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Modelling spatial closures and fishing effort restrictions in the Faroe Islands marine ecosystem☆

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Abstract

The Faroe Islands, located in the northeastern Atlantic Ocean, utilize a spatial- and effort-based system of fisheries management, explicitly incorporating ecosystem considerations in their policies. This management system was introduced relatively recently (mid-1990s). Given the importance of fishing to the Faroe economy and culture, considerable interest has been expressed in the evaluation of these new management measures at the ecosystem level. We used Ecopath with Ecosim to examine alternative management options for the Faroe Islands fisheries and compared these options with the status quo. Spatially explicit simulations were carried out using the Ecospace routine. Simulations suggest that current area closures could be considered beneficial in conserving major stocks of demersal species, with biomass for cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and other demersal species increasing over the 10-year simulation period. Simulated removal of the closure system reduced the effect of the projected stock increases considerably. Greenland halibut (*Reinhardtius hippoglossoides*), one of the major deep-water species, and blue whiting (*Micromesistius poutassou*), one of the main pelagic species, did not benefit from the existing spatial management. Simulated additional offshore closures of at least 20% of habitats deeper than 200 m benefited Greenland halibut only. Both, Greenland halibut and blue whiting stocks benefited from drastic reductions in fishing effort (between 20 and 50% reductions from 1997 effort levels). Considerable uncertainty underlies the basic input data, which might have major consequences for the dynamic behaviour of the simulations, and thus might significantly alter the outcomes.

Keywords: Ecosystem modelling; Faroe Islands; Fishing effort; Marine fisheries; Spatial closures

1. Introduction

The Faroe Islands, located in the northeastern Atlantic between Scotland and Iceland (Fig. 1), consist of a group of 18 islands inhabited by approximately 46,000 people and covering about 1400 km^2. Fishing represents the major commercial activity, accounting for over 95% of exports and 44.5% of GDP ('Statistics Faroe Islands': http://www.hagstova.fo). Both commercial and subsistence fisheries play a significant role in Faroese culture and society (Anon., 1999a).

The Faroe Islands are located within the International Council for the Exploration of the Sea (ICES) Fisheries Statistical Area Vb, which covers about 190,200 km^2 (Fig. 1). Two aspects of the current fisheries management system in the Faroe Islands are of particular interest in the present context (Anon., 1998a):

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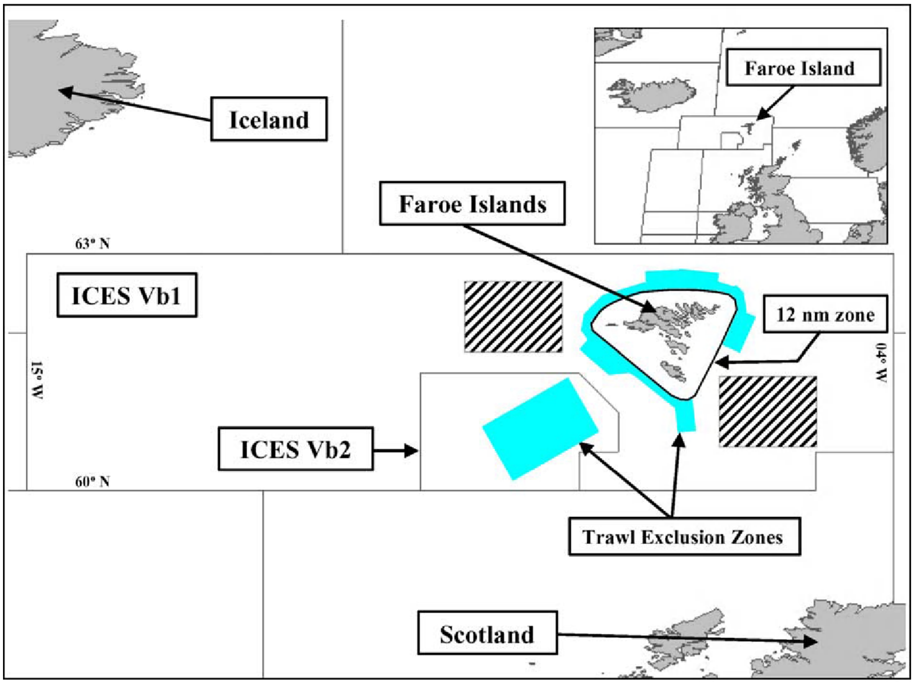


Fig. 1. Geographic location of Faroe Islands, located between Iceland and Scotland. Shown also are the ICES Fisheries Statistical Areas Vb1 and Vb2 associated with Faroe fisheries, and the Trawl Spatial Closures used in the management of the Faroe fisheries. The non-trawl area bounded by the 12-nm zone is augmented by additional trawl exclusion zones. The approximate size and locations of the hypothetical offshore, deep-water closures incorporated into the present simulations are also indicated by cross-hashed boxes.

1. An effort quota system for most demersal fish (groundfish) gear types based on gear-specific effort limitations rather than catch quotas. Effort quotas (fishing days) are transferable within the same gear categories only.
2. The use of a spatial and temporal closure system applicable to all or selected gear types. Particular measures include temporal all-gear closures during the spawning periods, as well as permanent spatial closures to trawl gear types. For example, no trawling is allowed within 12 nautical miles (nm) of the Faroese territorial limit. An exception exists during summer, when 10–15 small trawlers (<500 hp) are allowed to fish in specified subareas within the 12-nm limit, targeting mainly lemon sole and plaice with strict by-catch limits. Additional areas are closed to trawling on a seasonal basis (Fig. 1).

Additional management measures, such as total allowable catches (TAC) for some fleets and technical measures such as mesh size regulations and by-catch restrictions are also part of the management system.

1.1. Fisheries

The fisheries in the Faroe area (ICES Area Vb, Fig. 1) can be characterised as multigear and multispecies, targeting demersal, deep-water and pelagic species using handline, longline, gillnet, purse seine and various trawl gear types (Anon., 1997). Before 1960, all foreign vessels were allowed to fish around the Faroe Islands outside the 3-nm zone. Since the introduction of the 200-nm EEZ in 1977, the demersal fishery by foreign nations has decreased and Faroese vessels now take most of the demersal catches. However, the majority of the pelagic catch is by foreign vessels.

The species of major commercial value and cultural importance include demersal, deep-water and pelagic species, as well as marine mammals. Cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), saithe (*Pollachius virens*) and other demersal stocks form the economically most important component of the Faroese fishing industry (Anon., 1999a). Cod stocks in Faroese waters were reported to have declined substantially from the mid-1980s to mid-1990s, due to overfishing and environmental effects (Anon., 1999a). More recently, fishing mortality for cod is thought to have declined close to levels recommended by the ICES Working Group (Anon., 1999b). Fishing mortality of haddock has been very low since the 1980s, a result of very low stocks and poor recruitment, resulting in haddock being mainly taken as by-catch. During the late 1990s, however, haddock fishing mortality increased (Anon., 1999b). Fishing mortality for saithe increased considerably during the last few decades, primarily due to the introduction of pair-trawlers, but since 1995 has been decreasing steadily.

The main components of the pelagic fisheries (both foreign and domestic fleets) comprise blue whiting (*Micromesistius poutassou*), Norwegian spring spawning herring (*Clupea harengus*) and mackerel (*Scomber scombrus*). Blue whiting are caught from the Barents Sea to the Strait of Gibraltar, and the stock was perceived to be relatively constant since the early 1980s, although estimates of abundance are imprecise (Anon., 1997). However, the total 1997 landings of blue whiting in all ICES areas exceeded management advice by nearly 15% (Anon., 1998b), and by the year 2001 the catch exceeded the recommended TAC by 77% (Anon., 2001a). In ICES Area Vb, blue whiting are caught primarily by Russian and Norwegian vessels, and only about 4% of the 1997 catch was taken by Faroese vessels, while over 90% of the total herring catch, and nearly 40% of the mackerel catch in Area Vb during 1997 was taken by Faroese vessels.

The deep-water fisheries catch consists of Greenland halibut (*Reinhardtius hippoglossoides*), redfish (*Sebastes* spp.), silver smelt (*Argentina* spp.), blue ling (*Molva dypterygia dypterygia*) and others. The stock of Greenland halibut in the Faroe Islands area (a stock shared between Greenland, Iceland and Faroe Islands) is considered at low levels, and catches have routinely exceeded ICES advice (Anon., 2000b). In 1997, the Faroese fleets took over 97% of the Greenland halibut and redfish catch, and 78% of the other deep-water species in ICES Area Vb.

Marine mammals are hunted for local consumption, and are considered of cultural importance by the Faroe society. In 1997, the catch consisted of two species, the pilot whale (*Globicephala melas*) and the white sided dolphin (*Lagenorhynchus acutus*), with catches of approximately 1100 and 350 animals, respectively (D. Bloch, personal communication).

Given the exceptional importance of marine resources to the Faroese culture and economy, effective and sustainable fisheries management is of paramount importance to the Faroese society. Of particular interest in this regard at the present are ecosystem-level evaluations of the effects of the seasonal and gear-specific closure systems. We used Ecospace, a dynamic spatial modelling routine (Walters et al., 1999), which forms part of the Ecopath with Ecosim suite of ecosystem modelling approaches (Christensen et al., 2000; Pauly et al., 2000), to examine the potential ecosystem effects of some of the existing spatial management regimes used in the Faroe Islands on stocks and fisheries, as well as to examine alternative management strategies in light of existing stock trends.

2. Methods

An ecosystem model of the Faroese waters (based on ICES Area Vb, ~190,200 km^2, divided into Faroe Plateau Vb1 and Faroe Bank Vb2, Fig. 1) was constructed using Ecopath with Ecosim (version 4.0; http://www.ecopath.org; Christensen and Walters, 2004). The balanced model input data for the 19 trophic groups used are summarised in Table 1, the diet matrix underlying the model is presented in Table 2, and sources for the group-specific information are summarised in Table 3. Most data used for species of commercial importance were based on ICES Working Group stock assessments, or if not available for the present area, were taken from nearby or similar areas or models (e.g. Iceland). An earlier version of the model is documented elsewhere (Zeller and Freire, 2001). The present study examines the possible impacts of spatial closures and alternative management actions on changes in species biomass and catches by gear type in an ecosystem context. Spatial effects of gear-specific effort reductions were evaluated, using Ecospace. The current area closures

Table 1
Ecopath input data for the 19 groups used in the model. Main species included in the 'other' groups are listed at the bottom of the table. Trophic levels and values in parentheses were estimated by the model. *P/B*, production to biomass ratio; *Q/B*, consumption to biomass ratio; EE, ecotrophic efficiency; *P/Q*, production to consumption ratio

Group	Trophic level	Biomass ($t\,km^{-2}$)	*P/B* (per year)	*Q/B* (per year)	EE	*P/Q*	1997 catch ($t\,km^{-2}$)
Baleen whales	4.0	0.059	0.050	5.059	(0.354)	0.010	
Toothed mammals	4.7	(0.085)	0.050	12.266	0.8	0.004	0.005
Seabirds	3.8	0.017	0.010	35.000	(0)	0	
Cod	4.1	0.570	0.653	3.100	(0.679)	0.211	0.199
Haddock	3.6	0.723	0.346	3.800	(0.726)	0.091	0.095
Saithe	4.1	0.611	0.443	3.300	(0.805)	0.134	0.115
Redfish	3.7	2.133	0.350	4.500	(0.648)	0.078	0.038
Greenland halibut	3.6	(0.115)	0.446	3.500	0.95	0.127	0.026
Other demersal fish[a]	4.0	(2.602)	0.450	3.000	0.95	0.150	0.033
Other deep-water fish[b]	4.2	(0.908)	0.350	3.100	0.95	0.113	0.105
Herring	3.4	(3.111)	0.296	4.600	0.949	0.064	0.096
Blue whiting	3.6	(3.851)	0.355	9.060	0.95	0.039	0.570
Mackerel	3.7	(1.142)	0.276	4.400	0.95	0.063	0.059
Other pelagic fish[c]	3.2	(13.671)	0.585	4.500	0.947	0.130	0.021
Benthos	2.5	(8.737)	3.000	10.000	0.95	0.300	0.020
Squid	3.6	(9.983)	0.600	3.500	0.95	0.171	
Large zooplankton	2.6	16.193	(9.857)	40.000	0.95	0.246	
Small zooplankton	2.1	(11.698)	40.000	140.000	0.95	0.286	
Phytoplankton	1.0	54.360	50.000				

[a] *Ammodytes* spp., *Anarhichas lupus*, *Anarhichas* spp., *Brosme brosme*, *Glyptocephalus cynoglossus*, *Hippoglossus hippoglossus*, *Lepidorhombus whiffiagonis*, *Limanda limanda*, *Merlangius merlangus*, *Merluccius merluccius*, *Microstomus kitt*, *Pleuronectes platessus*, *Raja batis*, *Raja* spp., *Selachimorpha pleurotremata*, *Squalus acanthias*, Squalidae.
[b] *Aphanopus carbo*, *Argentina* spp., *Beryx decadactylus*, *Coryphaenoides rupestris*, *Hoplostethus atlanticus*, *Lophius piscatorius*, *Macrourus berglax*, *Molva dypterygia*, *Molva molva*, *Phycis blennoides*.
[c] *Mallotus villosus*, *Osmerus eperlanus*, *Trachurus trachurus*, *Trisopterus esmarkii*, *Tunus* spp.

cover approximately 11,500 km^2, and are applicable to trawl gears only (Fig. 1). This represents approximately 60% of the Faroe plateau shelf area less than 200 m depth (19,350 km^2).

Thirteen gear types/fisheries were defined for the model, including foreign and domestic fisheries. Landings for 1997 by species in ICES Area Vb were obtained from the ICES 'Statlant' database. No information on discards is currently incorporated into the model. All non-Faroese fleets (mainly Iceland, Norway, Russia, United Kingdom, Germany, France, Denmark and Estonia) were grouped into a single 'foreign' category fishing mainly on pelagics (Table 4). The Faroe domestic fleets were separated by gear type according to the ICES North-West Working Group report (Anon., 1999b) and the Faroe Fisheries Laboratory report (Anon., 1998a), with two changes: addition of a 'pelagic' gear type accounting for all Faroe catches of pelagic species; and pooling of 'industrial' and 'other' gear types due to low catches in these categories. ICES catches were allocated to domestic gear types according to the proportion of landings by gear type as documented in the Faroe Fisheries Laboratory report (Anon., 1998a).

For the spatial simulations, habitats were defined by four depth strata, and species preferences assigned to these habitat types (Table 5) based on their preferred depth distributions (Zeller and Pauly, 2001). Basic movement rates, which are not rates of directed migration, but rather basic relative population dispersal rates as a result of random movements (Christensen et al., 2000) were assumed to be of three relative magnitudes: 3, 30 and 300 km per year representing essentially nondispersing, demersal and pelagic groups, respectively (Table 5). The relative dispersal rate in 'bad' habitats (i.e. nonpreferred habitats) was assumed to be 5 times the basic movement rate, and

Table 2
Diet composition matrix for all functional groups of the Ecosystem model of the Faroe Islands marine ecosystem. Values represent the proportion each prey contributes to the diet of a predator. For example, large zooplankton (prey group 17) contributes 66% of the diet of baleen whales (predator group 1)

Prey group		Predator group																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Baleen whales		0.001																
2	Toothed mammals		0.001																
3	Seabirds																		
4	Cod		0.006						0.020	0.005									
5	Haddock		0.005		0.005		0.010			0.005	0.005								
6	Saithe		0.002		0.013					0.005	0.013								
7	Redfish		0.006		0.052	0.003	0.010		0.040	0.020	0.052								
8	Greenland halibut				0.005						0.005								
9	Other demersal fish	0.105	0.337		0.087	0.007	0.003	0.005	0.030	0.027	0.087								
10	Other deep-water fish	0.048	0.040								0.050								
11	Herring	0.095	0.072	0.005	0.005		0.001		0.040		0.005			0.021			0.015		
12	Blue whiting	0.010	0.008	0.010	0.050		0.091		0.040	0.030	0.050			0.010					
13	Mackerel	0.005	0.004	0.010			0.050			0.010				0.010					
14	Other pelagic fish	0.024	0.053	0.401	0.272	0.100	0.150	0.050	0.060	0.037	0.272			0.220			0.101		
15	Benthos		0.062	0.397	0.221	0.567	0.080	0.163	0.090	0.221	0.171					0.200	0.034		
16	Squid	0.048	0.402	0.040	0.085	0.013	0.260	0.040	0.250	0.480	0.085			0.010					
17	Large zooplankton	0.667		0.077	0.205	0.310	0.344	0.742	0.130	0.040	0.205	0.800	0.900	0.610	0.600		0.750	0.050	
18	Small zooplankton											0.100	0.100	0.119	0.200	0.200	0.100	0.500	0.050
19	Phytoplankton											0.100			0.200	0.200		0.450	0.950
20	Detritus			0.060			0.001		0.300	0.120						0.400			

Table 3
Sources of data used for Ecopath model. *B*: biomass; *P*/*B*: production to biomass ratio; *Q*/*B*: consumption to biomass ratio

Group	*B*	*P*/*B*	*Q*/*B*	Diet
Baleen whales	Trites and Pauly (1998), Pauly et al. (1998)	Mendy and Buchary (2001), V. Christensen, personal communication	Trites and Pauly (1998), Pauly et al. (1998)	Trites and Pauly (1998), Pauly et al. (1998)
Toothed mammals	Trites and Pauly (1998), Pauly et al. (1998)	Mendy and Buchary (2001), V. Christensen, personal communication	Trites and Pauly (1998), Pauly et al. (1998)	Trites and Pauly (1998), Pauly et al. (1998)
Seabirds	Mendy and Buchary (2001), Anon. (1998d, 1999e)	Iceland: Mendy and Buchary (2001), Anon. (1998d, 1999e)	Mendy and Buchary (2001), Anon. (1998d, 1999e)	Mendy and Buchary (2001)
Cod	ICES single species VPA: Anon. (1998c, 1999b)	ICES single species VPA: Anon. (1998c, 1999b)	Mendy and Buchary (2001)	Jákupsstovu and Reinert (1994), Mendy and Buchary (2001): adjusted with data from Du Buit (1989)
Haddock	ICES single species VPA: Anon. (1998c, 1999b)	ICES single species VPA: Anon. (1998c, 1999b)	Mendy and Buchary (2001)	Mendy and Buchary (2001): adjusted with data from Du Buit (1989)
Saithe	ICES single species VPA: Anon. (1998c, 1999b)	ICES single species VPA: Anon. (1998c, 1999b)	Mendy and Buchary (2001)	Mendy and Buchary (2001): adjusted with data from Du Buit (1989)
Redfish	Mendy and Buchary (2001), Anon. (1998e)	Mendy and Buchary (2001)	Mendy and Buchary (2001)	Mendy and Buchary (2001), Anon. (1998e)
Other deep-water fish	–	V. Christensen, personal communication	V. Christensen, personal communication	V. Christensen, personal communication, including Cannibalism: Anon. (1999d), Bjelland and Bergstad (1998)
Greenland halibut	–	Anon. (1999b)	Mendy and Buchary (2001)	Mendy and Buchary (2001): adjusted for herring and blue whiting (Michalsen and Nedreaas, 1998)
Other demersal fish	–	Mendy and Buchary (2001)	Mendy and Buchary (2001)	Mendy and Buchary (2001)
Herring	–	VPA adjusted to Area Vb: Holst et al. (1998), Anon. (1999c)	Mendy and Buchary (2001)	Christensen (1995), V. Christensen, personal communication
Blue whiting	–	ICES VPA: Anon. (1999c)	http://www.fishbase.com	http://www.fishbase.com
Mackerel	–	VPA (western stock): Anon. (2000a)	http://www.fishbase.com	North Sea (Christensen, 1995), West Atlantic (Studhome et al., 1999)
Other pelagic fish	–	Mendy and Buchary (2001), Christensen (1995)	Mendy and Buchary (2001), Christensen (1995)	Mendy and Buchary (2001)
Benthos	–	Mendy and Buchary (2001)	Mendy and Buchary (2001)	V. Christensen, personal communication
Squid	–	Mendy and Buchary (2001)	Mendy and Buchary (2001)	V. Christensen, personal communication
Large zooplankton	Dry weight south-west Iceland (Gislason and Astthorson, 1995); DW = 0.26 × WW, Opitz (1996)	–	V. Christensen, personal communication	V. Christensen, personal communication
Small zooplankton	–	V. Christensen, personal communication	V. Christensen, personal communication	V. Christensen, personal communication
Phytoplankton	*P*: Longhurst et al. (1995), Pauly and Christensen (1995)	Mendy and Buchary (2001)	–	NA

Table 4
Gear types used in the model, and their associated catch in 1997 (t km^{-2} per year) by species groups. 'Baleen whale' and 'Seabird' groups were not listed here, as no catches were reported for 1997. All gear types are Faroe domestic, except for the 'Foreign' gear type

Gear type	Toothed mammals	Cod	Haddock	Saithe	Redfish	Greenland halibut	Other demersal fish	Other deep-water fish	Herring	Blue whiting	Mackerel	Other pelagic species	Benthos
Foreign		0.0046	0.0011	0.0031	0.0010	0.0006	0.0035	0.0247	0.0069	0.5460	0.0355	0.0013	0.0000
Open boat		0.0055	0.0017				0.0002						
Longline $<$100 t		0.0503	0.0287	0.0001			0.0024	0.0041					
Longline $>$100 t		0.0563	0.0352	0.0005	0.0004		0.0032	0.0343					
Single trawl $<$400 hp		0.0078	0.0026	0.0001			0.0068						0.0060
Single trawl 400–1000 hp		0.0098	0.0054	0.0029		0.0006	0.0036	0.0011					0.0050
Single trawl $>$1000 hp		0.0057	0.0026	0.0122	0.0318	0.0103	0.0018	0.0248					0.0020
Pair trawl $<$1000 hp		0.0116	0.0054	0.0204	0.0011		0.0025	0.0038					0.0050
Pair trawl $>$1000 hp		0.0269	0.0110	0.0674	0.0042		0.0061	0.0094					0.0020
Gillnet		0.0011			0.0004	0.0140	0.0029	0.0025					
Jigger		0.0193	0.0007	0.0102			0.0003						
Other	0.0054	0.0004		0.0005			0.0002	0.0001					
Pelagic									0.0892	0.0238	0.0233	0.0196	

Table 5
Habitat definitions by depth, and model group associations with habitats (+) as used in Ecospace. Listed also are the base dispersal rates as applied to each group within Ecospace

Group	All habitats	<200 m	200–350 m	350–600 m	>600 m	Base dispersal rate (km per year)
Baleen whales	+					300
Toothed mammals	+					300
Seabirds	+					300
Cod		+	+	+		30
Haddock		+	+	+		30
Saithe			+	+	+	30
Redfish				+	+	30
Greenland halibut				+	+	30
Other demersal fish		+	+	+		30
Other deep-water fish				+	+	30
Herring			+	+	+	300
Blue whiting			+	+	+	300
Mackerel			+	+	+	300
Other pelagic species			+	+	+	300
Benthos	+					3
Squid	+					300
Large zooplankton	+					300
Small zooplankton	+					300
Phytoplankton	+					300
Detritus	+					3

it was further assumed that groups were twice as vulnerable to predation in bad habitats than in preferred habitats (Christensen et al., 2000). Individual fishing gear types were allocated to available depth strata and excluded from gear-specific closed areas as outlined in Table 6.

A clockwise surface water current system creates retention areas on the Faroe Plateau and on the Faroe Bank, resulting in strong retention of local recruitment and stocks (Anon., 1998a; Gaard and Hansen, 2000). Given these retention effects, a surface water advection field was incorporated in the spatial simulations

Table 6
Habitat-specific (depth) operation (+), and gear-specific access permission (X) to closed zones for each gear type as defined for the Ecospace model

Gear type	Habitats					Gear closures	
	All habitats	<200 m	200–350 m	350–600 m	>600 m	Plateau 12-nm zone	Bank <200 m
Foreign	+						
Open boat		+				X	
Longline <100 t		+	+	+		X	X
Longline >100 t		+	+	+		X	X
Single trawl <400 hp		+					
Single trawl 400–1000 hp		+	+	+			
Single trawl >1000 hp			+	+	+		
Pair trawl <1000 hp		+	+	+			
Pair trawl >1000 hp	+						
Gillnet	+					X	X
Jigger		+	+	+		X	X
Other		+				X	
Pelagic			+	+	+	X	X

(Christensen et al., 2000). This advection field was applied to the plankton groups in the model. The seasonal spawning area closures applicable to all gears, also used by the Faroe fisheries management system (Anon., 1998a), were not used in the present simulations.

The results presented here consist of 10-year forward simulations starting with an Ecopath model for 1997. All EwE parameters were retained at default settings unless otherwise specified. Changes in species biomass and catches (based on 1997 baseline with fixed fishing mortality rates and no quota transfers between gear types) were evaluated for:

- the present Trawl Spatial Closures;
- the hypothetical removal of the Trawl Spatial Closures (with an assumed 20% increase in trawl effort);
- the addition of off-shore deep-water closures applicable to all gears (chosen arbitrarily for waters deeper than 200 m); and
- for selected gear-specific effort restrictions applicable to major deep-water and pelagic species.

3. Results

3.1. Spatial closures

3.1.1. Trawl Spatial Closures

The results of the 10-year simulations using the presently applied Trawl Spatial Closures (Fig. 1) suggested a substantial increase in biomass of cod (+50%), haddock (+47%) and 'other demersal fish' (+32%) for Area Vb, respectively, while saithe biomass was projected to decrease marginally (−4%) (Fig. 2A). Two other species displayed considerable declines in biomass, the deep-water Greenland halibut and the pelagic blue whiting, with projected biomass declines of 47 and 44%, respectively (Fig. 2A).

The most negatively affected gear types were the foreign fleet (all foreign gears mixed) and the Faroe gillnet gear, with catches declining by 39 and 33%, respectively (Fig. 3A). It is obvious that the reduction in catches projected for the foreign and gillnet fleet (and to a lesser extent the large single trawlers) reflects the reduced biomass predicted for blue whiting and Greenland halibut, respectively (Fig. 2A). The 10% decline in catches by the Faroe pelagic gear type reflects the simulated general decline observed for the pelagic species, in particular the 6% drop in herring biomass (Fig. 2A), which comprises the majority of the Faroe pelagic catch.

3.1.2. Open Access

The hypothetical Open Access scenario assumed complete removal of the present gear-specific spatial closures (Fig. 1), and free access for all Faroe trawl gears to areas normally off limits. Our simulation assumed no changes in species being targeted by individual gear types. It was assumed that this scenario would increase effort of all trawl gears by 20% from current levels through industry pressure on the effort management regime currently in place.

Under conditions of free access by trawlers to all closure zones, the demersal fish biomass increases predicted under Trawl Spatial Closure conditions were drastically reduced, being 84 and 46% lower for cod and haddock, respectively (Fig. 2B). The other species of particular interest here, blue whiting and Greenland halibut, showed a decline in projected biomass (47 and 41%, respectively, Fig. 2B) similar to that under Trawl Spatial Closure conditions (44 and 47%, respectively, Fig. 2A).

Comparisons of projected catches by gear types between the Trawl Spatial Closure (Fig. 3A) and the Open Access scenario (Fig. 3B) suggested that, among trawl gears, only the two small single trawl categories would have increased catches at the end of the simulation period, while the other trawl gear types would not benefit from Open Access (Fig. 3B). Gear types other than trawl were projected to fare worse under Open Access (Fig. 3B) than under Trawl Spatial Closure conditions (Fig. 3A), with projected catches increasing between 3 and 23%. Exceptions were gillnets, for which catches were similar to status quo conditions, and 'foreign' and 'pelagic', for which catches were worse than under Trawl Spatial Closure conditions (Fig. 3A and B).

The spatial simulations of gear-specific effort indicated that under Trawl Spatial Closure conditions, effort for most trawl gears is concentrated along the boundary areas of the 12-nm zone (orange/red in Fig. 4A), while under Open Access, their effort would be more widely distributed across the Faroe plateau

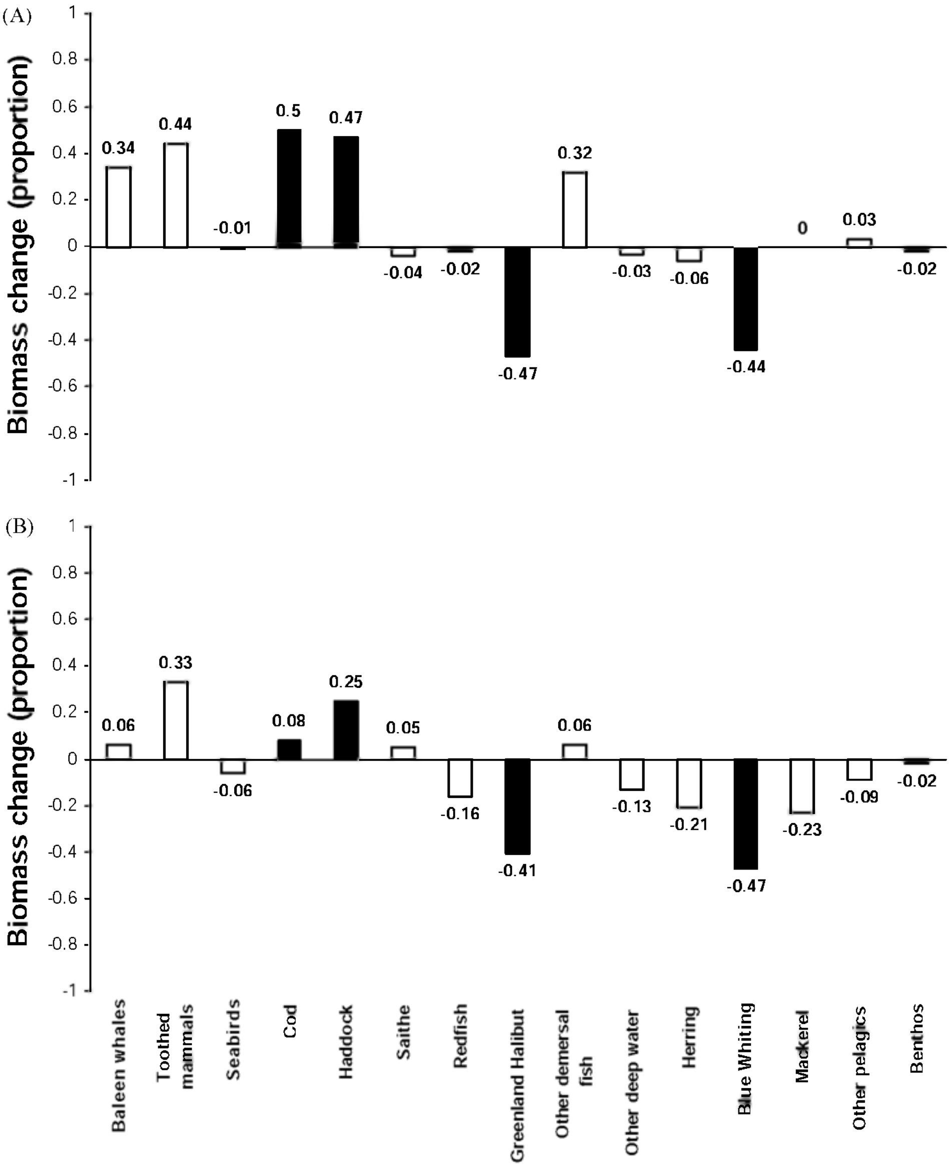


Fig. 2. Changes in group biomass after the 10-year simulation using the 1997 Ecopath model. Groups in black are of particular interest in the present context. Values are proportion of change after 10 years: (A) under conditions of the present Trawl Spatial Closure system; (B) under Open Access (without the Trawl Spatial Closure system), and with trawl gear effort increased by 20%.

(Fig. 4B). The only exceptions were the large single trawlers, which primarily target deep-water species such as Greenland halibut (Fig. 4B). The effort distribution of this gear type would only be expected to change if a change in targeted species would occur under Open Access.

3.1.3. Blue whiting and Greenland halibut

The initial simulations suggested that the trawl closures currently in place (Trawl Spatial Closure), in conjunction with the effort management system used in Faroese fisheries, appear to be effective in maintaining demersal fish stocks, especially cod and haddock.

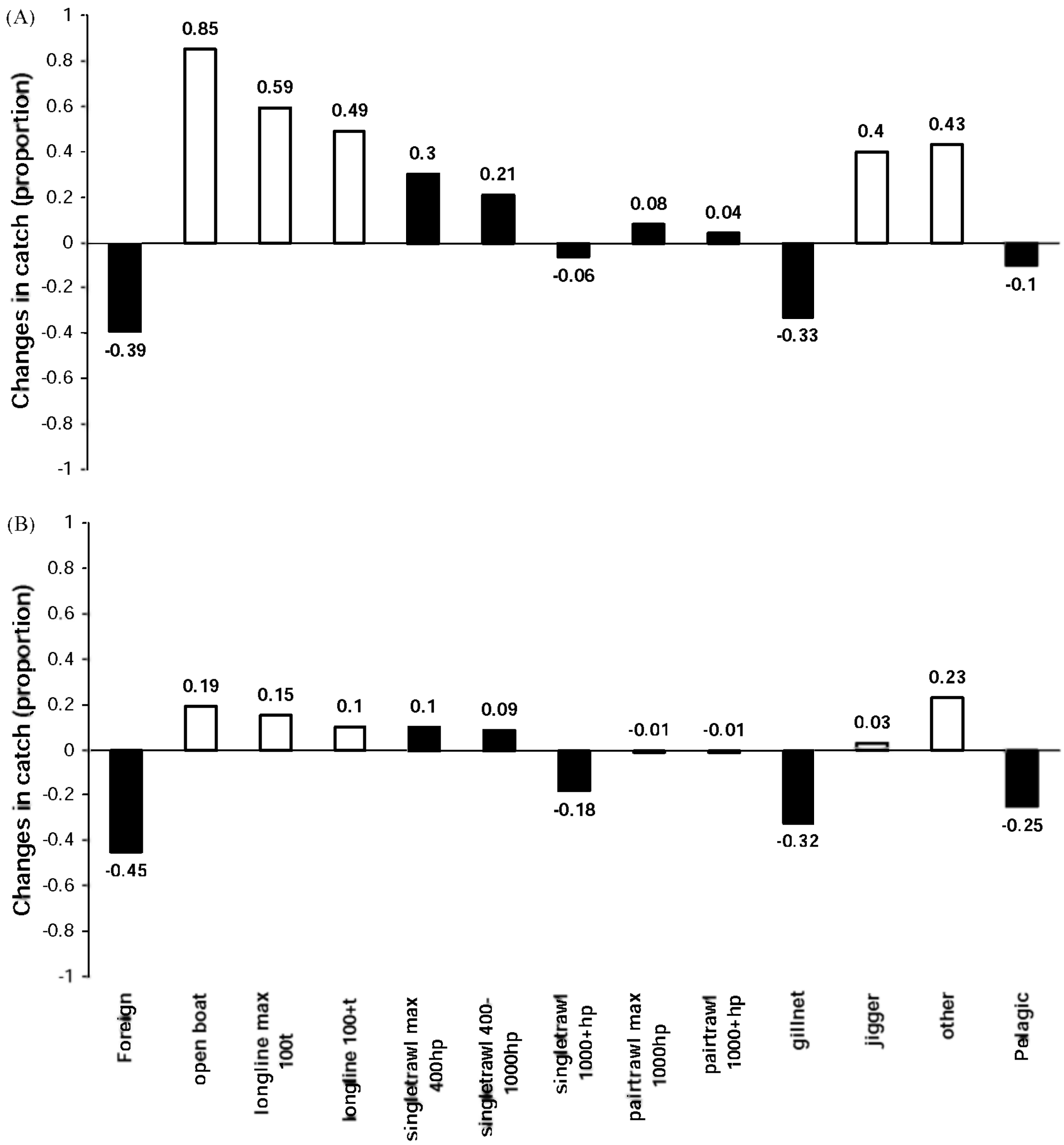
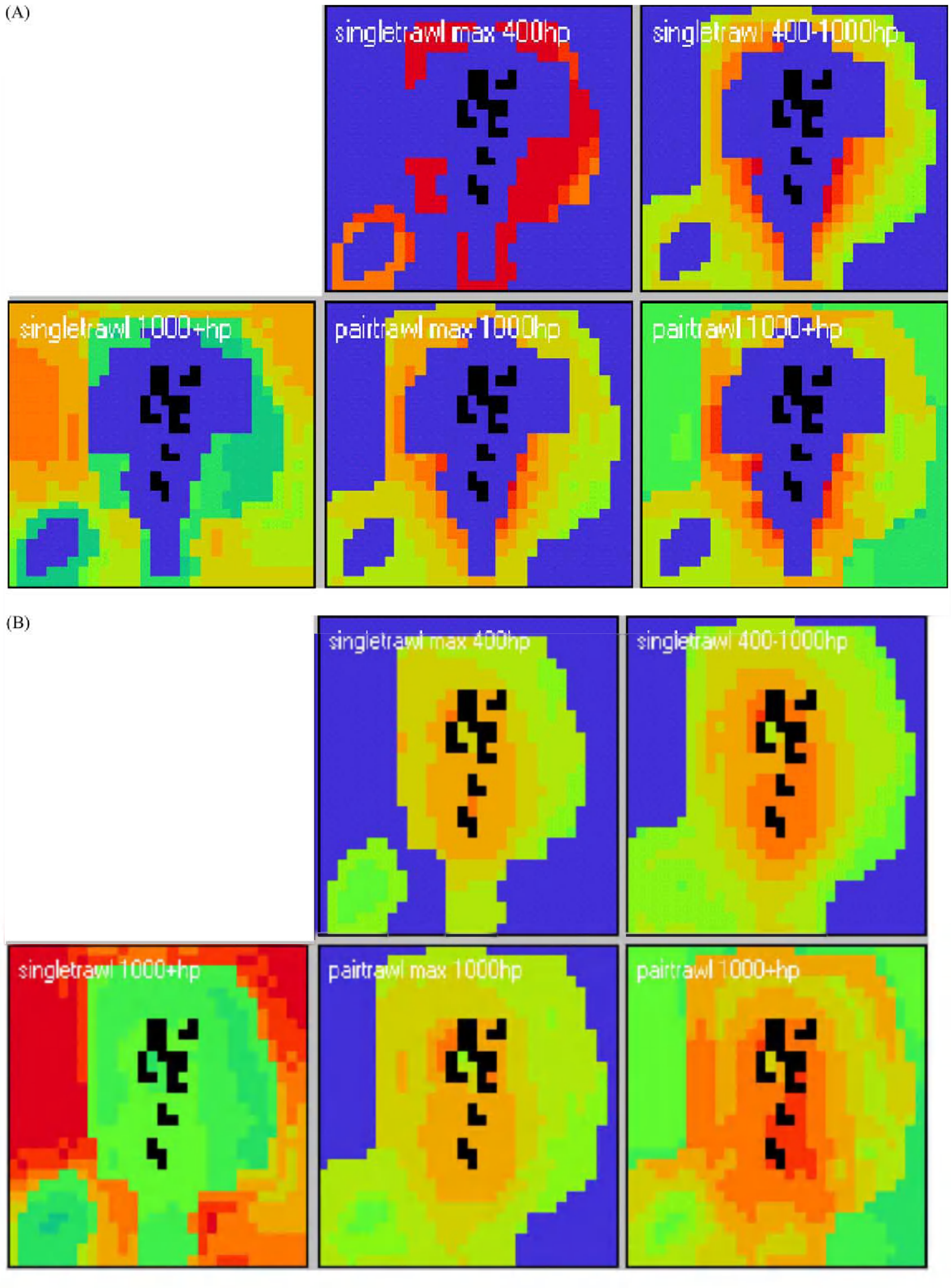


Fig. 3. Changes in catches by gear type at the end of the 10-year simulation using the 1997 Ecopath model. Gear types in black are of particular interest in the present context. Values are proportional change: (A) under conditions of the present Trawl Spatial Closure system; (B) under Open Access (without the Trawl Spatial Closure system), and with trawl gear effort increased by 20%.

However, the plateau closure does not contribute to the conservation of either blue whiting or Greenland halibut stocks (see Fig. 2A), because neither species is common on the shallow shelf area.

Two simulation scenarios were evaluated as potential options to address the projected decline in biomass observed for Greenland halibut and blue whiting (Fig. 2A).

1. The introduction of additional closed areas in offshore waters (10 and 20% of waters deeper than 200 m within the model area, Fig. 1). These


(A)
singletrawl max 400hp
singletrawl 400-1000hp
singletrawl 1000+hp
pairtrawl max 1000hp
pairtrawl 1000+hp
(B)
singletrawl max 400hp
singletrawl 400-1000hp
singletrawl 1000+hp
pairtrawl max 1000hp
pairtrawl 1000+hp

additional closures were applicable to all gear types, and designed primarily to protect Greenland halibut and the pelagic species. Present trawl closures were maintained. Closures were either permanent (12-month closure) or seasonal (6-month closure). Temporal rotation of closures for periods less than 6 months (e.g. 2-month closures) was not considered, being an impractical option in these fisheries.

2. Gear-specific effort reductions. The effort levels of the 'foreign' fleet (accounting for approximately 96% of the 1997 blue whiting catch), and the Faroese 'gillnet' and largest 'single trawl' gear types (accounting for approximately 95% of Greenland halibut catches, Anon., 1998e) were reduced by 10, 20, and 50%, with no spatial access limitations other than the existing Trawl Spatial Closure conditions. The hypothetical offshore pelagic closures areas (see option 1, above) were not included in these simulations.

3.1.4. Offshore closures

The locations of the offshore, deep-water closures used for the simulations are indicated in Fig. 1. Note that their location might not be ecologically optimal; they simply represent a 10–20% reduction in habitat available to the gear types within the model simulation area. The results, in the form of simulated biomass changes for the two groups of interest, Greenland halibut and blue whiting, are summarised in Table 7. The results for the two species differed distinctly, with offshore closures affecting the observed decline of Greenland halibut only. The simulations suggested that a 20% permanent closure would be required to reduce the drastic drop in biomass observed for Greenland halibut under Trawl Spatial Closure conditions (−47%, Table 7). It was evident that blue whiting did not respond to the spatial closure simulations; their simulated biomass reductions remained similar to the 44% drop recorded under Trawl Spatial Closure conditions (Table 7).

Table 7
Results of the offshore closure simulations, listing percentage changes in biomass for the two species of interest, Greenland halibut and blue whiting under the four simulation scenarios. The biomass changes observed under Trawl Spatial Closure conditions (as per Fig. 1) are included for comparison

Simulation scenario	Percentage change in biomass	
	Greenland halibut	Blue whiting
Trawl Spatial Closure (default)	−47	−44
10% offshore closure, permanent	−17	−45
10% offshore closure, seasonal	−12	−46
20% offshore closure, permanent	−3	−44
20% offshore closure, seasonal	−9	−46

Changes in catches by gear type targeting the two species of interest were only observed for the Faroese gillnet which accounts for over 54% of Greenland halibut catches (Table 8). The simulated offshore spatial closures reduced the predicted decline in catches of Greenland halibut from 33% (Trawl Spatial Closure) to 15% under a 20% closure regime, irrespective of seasonality (Table 8).

3.2. Gear-specific effort reductions

Given that the foreign fleet accounted for nearly all the blue whiting catches (96%), the effort reduction simulations were applied to this gear category only. The simulations indicated that a 50% effort reduction would be required to reverse the declining trend in biomass and catches for blue whiting observed under Trawl Spatial Closure conditions (Table 9). Such a reduction would result in an 11% increase in biomass and would increase catches by 7% (Table 9). Effort reductions of less than 50% do not change the negative trend observed under Trawl Spatial Closure conditions (Table 9).

The majority of the Greenland halibut is caught by gillnet and the largest single trawler gear type, both of

Fig. 4. Spatial fishing effort distributions for trawl gear after the 10-year simulation periods: (A) Trawl Spatial Closure, showing the exclusion of trawl gear from the 12-nm zone, and (B) free access, i.e. the 12-nm zone is opened to trawl gear and effort increased by 20%. Fleet effort is color coded, ranging from blue (no effort) to red (highest effort). Thus, the trawl exclusion zone is represented in part (A) as the blue zone around the black land masses. Maps shown in sequence (from left to right, top to bottom): single trawler up to 400 hp, single trawler 400–1000 hp, single trawler >1000 hp, pair trawler up to 1000 hp, and pair trawler >1000 hp.

Table 8
Results of the offshore closure simulations, listing percentage changes in catches for those gear types targeting the two species of interest, Greenland halibut and blue whiting. The changes in catches observed under Trawl Spatial Closure conditions (as per Fig. 1) are included for comparison

Simulation scenario	Percentage change in catches			
	Foreign gear	Single trawler >1000 hp	Gillnet	Pelagic
Trawl Spatial Closure (default)	−39	−6	−33	−10
10% offshore closure, permanent	−42	−5	−19	−13
10% offshore closure, seasonal	−42	−6	−21	−13
20% offshore closure, permanent	−42	−5	−15	−12
20% offshore closure, seasonal	−42	−5	−15	−13

which are Faroe domestic fleets (Table 4). The gillnets are large-meshed (200–280 mm stretched mesh) and specifically target Greenland halibut and monkfish in deep waters. The large single trawlers primarily fish in deep waters and thus their main targets are redfish and Greenland halibut (Table 4).

To evaluate effort reductions, the gear types were evaluated separately and then combined. The Trawl Spatial Closure conditions indicated a 47% decline in Greenland halibut biomass and a 39% reduction in catches over the 10-year simulation period (both gears combined, Table 10).

The simulations indicated clearly that in order to halt the decline in Greenland halibut biomass observed under simulated Trawl Spatial Closure conditions, a reduction in effort of 20–50% for gillnet only, or close to 50% for large single trawl only is required. A simultaneous reduction of 20% in effort for each gear type has the same effect (Table 10).

Table 9
Results of the 10-year simulation of effort reductions for the foreign fleet targeting blue whiting. Listed are percentage changes in biomass and catches of blue whiting. The changes in biomass and catches observed under Trawl Spatial Closure conditions are included for comparison

Effort reduction	Blue whiting	
	Change in biomass (%)	Change in catch (%)
Trawl Spatial Closure (default)	−44	−39
10%	−31	−30
20%	−18	−18
50%	+11	+7

4. Discussion

4.1. Present conditions (Trawl Spatial Closure)

The current fisheries management system in place in the Faroe Islands, simulated forward over 10 years from 1997, suggested that the biomass of most demersal species would increase during this period. Saithe was the exception, with a projected marginal decrease in biomass. However, given the short simulation time span and the relatively long generation time for the major demersal species, there is some doubt attached to the magnitude of the simulated changes in biomass (e.g. 50% increase for cod, Fig. 3A). This is discussed in the section below on Open Access.

In the present simulations we ignored the limited summer entry into a small section of the 12-nm zone permitted to 10–15 small trawlers (<500 hp). This fishery, which targets mainly flatfish, operates under strict rules of by-catch limits, and in situ by-catch reduction devices (i.e. sorting grids) are compulsory. Thus, we assumed these gears to exert minimal by-catch mortality on the demersal species emphasised here (i.e. cod and haddock). However, future studies should consider the potential habitat and juvenile mortality effects of this and other gear types within the trawl exclusion zones.

A further refinement in the simulations would be the incorporation of unreported catches and discards. This would increase the total catches, change fishing mortality rates, and increase mortalities of non-fisheries bycatch species. Future studies need to consider discard and bycatch issues (see Zeller et al., 2001).

The Trawl Spatial Closure simulations indicated that Greenland halibut and blue whiting did not

Table 10
Results of the 10-year simulations of effort reductions for the two gear types primarily targeting Greenland halibut. Listed are percentage changes in biomass and catches of Greenland halibut for gillnet and large single trawl gears, as well as for both gear types combined. The changes in biomass and catches observed under Trawl Spatial Closure conditions are included for comparison

Gear type	Effort reduction		Greenland halibut					
	Trawl Spatial Closure (default)		10%		20%		50%	
	Biomass	Catch	Biomass	Catch	Biomass	Catch	Biomass	Catch
Gillnet			−29	−20	−15	+8	*+32*	*+21*
Single trawl			−31	−4	−21	−2	*+8*	*+1*
Both gears	−47	−39	−18	−12/−2	*+6*	*+6/+1*	*+38*	*+32/+6*

benefit from the current spatial management regime. This is not surprising, given that the majority of their habitat, and thus fishing grounds, are outside of the present trawl-closure areas. Significantly, the stock of Greenland halibut in the Faroe Islands area (a stock shared between Greenland, Iceland and Faroe Islands) are considered at low levels, and catches have routinely exceeded ICES advice (Anon., 2000b). Thus, it is not really surprising that our present simulations (using 1997 catch levels) result in substantial declines in biomass of this species under all simulation conditions. Furthermore, overfishing of blue whiting seems to be occurring at a substantial rate, as the total 1997 landings of blue whiting in all ICES areas exceeded management advice by nearly 15% (Anon., 1998b), and by the year 2001 the catch exceeded the recommended TAC by 77% (Anon., 2001a). Average fishing mortality has increased drastically over the last few years, and the most recent estimate, for the year 2000 ($F = 0.86$), is considered outside suggested safe levels (Anon., 1998b, 2001a).

4.2. Removal of trawl closure (Open Access) and data concerns

The results obtained under conditions of free access by all gear types to the trawl exclusion zone illustrate a clear reduction in potential benefits. Indeed, one might have expected a stronger negative response in demersal stock biomass once protected areas are opened to increased fishing effort, particularly if one considers the general importance of shallow areas as juvenile nursery grounds for many commercial species (Zeller and Pauly, 2001), including cod in the Faroe Island area (Jákupsstovu and Reinert, 1994). The underlying Ecopath input data (to a large extent based on fisheries-dependent virtual population analysis (VPA)) suggest strong growth in most demersal stocks. However, recent events in Iceland raise increasing concerns on reliance on fisheries-dependent data. Reports from Iceland indicate that cod stock biomass was overestimated, resulting in considerable excess quota allocations (Valtýsson, The Marine Research Institute, University of Akureyri, Iceland, personal communication; Anon., 2001b). It has been suggested that such overestimations might relate to over-reliance on hyper-stable, fisheries-dependent data (Hilborn and Walters, 1992) for tuning of the VPA analyses, resulting in overestimated abundances and underestimated fishing mortality rates (Myers et al., 1996, 1997). If this observation is correct for the ICES-based VPA stock assessments, it will shed considerable uncertainty on the VPA-based biomass and fishing mortality rate estimates used in the present model, and the resulting dynamic projections. Future simulations should examine the effects of variation in biomass and fishing mortality rate estimates.

4.3. Pelagic closures and effort reductions

The simulations of both offshore closures in deep waters, and effort reductions for the main pelagic species, blue whiting, and a major deep-water species, Greenland halibut, clearly indicated that significant reductions in effort would be required to change the trend in declining biomass projections.

The simulated offshore spatial closures appeared to be effective for Greenland halibut only. The blue whiting is highly migratory and has large spatial distributions outside the area being modeled (Anon., 2001b).

In order for spatial closures to be effective for blue whiting, their whole stock distribution range would have to be considered for simulations.

An effort reduction in the vicinity of 50% for the gear taking the majority of the blue whiting catch, and a reduction by approximately 20% for each of the two major gear types targeting Greenland halibut would be required to reverse the projected biomass decline for both species. This reflects well calls for the reduction of global fishing fleet overcapacity (Pauly et al., 2002), as well as the advice from the ICES Working Group, that for the last few years the actual stock-wide catch of blue whiting was far in excess of the recommended TAC, resulting in a strong recommendation for sharply reduced exploitation levels (Anon., 2001b). Given that the majority of blue whiting catch in the Faroe Island area is taken by foreign fleets, and numerous nations participate in the stock-wide fishery, such a reduction requires urgent international agreement and action within the framework of ICES.

The Greenland halibut stock is also considered to be at a low level. There are no formal agreements between the three nations sharing the stock (Iceland, Greenland and Faroe Islands), and catches have been well in excess of the TACs advised by the ICES Working Group (Anon., 2000b). The significant reduction in fishing mortality called for by the ICES Working Group is corroborated by the present simulations.

4.4. Future studies

By its very nature, the present model has to be considered preliminary, and several improvements could be considered. First, improvements in basic input data are required. The paucity of local stock information for anything but the major fisheries species needs addressing. Furthermore, the potential problem of overestimation of biomass (and underestimation of fishing mortality) based on VPA assessments undertaken with hyper-stable, fisheries-dependent data needs to be addressed (Hilborn and Walters, 1992). Future simulations need to evaluate the effects of such biases in input parameters on the modelling outcomes prior to using findings such as those presented here for potential management decisions. As indicated earlier, unknown amounts of discarded and unreported bycatch need to be accounted for also. Second, future simulations should consider habitat-specific effects of fishing gear, as well as the effects of the spawning area closures not considered in the present simulations. Third, the major species could be evaluated under split-pool conditions, that is, modelling juveniles separately from their adult stage (Pauly et al., 2000). This would permit better evaluation of water current retention effects on the juvenile component of the demersal stocks.

5. Conclusions

The present simulations represent the first attempt to evaluate in an ecosystem context the potential effects of gear-specific spatial closures being used by the Faroe Islands. The simulation results suggest that the current management regime, which limits effort and spatial access by certain gears (trawls) is likely to be effective for demersal stocks. Furthermore, the simulations are also in line with single-species assessment advice, which indicated that the deep-water fisheries for Greenland halibut and the pelagic fisheries for blue whiting are being heavily overfished.

The present, preliminary simulations suggest that significant management changes would be required to halt the current declining biomass trend for Greenland halibut and blue whiting, including considerations for extensive spatial closures for deep-water fisheries (see also Koslow et al., 2001), as well as drastic reductions in real effort for both pelagic and deep-water fisheries (see also Pauly et al., 2002).

Given our primary interests in fisheries issues, the present model has to be considered 'fish-centric' in design and layout. Furthermore, this model is preliminary in nature, requiring input data improvements. Future simulations should consider habitat-specific effects of fishing gear, and the effects of the existing spawning area closures, excluded from the present simulations. Finally, the major species should be evaluated under split-pool conditions (Pauly et al., 2000), to permit better evaluation of the effects of surface water advection fields on demersal stock dispersal.

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