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Northwest Atlantic Fisheries Organization

Serial No. N5795 **NAFO SCR Doc. 10/37**

SCIENTIFIC COUNCIL MEETING – JUNE 2010

Exploring the role of environmental and anthropogenic drivers in the trajectories of core fish species of the Newfoundland-Labrador marine community

by

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Abstract

The influence of environmental variables and fisheries impacts on the trajectories of 5 key fish species of the Newfoundland-Labrador marine community was explored using dynamic factor analysis (DFA). The species considered for this analysis were cod, turbot (a.k.a. Greenland halibut), American plaice, redfish and yellowtail flounder. Four sets of time series were considered for analysis on the basis of geographical area, season, and gear employed in the research survey. For each dataset (area, gear and time period), several DFA models with different combinations of common trends and explanatory variables were explored. Models were selected using the Akaike Information Criterion (AIC). The results indicated that there were common trends in the biomass trajectories of the 5 fish species in all areas and time periods. Negative common trends were found from the early-mid 1980s to the mid 1990s, while positive common trends characterized the period from the mid 1990s to 2008. Fishing appears as a consistent and significant driver in the earlier period, but interestingly enough, still remains as an important driver in the more recent one, during which fisheries have been targeting mainly shrimp and crab. The North Atlantic Oscillation (NAO), sea surface temperature at Station 27 (ST27-SST) and the Composite Environmental Index (CEI) also appear as significant drivers, but their effect is less consistent than the one observed for fishing. The CEI appears as a driver in the northern region (2J3KL), while ST27-SST, and to a lesser extent NAO, appear more relevant in the Grand Banks region (3LNO).

Introduction

The marine community of the Newfoundland and Labrador (NL) shelf underwent dramatic changes during the late 1980s and early 1990s. These changes involved declines in many groundfish stocks, including the collapse of Northern cod, increases in the abundance of harp seals and shrimp stocks, and significant changes in the biology and availability of capelin (Atkinson 1994, Gomes et al 1995, Carscadden and Nakashima 1997, Healey and Stenson 2000, Lilly et al 2000, Mowbray 2002, Rice 2002, DFO 2006, DFO 2008 NAFO 2010).

Overfishing was decidedly a factor driving changes in some commercial stocks (Myers et al 1996, Shelton and Lilly 2000, Rice 2002, Rose 2004, Shelton et al. 2006), but changes also occurred in many non-commercial species (Atkinson 1994, Gomes et al 1995, DFO 2006, NAFO 2010). Although indirect effects of fishing can be a possible explanation for changes in these other species (e.g. Lilly et al 2000, Bundy 2001), this high fishing pressure also coincided with a period of extreme ocean conditions, including record cold temperatures (Drinkwater 2002). The influence of these factors, together with the effect of a recovering harp seal population, has been a matter of intense debate in trying to understand the changes in the NL marine community (Myers et al 1996, Bundy et al 2000, Bundy 2001, Rose and O'Driscoll 2002, Drinkwater 2002, Devine et al. 2007).

In this context, and considering the similar trajectories of many species in this ecosystem, the goal of this study was to explore these commonalities in key species of the Newfoundland-Labrador marine community, as well as the potential influences of environmental variables and fisheries impacts as common drivers for their dynamics.

Material and methods

Data

The entire Newfoundland-Labrador shelf (NAFO Subareas 2 and 3) has been identified as a Large Marine Ecosystem (LME), as well as a marine ecoregion by Fisheries and Oceans Canada (DFO 2009). Within its boundaries, and considering that Fisheries and Oceans Canada (DFO) survey efforts have historically being more focused on NAFO Divs. 2J3KLNO, the fish community in the NL ecosystem can be schematically described in terms of two major subunits, the southern Labrador and northeast Newfoundland shelf (NAFO Divs. 2J3KL), and the Grand Banks proper (NAFO Divs. 3LNO), where the northern part of the Grand Banks (NAFO Div. 3L) acts as a transition zone between these two major subunits (NAFO 2010).

Any examination of common trends among fish species will benefit from considering this general feature of ecosystem organization, and would require indentifying common study areas where to carry out the analyses. These two major ecosystem subunits emerge as natural and sensible study areas for consideration.

The species selected for this analysis were Atlantic cod (*Gadus morhua*), turbot (a.k.a. Greenland halibut) (*Reinhardtius hippoglossoides*), American plaice (*Hippoglossoides platessoides*), redfish (*Sebastes* spp.) and yellowtail flounder (*Limanda ferruginea*). Although management stocks for these species do not necessarily fully match the ecosystem subunits indicated above (i.e. 2J3KL and 3LNO) (Table 1), there is adequate spatial consistency to warrant meaningful results.

Data on the trajectories of these species were derived from the Spring and Fall Research Vessel (RV) surveys conducted by DFO in the NL shelf (NAFO Divs. 2J3KLNO). The coverage of these surveys has varied over the years; these changes have included the addition of near shore and deep water strata to the survey as well as the extension of the fall survey to the south to include the southern portion of the Grand Banks (NAFO Divs. 3NO) in 1990. For these reasons, the RV survey indices considered in this study were derived from a subset of the strata currently covered by these surveys. These “core” strata were selected using two basic criteria: a) to maximize the length of the time series that can be generated for analysis, and b) to maintain a relatively constant area that has been consistently covered by the RV surveys over time. This “core” survey area excludes both inshore and deepwater strata (Fig. 1).

The gear used in DFO RV surveys has also changed over time; most significantly for the analysis here, in the fall of 1995 DFO RV surveys moved from using a large mesh grounfish trawl (Engels 145) to using a small mesh shrimp trawl (Campelen 1800) (McCallum and Walsh 1997). Conversion factors were only developed for core commercial species. This situation prevents a full conversion of survey catches from Campelen to Engels, and hence, time-series analyses aimed at the fish community level using DFO RV survey data are bound to be constrained by the gear used (i.e. the full time series must be split in Engels and Campelen periods).

Based on the above considerations, four different sets of time series were assembled for analysis. These sets were defined by considering the species of interest in each geographical area and survey season (2J3KL-fall and 3LNO-spring) and the gear used in the corresponding RV survey (Engels or Campelen). These four sets of time series were:

1. 2J3KL Fall survey (1981-1994) [Engels gear]
2. 2J3KL Fall survey (1995-2008) [Campelen gear]
3. 3LNO Spring survey (1985-1995) [Engels gear]
4. 3LNO Spring survey (1996-2008) [Campelen gear]

In each dataset, the trajectories for each fish species considered in this analysis were described using the standard survey biomass index from stratified random sampling designs (Gunderson 1993) calculated from the “core” strata in the surveys.

Also for each dataset, four candidate drivers for the biomass of these fishes (i.e. explanatory variables) were considered; three environmental indices and one index of fishing impacts.

The environmental indices were the North Atlantic Oscillation (NAO), the sea surface temperature at Station 27 (ST27-SST), a long-term oceanographic station located near St. John's, and a physical environment composite index which is interpreted as a measure of the overall state of the climate system in the NL shelf (Colbourne et al. 2010). This Composite Environmental Index (CEI) includes NAO and ST27-SST, but it also incorporates information on air temperatures, cold intermediate layer, ice, and salinity, as well as water temperatures in a number of locations (Colbourne et al. 2010). The inclusion of these three variables into the analysis was an attempt to capture different scales and ways in which environmental forcing may influence the dynamics of fish.

The fishing impact was incorporated by calculating a general "Fishery Index" (FI). This index was intended to measure the overall impact of fishing on the marine community and it was calculated as the ratio between the sum of nominal fisheries catches for all finfish and invertebrate species in a given area (2J3KL or 3LNO) and the total fish biomass indices estimated for that area from DFO RV surveys (fall survey for 2J3KL and spring survey for 3LNO):

$$FI = \frac{\text{Total nominal fisheries catches in the area}}{\text{Total RV fish biomass index in the area}}$$

The consideration of overall fishing impact, as opposed to directed fishing mortality for each focal species, is also one reason behind the need of splitting the analysis by survey gear. Even though conversion factors may be available for the focal species of this study, there are no conversion factors for all the other species that would be needed to generate a common FI for the entire extent of the time series. Another reason is that reliable records of commercial invertebrate species in the RV surveys, like *Pandalus* shrimps and snow crab *Chionoecetes opilio*, are only available for the Campelen period. This means that two slightly different FI are used in the analyses presented here; an "Engels-period" FI which considers all finfish biomass in the RV surveys, and one "Campelen-period" FI that also includes *Pandalus* shrimp and snow crab in the total fish biomass. All survey biomass indices were calculated only from "core" strata data. Total nominal fisheries catches for each area were obtained from NAFO STATLANT 21A database.

Analysis

The commonalities in the trajectories of the focal commercial species, and the potential environmental and anthropogenic effects on these trajectories, were explored using dynamic factor analysis (DFA) (Zuur et al. 2003a, 2003b, 2007). This analysis allows detecting common trends in a set of time series, as well as relationships between these series and explanatory variables (Zuur et al. 2003b).

For each dataset (area, gear and time period) several DFA models were built. As a standard procedure, each dataset was initially explored considering up to 3 common trends, and without explanatory variables; results from these model runs were used to determine the number of common trends worth considering when including explanatory variables into the analysis. After these initial explorations, additional models were run in order to explore the effect of the candidate drivers, and their combinations. The high correlation between ST27-SST and CEI (r=0.88) prevented from including them together in a DFA model. All other permutations of candidate drivers were explored.

All models were fitted assuming a non-diagonal error covariance matrix. The Brodgar software package was used to fit the models (Zuur et al. 2003b). Model selection was based on the Akaike Information Criterion (AIC) (Burnham and Anderson 2002), and only those models with differences in AIC of less than 5 with the best models were highlighted as plausible models. All variables were normalized for the analysis (Fig. 2).

Results and discussion

The exploratory analysis carried out in this study involved more than 50 individual DFA models (Table 2). Although a detailed presentation and discussion of each individual model results is certainly possible, a more useful approach is to consider all results in a more holistic way to identify major patterns and signals, as well as a source of inquiry for the development of more focused hypotheses about the functioning of the NL marine ecosystem, and the main processes that drive its dynamics. In this context, even though results from the best DFA model in each dataset will be described in more detail, the interpretation of their results also considers other still plausible models.

Overall, the examination of results clearly indicates that common patterns in the trajectories of the focal fish species can be identified (Table 2, Figs. 3-6). Furthermore, the analyses suggest that for each dataset, the commonalities among fish species are reasonably captured by a single common trend. This trend is essentially a declining one in the 1980s and early 1990s in both the northern (NAFO Divs. 2J3KL) and southern (NAFO Divs. 3LNO) areas (Figs. 3 and 5), while the common trend appears positive in the more recent period (Figs. 4 and 6).

Although the trends of most focal species are positively correlated with the common trends among species, this is not always the case. For example, in the northern area (NAFO Divs. 2J3KL), although the declining common trend describes reasonably well all trajectories in the 1981-1994 period (Fig. 3), turbot is weakly correlated with the positive common trend in the more recent period (1995-2008), and the best DFA model does a poor job at capturing its trajectory (Fig. 4).

On the Grand Banks (NAFO Divs. 3LNO) during 1985-1995, redfish shows essentially no correlation with the monotonically declining common trend. Unlike the other species, redfish shows a declining trend until 1991, but it shows a clearly positive trajectory in the last few years covered by this dataset (Fig. 5). In the more recent period (1996-2008), neither redfish nor cod appear to be correlated with the common trend, while turbot appears to have a negative, but weak, correlation with the common trend, suggesting an underlying declining signal for turbot (Fig. 6).

In terms of explanatory variables, both environmental drivers and fishing consistently appear in the best and most plausible models (Table 2). This clearly indicates that the trajectories of these fish species are most certainly influenced by the environmental conditions and human exploitation. Although this finding is certainly not surprising (e.g. see Devine et al. 2007), it is relevant in the sense that the best and most plausible models actually require both types of drivers together. This highlights the fact that understanding what happened in the NL shelf marine community is not a question of exploitation versus environment, but an issue of exploitation plus environment.

With regards to environmental forcing, the best and most plausible models for the northern area (NAFO Divs. 2J3KL) clearly indicates that the CEI is the environmental variable that better captures the influence of ocean climate on the dynamics of the focal fish species considered in the study. This conclusion holds for both the earlier (1981-1994) and later (1995-2008) periods. Despite the high correlation between CEI and ST27-SST ($r=0.88$), models including CEI fared consistently better. In the southern area (NAFO Divs. 3LNO) this situation reverses; ST27-SST appears as the consistent environmental variable in the best models for both periods (1985-1995 and 1996-2008). The best model for the more recent period (1996-2008), however, also incorporates NAO as a driver (Table 2). It is worth noticing that, even though the difference in AIC was slightly larger than 5, both ST27-SST and NAO were the drivers included in the second best model for the Grand Banks in the earlier period (Table 2).

These results, although somehow puzzling, can provide some hints on the scale at which environmentally driven mechanisms affecting fish populations and communities may be acting. In principle, these results suggest that there are differences in the environmental forcing between the southern Labrador and northeast Newfoundland shelf, and the Grad Banks proper. However, these models are not providing any mechanistic explanation, and it is difficult to discern what could cause two highly correlated indices like CEI and ST27-SST to perform differently in the northern and southern areas.

The CEI is intended to be an “all-encompassing” ocean climate summary index for the entire northwest Atlantic (NAFO Subareas 2 and 3), and hence, it would be reasonable to expect that it will capture better the environmental conditions at the core of the Newfoundland-Labrador shelf system (i.e. NAFO Divs. 2J3KL). On the other hand, although ST27-SST is clearly a good barometer for the entire system, as indicated by its high correlation with CEI, it is also reasonable to expect that it would capture more closely the conditions in the Grand Banks (NAFO Divs. 3LNO). Finally, NAO is an indicator of large scale climate forcing, and as such, may reflect better those changes that affect large-scale boundary conditions of the northwest Atlantic climate system.

Therefore, the results pertaining to environmental indices as explanatory variables appear to suggest that those indices that would be expected to capture more closely the environmental conditions at the scale of each ecosystem subunits are the ones that performed better in each of those ecosystem subunits. Furthermore, because the Grand Banks represents the southern extreme of the NL ecosystem, the influence of the NAO as a distinct driver, most clearly in the recent period, may be linked to the spatially varying influence of the NAO on the circulation in the different subunits. Overall, it appears that the ecosystem subunits represent a reasonable spatial scale for exploring mechanistic hypotheses linking environmental conditions and fish dynamics.

Environmental indices appear as model drivers in both ecosystem subunits, and over many years, showing up in both earlier (Engels) and later (Campelen) periods. The large range of environmental conditions that occurred during the entire study period considered here (e.g. see Colbourne et al. 2010), together with the consistency in the role of these environmental variables in the DFA models, could suggest that the underlying mechanisms involved in these linkages may be more related to bottom-up ecological effects (e.g. regulation of food supply – primary and/or secondary production) rather than direct impacts of environmental conditions on fish physiology (e.g. exposure to lethal conditions).

Together with environmental forcing, fishing impacts also emerged as a consistent and important driver for the focal fish species. The FI was consistently included in all best and most plausible models for both areas and in both time periods (Table 2). This result was certainly expected for the earlier period; during the 1980s and early 1990s fisheries catches from the NL shelf system consisted almost exclusively of groundfish species (Fig. 7), and hence, the FI can be simply interpreted as a reflection of direct fishing mortality. However, fisheries catches dramatically shifted in the mid 1990s from groundfishes to invertebrates (Fig. 7), mainly *Pandalus* shrimp and, to a lesser extent, snow crab, in the mid 1990s as a result of a moratorium on exploitation of groundfish stocks. This implies that the FI is no longer a simple reflection of directed fishing mortality on groundfish species. Furthermore, available information on bycatch in the shrimp fisheries suggests that by-catch mortality of groundfish does not appear to be significant (Orr et al. 2000, 2010). Therefore, the consistent importance of FI in all best and most plausible models during the more recent period, needs to be interpreted as a reflection of some kind of indirect effect that the fisheries are exerting on the focal fish species. The nature of this indirect effect is currently unknown, as well as how much indirect versus direct effects may have been at play in the earlier period, when the fishery was targeting cod and other groundfish, or if there has been an actual transition from direct effects through fishing mortality to indirect effects involving other mechanisms.

After the collapse of the groundfish stocks in the late 1980s and early 1990s, total fisheries catches were significantly lower than in previous years (Fig. 7), but during this later period the overall fish biomass was also very low (NAFO 2010). Therefore, even though catches were low, the FI indicates that the impact of fishing actually increased in the northern region between 1995 and 2004, and its level in 2008 was still higher than it was in 1995-1996 (Fig. 2). On the Grand Banks, the FI indicates that fishing impact between 1996 and 2008 actually peaked in the early 2000s, and declined thereafter (Fig. 2). Considering that most fisheries catches consist of *Pandalus* shrimp, and that they, together with other key forage species like capelin *Mallotus villosus*, represent important prey for many grounfish species, one possible simple hypothesis to account for these indirect effects of FI on the common trends of key species could be that fisheries are actually affecting the availability of food for these main groundfish stocks.

Regardless the specific mechanisms involved, our results support two rather interesting and provocative ideas. The first one is that even today; with far less fisheries catches than in the past, overall fisheries impacts still have a detectable influence on the dynamics of the focal fish species considered here, and hence, have the potential for affecting their capacity for rebuilding. The second one is that, for the first time as far as we are aware of, there is clear and very suggestive evidence that the impact of fishing on these focal species may be acting through indirect effects. Under these circumstances, rebuilding and sustainable exploitation of these groundfishes would require to manage not just the fishing mortality levels at which they are exposed, it may also need to understand and implement tradeoffs between fisheries, as well as between potentially competing goals like rebuilding groudfish stocks and exploitation levels in shellfish fisheries.

Acknowledgements

The authors want to thanks to the many scientists and technicians at the Northwest Atlantic Fisheries Centre that participated in the DFO surveys over the years, and had contributed to the collection, processing and analysis of the many samples that produced the data used in this study. We also want to thanks to the members of the NAFO Working Group on Ecosystem Approaches to Fisheries Management, and the NAFO Scientific Council for their comments, discussions, and contributions to the process that led to the analysis presented here. Special thanks go to Bill Brodie, Joanne Morgan, Eugene Colbourne, Gary Maillet, Alfonso Pérez-Rodriguez, and Alejandro Buren for their contributions along the way. This work was supported by the DFO Ecosystem Research Initiative for the Newfoundland and Labrador Region, the NEREUS program.

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Table 1. Schematic mapping of NAFO Divisions, ecosystem subunits, and management stocks for the focal fish species considered in this study

<table>
<tr><th>NAFO Division</th><th colspan="2">Ecosystem subunit</th><th>Atlantic cod</th><th>American plaice</th><th>Redfish</th><th>Turbot</th><th>Yellowtail flounder</th></tr>
<tr><td>2J</td><td rowspan="3">2J3KL</td><td rowspan="2"></td><td rowspan="3">2J3KL</td><td rowspan="2">2J3K</td><td rowspan="2">2+3K</td><td rowspan="5">2+3KL (M)NO</td><td rowspan="2"></td></tr>
<tr><td>3K</td></tr>
<tr><td>3L</td><td rowspan="3">3LNO</td><td rowspan="3">3LNO</td><td rowspan="2">3LN</td><td rowspan="3">3LNO</td></tr>
<tr><td>3N</td><td rowspan="2"></td><td rowspan="2">3NO</td></tr>
<tr><td>3O</td><td>3O</td></tr>
</table>

Table 2. Results from DFA. The best model in each case is denoted in red and bold fonts, and in a grey background; other models still worthy of further consideration are denoted in red.

Dataset	Model: # common trends	Explanatory variable Included: NAO	ST27-SST	CEI	FI	# parameters in the model	Loglikelihood	AIC	Delta AIC
2J3KL Fall 1981-1994	1					25	-40.0	130.0	33.0
	2					29	-37.2	132.3	35.3
	3					32	-37.4	138.8	41.7
	1		X			30	-35.3	130.6	33.5
	1			X		30	-32.7	125.4	28.3
	1	X				30	-37.6	135.2	38.2
	1				X	30	-22.3	104.5	7.5
	2				X	34	-22.3	112.6	15.5
	1	X			X	35	-20.4	110.7	13.7
	1		X		X	35	-18.7	107.4	10.3
	1			**X**	**X**	**35**	**-13.5**	**97.1**	**0.0**
	1	X	X			35	-33.3	136.6	39.5
	1	X		X		35	-29.7	129.4	32.3
	1	X	X		X	40	-17.0	114.1	17.0
2J3KL Fall 1995-2008	1					25	-58.7	167.4	13.2
	2					29	-53.5	164.9	10.7
	3					32	-53.5	170.9	16.7
	1		X			30	-54.0	168.0	13.8
	1			X		30	-50.5	160.9	6.7
	1	X				30	-57.4	174.7	20.5
	1				X	30	-48.3	156.5	2.3
	2				X	34	-45.5	159.1	4.9
	1	X			X	35	-47.1	164.3	10.1
	1		X		X	35	-45.1	160.2	6.0
	1			**X**	**X**	**35**	**-42.1**	**154.2**	**0.0**
	2			X	X	39	-39.4	156.9	2.7
	1	X	X			35	-52.6	175.2	21.0
	1	X		X		35	-48.9	167.7	13.5
	1	X	X		X	40	-43.9	167.9	13.7
	1	X		X	X	40	-40.5	161.0	6.8

Table 2 (cont). Result from DFA analysis. The best model in each case is denoted in red and bold fonts, and in a grey background; other models still worthy of further consideration are denoted in red.

Dataset	Model					# parameters in the model	Loglikelihood	AIC	Delta AIC
	# common trends	Explanatory variable Included							
		NAO	**ST27 -SST**	**CEI**	**FI**				
3LNO Spring 1985-1995	1					25	-37.0	123.9	21.5
	2					29	-35.9	129.9	27.4
	1		X			30	-30.8	121.5	19.1
	1			X		30	-33.9	127.7	25.3
	1	X				30	-35.6	131.2	28.8
	1				X	30	-23.6	107.2	4.8
	2				X	34	-23.6	115.2	12.7
	1	X			X	35	-21.5	113.0	10.5
	1		**X**		**X**	**35**	**-16.2**	**102.4**	**0.0**
	1			X	X	35	-19.2	108.5	6.0
	1	X	X			35	-29.6	129.2	26.7
	1	X		X		35	-32.4	134.9	32.5
	1	X	X		X	40	-14.0	108.0	5.5
	1	X		X	X	40	-16.2	112.4	9.9
3LNO Spring 1996-2008	1					25	-56.6	163.2	25.6
	2					29	-56.0	170.0	32.4
	1		X			30	-51.0	162.0	24.5
	1			X		30	-53.5	166.9	29.4
	1	X				30	-51.8	163.7	26.1
	1				X	30	-46.6	153.2	15.6
	2				X	34	-45.3	158.7	21.1
	1		X		X	35	-37.9	145.8	8.2
	1			X	X	35	-41.1	152.1	14.6
	1	X			X	35	-41.7	153.5	15.9
	1	X	X			35	-46.3	162.5	25.0
	1	X		X		35	-48.7	167.3	29.8
	1	**X**	**X**		**X**	**40**	**-28.8**	**137.6**	**0.0**
	1	X		X	X	40	-35.3	150.5	13.0
	2	X	X		X	44	-28.8	145.6	8.0
	2	X		X	X	44	-35.3	158.5	21.0

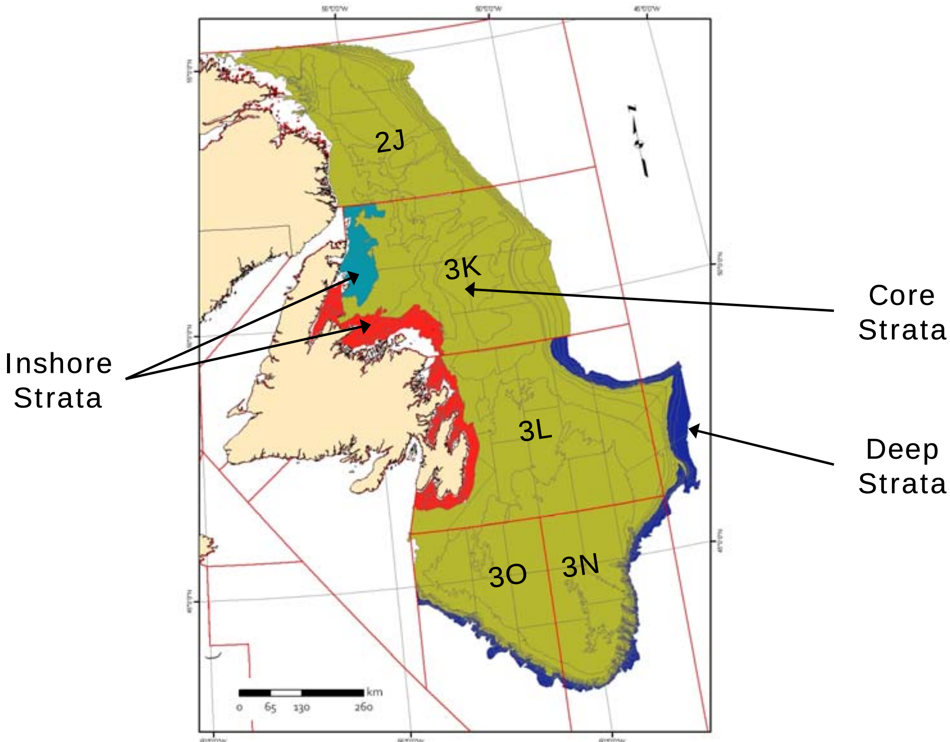

Figure 1. Area covered by DFO RV surveys with indication of the strata considered in this study. Only data from "core" strata, depicted in a green/yellow color in this figure, were employed to calculate the indices used in the analyses.

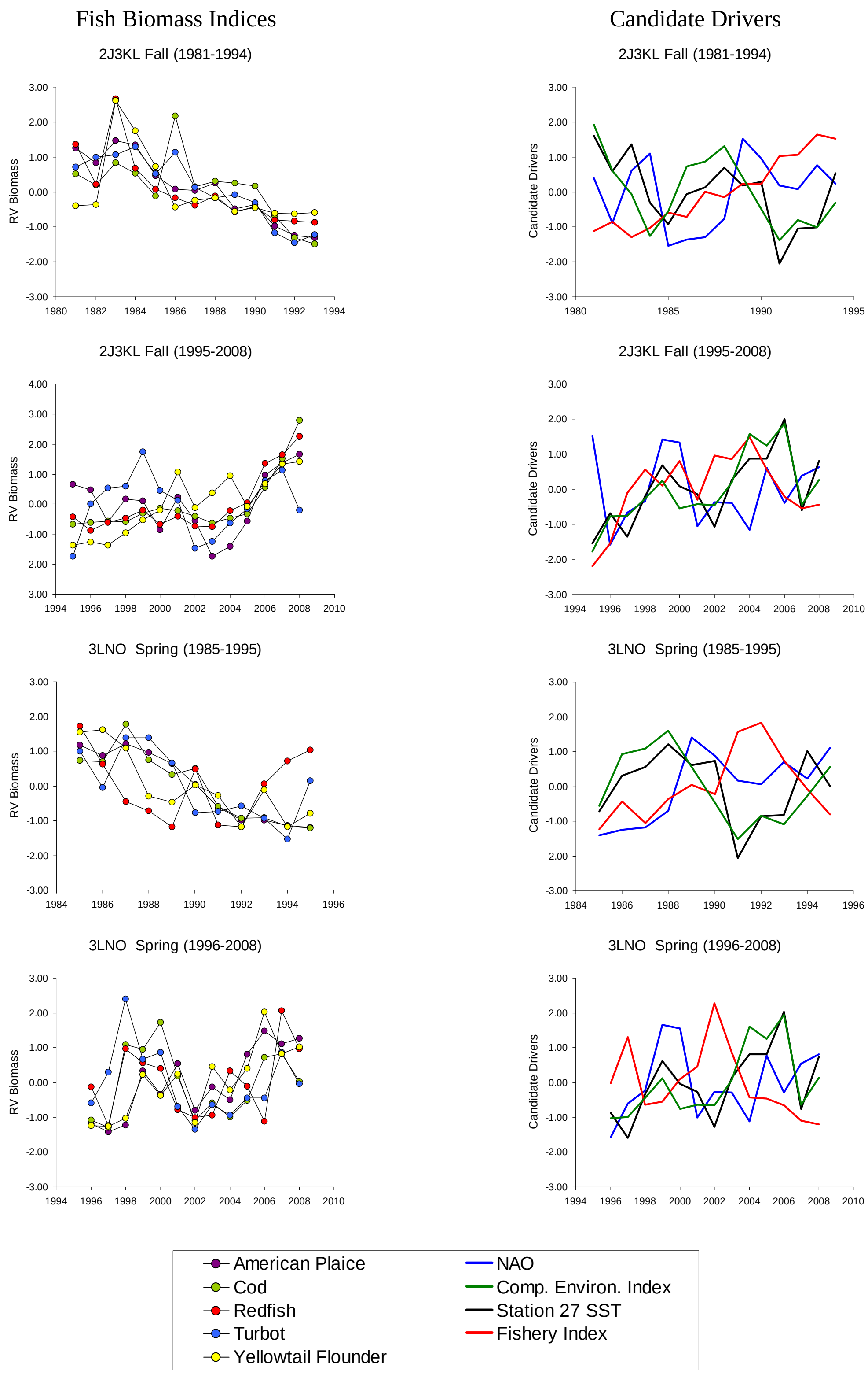

Figure 2. Survey biomass indices for fish species, and candidate drivers for each one of the dataset considered in this study. All variables are presented as normalized series; all analyses were based on these normalized time series.

2J3KL Fall (1981-1994)

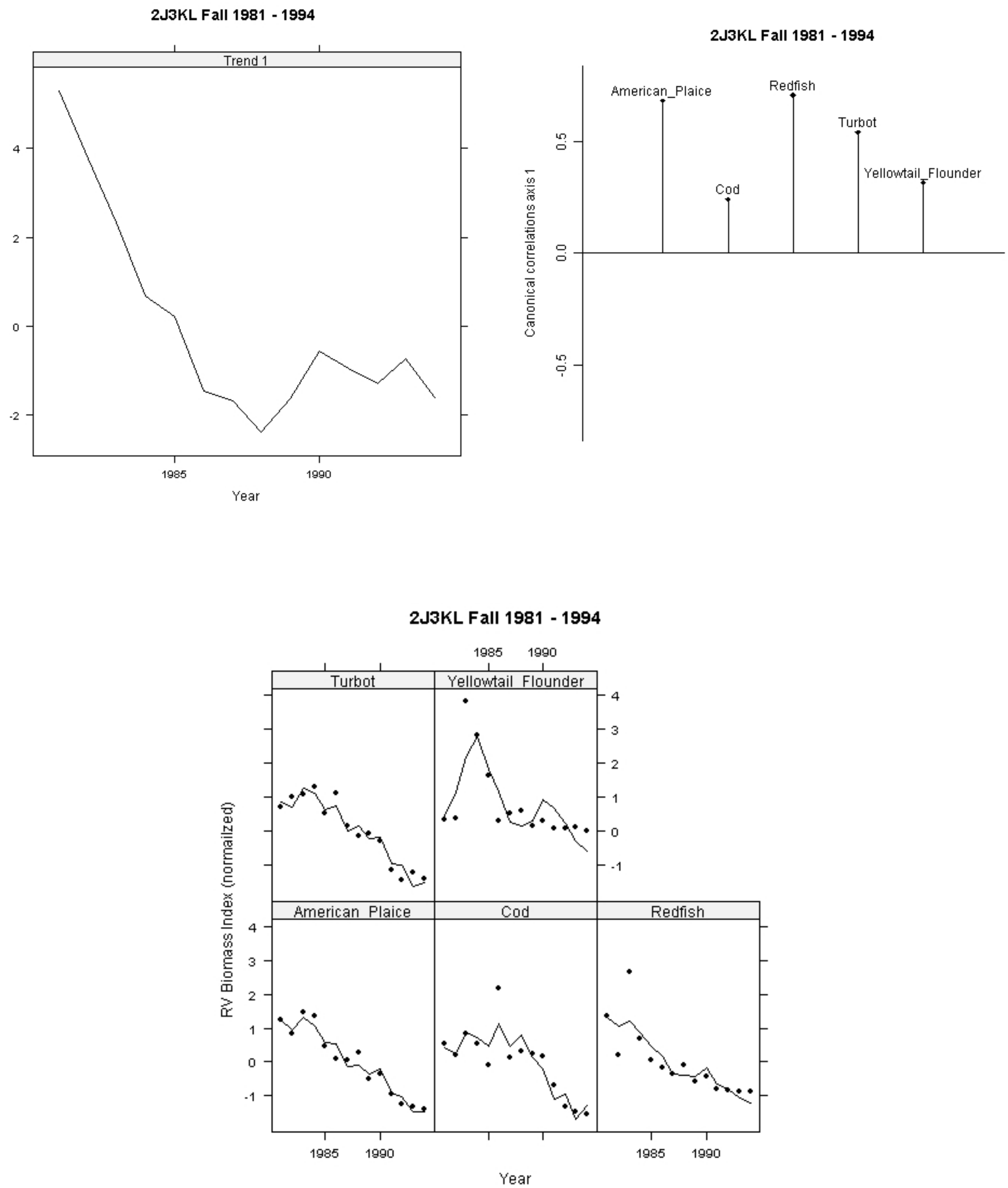

Figure 3. Detailed results from the best DFA model for the 2J3KL Fall (1981-1994) dataset. This model includes CEI and FI as explanatory variables. The upper left graph shows the estimated common trend, while the upper right one shows the canonical correlations between the fish biomass time series and this common trend. All canonical correlations are positive, indicating that the trajectories of these fishes are in the same (declining) direction as this common trend. The bottom graph shows the fits between this model and the data for each fish species considered.

2J3KL Fall (1995-2008)

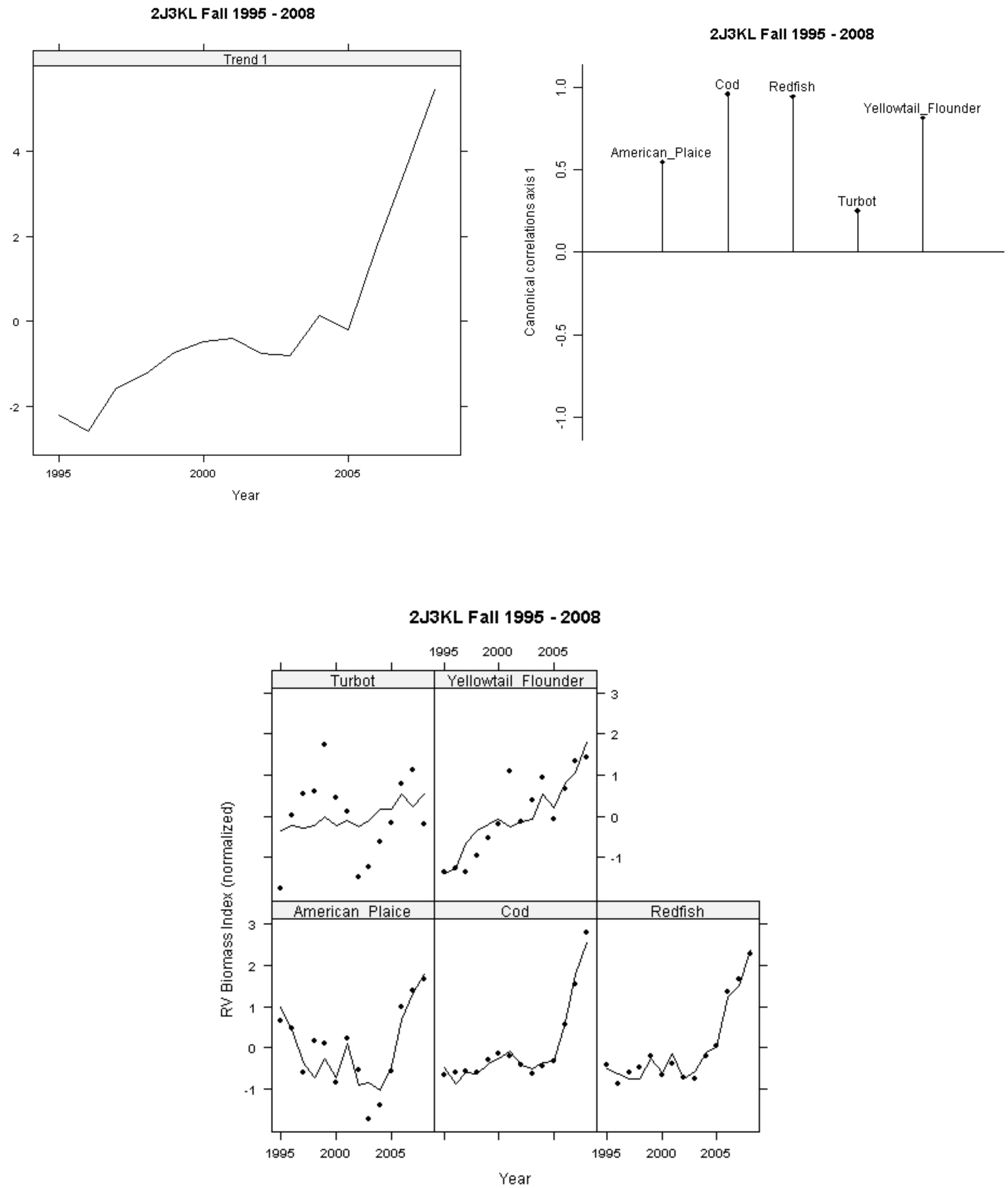

Figure 4. Detailed results from the best DFA model for the 2J3KL Fall (1995-2008) dataset. This model includes CEI and FI as explanatory variables. The upper left graph shows the estimated common trend, while the upper right one shows the canonical correlations between the fish biomass time series and this common trend. All canonical correlations are positive, indicating that the trajectories of these fishes are in the same direction as this common trend. The bottom graph shows the fits between this model and the data for each fish species considered; note that turbot trajectory is poorly captured by this model.

3LNO Spring (1985-1995)

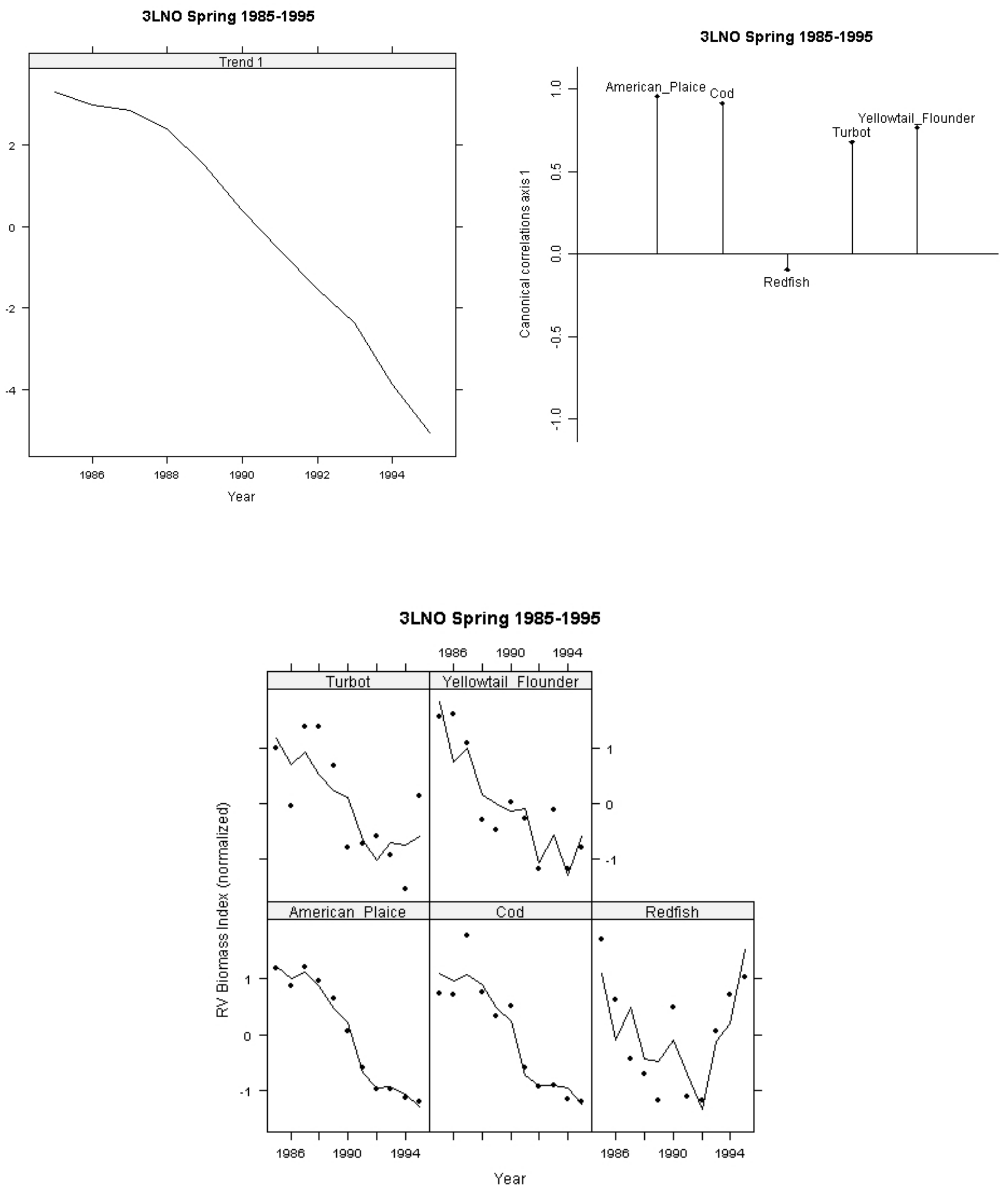

Figure 5. Detailed results from the best DFA model for the 3LNO Spring (1985-1995) dataset. This model includes ST27-SST and FI as explanatory variables. The upper left graph shows the estimated common trend, while the upper right one shows the canonical correlations between the fish biomass time series and this common trend. The bottom graph shows the fits between this model and the data for each fish species considered; note that, unlike the others, redfish shows and increasing trend towards the end of the period considered here.

3LNO Spring (1996-2008)

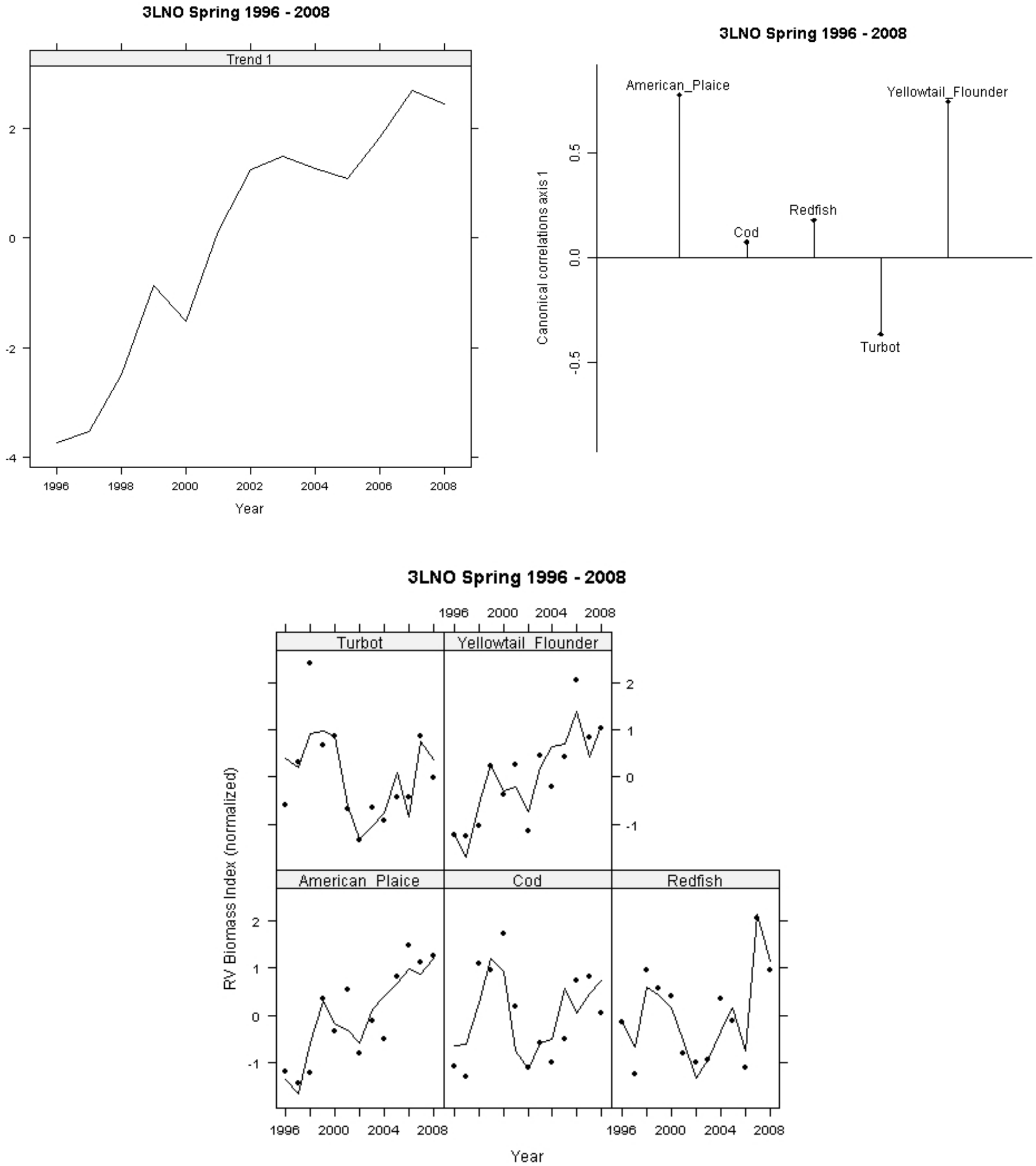

Figure 6. Detailed results from the best DFA model for the 3LNO Spring (1996-2008) dataset. This model includes NAO, ST27-SST and FI as explanatory variables. The upper left graph shows the estimated common trend, while the upper right one shows the canonical correlations between the fish biomass time series and this common trend. The bottom graph shows the fits between this model and the data for each fish species considered.

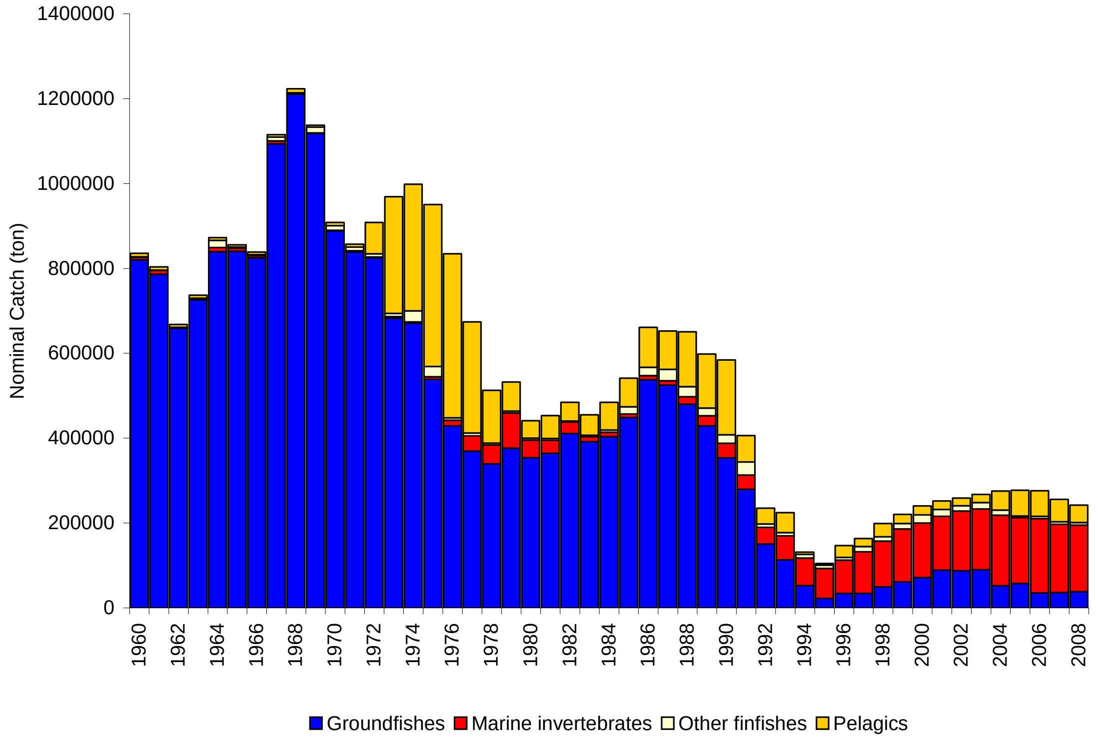

Figure 7. Nominal fishing catches in NAFO Divs. 2J3KLNO discriminated by species groups (source: NAFO STATLANT 21A database). Note that after the collapse of groundfish stocks in the early 1990s, most fisheries catches are marine invertebrates. The bulk of these marine invertebrates catches is composed by *Pandalus* shrimp.