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Status and trends of the fish community in the Flemish Cap (NAFO Div. 3M) bioregion

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Abstract

This report summarizes fish community trends for the Flemish Cap (NAFO Div. 3M) based on European Union summer trawl research vessel surveys between 1988 and 2018. Species were classified into eight functional groups and trends were described using biomass indices, biomass and abundance anomalies, and fish size (Biomass/Abundance Ratio) anomalies. In 2003, a replacement of the research vessel allowed extending the depth coverage of the survey from 700m to 1400m. The vessel change had an impact on survey catchability, so to account for it conversion factors were applied. Considering the change in depth coverage, trends were examined for 1988-2018 with data up to 700m, and for 2004-2018 with data up to 1400m. Fish community trends were similar between the two datasets, but the analyses including deeper waters showed a comparatively higher levels of benthivores, reflecting the changes in community structure with depth. Generally speaking, trends in average fish size as tracked by the Biomass/Abundance Ratio appeared driven by recruitment, where general declines in abundance and absences of good recruitments got reflected in increases of this ratio. Biomass of plankpiscivores (mostly *Sebastes* sp.) experienced a sharp increase in the early 2000s but then returned to levels comparable to the 1990s. Piscivores biomass showed a strong decline in the early 1990s due to the collapse of cod but has since shown signs of recovery. Shellfish, driven by northern shrimp, saw a sustained increase in biomass from the early 1990s until 2002, when started a decline that has persisted until 2018. The biomass of large benthivores decline in the late 1990s and remains low to this date.

Introduction

The Flemish Cap (NAFO Division 3M) has been identified by NAFO as one of the bioregions in the Northwest Atlantic, and is considered to contain a single Ecosystem Production Unit (EPU) (NAFO, 2014) (Figure 1). This ecosystem has been intensively fished since the 1950s, and major changes in the biomass and abundance of its most important commercial species have been reported since the late 1980s (Pérez-Rodríguez et al. 2012). Overall fishing pressure, environmental conditions, and predation pressure have been identified as important drivers of the dynamics of the fish community in this EPU (Pérez-Rodríguez et al. 2012), especially for the main species affecting the dynamics of piscivores (cod, *Gadus morhua*), plankpiscivores (redfish, *Sebastes* sp.) and shellfish (Northern shrimp, *Pandalus borealis*) (Pérez-Rodríguez et al, 2017)

The European Union (EU) has conducted Research Vessel (RV) surveys in this ecosystem since 1988 to this date. In 2003, the EU survey replaced the original research vessel used in the survey; this change allowed extending the survey to deeper waters since 2004, from the original survey area up 700m maximum depth to 1400m depth. This study describes the trends in the Flemish Cap fish community summarized by fish functional

groups, and compares the trends between the original survey footprint (shallower strata), and the expanded survey footprint including the deeper waters.

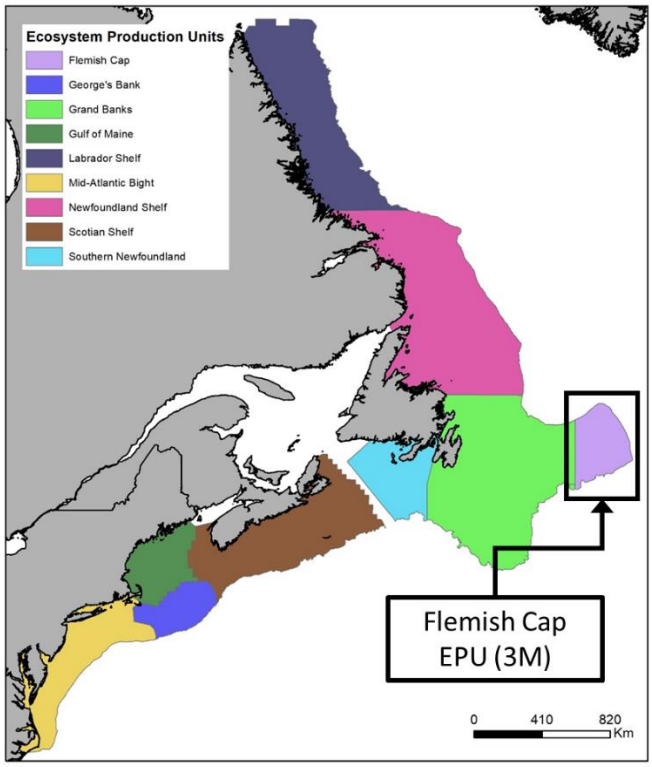

Figure 1. Ecological Production Units (EPUs) in the Northwest Atlantic Ocean

Materials and Methods

Fish community trends in the Flemish Cap were summarized by fish functional groups. All fish and decapod crustacean species were classified into these functional groups. Finfish functional groups were defined in terms of general fish size and feeding habits: small, medium, and large benthivores, piscivores, plank-piscivores, and planktivores (see Annex). Decapod crustacean species were grouped into two categories, "shellfish" which includes commercial species only (*Pandalus spp*. and *Chionoecetes opilio*) and "shellfish2" which comprises all other invertebrate species (see Annex); this distinction was made for consistency with Fisheries and Oceans (DFO) RV surveys in nearby EPUs, which have not consistently recorded non-commercial invertebrates until recent years. The functional group classification itself also follows previous work done in other NAFO EPUs (NAFO, 2017).

Species biomass and abundance data were obtained from the annual EU Flemish Cap summer survey (1988-2018). Standard RV Biomass and Abundance indices for all species were calculated using the swept area method (Gunderson, 1993) and subsequently used to generate the corresponding indices by functional group. Changes in fish size at the functional group level was evaluated using the Biomass/ Abundance Ratio (BA Ratio). These indices are also presented as cumulated anomalies for a better description of changes at the functional group level.

The EU Flemish Cap survey was initially conducted using the RV Cornide de Saavedra. In 2003, this platform was replaced by the RV Vizconde de Eza; even though the fishing gear continued to be the same, this change did imply some changes in catchability given the differences in equipment performance between vessels. In order to standardized the time series, conversion factors estimated by Pérez-Rodríguez and Koen-Alonso

(2010) were applied to the annual swept area biomass index by species over the period 1988-2002. The change of research vessel also allowed an increase in the depth range covered by the survey, going from a maximum 700m depth range (Flemish Cap strata 1-19) over the period 1988-2003 to a maximum depth of 1400 m from 2004 onward (Flemish Cap strata 1-34). As a result two different time series were constructed for the functional groups, one considering only strata up to 700m and covering 1988-2018, and another for 2004-2018 considering all strata.

Results and Discussion

Due to the relative simplicity of the Flemish Cap, with 80-85% of the annual biomass has been composed, on average, by six species; northern shrimp, cod, Acadian, golden and beaked redfish, and Greenland halibut), the patterns observed in the functional groups could easily be associated with the dynamics of a relatively minor number of species. Four main patterns were observed in the biomass index of the functional groups over the period 1988-2018 in depths up to 700 m (Figure 2). First, the biomass of plankpiscivores (mostly formed by *Sebastes* sp.) experienced a sharp increase from 2003 to 2006, resulting from successful recruitment events which occurred over the period 2001-2006 (Pérez-Rodríguez et al., 2017). This was followed by a steep decline after 2008 to values slightly higher than those observed in the 1990s. Second, the biomass of piscivores showed a strong decline in the early 1990s due to the collapse of cod. Since 2005, positive recruitments in the cod stock (González-Troncoso, 2017) allowed for the recovery of the piscivore biomass that, in 2016, was at 1989 levels. Third, the biomass shellfish followed the same pattern observed in the shrimp stock (Casas-Sánchez, 2017), with a sustained increase in the total stock biomass index from the early 1990s until 2002, when a marked decline began. Fourth, the biomass of large benthivores showed a steady decline from 1988 to 2006 and has oscillated at lower levels since. This functional group is mainly represented by American plaice, wolffishes and grenadiers. The cumulated normalized biomass anomalies suggest that when biomass of piscivores is above the average then the biomass of most functional groups like shellfish, plankpiscivores, small, medium and large benthivores is mostly below the average (Figure 2). In terms of total biomass, after the increase in the biomass index during the years 2004-2008 due to the growth of the plankpiscivore group, the Flemish Cap returned to levels comparable to those observed in the 1990s.

Even though total biomass seems to have been relatively constant during the study period, except for the outburst of plankpiscivores in the 2000s, the composition of the community has changed (Figure 3). Piscivores seem to have recovered their dominance in the community, while plankpiscivores have become more dominant in recent years. Conversely, shellfish, which showed an important increase in dominance in the late 1990s and early 2000s, has declined to its lowest dominance levels in the most recent years. Large benthivores, which were around 20% of the total biomass in the late 1980s and early 1990s, has shown important reductions in its dominance since then, and is only showing weak increases in dominance in recent years. This trend in large benthivores is similar to the one observed for this functional group in the Grand Bank (Koen-Alonso and Cuff, 2018).

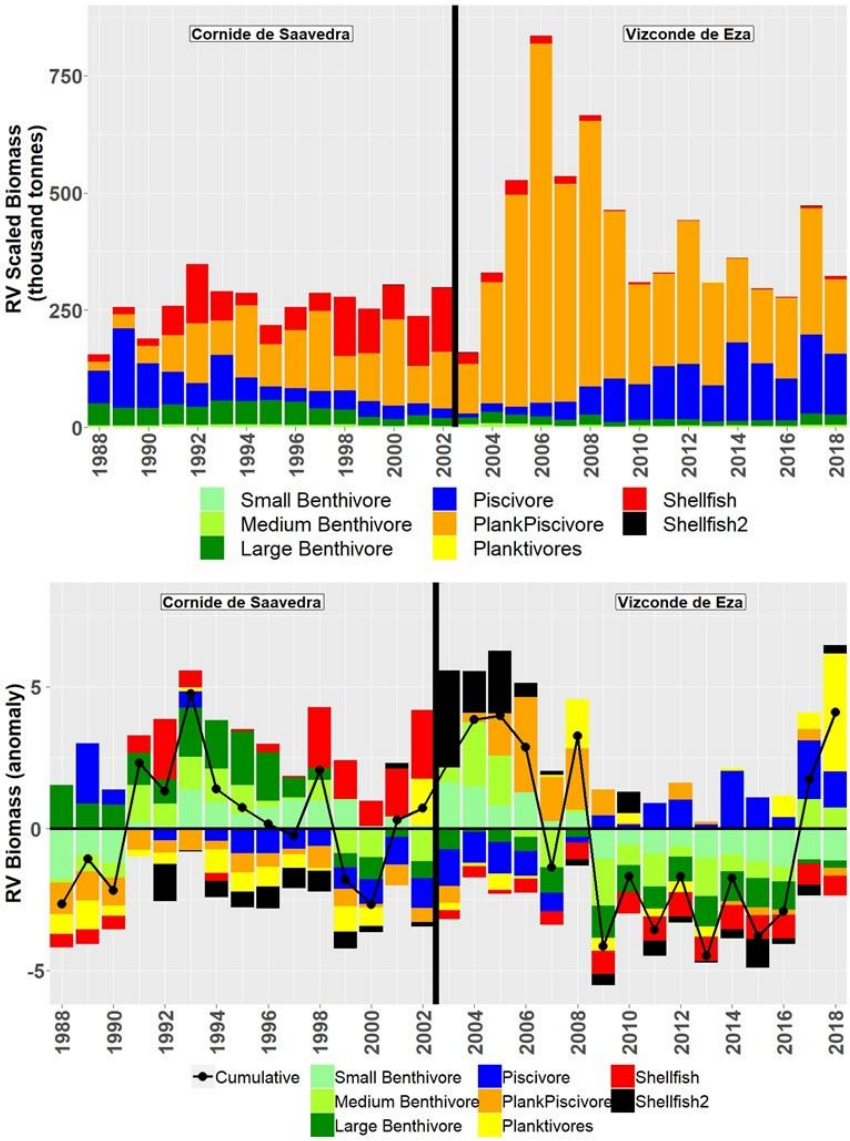

Figure 2. RV Biomass index by functional groups in the Flemish Cap (NAFO Div. 3M) up to 700m depth (strata 1-19). **Top**: RV Biomass index over time; this index has been corrected for the vessel change using the conversion factors in Pérez-Rodríguez and Koen-Alonso (2010). **Bottom**: Cumulated normalized anomalies of the RV biomass index by fish functional groups.

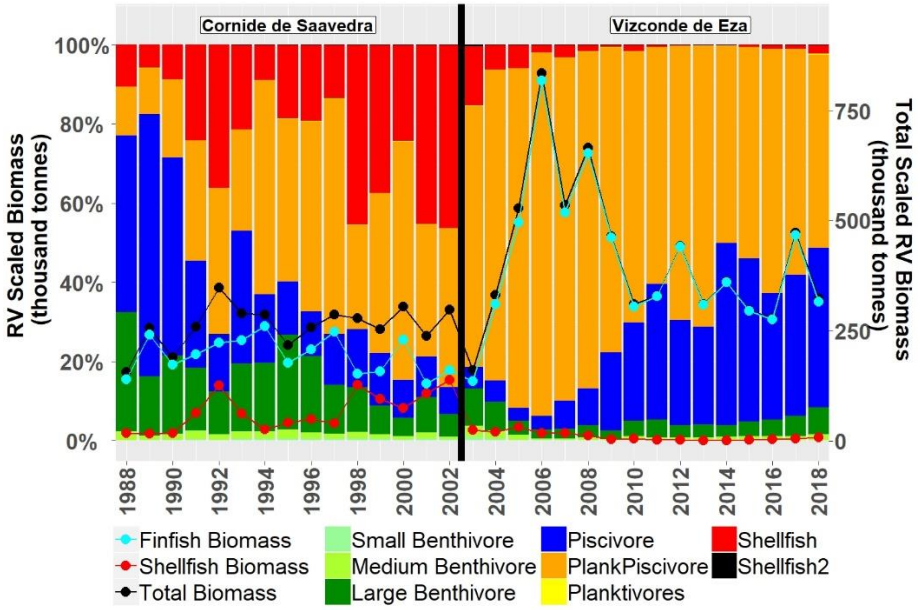

Figure 3. Changes in the structure of the Flemish Cap fish community in depths up to 700m depth (strata 1-19) for the 1988-2018 period.

The cumulated normalized BA Ratio anomalies (Figure 4) shows changes in the mean weight per individual, which may be due to variations in fish condition, but more importantly reflects changes in the size distribution within each functional group. This size distribution is greatly affected by sudden large recruitment event in the dominant species of each functional group, but also by the negative effect of intense fishing on the larger individuals. BA ratio is an indicator of average fish size, so increases can be deemed good if more large individuals are present, but it would also increase in the absence of recruitment. Conversely, a pulse in recruitment can drive BA Ratio down, so the interpretation of trends in BA Ratio requires understanding the underlying changes that drive the trend. In general, a sustained decline in the BA Ratio for all functional groups occurred from the late 1980s until mid-2000s, when this pattern was reversed, and ended in 2018 at similar levels to those observed in the late 1980s. The removal of the largest individuals during the collapse of cod and redfish (piscivores and plankpiscivores respectively) in the early-mid 1990s together with the good recruitments events of shrimp (shellfish), wolfishes (large benthivores), roughead grenadier (medium benthivores) and roundnose grenadier (small benthivore) explain the decline in the BA ratio. The increased recruitment of redfish (plankpiscivores) and cod (piscivores) during the 2000s explain the minimum accumulated BA ratio during the period 2003-2008. Since 2014, the lack of recruitment in all functional groups explain the higher BA ratio.

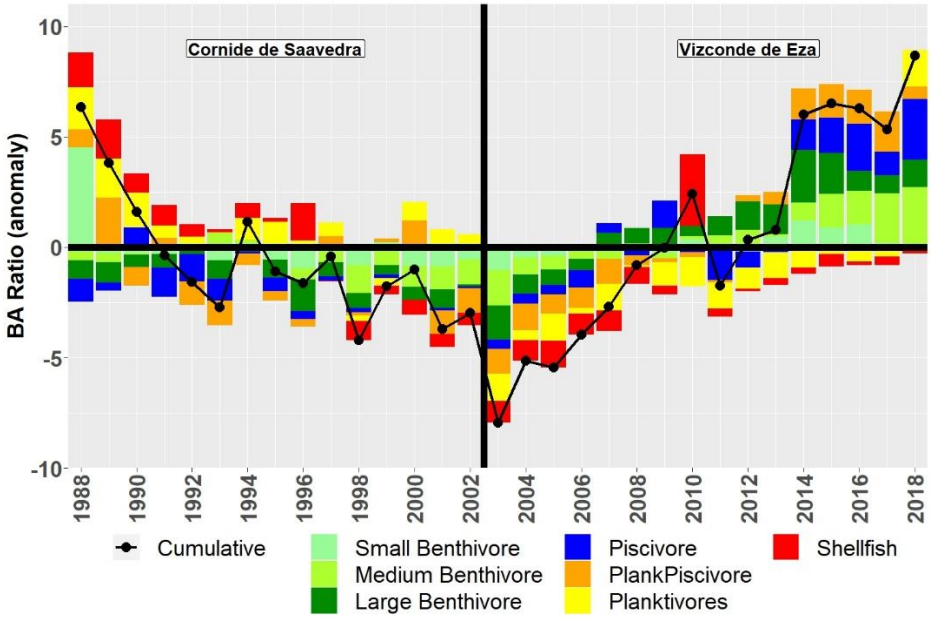

Figure 4. Cumulated normalized anomalies of the Biomass/Abundance (BA) ratio by fish functional groups in the Flemish Cap (NAFO Div. 3M) up to 700m depth (strata 1-19).

When considering the biomass of functional groups including deeper water strata (up to1400m depth, strata 1-34) (Figure 5), the trends for plankpiscivores and piscivores biomass indicate dynamics very similar to the ones described considering strata up to 700m depth. However, medium benthivores exhibit higher biomass levels, due to the larger abundance of some grenadiers, such as the roughead grenadier, at greater depths.

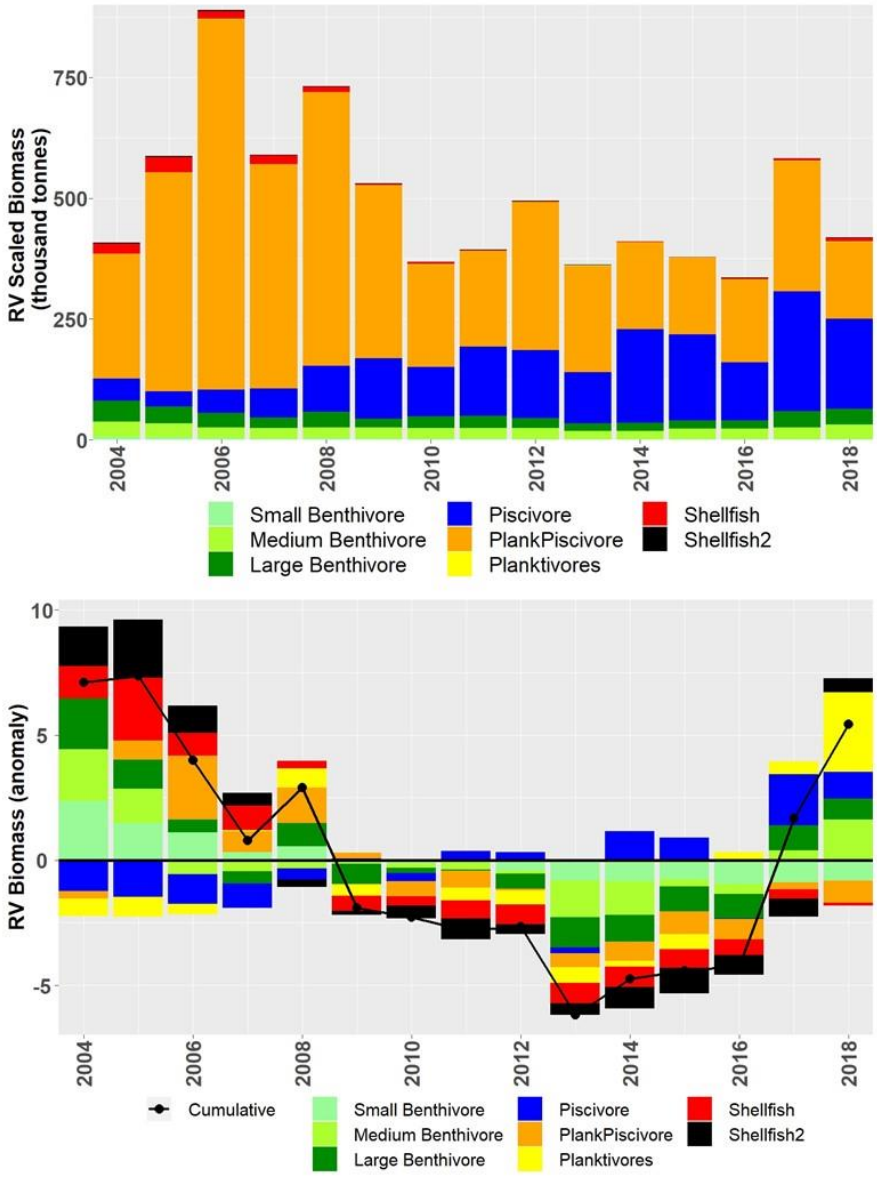

Figure 5. **Top:** RV Biomass index by fish functional groups in the Flemish Cap (NAFO Div. 3M) up to 1400m depth (strata 1-34). **Bottom:** Cumulated normalized anomalies of the RV Biomass index by fish functional groups considering strata up to 1400m depth (strata 1-34).

The cumulated normalized anomalies of the RV Abundance index and the BA Ratio by functional groups up to 1400m depth (strata 1-34) over the period 2004-2018 (Figure 6) show a very similar pattern to the one observed in waters up to 700m depth. From 2004 to 2018 an increasing trend in the BA ratio was observed for all the functional groups. This is a result of the decrease in abundance and absence of good recruitments, meaning older and larger individuals increase the average individual weight. The high abundance of plankpiscivores (*Sebastes* spp.) in the early 2000s result from the increased recruitments of *Sebastes fasciatus* and *Sebastes marinus.* The high abundance of small, large and medium benthivores reduced gradually with lack of new recruitments. In the period 2010-2012, recruitment of piscivores (cod) was above average therefore increasing the abundance. Since 2014, decreased recruitment has produced an increase in the BA ratio, indicating larger mean weight for all the functional groups.

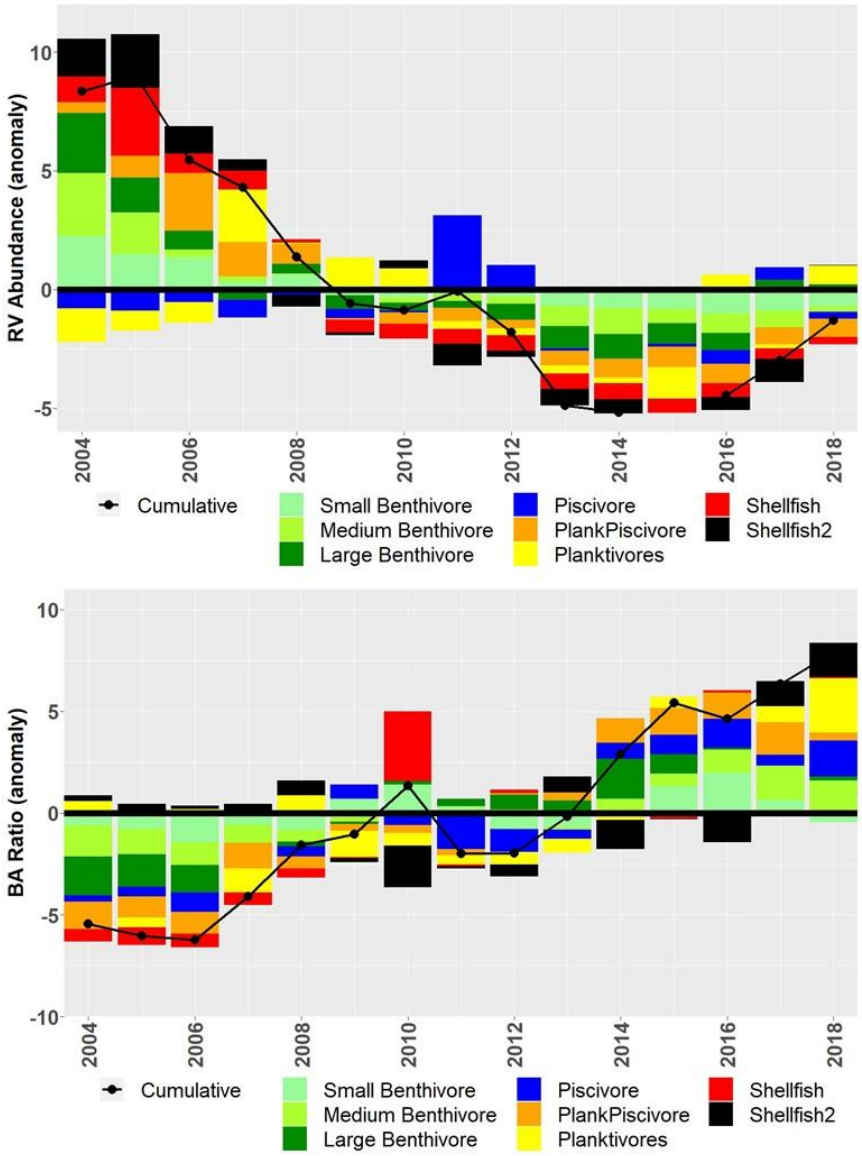

Figure 6. Cumulated normalized anomalies of the abundance index (Top) and the Biomass/Abundance (BA) Ratio (Bottom) by fish functional groups on the Flemish Cap (NAFO Div. 3M) to 1400m depth (strata 34).

The structure of the fish community by functional group considering waters up to 1400m depth (strata 1-34) (Figure 7) shows a very similar pattern to that observed in waters up to 700m depth (strata 1-19) (Figure 3). The percentage of piscivores increased over time, while shellfish almost disappeared and the plankpiscivores exhibited a declining trend. However, in comparison with the community structure up to 700m depth (Figure 3), the inclusion of deeper strata enhances the dominance of benthivore functional groups (small, medium, and large) (Figure 5). This difference speaks to the changes in community structure with depth, indicating a relative increase of benthivore species in deeper waters.

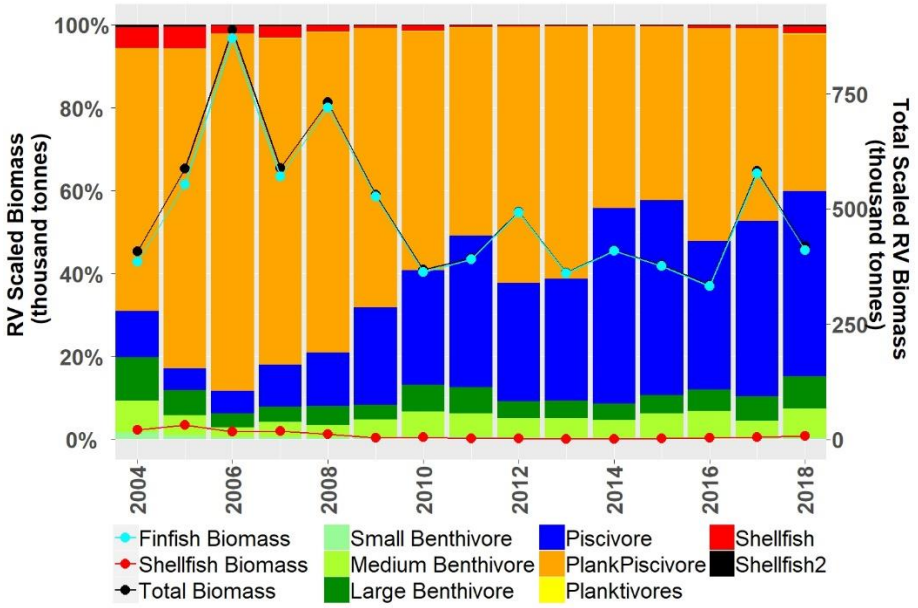

Figure 7. Changes in the structure of the Flemish Cap fish community in depths up to 1400m depth (strata 1-34) for the 2004-2018 period.

Acknowledgements

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Annex

Table A1. Benthivore species

Small Benthivore	**Medium Benthivore**	**Large Benthivore**
Gaidropsarus ensis	*Coryphaenoides rupestris*	*Anarhichas denticulatus*
Trachyrincus murrayi	*Urophycis chuss*	*Bathyraja spinicauda*
Cottunculus microps	*Micromesistius poutassou*	*Anarhichas lupus*
Aspidophoroides monopterygius	*Antimora rostrata*	*Anarhichas* sp.
Triglops murrayi	*Lycodes* sp.	*Macrourus berglax*
Enchelyopus cimbrius	*Malacoraja senta*	*Nemichthys scolopaceus*
Cottunculus thomsonii	*Coelorinchus caelorhincus*	*Melanogrammus aeglefinus*
Nezumia bairdii	*Glyptocephalus cynoglossus*	*Brosme brosme*
Nansenia sp.	*Synaphobranchus kaupii*	*Hippoglossoides platessoides*
Lepidion lepidion	*Serrivomer beanii*	*Raja* sp.
Sternoptyx pseudobscura	*Lycodes reticulatus*	*Notacanthus chemnitzii*
Xenodermichthys copei	*Lycodes esmarkii*	*Anarhichas minor*
Sternoptyx diaphana	*Lumpenus lampretaeformis*	*Amblyraja radiata*
Diretmus argenteus	*Lycodes vahlii*	*Alepocephalus bairdii*
Liparis fabricii	*Alepocephalus agassizii*	*Amblyraja jenseni*
Liparis liparis	*Simenchelys parasitica*	*Dipturus linteus*
Liparis sp.	*Rajella fyllae*	*Amblyraja hyperborea*
Caristius fasciatus	*Lumpenus* sp.	*Ceratias holboelli*
Nansenia groenlandica	*Malacoraja spinacidermis*	*Rajella bathyphila*
Lycenchelys paxillus	*Halargyreus johnsonii*	
Cottunculus sp.		
Cryptopsaras couesii		
Gonostoma elongatum		
Triglops sp.		
Lycodonus flagellicauda		
Ulcina olrikii		
Gaidropsarus argentatus		
Leptoclinus maculatus		
Polyacanthonotus rissoanus		
Melanostigma atlanticum		
Diretmidae Diretmidae		
Dibranchus atlanticus		

Table A2. Piscivores, plankpiscivores and planktivores species

Piscivore	**PlankPiscivore**	**Planktivore**
Hippoglossus hippoglossus	*Chauliodus sloani*	*Benthosema glaciale*
Chiasmodon niger	*Sebastes norvegicus*	*Scomberesox saurus*
Merluccius bilinearis	*Phycis chesteri*	*Magnisudis atlantica*
Gadus morhua	*Sebastes* sp.	*Notoscopelus kroeyeri*
Urophycis tenuis	*Sebastes* (juveniles)	*Myctophidae Mictofido*
Etmopterus princeps	*Malacosteus niger*	*Argentina silus*
Squalidae (escualos)	*Melanostomias* sp.	*Arctozenus risso*
Squalus acanthias	*Sebastes mentella*	*Bathylagus euryops*
Reinhardtius hippoglossoides	*Sebastes fasciatus*	*Stomias boa*
Alepisaurus brevirostris	*Borostomias antarcticus*	*Lampadena speculigera*
Lophius americanus	*Anoplogaster cornuta*	*Normichthys operosus*
Centroscyllium fabricii	*Boreogadus saida*	*Leptagonus decagonus*
Melanocetus johnsonii	*Photostomias guernei*	*Mallotus villosus*
Pollachius virens	*Rhadinesthes decimus*	*Poromitra megalops*
Anotopterus pharao	*Careproctus micropus*	*Myctophum punctatum*
Oneirodes eschrichtii	*Maulisia microlepis*	*Bajacalifornia megalops*
Aphanopus carbo	*Sudis hyalina*	*Scopelogadus beanii*
Petromyzon marinus	*Pachystomias microdon*	*Ceratoscopelus maderensis*
Saccopharynx sp.	*Centrolophus niger*	*Holtbyrnia anomala*
Bathysaurus ferox	*Eurypharynx pelecanoides*	*Protomyctophum arcticum*
Paralepis speciosa	*Sebastes (sobrecopo)*	*Haplophryne mollis*
Polyprion americanus	*Scopelosaurus lepidus*	*Cyclothone microdon*
Somniosus microcephalus	*Maulisia mauli*	*Melanonus zugmayeri*
	Melanostomias bartonbeani	*Argyropelecus hemigymnus*
Illex illecebrosus (cephalopoda)	*Borostomias* sp.	*Argyropelecus* sp.
Illex sp. (cephalopoda)	*Borostomias mononema*	*Maurolicus muelleri*
		Howella sherborni
Note: given their food habits, predatory squids have been included in the Piscivore functional group.		*Holtbyrnia macrops*
		Bathypterois dubius
		Stomiidae Stomiidae
		Argyropelecus aculeatus
		Argentinidae Argentinidae
		Venefica proboscidea
		Ammodytes dubius
		Flagellostomias boureei
		Rouleina attrita

Table A3. Shellfish species

Shellfish	**Shellfish2**
Pandalus borealis	*Spirontocaris liljeborgii*
Chionoecetes opilio	*Pasiphaea tarda*
Pandalus (sobrecopo)	*Acanthephyra pelagica*
Pandalus montagui	*Lithodes maja*
	Sabinea sp.
	Sergia robusta
	Parapasiphae sulcatifrons
	Stereomastis sculpta
	Eusergestes arcticus
	Neolithodes grimaldii
	Sabinea sarsii
	Sabinea hystrix
	Acanthephyra purpurea
	Aristaeopsis edwardsiana
	Pontophilus norvegicus
	Lebbeus polaris
	Pasiphaea multidentata
	Benthesicymus bartletti
	Hyas sp.
	Spirontocaris spinus
	Gnathophausia zoea
	Munidopsis curvirostra
	Hyas coarctatus
	Sabinea septemcarinata
	Argis dentata
	Stereomastis nana
	Eucopia sculpticauda
	Notostomus elegans
	Oplophorus spinosus
	Notostomus sp.
	Nematocarcinus rotundus
	Gnathophausia gigas
	Hyas araneus