Could population and community indicators contribute to identify the driver factors and describe the dynamic in the Flemish Cap demersal assemblages?

Authors:

Adriana Nogueira^{1,2,3}, Alfonso Pérez-Rodríguez³, Diana González-Troncoso⁴, and Fran Saborido-Rey³.

¹ Instituto Español de Oceanografía. Subida a Radio Faro, 50, 36390 Vigo, Spain

² Campus do Mar. Universidad de Vigo. As Lagoas, Marcosende, 36310, Vigo, Spain

³ Greenland Institute of Natural Resources. Kivioq 2 Postboks 570. 3900 Nuuk, Greenland.

⁴ Institute of Marine Research–CSIC, 6 Eduardo Cabello, 36208 Vigo, Spain.

Corresponding author: Adriana Nogueira, tlf: +299 361280; fax: +299 361212; e-mail: adno@natur.gl

Abstract

Flemish Cap is an isolated fishing ground located in the international waters of the Northwest Atlantic Fisheries Organization area (NAFO). In the last decades, the Flemish Cap demersal community has been subjected to strong and variable fishing intensities affecting different stocks over time. In this work, three ecological indices for individual populations (abundance, biomass, and intrinsic population rate of growth) and five community indicators (total abundance and biomass, community synchrony, ABC curves and proportion of non-commercial/commercial species) have been applied to data of 29 fish and 1 shrimp species to analyse the dynamics of the whole ecosystem and the major demersal fish assemblages. Different periods were detected, which may be explained by differences in the exploitation patterns and pressure for different stocks, prey-predators relationships and other environmental drivers affecting the reproductive capacity. This study shows that the selected ecosystem indicators are appropriate to detect changes in the demersal community of Flemish Cap in response to fishing, predation and variability in recruitment success. It has been also demonstrated that analyses revealed different trends for different parts of the community during periods with different fishing pressure. This knowledge could be useful to support management policies.

Key words: community indicators, fish assemblages, effects of fishing, community structure, ecosystem approach.

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53 **1. Introduction:**

54 Fisheries management is progressively switching the attention from a single
55 species approach focused on commercial species to an ecosystem approach, where
56 the management of exploited species is considered in a net of interactions with
57 other elements and services from the ecosystems, i.e. an integrated ecosystem
58 assessment and management (Levin and others 2009; Rochet and others 2010).
59 Useful elements towards this integration include the identification of species
60 assemblages, and the selection of metrics and indicators capable of integrating the
61 state of communities and/or the whole ecosystem using a low number of
62 manageable dimensions. Several studies have carried out critical revisions of the
63 indicators for the impact of fishing (Fulton and others 2004; Rochet and Trenkel
64 2003; Shin and others 2010). In order to deal with the high complexity at the
65 ecosystem level and the huge difficulties in studying all the interacting variables,
66 some authors have suggested using community indicators to measure the impacts
67 of fishing in demersal fish assemblages (Bianchi 1991; Jouffre and Inejih 2005;
68 Nogueira and others 2016; Nogueira and others 2015; Yemane and others 2005).
69 Multiple population and community indicators may be necessary to capture
70 changes in the community structure and provide a more complete understanding
71 of the ecosystem status (Bundy and others 2012; Pedersen and others 2017; Shin
72 and others 2010).

73 The Flemish Cap is located in the Northwest Atlantic, in the NAFO (Northwest
74 Atlantic Fisheries Organization) Division 3M (Figure 1). It is separated from the

Grand Banks of Newfoundland by the Flemish Pass, a channel with depth in excess of 1100 m that hinders the migration of shallow demersal species to the adjacent banks, species, such as Atlantic cod (*Gadus morhua*) (Templeman and Fleming, 1963; Konstantinov, 1970) and American plaice (*Hippoglossoides platessoides*) (Morgan and Bowering, 2004), although some migration does take place (de Cardenas et al., 1993). Whereas deeper species such as Greenland halibut (*Reinhardtius hippoglossoides*) is considered as a biological stock extending over NAFO from the Grand Banks and Flemish Cap, to Baffin Bay and West Greenland (Morgan and others 2013; Murua and de Cárdenas 2005). Compared with the Grand Banks, intensive fishing started late on the Flemish Cap because of its geographic isolation and mean depth (shallowest point at 120 m). The arrival of engine-powered trawlers in the mid 20th century and the establishment of a 200-mile Exclusive Economic Zone (EEZ) increased remarkably the fishing activity in the Flemish Cap (Wells and others 1984). During that period, fishing was mainly focused on Atlantic cod and redfish (*Sebastes* spp.) until the early 1990s, when both stocks declined sharply (Perez-Rodriguez and others 2012). In 1998, Atlantic cod collapsed on the Flemish Cap and a fishing moratorium was established. The collapse was attributed to three simultaneous circumstances: a stock decline due to overfishing, an increase in catchability at low abundance levels, and a series of poor recruitments starting in 1993 (González-Troncoso 2015). Since the collapse, four fisheries have been developed in the Flemish Cap (Table 1).

In the last century, changes in fish demersal communities have been found worldwide (Collie and others 2008; Fogarty and Murawski 1998; Gabriel 1992; Hall 1999; Tian and others 2006). Previous studies in Flemish Cap have also

shown changes in population indicators for the main commercial species (Casas 2014; González-Troncoso 2015), as well as at the whole community structure level (González-Troncoso and Paz 2007; Perez-Rodriguez and others 2012) and separately in each fish demersal assemblage (Nogueira and others 2016). In this study a new set of ecological indicators has been applied using an extended database (1993-2014).

The objective of this study was to analyse changes through time in the whole ecosystem of Flemish Cap to understand large-scale patterns of the main demersal assemblages (a shallow < 250 m, a mid at 251-600 m and a deep > 601 m) described by Nogueira and others (2017), and to evaluate how they have responded to different levels of exploitation within a changing environment affecting natural mortality and recruitment. For this purpose, we selected two categories of indicators: population indicators (abundance, biomass and intrinsic population rate of growth) and community indicators (total biomass, community synchrony, ABC curves and proportion of non-commercial species), to evaluate how they have responded to changes in environmental drivers and exploitation rates. These indices were applied to the ecosystem as a whole, but also separately for each of the three assemblages described by Nogueira and others (2017). Specifically, (1) we ask if community indicators could be used to understand changes in community structure (2) if the observed changes are related to fishing or other environmental drivers and (3) we discussed the appropriateness of analysing the whole ecosystem or each assemblage separately.

2. Material and methods

2.1. Data source:

We used data from the International European Union (EU) bottom trawl surveys, conducted every year in summer (June-July) since 1988, to estimate abundance and biomass of demersal resources in the Division 3M of the NAFO Regulatory Area. The surveys follow the NAFO recommendations (Doubleday 1981) and consist on a bottom trawl random stratified sampling design. From 1991 to 2003, the survey was conducted on board the RV *Cornide de Saavedra* to depths up to 730 m. In 2004, the RV *Vizconde de Eza* replaced the former vessel and the survey depth was extended down to 1460 m. A Lofoten type bottom trawl was used in both vessels, so we assume that selectivity is the same and no transformation was applied to combine data for the two periods (Nogueira and others 2016).

There are three species of redfish in the area: Acadian refish (*Sebastes fasciatus*), golden redfish (*Sebastes norvegicus*) and deepwater redfish (*Sebastes mentella*). Because redfish catches were properly split into species since 1993, only the period 1993-2014 has been considered in this study; individuals smaller than 15 cm were assigned to each species following the methodology described in Avila de Melo and others (2003). On average, 120 valid hauls were conducted every year from 1993 to 2003, while this value increased to 180 over the period 2004-2014 (Vázquez and others 2013). A total of 3 218 hauls were valid during the study period. The initial and final depths have been used to estimate the average depth for each haul, which ranged from 129 to 730 m over the period 1993-2003, and from 129 to 1460 m for the period 2004-2014.

Nogueira and others (2017) examined the assemblage structure of the 29 most abundant species in the survey. These 29 species amounted to 98 % and 98.9 % of the total fish catch of the survey, in terms of biomass and abundance respectively. All species were present at least in 7.59% of the total observed tows. Of these taxa, 26 were demersal species. Of the remaining three, Acadian redfish, deepwater redfish and golden redfish are demersal-mesopelagic, and can form large aggregations near the bottom. Their importance was considered in terms of occurrence, biomass and abundance (Nogueira and others 2017). A full list of all the fish species caught from 1993 to 2015 has been included as supplementary material (Table A.1). Some analyses were done with Northern shrimp (*Pandalus borealis*) because the fishery began in 1993, and this species is an important prey of cod.

Nogueira and others (2017) distinguished three main demersal communities of fish, namely a shallow community, mid community and deep community. Therefore, we summarized the catch data into the following depth categories: ≤ 250 m, 251-600 m and ≥ 601 m. In this study, the shallow assemblage included six species, the mid assemblage contained eight species and the deepest assemblage comprised sixteen species (Table 2). The community indicators used in this work were first applied to all the depth range sampled during the EU survey with the intention of analysing the general state of the ecosystem as a whole. Next, these community indicators were applied to each assemblage separately, in order to study the long term trend by demersal association. Since the EU survey was only conducted at depth shallower than 730 m until 2003, the analysis of the deep assemblage (depths > 601 m), was conducted only since 2004. For this reason, in order to homogenize the time series from 1993 to 2014, for the whole ecosystem

only data from 129 m to 730 m were used for all the time series. Analysis for the whole ecosystem only included 27 species because one species (*Apristus sp* [Demon catshark]) was not present at depth less than 730 m, and two species (*Amblyraja hyperbora* [Arctic skate] and *Lampanyctus sp* [Lanternfish]) were present only few years at depth less than 730 m.

Information on demersal fishing effort in Flemish Cap (NAFO Division 3M) for all countries from 1960 to 2013 was obtained from STATLANT 21B database compiled by NAFO (available at the,(NAFO) website). Fishing effort with depth information was available for Spanish vessels from 2001 to 2014 (based on NAFO observers). No fishing effort data by depth range from other countries was available for this work.

2.2. Statistical methodology:

We considered a suite of three indicators for populations and four for community. A full description of the models used and their characteristics is available in Nogueira and others (2015)

2.2.1. Population growth rate:

Population growth rate (r_i) was estimated using annual abundance estimates as the slope of the log total abundance against time:

$$\log(N_{i,t}) = \delta_i + r_i t + \varepsilon_{i,t}$$

where $N_{i,t}$ is the abundance of the species i in the year t and ε_i the residual error terms assumed to be normally distributed with 0 mean and variance σ_ε^2 . A log-transformation is applied to abundance estimates. Taking $r = 0$ (if the zero is among the 95% confidence interval) as reference point assumes that without any noticeable impact of fishing the population would be stable although randomly

194 varying between years (Nogueira and others 2015). The expected effect of fishing
195 is to slow population growth, although many other factors might also have the
196 same effect (Rochet and Trenkel 2003).

197 2.2.2. Biomass and abundance:

198 We estimated biomass and abundance for all the species included in the analysis
199 and then binned biomass in the three depth zones based on assemblages found by
200 Nogueira and others (2017). Total biomass and total abundance were estimated as
201 the sum of all species biomasses and abundances, which were calculated for the
202 whole ecosystem (with and without shrimp) as well as separately for the three
203 assemblages (shrimp was included). Abundance and biomass for all species were
204 estimated by the swept area method (Cochran 1977).

205 2.2.3. Community synchrony:

206 We calculated the community synchrony to examine how closely are
207 fluctuations in the biomass of different species for the whole community and for
208 each depth zone using the synchrony package of R (Gouhier and Guichard 2014).
209 The analysis were done with all species and with only non-commercial species.
210 The index drops to 0 when there is perfect asynchrony between species and is 1
211 when all species fluctuate in perfect unison. We calculated community synchrony
212 using a running 5-year window, ending in the year of interest. We used Monte
213 Carlo randomizations of each time series, with 999 replicates, to determine the
214 statistical significance (Pederson et al. 2017).

215 2.2.4: ABC method:

216 Distribution of abundance and biomass among species in the community were
217 compared to determine the level of disturbance in the communities via the ABC
218 method (Warwick 1986). Calculations were carried out with the function “abc” in

the “forams” (Aluizio 2015) package in R v.3.1.2 (R Core Team 2016). The ABC plots can be reduced to an univariate measure; this is the W statistic (Clarke 1990), which is the “difference curve” Biomass-Abundance for each sample.

The value of the W statistic depends on the relative position of the two k-dominance curves, and it takes values in the range [-1, 1], with W=1 being the undisturbed and W=-1 the heavily perturbed state.

2.2.5: Proportion non-commercial-commercial species:

The relative importance of non-commercial species in the community is expressed in terms of either abundance or biomass:

$$\frac{\hat{B}_n(t)}{\hat{B}(t)}, \frac{\hat{N}_n(t)}{\hat{N}(t)}$$

where

$\hat{B}_n(t)$ is the estimated biomass of all non-commercial species

$\hat{B}(t)$ is the estimated biomass of all commercial species

$\hat{N}_n(t)$ is the estimated abundance of all non-commercial species

$\hat{N}(t)$ is the estimated abundance of all non-commercial species

3. Results:

Fishing effort in Flemish Cap peaked in 1965 (more than 85% of the fishing effort corresponded to the former Soviet Union), then it peaked again in 1972 and 1978, (just after the 200-mile EEZ extension) (Figure 2). It then showed an increasing trend since mid-1980s until 1994, when the fishing effort focused in the traditional fisheries (cod and redfishes) started a declining trend. These fisheries operated in the shallower depths (< 600 m). However, the start of the shrimp fishery in 1993 kept the raising trend in total effort until 1998. Following the

241 moratoria for American Plaice in 1996 and for cod in 1999, the effort (excluding
242 shrimp fishery) remained relatively constant at low level since 1998 (and
243 especially since 2008), fluctuating in line with Spanish effort, corresponding to
244 the Greenland halibut fishery. Trend in total fishing effort is similar to the Spanish
245 fishing effort during the period 1998-2008 due to the Greenland halibut fishery,
246 and to the Portuguese since 2008 until the end of the studied period (redfish
247 fishery, then cod fishery since recovery in 2010). Shrimp fishery decreased
248 sharply since 2003 until the moratorium in 2011.

249 Spanish fishing effort was higher at depths greater than 600 m until 2003, when
250 NAFO Fisheries Commission established a 15 years rebuilding plan for the
251 Greenland halibut. Then it began to decrease strongly until 2008 and remained
252 constant until the end of the studied period, although it represents 80% of the total
253 Spanish effort (145 371 hours) of the total fishing effort (177 373 hours) (Figure
254 3).

255 Intrinsic population growth rates (r) indicated same trends for the 14 species
256 included in the shallow and mid zones and, in the whole ecosystem (Table 3,
257 Table B.1 for details). For 6 of those 14 species, r did not differ from zero,
258 indicating no evidence of long-term trends in population size and suggesting
259 stable populations for these species. However, for two populations in the shallow
260 assemblage (witch flounder and Atlantic cod), r was greater than zero
261 demonstrating long-term increase in population sizes for these species, and two
262 non-commercial populations decreased (Atlantic wolffish (*Anarhichas lupus*) and
263 spotted wolffish (*Anarhichas minor*). In the mid assemblage, the two species of
264 redfish, Acadian redfish and deepwater redfish increased, and two non-
265 commercial species decreased (spinytail skate (*Bathyraja spinicauda*) and Arctic

eelpout (*Lycodes reticulatus*). For deep species, trends found in the whole ecosystem and in the deep assemblage are not comparable because the different time series studied and the different deep range. In the deep assemblage, the 6 of the 16 species did not differ from zero (which included only one commercial species, Greenland halibut) and 10 species decreased (which included only one commercial species, roughhead grenadier).

Both population abundance and biomass indicators showed strong variations in several species, and with special importance in the commercial species of Flemish Cap: cod and redfish in terms of biomass, and shrimp in terms of abundance. (Figures B1 and B2). Considering all species and the whole depth range two periods are observed regarding total biomass: 1) 1993-2003: a period of very low biomass; 2) 2004-2014: a period of higher biomass due to the increase of redfish stocks first and cod stock since 2008. A similar division was observed in the intermediate assemblage, that accumulated most of the biomass all over the study period. Until the collapse, in 1999, only non-commercial species fluctuated increasingly synchrony when we studied the whole depth range. In the intermediate, both non-commercial and all the mid community showed increasing synchrony until the collapse. When including shrimp into the analysis, only difference in the total abundance were observed, it increased from 1997 to 2005, and then dropped until 2011. In the shallow assemblage, three periods were observed: 1) before 1995, when the community was mainly characterized by cod; 2) drop of cod to the collapse, reaching the lowest value in 2003 (829 t); 3) recovery of redfish from 2004 and cod from 2005. Total biomass increased mostly due to redfish and later to the increase of cod. Since 2009, biomass decreased but maintaining higher values than the period before 2003. This decline was due to

the decrease of redfish, that was not compensated by the increase of cod. In the shallow community, the estimated synchrony dropped in 2003 and then increased significantly until 2007. From 2007 until the end of the period the recovery of cod in contrast to the decline of redfish and shrimp, the synchrony decreased suggesting that species fluctuated independently. In the deep community, the time series is shorter. In that zone, lower biomass and abundance were found. Total biomass fluctuated in parallel to changes in Greenland halibut, and a decreasing trend for non-commercial species was observed all over the study period. This patterns produced an increasing synchrony of both all deep community and non-commercial species along with the fishing effort decline (Figure 4, B.1, B.2).

In the ABC curves, when all species were considered the abundance curve was above the biomass curve and the W-statistic was negative until 2006 (Figure 5a, Figure B.3a). Since then the two curves were very close, and W was almost 0. When shrimp was not included in the analysis the two curves remained very close during all the period with the exception of year 2001, when the W statistic reached the lowest value and abundance laid above the biomass curve (Figure 5a, Figure B.3b). Considering each assemblage separately (Figure 5b, Figure B.3c-e), the ABC plots confirmed the different nature of the three assemblages and distinguished different periods in the shallow and intermediate assemblage. In the shallow, from 1998 to 2003, abundance was above the biomass curve, where abundance reached more than 80 % asymptote. For the years 1993-1997 and 2011-2014, W was near to 0. Biomass lay above the abundance curve for years 2009 and 2010. In the intermediate assemblage, the abundance was above the biomass curve during all the period being W negative until 2005 and then almost

0. In the deep assemblage, W is negative for years 2005 and 2006, it is close to 0 in years 2004 and 2007 and since 2008 it presented positive values.

Trends in the ratios of non-commercial/commercial species were very similar for the whole ecosystem (when shrimp was considered), the shallow and the intermediate assemblages (which included shrimp) both with abundance and biomass (Figure 6), showing a decline since 1995 to 2010. When shrimp was not considered in the analysis, the ratio estimated with the abundance showed a similar pattern (although with higher values) but the ratio estimated with biomass showed a variable pattern until 2003, when it dropped and stayed in lowest values until 2014. In the deep assemblage, ratios with abundance and biomass showed opposite patterns.

4. Discussion:

A wide set of population and community indicators were applied to explore the temporal changes in the structure of an overexploited demersal community, to evaluate the relative importance of key ecosystem processes and their response to disturbance. Due to changes occurred during the studied time series, a period of heavy fishing pressure before the collapse, and recovery following the moratorium, the Flemish Cap constitutes a very suitable case study to explore the capacity of community indicators to identify changes in the community and disentangle the causal factors (Nogueira et al., 2016).

Changes over time at the community and ecosystem level are the ultimate expression of the fluctuations at lower levels of organization, i.e. at the population level. Community indicators should add another point of view to the diagnostic obtained from looking at single populations (Trenkel and Rochet 2003). Community indicators have been presented frequently as suitable tools to detect

the effect of fishing in ecosystems (Jennings and Kaiser 1998; Nogueira and others 2016; Nogueira and others 2015; Rochet and Trenkel 2003) although other abiotic (e.g. NAO, temperature) or biotic processes (predation, competition or recruitment) could also affect the community structure. In the Flemish Cap, due to the usual high degree of isolation, migration is expected to be of low importance and hence changes at the population level are presumed to be mostly related with variability in the degree of recruitment success (inputs) and levels of mortality rates at different ages (outputs). Mortality in turn could be due to fishing activity affecting differentially the different size/age classes and especially the large/older individuals; or natural causes among which predation can be of very high importance, mainly for the younger ages and smaller sizes (Bax 1998; Jennings and others 2001).

The results reflect changes mostly driven by variability of cod, shrimp, Greenland halibut and the three redfish species (82% of total biomass). Due to the dominance of those few species, trends are attenuated when we study the whole ecosystem and that the study of each zone separately help us to better understand trends and the dynamic of the communities. With the exception of Greenland halibut and roughhead grenadier all the above mentioned species present most of their biomass in the intermediate assemblage, which might explain why changes observed in the intermediate assemblage were very similar to the observed variations in the whole community.

The shallow and the intermediate assemblages were overexploited until the early 1990s by the directed cod and redfish fisheries (Avila de Melo and others 2015; Cerviño and Vázquez 2004). The collapse of cod by mid 1990s and the late recovery from 2006 has been presented in previous works as one of the main

reasons driving the changes and trends in the demersal community of Flemish Cap due to its predatory behaviour (Pérez-Rodríguez and others 2011; Pérez-Rodríguez and others 2017).

In the shallow community, cod and witch flounder showed positive slope in population growth rate over the study period. These patterns could be interpreted as signs of recovery of the two populations. Cod were recovered and witch flounder is a by-catch species in the directed cod fishery (González-Costas 2012), and the moratorium on cod fishery would have potentially favoured the increase in these population. Synchrony has been increasing previous and after the cod moratoria, and also during years 2004-2006. This suggests that the loss of biomass during the collapse and the later increase (mostly on redfish but also other species at a lower scale) was due to common drivers. Pedersen and others (2017) also found increasing synchrony during the biomass collapse for the entire groundfish community in the Grand Banks. That indicates that changes in communities appear on a large scale and are not limited to specific areas (Gomes and others 1992; Nogueira and others 2013). The ABC curves and their corresponding W-statistic, and ratio of non-commercial/commercial species suggested that the fish community of Flemish Cap was moderately disturbed until 1997, and strongly disturbed from 1998 to 2003. This is in line with cod collapse from mid 1990s that lasted until the recovery from 2005. Analysis of the mean trophic level by Nogueira and others (2016) also detected those changes confirming similar trends during the pre and post collapse periods. After the cod recovery, decreasing synchrony suggests again return tendency to the pre-collapse period, where changes were related by the dynamic of the communities (prey-predator

relationships). In the Grand Banks, similar tendency towards the pre-collapse period in the community could be sign of recovery (Pedersen and others 2017).

In the intermediate assemblage, redfish species were dominant all over the study period. The observed increase in biomass, abundance, and community synchrony (also in the shallow) since 2004 and the decline since 2010 should have been induced by the release and increase of cod predation respectively (Pérez-Rodríguez and others 2017). However in addition to predation, there was a strong reduction in fishing pressure and exceptional recruitments from 2001-2007 (Avila de Melo and others 2015). Increasing synchrony and biomass, in commercial and non-commercial species, suggested also that the entire community has responded to common drivers. Similar increase of redfish, previous to the cod increase, was found in the Southern Grands Banks (Nogueira and others 2016). ABC curves indicated that the community was disturbed since the beginning of the studied time-series, already before the shrimp fishery started. Both ratios of abundance and biomass for non-commercial and commercial species suggested that this zone suffered from the impact of fishing until mid 2000s when cod and redfish where at very low levels.

In the deep community, fishing pressure increased remarkably since 1990 due to the directed fishery on Greenland halibut fisheries until 2003 when Greenland halibut biomass was estimated to be at the lowest level in the recorded time-series (Darby and others 2004). Since then, fishing pressure has been very low. Deep water species are more sensitive to fishing pressure due to their usual life history traits, characterized by late age of maturity, low fecundity and slow growth (Jorgensen and others 2006; Koslow and others 2000). The results observed in the biomass trends, ABC curves and ratio of non-commercial/commercial species

suggest a transition from a low to a high disturbed status, which would be in line with the above mentioned low resilience of the deep water fish community to the high levels of fishing targeting Greenland halibut. The same conclusion was reached by Nogueira and others (2016) when analysing the mean trophic level in that stratum.

5. Conclusions

The results of this work have shown the usefulness of community indicators to describe the general dynamic of communities in the Flemish Cap, and that treating each depth zone separately help us to better detect changes in the community. This work represent a further step in understanding the large –scale ecological patterns of collapse and recoveries in the groundfish communities in the Flemish Cap, that were not limited to specific areas. Fishing, recruitment, migrations, predation or other natural mortality causes are in the basis of population and ecosystem dynamic. Understanding community composition and possible community shifts through time and space should be essential to assess changes in the availability of target species and associated non-target species. This research could be used to monitor any future changes in assemblages structure, it also provides new insights to management objectives by incorporating multispecies interactions into management policies under an ecosystem approach in NAFO, although further investigation is needed.

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Table 1: Fisheries developed in Flemish Cap since the cod collapse in 1999. At depths between 150 and 550 m a fishery targets cod since 2010, after a 10 year moratorium. Between 200 and 600 m, the fishery targets redfish. Until 2011, there was a shrimp fishery between 300 and 500 m (a moratorium under that fishery was initiated in 2011). A fishery for Greenland halibut exists at depths less than 600 m.

Depth range (m)	Target	By-catch
150-500	Atlantic cod (since 2010)	redfish shrimp
300-500	Shrimp (from 1993 to 2011)	
200-600	redfish	Atlantic cod shrimp
> 600	Greenland halibut	Black dogfish Roughhead grenadier

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Table 2: Scientific name, common name, FAO code and assemblage designation according to depth (shallow 129-250; mid 251-600; deep 601-1460) for 29 demersal species and one shrimp collected during the 1993-2014 EU Bottom Trawl Surveys. Their corresponding status (commercial and non-commercial) and depth range are shown for the period 1993-2014.

Main Fish Species	Common name	FAO Code	Status
SHALLOW ASSEMBLAGE (< 250 m)			
<i>Hippoglossoides platessoides</i>	American plaice	PLA	Commercial
<i>Glyptocephalus cynoglossus</i>	Witch flounder	WIT	Commercial
<i>Gadus morhua</i>	Atlantic cod	COD	Commercial
<i>Anarhichas lupus</i>	Atlantic wolffish	CAA	Non Commercial
<i>Sebastes norvegicus</i>	golden redfish	REG	Commercial
<i>Anarhichas minor</i>	Spotted wolffish	CAS	Non Commercial
MID ASSEMBLAGE (251-600 m)			
<i>Sebastes fasciatus</i>	acadian redfish	REN	Commercial
<i>Sebastes mentella</i>	deepwater redfish	REB	Commercial
<i>Lycodes reticulatus</i>	Arctic eelpout	LCT	Non Commercial
<i>Amblyraja radiata</i>	Thorny skate	RJR	Commercial
<i>Phycis chesteri</i>	Longfin hake	GPE	Non Commercial
<i>Bathyraja spinicauda</i>	Spinytail skate	RJQ	Non Commercial
<i>Anarhichas denticulatus</i>	Northern wolffish	CAB	Non Commercial
<i>Pandalus borealis</i>	Northern shrimp	SP5	Commercial
DEEP ASSEMBLAGE (> 600 m)			
<i>Reinhardtius hippoglossoides</i>	Greenland halibut	GHL	Commercial
<i>Antimora rostrata</i>	Blue antimora	ANT	Non Commercial
<i>Macrourus berglax</i>	Roughhead grenadier	RHG	Commercial
<i>Nezumia bairdii</i>	Marlin-spike	NZB	Non Commercial
<i>Centroscyllium fabricii</i>	Black dofish	CFB	Non Commercial
<i>Coryphaenoides rupestris</i>	Roundnose grenadier	RNG	Non Commercial
<i>Synaphobranchus kaupii</i>	Northern cutthroat eel	SSK	Non Commercial
<i>Amblyraja hyperborea</i>	Arctic skate	RJG	Non Commercial
<i>Notacanthus chemnitzii</i>	Snubnosed spiny eel	NNN	Non Commercial
<i>Chauliodus sloani</i>	Sloane s viperfish	CDN	Non Commercial
<i>Lycodes vahlii</i>	Vahl s eelpout	SP3	Non Commercial
<i>Stomias boa</i>	Scaly dragonfish	SBB	Non Commercial
<i>Serrivomer beanii</i>	Bean s sawtoothed eel	ASB	Non Commercial
<i>Gaidropsarus ensis</i>	Threadfin rockling	GDE	Non Commercial
<i>Apristurus sp.</i>	Demon catshark	API	Non Commercial
<i>Lampanyctus sp.</i>	Lanterfish	SP4	Non Commercial

Table 3: Trends for the population growth rate (r) for NAFO Regulatory Area Divisions 3M groundfish, for each species in the whole ecosystem, all depth range (129-730 m), and for populations of the shallow (<250 m) and mid (251-600 m) assemblages for the period 1993-2014, and deep (> 601m) assemblages for the period 2004-2014.

Increasing trend	Stable	Decreasing trend
All depth range (129 -730 m)		
<i>Witch flounder</i>	<i>Witch flounder</i>	<i>Atlantic wolffish</i>
<i>Atlantic cod</i>	<i>Atlantic cod</i>	<i>Spotted wolffish</i>
<i>acadian redfish</i>	<i>golden redfish</i>	<i>Spinytail skate</i>
<i>deepwater redfish</i>	<i>Longfin hake</i>	<i>Arctic eelpout</i>
<i>Blue antimora</i>	<i>Thorny skate</i>	<i>Greenland halibut</i>
<i>Scaly dragonfish</i>	<i>Northern wolffish</i>	<i>Roughhead grenadier</i>
<i>Black dofish</i>	<i>Northern shrimp</i>	<i>Marlin-spike</i>
<i>Roundnose grenadier</i>	<i>Northern cutthroat eel</i>	<i>Snubnosed spiny eel</i>
	<i>Threadfin rockling</i>	<i>Vahl s eelpout</i>
	<i>Bean s sawtoothed eel</i>	
	<i>Sloane s viperfish</i>	
Shallow (< 250 m)		
<i>Glyptocephalus cynoglossus</i>	<i>Hippoglossoides platessoides</i>	<i>Anarhichas lupus</i>
<i>Gadus morhua</i>	<i>Sebastes norvegicus</i>	<i>Anarichas minor</i>
Mid (251-600 m)		
<i>Sebastes fasciatus</i>	<i>Phycis chesteri</i>	<i>Bathyraja spinicauda</i>
<i>Sebastes mentella</i>	<i>Amblyraja radiata</i>	
	<i>Anarhichas denticulatus</i>	
	<i>Pandalus borealis</i>	
Depth (> 601 m)		
	<i>Reinhardtius hippoglossoides</i>	<i>Macrourus berglax</i>
	<i>Lampanyctus sp.</i>	<i>Nezumia bairdii</i>
	<i>Stomias boa</i>	<i>Notacanthus chemnitzii</i>
	<i>Serrivomer beanii</i>	<i>Lycodes vahlii</i>
	<i>Chauliodus sloani</i>	<i>Antimora rostrata</i>
	<i>Apristurus sp.</i>	<i>Amblyraja hyperborea</i>
		<i>Centroscyllium fabricii</i>
		<i>Coryphaenoides rupestris</i>
		<i>Synaphobranchus kaupii</i>
		<i>Gaidropsarus ensis</i>

Figure 1: Chart of the NAFO Regulatory Area showing Divisions 3LMNO of the Grand Banks and Flemish Cap. EU bottom trawl survey in Division 3M NAFO Regulatory Area is marked. The three assemblages in 3M are represented: shallow assemblage (≤ 250 m); mid assemblage (251-600 m); deep assemblage (≥ 601 m).

Figure 2: Total, total without shrimp fishery, Portuguese and Spanish fishing effort of the bottom trawl fishery in NAFO Regulatory Area Divisions 3M for the period 1960-2013 (Data were based on information from STATLANT 21B, www.nafo.int).

Figure 3 : Total Spanish fishing effort by depth range (≤ 250 m, 251-600 m and ≥ 601 m and overall 129-1460 m) from the bottom trawl fishery in NAFO Regulatory Area Division 3M (Data were based on information from NAFO Observers on board).

Figure 4: Total biomass (1) and community synchrony (2), for all the species (solid line) and for non-commercial species (dotted line) from the EU bottom trawl survey 3M in (a) all the depth range (129-730 m) and in each zone (b) shallow assemblage (129-250 m) (c) mid assemblage (251-600 m) (d) deep assemblage (601-1460 m). The inset shows biomass dynamics of the non-commercial species alone, to show the trend. Red/blue points denote insignificant/significant community-wide synchrony in that community.

Figure 5: Values of the W-statistic for all species, (a) for the whole ecosystem with shrimp (circle) for the whole ecosystem without shrimp (triangle), (b) for the shallow assemblage (circle), the mid assemblage (triangle), (1993-2014) and the deep assemblage (square), 2004-2014.

Figure 6: Ratio of abundance (solid lines) and biomass (dotted lines) of non-commercial/commercial species for (a) the whole ecosystem with N. shrimp (b) the whole ecosystem without shrimp (c) the shallow assemblage, (d) the mid assemblage for the period 1993-2014 and, (e) the deep assemblage, for the period 2004-2014. Note the different scales in ratio of Biomass and Abundance for the whole ecosystem (0.01-0.05 and 0.05-0.2), the whole ecosystem without N. shrimp (0.05-0.15 and 0.05-0.02), the shallow (0-0.15 and 0-4); the mid (0-0.05 and 0-0.15); the deep (0-2.2 and 0-1.6).

SUPPLEMENTAL MATERIAL

Appendix A

Table A.1: List of all species caught during the EU bottom-trawl survey, “Flemish Cap” on board the R/V Cornide de Saavedra from 1993 to 2002 and the R/V Vizconde de Eza from 2003 to 2014.

Appendix B

Table B.1: Hypothesis test for the population growth rate (r) for NAFO Regulatory Area Divisions 3M groundfish, for each species in the whole ecosystem, all depth range (129-730 m), and for populations of the shallow (<250 m) and mid (251-600 m) assemblages for the period 1993-2014, and deep (> 601m) assemblages for the period 2004-2014.

Figure B.1: Biomass and abundance estimate for the main species from EU bottom trawl survey Division 3M (1993-2014) in all the depth range (129-730 m) and in each zone (129-250 m, 251-600 m, 601-1460 m).

Figure B.2: Total biomass and abundance estimate for the total community EU bottom trawl survey Division 3M (1993-2014) in all the depth range (129-730 m) and in each zone (129-250m, 251-600 m, 601-1460 m). Colours denote the most abundant species and white area denotes the remaining 18 non-commercial species (2 in the shallow, 4 in the mid and 13 in the deep assemblage).

Figure B.3: ABC curves by year, for (a) the whole ecosystem with N. shrimp ,
(b) the whole ecosystem without N. shrimp, (c) the shallow assemblage, (d) the
mid assemblage, for the period 1993-2014 (e) the deep slope assemblage, for the
period 2004-2014. Broken lines indicate biomass and continuous lines abundance.
Values of the W-statistics are shown for each year.