

Discrimination between Icelandic cod (*Gadus morhua* L.) populations from adjacent spawning areas based on otolith growth and shape

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Received 23 July 2005; received in revised form 27 April 2006; accepted 5 May 2006

Abstract

Studies on Atlantic cod (*Gadus morhua* L.) have demonstrated extensive variation in life history characteristics among populations exposed to different environmental conditions. In Iceland, cod sampled from adjacent spawning areas, within the main spawning area at the southwest coast, exhibit variation in vital life history characteristics. In this study, we investigated the stock structure of Icelandic cod on the main spawning grounds to discriminate between these adjacent spawning groups by using otolith growth and shape. Otolith growth was based on annual increment width estimated for the major age groups (6–7 year olds) of the spawning stock. Otolith shape was determined using Fourier analysis and compared among cod sampled from the different spawning areas with stepwise canonical discriminant analysis (CDA). We found significant differences in growth and otolith shape between adjacent spawning groups of cod where those sampled close to the coast differed from those that were sampled further out on the bank and continental shelf. Our results suggest that these cod may belong to different populations and the large and fast growing cod spawning in the coastal area may need special protection given their significance to the overall productivity of the stock.

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Keywords: Atlantic cod (*Gadus morhua* L.); Spawning groups; Stock structure; Otolith growth; Otolith morphology

1. Introduction

Cod is distributed on the continental shelves and banks of the North Atlantic Ocean, forming valuable fisheries throughout its distribution (Schopka, 1994; Brander, 1995). Because of the species' extensive geographic range, the environments in which different populations or stocks of cod inhabit vary greatly (Brander, 1995). Consequently, extensive inter- and intra-stock variation in vital life history characteristics such as growth and maturity have been demonstrated (e.g., Beacham, 1982; Brander, 2000; Marteinsdottir and Begg, 2002; Lambert et al., 2003). Despite such life history variation and the existence of multiple spawning components within stocks (Begg and Marteinsdottir, 2002a), all regional cod stocks in the north Atlantic are currently assessed as single

homogenous units (Marteinsdottir et al., 2005). Likewise, cod in Icelandic waters have historically been assumed to belong to a single stock with major spawning areas identified off the south coast (Jonsson, 1982; Schopka, 1994; Marteinsdottir et al., 2000a). Assessment and management have based measures of vital life history characteristics such as growth, survival and reproductive success on this assumption. However, recent studies have shown that cod spawning at various locations at the south and southwest coast of Iceland display extensive variation with respect to genetics (Jonsdottir et al., 2002), life history (Marteinsdottir and Petursdottir, 1995; Marteinsdottir et al., 2000b; Begg and Marteinsdottir, 2000, 2003) and migration behavior (Pálsson and Thorsteinsson, 2003).

Numerous methods have been used for stock identification (see reviews in Cadrin et al., 2005). Some of these include the structure and shape of otoliths (e.g., Campana and Casselman, 1993; Friedland and Reddin, 1994; Begg

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and Brown, 2000). Otolith morphology and/or shape has also been used to demonstrate differences in growth and indicate which environment a fish has experienced during its life history (e.g., Campana and Neilson, 1985; Smith, 1992; Campana and Casselman, 1993). Furthermore, incremental patterns formed in otoliths have been used to provide a record of growth and other life history and habitat characteristics (e.g., Campana and Neilson, 1985; Dawson, 1991; Begg et al., 2001). So far, no studies on otolith morphology or incremental growth have been conducted on adult cod from Icelandic waters.

In this study we investigate the stock structure of Icelandic cod on the main spawning ground to discriminate between adjacent spawning groups by using otolith growth and shape. Our analysis focused on spawning cod sampled from three adjacent spawning areas located within the main spawning ground off the southwest coast of Iceland.

2. Material and methods

2.1. Sampling

Samples of spawning cod were collected with bottom trawl and gill nets during the spawning season (March–April) in 1996 from three adjacent, depth-stratified, areas (Coast <75 m; Bank 75–200 m; and Shelf >200 m; as described in Begg and Marteinsdottir, 2003) on the main spawning ground off the southwest coast of Iceland (Fig. 1; Table 1). To facilitate comparisons between areas and year classes, only 6 and 7 year old cod (i.e., 1990 and 1989 year classes) were used

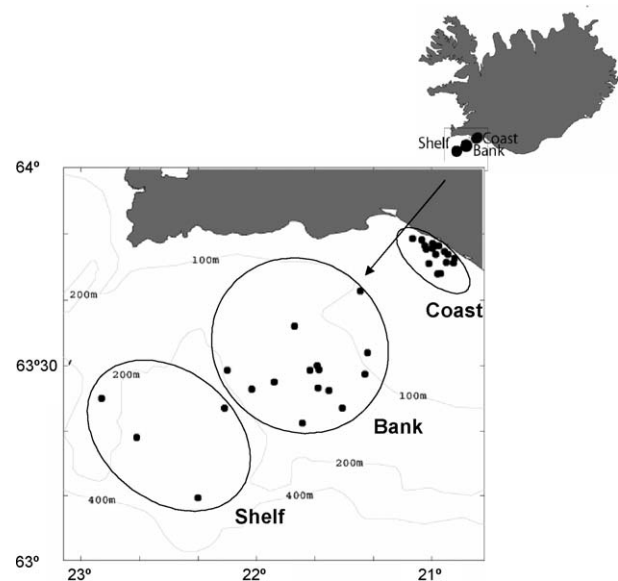


Fig. 1. The three sampling areas, Coast, Bank and Shelf, on the main spawning ground southwest of Iceland and the individual sampling locations (depth-stratified: Coast <75 m; Bank >75–200 m; Shelf >200 m).

in the study. In each area, otoliths were removed from 100 cod (i.e., 50 from each year class) selected at random from all cod sampled within the specific age range (Table 1). All cod were sexed, measured and weighed. Sex ratios were slightly skewed with 56%, 53% and 61% of the randomly picked samples classified as females at the Coast, Bank and Shelf, respectively. Somatic condition was defined as $K = (\text{total weight} / \text{total length}^3) \times 100$. The hepatosomatic index (H)

Table 1

Mean and standard deviation of cod (*Gadus morhua* L.) total fish length (L , cm), gutted fish weight (W_g , kg), total fish weight (W , kg), somatic condition factor (K), ovarian free condition factor (K_o) and liver condition factor (H) at the three sampling areas (Coast, Bank, Shelf) for each year class (1989, 1990) and results from analysis of variance (ANOVA) testing mean differences between areas

Year class	N	Coast	N	Bank	N	Shelf	F	P
$L \pm \text{S.D.}$								
1989	50	98.9 \pm 8.2	50	81.5 \pm 5.9	50	77.8 \pm 4.6	154.45	***
1990	50	95.2 \pm 7.3	50	75.6 \pm 7.1	50	72.0 \pm 5.1	181.32	***
$W_g \pm \text{S.D.}$								
1989	50	8.62 \pm 2.3	50	4.10 \pm 1.2	50	3.39 \pm 0.6	167.44	***
1990	50	7.96 \pm 2.0	50	3.23 \pm 1.0	50	2.72 \pm 0.7	218.98	***
$W \pm \text{S.D.}$								
1989	50	11.05 \pm 3.5	50	5.38 \pm 1.6	50	4.21 \pm 0.9	128.67	***
1990	50	10.01 \pm 2.7	50	3.99 \pm 1.3	50	3.42 \pm 0.8	207.12	***
$K \pm \text{S.D.}$								
1989	50	1.11 \pm 0.1	50	0.97 \pm 0.2	50	0.88 \pm 0.1	36.21	***
1990	50	1.13 \pm 0.2	50	0.89 \pm 0.1	50	0.90 \pm 0.1	64.40	***
$K_o \pm \text{S.D.}$								
1989	44	0.99 \pm 0.1	50	0.89 \pm 0.2	49	0.80 \pm 0.1	31.56	***
1990	46	1.03 \pm 0.1	49	0.81 \pm 0.1	49	0.82 \pm 0.1	65.87	***
$H \pm \text{S.D.}$								
1989	44	6.583 \pm 1.9	49	7.408 \pm 2.6	48	7.357 \pm 2.5	1.752	n.s.
1990	46	5.360 \pm 1.8	49	5.911 \pm 2.4	49	5.872 \pm 2.5	0.873	n.s.

n.s. $p > 0.05$; *** $p < 0.001$.

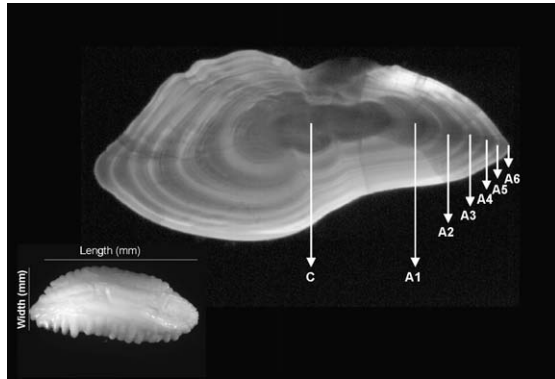


Fig. 2. An otolith section from a 6 year old Cod (*Gadus morhua* L.) showing the core (c) and the increment used in the study (A1–A6). Each increment was measured to the outer margin of the winter zone. Inset: Sagittal otolith with the proximal surface facing up and the anterior part of the otolith to the left.

was defined as the proportion of liver weight to ovarian free weight.

2.2. Otolith preparation and interpretation

Otoliths used for morphological analysis were cleaned in fresh water; stored dry and weighed to the nearest 0.01 mg. Either the left or right otolith from each sagittae pair was used as no consistent differences in morphology have been detected between left and right otoliths (Campana, pers. com.) Video images of each otolith were captured at 4.8 \times magnification and stored for further analysis. The otolith direction was standardized by positioning the proximal side of each otolith facing up and the anterior side to the left (Fig. 2). Transverse sectioning of each otolith was performed according to standard procedures routinely used at the Marine Research Institute (Petursdottir, unpublished). Images (1.6 \times magnification) of sectioned otoliths were stored for later estimation of otolith growth. Growth estimates were based on measurements of annual increments (i.e., annuli) from the core of the otolith section to the outer margin of each opaque zone (Fig. 2). All measurements were conducted along the largest radius of the otolith.

2.3. Otolith morphology

Otolith morphometric measurements were obtained using the OPTIMASTM image analysis system (version 6.5). These included: Fast Fourier Transform (FFT) of the outline shape (Campana and Casselman, 1993), length, width, area, perimeter, circularity (squared otolith perimeter/area) and rectangularity (otolith area of the minimum-enclosing rectangle). A total of 10 amplitudes were calculated from the FFT and prior to statistical analysis standardized by dividing each amplitude by the mean radial length (Campana and Casselman, 1993).

2.4. Statistical analysis

Mean size, age and condition of spawning cod were initially compared between areas within each year class using one-way analysis of variance (ANOVA). A total of 18 otolith growth and morphometric variables were then used to discriminate between spawning cod collected from the three adjacent spawning areas and 2 year classes. These included the 10 shape amplitudes and 6 morphometric characteristics, otolith weight and the growth parameter, length at age. All variables were examined for normality and homogeneity of variances and log_e-transformed if these assumptions were not satisfied. Analysis of covariance (ANCOVA) was used to test the effect of fish length on each individual otolith morphometric variable between cod from different areas and year classes (Zar, 1999). Area and year classes were treated as fixed factors and fish length the covariate. One of the variables, otolith length, was found to have a significant interaction with fish length and area ($p < 0.05$) and was excluded from further analysis as it could not be corrected for fish length. The remaining otolith size variables (area, perimeter, weight and width) did not show significant interactions ($p > 0.05$; i.e. samples with equal slopes) but correlated significantly with fish length. These were adjusted using their respective common within-group slope (b) to standardize the samples. None of the shape variables (rectangularity, circularity and the Fourier amplitudes) correlated significantly with length. Two-way fixed effects ANOVA was used to test differences in mean otolith variables such as otolith length, width, area and weight between cod from different areas and year classes. Tukey's Honestly Significant Difference (HSD) test was used for *a posteriori* comparisons. Growth based on annual increment width was compared among cod from different areas and year classes using ANOVA. Forward stepwise Canonical Discriminant Analysis (CDA) was used to detect differences in Otolith shape between cod sampled from the different areas and year classes. Two discriminant analyses were performed, one including both shape and standardized size variables (Fourier amplitudes, otolith circularity and rectangularity and standardized otolith weight, length, area and perimeter and length at age) and another one including only the shape variables (otolith circularity, rectangularity and the Fourier amplitudes). Jack-knifed cross-validation procedures were used to give unbiased estimates of classification success. When comparing cod from the different areas and year classes, only those of sampled lengths common to all areas and year classes (75–96 cm) were used in the analysis. All statistical procedures were conducted with the SPSS 9.0 statistical program (SPSS, 1997).

3. Results

3.1. Fish size and condition

Within each year class, fish size and somatic condition of cod differed significantly between areas (ANOVA, $p < 0.001$;

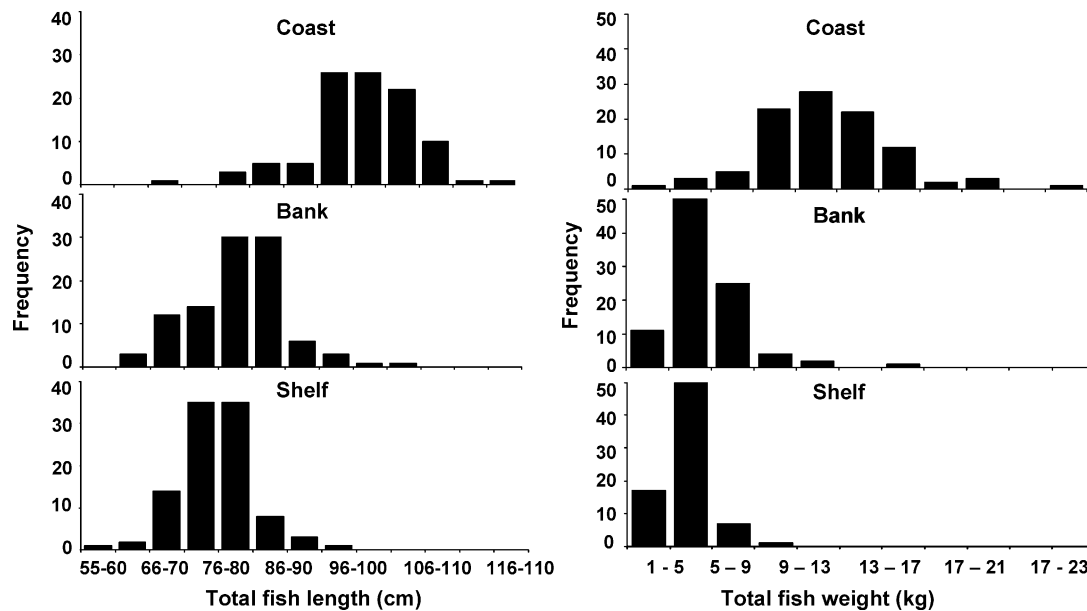


Fig. 3. Total length and total weight distribution of all cod (*Gadus morhua* L.) pooled for both year classes at the three sampling areas (Coast, Bank and Shelf).

Table 1). Cod from the Coast were in better condition and on average twice as large and heavy as those from the more off-shore Bank and Shelf areas (Fig. 3; Table 1). Liver condition, however, did not vary among cod from the different areas ($p > 0.05$). The fish length-weight relationship was highly significant in all areas ($r^2 = 0.79 - 0.92$, $p < 0.001$; Table 2). The slopes of the total fish length-fish weight relationship (log transformed data) were not significantly different among areas within each year class (ANCOVA, $p > 0.05$). However, the intercepts for each relationship were significantly different among areas within each year class (ANCOVA, $p < 0.001$).

3.2. Otolith growth

Otolith growth was affected significantly by area and annual increment (two-way ANOVA for each year class, $p < 0.0001$). Comparisons of mean growth among areas within each year class revealed that cod from the Coast area were growing significantly faster during the 6–7th increment years compared to those from the Bank or Shelf areas

(ANOVAs performed for each year class and annual increment, $p < 0.01$; HSD; $p < 0.01$; Fig. 4; Table 3). Significant differences were also detected during the 2–3rd increment years in the 1990 year class, with the fastest growth among cod from the Coast and the slowest growth among cod from the Bank (Fig. 4; Table 3)

3.3. Otolith morphology

All of the otolith size variables (length, weight, width, area and perimeter), but not the otolith shape variables (rectangularity and circularity) were significantly different between year classes and areas (two-way ANOVA, $p < 0.05$). With respect to the otolith size variables, significant differences were detected in all cases between the Coast and two off-shore areas (HSD, $p < 0.001$). No significant interactions

Table 3

Results from Tukey's HSD comparison test for mean difference in otolith increment growth among the 1989 and 1990 year classes of cod from the three areas, Coast, Bank and Shelf

Year class	Mean otolith increment growth	Coast versus Bank	Coast versus Shelf	Bank versus Shelf
1989	2nd increment year	n.s.	n.s.	n.s.
	3rd increment year	n.s.	n.s.	n.s.
	4th increment year	n.s.	n.s.	n.s.
	5th increment year	n.s.	n.s.	n.s.
	6th increment year	***	*	***
	7th increment year	***	***	n.s.
		***	*	n.s.
1990	2nd increment year	***	*	n.s.
	3rd increment year	*	n.s.	*
	4th increment year	n.s.	n.s.	n.s.
	5th increment year	n.s.	n.s.	n.s.
	6th increment year	***	***	n.s.

n.s. $p > 0.05$, * $p < 0.05$; *** $p < 0.001$.

Table 2

The relationship between total fish length (L) and total fish weight (W) among cod (*Gadus morhua* L.) in all areas and both year classes

Areas	Year class	Relationship	r^2	F	P
Coast	1989	$W = 1.23E-06L^{3.4764}$	0.86	302.84	***
	1990	$W = 2.32E-06L^{3.3468}$	0.80	192.94	***
Bank	1989	$W = 4.61E-06L^{3.1676}$	0.70	111.99	***
	1990	$W = 4.34E-06L^{3.1676}$	0.92	563.10	***
Shelf	1989	$W = 4.34E-06L^{3.1676}$	0.79	179.82	***
	1990	$W = 9.46E-06L^{2.9877}$	0.81	206.36	***

*** $p < 0.001$.

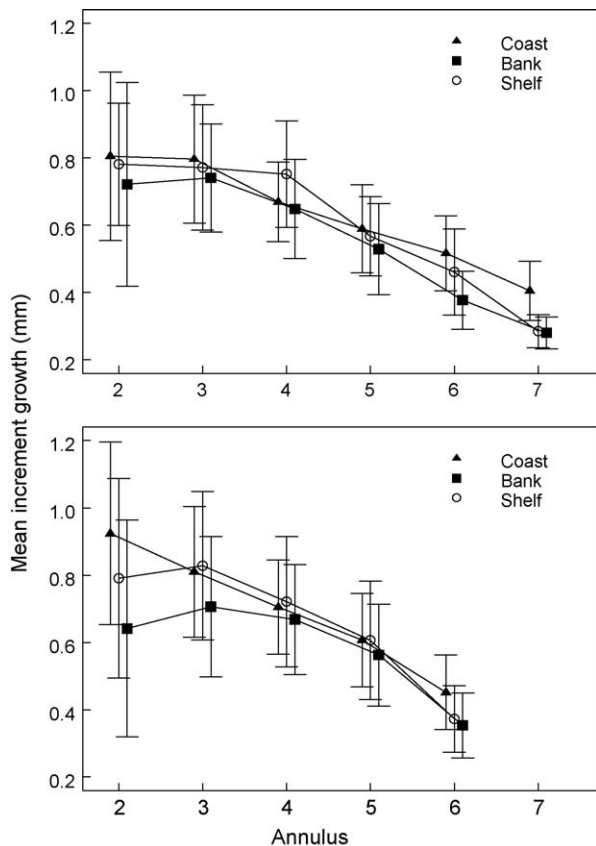


Fig. 4. Mean otolith growth (and standard deviations) for the year classes 1989 (top panel) and 1990 (bottom panel) during each increment year (1991–1996) and (1992–1996) at the three sampling areas; Coast, Bank and Shelf.

were detected between cod from the different areas and year classes for any of the otolith variables ($p > 0.05$).

The CDA including all variables (except otolith length) discriminated between cod from the different areas (Table 4; Fig. 5). Only the first discriminant function (DF1) which explained 99.8% of the total variance was significant (Table 4). Accordingly, 59% of the variability of the scores for the first DF was accounted for by the differences among the three areas. Based on the first CDA, cod were separated into those from the Coast and those from the more offshore Bank and Shelf areas (Fig. 5). Length at age, otolith weight and amplitude 9 and 4 contributed most to the explanatory power of CDA. Mean DF1 scores for cod from the Coast were significantly different from the others, while no significant differences were detected between those from the Bank and Shelf (HSD; $p > 0.05$). Nearly 80% of cod from the Coast were correctly classified (Table 5). Only 20% were classified to the Bank and no cod from the Coast were classified to the Shelf area. Classification success between the Bank and Shelf groups was less clearly defined where less than 55% (Bank) and 51% (Shelf) were correctly classified. However, most of those that were mis-classified were grouped with the other area (i.e., Shelf or Bank). As such, only 12% of the Bank

Table 4

The significant standardized canonical coefficients based on discriminant function analysis performed by entering into the analysis: (a) All variables except otolith length (which was excluded from the analysis) and (b) only the shape variables (Fourier amplitudes and otolith rectangularity and circularity)

	Standardized canonical coefficients	
	DFA functions	
	1	2
(a) All variables		
FFT4	−0.374	0.664
FFT9	0.465	−0.843
Standardized weight	0.345	0.203
Length at age	0.925	0.398
Wilk's Lambda	0.41***	0.98 ns ^a
Squared canonical correlation	0.59	0.2
Proportion of expl. variance	99.8	0.2
(b) Only shape variables		
FFT1	0.426	0.910
FFT4	−0.672	0.322
FFT9	0.843	−0.504
Wilk's Lambda	0.76***	0.98 ns ^a
Squared canonical correlation	0.22	0.02
Proportion of expl. variance	94.1	5.6

For each function are also listed the standardized canonical function coefficients, Wilk's Lambda, squared canonical correlations (proportion of variability of each functions scores accounted for by differences among areas) and the proportion of the explained variance accounted for by each function; *** $p < 0.001$.

^a $p > 0.05$.

samples and 3.5% of the Shelf samples were classified to the Coast area (Table 5).

The CDA performed using only the shape variables also discriminated between cod from the different areas (Table 4). Identical to the first CDA, only the first function, accounting for 94.4% of the explained variance, was significant.

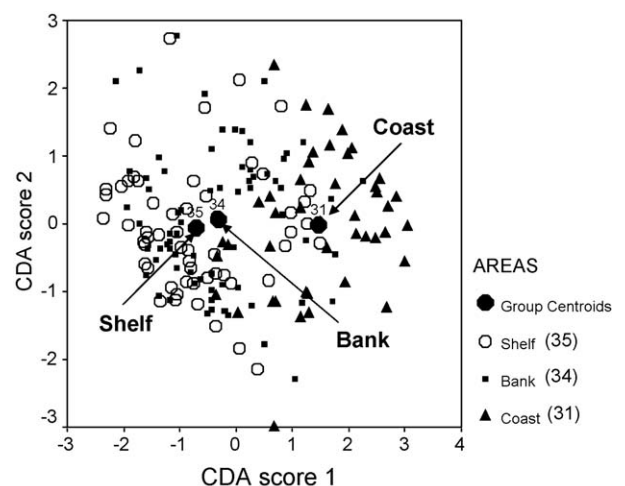


Fig. 5. Scatter plot showing the scores for Canonical Discriminant Analysis (CDA) 1 and 2 of cod (*Gadus morhua* L.) from the three sampling areas; Coast, Bank and Shelf for pooled year classes 1989 and 1990. The centroids are marked (31) for the Coast (34) for the Bank and (35) for the Shelf.

Table 5

Jack-knifed cross-validation classification matrices including (a) all variables and (b) only the shape variables (Fourier amplitudes and otolith rectangularity and circularity)

Areas		Pooled data	Classification success (%)			
			Areas			
		<i>N</i>	Coast	Bank	Shelf	
(a) All variables						
Coast	1989 and 1990	44	79.5	20.5	0	
Bank	1989 and 1990	73	12.3	54.8	32.9	
Shelf	1989 and 1990	57	3.5	45.6	50.9	
(b) Only shape variables						
Coast	1989 and 1990	44	45.5	50.0	4.5	
Bank	1989 and 1990	73	16.4	60.3	23.3	
Shelf	1989 and 1990	57	10.5	68.4	21.1	

Both analysis were based on data pooled for both year classes including only cod within the length range 75–96 cm from the three areas: Coast, Bank and Shelf.

Comparisons of mean scores for this function demonstrated significant differences between cod from the Coast and those from the Bank and Shelf areas (HSD; $p > 0.05$). However, only 22% of the variability of the scores for the first DF was accounted for by the differences among the three areas. Accordingly, classification success was much lower compared to the analysis containing both size and shape data. Only 45.5% of the cod from the Coast were classified correctly. Many of these (50%) were classified to the Bank while relatively few cod from the Coast (4.5%) were classified to the Shelf area. Greatest classification success (60%) was detected among cod from the Bank and the lowest classification success among cod from the Shelf, although most of these were classified to the Bank area (Table 5).

4. Discussion

A great differentiation in size, growth and condition was detected between spawning cod in adjacent spawning areas within the main spawning ground off the southwest coast of Iceland. Cod from the inshore Coast area were significantly larger at age and in greater condition than those from the more offshore Bank and Shelf areas. Differences were also demonstrated in the otolith increment growth, as well as in the otolith morphology, with cod at the Coast being distinctly different from those from the more offshore areas. These results add to the growing literature providing increasing evidence for local population structures among cod residing within small geographical areas. Many local cod populations have been characterized by life history differences (Marteinsdottir et al., 2000b; Jonsdottir et al., 2001; Olsen et al., 2004; Salvanes et al., 2004; Yoneda and Wright, 2004), limited home range (Neat et al., 2006), different migration patterns (Palsson and Thorsteinsson, 2003) and genetic differences (Ruzzante et al., 1999, 2000; Hutchinson et al., 2001; Knutsen et al., 2003; Nielsen et al., 2003).

Although life history variation, reflected in the different growth and otolith morphology observed among the adjacent spawning groups, indicates the existence of distinct populations it does not confirm reproductive isolation. Former research has shown differences at the *Pan I* locus between cod spawning in the Coast area and those at greater depth on the slope of the continental shelf at a location directly south of the country (Jonsdottir et al., 1999). However, the *Pan I* locus has been shown to be under selection (Pogson and Mesa, 2004). Therefore, any variation at this locus does indeed support the existence of different life history units but it does not provide undisputable evidence for genetically distinct populations.

The different growth and otolith morphometric patterns of cod from the adjacent spawning areas are not likely to be solely influenced by prevailing environmental conditions on the main spawning ground, as cod in this area do not stay on the spawning areas after completion of spawning (Jonsson, 1996; Thorsteinsson and Marteinsdottir, 1998). Instead they are more likely to result from different migration patterns and associated environmental conditions experienced by the cod during the migration to and from the feeding areas. Iceland is located in the north Atlantic where cold currents from the north meet the warmer water masses from the south. Therefore, the hydrographical conditions and temperatures vary both spatially and temporally (Malmberg and Valdimarsson, 2003). As a result, the distribution of post-spawning cod into areas of different temperatures and food availability will influence the growth rate expressed by the different components of the stock. In general, immature cod in Icelandic waters reside in colder waters, northwest, north and east of the country, until they become mature and start their spawning migration into warmer waters off the south coast (Jonsson, 1996; Begg and Marteinsdottir, 2002b). It has also been demonstrated that after spawning, many of these cod return to the relatively colder waters of the main feeding ground northwest and east of the country (Schopka, 1994; Jonsson, 1996). However, recent tagging studies involving cod from the main spawning area off the southwest coast have shown that cod from this area display at least two alternative foraging strategies, e.g., either shallow or deep water migrations (Palsson and Thorsteinsson, 2003). After leaving the spawning areas, cod migrating to shallow waters experience seasonal changes in temperatures while those that migrated into deeper waters experienced extreme differences in temperatures while displaying extensive vertical movements (Palsson and Thorsteinsson, 2003). Growth has been found to be positively related to temperature and food abundance and was therefore greater among cod migrating into shallow waters (Palsson and Thorsteinsson, 2003). In our study, otolith growth also varied between cod from the different spawning areas and year classes. The main differences between the areas were observed during the 6th and 7th increment years for the 1989 year class and 2nd and 6th increment years for the 1990 year class. In all cases, growth was significantly faster among cod from the inshore coastal area

compared to either of the offshore areas. The observed differences during the 6th and 7th increment years may possibly be related to maturation, although this has not been examined for cod from these spawning areas. Age at 50% maturity (A_{50}) for cod south of Iceland, however, has been shown to be 5.9 years compared to 6.6 years among the slower growing cod north of Iceland (Marteinsdottir and Begg, 2002). In fishes, growth is usually expected to decline at maturation. However, such a decline may be less pronounced among cod from the Coast area if they, following the first spawning season, take up residency in the warm waters of the south coast instead of migrating back to the cold waters of the northern located nursery areas.

This hypothesis is supported by reports based on fishermen's logbooks, observers on board trawlers and gill net fishing boats, as well as recaptured tags, but these have indicated frequent occurrences of large cod (>100 cm) in southern located feeding areas throughout the summer, autumn and early winter months (i.e., along the south and southwest coast including the Reykjanes ridge SW of the country; unpublished observations by the authors and results from tagging experiments by Thorsteinsson at the Marine Research Institute).

Increment growth during the juvenile years varied also among cod from the different spawning areas. This was especially pronounced among juveniles of the 1990 year class (Fig. 4). Such intra-annual differences indicate that juveniles from the different spawning groups may have inhabited different nursery areas. However, little information exists on temporal or spatial differences in dispersal of juveniles originating from different spawning areas. In general, most eggs and larvae are thought to drift from the southern located spawning grounds into nursery areas west, north and east of the country where they distribute over a wide range of depth and temperatures (Marteinsdottir et al., 2000; Begg and Marteinsdottir, 2000). In 1990–1992, juvenile cod of the 1990 cohort were distributed over a greater area (both further northward into deeper water as well as into more easterly waters) compared to those of the 1989 cohort (Saemundsson, unpublished). Juveniles of the 1990 year class, therefore, may have been exposed to a wider range of environmental conditions than those of the 1989 year class.

Cod from the three areas have been exploited since the beginning of fishing in Iceland (Saemundsson, 1924; Jonsson, 1996). Every year a great part of the Icelandic cod stock migrates to these areas to spawn and as they are located conveniently close to shore they have been heavily exploited (Begg and Marteinsdottir, 2002b). Today, cod from these areas, especially those from the Coast, show a definite sign of over-exploitation (Thorsteinsson et al., 1997, 1998; Gudmundsdottir et al., 1998; Marteinsdottir and Björnsson, 1999). Due to its great size, fish from the Coast are particularly valuable and are exported as salted goods to markets in southern Europe. Incidentally, these cod have also been shown to be especially valuable biologically due to their distinct phenotypic characteristics such

as; faster growth rate, longer duration of spawning, lower intensity of atresia, better quality eggs, greater larval survival and more viable juveniles (Marteinsdottir and Björnsson, 1999; Marteinsdottir and Steinarrsson, 1998; Marteinsdottir and Begg, 2002; Harðardottir et al., 2003).

The existence of distinct life history groups of cod, that have in many cases been shown to be genetically distinct (Knutson et al., 2003; Nielsen et al., 2001, 2003), is likely to be a valuable source of both phenotypic and genotypic variation within all of the major cod stocks. Lack of recognition of stock sub-structures will result in loss of stock-richness, which in turn will lead to declines in genetic diversity and reproductive potential of the stocks as whole. Likewise, the distinctive cod spawning in the Coast area is a highly valuable source contributing to the stock-richness and sustainability of the Icelandic cod stock, and should therefore be managed as a separate group of an exceptional value.

Acknowledgements

We thank Skuli Skulason, Jakob Jakobsson, Sigmar Steingrímsson, and Vilhjalmur Thorsteinsson for their comments on an earlier draft, Eiríkur Einarsson and Sigurlína Gunnarsdóttir for literature, Steven Campana for helpful advice, Ingibjörg G. Jónsdóttir and Jonas P. Jonasson for statistical help and finally our colleagues at the otolith department for their assistance.

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