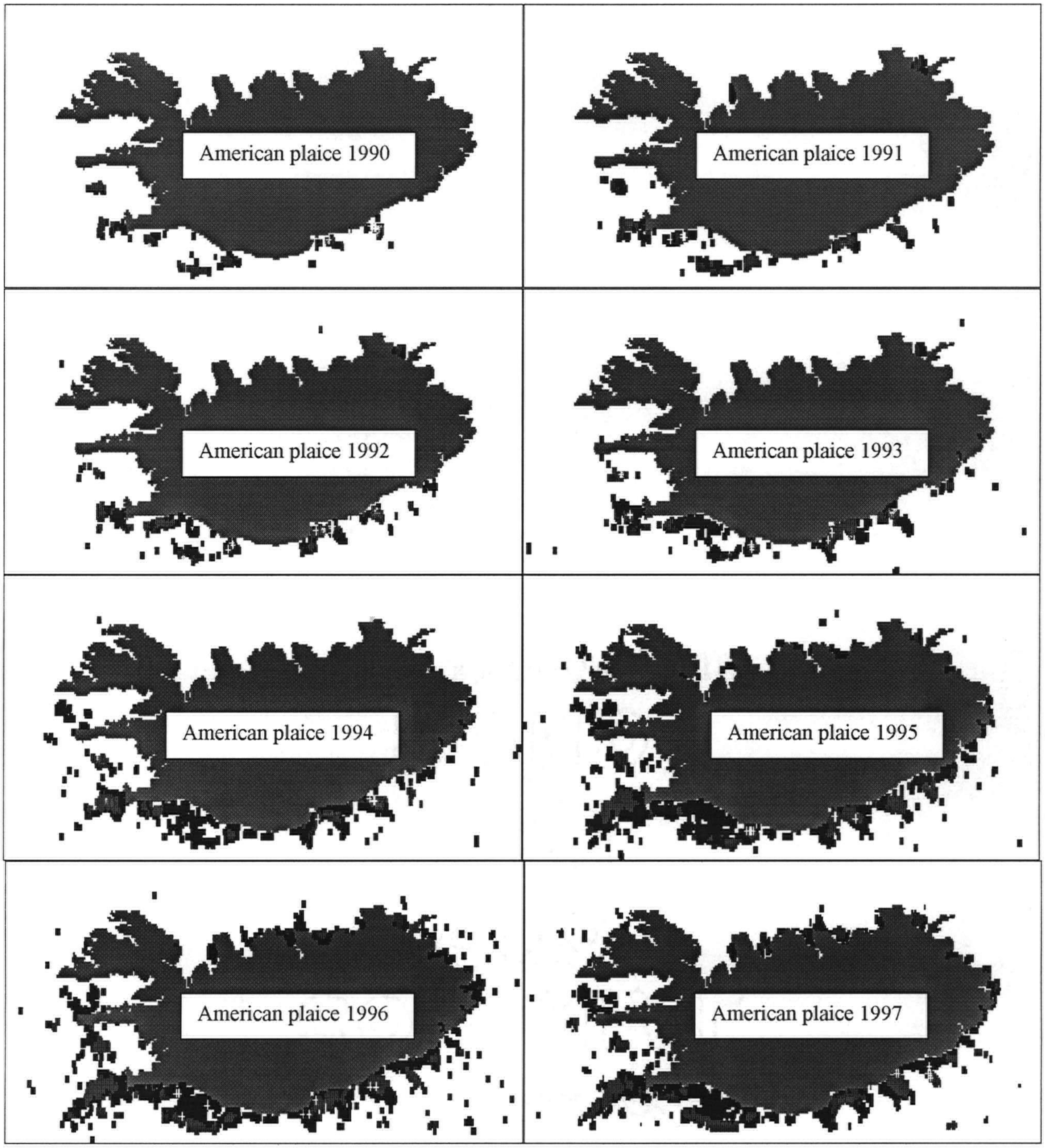

Figure 36: American plaice, distribution of catches from Danish seine fleet since 1990. Dark areas indicate low CPUE and light areas high; crosses are the cleanest sets, i.e. where the percentage of the species under consideration of the total catch is the highest

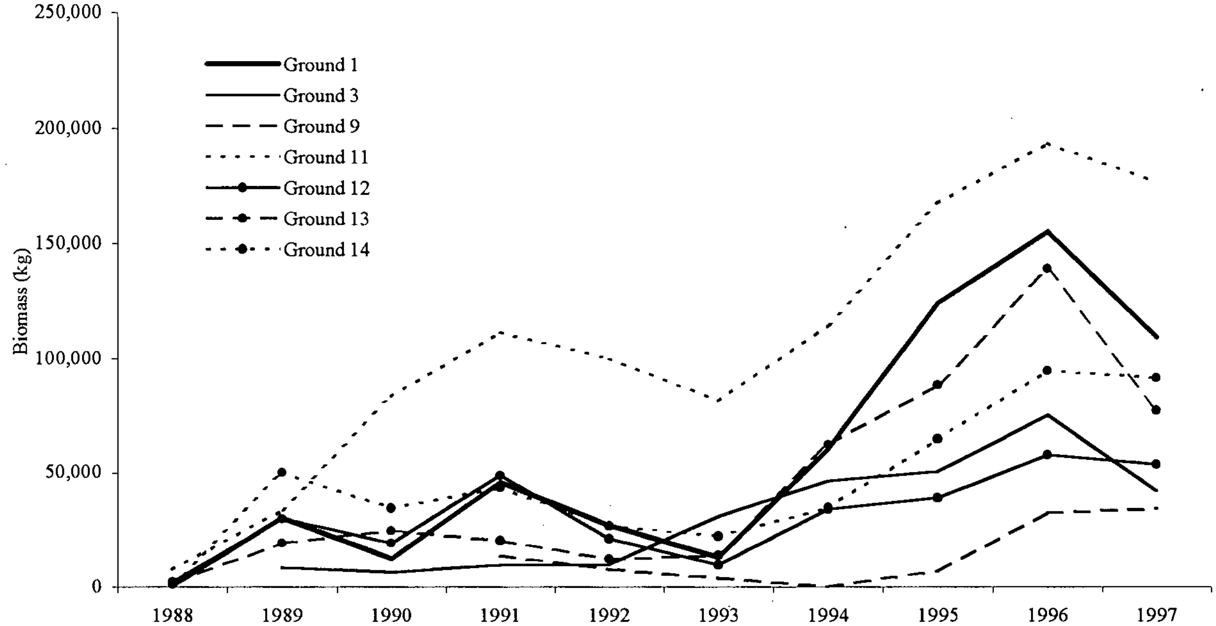

Figure 37: American plaice, estimated minimum biomass by 7 of the grounds with the highest biomass, Fishmap analysis.

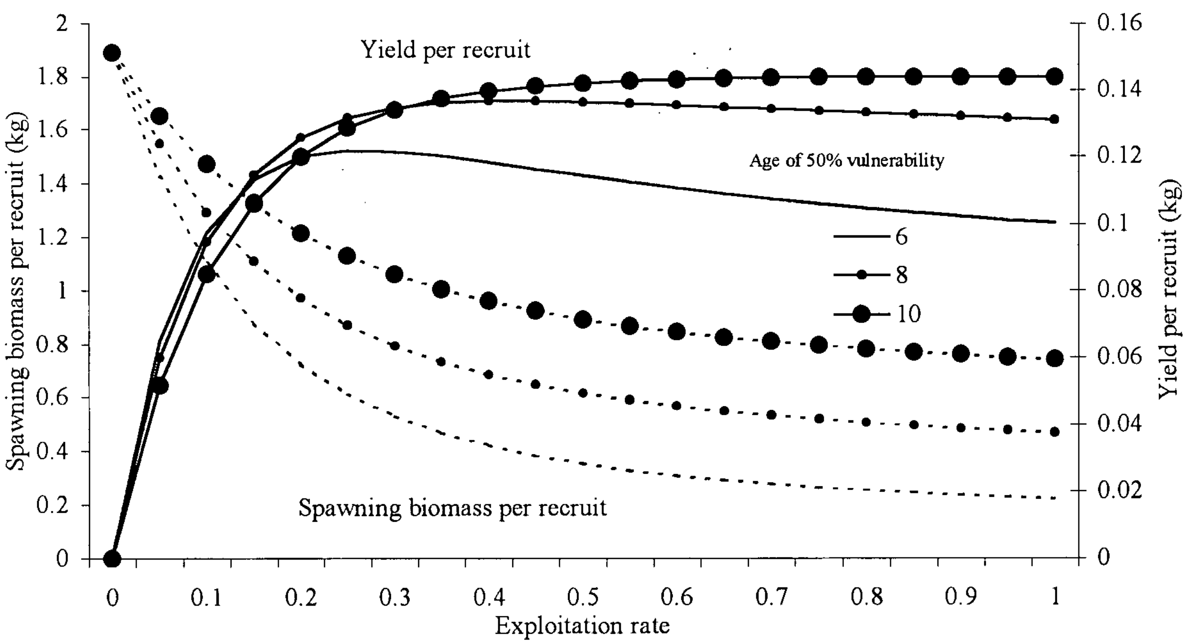

Figure 38: American plaice, Yield and spawning stock per recruit with different age of 50% vulnerability

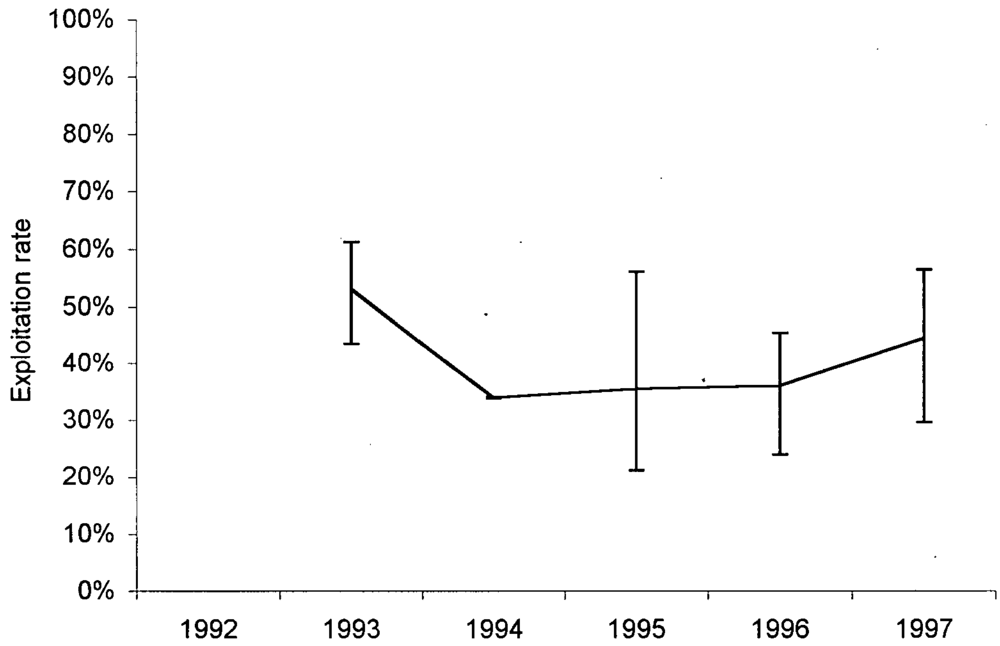

Figure 39: American plaice, estimated exploitation rate and standard deviation for catch curve analysis.

3.5 Dab - *Limanda limanda* (linnaeus, 1758)

3.5.1 Introduction

Dab is small compared to other flatfishes of commercial importance in Icelandic waters, usually between 20 and 35 cm in total length. The largest individual found in Icelandic waters was 48 cm (Jónsson 1992) which is a world record. The growth is fast the first years but slows after reaching sexual maturity at the age of 2 to 3 for males and 3 to 4 for females. The females grow faster and get older than males or up to 14 years old. Dab in the colder waters of the north and north-east coast grow faster than dab in warmer waters off the south and west coasts (Jónsson 1966). It probably spawns all around Iceland, first from middle of April off the southeast coast spreading clockwise around the country. The last spawners are along the east coast where spawning probably starts around middle of June. The diet of the dab is variable; it is an opportunistic feeder and can handle large food items (Óskarsson 1997). Various benthic invertebrates are common in the died, as are sandeels and capelin. Discards from fishing boats are commonly found in dab stomachs.

The dab is common on sand or mud bottoms from 0 to 40 m all around Iceland, and is rare below 120 m (Sæmundsson 1926, Jónsson 1966). It is more abundant in the warmer waters along the south and west coasts than along the north and east coasts. It presumably does not migrate long distances but generally goes a deeper in winter. Dab is only found in the eastern part of the North Atlantic, from the Barents Sea to the Bay of Biscay. In the North Sea, it is the most common fish species.

Until 1984 dab was not caught in large numbers in Iceland (fig. 40). English boats reported from 500 to 1 000 t/y until W.W.II, but catches were even lower after the war, then mainly by English, and Belgian trawlers (Hjörleifsson et al. 1998a). It is difficult to evaluate if dab was discarded in large quantities at that time. The dab lives in very shallow waters and after the extension of the Icelandic EEZ to 4 miles in 1952, trawlers (this does also apply for the Icelandic trawlers) were not able to catch it, since most of its preferred grounds were now within the 4 mile EEZ. Generally, the dab cannot be caught in large quantities with nets, longlines, or handlines used in the shallow waters. The only fishing gear that could tackle the dab was the Danish seine. Due to its low value, it was until recently primarily a bycatch in Icelandic Danish seine fisheries, and might in many cases have been discarded or reported with other flatfish species. After 1984, catches have increased, mainly because Faxaflói Bay, where the main fishing grounds are, has been opened for Danish seine fishing. More than 95 % of the current catches of 8 000 t/y are from Danish seine (table 1).

There is no trend in the CPUE from the Danish seine fleet (anon 1998) or in the abundance index from the trawl survey (table 4, Jónsson et al. 1997). There is however a slight upward trend in the recently established flatfish survey in Faxaflói Bay (Pálsson et al. 1998) and therefore no indications that the current increase in catch has had any effect on the stock. Since catches have been rising rapidly recently, precaution is advised in this harvest and the current TAC is set at 7 000 tons. Before 1996, there was no TAC.

Overall, dab catches are evenly spread over the year (fig. 41); with differences between grounds. On the grounds along the south shore (gr. 11 to 13) the catches are highest during late winter and spring, but catches in Faxaflói Bay (gr. 2) are highest during late summer and autumn. This is not because of seasonal movements of the dab, but because Faxaflói bay is closed from late winter to mid summer. The CPUE of dab is highest from October to December (fig. 41). It is however to discern if this is because of the movement of the fleet, migration of the dab, or seasonal closures. The CPUE of dab seems to be increasing with time for many of the grounds (fig. 42), and this is probably because of increasing targeting or retaining. No grounds show a consistent decline.

Since 1950, world catches of dab have been stable at about 10 000 to 15 000 t/y. Until 1984, the main nations fishing for dab were Denmark, France, and the Netherlands. After 1984, Dutch catches have been very low but Icelandic catches increased rapidly from almost zero. In 1994 the Icelandic share was the largest or one third of the total catches of 15 000 t.

3.5.2 Results

Fishmap: The trend in distribution for dab is similar to American plaice, both show an increase with time and both are found all around the country but are most abundant in southern waters (fig. 43). The plaice is however generally closer to shore and very abundant in Faxaflói Bay where the American plaice is virtually absent. The biomass trend by grounds is also similar (fig. 44) as catches for the dab have been increasing rapidly lately.

Effmod: The current biomass estimates for the dab are quite variable between models or from 40 000 to 350 000 t (table 7). The unusually high biomass estimates for model 1 are primarily because of high estimates for ground 2. The areas with the highest biomass are the shallow waters south of Iceland (gr. 2, 11 and 12) with more than 4 000 t each, and to a lesser extent ground 13 and 14. The estimate of the current status compared to unfished biomass varies between grounds and models used. Model 2 indicates an almost virgin stock in all grounds except 6 and 13, where the ratio is 37%. Model 2 gives more pessimistic results, but still a biomass of more than 50% unfished except for grounds 1, 6, 9, 10, and 13. Except for grounds 6 and 13 the likelihood profiles are broad or reach an asymptote (fig. 9) so they have to be taken with great precaution. The MSY estimates vary from 4 000 to 27 000 t/y. This is the highest MSY for any flatfish. Dab is fast growing at early stages and it matures at an early age. It is, therefore, the flatfish species that can most easily withstand heavy fishing effort.

Other models: Due to the lack of any trend in the trawl survey it was not possible to do a SSDD model on dab. Cohort analysis indicates that the biomass for the last five years has been 15 000 to 25

000 t (fig. 45). This is lower than the most pessimistic estimates by Effmod, but has no consistent decline or increase. The exploitation rate has been from 0.4 to 0.6, highest in 1997. The age of 50% vulnerability has been around 5 since 1993 (fig. 46). Equilibrium analysis indicates a MSY of 8 000 t/y at an exploitation rate of 1 (fig. 47). Although this might seem high, the spawning biomass is still around half of its unfished state at that exploitation rate. The likelihood for the cohort analysis is reasonably well defined (fig. 48) and indicates a current age of vulnerability at 5.5. Catch curve analysis indicates a similar exploitation rate as the cohort analysis, but shows no consistent trend and has high variation.

3.5.3 Discussion

There are great uncertainties about the current stock status of dab because of widely varying current biomass estimates. If Effmod model 2 is considered closest to the truth, the current catches are too high to be sustainable over the long term. According to cohort analysis, the current catches and recommendations by the MRI are exactly at MSY. Because of this, the fast growth rate, early maturation, low price, lack of downward trend in survey index and CPUE (assuming they reflect the actual abundance), it is unlikely that the stock will be overfished in the near future, even if the TAC were unrestricted. There are however warning signs in the data. The only grounds that are declining according to model 1 in Effmod (gr. 6 and 13) are the fringe areas. Furthermore all the grounds that have less than 50% of unfished biomass in model 2 are also fringe areas. This indicates a range decline. This analysis does not yet justify any further restrictions on the fishery for the dab, because of the dab itself, but continued monitoring of its abundance and age structure is necessary.

The problem with dab, as with American plaice, is that it shares habitat with another species that needs protection, the plaice in this case. Although the spatial distribution of these species overlaps, there are certain differences in catches between seasons. Both species go deeper during the winter, this seems to have opposing effects on catchability. The CPUE of plaice is generally highest during late spring or early summer when they go to shallower areas. Since adult dabs live on the average in shallower waters than plaice, the CPUE of dab is generally highest during late fall or early winter, when it goes to deeper waters. This can be used to restrict the fishery on plaice so that at the same time the effects on dab are minimised. Seasonal openings are already used to control the Danish seine fleet in some areas around Iceland. These can be expanded so that dab can only be caught as bycatch during the spring and summer months (the dab catch only allowed to be a certain percentage of the plaice catch), but targeting of the dab would be allowed in the autumn and winter months. The direct targeting should also be confined to a few well-defined areas where dab is abundant, such as the southern part of Faxaflói Bay and in shallow waters along the south shore.

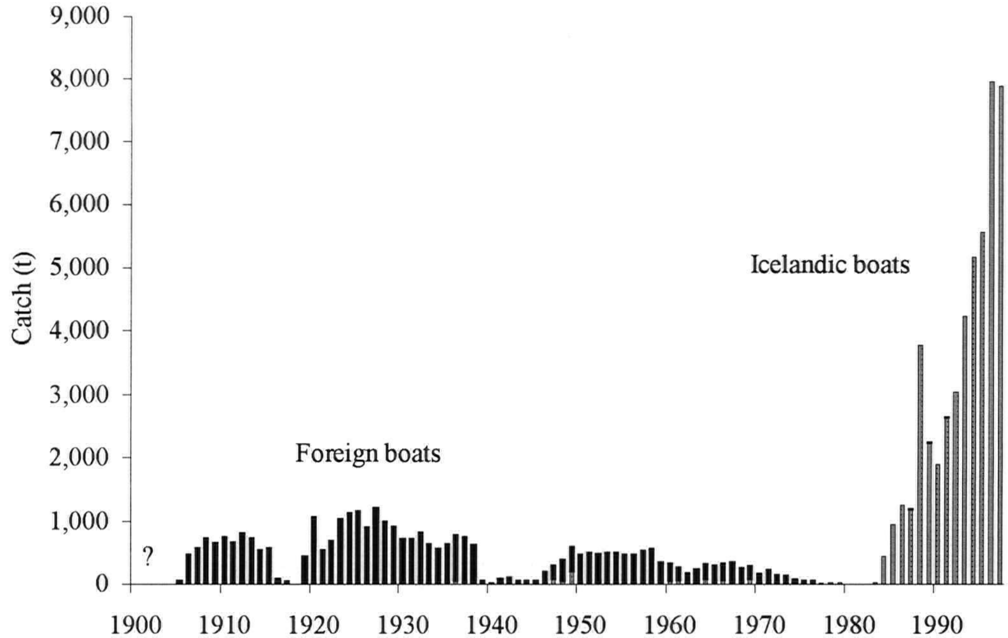

Figure 40: Dab, historical catches since 1906, dark columns are foreign catches and light columns Icelandic catches

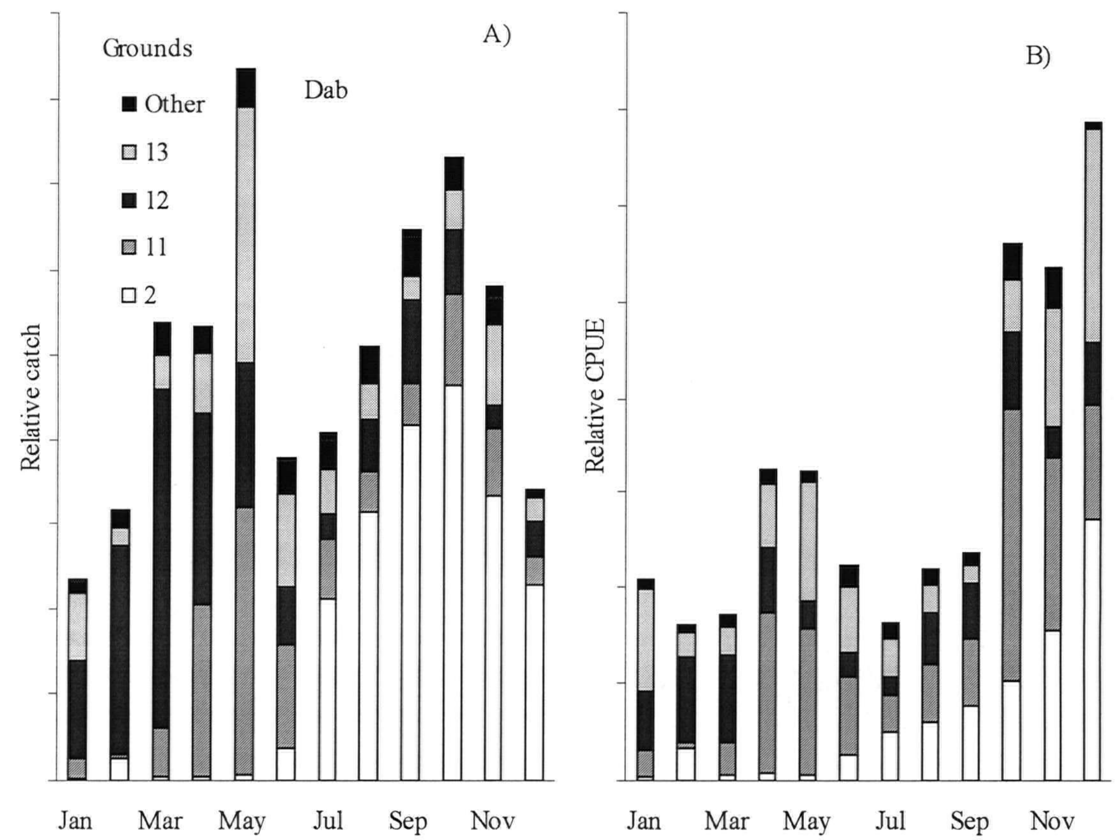

Figure 41: Dab, average catch (a) and CPUE (b) per month on 4 of the major grounds, values are average since 1979. Catches in other grounds are sum of the average per ground and CPUE is average from all the grounds

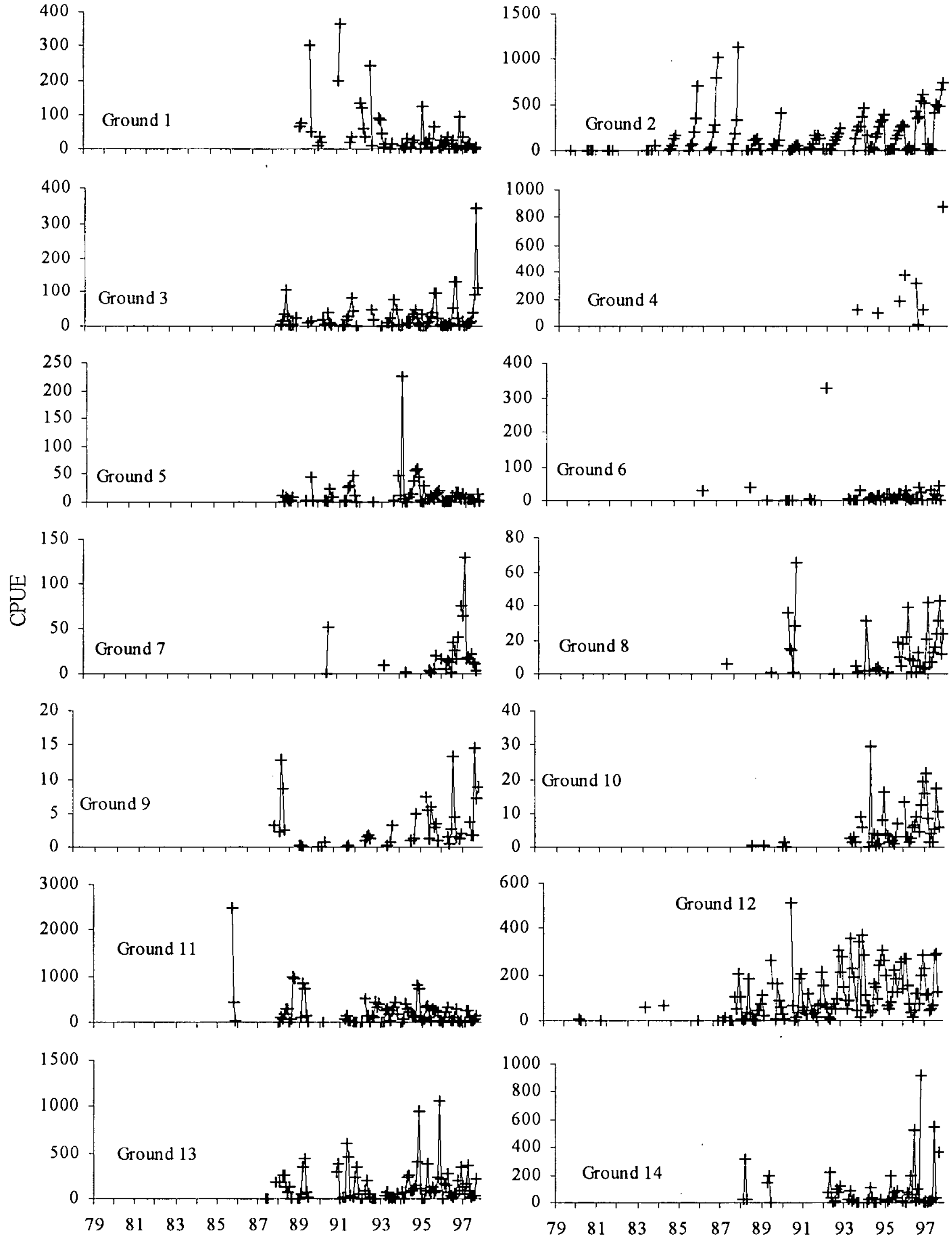

Figure 42: Dab, CPUE per month by grounds since 1979

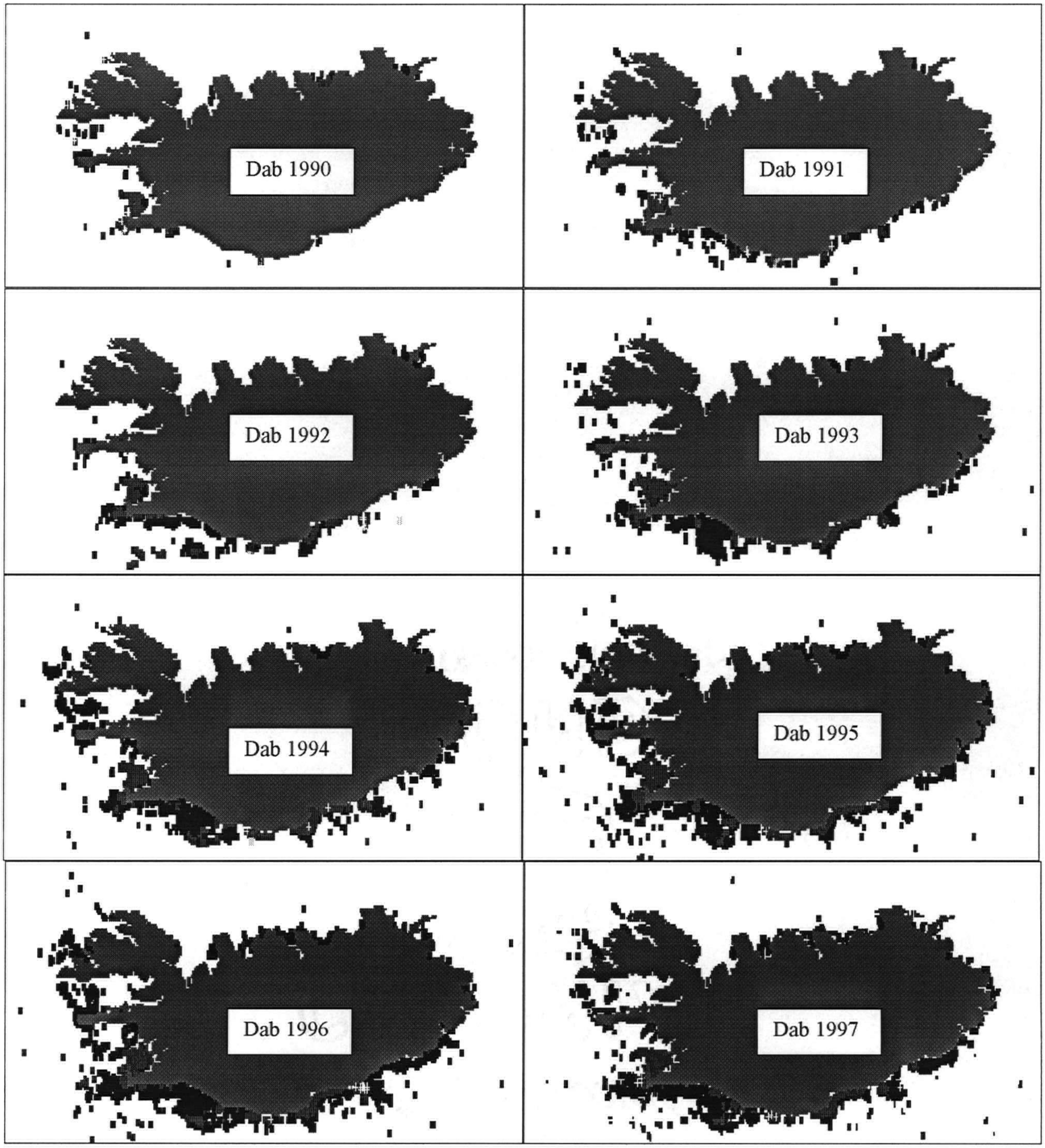

Figure 43: Dab, distribution of catches from Danish seine fleet since 1990. Dark areas indicate low CPUE and light areas high; crosses are the cleanest sets, i.e. where the percentage of the species under consideration of the total catch is the highest

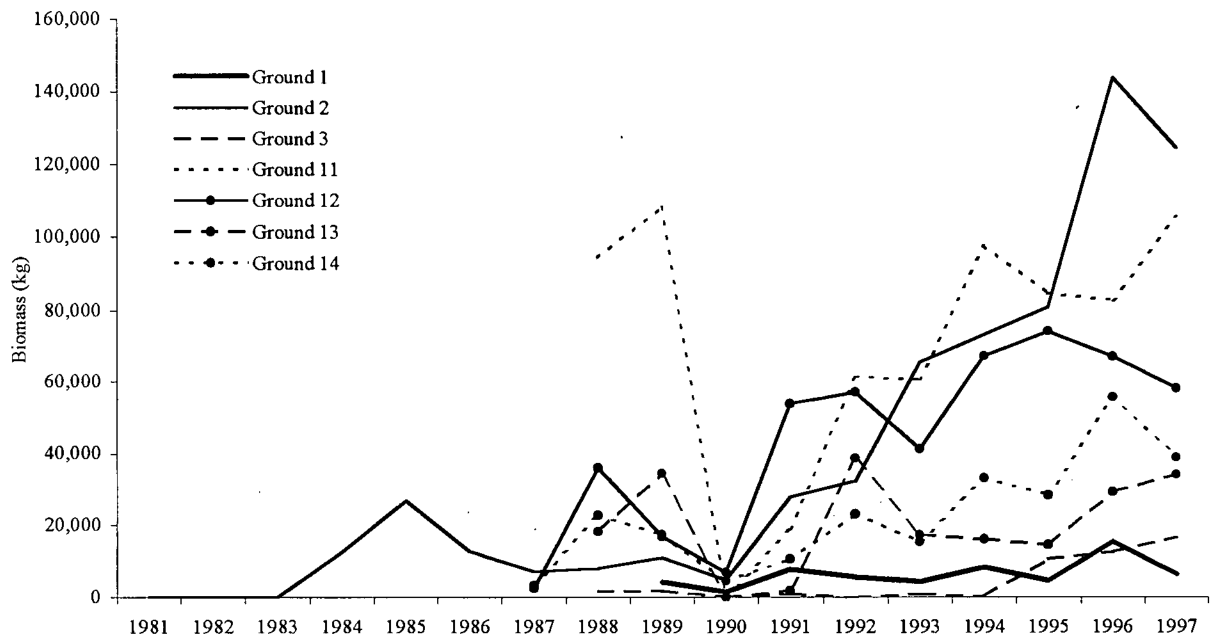

Figure 44: Dab, estimated minimum biomass by 7 of the grounds with the highest biomass, Fishmap analysis.

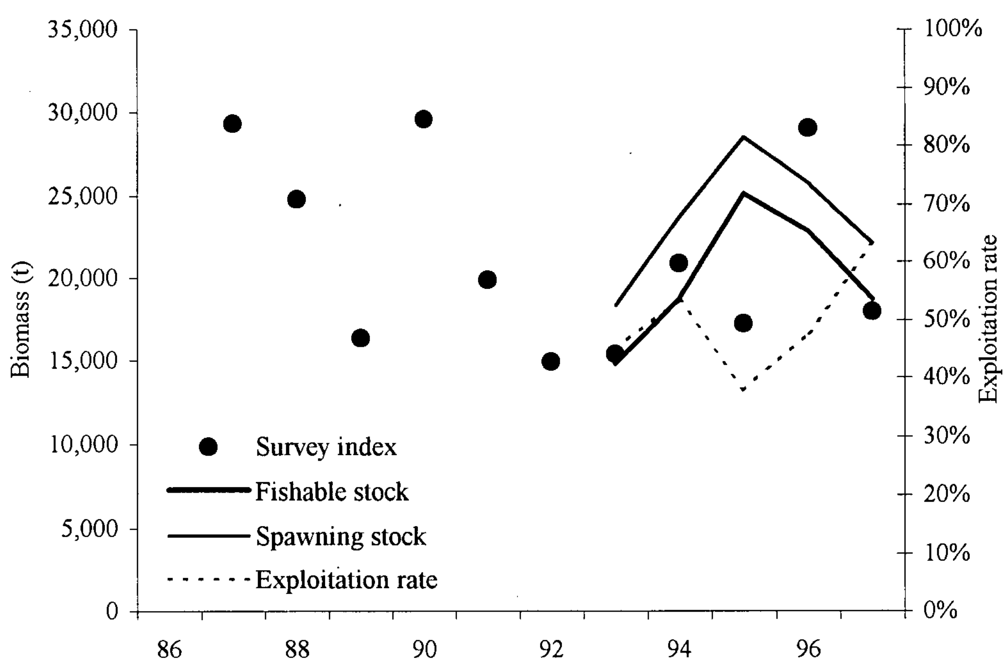

Figure 45: Dab, estimated biomass of exploitable (thick line) and spawning stock (thin line), survey index (circles) and exploitation rate (broken line), cohort analysis.

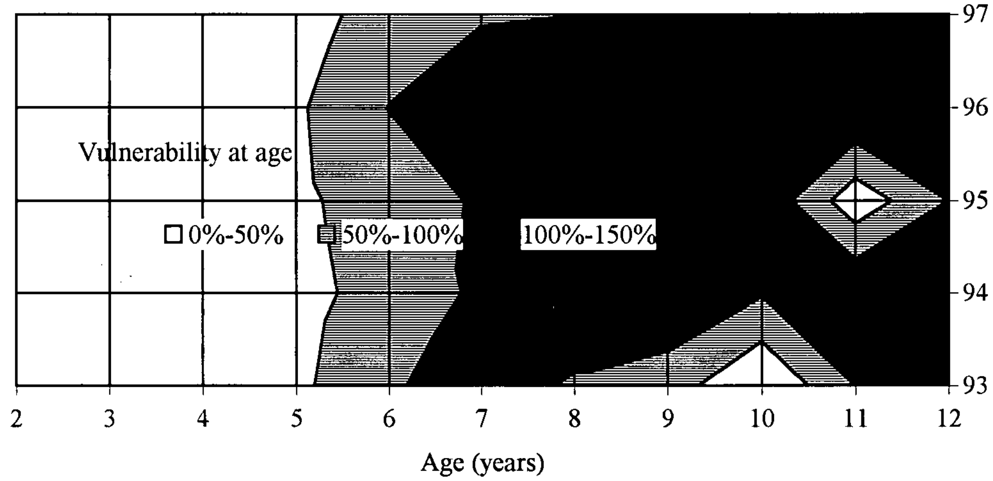

Figure 46: Dab, vulnerability at age, cohort analysis

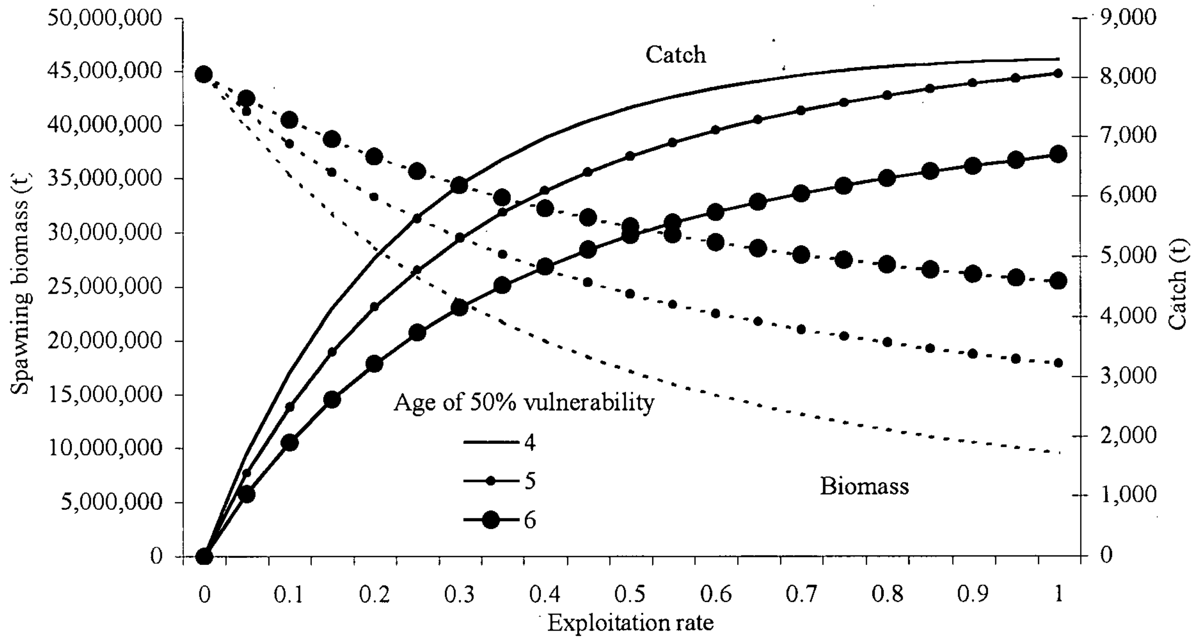

Figure 47: Dab, biomass (broken line) and catches (solid line) at equilibrium, cohort analysis

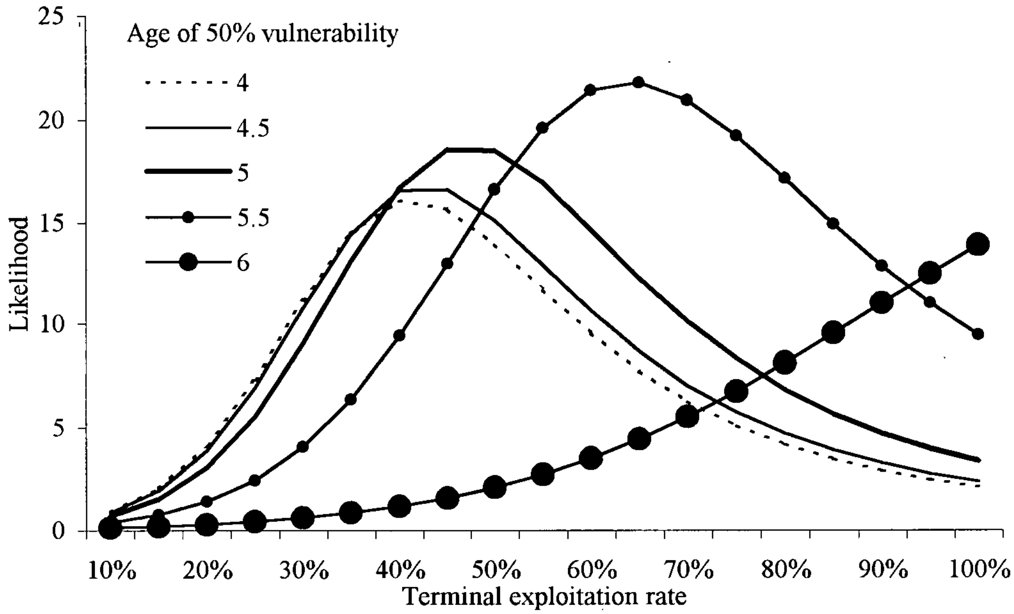

Figure 48: Dab, likelihood profile for the terminal exploitation rate and different age of 50% vulnerability, cohort analysis

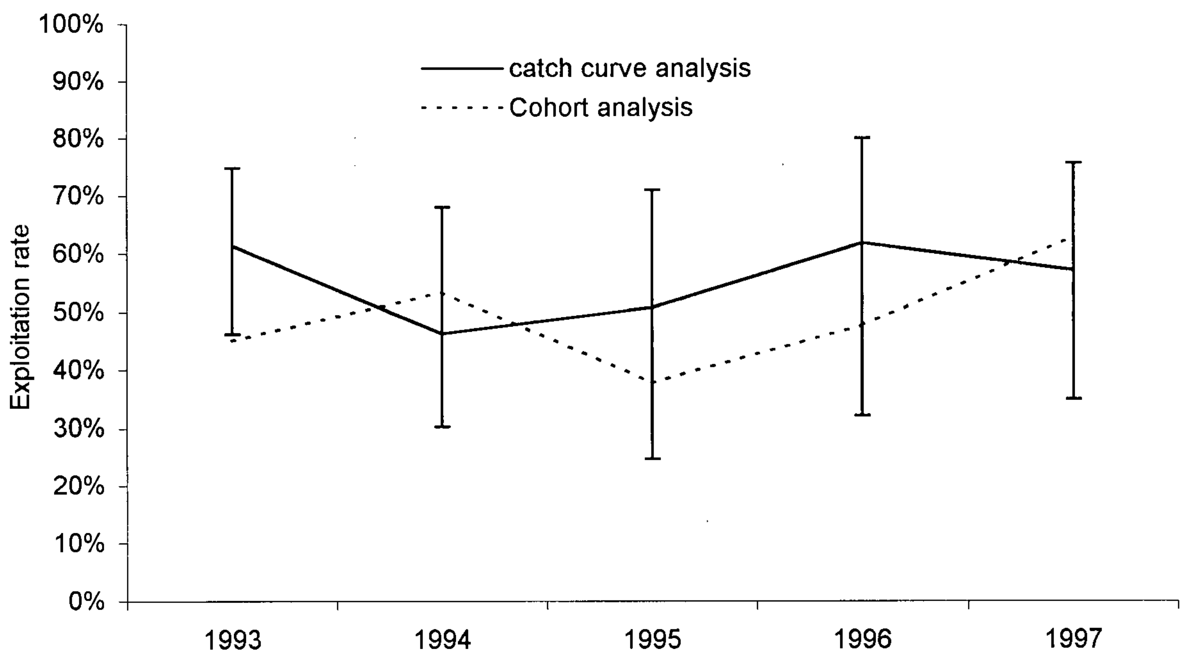

Figure 49: Dab, estimated exploitation rate and standard deviation for catch curve analysis (solid line) and for cohort analysis (broken line).

3.6 Lemon sole - *Microstomus kitt* (Walbaum, 1792)

3.6.1 Introduction

The lemon sole is a medium sized flatfish, usually around 30 cm long, but the largest individual caught in Icelandic waters measured at 63 cm (Sæmundsson 1926, Jónsson 1992). It is found all around Iceland, but is much rarer in the colder waters north and east of the country. It is mostly found on rocky or sandy bottoms at depths between 50 to 300 m, but has been found as deep as 1 500 meters in other waters. It is found in European waters from Murmansk in the north to the Bay of Biscay in the south. Also around the Faroe Islands, in Greenlandic waters and from Labrador to Cape cod in North America. Lemon sole feeds primarily on polychaetes, but also to a lesser extent on other groups such as sandeels (*Ammodytes* sp), its small mouth however restricts its feeding range (Steinarsson 1979). Spawning takes place along the south and southwest coasts, in March to June. Growth is slow, but females grow faster than males. Most of the males are sexually mature at 5, and females at 7. In Icelandic waters, the lemon sole can reach 14 years of age.

Per unit weight, the lemon sole is the most valuable species included in this assessment (table 5). After halibut (which is still more valuable) and plaice (which is much more abundant), lemon sole was the most sought after flatfish by foreigners in Icelandic waters. The total catch increased from around 300 t/y shortly after the turn of the century to 1 000 t in 1911 (fig. 50). Foreign fishing was limited during W.W.I, but catches increased rapidly after the war and peaking at 3 000 tonnes in 1937. Catches fell again during W.W.II, but increased again shortly after the war. Catches then started to drop when Icelanders gradually extended their EEZ. Originally catches were almost exclusively by English and German boats, but after W.W.II by English and Icelandic boats. Lemon sole has never been an important fish in Icelandic fisheries; it has usually been a bycatch. Reported catches by Icelanders are negligible before 1940, but have fluctuated between 0 to 1 400 tonnes annually since then. During the period from 1974 to 1984 catches were very low, but increased rapidly after 1985 and have been relatively stable at around 800 tonnes annually since. Roughly half of the catch is by Danish seine (table 1), the rest mainly by bottom trawl and to a lesser degree lobster trawl.

According to trawl surveys the catchable stock has declined rather steadily and is now roughly two thirds of the stock at the beginning of the survey in 1985. The recruitment index is however stable (table 4, Jónsson et al. 1997). Catch per set from the Danish seine fleet has been fluctuating during this period, but on the main fishing grounds it has fallen from 350-400 kg from 1991 and 1992 to 200 kg from 1993 to 1997 (Anon 1998). Beside this, there is no assessment on the lemon sole and no TAC.

Most of the lemon sole catches by the Danish seine fleet are from May to July on all the major grounds (fig. 51). This is reflected in the CPUE for the waters west of Iceland (gr. 5 and 6). The CPUE for the waters south of Iceland (gr. 11 to 14) is higher during the summer. The high catches in ground 6 in April are because of very high reported catch in April 1992, this is an obvious outlier and could be an error in the data. Because lemon sole is mainly a bycatch species in the Danish seine fleet, these differences between season probably reflect seasonal movements of the fish. The bottom type preferred by the lemon sole is ill suited for Danish seining. This increase in CPUE might thus reflect seasonal spawning movements outside these areas. This is supported by the fact that catches of lemon sole are very low from December to March. It is very difficult to discern any trend in the CPUE with time (fig. 52). It does not increase as catch increases, probably because it probably has never been discarded in any quantities because of its high value.

All of the reported catches of lemon sole are in European waters. Catches have been remarkably stable at around 7 000 to 9 000 t/y from 1950 to 1977 and around 11 000 t/y since then. The majority of the catches have been by Scottish and English boats, but catches by Denmark and France have been increasing recently. The Icelandic part of the catches has been fluctuating from below 1 % to maximum of 16 % in 1961, it has been between 6 and 7 % for the last decade.

3.6.2 Results

Fishmap: Lemon sole is mainly caught in shallow waters along the south and west coast of Iceland (fig. 53). There is no observable trend in the catch except that catches and catch reports have been increasing. Minimum biomass does not show any trend with time and has been stable for the last 5 years (fig. 54).

Effmod: The present biomass estimates by Effmod are variable depending on the model, from 4 000 to 11 000 t (table 7). The highest biomass is in the waters west and south of Iceland (gr. 3, 5, and 11 to 14), and lemon sole is virtually absent from the waters north and east of the country. There is a high variation between models on what the current biomass is compared to unfished biomass. Ground 14 seems to be the worst off, and the stock is only 17 to 28% of unfished biomass. The stock seems to be in worse condition on the grounds south of the country than in the west. Ground 6 is remarkably consistent, all models indicate that the ratio of current biomass to unfished biomass is 22%, the unfished biomass was however low. The likelihood curves for lemon sole are intermediate compared to other flatfishes (fig. 9). The bounds are narrow for grounds 1, 11, and 14 but not for other grounds. The MSY estimates range from 400 to 750 t/y depending on models, the current harvest is a little higher.

Other models: The SSDD model gives a very different picture from the effort model, according to the SSDD model the stock is at a very low level compared to unfished biomass because of previous overfishing by foreign fleets (fig. 55). The current biomass estimate is 1 100 t or 4% of unfished biomass. The likelihood curve is however unclear (fig. 56). The resolution in this graph is not fine enough to show the high peaks at low K values. If high K values were used in the model the stock should have been able to recover after the foreign fishery stopped, and the current Icelandic catches should not have caused the stock to decline as indicated by the survey index. Low K indicates that the stock does not show strong increases in recruitment per spawner when spawning stock declines. A K value of 3 was used here. MSY at equilibrium is estimated at 1 300 t/y at an exploitation rate of 0.15 (fig. 57). This is higher than current catches but the current exploitation rate is much higher since the stock is probably at a low level. The survey biomass index and biomass estimated from model are almost the same.

Yield per recruit analysis indicates a Y/R of about 0.1 at high exploitation rates and a corresponding spawning stock biomass of half unfished biomass. This reflects the fact that the lemon sole matures long before it gets vulnerable for fishing gears. Catch curve analysis estimate the exploitation rate to be 38% in 1995 and 27% in 1996; lower than the SSDD model. The variation is low (the maximum estimate is 43% in 1995 and 29% in 1996 and the minimum is 31% in 1995 and 25% in 1996), samples are however few.

3.6.3 Discussion

There is a large difference in stock status estimates between models used. The difference between the models used in Effmod is not as much as for the other flatfish species. The Effmod models estimate that the catches are about twice as high as they should be, and therefore they should be reduced by at least that amount. Single stock assessment does however indicate that the current catches are below MSY, but also that the stock is at such a low level that the catches are not sustainable. This seems to be a similar situation as for megrim. The survey index decline is much steeper for the megrim. Further, the CPUE of the megrim from the commercial fleet is rapidly declining, while it is not for the lemon sole. There are, therefore, much more uncertainties about the stock status of the lemon sole, and furthermore it matures before it becomes vulnerable to fisheries, while these two ages are similar for the megrim. This makes the former species less vulnerable to the fishery. Currently there is no TAC on the lemon sole since it is primarily a bycatch in other fisheries and reducing catches is thus difficult to employ. Also compared to other flatfish, a large part of the lemon sole catch is with gear other than Danish seine. This is primarily because it prefers hard and rough bottom types, but Danish seines can only operate on relatively smooth and even grounds. The fishery with Danish seine might thus not be the main culprit for the decline of the stock, bottom trawls that are able to operate on rougher grounds are likely candidates. Where these fisheries operate is not available here, but will have to be looked at for future evaluation on the stock.

This analysis cannot provide any definite TAC for lemon sole, since the results are too contradictory. The precautionary advice would be to ban all direct targeting of the lemon sole, if it exists, and find ways to reduce the bycatch of lemon sole. Effort restrictions in the deeper grounds south of Iceland would also be advisable, especially in April and May when CPUE is highest. This would also help protect megrim and witch flounder. Another wise step would be to ban all trawling on hard bottom areas, a move that should probably have been taken long time ago, not primarily to protect the lemon sole, but the sessile fauna in these areas which is very vulnerable to trawls. This is however outside the scope of this project and would require much more study. Since the Danish seine is not able to target lemon sole on its major grounds, and may only take the fishes that seasonally migrate from the main grounds, it is also quite possible that the data from the Danish seine fleet used here is inadequate for the models. It is therefore quite possible that the lemon sole is much more abundant than estimated here.

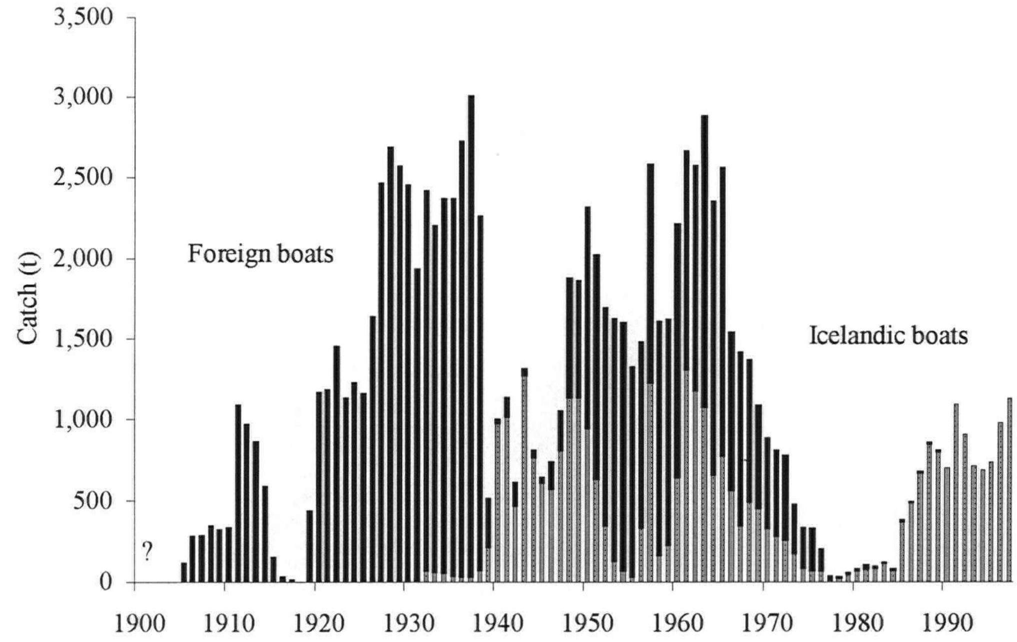

Figure 50: Lemon sole, historical catches since 1906, dark columns are foreign catches and light columns Icelandic catches.

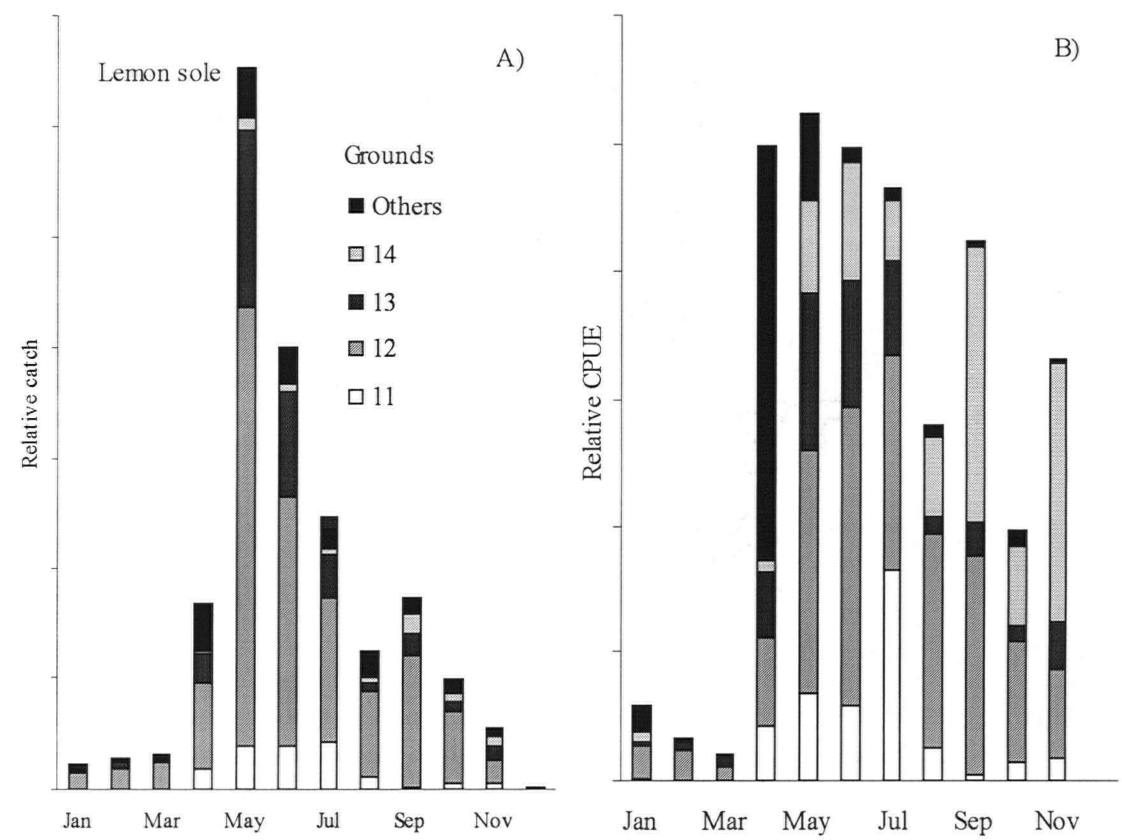

Figure 51: Lemon sole, average catch (a) and CPUE (b) per month on 4 of the major grounds, values are average since 1979. Catches in other grounds are sum of the average per ground and CPUE is average from all the grounds

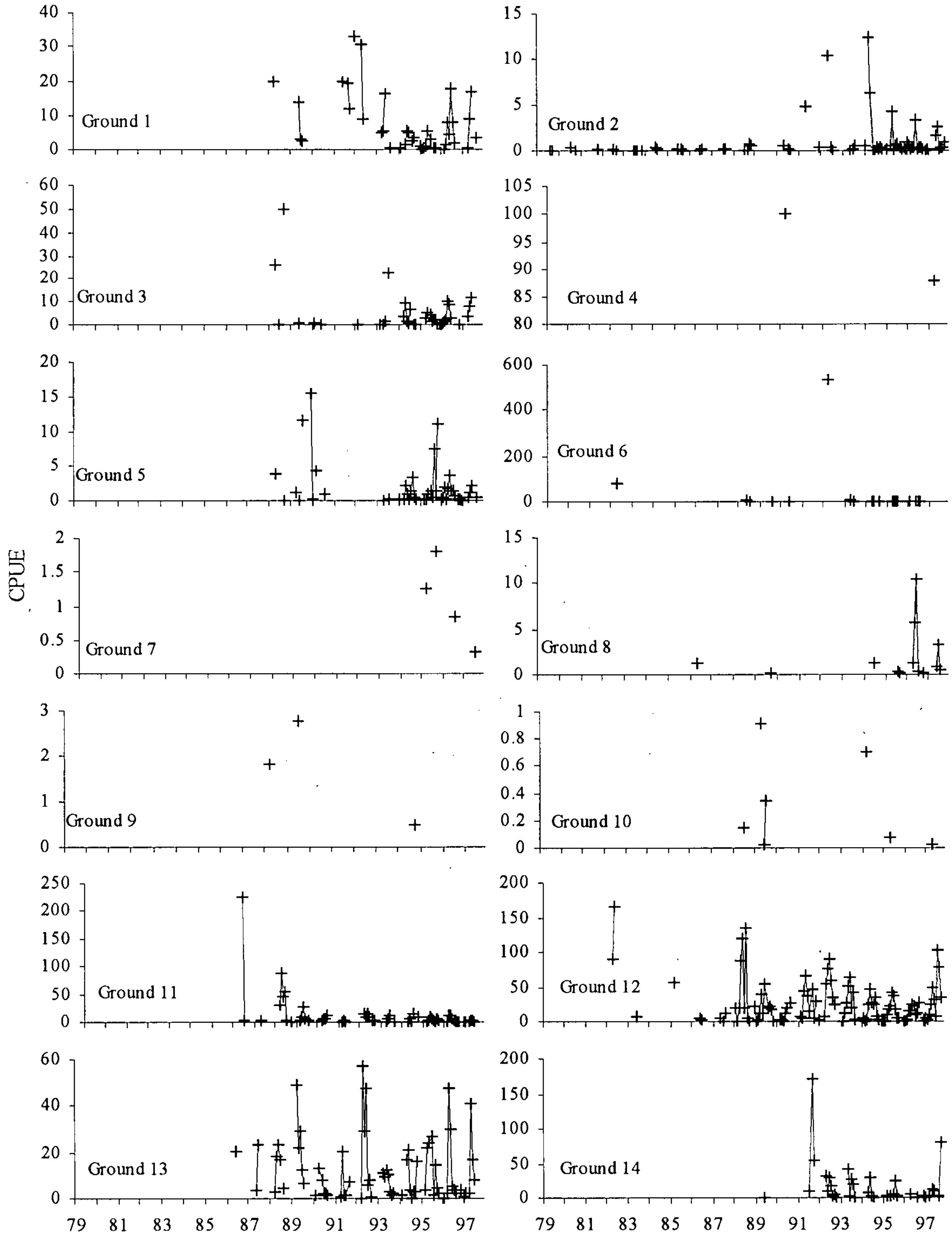

Figure 52: Lemon sole, CPUE per month by grounds since 1979

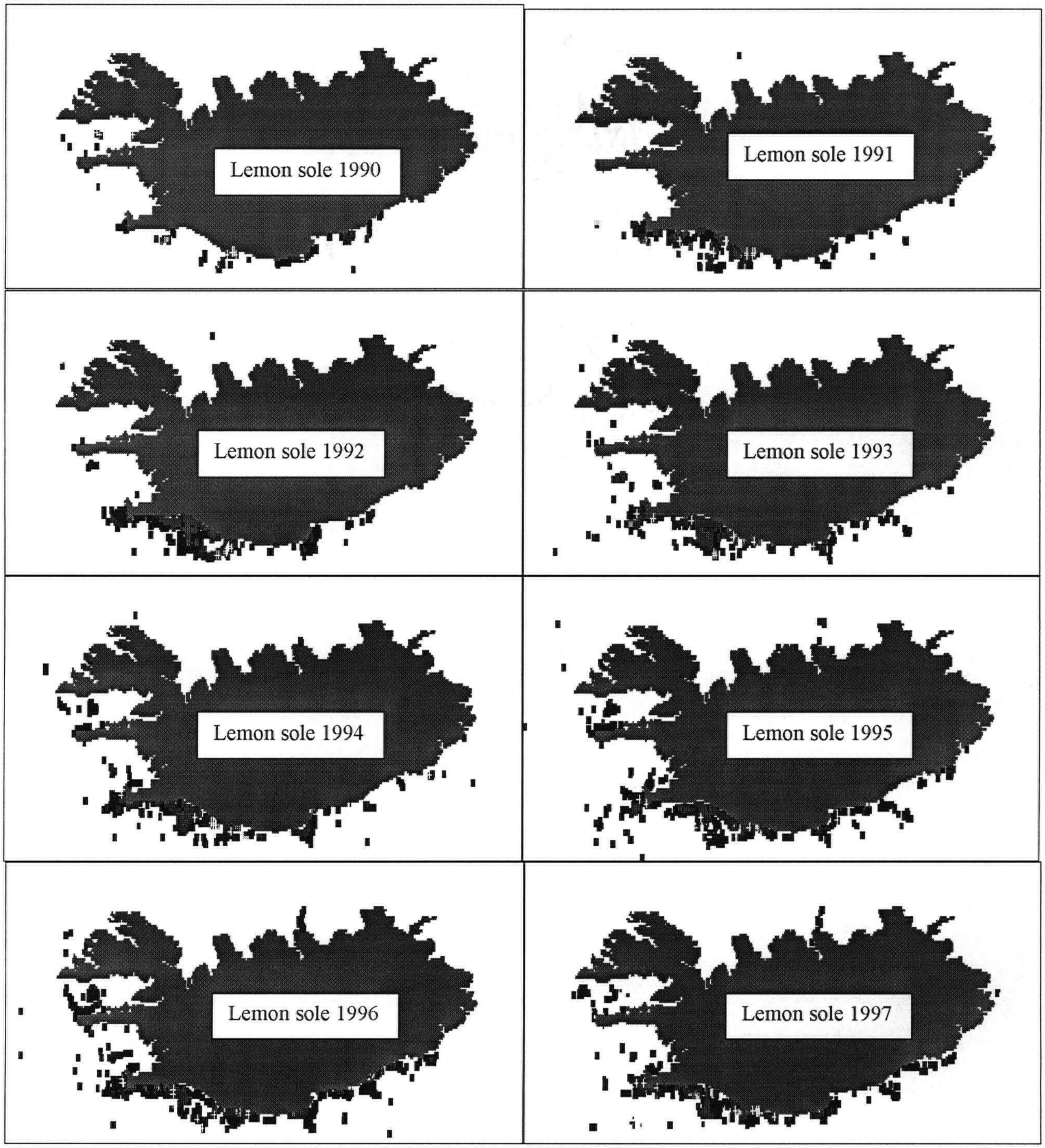

Figure 53: Lemon sole, distribution of catches from Danish seine fleet since 1990. Dark areas indicate low CPUE and light areas high; crosses are the cleanest sets, i.e. where the percentage of the species under consideration of the total catch is the highest

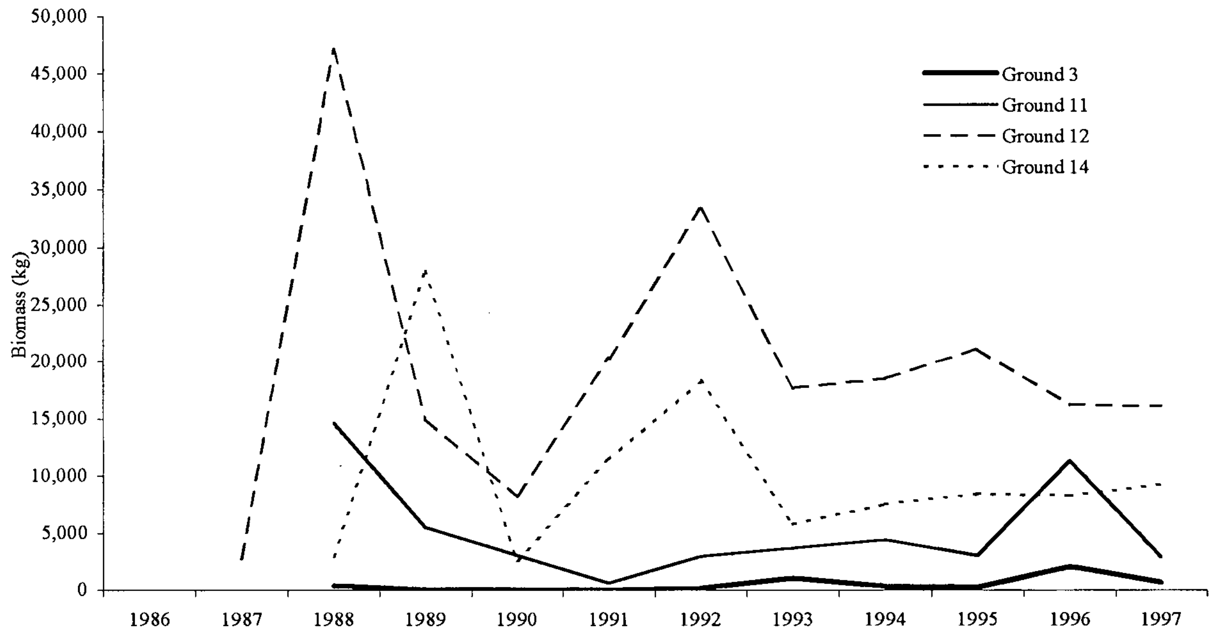

Figure 54: Lemon sole, estimated minimum biomass by 4 of the grounds with the highest biomass, Fishmap analysis.

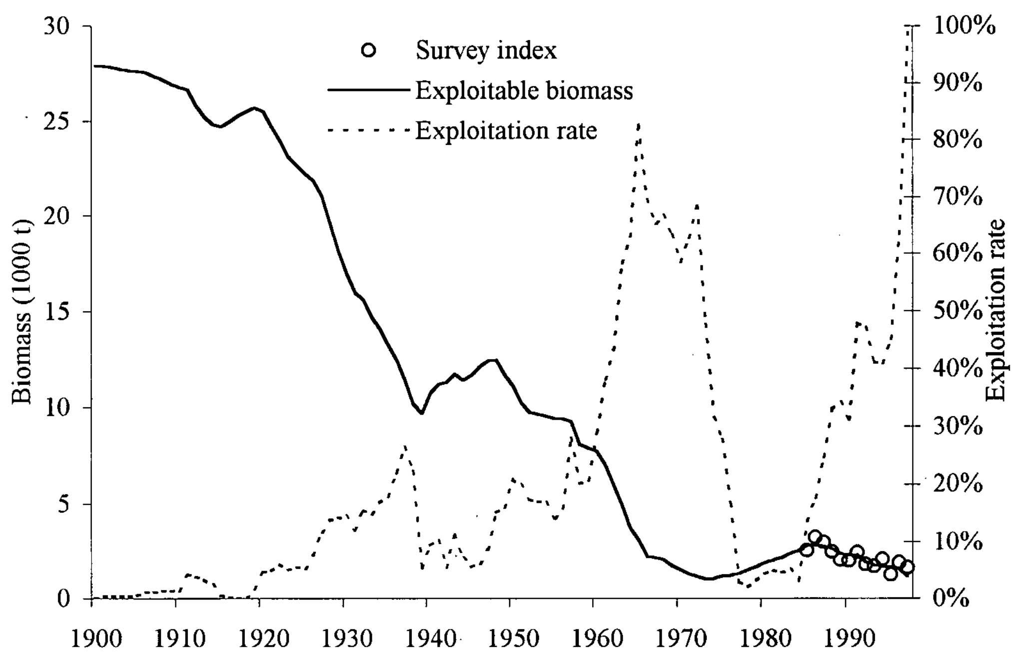

Figure 55: Lemon sole, estimated biomass of exploitable stock biomass (solid line), survey index (circles) and exploitation rate (broken line), single stock delay difference model.

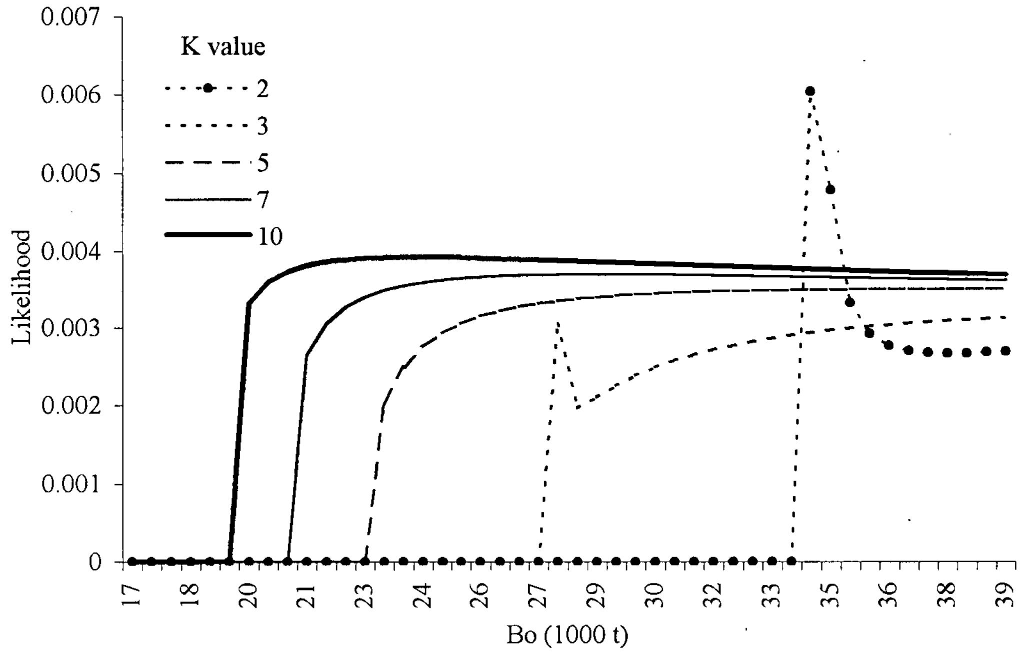

Figure 56: Lemon sole, likelihood profile with different stock recruitment "K" values and unfished biomass (B_0), single stock delay difference model.

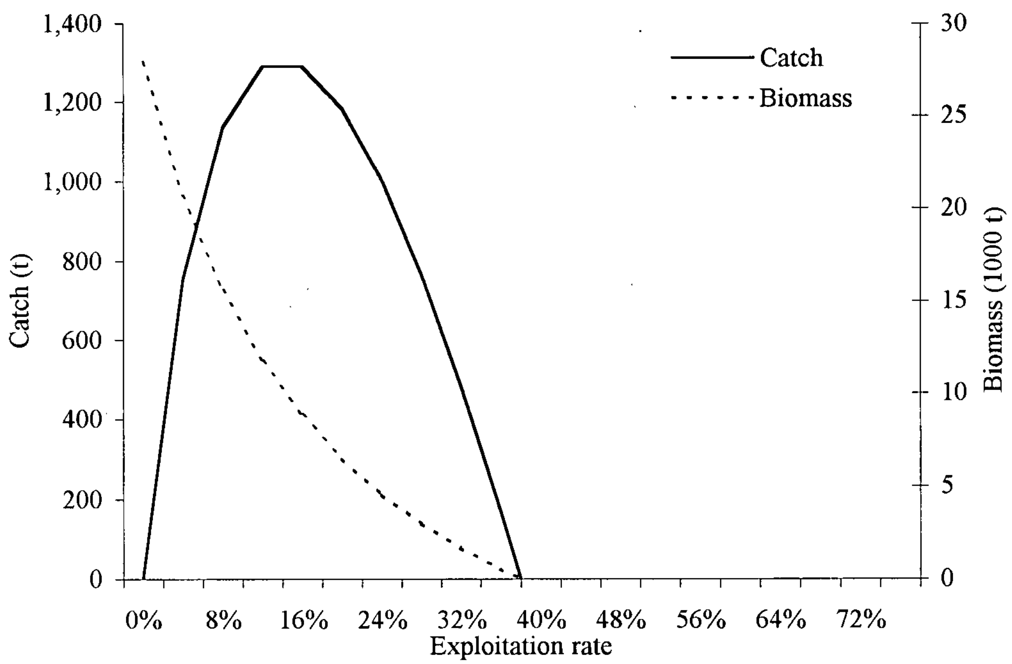

Figure 57: Lemon sole, biomass (broken line) and catches (solid line) at equilibrium, single stock delay difference model.

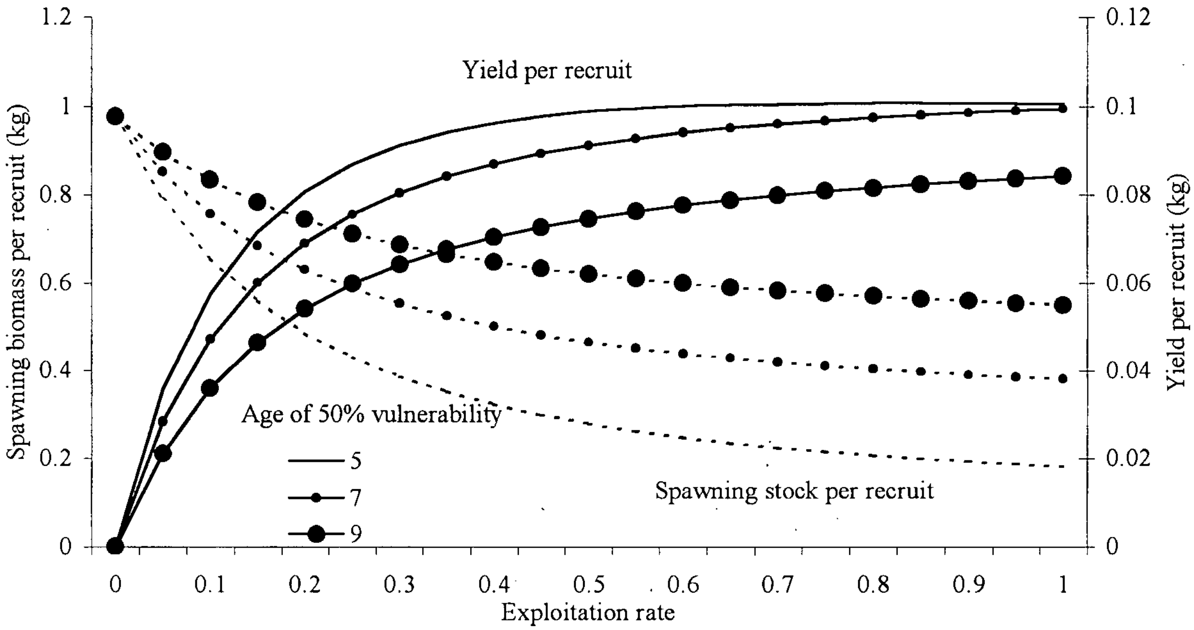

Figure 58: Lemon sole, Yield and spawning stock per recruit with different age of 50% vulnerability

3.7 Plaice – *Pleuronectes platessa* (Linnaeus, 1758)

3.7.1 Introduction

Plaice is a medium to large sized flatfish. The maximum recorded size in Icelandic waters is 85 cm, but the usual size in catches is from 30 to 50 cm, which is larger than in most other waters in Europe (Sæmundsson 1926, Jónsson 1992). Plaice is common all around Iceland from 0 to 200 m, on sandy or muddy bottoms. It can also tolerate fresh waters for some time. In European waters it is found from the White Sea and the Barents Sea in the north down to the western part of the Mediterranean Sea in the south. It is not found in North American waters. Previously flatfishes were considered rather immobile. Tagging studies on the plaice have however shown that this does not hold true (Sigurðsson 1982, Sigurðsson 1989). The plaice undertakes large scale feeding and spawning migrations in the waters around Iceland, fishes tagged on one side of the country were even found at the other side, a few of the tag returns were also in Norwegian and Russian waters.

Spawning mostly takes place in the warmer waters south and west of Iceland at 50 to 100 m (Jónsson 1992). Eggs and larvae have also been found in colder northern waters so at least some limited spawning occurs there. In the southern waters the peak spawning season is in March and April but in May and June in northern waters. Plaice is relatively fast growing and can reach a larger size than other flatfishes except for halibut and Greenland halibut. Females grow larger than males. Growth is however quite variable and has been shown to depend on temperature, food abundance and stock size among other things (Rijnsdorp 1994). There is a clear difference in size at age between regions in Icelandic waters (Tåning 1929), even between fjords close by in the same region (Einarsson 1956). The plaice reaches 50% maturity at around the age of 5, and the maximum age is more than 20 years. The food of plaice mainly consists of various benthic invertebrates, dominated by polychaetes and bivalves, but also sandeels to some extent (Pálsson 1983).

Because of its good taste, abundance and shallow water distribution plaice has sustained high catches in Icelandic waters since the beginning of the trawler age. Catches have usually been similar or higher than for all other flatfish species combined in Icelandic waters. British trawlers were the first to catch plaice in substantial amounts (Thor, 1992). Unfortunately, the quantities of these catches are not available until 1906 (fig. 59). Presumably they must have been high since at that time there is already a sign that the plaice stock was being overexploited as both the catches, CPUE and the proportion of large individuals in catches were declining (Tåning 1929). This decline continued until 1915 when the fishery stopped due to W.W.I. The stock seems to have recovered during the war and sustained catches of around 6 000 t/y, mainly by British boats, until their fishery stopped again in 1939 due to W.W.II. The CPUE was however slowly declining during this entire period. During W.W.II Icelandic catches, which were negligible before, increased to 3 000 to 4 000 t/y because of the new markets in the British Islands. When British trawlers came back after the war and were able to satisfy the British market the Icelandic catches declined again to very low levels. After the war, the CPUE of the British fleet was much higher than before the war. Despite Icelandic catches, the stock thus seems to have therefore recovered somewhat. The British boats used after the war, however, were more powerful and technologically better than their predecessors, this could partly explain the increasing CPUE. The CPUE then declined rapidly until 1954 when it increased again to levels similar as just after the war. The CPUE then generally slowly declines until foreign boats were expelled from Icelandic waters. This decline does not indicate a decline in stock size, since the Icelandic EEZ was increased during this period from 4 miles to 12 miles in 1958, 50 miles in 1972 and finally 200 miles in 1975, and the foreign fleets gradually retreated from Icelandic waters. The decline in foreign catches was more than compensated by increase in Icelandic catches. Icelandic catches then declined and were relatively low during the 1970's, but then increase again mainly because of increased number of boats targeting it with Danish seines. Recent catches have been 10 000 to 14 000 t/y, higher than ever before. Most of the current catches are by Danish seine (table 1), but a considerable share is taken by bottom trawls.

Catches of plaice are highest during late spring and summer depending on grounds (fig. 60). South of Iceland (gr. 12) and in Breiðafjörður Bay (gr. 5) catches are highest in spring, out of Vestfirðir Peninsula (gr. 6) and north-east of Iceland (gr. 9) catches are highest during summer, and in Faxaflói Bay catches are highest in summer and autumn. Fishing in Faxaflói Bay is however restricted from January to June. The CPUE reflects the catches to some extent, but is more evenly distributed among months. The CPUE is variable between grounds (fig. 61), but a consistent decline is discernible in some of them after 1991.

How much fishing the plaice stock can take has for long been a subject of interest. Friðriksson (1932) hinted that the stock might easily be overfished by the foreign fleets, but still suggested that Icelanders, whose catches were small at that time, should catch more. His argument was that plaice was more valuable than cod per weight and since the fishery by the foreign fleets was not controlled, Icelanders should try to fish as much plaice as they could, before the foreign fleets finished it up. Later Graham (1948) suggested a MSY of 6 000 t/y, because the density of the stock showed a state of equilibrium from 1924 to 1927 when catches were around 6 000 t/y. According to this, the increase in catches shortly afterward caused the stock to decline to a new equilibrium level with sustainable catches of only 5 000 t/y. Currently the stock has been assumed to be able to sustain long-term catches of 10 000 t/y (anon 1998), based on catch history (Anon 1985). Until 1984 the MRI recommended more fishing for plaice. Since catches were low until that time, no TAC was provided. After this the MRI gave an annual recommendation of 10 000 t/y until 1997. During this period the total catches were always higher than recommended, despite the fact that plaice was the first flatfish stock to be controlled by TAC. The plaice stock is now considered to be overexploited and the recommended TAC by the MRI has declined to the current level of 7 000 t (anon. 1998).

Stock size index from trawl surveys indicates an almost continuous decline since the first survey in 1985. The current level is only about 10% of the 1985 level. The recruitment index has however been increasing (Jónsson et al. 1997). Results from flatfish surveys in Faxaflói Bay since 1995 support these results, or even paints a bleaker picture, since catch there has decreased from 160 t in 1995 to 60 t in 1997 (Pálsson et al. 1998). The same stations and fishing gear were used throughout this period. From 1979 to 1990 the CPUE from the Danish seine fleet also declines continuously, increases sharply in 1991 and then declines again (anon 1998). The increase in 1991 is considered to be mostly because of increased catchability of the plaice, better fishing gear and better logbook reporting.

World catches of plaice have been 100 000 to 200 000 t/y since 1950. As with the catches in Icelandic waters, these are generally higher than the combined catches of all the other flatfish species considered here. The majority of the catches are in the North Sea by boats from the Netherlands, England, and Denmark. The Icelandic part of the catch has been increasing recently to the current level of about 7 %.

The plaice is the most studied of Icelandic flatfishes. Studies on population dynamics have however been hampered by the different fishing gears used and lack a of any continuity in the studies. Early this century Danish and, later, Icelandic scientists conducted tagging studies (Scmidt 1907, Sæmundsson 1913). Research topics in the inter-war period were diverse. Sæmundsson (1926) and Tåning (1929) studied life history and touched on the effects of fisheries, and Friðriksson (1932) evaluated the ecological and economical effects of Danish seine fisheries on plaice. After W.W.II and until 1979, when annual surveys were conducted for 6 years by Sigurðsson (1986) in Faxaflói Bay, studies were limited to tagging (Sigurðsson 1989) and limited biological studies in eastern Iceland (Einarsson 1956). The latest period is since 1995, when annual surveys have been conducted in Faxaflói Bay to monitor the growth, age distribution, and relative abundance of plaice and dab (Steinarsson et al. 1996, Pálsson et al. 1998). This has been supplemented by increased sampling effort from ports of landing all around the country. Annual trawl surveys since 1985 (Pálsson et al. 1989, Pálsson et al. 1997), covering most of the fishing grounds in Iceland, give valuable information on the trend in stock size of all the flatfish species.

3.7.2 Results

Fishmap: Plaice is caught all around Iceland, usually close to shore or in bays and fjords (fig. 62). The southwestern and western areas have the highest catches. Except for Faxaflói Bay, there is no discernible decline in any area. This is however masked by improvements in catch reports for the period. In Faxaflói Bay, the main plaice fishing areas are moving north. Until 1992, most of the catches are in the southern part, but move after that to northern areas, a possible indication of local depletion. The minimum biomass estimates are continuously increasing over the entire period for all of the grounds (fig. 63). This partly reflects better catch reports with time.

Effmod: The present biomass is estimated at between 35 000 and 85 000 t depending on models used (table 7). The high biomass estimate for model 1 is because of high estimates for areas 9 and 13, where there is no obvious trend in survey or CPUE. According to these models the highest biomass is in grounds 2, 6, 9 and 13, but these areas are widely dispersed. Compared to other flatfish the biomass of plaice is also even over grounds. This is consistent with the catch distribution since plaice is the only flatfish caught in quantities all around Iceland. Compared to unfished biomass the plaice stock is currently at a very low level. The stock is between 10 and 20 % of unfished biomass in most of the grounds. According to model 1, the only areas where the stock is not estimated to be severely overfished (less than 30% of unfished biomass) are grounds 4, 9, and 13. These grounds do however not have a good likelihood distribution and the stock status has thus to be taken with precaution (fig. 9). The likelihood profiles for the other grounds are however quite narrow. The MSY is estimated to be between 4 000 and 5 500 t/y. This is much lower than current catches, and lower than the 10 000 to 11 000 t/y recommended by the MRI.

Other models: According to the SSDD model the stock has been declining throughout this century and has only showed limited recovery when catches were low (fig. 64), mainly during the wars, but also after foreign fleets were expelled from Icelandic waters. The stock has been declining rapidly lately to about 8 000 t, or 6 % of unfished biomass. The biomass estimates by single stock assessment are lower than Effmod estimates, and the current stock status compared to unfished biomass is lower than on most of the grounds in Effmod. The current exploitation rate is close to 100%, which is very high. According to the equilibrium model (fig.65) catches of up to 4 000 t/y can be sustained at that level. The spawning biomass is very low and the fishery is primarily recruitment driven. The likelihood profile is narrow for each K value (fig. 66), but a wide range of K values are likely, considerably more so than for other species. Because of this, a relatively high value of 18 was used in subsequent analysis. The survey biomass index and biomass estimated from model are similar (survey index = 0.7 * biomass).

The cohort analysis suggests that the exploitable stock has declined from 40 000 t in 1988 to the current level of 17 000 t (fig. 67), slightly higher than estimated by the SSDD model but lower than Effmod. The most likely terminal exploitation rate is 69% (fig. 68) and the age of 50% vulnerability is 5 (fig. 69). MSY at equilibrium is 10 000 t/y at an exploitation rate of 30% and spawning stock size of 20% unfished biomass (fig. 70). This is almost the same MSY estimate as in the SSDD model. The equilibrium model however assumes recruitment to be the same as the average for 1993 to 1995, years with generally lower recruitment than previous years. Higher MSY is therefore not unlikely. The variation is high for the exploitation rate estimated by the catch curve model (fig. 71). The average is however very similar to the cohort analysis.

3.7.3 Discussion

All models, as well as the survey index and CPUE from fishing fleets, indicate that the plaice stock is declining rapidly, and on virtually all the grounds according to Effmod. Equilibrium models indicate a similar MSY of 5 000 to 10 000 t/y; the same range as previously assumed (Graham 1948, anon. 1998). Taking these estimates into account, the previous fishery, the current large mesh size (which is larger than used by the foreign fleets in previous decades), and assuming low variation in recruitment, long-term yield is probably at a level of around 10 000 t/y. The problem is however that the current situation seems rather dire and the stock would be put at risk with such catches.

The SSDD model predicts that the current very low biomass will increase twofold in 5 years if catches are kept at constant level of 3 500 t/y, or the exploitation rate constant at around 22%. The fixed exploitation rate will give more total catch for the period but catches would have to be reduced to less than 2 000 t the first year. Catches of 6 000 t/y or more for the next 5 years will reduce or maintain the current low stock level. The forwarded cohort analysis predict that the current low fishable stock will increase twofold in five years if catches are kept at around 5 000 t/y, or the exploitation rate at 30% during the period. The fixed exploitation rate will give slightly higher total catches for the period, but catches will have to be reduced to 3 000 t in the first year. Catches of 8 000 t/y will maintain the stock at current low level. It is difficult to give exact advice on the TAC based on this. It is however obvious that the catch has to be reduced from the current level, preferably to below 5 000 t. All the grounds are equally bad off so no special measures need to be taken to try to redirect effort.

According to changes in CPUE from the English trawler fleet, the stock seems to be able to recover quickly if catches are low. The use of CPUE can however be misleading. It can show direct relationship with stock size (as assumed here with the survey index). It can show hyperstability as was the case with the Newfoundland cod (Hutchings and Myers 1994, Walters and Maguire 1996), and it can show hyperdepletion as probably happened in the Australian Rock lobster (*Jasus novahollandiae*) fishery (Hilborn and Walters 1992). There are several factors that can influence the relationship between CPUE and stock size, mainly linked to the behaviour of fishermen and the fish. The plaice was not a direct target species for the English trawlers for most of their time in Icelandic waters, although it was a welcome bycatch. Plaice has been shown to do some migration (Sigurðsson 1982), it is however much more sedentary than cod, which was the main target species by English trawlers, and certainly the plaice is not a schooling species like cod is sometimes. All this would imply hyperdepletion, since there were probably large areas where plaice was abundant but fishing was limited due to lack of cod. In the areas most intensely fished, plaice would quickly be fished up, while the catch for the cod would not decline as rapidly because of more rapid dispersion from other areas. In light of this the much more rapid decline observed in the CPUE from the English fleet than the estimated biomass becomes understandable (fig. 72). It is obvious that the current Danish seine fishery is very different, since it is targeting plaice and the gear used is more cost effective than trawls, so that the fishery can be profitable where the abundance of plaice is relatively low. This explains the hyperstability observed in figure 72.

Previously it has been pointed out that the plaice stock would give more yield if the fishes were allowed to reach a certain age before fishery started (Sigurðsson 1962). It was also pointed out that this might have explained the increase in CPUE by the English fleet after 1953 despite no observable increase in recruitment. At that time, some of the main plaice grounds were actually closed to fishing because of the extension of the Icelandic EEZ. Presumably, the plaice just got a chance to reach greater sizes before it was a subject of exploitation. This is also consistent with the equilibrium analysis (fig. 70), where the yield gets higher as age of 50% vulnerability is higher. Direct comparison to the current situation is however difficult. Most of the areas that were closed at that time are open now for Danish seines. On the other hand, mesh size is much larger now and the fishing gear is different. This however weakens the credibility of the SSDD model used here. It assumes the age of vulnerability is constant with time. A large part of the apparent recoveries after the wars and when the EEZ was extended might thus be simply because the fish were allowed to grow larger and subsequent dispersion from non-fishable grounds.

Comparing the situation in Icelandic waters to the situation in the North Sea seems at first glance to be somewhat reassuring. The North Sea stock, which has sustained exploitation for much longer time than the Icelandic stock, seems to be able to sustain high and constantly increasing exploitation rates for a long time without an obvious decline in stock size (Serchuk et al. 1996). This was however only because of subsequent increases in recruitment, earlier maturation, and faster individual growth rates (Bannister 1978), quite possibly density dependent responses (Rijnsdorp 1994, Rijnsdorp and van Leeuwen 1996). The limit of the plaice in the North Sea to compensate for the increase in exploitation rate might already have been reached since the stock has declined for the last 10 years. Currently there are few indicators that the Icelandic stock is responding in the same manner (time series are however short) and we therefore cannot count on these effects to save the fishery. In fact, the recruitment estimates from the cohort analysis seem to be declining faster than the spawning stock.

Evaluation of stock size is, in most cases, hampered by lack of information on catches in early periods. Studies on the North Sea plaice have mostly been conducted during this century, and the biomass then usually compared to estimated biomass during other periods this century. There are however indicators that the biomass during this century has never even reached half of the biomass during the mid 19^{th} century (Rijnsdorp and Millner 1996) (this is based on CPUE, see above for error that can arise if it is used as a biomass index). After 1890, the biomass index in the North Sea had declined to levels similar to later during the 20th century. It might, therefore, not be a coincidence that this is exactly the period the English trawlers started fishing in Icelandic waters. In a short period, that we do not have much information on, they might have overfished the North Sea plaice and then moved to Icelandic waters. They might then again have overfished another plaice stock there before information on the catches or catch composition were made available. According to this, the plaice stock in Icelandic waters might be at a lower level compared to unfished biomass, than the most pessimistic estimates from models used here.

Another factor that might influence the stock status of the plaice and thus require further study, is the apparent increase in the dab stock. These two species might be directly linked by competition since they share similar body plans and distributions. The dab might be taking over areas where plaice has been depleted, and then suppressing its comeback. To establish if dab is taking over the grounds of plaice is rather easy with further analysis of available data (using Fishmap or survey data). However to find out if the dab stock is suppressing the plaice stock is much more difficult to establish. Further species interaction models will have to be made to evaluate this theory. Based on this study the catches of the Icelandic plaice should be severely restricted.

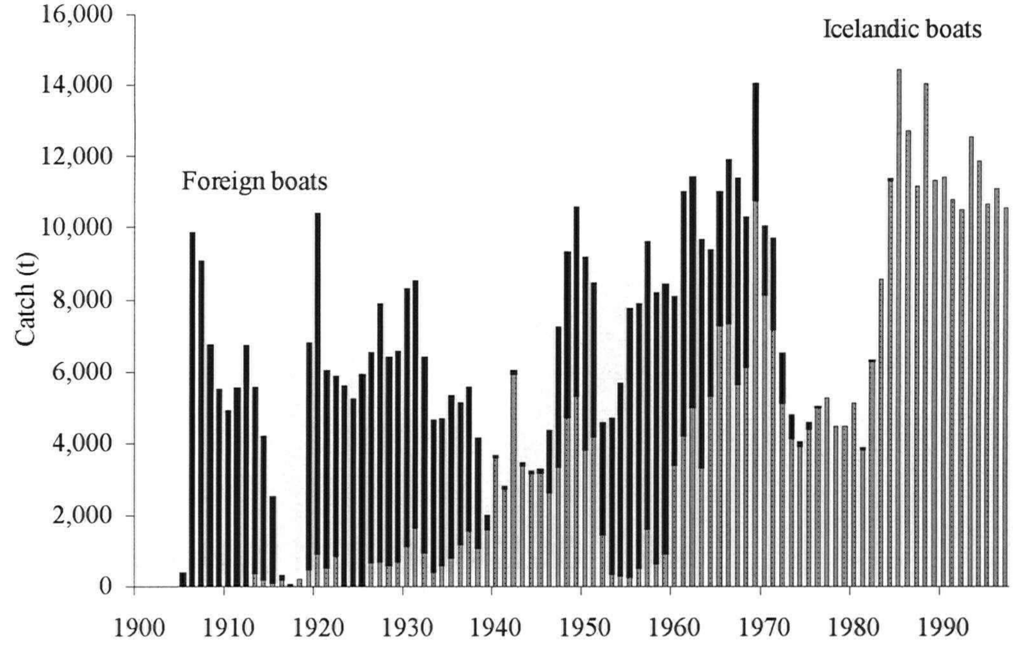

Figure 59: Plaice, historical catches since 1906, dark columns are foreign catches and light columns Icelandic catches

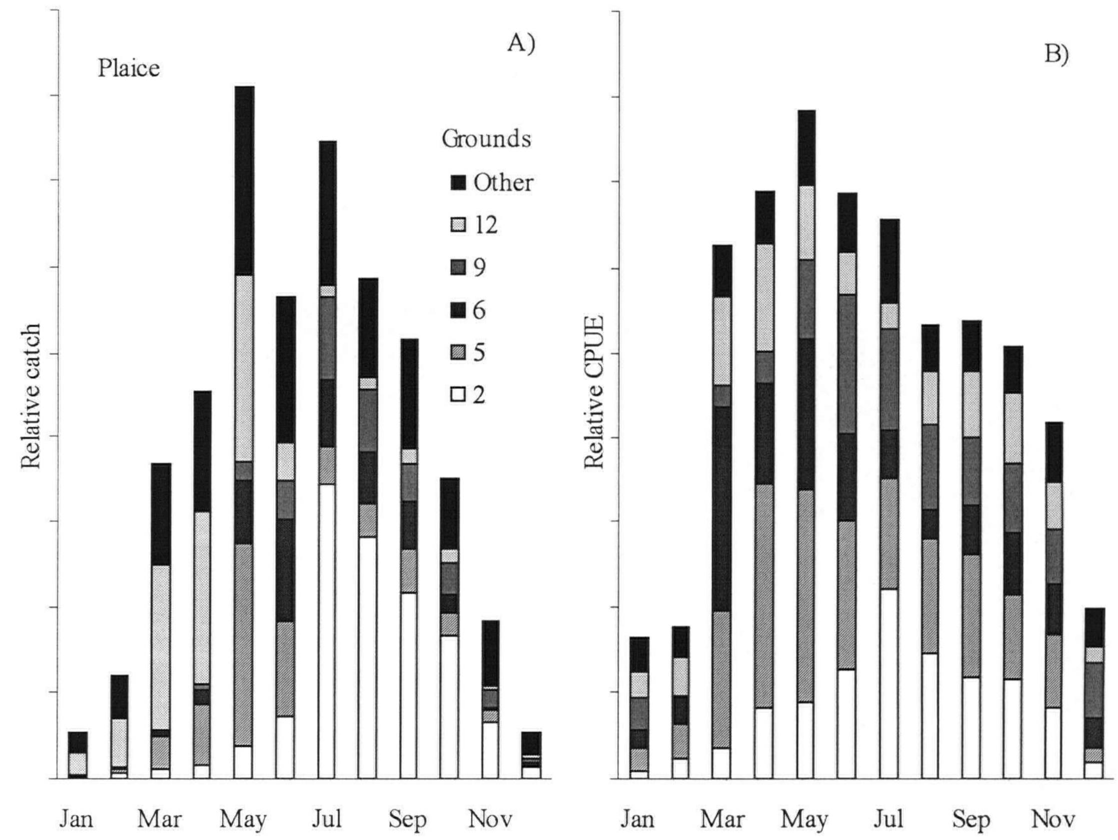

Figure 60: Plaice, average catch (a) and CPUE (b) per month on 5 of the major grounds, values are average since 1979. Catches in other grounds are sum of the average per ground and CPUE is average from all the grounds

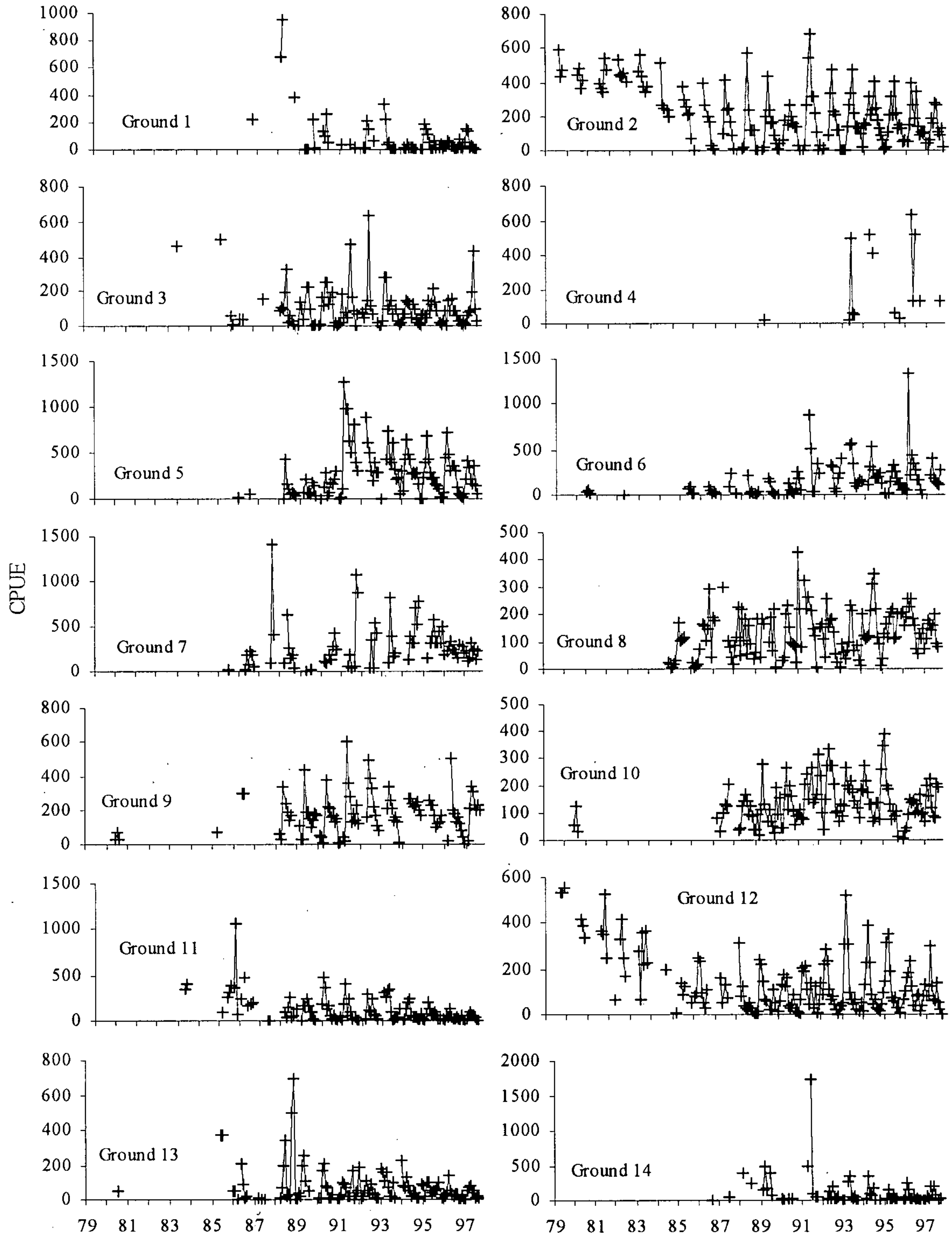

Figure 61: Plaice, CPUE per month by grounds since 1979

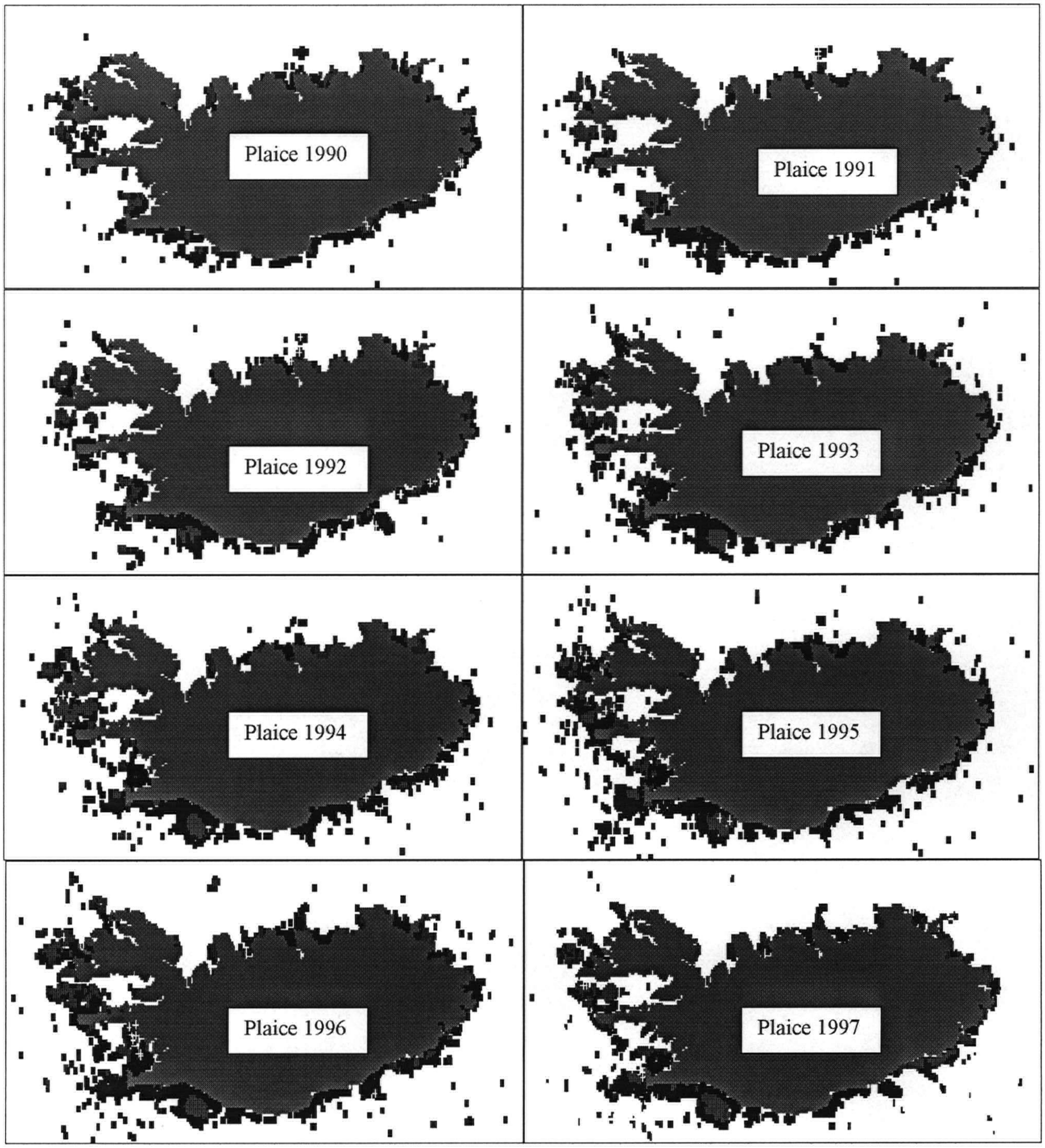

Figure 62: Plaice, distribution of catches from Danish seine fleet since 1990. Dark areas indicate low CPUE and light areas high; crosses are the cleanest sets, i.e. where the percentage of the species under consideration of the total catch is the highest

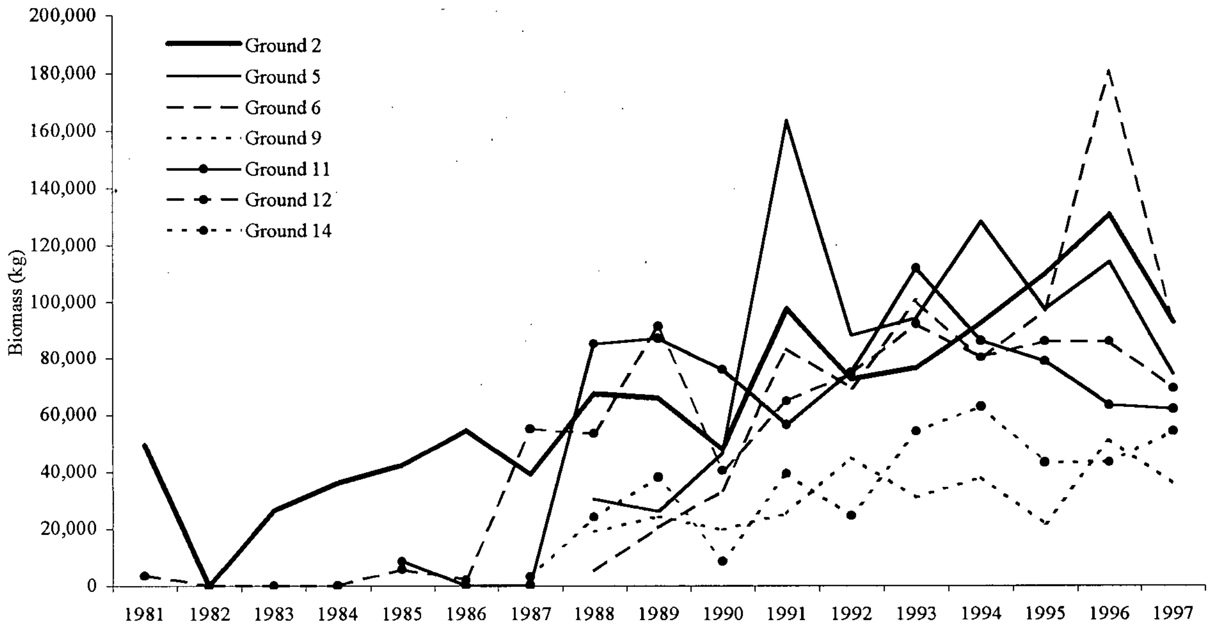

Figure 63: Plaice, estimated minimum biomass by 7 of the grounds with the highest biomass, Fishmap analysis.

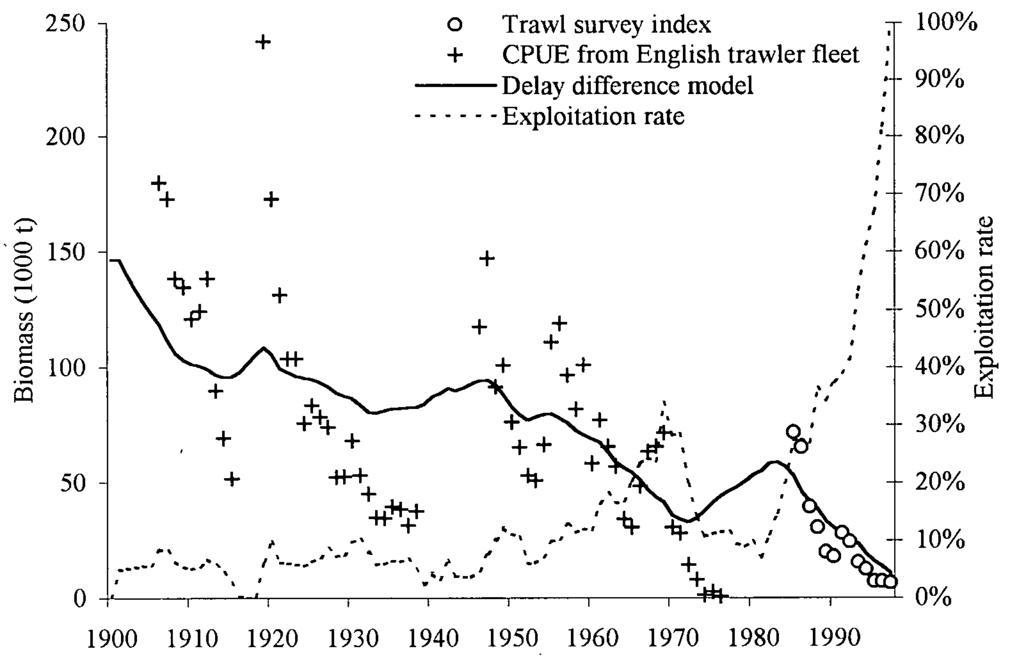

Figure 64: Plaice, estimated biomass of exploitable stock biomass (solid line), survey index (circles), CPUE from the English fleet (X's) and exploitation rate (broken line), single stock delay difference model.

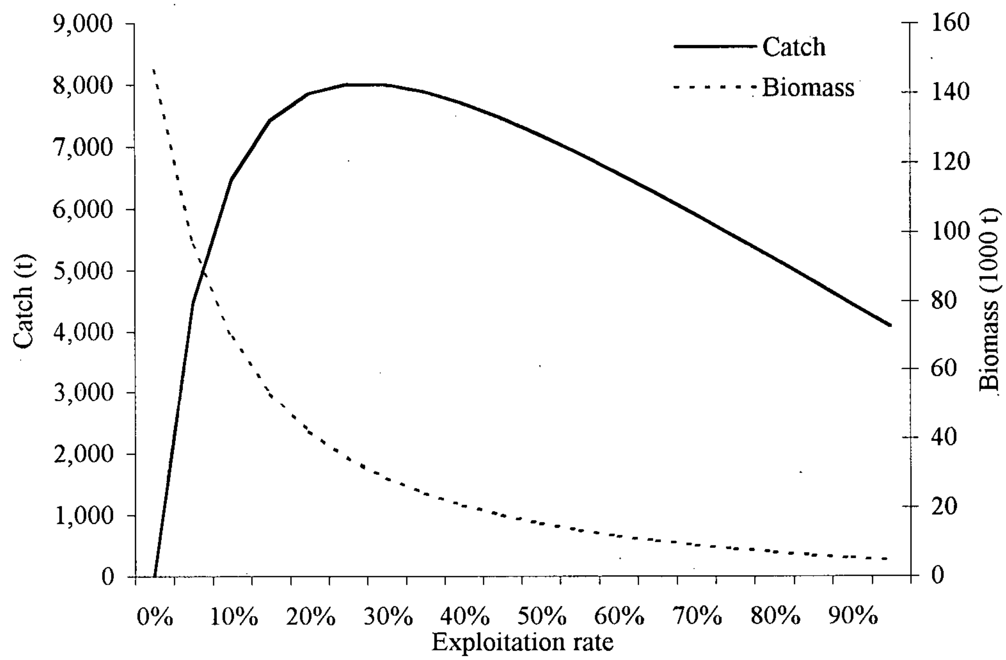

Figure 65: Plaice, biomass (broken line) and catches (solid line) at equilibrium, single stock delay difference model.

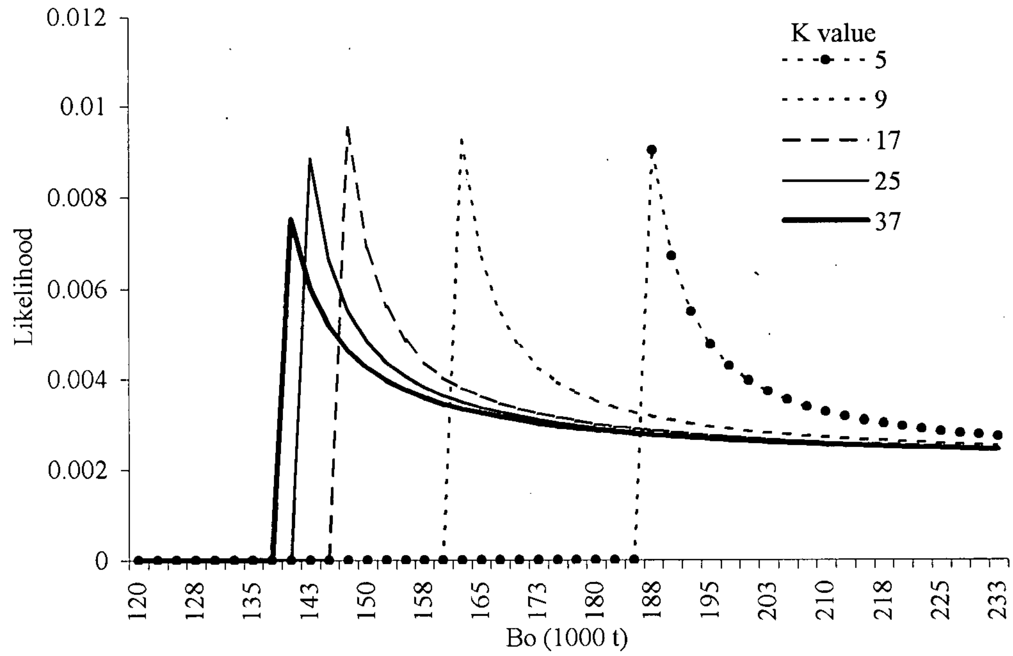

Figure 66: Plaice, likelihood profile with different stock recruitment "K" values and unfished biomass (B_0), single stock delay difference model.

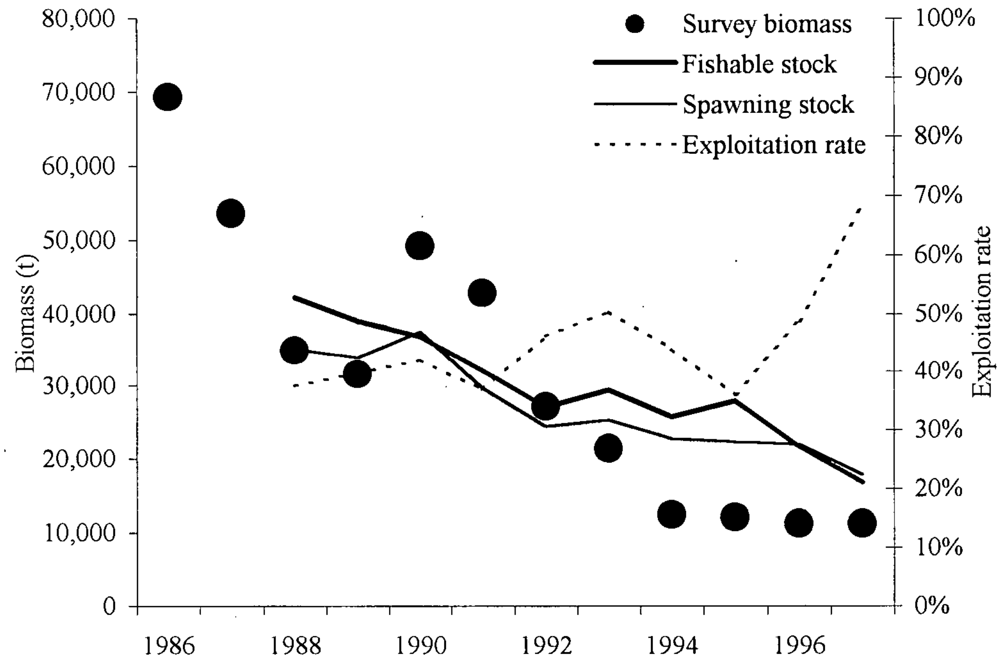

Figure 67: Plaice, estimated biomass of exploitable (thick line) and spawning stock (thin line), survey index (circles) and exploitation rate (broken line), cohort analysis.

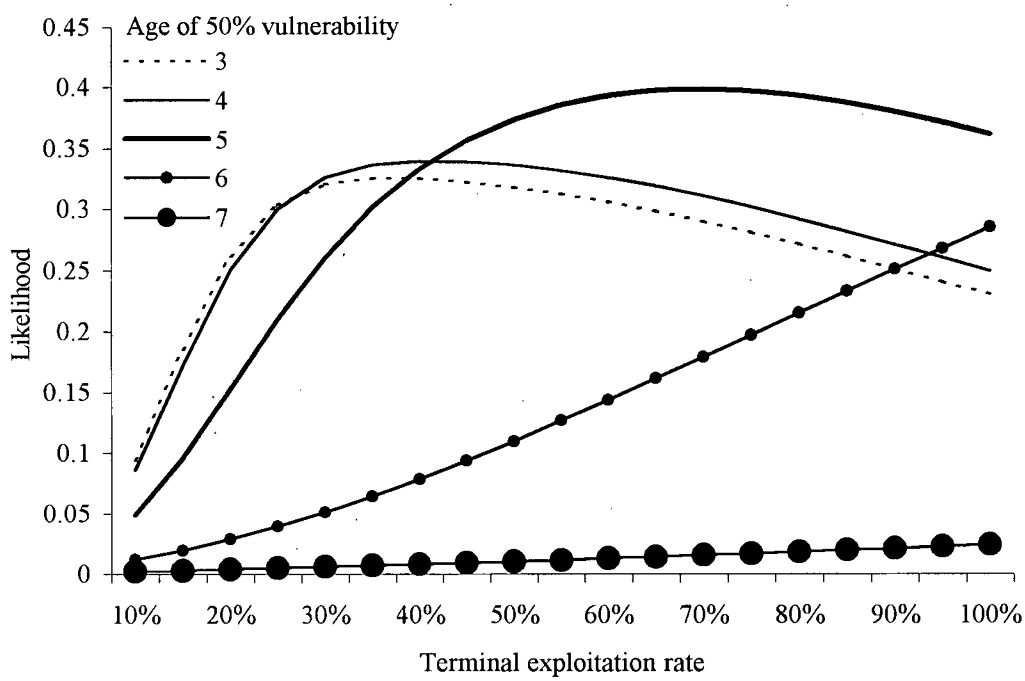

Figure 68: Plaice, likelihood profile for the terminal exploitation rate and different age of 50% vulnerability, cohort analysis

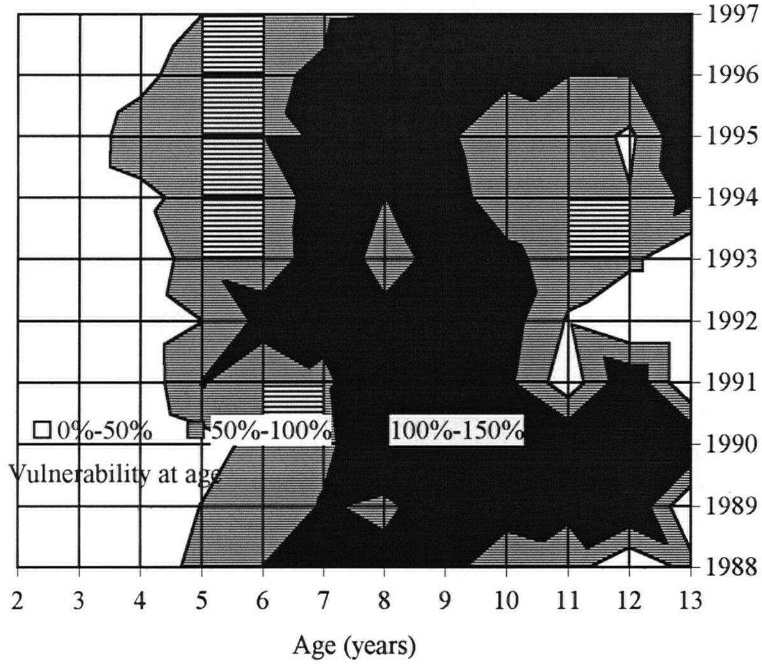

Figure 69: Plaice, vulnerability at age, cohort analysis

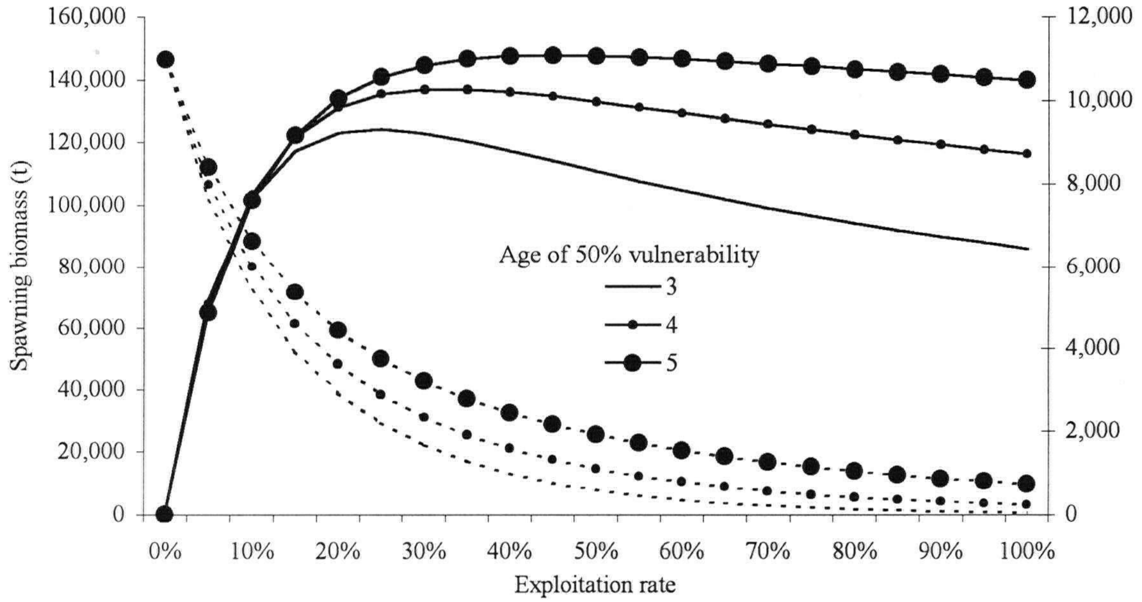

Figure 70: Plaice, biomass (broken line) and catches (solid line) at equilibrium, cohort analysis

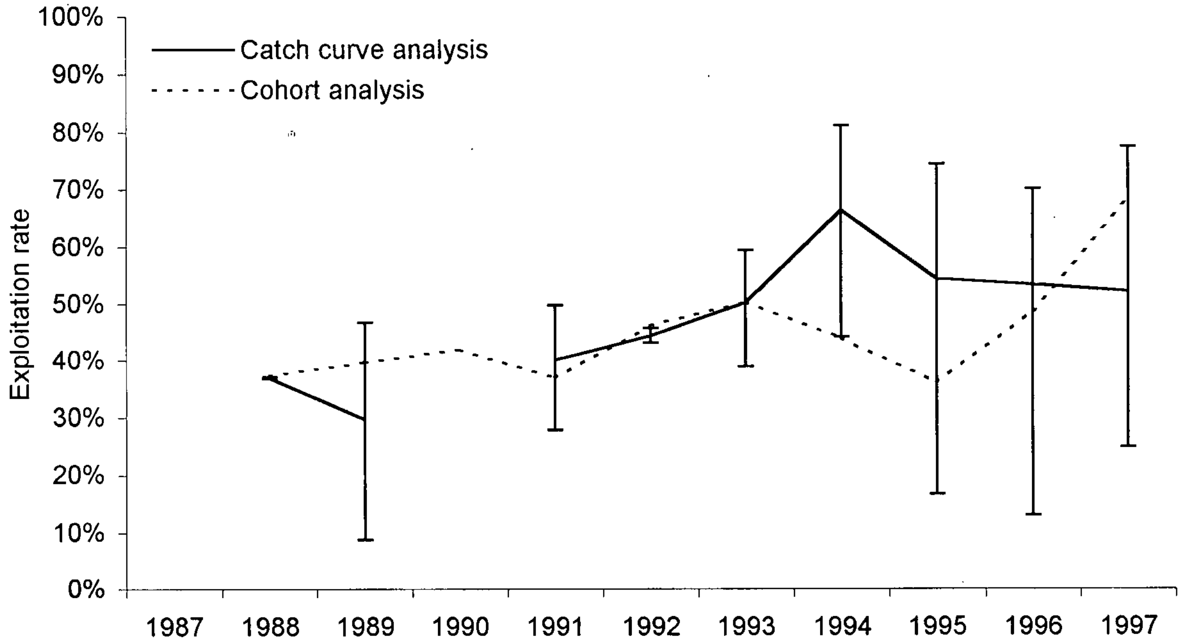

Figure 71: Plaice, estimated exploitation rate and standard deviation for catch curve analysis (solid line) and for cohort analysis (broken line).

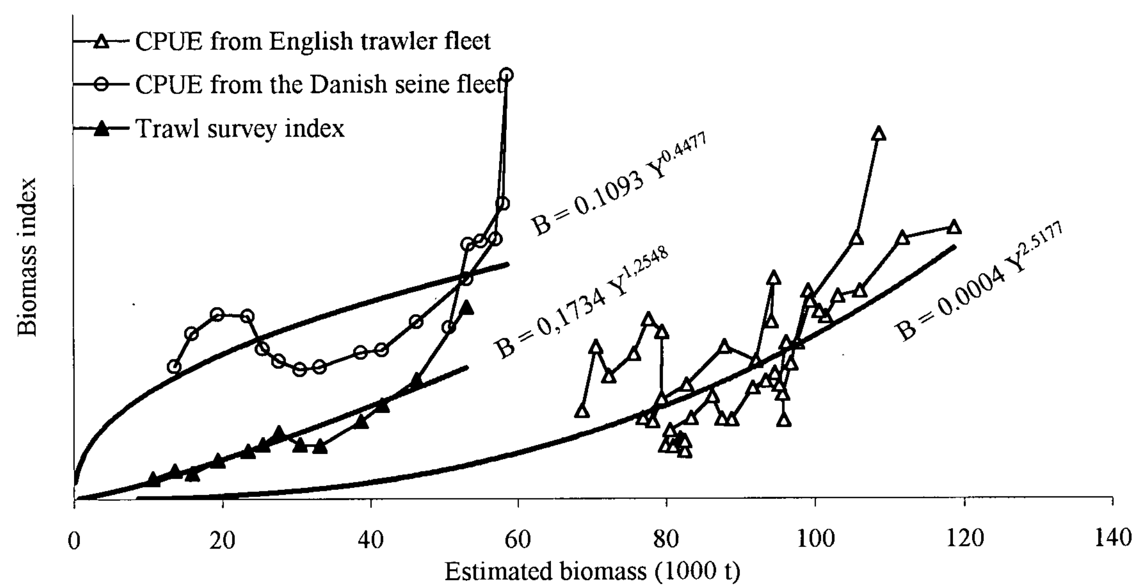

Figure 72: Plaice, the relationship between CPUE of the Icelandic Danish seine fleet, CPUE of the English trawler fleet, trawl survey index, and estimated biomass by the single stock delay difference model

3.8 Comparison of models

This study does not give any objective methods to compare the models used, and the results are in some respects different. There is however not much consistence in the differences between the models. The Fishmap minimum biomass estimates are always lower than other models, even lower than catches in some areas. The Fishmap minimum biomass is thus only looked at as an index of abundance in this analysis. For megrim and witch flounder the Fishmap index is declining as is biomass estimates from other models, survey index and CPUE from the commercial fleet. The Fishmap index is increasing for American plaice, dab, and plaice. This cannot be proved as wrong for the two first species, but is in stark contrast to estimated biomass trend by other models and indices for plaice. The Fishmap index for lemon sole is stable, but is declining in other models.

It is difficult to compare B_0 from Effmod to B_0 from SSDD model, because in Effmod the stocks were presumed unfished in 1981, as opposed 1900 for the SSDD. The foreign fishing will thus effect the B_0 estimate by SSDD model but not Effmod. The second factor is the different likelihood distribution between grounds. In Effmod, the level of uncertainty is large in some grounds, and probably results in an overestimate of the stock size. When all the grounds are summed up to get total biomass, these grounds will severely skew the picture. It is however notable that Effmod and the SSDD models are very similar regarding witch flounder, but catches of witch flounder were low by the foreign fleets.

It is interesting to compare the differences between the SSDD model and cohort analysis. The cohort analysis has often been found to underestimate the most recent exploitation rate (Hilborn and Walters 1992, Brodie and Bowering 1991). In this study only witch and plaice can be compared regarding this. The results from these species cannot support that the cohort analysis underestimates the exploitation rate. For witch the biomass estimates are twice as high for the SSDD model than for the cohort analysis. Consequently the current exploitation rate in the SSDD is only half that in the cohort analysis. This is reversed for plaice in which the cohort analysis biomass estimates are twice as high as in the SSDD model.

The catch curve analysis generally gives average results similar to as the cohort analysis. This is hardly surprising since they are using the same data, although the catch curve analysis used pseudo-cohorts, while the cohort analysis real cohorts. The general trend in exploitation rate with time is however different. Since the cohort analysis is a more detailed model, we would expect its exploitation rate pattern to be more trustworthy. We cannot prove however which one is more valid.

The equilibrium yield models from the SSDD model and forwarded cohort analysis do show generally similar MSYs. The MSY of the witch flounder is close to 1 300 t/y in both cases and the MSY of plaice is 8 000 to 10 000 t/y. They however differ considerably at high exploitation rates, because the cohort analysis assumes constant recruitment, but the SSDD model assumes reduced recruitment at low stock sizes. According to the SSDD, a long-term exploitation rate higher than approximately 40% will severely reduce catches. The plaice sock is however more resilient and should be able to withstand very high exploitation rates. This is because the plaice is assumed to have higher recruitment response at low stock sizes (high K value).

All models have assumptions (table 6) and therefore weaknesses. The models used here usually have different parameter or data assumptions. When these models agree on the situation they strengthen each other, when they diverge, they stress uncertainty.

4 GENERAL DISCUSSION

4.1 Sources of uncertainty and errors

Recruitment: Studies on stock/recruitment relationships indicate that the connection between the two is weaker for flatfishes than for other fish groups (Myers and Borrowman 1996). That is, a small spawning stock of flatfishes is likely to give similar average recruitment to a large spawning stock, implying a high K value (eq. 13), while for most other fish groups small spawning stock is likely to give lower recruitment. There are however differences between flatfish stocks, even between the same species in different areas. Preliminary analysis on plaice (Myers et al. 1995), indicates that two stocks show a visible decline at lower spawning stock sizes (the value of K or equivalent to alpha is less than 6), one shows an increase (coefficient of variation between stock and recruitment is much lower for a Ricker fit than a Beverton and Holt fit) and five show no visible relationship. Iles (1994) using different data and methods found that only two flatfish stocks out of 20 showed significant declining recruitment with declining spawning stock, but none of them were plaice stocks. For three stocks, including two plaice stocks, recruitment increased at declining spawning stock (the right hand side of the Ricker stock-recruitment curve). One plaice stock showed a Ricker type of spawning stock relationship where recruitment was highest at intermediate spawning stock sizes. Fourteen stocks did not show any trend, including 3 plaice stocks.

On these grounds it is not possible to generalise about how recruitment of flatfish stocks in Icelandic waters could be related to spawning stock. Since it has been shown that recruitment responses in some fish stocks is slower in colder waters (Myers and Mertz 1997, Walsh 1994a) and the flatfish stocks in Icelandic waters are in the northern part of their distribution a conservative approach to assume K (eq. 13) as 5 in Effmod is justifiable. The SSDD model even gives a lower best estimate of K for megrim, witch and lemon, the best estimate for plaice is however higher. This actually fits well with previous studies (Myers and Mertz 1997, Walsh 1994a) since the former three species are not as cold adapted as plaice (since their distribution in Icelandic waters is mostly limited to warmer waters). They are living closer to the northern edge of their distribution and the K is therefore lower. Plaice might however be living closer to its optimum temperature regime and the K is thus higher. It is obvious that even using a high K value as for the plaice, catches will be reduced considerably at high long-term exploitation rates (fig 64). This undermines the credibility of the equilibrium models which assume constant recruitment, since they indicate that high catches can be maintained at high exploitation rates (Walters 1969 as in Pitcher and Hart 1982).

There are great uncertainties regarding the controls on recruitment in flatfish stocks if it is not the spawning stock. Suggestions have been made that factors controling recruitment variability are food, predators, and temperature extremes (Gibson 1994, Lockwood 1980). The quality and quantity of the nursery areas however seem to influence the overall population size and dampen rather than generate recruitment variability (Gibson 1994). No studies have been conducted in Icelandic waters on these factors. A recruitment index based on length data is only available from trawl surveys. This is probably not a very reliable index since length at age can change, sex ratio is badly skewed since males are usually smaller than female flatfishes and catchability of juveniles is low since they often live in shallow areas that the survey does not cover. Further studies on what controls recruitment of flatfishes in Icelandic waters is thus essential for better evaluation of the stocks in the future. In 1997 and 1998, a preliminary survey was conducted with a small beam trawl on 0-group plaice in shallow waters in Breiðafjörður and Faxaflói Bays (Hjörleifsson et al. 1998). In light of the current uncertainties about the recruitment of the plaice and the decline of the stock, it is essential that these studies be continued.

Natural mortality: The M value estimated for plaice here is higher than for plaice in the North Sea (Cushing 1975). Values from other species of the same genus however range from 0.12 for yellowfin sole (*Pleuronectes asper*) (Wilderbuer et al. 1992), 0.15 for yellowtail flounder (*Pleuronectes ferruginea*) (Lux and Nichy 1969) to around 0.25 for Hecate strait rock sole (*Pleuronectes bilineatus*) (Fargo 1995). The M estimated here for the American plaice is lower than in the northeastern Atlantic (Pitt 1975). The American plaice however shows a wide range of life history patterns over its range (Walsh 1994, Walsh 1994a), so that natural mortality rate may likely vary. Our estimate of natural mortality of megrim is lower than the 0.38 estimated for the four-spot megrim (*Lepidorhombus boscii risso*) (Santos 1993). Our estimates for the natural mortality of dab are very similar as to the marbled sole (*Limanda yokohamae*), a related species (Park and Simizu 1991). No M estimates were found in the literature for the other flatfish species. Based on this our M estimates seem justifiable.

The natural mortality is an assumed value in all models except the ones based on area swept (Fishmap minimum biomass estimates and survey index). Changing the value does not affect the estimated biomass trends in cohort analysis greatly, except if M is seriously underestimated. It will however affect the absolute biomass estimates, and will give different MSY results. If the age of recruitment is assumed as 5, setting M as 0.07 instead of 0.14, the present biomass estimate is 14 500 t instead of 16 500 t and the current exploitation rate is 0.8 instead of 0.69. This will therefore mean that the stock is in more serious trouble than if M is assumed as 0.14. Setting M as 0.28 however gave a current biomass estimate of 21 000 t and an exploitation rate of 0.55. High natural mortality will cause the stock to be less vulnerable to high exploitation rate, i.e. high catches can be sustained at high exploitation rates if recruitment is not affected. If M is however low, high catches cannot be maintained at high exploitation rates (fig. 73). The difference between the catch values at optimum exploitation rates is rather small though. The highest catch is around 13 000 t/y at a low M, but at around 10 000 t/y at a high M. Regarding possibly wrong M-values the recommended long term catch of 10 000 t/y thus seems conservative. Changing the M in the delay difference model has more complicated effects, since this model requires more parameters and the natural mortality is used as a factor in some of them. If assuming that K is the same for all M's used, lowering the M will increase the probability that B_0 is higher and vice versa. This will mean, to explain the current downward trend in survey index, that if the M is lower than estimated here the stock decline is more serious. This is reversed if the M is higher. Then the unfished biomass is lower, but the stock is more robust to the fishing effort since the recovery phase is faster if the fishing effort is reduced. A high M means that the stock can sustain a much higher fishing effort since recruitment per spawner is higher, more fish come into the fishery at a early age but they die sooner.

It is difficult to get good estimates on the components of the natural mortality of the Icelandic flatfishes. Flatfish species, mainly American plaice and dab, have been found in the diet of haddock (Einarsson 1997), Greenland halibut (Sólmundsson 1997), starry ray (*Raja radiata*) (Galan 1997), catfish (*Anarhichas lupus*), cod (Pálsson 1983), and auks (*Alca torda*) (Lillendahl and Sólmundsson 1997). Cannibalism has also been reported for American plaice (Pálsson 1997). The diet composition is usually around 1% of total weight, and is thus very low and probably a subject of large fluctuations and uncertainties. Rough analysis indicates that the cod stock might eat around 2 000 000 t/y (Björnsson 1997), if flatfish is 1% of the diet the consumption is therefore around 20 000 t/y. Other species that eat flatfish are not as abundant as cod. Their combined biomass is probably only about half the cod (based in information in anon 1998). Their consumption can therefore be estimated at about 10 000 t/y. The highest mortalities caused by one group besides cod on flatfishes seems to be by seals (Bogason 1997, Hauksson 1997). Their annual consumption was estimated at 1 100 t/y of plaice, 1 100 t/y of dab, 700 t/y of lemon sole and 1 300 t/y of American plaice. Combined this gives around 35 000 t of flatfish eaten each year. This is 10 000 to 15 000 t higher than annual catches for the last decade, but is however only a small fraction of total flatfish biomass estimated in Effmod (table 7). The problem here lies in the species composition. All flatfish eaten by other fish species were identified as American plaice or dab, these are roughly half of the samples. What the other half consists of is impossible to say. If this part is only American plaice and dab, and the stocks of these two species seem to be able to withstand this predation very well, the only mortalities on the other species are due to predation by the seals. If we are to assume that seals do not choose among flatfishes, their consumption on plaice and lemon sole, both of which seem to be declining, is low. These samples were taken in 1993 when estimated biomass for these species was higher. If seals are choosing species, and they have the same taste as humans (lemon sole and plaice much more valuable than American plaice and dab) the situation could be different. Their predation could be able to maintain the current low levels, especially on lemon sole. As can be seen there are great uncertainties about the mortalities on flatfishes due to predation, we can get the results we want by changing these assumptions. Further biological studies and better analysis on available data are necessary to reduce the uncertainties regarding this.

Other factors also contributing to mortality. Parasitic infection on plaice by *Ichthyophonus hoferi* is studied in the newly established flatfish survey in Faxaflói Bay (Pálsson et al. 1998). Other studies indicate that this infection is deadly for the fish within 2 months (McVicar 1981). From these preliminary studies, the rate of infection in plaice in Faxaflói Bay is very high, or around 30% in the survey 1997, much higher than assumed annual natural mortality. Currently this infection seems to be increasing rapidly from a level around 5% in 1995 and 10% in 1996. This is at the same time that the stock is declining; density dependent effects therefore cannot explain this. This could be a factor in the current decline. This preliminary study on the infection does however undermine the credibility of the models used here since they assume that natural mortality is constant with time. If the natural mortality is changing with time, due to predation or parasites, the biomass estimates can be severely skewed. It would be a very valuable tool for future stock evaluations to be able to explain the rate of infection and mortality component due to predation by other species.

Discards: This is currently not permitted in Icelandic waters but difficult to enforce. The reported mortality rate of discarded flatfish is contradictory (probably depending on fishing gear, temperature, and depth). Some studies report high mortality estimates either because the fish do not survive the handling or they are eaten by seabirds after being discarded (Evans et al. 1994, Van Beek et al. 1989), while others claim lower estimates (Millner et al. 1993). From the Effmod analysis we can get rough estimates on discards, i.e. where there is a large difference between observed and predicted catches (fig. 10) discards are likely to have occurred. The American plaice and dab are the species that seem to have been discarded the most in the past, as the predicted catches are much higher than observed catches during most of the period. This is according to expectations since they are of the lowest value. This does not however seem to have effects on these stocks, as they do not show any decline with time. The species that are declining are the ones that are most valuable, and have therefore probably not been discarded. It is therefore unlikely that discards will have a major impact. They can however be a problem in the future if catches of the valuable species will have to be lowered, but not the catches of the low value species.

Grounds used: It is possible to define grounds in Fishmap in many ways and on various spatial scales. The choice here was to split the waters into 16 grounds mostly based on distribution patterns. To be able to use the survey data to fit to the biomass trends it was chosen to base the grounds on statistical areas as used by the MRI. This however meant that the spatial scale was not fine enough in some cases to be able to split the grounds according to the species distribution. This is especially the case for the grounds south of Iceland, where the continental shelf is narrow (fig. 1) and the species composition can change rapidly over a few miles. It also proved to be problematic since the

Snæfellsnes peninsula (between Faxaflói and Breiðafjörður) went right through the middle of one statistical area. Area 2 does thus not only cover the Faxaflói Bay, but also part of the Breiðafjörður Bay. Originally it was also chosen to make special grounds for the stations far away from land, this was primarily because of the suspicion that these were misreportings or errors when the data was put into the computer. Some logbook entries were definitely errors since they reported catches in the interior of Iceland. Grounds 15 and 16 are therefore not included in this analysis. The total number of sets in these grounds for all the years is 2 109 or 0.6% of total. Catches and biomass estimates for these grounds are also low and should therefore not have a major impact on this analysis. The only minor exception is plaice on ground 16, these are probably not misreportings but come from the grounds slightly east of ground 9. These reporting could probably cause some errors, but it is interesting to see that the ratio of current to unfished biomass is similar for areas 9 and 16.

Fishmap assumes that the environment within each ground is homogenous. This is however not true for at least some of the grounds, where there are well-defined areas with lava or other rough ground. The Danish seine boats cannot fish these grounds. The error due to them should therefore not change with time. Another factor that might justify ignoring them is that most of the species, most notably witch flounder do not generally live in these areas, as they prefer smooth bottoms. The major exception to this is lemon sole, this species actually prefers rough bottoms. This can therefore cause errors in evaluating the size of the lemon sole stock and is perhaps the reason why the models show contradicting results regarding this species.

Migration to other waters: Immigration of adult fish from other areas can have a major effect on stock assessment, and this will cause recruitment to be overestimated and exploitation rate to be underestimated in cohort analysis. This has caused problems with assessing the cod stock in Icelandic waters. Every now and then larval drift occurs from Icelandic spawning grounds to Greenland. When these fish mature they migrate back to the spawning grounds in Icelandic waters and consequently catches of cod increase there, implying that the stock was actually larger than estimated. Emigration of fish from Icelandic waters can also cause the age groups to disappear sooner than anticipated. This is however a less serious problem in stock assessment since this could be considered to be a part of the natural mortality and would probably be density dependent. These factors are however not a major concern with the flatfishes. Tagging studies do not reveal any significant movement of plaice to and from Iceland, and although tagging studies have not been conducted on other species, they are probably not strong long distance swimmers.

Individual growth: In this analysis, the data was assumed to reflect the true state of nature, this is however almost certainly not true. All of the models considered the growth to be the same in all grounds and Effmod and the SSDD models assumed growth constant over time. Limited time series however limits our ability to include changing growth rate or difference between grounds in the models.

Some flatfish stocks show density dependent responses in growth (Rijnsdorp 1994). There however seems to be some threshold level, i.e. they only increase the growth rate to a certain stock level but change little if the stock size goes below that, probably since the food is no longer limiting. Decreasing a stock from a medium level to a low level does thus not guarantee an increase in individual growth. The data used here indicates that the growth of plaice and witch is increasing. Average weight of 6 and 7 year old plaice was 0.53 and 0.56 kg respectively in 1991, but 0.62 and 0.68 kg in 1997 (table 26), showing a steady increase in the period between. Witch flounder does not show any trend until 1995 when weight at age increases substantially in 1996 and again in 1997 (table 18). These weight increases are incorporated in the cohort analysis but not in Effmod and the SSDD model. The samples are however few, especially in the beginning of the period of sampling. This increases the likelihood of errors, due to difference in growth between areas. More samples one year from areas where growth is naturally faster will cause the average growth rate of the stock to increase. Currently the sampling effort is quite extensive and if sustained should make stock assessment more reliable in the future.

The delay difference model (Deriso 1980, Schnute 1985) uses growth rate according to the Ford-Brody equation (eq. 1). This use of biologically meaningful parameters is the strength of this surplus production model compared to older models (Scaefer 1954, Pella and Tomlinson 1969). Although it was not done here, changing growth rate with time can also be incorporated in the models simply by using different parameters each year. The model does have its limits. For example, it assumes knife-edge recruitment. This is valid for species that are still growing fast at the age of recruitment, but might not be the case with slow growing species. Plaice is an example of a fast growing species, the difference between age of 50 % and 100 % vulnerability to the fishing gear, is according to cohort analysis approximately 2 years (fig. 46). The plaice, therefore, meets the assumption of knife-edge recruitment. Witch flounder however has a wider selection curve (fig. 29) where the difference between age of 50% and 100% vulnerability can be over 3 or even 4 years. This can cause errors in estimating the size of the stock since the exploitation will effect cohorts that are not recruited to the fishery according to the model. This can cause the biomass to be overestimated at high exploitation rates, since high catches that cause relatively small changes in observed biomass index will imply large fishable biomass, when the actual catches of the fishable biomass could be lower than implied by the observed catch. The catches are thus not affecting the current biomass as much as predicted but reducing the recruitment to the fishable biomass (as defined by the knife edge assumption) in the future. The knife edge assumption might thus be the reason for the differences in predicted biomass for the witch between the delay difference model and cohort analysis. A more serious problem is however that for some species, the catchability decreases with age, due to gear selectivity or migrations from fishing areas, and often it is not possible to fit a Ford-Brody relationship because the age of recruitment is before the age of growth inflection. This does not apply to the species under consideration here, but does apply to the halibut that was originally supposed to be included in this analysis. A possible remedy for this is to use different production models that use the von Bertalanffy equation instead of the Ford-Brody equation (Horbowy 1992).

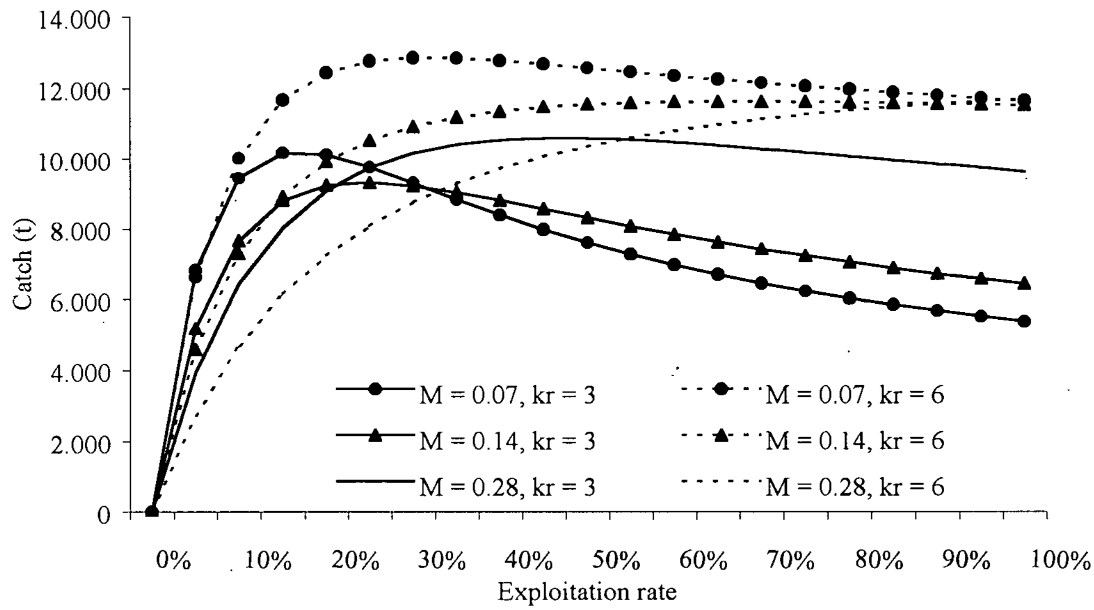

Figure 73: Equilibrium yield of plaice from forwarded cohort analysis assuming different natural mortality (M) and age of recruitment (k_r)

4.2 Further studies

In 1998, the quotas were set exactly as recommended by the MRI. This places a great responsability on fishery biologists. If this is continued the excuse that catches are too high and therefore the stock is declining cannot be used again. This coupled with the ITQ system means that fishery biologists have to be more accurate now and preferably be conservative in face of uncertainty (Walters and Pearse 1996). Only continuous and improved sampling can attain this and more importantly, greater time spent at looking at available samples, evaluate them, and incorporationg the results into different models. If this is not possible (because of few or bad samples) fishery biologists at least have to be able to express their uncertainty. Not just to cover their backs, but simply to be honest. The stocks that are arguably the best-managed in Icelandic waters are the cod and the herring. This currently successful management is not a coincidence. This is the fruit of a long history of catches that are very important for the society and consequently long time series of sampling and time-consuming analysis. The flatfish stock assessment might never reach the same level, but there is certainly room for improvements. The trawl survey, initiated because of the cod, is an invaluable contribution for many species in Icelandic waters. Currently the survey index is mainly used for tuning biomass models. There are however many otolith samples available but unread from the survey and also other data available that has not been analysed. If these would have been available for this study, the level of uncertainty could possibly have been reduced. Continuity in the surveys (i.e. flatfish survey in the Faxaflói Bay) is also necessary. The first year of survey will not give any information on the dynamics of the stock; it is only a snapshot of the system. The second year gives some information on the dynamics but the level of uncertainty is high. As the years pass and the survey continues the uncertainty will be reduced and we will start to learn new things about the stock. Gathering data in the future is not the only way to help assess the stocks. Gathering information and evaluating data from the past is also important. We can only see from the past how the stocks respond to a fishery. If some type of abundance indices (other than traditional CPUE from the commercial fleet) from the past were available, and they could be directly compared to the survey index the uncertainty in the SSDD would have been reduced substantially.

4.3 Conclusion

The status of flatfish stocks is quite variable. Dab and American plaice are abundant and do not show clear signs of decline. No specific TAC can be recommended for those species based on this analysis, but target fisheries for them should be limited to a few grounds where they are abundant, to limit catches of other species. The Witch flounder stock might be close to optimum and the catches should be kept at current level, they should however be restricted on the southwestern grounds. The other stocks are overfished but face different management problems. The plaice is historically the most important of all these flatfish species, and it is also the stock that is easiest to manage and reverse its downward trend by simply lowering the TAC. Lemon sole and megrim are more problematic. It is fairly certain that the megrim stock is declining to a very low level. Lemon sole also seems to be declining, but not as rapidly as megrim and the level of uncertainty is higher. The catches of these species cannot easily be controlled by a TAC since they are both mainly bycatch. Seasonal and area closures together with the banning of direct targeting seem to be the most promising option.

The boats will probably not switch to a large extent between grounds if one area is closed; i.e. closing one ground would not mean much more effort in others and then further decline in the stocks there. The boats are generally small and cannot be many days at sea, therefore movements between grounds are limited. More important is however that the boast are only allowed to fish in the area of the homeport (anon 1997c). For this the waters around Iceland are split into 4 major areas, the south and west areas correspond to grounds 1, 3, and 11 to 14, the Breiðafjörður and Vestfirðir area correspond to grounds 4 to 6, the north areas are grounds 7 and 8 and the north-east and east areas are grounds 9 and 10. There is however a slight overlap between the fishing areas so that for example boats from the eastern area are reported with some catches in ground 11 (table 8), although in our analysis it is not part of the eastern area. Faxaflói bay (gr. 2) can be defined as the 5th area, only a limited number of boats are allowed to fish there in summer and early winter.

The effort might, because of these regulations, move to some extent between adjacent grounds, but not between regions. In 1996 for example the Danish seine fleet did not generally move much between the grounds (table 8). Boats from Faxaflói Bay (gr. 2) spent 64% of their effort in Faxaflói Bay, 35% of the effort in adjacent areas (gr. 1, 3, 5, 12, and 14), but only 1% of the effort in ground 11, although they were not hindered by regulations from going there. Boats from grounds 5 and 6 spent the majority of their effort on their home grounds, although they are allowed to fish in each other's ground. Boats from northern Iceland (gr. 8) spent 100 % of their effort in northern Icelandic waters (gr. 7, 8, and 16) since they were not allowed to go elsewhere. Boats from north-eastern and eastern Iceland spent 99% of their effort in north-eastern and eastern Iceland and although boats from ground 10 were allowed to fish in ground 9 and vice versa, they seems to prefer not to do that. The same is true for boats from southern Iceland (gr. 11 and 12). Profitability probably decreases quickly if they have to move their effort some distance from the homeport, even to adjacent areas. Effmod can potentially evaluate this, but uncertainties in biomass estimates in some grounds make this unreliable. The model predicted that most of the effort moved to ground 9 in 1998 (assuming free movement between grounds), since Effmod estimated the ground with a very large, almost virgin, plaice stock. The uncertainty about the status of this stock is however large (fig. 9). The very high biomass of American plaice and dab in many areas did also make the results unreliable. Nevertheless, it is probably necessary to reduce the TAC to some extent if grounds are to be closed, since the status of the stocks are different between some of the adjacent grounds.

It would also be advisable to limit fishing on spawning and juvenile areas. The reason the juvenile areas should be protected is that we want the fish to reach a certain size before they are caught and to gives them a chance to spawn at least once in their lifetime. Protecting the spawning areas not only to give them chance to go through the spawning process but also since this is the only time flatfishes aggregate. Flatfishes are usually spread over large areas, so that the fishery should become unprofitable before they are fished out (except for species that are primarily bycatch). During spawning aggregations and migrations they however become vulnerable and the stock can be severely depleted. It is not certain if this is the main reason for the decline of some flatfish stocks; further analysis could verify that. There is however a clear example of this type of disaster in Icelandic fisheries. The blue ling stock (*Molve dyprerygia*) was fished to a very low level when aggregating grounds were found in deep waters (Gunnarsson et al. 1998). Using only a TAC to control these fisheries becomes dangerous if the stock-size is not well known. Currently it is not possible to detect these effects with the models used here, Fishmap can however be modified to show seasonal distribution of catches of individual species and thus pinpoint the time of year and area where they aggregate.

Although the current recommended TACs set on the flatfish stocks by scientists at the MRI are based on limited knowledge (because of short time series and problems with the data), they are in many ways quite similar to estimates here. The long term MSY for witch, dab, and plaice are, for example, very similar and the survey biomass estimates for lemon sole, plaice and megrim are quite similar to biomass estimates by the SSDD model. The problem is however that catches have until last year usually been higher than recommended and probably because of that some of the stocks are at a low level. Fishery management in Iceland is quite flexible and if there is a will to protect the stocks they can be protected, perhaps only with the exception of megrim. The current system is described as an ITQ one, but this is however only half of the truth. Large areas are closed permanently or seasonally to various fishing gears. The Ministry of fisheries and to some extent the MRI can on a real time basis close areas for some or all fishing. All the means to control the fishery efficiently for the long term are thus available.

Table 8: Effort distribution (%) by grounds, total effort by fleet on ground divided by total effort by fleet. Effort measured in number of sets. Cells with less than 0.5% not shown

	Grounds fished															
Boats from ground (fleets)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	5	64	5		2						1	22		1		
5	2	27	10		56	1						3				
6	7	2	7		14	64						6				
8							23	75								2
9									98	1						1
10									8	89	2					
11	4					1					59	8	5	21		
12	11	6	3		1	2					3	67		8		

Glossary of symbols and abbreviations

α	Ford-Brody growth model intercept
ρ	Ford-Brody growth model slope
σ^2_0	index of local variance between block
σ^2_d	index of local variance within block
a	age
a^*	length/weight relationship constant
a'	age of 100 % recruitment to the fishery
a''	The last age class in cohort analysis
a_R	Shepherd model maximum age k_r recruits per unit spawning biomass
B	biomass
b	Shepherd model recruitment carrying capacity parameter
b^*	length/weight relationship constant
B_0	unfished biomass
B_e	biomass at equilibrium
b_{ij}	Shepherd model recruitment carrying capacity parameter for species i on ground j
$B_{ij,0}$	unfished biomass of species i on ground j
$B_{ij,t}$	biomass of species i on ground j in year t
c	Shepherd model recruitment curve shape parameter
C	catch
C_{at}	catch at age a in year t
C_e	catch at equilibrium
$C_{i,t}$	catch of species i during year t
CPUE	catch per unit effort
ð	steepness of the slope through a_{50}
d_{bn}	distance from block b to block n
EEZ	economic exclusive zone
$e_{i,t}$	effort in ground j during year t
e_n	observed effort in block n
eq.	equation
fig.	figure
$F_{ij,t}$	fishing mortality rate of species i on ground j in year t
gr.	ground or grounds as used in Fishmap and Effmod
i	index of species
ITQ	individually transferable quotas
j	index of grounds
K	maximum possible increase in mean recruitment rate per unit spawning biomass
k	growth coefficient for the von Bertalanffy equation
k_r	age of 50 recruitment to the fishery
L	body length of fish
L_∞	or L_{inf}, theoretical maximum length
$L^{(CPUE)}$	likelihood of CPUE from commercial fleet fitting biomass index
$L^{(survey)}$	likelihood of survey index fitting biomass index
$L^{(y)}$	likelihood of biomass fitting biomass index
L_a	body length of fish at age a
M	natural mortality rate
MRI	the Marine Research Institute in Iceland
MSY	maximum sustainable yield
N	number of fish
n	index for spatial blocks

N_{at}	number of fish at age a in year t
$N_{ij,t}$	number of fish of species i on ground j in year t
q_{ij}	catchability of species i on ground j
R	recruitment
R_0	recruitment when stock is at B_0
$R_{ij,t}$	recruitment of species i on ground j in year t
S	spawning stock
s	survival rate
$s_{ij,t}$	survival rate of species i on ground j in year t
SSDD	single stock delay difference model
T	temperature
t	time (year)
t’	the last year in cohort analysis
t’	first year we have information on y
t”	last year we have information on y
t_0	theoretical age at zero length
TAC	total allowable catch
t/y	tons per year
U	exploitation rate
$V_{a,t}$	vulnerability at age a during year t
w	body weight of fish
w_∞	or w_{inf}, theoretical maximum weight
w_0	unfished average body weight
w_a	body weight of fish at age a
w_{kr}	body weight of fish at age of recruitment
w_n	Weighing factor for CPUE on block n
W.W.I	World War I
W.W.II	World War II
y	stock size index from survey or CPUE
y^*_b	weighted average CPUE in block b
Y/R	yield per recruit
$y_{ij,t}$	stock size index of species i on ground j during year t
y_n	observed CPUE in block n

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Appendix A: Catches of flatfish species in Icelandic waters

Table 9: Catches of megrim in Icelandic waters by nation

	Belgium	Denmark	England	Faroe Islands	France	(West) Germany	Iceland	Netherlands	Scotland	Sweden
1906										
1907			208							
1908			119			1			25	
1909			95						5	
1910			107						23	
1911			65						28	
1912			57						32	
1913			65						21	
1914			77							
1915			19							
1916			3							
1917			1							
1918										
1919			12						3	
1920			24						4	
1921			11						1	
1922			50						52	
1923			19						138	
1924			21						66	
1925			7						34	
1926			6						18	
1927			8					1	21	
1928		6	45			225		2	1	
1929		1	50			311		12	1	
1930		3	29			282		4	3	
1931		1	16			293		7	5	
1932		3	34			263	5	2	3	2
1933		8	14			213	1		3	
1934		11	27			313	1		4	
1935		8	36			338	1		2	
1936		6	108			273			10	
1937		10	48	2		255	1		8	
1938		33	42	7		312	1	1	19	
1939				7		214	0		8	
1940							0		11	
1941							13		20	
1942							26		25	
1943							1		29	
1944							25		52	
1945							9	1	38	
1946	14		34				3		21	
1947	88		56						59	
1948	174		112			199	13	6	36	
1949	73		82			243	128		117	

Table 9 (cont.): Catches of megrim in Icelandic waters by nation

	Belgium	Denmark	England	Faroe Islands	France	(West) Germany	Iceland	Netherlands	Scotland	Sweden
1950	61		102			231	45	21	56	
1951	111		132			265	76		54	
1952	97		108			218	69	2	9	
1953	134		76			315	139		9	
1954	123		105			292	166	2	10	
1955	272		81			197	35		12	
1956	269		44			148	89		9	
1957	312		65			221	104		8	
1958	256		102			165	170		8	
1959	230		70			144	148		8	
1960	257		18			128	133		12	
1961	186		93			79	39	3	97	
1962	167		89			65	111	7	70	
1963	208		55			78	66	10	54	
1964	193		29			113	69	1	35	
1965	262		48		47	79	254	2	29	
1966	223		10			38	102		9	
1967	270		23		12	45	46		18	
1968	343		28			60	41		23	
1969	383		28			53	172		24	
1970	420		18		5	39	117		39	
1971	394		64		2	39	61		24	
1972	290		43			29	64		9	
1973	247		58			17	81		2	
1974	200		58			16	27		9	
1975	188		20			8	7		12	
1976	119		7			19	17		6	
1977	147					18	3			
1978	125						11			
1979	101						10			
1980	114						104			
1981	70						1			
1982	35						3			
1983	62						4			
1984	95						9			
1985	44						17			
1986	35						42			
1987	21						161			
1988	65						282			
1989	51						345			
1990	22						154			
1991	20						186			
1992							246			
1993							224			
1994	2						301			
1995							405			
1996							419			
1997							281			

Table 10: Catches of witch flounder in Icelandic waters by nation

	Belgium	Denmark	England	Faroe Islands	France	(West) Germany	Iceland	Scotland	Sweden
1905									
1906			338					13	
1907	4		374			395		73	
1908			227			529		68	
1909			206			664		22	
1910			165			702		62	
1911			137			13		77	
1912			117			31		56	
1913			107			25		87	
1914			102			14		39	
1915			61					6	
1916								7	
1917								8	
1918									
1919			123			2		38	
1920			140			42		300	
1921			62			19		11	
1922			145			27		137	
1923			186			18		494	
1924			262			62		237	
1925			151			77		215	
1926			163			112		137	
1927			251			180		134	
1928	7	29	457			472		6	1
1929	6	16	407			549		17	1
1930	2	39	209			387		18	8
1931		56	138	8		1105		16	
1932		103	237	19		767	12	18	26
1933		198	132	1		710	6	8	
1934		189	231	5		830	7	21	
1935		90	306			808	7	18	
1936	1	46	508			623	14	84	13
1937		102	258	17		610	12	59	
1938		181	187	39		684	10	65	
1939	1	261		38		457		56	
1940								48	
1941								120	
1942								84	
1943								36	
1944								7	
1945								37	
1946			89					57	
1947			478					210	
1948		20	1014			111	202	323	48
1949	107	110	715			111	486	268	26

Table 10 (cont.): Catches of witch flounder in Icelandic waters by nation

	Belgium	Denmark	England	Faroe Islands	France	(West) Germany	Iceland	Scotland	Sweden
1950	104	204	459			93	88	149	9
1951	177	267	503			69	81	67	
1952	120	103	358			107	30	32	
1953	139		226			72	138	19	
1954	331	1	242			81	112	11	
1955	507	1	174			33	34	26	
1956	466		100			132	167	17	
1957	638		184			49	200	21	
1958	506		249			42	372	17	
1959	415		172			17	646	49	
1960	432		32			10	931	12	
1961	381		84			8	725	97	
1962	473		62		50	9	559	50	
1963	537		50			7	431	20	
1964	296		40			10	469	9	
1965	303		84		21	42	412	23	
1966	229		1			4	122	3	
1967	178		24		3	15	162	4	
1968	181		40			3	132	2	
1969	189		14			6	166	4	
1970	157		37			8	169	10	
1971	169		40			2	125	10	
1972			61			1	138	3	
1973			35				22	2	
1974			24			1	52	1	
1975			8				69	2	
1976			3				143	1	
1977							115		
1978							120		
1979							140		
1980							19		
1981							3		
1982							54		
1983							10		
1984							11		
1985							32		
1986							334		
1987							4565		
1988							2974		
1989							2267		
1990							1278		
1991							1775		
1992							2564		
1993							1658		
1994							1771		
1995							1816		
1996							1486		
1997							1272		

Table 11: Catches of American plaice in Icelandic waters by nation

	Belgium	(West) Germany	Iceland
1904			
1905	21	12	
1906	6	2	
1907	10	62	
1908	13	65	
1909	14	6	
1910	12		
1911	4	6	
1912	4	9	
1913		9	
1914		6	
1915			
1916			
1917			
1918			
1919		5	
1920		15	
1921		30	
1922		55	
1923			
1924			
1925			
1926			
1927			
1928			
1929			
1930			
1931			
1932			
1933			
1934			
1935			
1936			
1937			
1938			
1939			
1940			
1941			
1942			
1943			
1944			
1945			
1946			
1947			
1948			
1949			

Table 11 (cont.): Catches of American plaice in Icelandic waters by nation

	Belgium	(West) Germany	Iceland
1950			
1951			
1952			
1953			
1954			
1955			
1956			
1957			
1958			
1959			
1960			
1961			
1962			
1963			
1964			
1965			
1966			
1967			
1968			
1969			
1970			
1971			
1972			
1973			
1974			
1975			
1976			
1977			
1978			
1979			
1980			
1981			
1982			
1983			
1984			
1985			1
1986			0
1987			32
1988			166
1989			565
1990			653
1991			1710
1992			1468
1993			1350
1994			2694
1995			5356
1996			6435
1997			5705

Table 12: Catches of dab in Icelandic waters by nation

	Belgium	Denmark	England	Faroe Islands	(West) Germany	Iceland	Netherlands	Scotland
1904								
1905	29				36		2	
1906	23		440		14		1	3
1907	19		445		105		3	14
1908	24		479		217		2	9
1909	27		458		152		9	4
1910	23		406		301		5	8
1911	10		276		381		2	2
1912	6		527		272		2	1
1913			532		195		1	1
1914			454		93		1	9
1915			558				2	24
1916							17	81
1917								40
1918								
1919			393		41			14
1920			474		185		393	10
1921			380		169		3	1
1922			359		313		1	19
1923			800		177			68
1924			815		246		1	68
1925			862		247			53
1926			693		183		1	17
1927			997		198			8
1928	4	16	943		24			1
1929	8	5	876		20			9
1930	1	15	665	5	25		1	2
1931	1	37	635	13	32		3	3
1932	7	40	709	7	15	29		12
1933	2	44	554		16	22		4
1934	2	18	514		7	13	1	7
1935	8	12	574		7	26		18
1936	4	18	695		3	45		16
1937	10	19	662	8	3	27		18
1938	9	16	532	5	11	36		17
1939	11			5	16			23
1940								22
1941								87
1942								110
1943								58
1944								64
1945							4	56
1946	3		135					55
1947	50		151			72		30
1948	67	6	217			47	7	53
1949	118	19	187		4	192		80

Table 12 (cont.): Catches of dab in Icelandic waters by nation

	Belgium	Denmark	England	Faroe Islands	(West) Germany	Iceland	Netherlands	Scotland
1950	99	19	236		2	22	32	65
1951	140	7	288		3	34	7	26
1952	179	2	261		1	26	1	19
1953	273		198		2	14		11
1954	301	2	171			3		20
1955	270	1	188			4		6
1956	310		131		1	17		10
1957	304		226					5
1958	333		199		2	24		5
1959	170		149			25		10
1960	194		93			49		3
1961	114		94			55		12
1962	87		78		1	11		4
1963	100		136				1	5
1964	92		144			69	4	8
1965	92		145			24		51
1966	56		168			58		47
1967	67		225			30		31
1968	41		166		1	37		17
1969	33		151			76		29
1970	9		94			11		49
1971	5		150			11		63
1972	2		104			12		41
1973	2		103	2		3		22
1974	6		47		1	4		18
1975			32			5		19
1976	6		45		1	8		3
1977					1	8		
1978						34		
1979						32		
1980						5		
1981								
1982								
1983	1					24		
1984	1					446		
1985	1					948		
1986						1254		
1987	2					1184		
1988	1					3776		
1989	1					2238		
1990						1898		
1991	4					2632		
1992						3045		
1993						4233		
1994						5159		
1995						5557		
1996						7954		
1997						7886		

Table 13: Catches of lemon sole in Icelandic waters by nation

	Belgium	Denmark	England	Faroe Islands	France	(West) Germany	Iceland	Netherlands	Scotland	Sweden
1904										
1905	11					102		2		
1906	7		202			62		2	10	
1907	7		261					4	17	
1908	13		263					12	59	
1909	11		276					13	19	
1910	10		283			7		8	27	
1911	4		401			645		6	36	
1912	2		413			506		10	41	
1913			354			466		8	35	
1914			275			259		4	55	
1915			138					6	8	
1916								18	14	
1917									10	
1918										
1919			206			217			11	
1920			317			841		1	7	
1921			306			799		76	6	
1922			350			1069		4	34	
1923			564			515		6	49	
1924			539			593		9	87	
1925			462			597		13	91	
1926			706			850		5	77	
1927		100	1204			1054		4	102	
1928	5	77	1471			1039		6	45	38
1929	17	16	1437			1066		6	23	
1930	7	32	1345			1038		7	22	
1931	5	52	1629	5		217		6	16	
1932	8	34	2066	2		202	64	6	26	8
1933	6	157	1701	3		244	59		31	
1934	6	129	1864	2		255	52		60	
1935	16	78	1989	1		187	35		60	
1936	14	38	2313	2		259	27		66	
1937	30	27	2639	9		188	31		79	
1938	25	50	1848	19		175	69	1	70	
1939	22			19		155	213		102	
1940							979		25	
1941							1017		123	
1942							473		140	
1943							1276		40	
1944							767		42	
1945							613	2	27	
1946	11		136				575		19	
1947	40		149				808		58	
1948	21		416			56	1140	7	127	110
1949	20		403			57	1141		120	118

Table 13 (cont.): Catches of lemon sole in Icelandic waters by nation

	Belgium	Denmark	England	Faroe Islands	France	(West) Germany	Iceland	Netherlands	Scotland	Sweden
1950	36	53	1089			30	949	20	85	51
1951	78	77	1119			23	634	9	83	
1952	95	13	1162			36	347	2	39	
1953	68		1391			32	128		9	
1954	208	17	1253			32	66		29	
1955	86	15	1118			74	30		6	
1956	154		946			34	336		14	
1957	169		1125			35	1230		19	
1958	194		1195			41	159		23	
1959	78		1257			41	224		24	
1960	156		1317			43	646		53	
1961	80	29	1089			40	1314		108	
1962	70		1144			39	1183	2	129	
1963	39		1594			31	1077	3	135	
1964	23		1468			23	660	2	176	
1965	31		1544			28	774	3	180	
1966	15		881			7	564		75	
1967	20		975		14	10	347		52	
1968	20		771			9	497		73	
1969	24		527			12	453		76	
1970	30		337			63	328		133	
1971	33		433			22	283		42	
1972	35		455			4	255		32	
1973	34		254	3		3	175		6	
1974	27		184			2	84		35	
1975	23		174	1			67		61	
1976	23		95			4	63		17	
1977	12			7		8	11			
1978	6			1			24			
1979	5			2			47			
1980	5			11			63			
1981	10			12			77			
1982	4			8			86			
1983	7						112			
1984	7						73			
1985	12			1			367			
1986	8						488			
1987	5						675			
1988	5						855			
1989	4			2			805			
1990	2						704			
1991	3						1095			
1992							912			
1993							716			
1994							693			
1995							741			
1996							984			
1997							1135			

Table 14: Catches of plaice in Icelandic waters by nation

	Belgium	Denmark	England	Faroe Islands	France	(West) Germany	Iceland	Netherlands	Norway	Scotland
1904										
1905	44					194		66		84
1906	36		9468			181		44		107
1907	19		8755			188		8		104
1908	30		6326			296		19		76
1909	33		5093			305		53		38
1910	38		4610			263		23		
1911	20		5139			290		18		85
1912	11		6160			438		14		109
1913			4889			190	387	7		92
1914			3852			74	175	8		96
1915			2315				109	13		69
1916							178	21		104
1917							5			36
1918							202			
1919			6094			65	473			171
1920			9104			283	912	2		67
1921			5225			210	527	26		26
1922			4421			366	864	14		207
1923			5134			157		3		307
1924			4582			280		7		375
1925			5048			507		16		349
1926			5207			397	670	10		242
1927		320	6335			382	688	3		153
1928	2	201	5222			347	601	2		18
1929	11	101	5240			479	687	8		37
1930	2	338	6219	19		479	1139	7		75
1931	3	440	5816	109		417	1650	8	13	41
1932	5	424	4668	68		252	932	1		45
1933	4	380	3557	41		162	413			25
1934	1	341	3587	23		104	597	1		16
1935	11	343	4094	28		45	796			20
1936	9	376	3487	20		60	1172			25
1937	8	273	3612	30		53	1565			26
1938	11	248	2710	39		46	1077			19
1939	11	300		39		43	1575			30
1940							3619			28
1941							2742			57
1942							5949			74
1943							3399			59
1944							3167			60
1945							3193	1		96
1946	8		1575			22	2638			123
1947	49		3548				3363			277
1948	25	58	4289			7	4730	6		175
1949	28	132	4783			11	5334			230

Table 14 (cont.): Catches of plaice in Icelandic waters by nation

	Belgium	Denmark	England	Faroe Islands	France	(West) Germany	Iceland	Netherlands	Norway	Scotland
1950	49	268	4785			11	3834	19		199
1951	91	239	3829			24	4183	5		68
1952	93	216	2726	5		9	1457	2		70
1953	135	5	3882	280		16	350			25
1954	154	4	5094	74		14	289			34
1955	256	23	6905	215		56	259			19
1956	311		6788	228		31	515			15
1957	384		7431	132		20	1622			14
1958	492		6655	271		51	648			46
1959	18		7270	75		88	921			56
1960	22		4525	71		34	3405			2
1961	17		6660	56		32	4226			10
1962	22		6149	84		39	5010			107
1963	24		6215	7		41	3325	2		44
1964	9		3956	4		7	5336			56
1965	61		3443		92	7	7286			101
1966	14		4393			1	7354			113
1967	6		5652		54	1	5644			23
1968	3		4095			1	6144			27
1969	1		3242			7	10764			17
1970			1758	92			8117			51
1971	1		2440	44		11	7179			13
1972	20		1323	20			5129			4
1973			635			5	4137			1
1974			82	1			3936			2
1975			141	31			4399			4
1976	1		28	1	1		4993			1
1977				3			5267			
1978	1			4			4499			
1979				1			4491			
1980							5145			
1981				35			3840			
1982				28			6303			
1983							8552			
1984	1						11334			
1985	2						14446			
1986							12700			
1987							11162			
1988	9						14040			
1989							11330			
1990							11400			
1991							10792			
1992							10494			
1993							12522			
1994							11854			
1995							10649			
1996							11070			
1997							10552			

Appendix B: Age distribution and weight at age in catches

Table 15: Megrim, age distribution in catches, sexes combined, from lobster trawl.

Year / age	1995	1996
5	4	
6		3
7	7	18
8	13	15
9	19	28
10	17	15
11	18	10
12	8	4
13	4	2
14	2	2
15	1	1
Grand total	93	98

Table 16: Megrim, average weight at age (kg), sexes combined, from lobster trawl.

Year / age	1995	1996
5	0.19	
6		0.27
7	0.48	0.37
8	0.42	0.44
9	0.60	0.65
10	0.81	0.70
11	0.90	0.97
12	0.88	1.06
13	1.00	1.26
14	1.14	1.79
15	1.41	1.44
Average total	0.72	0.66

Table 17: Witch flounder, age distribution in catches, sexes combined, from all gear except lobster trawl.

Year / age	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
2												1
3						2			5	13	1	14
4	1	2	12			2	1		56	13	31	2
5	5	7	47	11	7	18	3	3	43	75	101	50
6	10	13	131	81	50	40	2	3	45	42	187	100
7	43	15	60	136	88	55	4	12	70	52	106	164
8	87	17	95	46	58	40	48	18	35	70	119	66
9	80	22	119	33	27	18	86	55	75	49	95	62
10	64	32	104	38	26	3	47	88	100	41	79	39
11	16	45	50	17	13	7	36	57	60	68	77	32
12	19	18	39	7	8	1	21	34	39	26	46	19
13	8	13	7	3	10	1	18	9	18	14	23	13
14	2	2	4	2	3		6	8	11	7	8	4
15	1	5	3				5	6	10	2	1	
16		3	2		1		3	1	6	2	1	1
17		1						1		1	2	1
18		2	1				5		3	3		
19							2			2		
20 +							5	1	13	1		
Grand total	336	197	674	374	291	187	292	296	589	481	877	568

Table 18: Witch flounder, average weight at age (kg), sexes combined, from all gear except lobster trawl.

Year / age	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
2												0.13
3						0.10			0.10	0.11	0.15	0.11
4	0.09	0.18	0.11			0.16	0.09		0.16	0.18	0.22	0.19
5	0.13	0.11	0.17	0.13	0.12	0.19	0.22	0.18	0.19	0.21	0.27	0.33
6	0.20	0.18	0.20	0.19	0.19	0.24	0.22	0.21	0.22	0.24	0.28	0.33
7	0.24	0.19	0.29	0.23	0.23	0.26	0.22	0.21	0.27	0.28	0.35	0.36
8	0.29	0.27	0.32	0.31	0.25	0.31	0.30	0.21	0.29	0.31	0.39	0.42
9	0.33	0.30	0.33	0.33	0.30	0.39	0.30	0.28	0.34	0.35	0.42	0.50
10	0.39	0.36	0.37	0.36	0.33	0.34	0.31	0.35	0.38	0.34	0.48	0.56
11	0.45	0.36	0.39	0.49	0.48	0.47	0.40	0.35	0.45	0.35	0.48	0.59
12	0.51	0.44	0.44	0.49	0.41	0.50	0.52	0.39	0.47	0.37	0.52	0.71
13	0.49	0.44	0.44	0.61	0.63	0.39	0.45	0.49	0.51	0.36	0.53	0.75
14	0.65	0.35	0.43	0.74	0.60		0.44	0.49	0.46	0.29	0.54	0.36
15	0.70	0.71	0.54				0.62	0.54	0.48	0.76	0.55	
16		0.49	0.35		1.09		0.44	0.46	0.62	0.45	0.29	0.94
17		0.32						0.50		0.35	0.43	1.01
18		0.60	0.39				0.44		0.57	0.35		
19							0.55			0.37		
20+							0.42	0.42	0.55	0.32		
Average total	0.33	0.34	0.30	0.27	0.27	0.28	0.35	0.34	0.34	0.29	0.37	0.42

Table 19: American plaice, age distribution in catches, sexes combined, from all gear.

Year / age	1993	1994	1995	1996	1997
2		1	47	7	1
3		2	115	63	17
4		7	171	75	60
5		20	233	145	64
6	5	68	253	163	80
7	11	40	176	222	70
8	19	34	142	222	109
9	29	7	77	196	80
10	46	7	40	128	46
11	38		34	76	26
12	25	3	22	51	10
13	7		9	29	2
14	3		7	13	3
15	2		2	9	1
16				5	
17					1
Grand total	185	189	1328	1404	570

Table 20: American plaice, average weight at age (kg), sexes combined, from all gear.

Year / age	1993	1994	1995	1996	1997
2		0.00	0.02	0.01	0.01
3		0.02	0.04	0.02	0.03
4		0.03	0.06	0.05	0.05
5		0.07	0.09	0.07	0.08
6	0.19	0.11	0.14	0.12	0.11
7	0.24	0.19	0.26	0.24	0.18
8	0.28	0.25	0.32	0.32	0.24
9	0.31	0.30	0.36	0.39	0.30
10	0.39	0.37	0.35	0.42	0.37
11	0.46		0.41	0.48	0.41
12	0.49	0.62	0.46	0.49	0.47
13	0.51		0.52	0.55	0.35
14	0.49		0.59	0.65	0.63
15	0.53		0.53	0.66	0.50
16				0.71	
17					0.52
Average total	0.39	0.17	0.18	0.27	0.20

Table 21: Dab, age distribution in catches, sexes combined, from Danish seine.

Year / age	1993	1994	1995	1996	1997
2		1	1		3
3	2	2	24	2	9
4	40	29	230	68	58
5	169	174	623	455	293
6	225	200	586	976	673
7	128	116	265	402	497
8	17	45	117	122	158
9	11	12	16	25	48
10		8	4	5	7
11		2	1	2	2
12				4	
Grand total	592	589	1867	2061	1748

Table 22: Dab, average weight at age (kg), sexes combined, from Danish seine.

Year / age	1993	1994	1995	1996	1997
2		0.11	0.09		0.07
3	0.13	0.12	0.19	0.24	0.13
4	0.19	0.20	0.23	0.20	0.15
5	0.27	0.29	0.30	0.25	0.22
6	0.30	0.33	0.33	0.30	0.30
7	0.32	0.32	0.35	0.35	0.35
8	0.29	0.33	0.39	0.37	0.39
9	0.32	0.33	0.39	0.36	0.40
10		0.37	0.51	0.42	0.45
11		0.46	0.49	0.49	0.40
12				0.42	
Average total	0.29	0.31	0.31	0.30	0.31

Table 23: Lemon sole, age distribution in catches, sexes combined, from lobster trawl.

Year / age	1995	1996
4	4	
5	23	7
6	68	26
7	75	31
8	75	18
9	60	12
10	50	10
11	20	10
12	4	5
13	3	2
14	2	
Grand total	384	121

Table 24: Lemon sole, average weight at age (kg), sexes combined, from lobster trawl.

Year / age	95	96
4	0.15	
5	0.19	0.14
6	0.27	0.21
7	0.32	0.34
8	0.33	0.36
9	0.34	0.35
10	0.36	0.32
11	0.39	0.35
12	0.48	0.44
13	0.46	0.52
14	0.45	
Average total	0.32	0.31

Table 25: Plaice, age distribution in catches, sexes combined, from Danish seine.

Year / age	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
2						2		16	4	40
3		1		2	1	30	34	192	68	77
4	23	8		33	18	80	145	438	304	326
5	56	69		215	38	77	166	1170	367	675
6	53	76		73	62	44	89	674	941	412
7	26	54		87	33	27	83	272	477	893
8	25	21		69	26	13	23	201	216	434
9	16	25		22	15	12	22	59	101	148
10	3	15		10	4	7	9	18	40	68
11	4	8		1	1	1	4	26	32	27
12		9		2		1	1	8	26	30
13	1						3	9	19	24
14							6	1	6	16
15		1		1		1	1	6	3	6
16							2	2	2	7
17							3	1		6
18							2			
19								3	1	2
20								8		
Grand total	207	287		515	198	295	593	3104	2607	3191

Table 26: Plaice, average weight at age (kg), sexes combined, from Danish seine.

Year / age	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
2						0.35		0.31	0.30	0.32
3		0.39		0.28	0.35	0.39	0.37	0.37	0.39	0.43
4	0.45	0.43		0.42	0.40	0.42	0.45	0.43	0.47	0.53
5	0.52	0.50		0.46	0.47	0.50	0.51	0.49	0.53	0.58
6	0.57	0.54		0.53	0.50	0.60	0.57	0.54	0.57	0.62
7	0.54	0.57		0.56	0.53	0.63	0.61	0.72	0.65	0.68
8	0.72	0.71		0.60	0.48	0.73	0.76	0.79	0.78	0.76
9	0.66	0.64		0.62	0.51	0.83	1.00	0.94	0.96	0.90
10	0.71	0.79		0.83	0.93	0.76	0.97	0.87	0.95	1.02
11	0.63	0.71		1.51	0.80	0.86	0.77	0.99	1.03	0.98
12		0.89		1.39		1.78	0.69	1.02	1.22	1.06
13	0.59						0.99	0.97	0.99	1.22
14							1.19	1.17	1.05	1.26
15		1.51		1.19		1.51	1.69	1.29	1.96	1.30
16							0.73	1.26	1.49	1.31
17							1.14	1.64		1.50
18							1.15			
19								1.09	1.71	1.80
20								1.26		
Average total	0.56	0.59		0.52	0.50	0.53	0.56	0.55	0.62	0.67