Fisheries and Oceans Canada | Pêches et Océans Canada
Science | Sciences

Canadian Science Advisory Secretariat (CSAS)

Research Document 2013/085

Newfoundland and Labrador Region

Morphometric and meristic variability of wolffish (*Anarhichas* sp.) in Newfoundland and Labrador waters

M.R. Simpson, L.G.S. Mello, and C.M. Miri

Science Branch
Fisheries and Oceans Canada
PO Box 5667
St. John's NL Canada A1C 5X1

December 2013

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Simpson, M.R., Mello, L.G.S. and Miri, C.M. 2013. Morphometric and meristic variability of wolffish (*Anarhichas* sp.) in Newfoundland and Labrador waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/085. iv + 34 p.

ABSTRACT

Morphological variation within Northern Wolffish (*Anarhichas denticulatus*), Spotted Wolffish (*A. minor*), and Atlantic Wolffish (*A. lupus*) in Newfoundland and Labrador continental shelf waters were examined, and observed patterns utilized as a basis for delineating distinct groups of wolffish in the study area. A total of 1,425 specimens (136 Northern Wolffish; 244 Spotted Wolffish; 1,045 Atlantic Wolffish) collected during Fisheries and Oceans Canada Newfoundland and Labrador Region (DFO-NL) research surveys in the Northwest Atlantic Fisheries Organization (NAFO) Div. 2HJ3KLMNO and Subdiv. 3Ps were sampled for standard morphometric and meristic characteristics. Principal Component Analysis (PCA) explained between 74-79% and 84-88% of the variance in morphometric and meristic measurements, respectively. Bivariate plots of Principal Components (PC) exhibited patterns of variation in morphometric characteristics of Northern Wolffish, and in morphometric and meristic characteristics of Atlantic Wolffish from different areas.

Based on this analysis, it appeared that Northern Wolffish comprise at least two distinct groups in NL waters: a southern group centered on the northern and southeastern Grand Bank (Div. 3LN), and another smaller group scattered over much of the northeast Newfoundland (Div. 3K) and Labrador shelves (Div. 2J). For Atlantic Wolffish, it also appeared that there are two distinct groups: one centered on the southern Labrador shelf (Div. 2J); and another group centered on the southwest Grand Bank (Div. 3O). Atlantic Wolffish from Div. 3KLN and Subdiv. 3Ps were neither morphometrically nor meristically distinguishable from the other two groups of this species. This study provides potentially useful evidence for delineating boundaries of different groups of Northern Wolffish and Atlantic Wolffish in Newfoundland and Labrador waters.

Variabilité morphométrique et méristique du loup de mer (*Anarhichas* sp.) dans les eaux de Terre-Neuve-et-Labrador

RESUME

Les variations morphologiques du loup à tête large (*Anarhichas denticulatus*), du loup tacheté (*A. minor*) et du loup atlantique (*A. lupus*) dans les eaux de la plate-forme continentale à Terre-Neuve-et-Labrador ont été examinées, et les tendances observées ont servi de fondement pour délimiter les groupes distincts de loups dans la zone étudiée. Au total, 1 425 spécimens (136 loups à tête large; 244 loups tachetés; 1 045 loups atlantiques) ont été recueillis au cours des relevés de recherche effectués par Pêches et Océans Canada, région de Terre-Neuve-et-Labrador, dans la division 2HJ3KLNO et la sous-division 3Ps de l'Organisation des pêches de l'Atlantique Nord-Ouest (OPANO). Les spécimens ont été échantillonnés pour leurs caractéristiques morphométriques et méristiques standard. Une analyse des principales composantes a permis d'expliquer, respectivement, de 74 à 79 % et de 84 à 88 % de la variance entre les mesures morphométriques et les mesures méristiques. Des diagrammes à deux variables des principales composantes ont montré des tendances de variation dans les caractéristiques morphométriques du loup à tête large, ainsi que des tendances de variation dans les caractéristiques morphométriques et méristiques du loup atlantique provenant de zones différentes.

En se basant sur cette analyse, il semble que la population du loup à tête large dans les eaux de Terre-Neuve-et-Labrador est formée d'au moins deux groupes distincts : un groupe au sud situé dans les parties nord et sud-est du Grand Banc (division 3LN) et un autre groupe, plus petit, dispersé dans une grande partie des plateaux du nord-est de Terre-Neuve (division 3K) et des plateaux du Labrador (division 2J). En ce qui concerne le loup atlantique, il semble également qu'il y a deux groupes distincts : l'un est situé dans le plateau du sud du Labrador (division 2J) et l'autre, dans le sud-ouest du Grand Banc (division 3O). Les loups atlantiques de la division 3KLN et de la subdivision 3Ps ne se distinguaient pas des deux autres groupes de cette espèce quant à leurs caractéristiques morphométriques ou méristiques. Cette étude a fourni une preuve potentiellement utile pour la délimitation des différents groupes de loups à tête large et de loups atlantiques dans les eaux de Terre-Neuve-et-Labrador.

INTRODUCTION

Wolffish (family Anarhichadidae) are large demersal fish found in subarctic to temperate latitudes in North Atlantic and Pacific Oceans and adjacent seas. The species are mostly distinguishable by their large jaws and canine-like teeth, long dorsal fin, and absence of pelvic fins. Three wolffish species are found in Canadian Atlantic waters: Northern Wolffish (*Anarhichas denticulatus*), Spotted Wolffish (*A. minor*), and Atlantic Wolffish (*A. lupus*).

Although no major directed fisheries for wolffish have occurred in Canadian Atlantic waters, population abundance/biomass of all three species declined significantly during the 1980s and 1990s. Subsequent recommendations from the Committee On the Status of Endangered Wildlife In Canada (COSEWIC) prompted the Canadian Government to protect these species under the federal *Species at Risk Act* (*SARA*; Kulka et al. 2004). Consequently, DFO developed a joint Recovery Strategy/Management Plan for all three wolffish species (Kulka et al. 2008). However, for effective management of wolffish in Canadian Atlantic waters, a clear understanding of stock structure and population dynamics is required. Within such a large marine area, species that have limited dispersal capabilities (e.g., wolffish) could be expected to show morphometric, meristic, and genetic variations, which may be useful for delineation and management of distinct stocks, or sub-populations.

In a previous study, Templeman (1984) analysed meristic variation (number of vertebrae and dorsal fin rays) in Atlantic Wolffish in the Northwest Atlantic Ocean (i.e., from Western Greenland to the Scotian Shelf), and found significant differences in the mean number of vertebrae in Newfoundland and Labrador waters. No significant differences were found for Spotted Wolffish (Templeman 1986).

More recently, Imsland et al. (2008) investigated the genetic structure of Spotted Wolffish populations from the North Atlantic Ocean and the Barents Sea, and found statistically significant differences across the distribution range of this species. Of particular interest, Canadian samples from two geographic areas (i.e., Cabot Strait off of the southwestern coast of Newfoundland; Bauge Bank off of eastern Anticosti Island) were found to be significantly different; thus, suggesting genetic substructure of Spotted Wolffish populations within Canadian waters.

McCusker and Bentzen (2010, 2011) used microsatellite DNA analysis to evaluate genetic differentiation in wolffish from various areas across the North Atlantic Ocean. Significant differences were observed between Northern Wolffish from the Barents Sea and other regions (Canadian Atlantic waters; Greenland; Iceland; the Mid-Atlantic Ridge), as well as between those from Canadian Atlantic waters and the Mid-Atlantic Ridge. Barents Sea Spotted Wolffish were significantly different from both Canadian Atlantic and West Greenland specimens (McCusker and Bentzen 2011). The authors also found that population structure was not pronounced in either species, and no significant differences were detected between specimens from Newfoundland and Labrador waters and the Maritimes region; thus contrasting with the results of Imsland et al. (2008) for Spotted Wolffish. McCusker and Bentzen (2010) also observed significant genetic differences between Atlantic Wolffish from Canadian Atlantic waters, the North Sea, and Rockall Bank (off of western Scotland). Within Canadian waters, no significant differences were found between Atlantic Wolffish from the Scotian Shelf, southern Gulf of St. Lawrence, and southern Newfoundland waters. However, significant differences were observed between the northern and southern Gulf of St. Lawrence; as well as between southeast and northeast areas of the Grand Bank.

This study evaluated morphometric and meristic variations in each of three wolffish species in Newfoundland and Labrador waters, as a basis for delineation of distinct populations or stocks. Its findings could then be applied in support of more effective management of these species.

METHODS

Morphometric and meristic data were obtained mainly from specimens caught during Canadian spring (NAFO Div. 3LMNO and Subdiv. 3Ps) and fall (NAFO Div. 2HJ3KLNO; Fig. 1) research surveys conducted in 2003-11 using a Campelen 1800 shrimp trawl. The surveys employed a stratified random sampling design as described by Doubleday (1981). A total of 1,425 specimens (136 Northern Wolffish; 244 Spotted Wolffish; 1,045 Atlantic Wolffish) were frozen aboard vessel, and subsequently thawed and processed in a DFO laboratory located at the Northwest Atlantic Fisheries Center (St. John's, Newfoundland, Canada). The following data were collected on each specimen: sex, maturity stage, total weight (in grams), standard length (in centimeters), total length, head length, eye diameter, inter-orbital width, jaw length, girth length, nose to anus length, pectoral fin length and width, dorsal fin length, anal fin length, caudal fin length and width, gill raker count, pectoral fin ray count, dorsal fin ray count, anal fin ray count, and caudal fin ray count. Principal Component Analysis (PCA) was used to identify groups of fish having similar morphometric and meristic characteristics.

PRELIMINARY ANALYSIS

Preliminary analyses were conducted for both morphometric and meristics variables before PCA was ran. Morphometric measurements were examined for sexual dimorphism, and were subsequently standardized using individual body length in order to remove any effect of allometric growth, because PCA characterizes variance only within homogeneous samples (Cadrin 2000). Most morphometric variables for females and males exhibited similar strong linear relationships with fish size ($R^2 > 0.9$, $p < 0.05$); thereby supporting an assumption of no sexual dimorphism (Figs. 2-4). However, sexual dimorphism was observed for jaw length on Northern and Spotted Wolffish; eye diameter, caudal and pectoral fin lengths on Northern Wolffish; and caudal and pectoral fin widths on Atlantic Wolffish. These variables were thus not included in PCA. These apparent sexual dimorphisms may be partially explained by the low number of samples from female specimens. The procedure used to remove size-dependent variation is based on Elliott et al. (1995):

$$M_{iadj} = M_i \, (L_s/L_{io})^b$$

where M_i is the original morphometric measurement of fish i, M_{iadj} is the size-adjusted measurement, L_{io} is the standard length of fish i, and L_s is the overall mean standard length for all fish. Parameter b represents the coefficients of allometric ratio between standard length and variable M, and is the slope of the regression of log M on log L_o.

In general, variability of meristic characteristics tended to be low and similar for male and female wolffish of all sizes; except for Spotted Wolffish and Atlantic Wolffish < 15 cm TL, which generally displayed the largest range of values for most variables (Figs. 5-7). This is likely due to the difficulty in counting number of fin rays in very small specimens. A Kruskal-Wallis non-parametric ANOVA indicated that meristic characteristics did not vary significantly in relation to wolffish size and sex (Table 1).

The initial PCA of the combined sexes included all (size-adjusted) morphometric and meristic variables that did not violate an assumption of homogeneity in samples; however, the final analysis included only those variables that maximized the explanatory power of PCA models. Both morphometric and meristic data were log-transformed prior to conducting PCA.

RESULTS

NORTHERN WOLFFISH

The pairwise correlation matrix from PCA indicated that all morphometric variables were correlated to various degrees ($0.41 > R^2 > 0.78$; Table 2). Eigenvalues of the correlation matrix showed that the first Principal Component (PC1) provided a reasonable summary of the data, explaining nearly 61% of the variance; while PC2 and PC3 explained an additional 10% and 8%, respectively. PC1 adequately measured the overall morphometric variability of Northern Wolffish, as the first eigenvector showed similar positive loading on all variables. The second eigenvector had high positive loading on the variable “caudal fin width”, and high negative loading on “girth length”; while the third component had high positive loading on “pectoral fin width”, and high negative loading on “inter-orbital width”. The bivariate plot of PC1 and PC2 scores by NAFO Division overlapped to a large degree; with most negative PC1 scores for fish from all Divisions, and several PC1 scores > 4 (Fig. 8). However, despite a limited number of observations in some cases, some trends were identified: notably, for fish from Div. 3L and Div. 3N, a higher frequency of negative scores for PC2 was observed. Plots for PC2 and PC3 scores overlapped in all Divisions; except for a high frequency of positive scores for PC2 in Div. 3L and negative scores in Div. 3N. These patterns for PC1 and PC2 were accentuated when considered at larger scales (Grand Bank in Div. 3LNO), but were masked for PC2 and PC3 when compared with patterns observed at the NAFO Division scale.

The correlation matrix for meristic variables resulted in R^2 values of 0.16-0.33, and eigenvalues indicated that nearly 42% of the variance was explained by PC1; while PC2 explained an additional 22%, and PC3 another 20% (Table 3). The first eigenvector had similar loading on all meristic variables; while the second and third eigenvectors had high positive and negative loading on “number of caudal fin rays” and “number of pectoral fin rays”, respectively. No trends were observed for plots of any PC scores by NAFO Division or on the Grand Bank, because they overlapped across the range of values (Fig. 9).

SPOTTED WOLFFISH

Morphometric variables were correlated to various degrees ($0.28 > R^2 > 0.72$), and eigenvalues indicated that PC1 explained > 57% of the variance; while PC2 and PC3 explained an additional 12% and 8%, respectively (Table 4). Eigenvectors for PC1 had similar positive loading for all variables, and strong positive loading on “girth” and “pectoral fin width” for PC2 and PC3, respectively. Plots of PC1 and PC2, and PC2 and PC3 scores, overlapped in most Divisions, but a trend could still be detected in Div. 2J in both plots; with most negative scores for PC2 and positive scores for PC3 (Fig. 10). No patterns were detected in the Grand Bank plot.

The pairwise correlation matrix for meristic variables yielded R^2 values of 0.28-0.47, and eigenvalues indicated that PC1 through PC3 explained 53%, 19%, and 16% of the variance, respectively (Table 5). PC1 had similar loading for all variables; while PC2 and PC3 had high positive loadings on “number of anal fin rays” and “number of caudal fin rays”, respectively. Plots of PC1 and PC2 scores, and PC2 and PC3 scores, overlapped for fish from all NAFO Divisions and on the Grand Bank; thus, no trends were detected (Fig. 11).

ATLANTIC WOLFFISH

The pairwise correlation matrix from PCA showed weaker linear relationships among morphometric measurements for Atlantic Wolffish ($-0.04 > R^2 > 0.32$; Table 6). Eigenvalues indicated that PC1 explained 35% of the variance, and PC2 and PC3 explained an additional 23% and 16%, respectively. The first eigenvector had similar positive loading on all variables;

whereas PC2 had high positive loading on “jaw length” and PC3 had high negative loading on “caudal fin length”. Plots of PC1 and PC2 scores, as well PC2 and PC3 scores overlapped in most cases, but trends were also detected in this case (Fig. 12). In particular, the majority of PC2 scores were positive in Div. 2J and negative in Div. 3O (PC1 and PC2 plot). PC3 scores were also mostly negative in Div. 3O (PC2 and PC3 plot). Nevertheless, no trends were observed on the Grand Bank; despite trends detected in Div. 2J and Div. 3O.

The pairwise correlation matrix for meristic variables resulted in R^2 values of 0.24-0.43, and eigenvalues indicated that PC1, PC2, and PC3 explained 48%, 20%, and 17% of the variance, respectively (Table 7). The first eigenvector had similar loadings on all variables, and the second and third eigenvectors had high positive loadings on “number of caudal fin rays” and “number of pectoral fin rays”, respectively. Noticeable trends were observed for plots of PC1 and PC2 scores for wolffish from Div. 2H, Div. 2J, and Div. 3K (i.e., mostly negative scores for PC1), and from Div. 3O (i.e., mostly positive scores for PC1). For fish from Div. 3L and Div. 3N, scores overlapped across the range of values for PC1 and PC2, and for PC2 and PC3, in all Divisions and on the Grand Bank (Fig. 13).

DISCUSSION

In this study, PCA was used to: (i) assess the variability of morphometric and meristic characteristics of three wolffish species found in Newfoundland and Labrador waters; and (ii) utilize the patterns of variation detected to provide an indirect basis for delineating stock or population structure. Principal Component Analysis models explained 74-79% and 84-88% of the variance in morphometric and meristic measurements, respectively.

Distinct patterns of morphometric variability were detected among Northern Wolffish and Atlantic Wolffish from different areas. For Northern Wolffish, almost all negative scores for PC1, PC2, and PC3 were observed for specimens caught in Div. 3L and Div. 3N; suggesting that fish from these areas have morphological traits distinct from those of fish from other areas on the continental shelf. Furthermore, patterns observed in bivariate plots appeared to be influenced primarily by high negative loading on “girth length” for PC2, and “inter-orbital width” for PC3; suggesting that these variables are good indicators for identifying different groups of Northern Wolffish in Newfoundland and Labrador waters. Analyses conducted over a larger scale produced similar results. In contrast, no trends were detected in meristic characteristics.

For Atlantic Wolffish, most PC2 scores were positive for specimens captured in Div. 2J, and most scores for PC2 and PC3 were negative for wolffish from Div. 3O; suggesting differences in morphometric characteristics between fish from these two Divisions. High positive loading on “jaw length” (PC2), and high negative loading on “caudal fin length” (PC3), suggest that these variables are good indicators for differentiating between groups of Atlantic Wolffish from Div. 2J and Div. 3O, respectively. Results from PCA of meristic characteristics corroborated findings based on morphometric analyses, because it detected similar patterns in wolffish from Div. 2H, Div. 2J, and Div. 3K (i.e., mostly negative scores for PC1); in contrast with the pattern observed for fish from Div. 3O and Subdiv. 3Ps (i.e., mostly positive scores for PC1). In addition, no trends were detected when PCA was conducted for morphometric and meristic characteristics over a larger spatial scale; highlighting an importance of conducting multi-scaled analyses when trying to differentiate between groups of fish.

No differences in morphometric and meristic characteristics were detected for Spotted Wolffish on either spatial scale; except perhaps for morphometric characteristics of fish in Div. 2J, because most scores were negative for PC2 and positive for PC3. However, the small number of observations presently precludes any further interpretation of these results.

Results of this study are partially supported by several findings from previous research focused on differentiating wolffish populations in Canadian waters and other regions. Templeman (1984) differentiated between groups of Northern Wolffish in the Newfoundland and Labrador region and from other Canadian Atlantic regions using “mean number of vertebrae”; while no differences were detected for Spotted Wolffish between the same regions (Templeman 1986). Imsland et al. (2008) identified distinct groups of Spotted Wolffish from the south coast of Newfoundland (Cabot Strait) and from the Gulf of St. Lawrence utilizing genetic analyses. Similarly, McCusker and Bentzen (2010, 2011) found significant genetic differences between Atlantic Wolffish from the southeast and northeast regions of the Grand Bank, as well as between the southern and northern regions of the Gulf of St. Lawrence. However, these authors found no genetic differences for Spotted Wolffish in Canadian Atlantic waters.

Despite some discrepancies between previous studies, a prevailing view is that, at least for Northern Wolffish and Atlantic Wolffish, distinct groups or populations have been detected in Canadian Atlantic waters; especially within the Newfoundland and Labrador region. Findings in this study are consistent with this view. Accordingly, Northern Wolffish seems to comprise at least two distinct groups: a southern group centered in the northern and southeastern Grand Bank (Div. 3LN), and a smaller group scattered over much of the Northeast Newfoundland (Div. 3K) and Labrador shelves (Div. 2J). Similarly, two distinct groups of Atlantic Wolffish are apparent: one centered on the southern Labrador shelf (Div. 2J), and another group centered on the southwest Grand Bank (Div. 3O). Furthermore, Atlantic Wolffish from Div. 3KLN and Subdiv. 3Ps are neither morphometrically nor meristically distinguishable from these other two groups of Atlantic Wolffish.

This study provided evidence for delineating boundaries of different groups of Northern Wolffish and Atlantic Wolffish in Newfoundland and Labrador waters. Its findings can now be used as a basis for identifying stocks or population structures of both species in Canadian Atlantic waters by direct methods (e.g., genetic analyses; fish tagging and telemetry).

ACKNOWLEDGEMENTS

We thank Fisheries and Oceans Canada staff who participated in Canadian research surveys, and Dave Sears, Barry McDonald, Dennis Rice, and Brad Vaters for meticulously processing samples in the DFO-NL Region lab.

REFERENCES

Cadrin, S.X. 2000. Advances in morphometric analysis of fish stock structure. Rev. Fish Biol. Fish. 10: 91-112.

Doubleday, W.G. 1981. Manual on groundfish surveys in the Northwest Atlantic. NAFO Sci. Counc. Studies No. 2. 55p.

Elliott, N.G., Haskard, K., and Koslow, J.A. 1995. Morphometric analysis of orange roughy (*Hoplostethus atlanticus*) off the continental slope of southern Australia. J. Fish Biol 46: 202-220.

Imsland, A.K., Stensland, K., Johansen, T., Le Francois, N., Lamarre, S., Naevdal, G., and Foss, A. 2008. Population genetic structure of the Spotted Wolffish, *Anarhichas minor*, in the North Atlantic. The Open Mar. Biol. J. 2: 7-12.

Kulka, D.W., Simpson, M.R., and Hooper, R.G. 2004. Changes in distribution and habitat associations of wolffish (Anarhichidae) in the Grand Banks and Labrador Shelf. DFO Atl. Fish. Res. Doc. 04/113. 44p.

Kulka, D.W., Hood, C., and Huntington, J. 2008. Recovery strategy for Northern Wolffish (*Anarhichas denticulatus*) and Spotted Wolffish (*Anarhichas minor*), and management plan for Atlantic Wolffish (*Anarhichas lupus*) in Canada. Fisheries and Oceans Canada: Newfoundland and Labrador Region. St. John's, NL. x + 103 pp.

McCusker, M.R., and Bentzen, P. 2010. Phylogeography of 3 North Atlantic wolffish species (*Anarhichas* spp.) with phylogenetic relationships within the Family Anarhichadidae. J. Hered. 101(5): 591-601.

McCusker, M.R., and Bentzen, P. 2011. Limited population structure in Northern and Spotted Wolffishes (*Anarhichas denticulatus* and *A. minor*) despite low apparent dispersal potential. Mar. Biol. 158: 1869-1878.

Templeman, W. 1984. Vertebral and dorsal fin-ray numbers in Atlantic Wolffish (*Anarhichas lupus*) of the Northwest Atlantic. J. Northw. Atl. Sci. 5: 207-212.

Templeman, W. 1986. Contribution to the biology of the Spotted Wolffish (*Anarhichas minor*) in the Northwest Atlantic. J. Northw. Atl. Sci. 7: 47-55.

Table 1a. Kruskal-Wallis ANOVA test results for meristic characteristics of Northern Wolffish in relation to sex and fish size (standard length).

Dependent Variable: No. of dorsal fin rays

Source	DF	SS	Mean Square	F Value	Pr > F
Model	29	4278.500000	147.534483	1.53	0.2432
Error	10	963.500000	96.350000	-	-

R-Square	CV	Root MSE
0.816196	47.88197	9.815804

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Sex	1	15.187500	15.187500	0.16	0.6997
Standard length	28	4278.368421	152.798872	1.59	0.2248

Dependent Variable: No of anal fin rays

Source	DF	SS	Mean Square	F Value	Pr > F
Model	29	4134.958333	142.584770	1.56	0.2320
Error	10	912.041667	91.204167	-	-

R-Square	CV	Root MSE
0.819290	46.58579	9.550087

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Sex	1	85.333333	85.333333	0.94	0.3562
Standard length	28	4126.537281	147.376331	1.62	0.2151

Dependent Variable: No of caudal fin rays

Source	DF	SS	Mean Square	F Value	Pr > F
Model	29	2755.583333	95.020115	0.43	0.9644
Error	10	2231.916667	223.191667	-	-

R-Square	CV	Root MSE
0.552498	72.87610	14.93960

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Sex	1	85.333333	85.333333	0.38	0.5502
Standard length	28	2721.899123	97.210683	0.44	0.9593

Dependent Variable: No. of pectoral fin rays

Source	DF	SS	Mean Square	F Value	Pr > F
Model	29	4299.583333	148.261494	2.31	0.0815
Error	10	640.916667	64.091667	-	-

R-Square	CV	Root MSE
0.870273	39.05233	64.091667

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Sex	1	13.020833	13.020833	0.20	0.6618
Standard length	28	4109.583333	146.770833	2.29	0.0845

Table 1b. Kruskal-Wallis ANOVA test results for meristic characteristics of Spotted Wolffish in relation to sex and fish size (standard length).

Dependent Variable: No. of dorsal fin rays

Source	DF	SS	Mean Square	F Value	Pr > F
Model	114	214153.3252	1878.5379	1.29	0.2032
Error	32	46481.1748	1452.5367	-	-

R-Square	CV	Root MSE
0.821661	51.50292	38.11216

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Sex	2	1813.2419	906.6209	0.62	0.5421
Standard length	112	213439.4737	1905.7096	1.31	0.1902

Dependent Variable: No of anal fin rays

Source	DF	SS	Mean Square	F Value	Pr > F
Model	114	210235.1923	1844.1684	1.58	0.0676
Error	32	37270.8077	1164.7127	-	-

R-Square	CV	Root MSE
0.849415	46.11877	34.12789

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Sex	2	2365.5465	1182.7732	1.02	0.3736
Standard length	112	205508.0512	1834.8933	1.58	0.0700

Dependent Variable: No of caudal fin rays

Source	DF	SS	Mean Square	F Value	Pr > F
Model	114	176877.1829	1551.5542	0.69	0.9165
Error	32	71553.3171	2236.0412	-	-

R-Square	CV	Root MSE
0.711979	63.90108	47.28680

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Sex	2	3623.6621	1811.8310	0.81	0.4536
Standard length	112	176261.2137	1573.7608	0.70	0.9075

Dependent Variable: No. of pectoral fin rays

Source	DF	SS	Mean Square	F Value	Pr > F
Model	114	193684.6383	1698.9881	1.08	0.4128
Error	32	50275.3617	1571.1051	-	-

R-Square	CV	Root MSE
0.793920	53.56374	39.63717

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Sex	2	706.8258	353.4129	0.22	0.7998
Standard length	112	192843.2615	1721.8148	1.10	0.3950

Table 1c. Kruskal-Wallis ANOVA test results for meristic characteristics of Atlantic Wolffish in relation to sex and fish size (standard length).

Dependent Variable: No. of dorsal fin rays

Source	DF	SS	Mean Square	F Value	Pr > F
Model	319	11671119.48	36586.58	1.04	0.3477
Error	341	11950850.52	35046.48	-	-

R-Square	CV	Root MSE
0.494079	56.55802	187.2071

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Sex	2	42284.19	21142.09	0.60	0.5476
Standard length	317	11306981.23	35668.71	1.02	0.4362

Dependent Variable: No of anal fin rays

Source	DF	SS	Mean Square	F Value	Pr > F
Model	319	11927454.18	37390.14	1.17	0.0757
Error	341	10887089.32	31926.95	-	-

R-Square	CV	Root MSE
0.522800	53.98222	178.6811

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Sex	2	46471.58	23235.79	0.73	0.4837
Standard length	317	11321798.71	35715.45	1.12	0.1545

Dependent Variable: No of caudal fin rays

Source	DF	SS	Mean Square	F Value	Pr > F
Model	319	11865104.96	37194.69	1.18	0.0658
Error	341	10742870.54	31504.02	-	-

R-Square	CV	Root MSE
0.524819	53.62348	177.4937

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Sex	2	21433.25	10716.63	0.34	0.7119
Standard length	317	11747878.49	37059.55	1.18	0.0704

Dependent Variable: No. of pectoral fin rays

Source	DF	SS	Mean Square	F Value	Pr > F
Model	319	10565056.70	33119.30	1.05	0.3191
Error	341	10724575.30	31450.37	-	-

R-Square	CV	Root MSE
0.496254	53.57780	177.3425

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Sex	2	199313.75	99656.88	3.17	0.0433
Standard length	317	10520245.77	33186.90	1.06	0.3127

Table 2. Results of Principal Component Analysis for morphometric characteristics of Northern Wolffish captured in Newfoundland and Labrador waters (NAFO Division 2J3KLNO).

Correlation Matrix: Observations 123, Variables 8

-	log_head_leng	log_nose_anus_leng	log_girth	Log_dorsal_fin_leng	Log_anal_fin_leng	log_caudal_fin_width	log_pectoral_fin_width	Log_dorsal_fin_leng
log_head_leng	1.0000	0.6506	0.5771	0.7285	0.7192	0.5946	0.6065	0.6879
log_nose_anus_leng	0.6506	1.0000	0.6356	0.5389	0.5865	0.4211	0.4186	0.4539
log_girth	0.5771	0.6356	1.0000	0.7842	0.5825	0.4114	0.4677	0.4401
log_dorsal_fin_leng	0.7285	0.5389	0.7842	1.0000	0.7340	0.4802	0.4893	0.4952
log_anal_fin_leng	0.7192	0.5865	0.5825	0.7340	1.0000	0.4715	0.4354	0.4777
log_caudal_fin_width	0.5946	0.4211	0.4114	0.4802	0.4715	1.0000	0.4648	0.4656
log_pectoral_fin_width	0.6065	0.4186	0.4677	0.4893	0.4354	0.4648	1.0000	0.4124
log_inter_orbital_width	0.6879	0.4539	0.4401	0.4952	0.4777	0.4656	0.4124	1.0000

Eigenvalues of the Correlation Matrix

-	Eigenvalue	Difference	Proportion	Cumulative
1	4.85015208	4.06729372	0.6063	0.6063
2	0.78285836	0.17610934	0.0979	0.7041
3	0.60674901	-	0.0758	0.7800

Eigenvectors

-	Prin1	Prin2	Prin3
log_head_leng	0.409148	0.162844	-0.140336
log_nose_anus_leng	0.344961	-0.264050	-0.115836
log_girth	0.360933	-0.458124	0.179815
log_dorsal_fin_leng	0.389072	-0.315340	0.070621
log_anal_fin_leng	0.370493	-0.222990	-0.134423
log_caudal_fin_width	0.309558	0.515104	0.079620
log_pectoral_fin_width	0.308963	0.358691	0.731159

Table 3. Results of Principal Component Analysis for meristic characteristics of Northern Wolffish captured in Newfoundland and Labrador waters (NAFO Division 2J3KLNO).

Correlation Matrix: Observations 132, Variables 4

-	log_dorsal_ fin_rays_no	Log_anal_ fin_rays_no	log_caudal_ fin_rays_no	Log_pectoral_ fin_rays_no
log_dorsal_fin_rays_no	1.0000	0.3278	0.1838	0.2449
log_anal_fin_rays_no	0.3278	1.0000	0.1656	0.1709
log_caudal_fin_rays_no	0.1838	0.1656	1.0000	0.2180
log_pectoral_fin_rays_no	0.2449	0.1709	0.2180	1.0000

Eigenvalues of the Correlation Matrix

-	Eigenvalue	Difference	Proportion	Cumulative
1	1.66112158	0.76653786	0.4153	0.4153
2	0.89458371	0.10857623	0.2236	0.6389
3	0.78600748	0.12772025	0.1965	0.8354

Eigenvectors

-	Prin1	Prin2	Prin3
log_dorsal_fin_rays_no	0.555734	-0.358773	-0.111280
log_anal_fin_rays_no	0.511363	-0.548003	0.258248
log_caudal_fin_rays_no	0.442198	0.632907	0.631700
log_pectoral_fin_rays_no	0.483869	0.412799	-0.722412

Table 4. Results of Principal Component Analysis for morphometric characteristics of Spotted Wolffish captured in Newfoundland and Labrador waters (NAFO Division 2J3KLN).

Correlation Matrix: Observations 211, Variables 8

-	log_head_leng	log_nose_anus_leng	log_girth	Log_dorsal_fin_leng	Log_anal_fin_leng	log_caudal_fin_width	log_pectoral_fin_leng	Log_pectoral_fin_width
log_head_leng	.6346	1.0000	0.5483	0.5809	0.5703	0.6347	0.6703	0.5050
log_nose_anus_leng	0.3969	0.5483	1.0000	0.6132	0.4597	0.5127	0.5282	0.4820
log_girth	0.5758	0.5809	0.6132	1.0000	0.7160	0.3270	0.2759	0.4829
log_dorsal_fin_leng	0.5944	0.5703	0.4597	0.7160	1.0000	0.4387	0.4464	0.5168
log_anal_fin_leng	0.6347	0.5127	0.3270	0.4387	0.4392	0.4392	0.4050	0.4692
log_caudal_fin_width	0.6703	0.5282	0.2759	0.4464	0.4050	1.0000	0.5171	0.3220
log_pectoral_fin_width	0.5050	0.4820	0.4829	0.5168	0.4692	0.5171	1.0000	0.4949
log_inter_orbital_width	.6346	1.0000	0.5483	0.5809	0.5703	0.3220	0.4949	1.0000

Eigenvalues of the Correlation Matrix

-	Eigenvalue	Difference	Proportion	Cumulative
1	4.56609336	3.61314713	0.5708	0.5708
2	0.95294623	0.29876626	0.1191	0.6899
3	0.65417996		0.0818	0.7717

Eigenvectors

-	Prin1	Prin2	Prin3
log_head_leng	0.392006	-0.320413	-0.035129
log_nose_anus_leng	0.379171	0.016715	-0.096530
log_girth	0.314610	0.549657	-0.015720
log_dorsal_fin_leng	0.381714	0.319221	-0.183972
log_anal_fin_leng	0.364333	0.201180	-0.314788
log_caudal_fin_width	0.323295	-0.444831	-0.405191
log_pectoral_fin_leng	0.335798	-0.476172	0.383473
log_pectoral_fin_width	0.328416	0.167166	0.738263

Table 5. Results of Principal Component Analysis for meristic characteristics of Spotted Wolffish captured in Newfoundland and Labrador waters (NAFO Division 2J3KLN).

Correlation Matrix: Observations 233, Variables 4

-	log_dorsal_ fin_rays_no	Log_anal_ fin_rays_no	log_caudal_ fin_rays_no	Log_pectoral_ fin_rays_no
log_dorsal_fin_rays_no	1.0000	0.4169	0.3508	0.4710
log_anal_fin_rays_no	0.4169	1.0000	0.3028	0.2803
log_caudal_fin_rays_no	0.3508	0.3028	1.0000	0.4061
log_pectoral_fin_rays_no	0.4710	0.2803	0.4061	1.0000

Eigenvalues of the Correlation Matrix

-	Eigenvalue	Difference	Proportion	Cumulative
1	2.11954416	1.36891524	0.5299	0.5299
2	0.75062892	0.10337186	0.1877	0.7175
3	0.64725707	0.16468722	0.1618	0.8794

Eigenvectors

-	Prin1	Prin2	Prin3
log_dorsal_fin_rays_no	0.539164	0.150393	-0.464301
log_anal_fin_rays_no	0.460058	0.771281	0.264215
log_caudal_fin_rays_no	0.480644	-0.439782	0.728549
log_pectoral_fin_rays_no	0.516362	-0.434855	-0.428755

Table 6. Results of Principal Component Analysis for morphometric characteristics of Atlantic Wolffish captured in Newfoundland and Labrador waters (NAFO Division 2J3KLMNO and Subdivision 3Ps).

Correlation Matrix: Observations 655, Variables 5

-	log_head_ leng	log_nose_ anus_leng	log_caudal_fin_leng	log_pectoral_fin_leng	log_jaw_leng
log_head_leng	1.0000	0.2049	0.2450	0.2967	0.3231
log_nose_anus_leng	0.2049	1.0000	0.1265	0.2496	-.0416
log_caudal_fin_leng	0.2450	0.1265	1.0000	0.2095	0.1626
log_pectoral_fin_leng	0.2967	0.2496	0.2095	1.0000	0.0173
log_jaw_leng	0.3231	-.0416	0.1626	0.0173	1.0000

Eigenvalues of the Correlation Matrix

-	Eigenvalue	Difference	Proportion	Cumulative
1	1.75814932	0.62621159	0.3516	0.3516
2	1.13193772	0.31787506	0.2264	0.5780
3	0.81406266	-	0.1628	0.7408

Eigenvectors

-	Prin1	Prin2	Prin3
log_head_leng	0.571767	0.191388	0.310473
log_nose_anus_leng	0.368065	-0.555458	0.347876
log_caudal_fin_leng	0.448696	0.092946	-0.839347
log_pectoral_fin_leng	0.476465	-0.379673	-0.042483
log_jaw_leng	0.330550	0.708552	0.276189

Table 7. Results of Principal Component Analysis for meristic characteristics of Atlantic Wolffish captured in Newfoundland and Labrador waters (NAFO Div. 2J3KLMNO and Subdivision 3Ps).

Correlation Matrix: Observations 987, Variables 4

-	log_dorsal_ fin_rays_no	Log_anal_ fin_rays_no	log_caudal_ fin_rays_no	Log_pectoral_ fin_rays_no
log_dorsal_fin_rays_no	1.0000	0.4285	0.2610	0.3214
log_anal_fin_rays_no	0.4285	1.0000	0.2448	0.3318
log_caudal_fin_rays_no	0.2610	0.2448	1.0000	0.2619
log_pectoral_fin_rays_no	0.3214	0.3318	0.2619	1.0000

Eigenvalues of the Correlation Matrix

-	Eigenvalue	Difference	Proportion	Cumulative
1	1.93322943	1.13548570	0.4833	0.4833
2	0.79774373	0.09913011	0.1994	0.6827
3	0.69861363	0.12820042	0.1747	0.8574

Eigenvectors

-	Prin1	Prin2	Prin3
log_dorsal_fin_rays_no	0.535357	-0.316313	-0.356014
log_anal_fin_rays_no	0.534016	-0.378876	-0.254688
log_caudal_fin_rays_no	0.428612	0.869709	-0.238212
log_pectoral_fin_rays_no	0.494481	-0.002228	0.866974

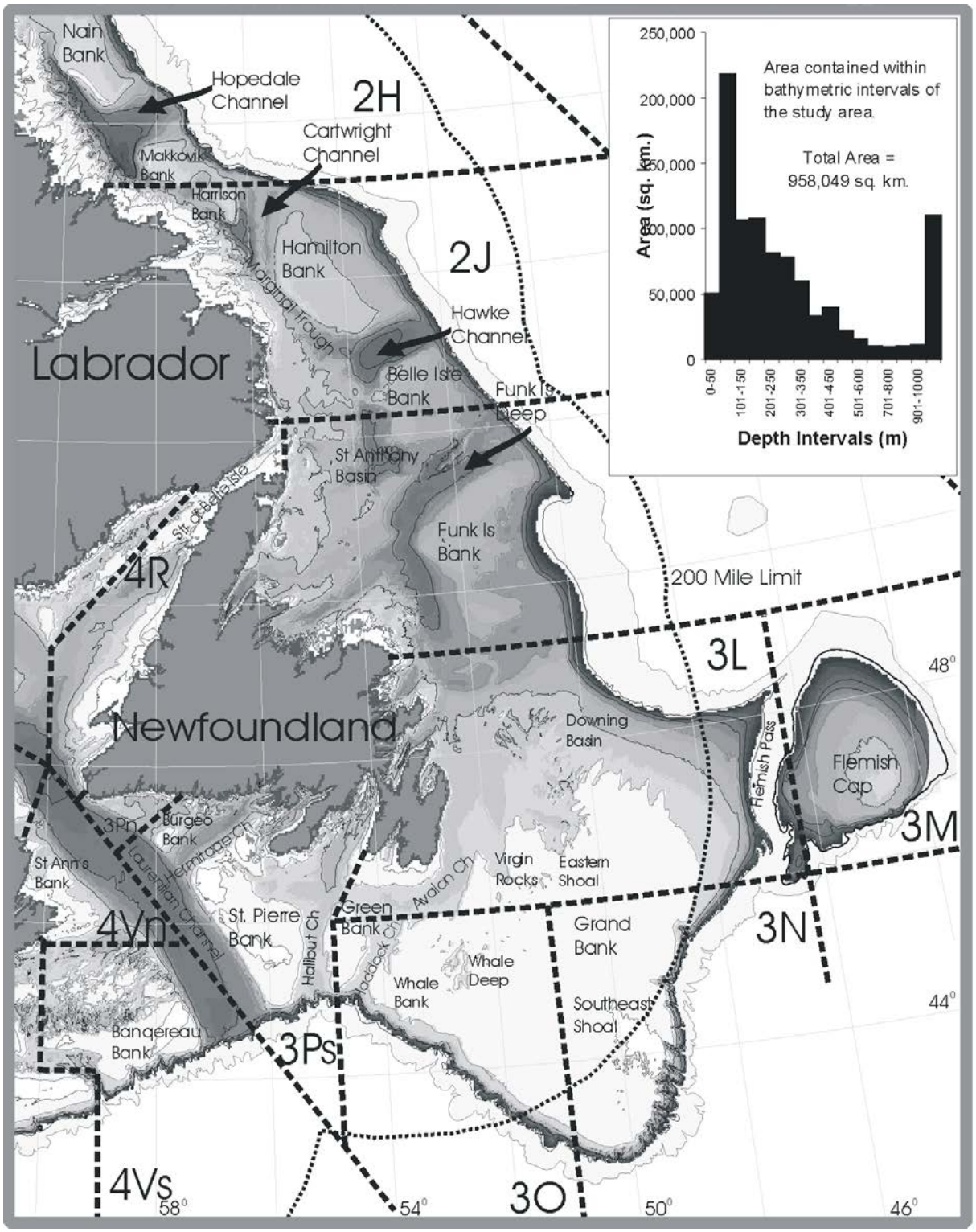

Figure 1. Map of the continental shelf off Eastern Canada and geographic features mentioned in the text. Depth range: <100 m (light grey) to >1000 m (dark grey). Canada's 200-Mile Limit is delineated by a thin dotted line, and NAFO Divisions by thick dotted lines.

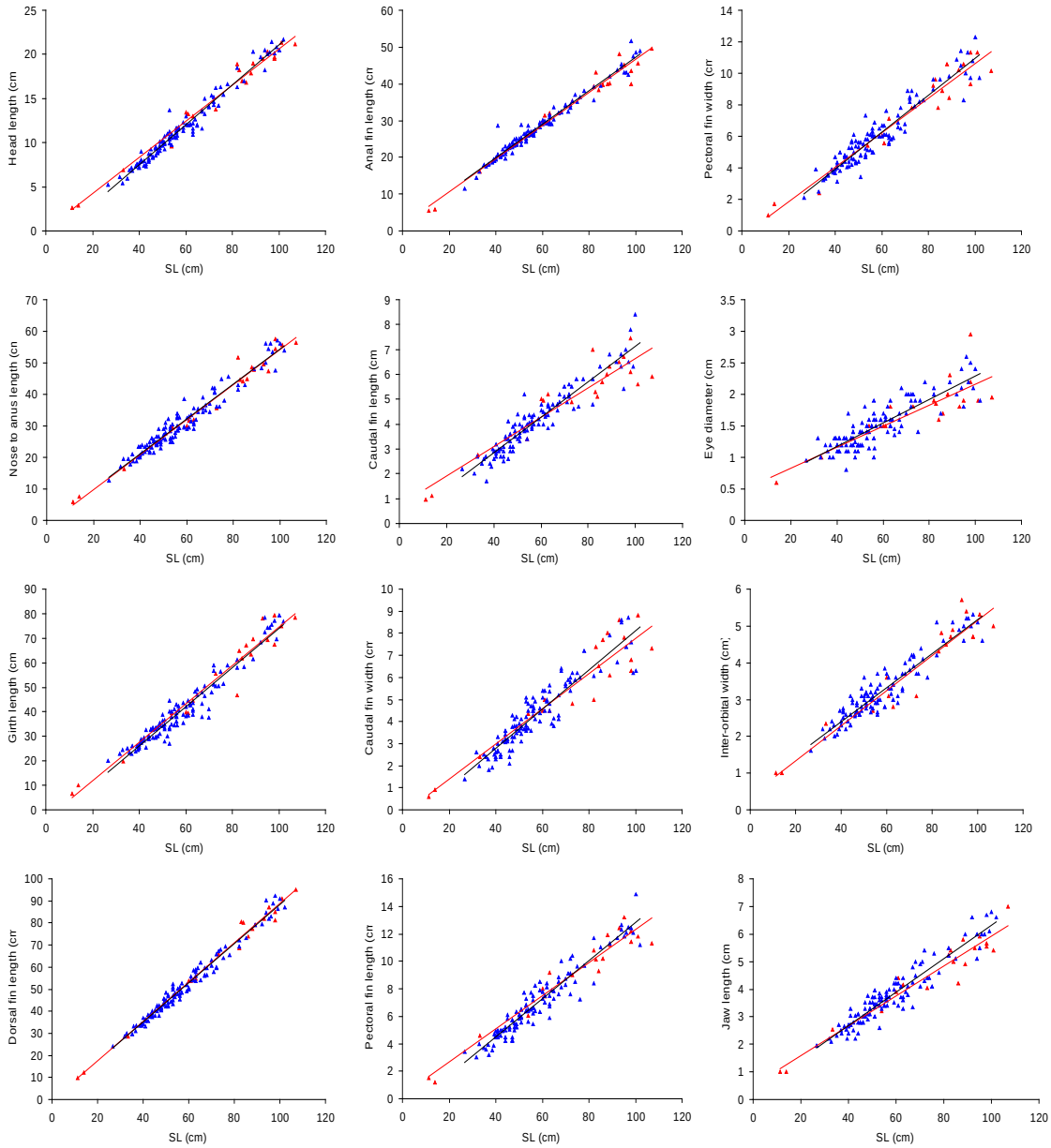

Figure 2. Morphometric measurements of male (blue) and female (red) Northern Wolffish (all NAFO Divisions) in relation to standard length (SL).

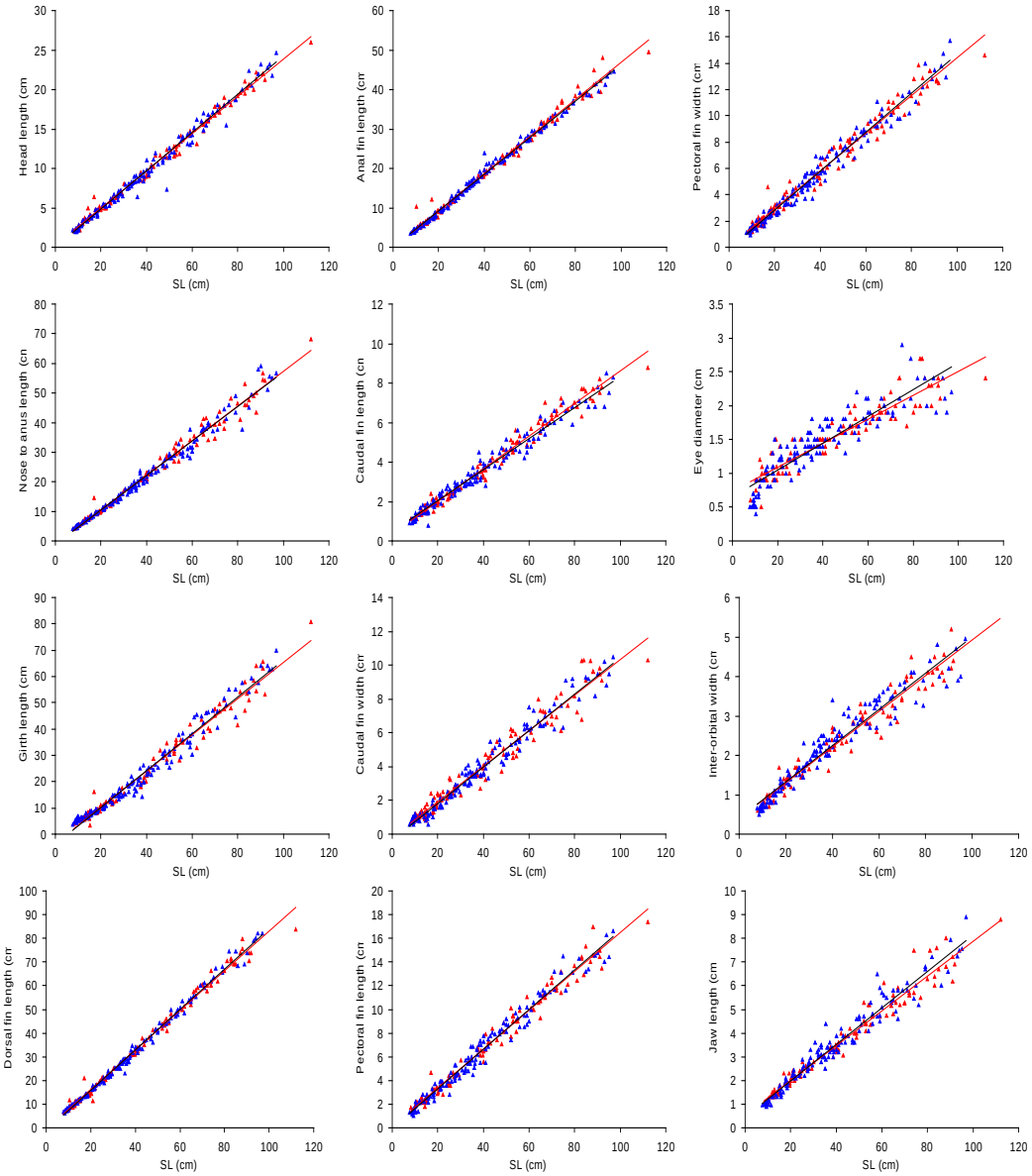

Figure 3. Morphometric measurements of male (blue) and female (red) Spotted Wolffish (all NAFO Divisions) in relation to standard length (SL).

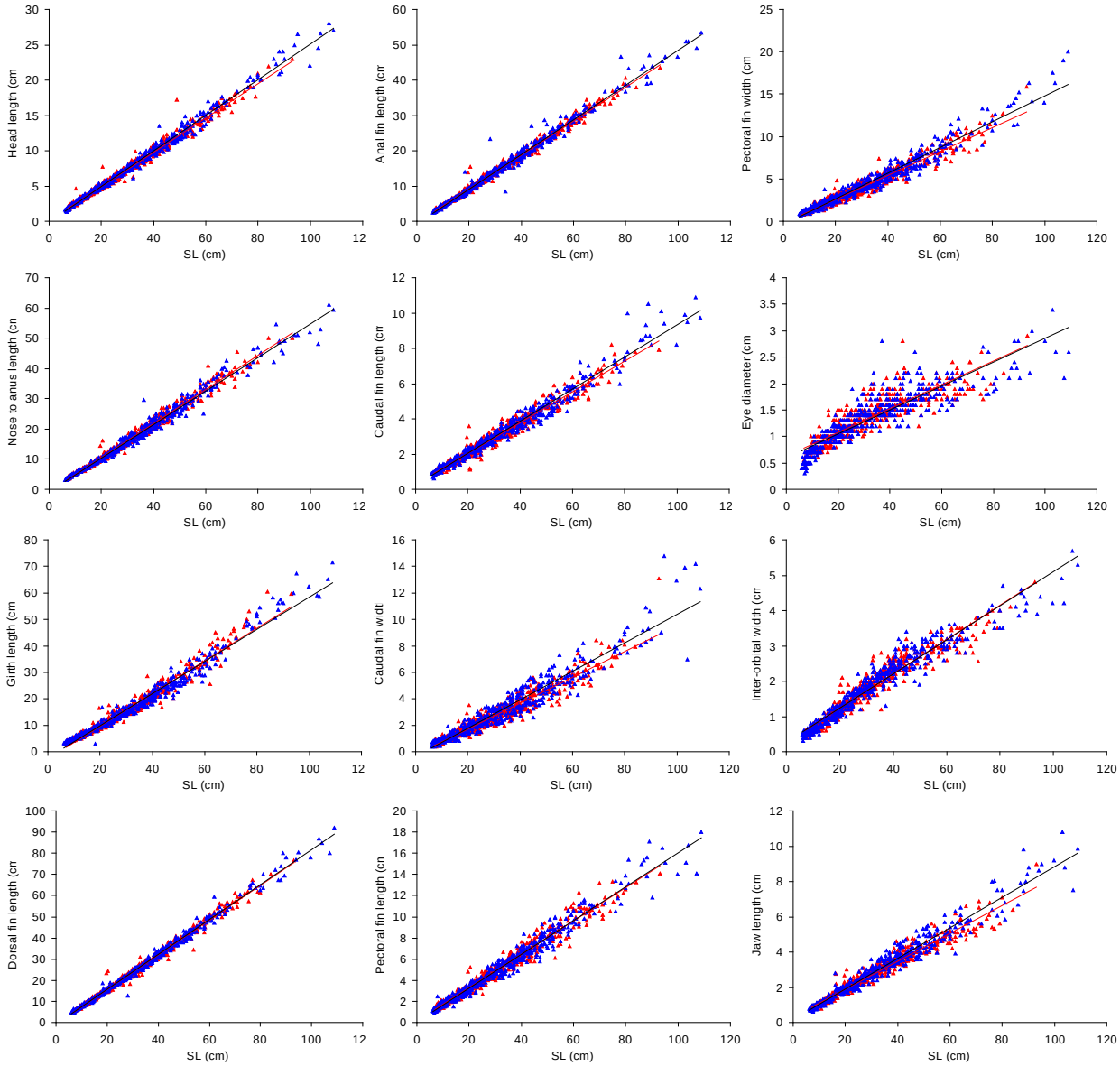

Figure 4. Morphometric measurements of male (blue) and female (red) Atlantic Wolffish (all NAFO Divisions) in relation to standard length (SL).

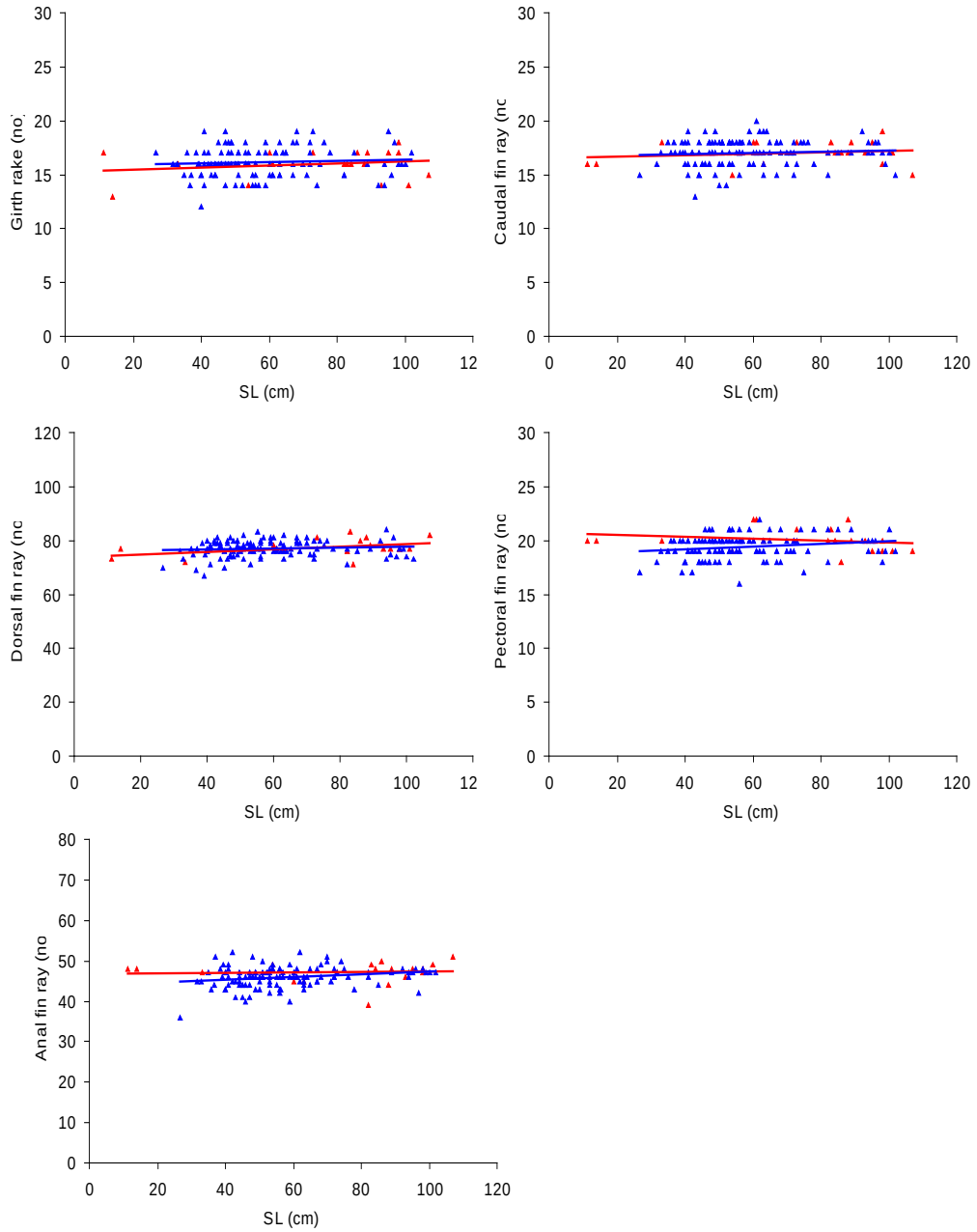

Figure 5. Meristic measurements of male (blue) and female (red) Northern Wolffish (all NAFO Divisions) in relation to standard length (SL).

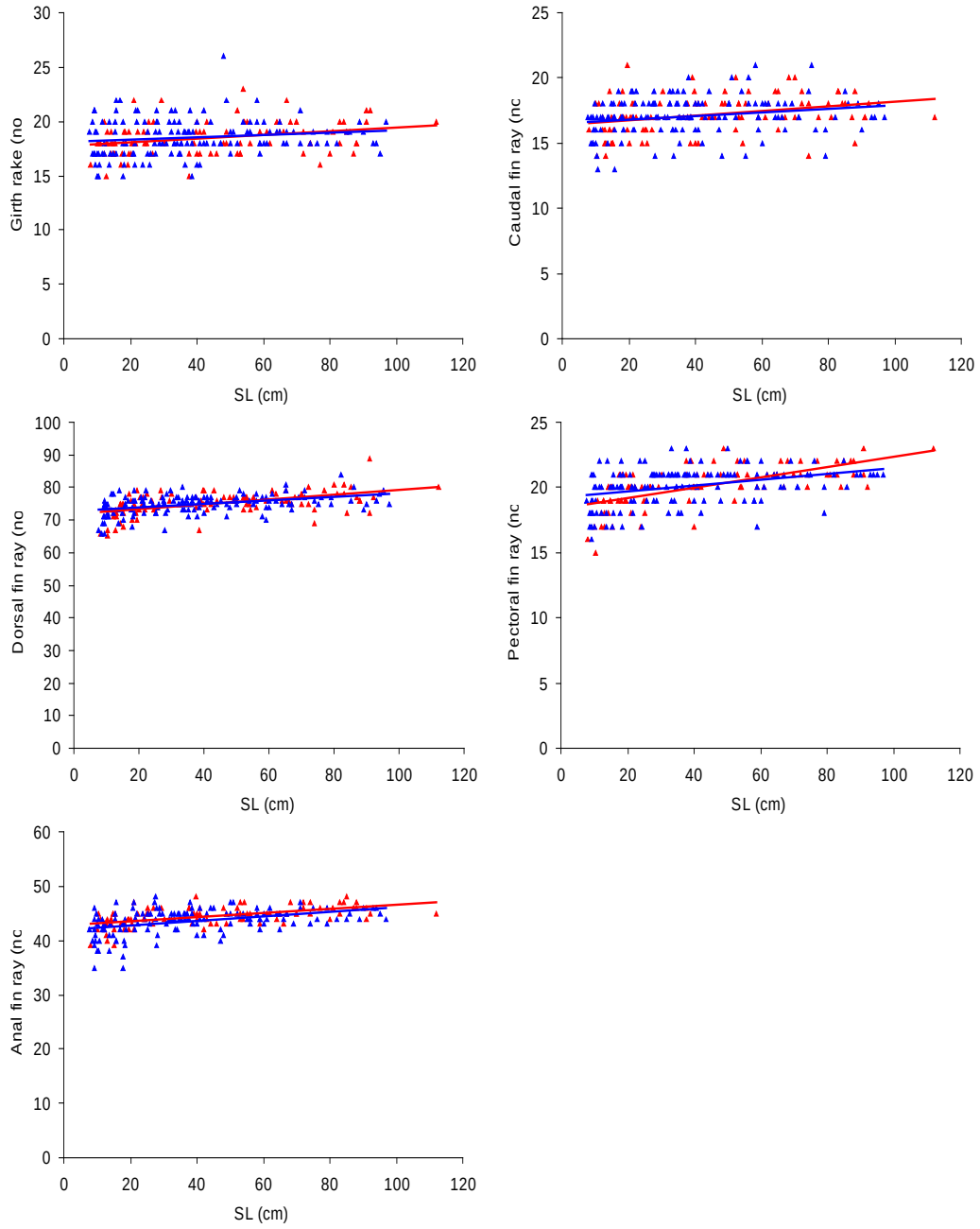

Figure 6. Meristic measurements of male and female Spotted Wolffish (all NAFO Divisions) in relation to standard length (SL).

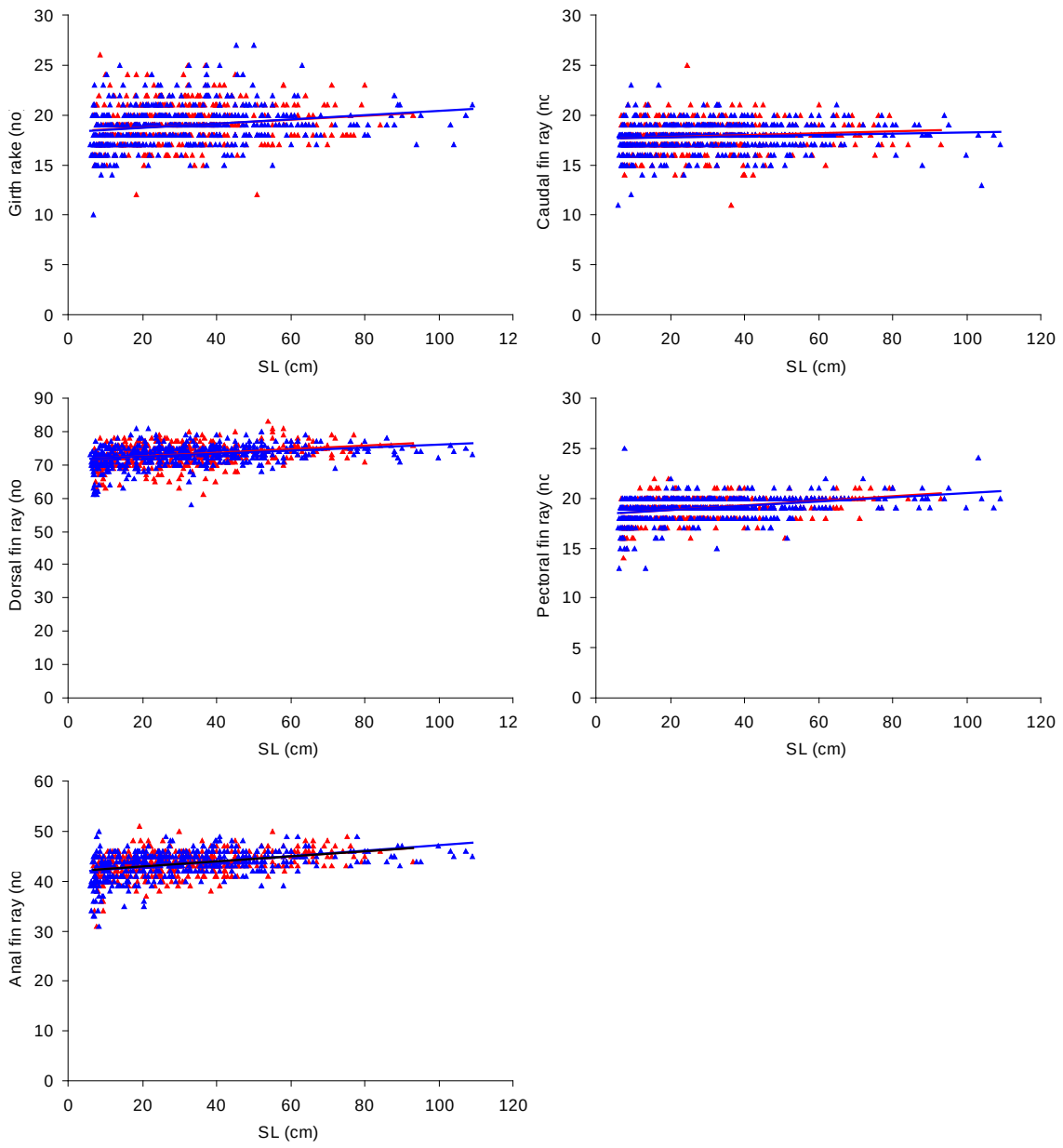

Figure 7. Meristic measurements of male and female Atlantic Wolffish (all NAFO Divisions) in relation to standard length (SL).

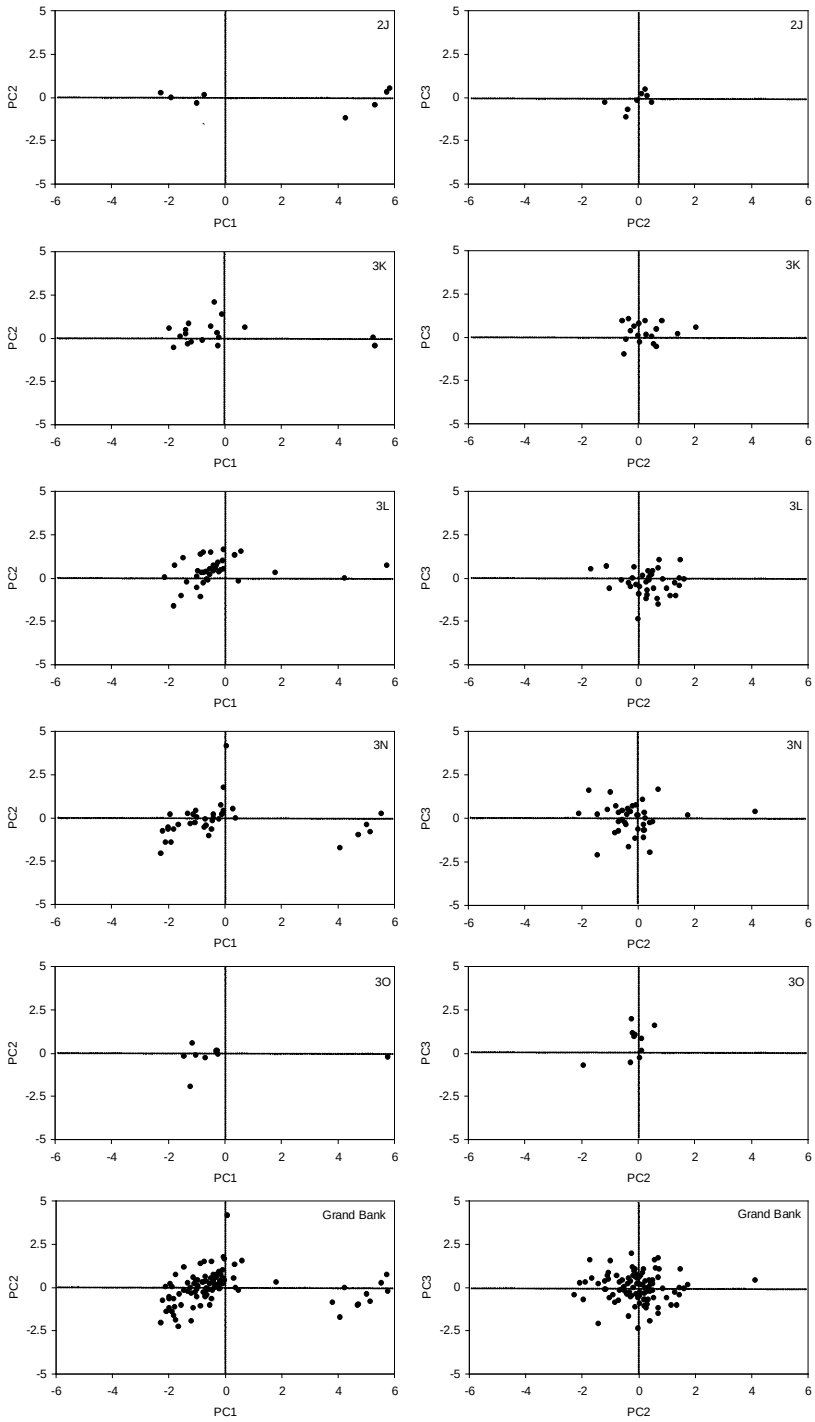

Figure 8. Scatter plots of PC1 versus PC2, and PC2 versus PC3 scores using morphometric characteristics of Northern Wolffish by NAFO Division and the Grand Bank region. No data are available for Division 2H and Subdivision 3Ps.

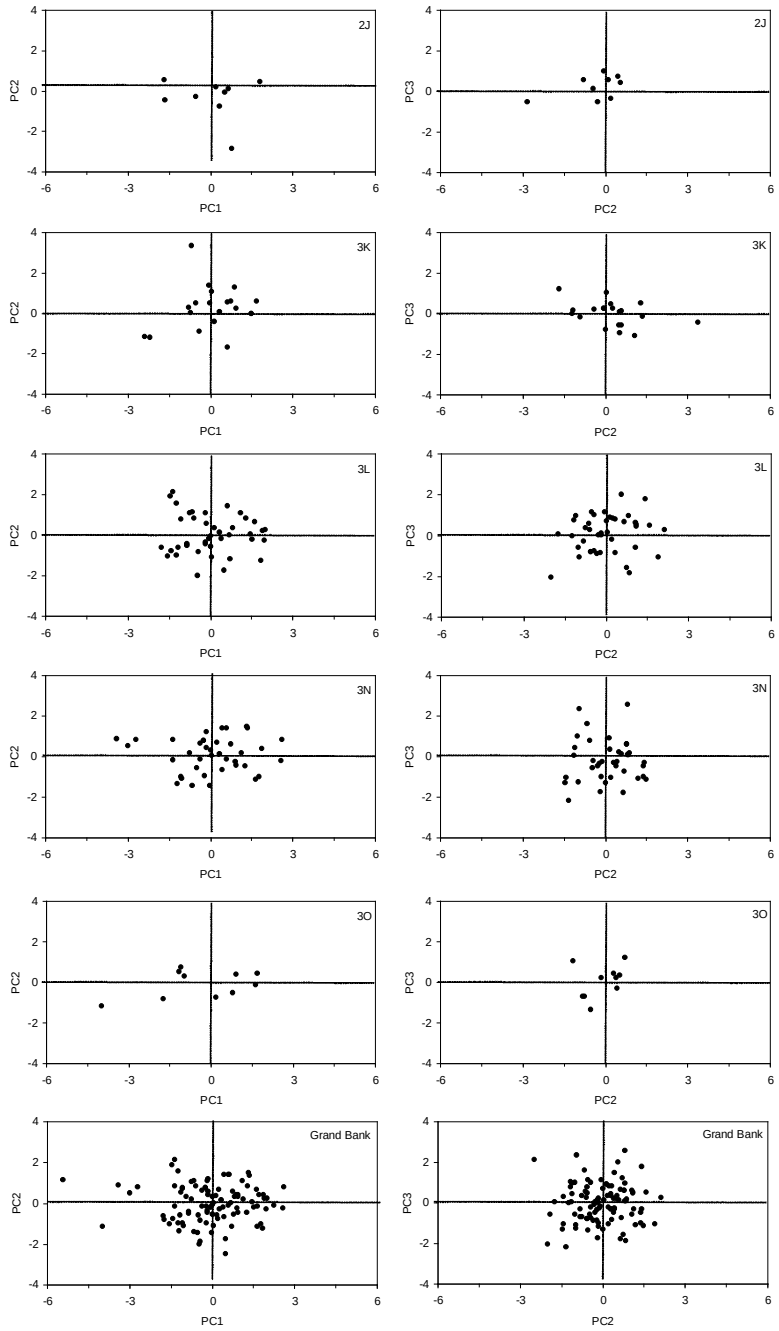

Figure 9. Scatter plots of PC1 versus PC2, and PC2 versus PC3 scores using meristic characteristics of Northern Wolffish by NAFO Division and the Grand Bank region. No data are available for Division 2H and Subdivision 3Ps.

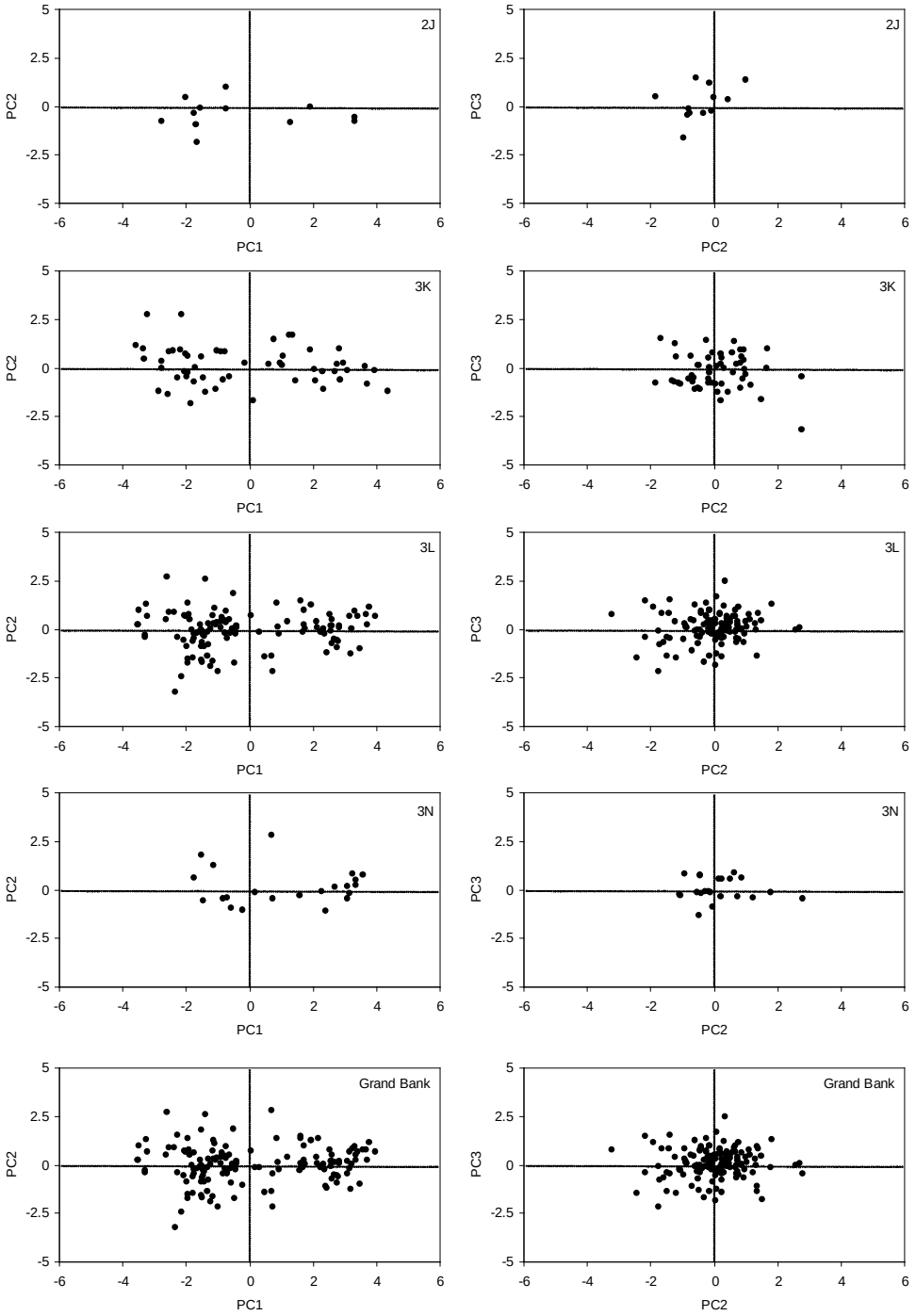

Figure 10. Scatter plots of PC1 versus PC2, and PC2 versus PC3 scores using morphometric characteristics of Spotted Wolffish by NAFO Division and the Grand Bank region. No data are available for Division 2H, Division 3O, and Subdivision 3Ps.

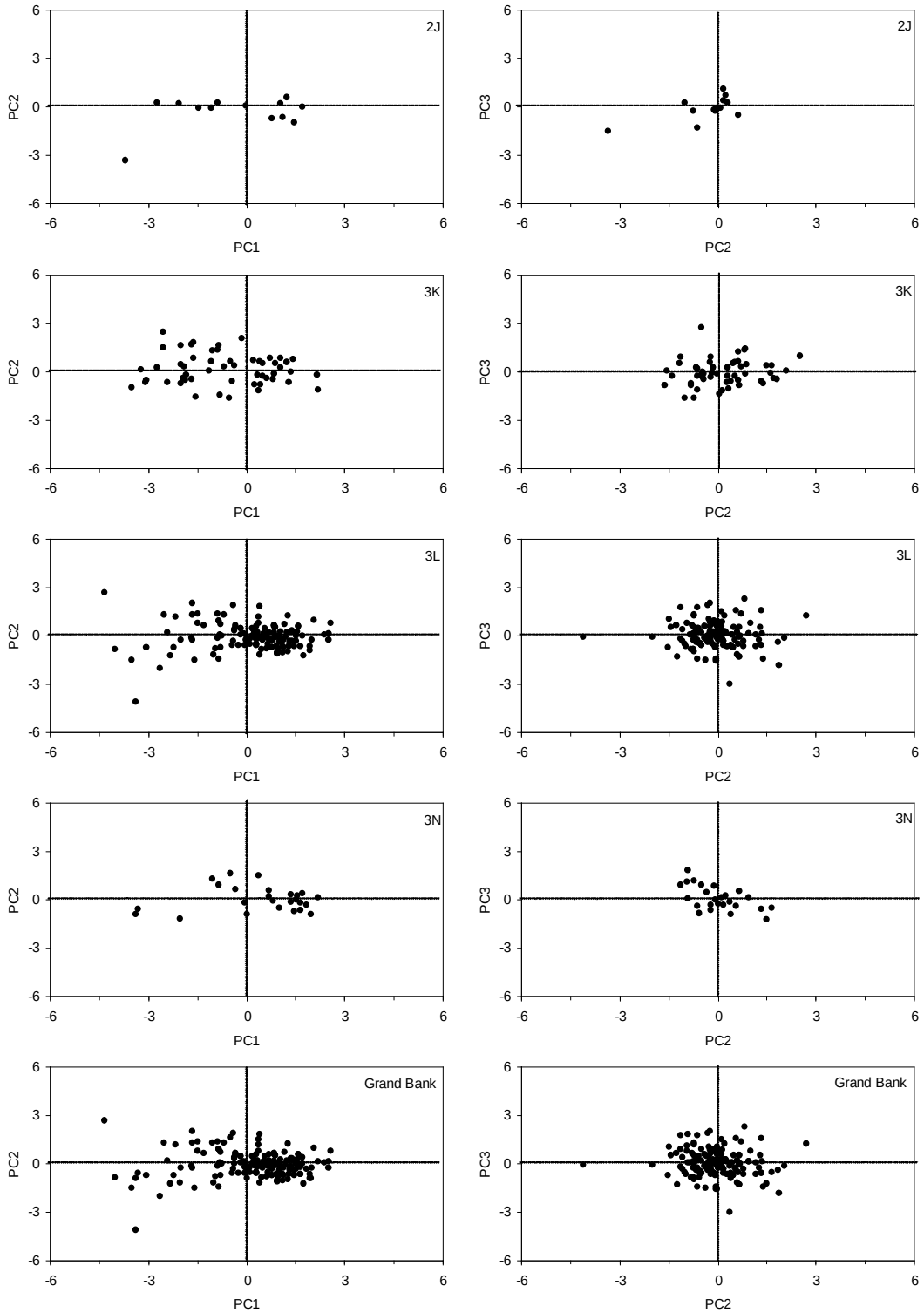

Figure 11. Scatter plots of PC1 versus PC2, and PC2 versus PC3 scores using meristic characteristics of Spotted Wolffish by NAFO Division and the Grand Bank region. No data are available for Division 2H, Division 3O, and Subdivision 3Ps.

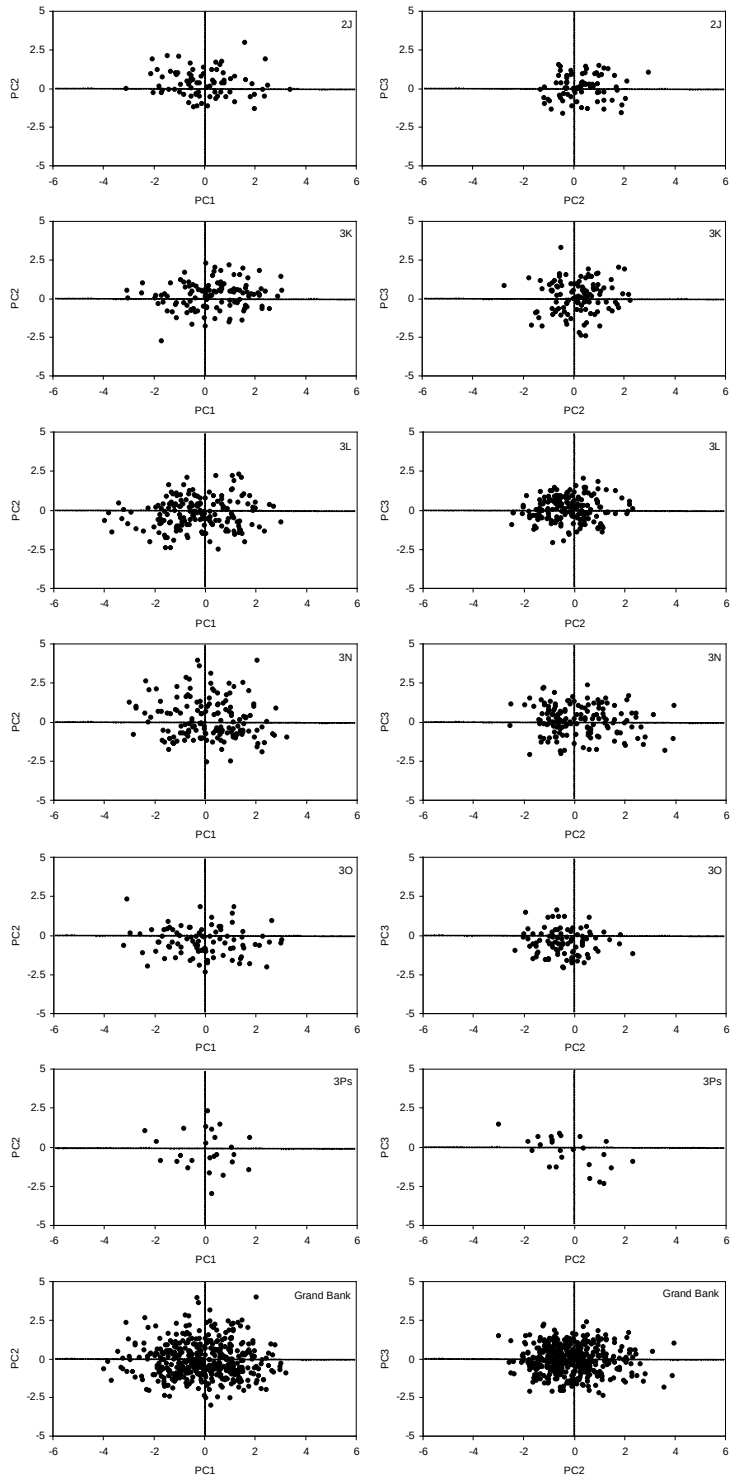

Figure 12. Scatter plots of PC1 versus PC2, and PC2 versus PC3 scores using morphometric characteristics of Atlantic Wolffish by NAFO Division and the Grand Bank region. No data are available for Division 2H.

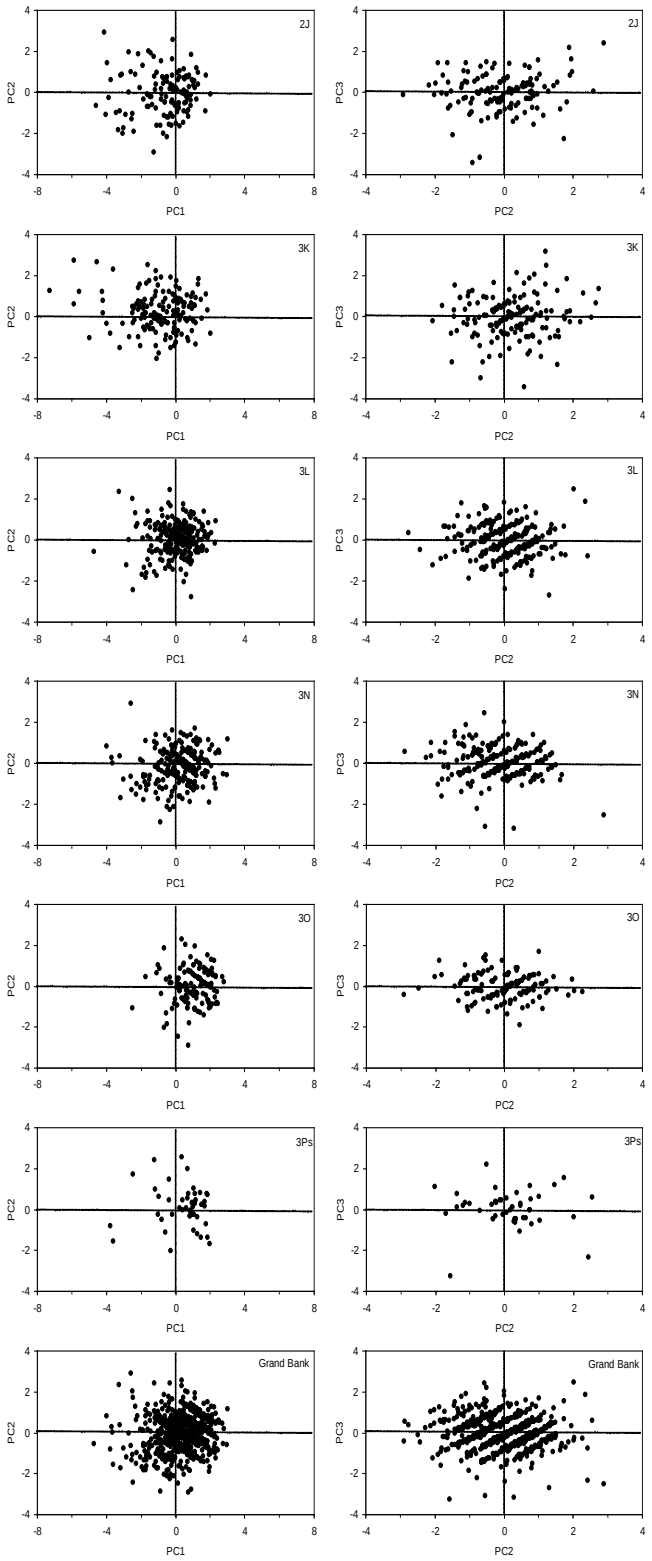

Figure 13. Scatter plots of PC1 versus PC2, and PC2 versus PC3 scores using meristic characteristics of Atlantic Wolffish by NAFO Division and the Grand Bank region. No data are available for Division 2H.