Morphometric and meristic differences between shallow- and deep-water populations of white hake (*Urophycis tenuis*) in the southern Gulf of St. Lawrence

Thomas Hurlbut and Douglas Clay

Abstract: Linear discriminant function analysis of morphometric and meristic characters was used to assess the extent of differentiation between shallow- (<100 m) and deep- (>200 m) water populations of white hake (*Urophycis tenuis*) from the southern Gulf of St. Lawrence (NAFO Division 4T). Although meristic characters provided some evidence for stock separation, the best statistical separation was obtained with morphometric characters. Morphometric discriminant functions derived from "learning" samples were able to correctly classify 82 and 84% of the "test" samples for both females and males, respectively. A greater relative snout length in fish sampled from along the Laurentian Channel compared with those from the Northumberland Strait area was the primary discriminating character for both sexes. Our morphological evidence and previous tagging and distributional studies suggest that the populations from these two areas represent separate stocks; therefore, the traditional management unit for white hake in NAFO Division 4T may no longer be appropriate.

Résumé : Nous avons effectué une analyse discriminante linéaire d'une série de caractères morphométriques et méristiques afin d'évaluer le degré de différenciation entre la population de merluche blanche (*Urophycis tenuis*) vivant en eau peu profonde (<100 m) et la population vivant en eau plus profonde (>200 m) dans le sud du golfe du Saint-Laurent (division 4T de l'OPANO). Si les caractères méristiques ont révélé d'une façon plus ou moins nette la présence de deux stocks distincts, les caractères morphométriques se sont révélés beaucoup plus efficaces à cet égard. Les fonctions discriminantes morphométriques dérivées des échantillons d'apprentissage ont permis de classifier correctement 82 et 84% des échantillons « expérimentaux » de femelles et de mâles, respectivement. La longueur relative du museau était le principal caractère discriminant, les valeurs étant chez les deux sexes plus élevées chez les spécimens provenant du chenal Laurentien que chez ceux capturés dans le détroit de Northumberland. Nos observations morphométriques et les résultats d'études antérieures de marquage et de répartition donnent à croire que les populations associées à ces deux régions constituent des stocks différents. Il n'est donc plus approprié de maintenir l'unité de gestion qui est actuellement prévue pour la merluche blanche dans la division 4T de l'OPANO.

[Traduit par la Rédaction]

Introduction

The white hake (*Urophycis tenuis*) is a demersal fish that inhabits the continental shelf and upper continental slope of the western Atlantic Ocean. They occur from southern Labrador, and the Grand Bank southward to North Carolina, occasionally straying to deep waters off Florida (Musick 1974). White hake are exploited throughout their geographical range by seasonal fisheries, but the most important directed fishery for this species has occurred in the southern Gulf of St. Lawrence (Northwest Atlantic Fisheries Organization (NAFO) Division 4T).

The current management of marine fish stocks in Atlantic Canada assumes the presence of a single stock per management area (Parsons 1993), with no stock mixing during periods of fishing. Despite the fundamental importance of this concept and the significant local commercial fishery for white hake in the southern Gulf of St. Lawrence, there have been no studies of stock structure in the northwest Atlantic.

A tagging study conducted off eastern Prince Edward Island in the late 1960s suggested that white hake in the southern Gulf of St. Lawrence are distinct from white hake in other areas of the northwest Atlantic (Kohler 1971). Consequently, NAFO Division 4T was adopted as the management unit for white hake in the southern Gulf of St. Lawrence, which are currently assessed and managed as a single stock (Morin and Hurlbut 1994). However, white hake exhibit a disjunct distribution in the southern Gulf during the summer and early fall, occurring either in shallow (<100 m) inshore areas in the vicinity of the Northumberland Strait or in deep (>200 m) water along the Laurentian Channel (Fig. 1*a*)

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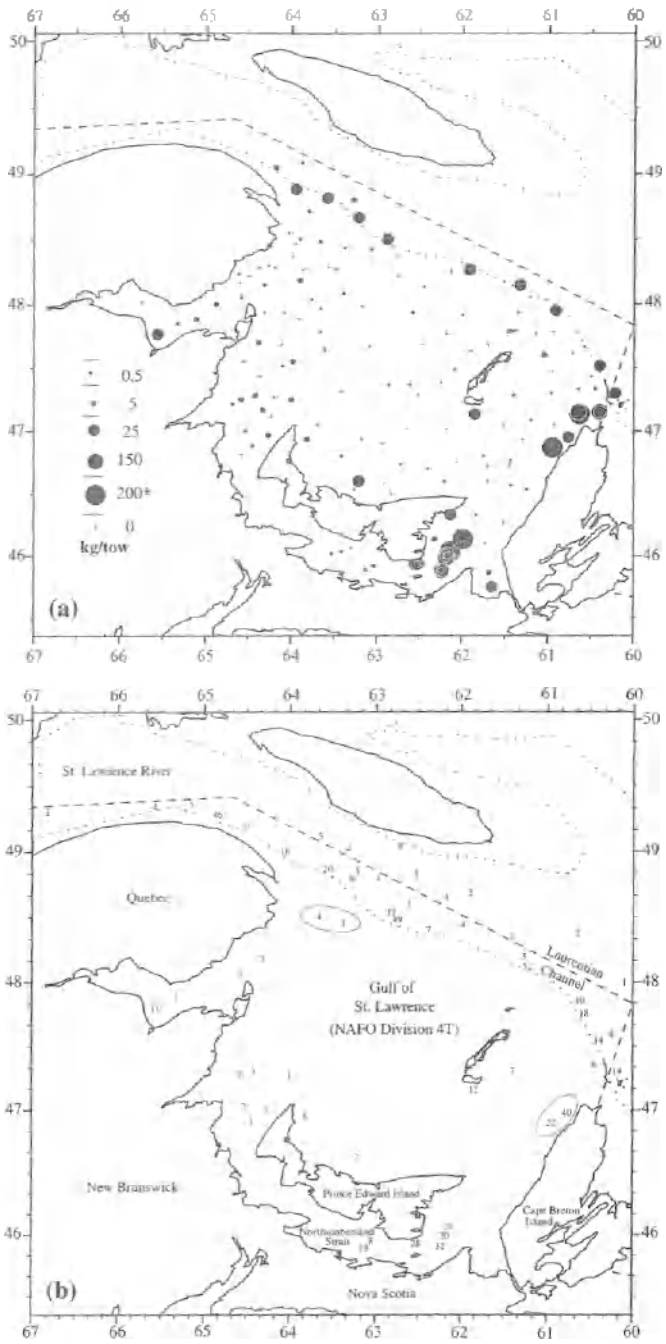
T. Hurlbut.[1] Department of Fisheries and Oceans, Maritimes Region, Gulf Fisheries Centre, P.O. Box 5030, Moncton, NB E1C 9B6, Canada.
D. Clay. Revenue Canada, Scientific Research and Experimental Development, 220 4th Ave. SE, Calgary, AB T2G 0L1, Canada.

[1]Author to whom all correspondence should be addressed. e-mail: hurlbutt@mar.dfo-mpo.gc.ca

Fig. 1. (*a*) Distribution of white hake catches during the September 1986 demersal fish survey of the southern Gulf of St. Lawrence. (*b*) Sample sites during the two RV *Lady Hammond* surveys of 1986 (numbers indicate the sample size at each location and the ellipses enclose samples from depths between 100 and 200 m). In both panels, the dashed line represents the border of NAFO Division 4T and the dotted line represents the 200-m depth contour.



(Koeller and LeGresley 1981; Clay and Hurlbut 1989; Clay 1991; Morin and Hurlbut 1994). Clay and Hurlbut (1989) and Clay (1991) postulated that these two components may represent completely or partially independent stocks. They referred to the inshore and offshore components as the Strait and Channel components, respectively.

Our objective was to test the hypothesis that white hake from the Strait and Channel groups represent discrete stocks by assessing morphometric and meristic differences between the two groups.

Table 1. Morphometric and meristic characters and their acronyms that were assessed in this investigation.

Character acronym	Description
Morphometric	
PECTBGIR	Pectoral body girth
OTOLHSL	Length of the sagittal otolith (left side)
OTORHSL	Length of the sagittal otolith (right side)
Meristic	
FDORFR	First dorsal fin rays
SDORFR	Second dorsal fin rays
ANALFR	Anal fin rays
PECTFR	Pectoral fin rays (left side)
CAUDFR	Caudal fin rays
TOTVERT	Total vertebrae
ABDVERT	Abdominal vertebrae
EPIRAK	Gill rakers on the epibranchial of the first left arch
CERRAK	Gill rakers on the ceratobranchial of the first left arch

Note: See Fig. 2 for the other morphometric characters.

Materials and methods

Sample collection

Samples of white hake were collected during two consecutive bottom trawl surveys (RV *Lady Hammond*) conducted from August 4 to September 24, 1986. Seasonal groundfish surveys of the southern Gulf indicate that at this time of year, white hake from the Strait and Channel groups are most widely distributed and have reached the limits of their summer distribution (Clay 1991). Survey procedures are described in Hurlbut and Clay (1990).

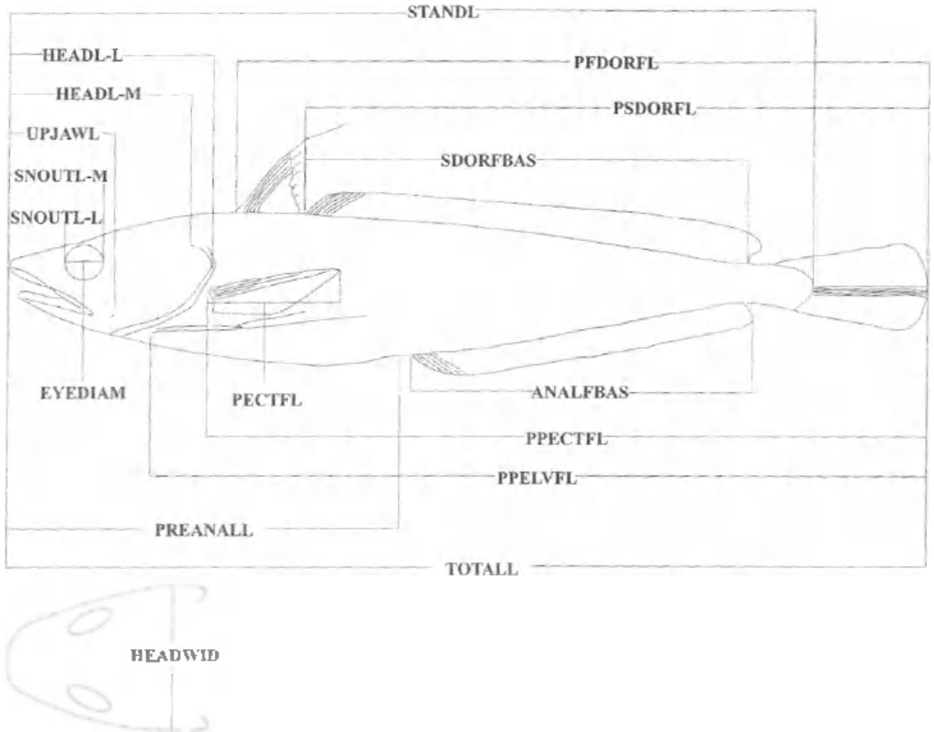
Specimens between 35 and 50 cm (total length) were selected to minimize the effects of allometric growth within the samples. The collected fish were bagged and packed in an undistorted condition in cardboard cartons and then were rapidly frozen (–16.0°C). The resulting collection (Fig. 1*b*) had a preponderance of samples from the northern and southeastern extremes of NAFO Division 4T, although there were some from as far west as the mouth of the St. Lawrence River.

Laboratory methods

Previously, there has been a great deal of confusion regarding the species of *Urophycis* that occurs in the Gulf of St. Lawrence (Leim and Scott 1966; Musick 1969, 1972). This confusion persisted until Musick (1969, 1972) revised the taxonomic characters that permit distinction between *U. tenuis* and its morphologically similar congener *Urophycis chuss* (red hake). These characters were examined for each specimen, and any that could not be positively identified as white hake were forwarded to the Atlantic Reference Centre (St. Andrews, N.B.) for confirmation. All specimens were confirmed to be *U. tenuis*.

For each specimen, nine meristic and 20 morphometric characters were counted or measured (Table 1; Fig. 2). Most of the morphometric characters were measured as described by Hubbs and Lagler (1958). The exceptions included two of the characters

Fig. 2. Morphometric measurements (mm) used in this investigation.



described by Musick (1969, 1972) specifically for morphometric comparisons of *U. tenuis* and *U. chuss*. These characters are differentiated from analogous characters described by Hubbs and Lagler (1958) by use of the extensions -M or -L in the character names.

Three different sizes of calipers were used for the morphometric measurements. SNOUTL-L, SNOUTL-M, EYEDIAM, HEADL-L, HEADL-M, HEADWID, UPJAWL, and PECTFL, which were <30 cm long for all of the specimens, were measured to the nearest 0.1 mm with vernier callipers. SDORFBAS, ANALFBAS, PREANALL, PFDORFL, PSDORFL, PPECTFL, and PPELVFL tended to be >30 cm and were measured to the nearest millimetre with modified callipers constructed from a meter stick with sliding needle points. OTOLHSL and OTORHSL were measured to the nearest 0.01 mm with dial vernier callipers. TOTALL and STANDL were measured to the nearest millimetre on a measuring board. PECTBGIR was measured with a piece of nylon twine to the nearest millimetre.

Meristic counts were made from X-ray images. The left pectoral fin and first right gill arch were excised and X-rayed separately from the remainder of the carcass. All vertebrae with hemal arches or spines were counted as abdominal vertebrae, and the total vertebra counts excluded the urostyle.

Statistical analysis

Analyses were performed using Statistical Analysis System software (SAS Institute Inc. 1985). Due to the distributional differences between morphometric and meristic characters and because morphometric characters are size dependent (Sokal and Rohlf 1981), the two types of characters were analyzed separately. Morphometric measurements were transformed to common logarithms. Because sexual dimorphism with respect to growth in white hake (Clay 1987) could result in greater variations in morphology than may be attributable to geographic variation between populations, we used ANCOVA, with TOTALL as the covariate, to test for differences in shape between males and females. We also used ANOVA to test for differences between the sexes in the meristic characters because it has been demonstrated that sexual dimorphism may also be manifest in the expression of meristic characters (Kirpichnikov 1981; Lindsey 1988). Sex and its interaction with area were included in the ANCOVA and ANOVA models.

The morphometric characters were standardized to the overall mean total length before discriminant function analyses using pooled within-group slopes determined by ANCOVA and the following formula:

$$\mathrm{ADJCHAR} = \mathrm{ORGCHAR} - [\mathrm{SLOPE} \times (\mathrm{TOTALL} - \mathrm{MEANTOT})]$$

where ADJCHAR is the value of the size-adjusted character, ORGCHAR is the original value of the character, SLOPE is the pooled within-group slope of the respective characters, TOTALL is the total length of each fish, and MEANTOT is the overall mean total length for each sex (43.9 and 42.2 cm for females and males, respectively).

We confirmed that the slopes did not differ significantly among the two groups by comparing models with a constant slope over all groups with those with separate slopes within each group. In all cases, correlation coefficients differed between the two models by <5%, confirming that there were no significant differences in allometric relationships between the areas. A wide variety of statistical procedures, in addition to pooled within-group slopes, have been used to adjust for the effect of size on shape in stock identification studies using morphometrics, but there is currently no clear consensus as to which procedure is superior (i.e., Reist 1985; Claytor and MacCrimmon 1986). An alternative approach is to use the overall regression slope (i.e., the slope over all the groups combined). To confirm that the results were not contingent on the procedure used for size adjustment, we also performed the analysis using characters adjusted with overall regression slopes. This analysis, not presented here, led to the same conclusions reached using characters adjusted with pooled within-group slopes.

Discriminant function analyses contrasted white hake sampled from depths ≤100 m (Strait component) with those from depths >200 m (Channel component). Samples from depths between 100

Table 2. Morphometric characters (means ± SD) of female and male white hake standardized to the overall mean total length (43.9 and 42.2 cm for females and males, respectively) using pooled within-group regression slopes and results of ANCOVA for sexual dimorphism in morphometric characters.

	Sample						
	Strait		Channel		p value		
Morphometric character	Females (n = 92)	Males (n = 167)	Females (n = 171)	Males (n = 169)	Sex effect	Area effect	Sex × area interaction
STANDL	384.6±2.6	369.6±2.6	384.7±2.6	368.9±2.3	0.8462	0.1944	0.0742
SNOUTL-L	23.9±1.8	22.1±1.8	24.3±1.8	22.6±1.4	0.0001	0.0006	0.6387
SNOUTL-M	42.2±2.4	40.5±2.4	44.7±2.5	43.1±2.0	0.5161	0.0001	0.4352
EYEDIAM	16.0±0.9	15.9±1.0	16.3±1.1	16.3±1.3	0.0001	0.0021	0.5479
HEADL-L	96.7±3.1	91.1±3.1	97.7±3.0	92.4±2.5	0.0001	0.0001	0.5685
HEADL-M	91.9±3.0	86.7±3.2	93.1±3.0	88.0±2.6	0.0001	0.0001	0.8796
HEADWID	56.1±5.3	53.6±3.9	55.2±5.8	51.8±5.0	0.9155	0.0009	0.2419
UPJAWL	42.9±3.2	40.5±3.0	42.3±3.1	39.9±2.8	0.0138	0.0293	0.7329
PECTFL	70.2±3.1	67.6±2.7	70.4±2.8	67.3±3.3	0.5411	0.8830	0.2201
SDORFBAS	220.4±4.9	214.0±4.7	219.9±4.8	213.3±4.5	0.0001	0.0862	0.8678
ANALFBAS	171.6±4.7	166.0±4.1	169.6±5.2	165.2±4.5	0.0028	0.0001	0.0991
PREANALL	183.6±4.2	173.7±4.4	183.1±5.3	172.4±4.7	0.0001	0.0422	0.1923
PFDORFL	331.3±2.8	320.0±3.1	330.2±3.5	319.1±3.0	0.0001	0.0001	0.6643
PSDORFL	295.9±4.1	285.8±3.5	294.9±4.2	285.5±3.4	0.0001	0.0284	0.2856
PPECTFL	345.9±3.7	334.2±3.6	346.1±4.1	334.1±3.7	0.0001	0.8292	0.8248
PPELVFL	374.0±5.4	360.9±4.7	375.4±4.7	361.8±4.4	0.0013	0.0061	0.5997
PECTBGIR	211.5±12.3	202.5±13.1	214.7±14.5	202.5±13.9	0.5358	0.1521	0.1724
OTOLHSL	18.8±0.7	18.2±0.6	18.6±0.7	18.2±0.6	0.0739	0.2934	0.1793
OTORHSL	18.7±0.7	18.1±0.7	18.6±0.6	18.2±0.6	0.0650	0.4870	0.0364

and 200 m were not included in the discriminant function analyses (24 females and 43 males; see Fig. 1*b*). A forward, stepwise discriminant function analysis was used to select the characters that best distinguished between the two areas and to evaluate the relative contribution of each character. In the case of highly correlated morphometric characters (i.e., SNOUTL-L and SNOUTL-M and HEADL-L and HEADL-M), the characters with the lowest Wilk's lambda (SNOUTL-L and HEADL-M) were eliminated from subsequent discriminant analyses. We used the kappa (K) statistic to determine the improvement over chance of the classifications derived from the discriminant functions (Titus et al. 1984). A K of zero indicates that no improvement over chance was provided by the discriminant analysis, while a K of 1 occurs only with perfect agreement. To obtain a better estimate of the misclassification rate, the samples were split into two data sets (even versus odd fish numbers). The first data set was then used to derive the discriminant function ("learning" sample) and the second to determine the efficiency of the function ("test" sample) (Pella and Robertson 1979). The samples from depths between 100 and 200 m were classified with discriminant functions derived from the previous classification of samples from the Strait and Channel components.

Results

The ANCOVA for differences in morphometric characters between female and male white hake (Table 2) revealed sexual dimorphism ($p < 0.01$) in 11 of the 19 morphometric characters. A difference ($p < 0.01$) was also detected between female and male white hake for the number of abdominal vertebrae (Table 3). Therefore, the analyses of morphometric and meristic characters were conducted with the sexes separated.

Differences ($p < 0.01$) between the shallow- and deep-water areas were observed for nine of the morphometric characters (Table 2) and three of the meristic characters (Table 3). The interaction between sex and area was not significant for any of the characters except for the number of pectoral fin rays (Tables 2 and 3).

Character correlations were much lower after size adjustment using the pooled within-group regression slopes and averaged 0.017 and 0.009 for females and males, respectively.

Forward, stepwise discriminant function analysis revealed that six of the 19 morphometric characters contributed significantly to the multivariate discrimination between the two areas for female white hake (Table 4). In contrast, eight of the 19 morphometric characters contributed to the multivariate discrimination between the areas for male white hake (Table 4). A greater relative SNOUTL-M in fish sampled from along the Laurentian Channel (Channel component) compared with those from the southern Gulf (Strait component) was the primary character difference for both sexes. Of the remaining morphometric characters selected in the stepwise discriminant function analyses, HEADL-L and PREANALL were the most important, in terms of their discriminating power, for female and male white hake, respectively.

Forward, stepwise discriminant function analysis applied to the meristic data resulted in four characters contributing to the discriminant functions for females and two characters for males (Table 4). PECTFR was the primary character difference between female white hake of Strait and Channel origin (Channel fish > Strait fish), and CERRAK was the

Table 3. Meristic characters (means ± SD) of female and male white hake and results of ANOVA for sexual dimorphism in meristic characters.

Meristic character	Sample: Strait Females (n = 92)	Strait Males (n = 167)	Channel Females (n = 171)	Channel Males (n = 169)	p value: Sex effect	Area effect	Sex × area interaction
FDORFR	9.6±0.7	9.4±0.7	9.4±0.7	9.4±0.8	0.1959	0.2250	0.1953
SDORFR	53.9±1.9	54.2±1.9	54.5±2.0	54.3±1.9	0.7467	0.0464	0.2348
CAUDFR	35.0±1.1	35.0±1.1	35.3±1.1	35.0±1.0	0.1700	0.0680	0.1330
ANALFR	47.8±1.6	47.9±1.8	47.6±1.8	47.9±1.8	0.1835	0.2869	0.4473
PECTFR	16.2±0.8	16.3±0.6	16.6±0.7	16.3±0.8	0.0437	0.0001	0.0023
TOTVERT	48.7±0.6	48.7±0.6	48.8±0.6	48.8±0.6	0.7504	0.3497	0.6677
ABDVERT	15.9±0.4	15.8±0.5	16.1±0.5	15.9±0.4	0.0092	0.0001	0.1584
CERRAK	13.0±0.9	12.9±0.8	13.4±1.0	13.3±0.8	0.2701	0.0001	0.9379
EPIRAK	2.1±0.3	2.1±0.2	2.1±0.3	2.1±0.3	0.5315	0.1490	0.3745

Table 4. Results of forward stepwise and canonical discriminant function analyses using morphometric and meristic characters.

Characters	Sex	Total no.	Characters selected in forward stepwise discriminant function analysis	Standardized coefficients of first canonical variable	Average % correctly classified	K statistic
Morphometric	Female	239	SNOUTL-M	−1.5423	81.30	0.59
			HEADL-L	0.6833		
			UPJAWL	0.4986		
			PECTBGIR	−0.3626		
			PREANALL	0.5776		
			ANALFBAS	0.4654		
	Male	293	SNOUTL-M	−1.4113	83.57	0.66
			HEADL-L	0.2418		
			PREANALL	0.8592		
			UPJAWL	0.5603		
			PECTBGIR	−0.2675		
			ANALFBAS	0.5083		
			SDORFBAS	−0.2492		
			PSDORFL	0.0917		
Meristic	Female	239	PECTFR	0.5876	62.67	0.24
			ABDVERT	0.4458		
			CAUDFR	0.3697		
			CERRAK	0.3824		
	Male	293	CERRAK	0.8628	56.31	0.16
			EPIRAK	0.4732		

primary character difference between male white hake (Channel fish > Strait fish).

A posteriori classifications of white hake into the two areas using discriminant functions derived from morphometric characters were 81% correct for females and 84% correct for males (Table 4). The K statistics indicate that these classifications were significantly better than chance alone (0.59 and 0.66 for females and males, respectively). In contrast, a posteriori classifications using discriminant functions derived from meristic variables were considerably less successful in their ability to correctly classify samples (63 and 56% correct for females and males, respectively; Table 4). These classifications were only marginally better than chance alone (K = 0.24 and 0.16, respectively).

There was considerably more overlap in the distributions of first canonical variable scores with the meristic discriminant functions (Fig. 3*b*) than with the morphometric discriminant functions (Fig. 3*a*). The majority of the specimens that were misclassified by the morphometric discriminant functions (77% of the females and 60% of the males) were sampled from stations near the 200-m depth contour (Fig. 4). These misclassified specimens represent 19% of all of the fish (both sexes) that were sampled from this area.

The test samples could not be efficiently classified with either of the meristic discriminant functions (i.e., males or females). The observed percentages of correct classification (63% for females and 53% for males) were only slightly better than would have been obtained by chance alone (K = 0.18 and 0.08, respectively; Table 5). In contrast, morphometric discriminant functions, derived from learning sam-

Fig. 3. Mean first canonical variable scores for the discriminant function analyses of (a) morphometric and (b) meristic characters of female and male white hake.

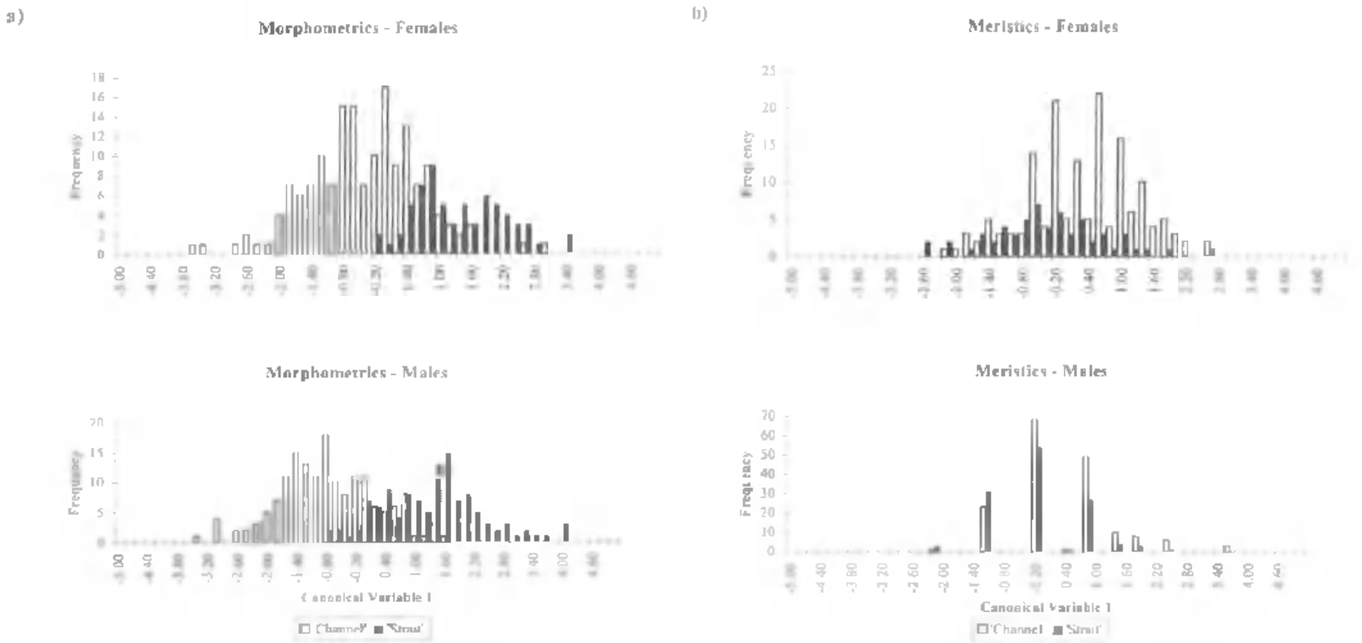
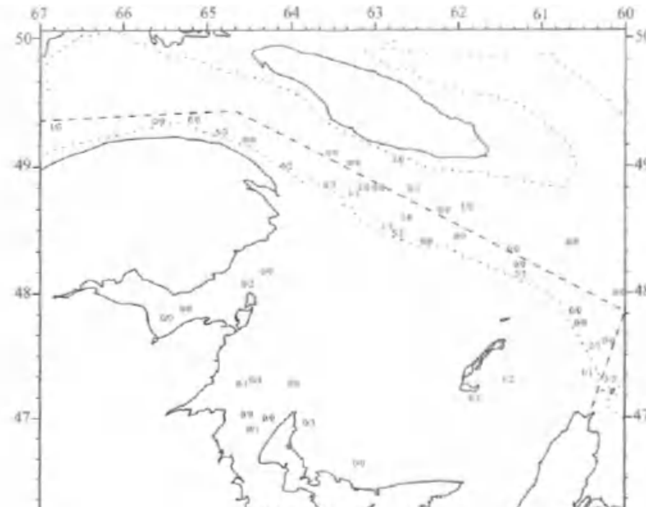


Fig. 4. Number and positions of female and male white hake that were misclassified by the morphometric discriminant functions. The first number at each location represents the number of females and the second the number of males.



ples, were able to correctly classify 82 and 84% of the females and males, respectively, from the test samples. These classifications were significantly higher than chance alone (K = 0.58 and 0.68, respectively; Table 5).

When the samples from depths between 100 and 200 m were classified with discriminant functions derived from the classification of samples from the Strait and Channel components, the majority (59%) were classified as Strait component.

Table 5. Results of the classification of test samples using discriminant function rules derived from learning samples.

Characters	Sex	No. in test data set	Average % correctly classified	K statistic
Morphometric	Female	113	82.30	0.58
	Male	143	83.92	0.68
Meristic	Female	106	63.21	0.18
	Male	150	53.33	0.08

Discussion

This study demonstrates that there is considerable morphological divergence between white hake from the southern Gulf (depths ≤100 m), principally the Northumberland Strait area, and white hake from along the Laurentian Channel (depths >200 m). The best statistical classification of these populations was obtained with morphometric characters, and meristic characters provided limited but congruent evidence for separation. If a "stock" is considered to be an intraspecific group of individuals with recognizable geographic boundaries that exhibit unique phenotypic or genotypic attributes, then based on these results, white hake from the Strait and Channel areas should be regarded as separate stocks. This conclusion is consistent with the results of previous analyses of the distribution of catches of white hake during seasonal and annual surveys of the southern Gulf (Koeller and LeGresley 1981; Clay and Hurlbut 1989; Clay 1991; Morin and Hurlbut 1994) and with the results of a

rence of two stocks in it, during the summer and early fall, when there has historically been an important directed fishery for this species. From a fishery management perspective, subdividing the NAFO Division 4T management unit into two zones (≤ 100 and >200 m) would create the problem of how to apportion catches from depths between 100 and 200 m. Since the majority (59%) of the samples in this study from depths between 100 and 200 m were classified as Strait stock, the most tractable approach to this problem would be to subdivide NAFO Division 4T into two zones (≤ 200 and >200 m). An additional fishery management problem occurs when fish from the Strait stock migrate to overwinter along the Laurentian Channel, conceivably outside NAFO Division 4T, when they would become vulnerable to harvest with fish from the Channel stock. In this case, morphometric discriminant functions could be used to apportion catches in the mixture to their respective stocks.

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