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Morphometric variation of yellowtail flounder

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Significant variation in morphometry was found between sexes of yellowtail flounder and among eight geographic areas, from the Grand Bank to the Mid-Atlantic Bight. Females had relatively deeper abdomens and larger heads than males. Newfoundland samples had relatively shorter bodies, deeper abdomens and longer heads than those from south of Nova Scotia. Morphometric analyses classified 71–95% of yellowtail to the correct Canadian area, but accuracy was lower for areas off the northeastern United States (43–76%). Morphometric differences are consistent with differences in ontogenetic rates among groups. However, shape differences were not strong enough to delineate geographic stocks off the northeastern United States.

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Introduction

Yellowtail flounder, *Limanda ferruginea*, inhabit relatively shallow waters of the continental shelf from the Labrador Shelf to the Mid-Atlantic Bight (Figure 1), and have supported major fisheries off southern New England, on Georges Bank, and on the Grand Bank (Murawski *et al.*, 1997), and minor fisheries off Cape Cod (Cadrin and King, 2002), in the Mid-Atlantic Bight (Cadrin, 2002), and in the Gulf of Maine (Bigelow and Schroeder, 1953; Collette and Klein-MacPhee, 2002). Yellowtail are discontinuously distributed among coastal areas and offshore banks. Accordingly, distinct fishing grounds are considered as separate management areas, though not necessarily separate stocks.

Identification of intraspecific groups with different life history attributes is essential for understanding population dynamics and the evaluation of sustainable harvests. Geographic patterns in body form are important for identifying discrete phenotypic stocks (Winans, 1987). Morphometric variation results from differences in developmental rates. Despite dependence on the environment, ontogenetic rates influence many population attributes that are intimately related to population dynamics and determine how each stock responds to exploitation. Therefore, for the purpose of fishery stock assessment, groups with different growth or reproductive dynamics should be modelled and managed separately. Morphometric variation has been used as a method of stock identification for many fishery resources (see examples cited in Cadrin, 2000, 2005).

Based on geographic variation in ontogenetic rates, morphometric differences are expected among remote fishing grounds. Yellowtail generally grow and mature slower in northern, colder waters (Lux and Nichy, 1969; Pitt, 1974; Moseley, 1986; Begg *et al.*, 1999). Considering the differences in energetic investment, growth and maturity between genders (Moseley, 1986; O'Brien *et al.*, 1993; Begg *et al.*, 1999), sexual dimorphism is also expected. Yellowtail flounder from southern New England and Georges Bank have significantly fewer dorsal and anal fin rays, relatively smaller head size, shorter pectoral fins and larger otoliths with wider annual increments, and different general morphology than those from the Scotian Shelf (Scott, 1947, 1954; Berthome, 1974; Neilson *et al.*, 1986). However, the number of dorsal and anal fin rays is similar among yellowtail from the three principal US fishing grounds (Lux, 1963).

Significant advances in morphometric analysis have occurred in the last two decades, offering more efficient and powerful techniques, such as image analysis (Cadrin and Friedland, 1999) and geometric landmark methods (Rohlf and Marcus, 1993), for detecting differences among groups. The objective of this study was to explore patterns of morphometric variation in yellowtail flounder, using

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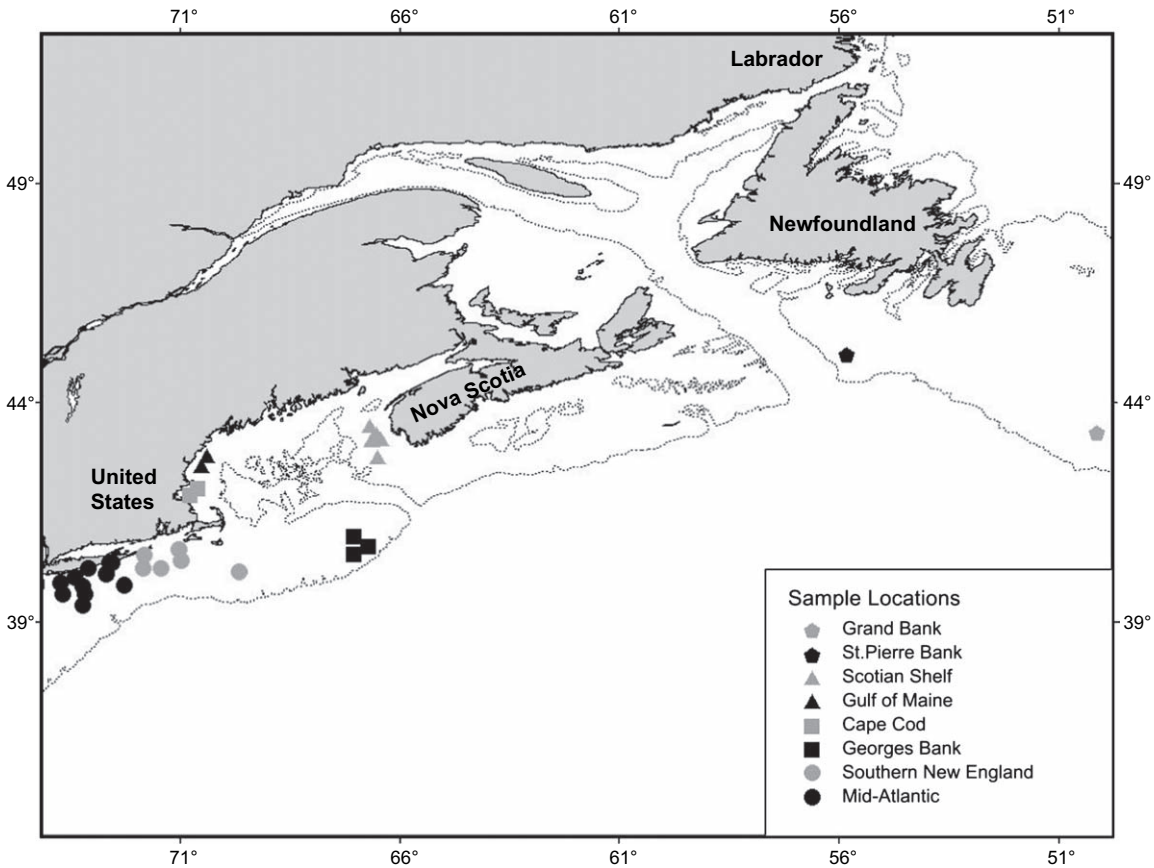

Figure 1. Sampling locations for yellowtail flounder (dashed line indicates 200-m depth contour).

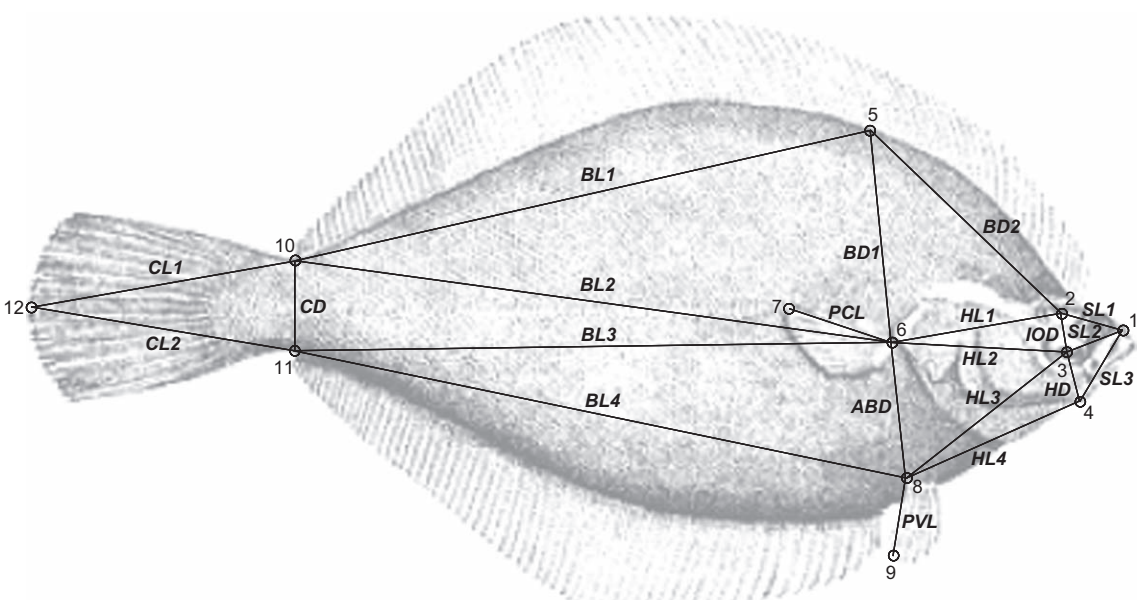

Figure 2. Morphometric landmarks (numbered circles) and distances (labelled line segments) of yellowtail flounder.

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image analysis, multivariate morphometric analysis, and geometric landmark analysis.

Methods

Yellowtail flounder were collected from research surveys in spring 2000. Yellowtail that represented the general size range in the survey catch (11–51 cm) were subsampled at six general locations from the Northeast Fisheries Science Center's groundfish survey: the Scotian Shelf, the Gulf of Maine, the Cape Cod grounds, Georges Bank, southern New England, and Mid-Atlantic (totalling 464 fish, Table 1, Figure 1). Samples from the Grand Bank and St. Pierre Bank were collected from the Canadian Department of Fisheries and Oceans 2000 spring groundfish survey (192 fish, Table 1, Figure 1). Fish were frozen onboard, transported and stored frozen, then thawed in room-temperature water baths prior to laboratory processing. Digital images of thawed fish in a standard position were analysed to measure morphometric variables using methods described by Cadrin and Friedland (1999). Error in measurement distances from image analysis was evaluated by comparison with three manually measured distances for each specimen, total length (measured on deck before freezing), horizontal and vertical grid distances, and diameter of tissue core taken for genetic analysis. Location coordinates of homologous landmarks (Table 2, Figure 2) were digitized using tpsDig (Rohlf, 1998), and used to derive box-truss dimensions (Strauss and Bookstein, 1982; Table 3, Figure 2). Maturity stages were determined for each specimen using the method described by O'Brien *et al.* (1993). Tissue samples were preserved for an associated genetic study (Kuzirian and Chikarmane, 2003).

Statistical outliers were identified using principal components analysis (PCA) of the variance–covariance matrix of log-transformed variables to explore patterns of variance in size and shape. Individual fish with standardized scores greater than 3.0 for the first three components were re-digitized, and revised data were compared with original data to confirm that outliers were not the result of processing errors. Patterns of morphometric variation were explored using multiple-group PCA (Thorpe, 1988).

Data were adjusted for isometric size differences using Burnaby's multivariate size adjustment to test for shape differences among groups (Burnaby, 1966; Rohlf and Bookstein, 1987). Multivariate analysis of variance was

Table 1. Sample sizes (number of fish) used for morphometric analysis of yellowtail flounder.

Management area	Males	Females	All
Grand Bank	60	37	97
St. Pierre Bank	52	43	95
Scotian Shelf	9	8	17
Gulf of Maine	41	42	83
Cape Cod	70	32	102
Georges Bank	55	43	98
S. New England	70	40	110
Mid-Atlantic	22	32	54
Total	379	277	656

Table 2. Morphometric landmarks of yellowtail flounder used to derive morphometric distances (see Figure 2).

Landmark	Description
1	Anterior extent of premaxillary
2	Center of left eye
3	Center of right eye
4	Posterior extent of dentary
5	Insertion of dorsal fin in line with 6 and 8
6	Dorsal insertion of pectoral fin
7	Distal extent of pectoral fin
8	Posterior insertion of pelvic fin
9	Distal extent of pelvic fin
10	Posterior insertion of dorsal fin
11	Posterior insertion of anal fin
12	Posterior extent of caudal fin

Table 3. Morphometric distances and associated landmarks of yellowtail flounder (see Figure 2).

Distance	Landmarks	Description
SL1	1–2	Snout length 1
SL2	1–3	Snout length 2
SL3	1–4	Snout length 3
IOD	2–3	Interorbit distance
HD	3–4	Head depth
HL1	2–6	Head length 1
HL2	3–6	Head length 2
HL3	3–8	Head length 3
HL4	4–8	Head length 4
BD1	5–6	Body depth 1
BD2	2–5	Body depth 2
ABD	6–8	Abdomen depth
PCL	6–7	Pectoral fin length
PVL	8–9	Pelvic fin length
BL1	5–10	Body length 1
BL2	6–10	Body length 2
BL3	6–11	Body length 3
BL4	8–11	Body length 4
CD	10–11	Caudal depth
CL1	10–12	Caudal fin length 1
CL2	11–12	Caudal fin length 2

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used to test stock, sex, maturity, and interaction effects on shape according to Pillai's trace statistic, which is robust to moderate departures from parametric assumptions. Classification functions were derived from canonical variates analysis (CVA, also referred to as discriminant function analysis) to assign individual specimens to putative stocks based on shape differences among stocks. Accuracy of classifications was evaluated using extrinsic jackknife cross-validation, in which each specimen is removed from a discriminant function and classified to group (Marcus, 1990). Significant departures from random classification accuracies were assessed using a randomization test (Solow, 1990). Pairwise classification accuracy was assessed by separate pairwise CVAs. Thin-plate spline analysis (Rohlf, 1997) was also used on non-articulating landmarks (i.e. excluding landmarks 7 and 9, Figure 3) to depict shape differences between individuals with extreme canonical variates scores (Rohlf and Marcus, 1993).

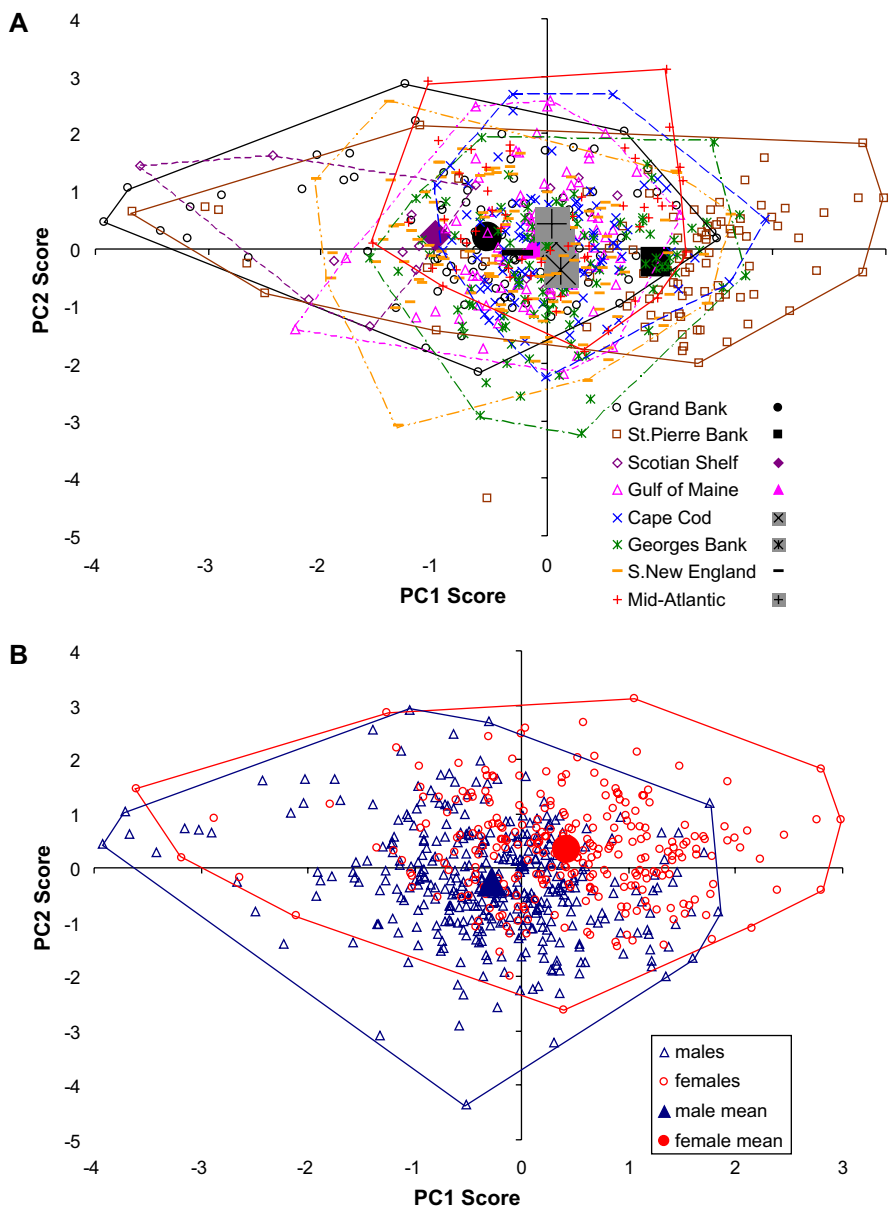

Figure 3. Multiple-group principal component scores for yellowtail flounder morphometric data by stock (A) and by sex (B). Large solid symbols represent group centroids.

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Thin-plate splines describe the deformation of one set of landmark coordinates relative to another.

Results

The maximum observed difference between known distances and those calculated via image analysis was 0.46 mm. Therefore, measurement error of morphometric distances, which range from 50 to 350 mm, was estimated to be less than 0.5 mm. Measurement error was similar for all three known distances (total length, background grid distances, and tissue core diameter), indicating no shrinkage or swelling from the freezing and thawing process.

The first principal component (PC1) of all observations accounted for 83% of total variation and represented overall size, because all variables loaded significantly positive and approximately equal (Table 4). The second principal component (PC2) accounted for 3% of total variation (17% of residual variation) and was most correlated to relative body depth and head size vs. pectoral fin, body length, and tail size (e.g. BD1, BD2, and snout lengths loaded strongly positive, but PCL, body lengths, and tail dimensions loaded strongly negative). Principal component scores indicated several statistical outliers, all of which remained outliers after reprocessing, and were retained in the analyses to represent natural morphometric variation. Principal component scores overlapped extensively among stock areas (Figure 3A), and although PC score distributions of males and females also overlapped, females had generally greater PC1 scores (i.e. were larger) and PC2 scores (i.e. were relatively deeper) than males (Figure 3B).

Multivariate analysis of variance indicated that morphometric differences were significant among stocks and between sexes, and some interactions were also significant (Table 5). A CVA by gender revealed that females have

Table 5. Results of multivariate analysis of variance that tested the effect of stock, sex, maturity, and interactions on size-adjusted morphometric variables.

Effect	Pillai's trace	F	Degrees of freedom	Probability
Stock	0.7137	3.4854	140	0.0001
Sex	0.0601	1.9423	20	0.0084
Maturity	0.0447	1.4221	20	0.1046
Stock × sex	0.2740	1.2505	140	0.0260
Stock × maturity	0.2571	1.3719	120	0.0050
Sex × maturity	0.0656	2.1350	20	0.0029
Stock × sex × maturity	0.1876	1.1927	100	0.0960

Table 4. Eigenvector elements and percentage of total variance of multiple-group principal components of morphometric data from all yellowtail flounder specimens (strong loadings indicated in bold).

Distance	Description	PC1	PC2	PC3
SL1	Snout length 1	**0.21**	0.15	−0.10
SL2	Snout length 2	**0.19**	0.18	0.01
SL3	Snout length 3	**0.21**	0.12	−0.09
IOD	Interorbit distance	**0.22**	−0.01	0.02
HD	Head depth	**0.21**	0.17	**−0.20**
HL1	Head length 1	**0.21**	0.16	0.00
HL2	Head length 2	**0.22**	0.17	−0.04
HL3	Head length 3	**0.23**	−0.01	**−0.31**
HL4	Head length 4	**0.22**	−0.03	**−0.35**
BD1	Body depth 1	**0.22**	**0.27**	**0.33**
BD2	Body depth 2	**0.22**	**0.40**	**0.41**
ABD	Abdomen depth	**0.25**	0.13	−0.20
PCL	Pectoral fin length	**0.22**	**−0.68**	**0.30**
PVL	Pelvic fin length	**0.22**	−0.04	**0.53**
BL1	Body length 1	**0.23**	**−0.22**	−0.15
BL2	Body length 2	**0.23**	−0.14	−0.07
BL3	Body length 3	**0.23**	−0.13	−0.07
BL4	Body length 4	**0.23**	−0.06	−0.05
CD	Caudal depth	**0.21**	−0.13	0.06
CL1	Caudal fin length 1	**0.21**	−0.13	0.00
CL2	Caudal fin length 2	**0.21**	−0.12	0.02
% Variance		81.04	3.20	2.91

Table 6. Sexual dimorphism of yellowtail flounder, as indicated by univariate F statistic and within-group correlation of size-adjusted variables to the canonical function (bold values indicate strong loadings).

Distance	Description	Univariate F	Canonical correlation
SL1	Snout length 1	0.1	−0.02
SL2	Snout length 2	4.1	−0.13
SL3	Snout length 3	23.4	**0.31**
IOD	Interorbit distance	4.6	−0.13
HD	Head depth	37.1	**0.38**
HL1	Head length 1	2.9	0.11
HL2	Head length 2	10.9	0.21
HL3	Head length 3	42.3	**0.41**
HL4	Head length 4	10.5	0.20
BD1	Body depth 1	0.2	−0.02
BD2	Body depth 2	0.8	0.06
ABD	Abdomen depth	96.1	**0.62**
PCL	Pectoral fin length	69.0	**−0.52**
PVL	Pelvic fin length	4.6	−0.14
BL1	Body length 1	2.2	−0.09
BL2	Body length 2	0.3	−0.04
BL3	Body length 3	0.1	−0.02
BL4	Body length 4	2.1	0.09
CD	Caudal depth	29.7	**−0.34**
CL1	Caudal fin length 1	19.8	**−0.28**
CL2	Caudal fin length 2	25.8	**−0.32**

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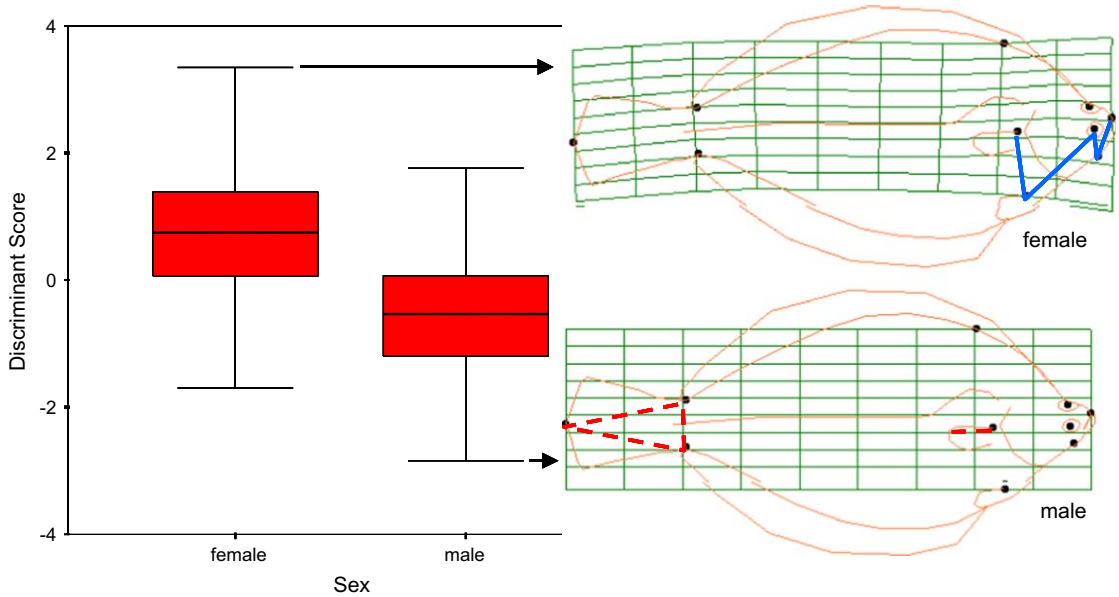

Figure 4. Sexual dimorphism of yellowtail flounder as illustrated by distribution of discriminant scores (range, interquartile range, and median) from size-adjusted morphometric data and thin-plate splines between extreme examples (solid line features load positively; dashed lined load negative).

relatively deeper abdomens and larger heads (ABD, HL3, HD, and SL3 loaded positively), and smaller pectoral fins and tails (PCL, CD, CL1, and CL2 loaded negatively; Table 6, Figure 4). Thin-plate spline comparison of specimens with extreme male and female discriminant scores confirms that females are anteriorly deeper (Figure 5). Extrinsic accuracy of classification to sex was 72%, which is significantly greater than random accuracy ($p < 0.001$, Table 7). Therefore, separate size-adjusted CVAs were performed for each sex to remove the effect of sexual dimorphism from the evaluation of geographic differences.

Males were significantly different among stocks, with moderate overlap of distributions between stocks off Newfoundland and more southern stocks, and extensive overlap among southern stocks (Figure 5A). The first

Table 7. Classification of yellowtail flounder to sex using size-adjusted morphometric data (bold values indicate correct classifications).

Group	Classified as male	Classified as female	Sum	% Correct
Male	**301**	78	379	79
Female	106	**171**	277	62
Total	407	249	656	72
Random probability of 72% accuracy				<0.001

Table 8. Morphometric variation among stocks of male yellowtail flounder as indicated by univariate F statistic and within-group correlation of variables to the canonical variates (CV; bold values indicate the greatest discriminating power).

Distance	Univariate F	CV1 correlation	CV2 correlation	CV3 correlation
Snout length 1	6.4	0.20	−0.22	0.23
Snout length 2	4.4	0.14	−0.29	0.19
Snout length 3	7.0	0.29	−0.11	0.07
Interorbit distance	9.7	−0.28	−0.04	**0.55**
Head depth	3.6	0.15	0.02	−0.32
Head length 1	4.0	−0.09	−0.34	−0.15
Head length 2	2.5	0.04	−0.28	−0.13
Head length 3	7.5	0.27	0.05	−0.16
Head length 4	5.1	0.18	−0.07	−0.03
Body depth 1	3.9	−0.10	−0.08	−0.28
Body depth 2	4.2	−0.14	−0.07	−0.24
Abdomen depth	18.4	**0.42**	**0.45**	−0.03
Pectoral fin length	5.0	0.21	−0.18	−0.07
Pelvic fin length	5.6	0.13	0.19	**0.39**
Body length 1	12.3	**−0.33**	0.28	0.13
Body length 2	20.4	**−0.46**	**0.42**	−0.07
Body length 3	23.1	**−0.49**	**0.44**	−0.07
Body length 4	22.4	**−0.48**	**0.47**	0.09
Caudal depth	5.9	−0.10	0.34	**−0.39**
Caudal fin length 1	5.3	−0.04	**−0.41**	0.07
Caudal fin length 2	4.5	−0.10	−0.33	0.02
		56.22	19.91	10.29

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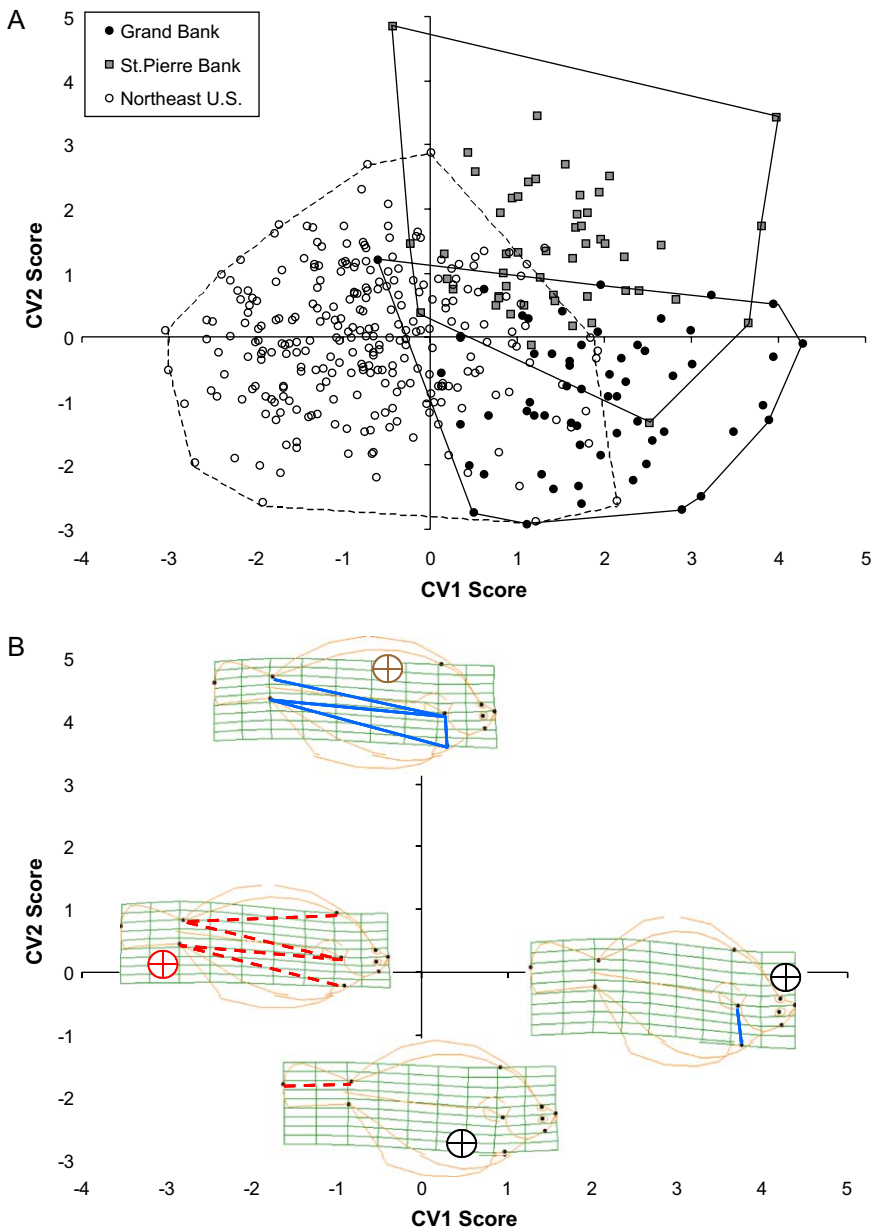

Figure 5. Geographic variation of male yellowtail flounder as illustrated by canonical variates scores of size-adjusted morphometric data (A), and thin-plate splines for four extreme examples (B; dashed features load negatively; solid features load positively; symbols indicate extreme CV scores).

canonical variate (CV1) accounted for 56% of total variance and essentially separated the two Newfoundland stocks from the more southern stocks, because Newfoundland males have relatively deeper abdomens (ABD loaded positively) and shorter bodies (BL1, BL2, BL3, and BL4 loaded negatively; Table 8). The second canonical variate (CV2) accounted for 20% of total variance (45% of residual variance) and separated St. Pierre Bank males, because they have short tails (CL1 loaded negatively) in relation to body size (ABD, BL2, BL3, and BL4 loaded positively). Scotian Shelf males also scored negatively on CV2 because they have relatively long tails. Thin-plate spline analyses confirm that southern males are relatively longer than those off Newfoundland, and males from St. Pierre Bank have relatively longer bodies and shorter heads than Grand Bank males (Figure 5B).

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Table 9. Classification of male yellowtail flounder to stock using size-adjusted morphometric data (bold values indicate correct classifications).

	Classified as									
	Grand Bank	St. Pierre Bank	Scotian Shelf	Gulf of Maine	Cape Cod	Georges Bank	S. New England	Mid-Atlantic	Sum	% Correct
Grand Bank	**37**	5	0	2	8	0	8	0	60	62
St. Pierre Bank	8	**20**	0	1	6	2	15	0	52	38
Scotian Shelf	1	0	**0**	0	3	3	2	0	9	0
Gulf of Maine	8	0	0	**8**	11	3	11	0	41	20
Cape Cod	3	1	0	5	**27**	13	21	0	70	39
Georges Bank	1	3	0	3	12	**11**	25	0	55	20
S. New England	2	5	0	2	16	25	**20**	0	70	29
Mid-Atlantic	0	0	0	0	5	5	12	**0**	22	0
Total	60	34	0	21	88	62	114	0	379	32
Random probability of 32% accuracy				<0.001						

Extrinsic classification accuracy of males to correct stocks was only 32%, which although low, was significantly greater than random accuracy with eight groups and the observed sample sizes ($p < 0.001$, Table 9). Extrinsic classification accuracy of pairwise discriminant functions indicates that males can be classified among Canadian stocks (Grand Bank, St. Pierre, and Scotian Shelf) with 82–95% accuracy, but to US stocks with only 60–76% accuracy (Table 10). Discriminant analysis of males from the principal US stocks (i.e. Cape Cod, Georges Bank, and southern New England) produced only 49% extrinsic classification accuracy ($p < 0.001$, Table 11).

Females were also significantly different among stocks, with similar patterns of variation among stocks as males. Distributions between stocks off Newfoundland and more southern stocks overlapped somewhat, and overlap was more extensive among southern stocks (Figure 6A). The first canonical variate accounted for 59% of total variance and separated the two Newfoundland stocks from the more southern stocks, because Newfoundland females have relatively longer snouts (SL1 loaded positively) and shorter bodies (BL1, BL2, BL3, and BL4 loaded negatively; Table 12). The second canonical variate accounted for 24% of total variance (57% of residual variance) and separated St. Pierre Bank females from those in other areas, because they have relatively long heads and deeper peduncles (HL3 and CD loaded positively) and shorter tails (CL1 and CL2 loaded negatively). Scotian Shelf females scored negatively on CV2, because they have relatively narrow peduncles and long tails. Thin-plate spline comparison of females with extreme CV scores confirms that southern females are relatively longer than those off Newfoundland, and females from St. Pierre Bank have relatively deeper peduncles and bigger heads (Figure 6B).

Extrinsic classification accuracy of females to correct stocks was only 24%, but was significantly greater than

Table 10. Extrinsic classification accuracy of male yellowtail flounder to stock from pairwise analysis of size-adjusted morphometric data.

	Grand Bank (%)	St. Pierre Bank (%)	Scotian Shelf (%)	Gulf of Maine (%)	Cape Cod (%)	Georges Bank (%)	S. New England (%)	Mid-Atlantic (%)
Grand Bank	—	82	90	73	78	92	89	73
St. Pierre Bank	82	—	95	77	87	89	83	93
Scotian Shelf	90	95	—	72	78	80	86	65
Gulf of Maine	73	77	72	—	63	65	73	63
Cape Cod	78	87	78	63	—	63	64	76
Georges Bank	92	89	80	65	63	—	60	69
S. New England	89	83	86	73	64	60	—	76
Mid-Atlantic	73	93	65	63	76	69	76	—

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Table 11. Classification of male yellowtail flounder to principal US stock areas using size-adjusted morphometric data (bold values indicate correct classifications).

	Classified as				
Group	Cape Cod	Georges Bank	S. New England	Sum	% Correct
Cape Cod	**40**	16	14	70	57
Georges Bank	14	**24**	17	55	44
S. New England	21	17	**32**	70	46
Total	75	57	63	195	49
Random probability of 49% accuracy				<0.001	

Table 12. Morphometric variation among stocks of female yellowtail flounder as indicated by univariate F statistic and within-group correlation of variables to the canonical variates (CV; bold values indicate the greatest discriminating power).

Distance	Univariate F	CV1 correlation	CV2 correlation	CV3 correlation
Snout length 1	11.1	**0.37**	−0.29	−0.20
Snout length 2	8.9	0.32	−0.25	0.21
Snout length 3	5.1	0.26	0.01	0.16
Interorbit distance	4.8	−0.23	−0.21	0.20
Head depth	4.0	0.17	0.28	−0.04
Head length 1	2.0	0.05	−0.26	0.04
Head length 2	4.5	0.20	−0.28	0.06
Head length 3	5.9	0.14	**0.42**	0.03
Head length 4	1.6	0.12	0.04	0.05
Body depth 1	1.3	0.07	0.00	−0.09
Body depth 2	1.9	0.08	−0.16	−0.10
Abdomen depth	5.2	0.04	0.41	0.24
Pectoral fin length	7.7	0.30	0.12	−0.27
Pelvic fin length	4.3	0.13	0.22	**0.39**
Body length 1	10.8	**−0.40**	−0.04	−0.25
Body length 2	25.8	**−0.63**	0.14	−0.31
Body length 3	25.1	**−0.63**	0.02	−0.21
Body length 4	22.8	**−0.60**	0.06	−0.02
Caudal depth	8.3	−0.22	**0.39**	**−0.39**
Caudal fin length 1	5.1	−0.13	**−0.39**	0.06
Caudal fin length 2	5.6	−0.14	**−0.35**	0.32
% Variance		58.66	23.75	7.12

random accuracy with eight groups of the observed sample sizes ($p < 0.001$, Table 13). Extrinsic classification accuracy of pairwise discriminant functions indicates that females can be classified to Canadian stocks (Grand Bank, St. Pierre, and Scotian Shelf) with 71−86% accuracy, but to US stocks with only 43−72% accuracy (Table 14). Discriminant analysis of females from the principal US stocks (i.e., Cape Cod, Georges Bank, and southern New England) produced only 35% extrinsic classification accuracy, which is not significantly greater than random accuracy ($p = 0.375$, Table 15).

Discussion

These results indicate significant sexual dimorphism and geographic variation in morphometry of yellowtail flounder. The geographic variation observed in this study is consistent with the findings of Scott (1947, 1954), who concluded that yellowtail from southern New England had relatively shorter heads (measured "from the tip of the upper lip to the poster edge of the opercular flap") and shorter pectoral fins. Pairwise comparisons of Scotian Shelf and southern New England samples in this study confirmed that all of the corresponding morphometric distances (SL1, SL2, HL1, HL2, and PCL) were relatively shorter for yellowtail from southern New England than those from the Scotian Shelf. The greatest differences were shorter snout length (SL1 and SL2) for females, and shorter pectoral fins (PCL) for males from southern New England. Variation in relative snout and head size may be related to differences in diet (Albertson and Kocher, 2001).

The greater morphometric difference between Newfoundland and southern stocks than among southern stocks is consistent with the degree of geographic variation in ontogenetic rates. For example, the difference in age at which 50% of females are mature is relatively small among US stocks (1.7 y in southern New England, 1.8 y on Georges Bank, and 2.6 y off Cape Cod; O'Brien *et al.*, 1993), but is much greater on the Grand Bank (6 y; Pitt, 1970). If morphometric variation is viewed as a product of ontogenetic variation, then groups that have greater differences in growth and maturity should have greater morphometric differences as well.

Sexually dimorphic growth (Scott, 1947, 1954; Lux and Nichy, 1969; Pitt, 1974; Moseley, 1986; Begg *et al.*, 1999) and differences in rates of maturation (Pitt, 1970; Beacham, 1983; O'Brien *et al.*, 1993; Begg *et al.*, 1999; Durán *et al.*, 1999; Walsh and Morgan, 1999) have been well documented for yellowtail and are common for many flatfish species. Sexual dimorphism, which presumably results from allometric effects of different ontogenetic rates, has been documented for several flatfish, with males generally having relatively longer pectoral fins and wider interorbital distance (Hoshino *et al.*, 2000). This study is consistent with those tendencies, because male yellowtail had relatively greater pectoral length (PCL) and interorbital distance (IOD), though the difference in IOD was not as strong as in PCL. The greater relative head size (HD, HL1, HL2, HL3, and HL4) of females observed in this study is also consistent with sexual dimorphism of witch flounder (*Glyptocephalus cynoglossus*; Gutvik *et al.*, 1992). Presumably, greater head and abdomen size facilitates faster growth rates for females.

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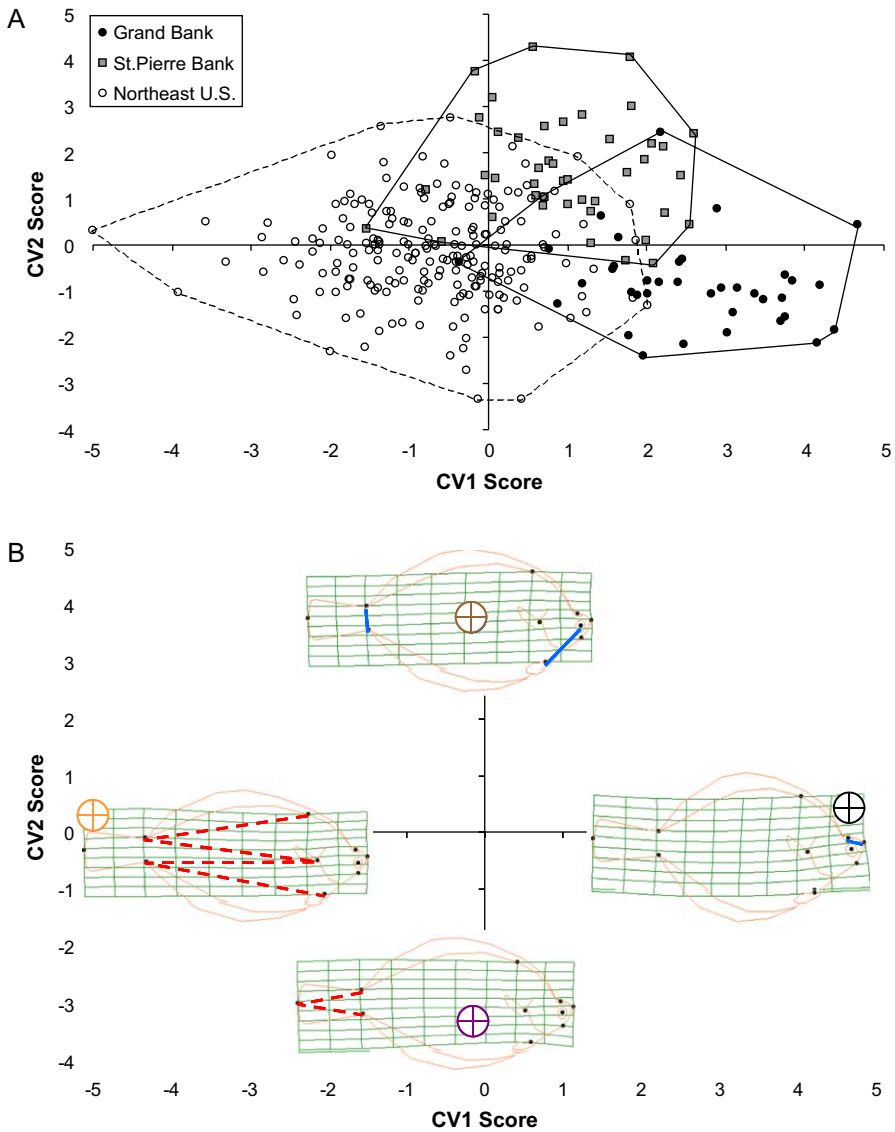

Figure 6. Geographic variation of female yellowtail flounder as illustrated by canonical variates scores of size-adjusted morphometric data (A), and thin-plate splines for four examples (B; dashed features load negatively; solid features load positively; symbols indicate extreme CV scores).

For example, females of a congener of yellowtail flounder (the dab *Limanda limanda*) have greater feeding rates, larger digestive tracts and larger livers than males (Lozan, 1990). Sexual dimorphism may also be related to mating behaviour, which is elaborate for some flatfish species (e.g. Forster, 1953; Konstantinou and Shen, 1995; Stoner *et al.*, 1999).

This case study illustrates the utility of advanced techniques in morphometric analysis for identifying phenotypic stocks. Results from the associated genetic study of the same specimens (Kuzirian and Chikarmane, 2003), which excluding samples from off Newfoundland, from which tissues were degraded, are congruent with these morphometric results in that no significant genetic differences were found among yellowtail samples south of Nova Scotia. Apparently movement of yellowtail among US fishing grounds is sufficient to blend genetic and morphometric characters.

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Table 13. Classification of female yellowtail flounder to stock using size-adjusted morphometric data (bold values indicate correct classifications).

	Classified as									
	Grand Bank	St. Pierre Bank	Scotian Shelf	Gulf of Maine	Cape Cod	Georges Bank	S. New England	Mid-Atlantic	Sum	% Correct
Grand Bank	**18**	7	0	3	2	1	4	2	37	49
St. Pierre Bank	2	**16**	0	7	3	4	8	3	43	37
Scotian Shelf	1	1	**0**	3	0	1	2	0	8	0
Gulf of Maine	1	4	0	**8**	10	12	6	1	42	19
Cape Cod	3	3	0	9	**7**	4	3	3	32	22
Georges Bank	3	2	0	11	8	**8**	9	2	43	19
S. New England	2	4	0	6	4	15	**5**	4	40	13
Mid-Atlantic	0	1	0	5	10	8	4	**4**	32	13
Total	30	38	0	52	44	53	41	19	277	24
Random probability of 24% accuracy				<0.001						

Table 14. Extrinsic accuracy of discriminating female yellowtail flounder to stock from pairwise analysis of size-adjusted morphometric data.

	Grand Bank (%)	St. Pierre Bank (%)	Scotian Shelf (%)	Gulf of Maine (%)	Cape Cod (%)	Georges Bank (%)	S. New England (%)	Mid-Atlantic (%)
Grand Bank	—	83	71	84	65	95	94	84
St. Pierre Bank	83	—	86	82	63	88	81	79
Scotian Shelf	71	86	—	82	75	80	81	70
Gulf of Maine	84	82	82	—	43	60	72	61
Cape Cod	65	63	75	43	—	52	65	47
Georges Bank	95	88	80	60	52	—	57	68
S. New England	94	81	81	72	65	57	—	64
Mid-Atlantic	84	79	70	61	47	68	64	—

Table 15. Classification of female yellowtail flounder to principal US stock using size-adjusted morphometric data (bold values indicate correct classifications).

	Classified as				
Group	Cape Cod	Georges Bank	S. New England	Sum	% Correct
Cape Cod	**12**	14	6	32	38
Georges Bank	11	**14**	18	43	33
S. New England	5	21	**14**	40	35
Total	28	49	38	115	35
Random probability of 35% accuracy				0.375	

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