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On recruitment of the Flemish Cap cod stock

by

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**Abstract**

The possibility that shrimp fishery in Flemish Cap has impeded survival of any good cod year-class from 1993 to 2004 is analysed. By-catches were estimated to be low in that fishery. However, the effect of small mesh size cod-ends used in that fishery, even only insignificant by-catch was recorded, could produce important escape mortality on fry cod. Main support to this hypothesis is the coincidence of dates the fleet was fishing shrimp and the occurrence of very poor year-classes.

**KEYWORDS:** Cod, recruitment, Flemish Cap, shrimp.

**Introduction**

Species in Flemish Cap underwent deep changes in abundance in last twenty years, as recorded by the EU bottom trawl survey of Flemish Cap and confirmed for main species by the NAFO Scientific Council (SC). Most visible changes were the collapse of the cod and American plaice stocks in 1993, the increase of the shrimp abundance that allowed an intense fishery 1993-2004, the spread of Greenland halibut over the bank to occupy zones left by cod when restricted to shallowest part of the bank, and the remarkable increase of redfish. Since 2005, most of these species reverted to their former abundance; only American plaice remain collapsed.

Apparently, the main factor that triggered out these changes was the cod and American plaice overfishing, leading to a sequence of events already documented in other areas, e.g., the Scotian Shelf of Canada's East coast (Frank *et al.* 2011). Being cod a top predator, the first response of the system was the increase of forage species: shrimp and redfish are among main prey items for cod (Konstantinov *et al.* 1985, Lilly 1985, Albikovskaya and Gerasimova 1993, Paz *et al.* 1993, Román *et al.* 2004).

**Elements**

*Cod fishery*

Flemish Cap cod stock declined due to overfishing and it collapsed due to poor recruitment (Vázquez and Cerviño 2005). The last two abundant year-classes (1990 and 1991) were deep fished at too early ages, and the next year-classes in 13 years were very poor: recruitments were poor for the 1992-1994 cohorts and almost null for the following nine years. The adult stock was reducing its size because no new recruitment appeared; it was at an intermediate level in 1992-1995, but it was at a very low level since 1996 (Cerviño and Vázquez 2004). The first

recruitment break down was the 1992 cohort, and it was noted weak at age 1 in 1993 during the EU bottom trawl survey. The importance that this fact could be unrecognizable because the 1987 and 1989 cohorts had been at the same range or lower (Vázquez 1994), so that was nothing new. The NAFO SC had still not recognized it in 1995, when two poor recruitments had occurred, and recommended “*catch be limited to the vicinity of the current TAC*” (11.000 t) for 1996 (NAFO 1995). The fishery was maintained up to 1997, even with decreasing yield, and a fishing moratorium was agreed for 1999 onwards.

### *Shrimp fishery*

The shrimp fishery started in 1993 (NAFO 1993):

*Although the presence of shrimp on Flemish Cap has been known for many years, no significant shrimp commercial effort was reported from the area before spring 1993. A shrimp fishery began in late-April 1993 when two Canadian vessels were granted exploratory permits to fish the species in Div. 3M. By late-July, about 50 vessels from several nations were reported fishing for shrimp in the area. Preliminary reports (to August 23) indicated that over 21 000 tons of shrimp have been taken so far in 1993 and that, as of August 31, 18 vessels were still active in the fishery.*

The number of vessels varied between 40 and 110 in the 1993-2005 period; they were approximately 50 in 2004 and 20 in 2006 (Casas 2011). Shrimp fishing was forbidden from 2002 in an area with less than 140 fathoms depth approximately (NAFO 2005).

The EU survey biomass indices for female shrimp remained relatively high until 2008, and a sharp decline occurred in 2009. The fleet reduced its presence from 2005 onwards due to the market situation; because of that, subsequent shrimp stock decline was not a consequence of overfishing but, more likely, produced by predation of the increasing cod stock. NAFO SC is quite precautionary about it:

*Scientific Council notes that there are indications of factors other than fishery that may be involved in the current decline of the stock. (NAFO 2011)*

Reduction of fishing effort produced an immediate increase in cod recruitment in 2005-2008 and a step forward in 2009-2010, when the shrimp fleet leave the shrimp fishery (Figure 1).

### *By-catch*

Shrimp fishery in Flemish Cap was carried out with 40 mm cod-end mesh size; sorting grates with 28 mm spacing bars were introduced in 1994, and reduced to 22 mm spacing in 1995 (Kulka 1999). The grates were designed to prevent the catch of large fish, particularly redfish, whose presence in the cod-end might spoil shrimp. The by-catch composition changed with the introduction of the grate in 1994, being made up of small size specimens of redfish, wolfish, Greenland halibut, American plaice and cod, among regulated species.

By-catch information was available for several countries attending the shrimp fishery. Main by-catch item was juvenile redfish, with a mode length of 14 cm (Parsons *et al.* 1998).

Reports from Iceland in years 1996-2005 only indicate cod by-catch in 1999 (Skúladóttir 1997, 1998, 2005). No cod was recorded in an exploratory fishing from Faroese trawlers in 3M, probably in 1993 (Nicolajsen 1994). Observers on board from Canada (1993-1998) and Norway (1995-1998) reported cod by-catches in years 1993 to 1997, but not in 1998 (Kulka and Power 1996; Kulka 1998, 1999). We conclude that cod by-catch happened, even in small amounts, particularly before 2000, when most information is available. Only Iceland reported no by-catches in 2000 onwards.

Figure 2 shows distribution of shrimp and age 1 cod by depth in July, when the EU bottom trawl survey takes place. Most of shrimp is distributed in areas deeper than 140 fathoms depth, while age 1 cod congregates in the area with less than 140 fathoms depth. However, percentage of age 1 cod occurring in deeper areas has been around 10% when recruitment was abundant and almost null since 1995 to 2009, years with very poor recruitment (Figure 3). When abundant cod year-classes occurred, that percentage had an annual variation not linked to abundance and exceeding 10% some years. The fishing shrimp fleet operated outside the exclusion zone, being current visitors of strata between 140 and 200 fathoms (Kulka and Power 1996, Parsons *et al.* 1998, Skúladóttir and Nicolajsen 2002), where they could coincide with small cod.

A key issue in our analysis is to determine if the shrimp fishing fleet have the capacity to decimate a complete cod cohort at age 1. It should be done before July, because it was at that time when the UE bottom trawl survey observed weak or almost null cod recruitment. With age 1 cod weighting 35 g as a mean in July, and a moderate abundant cod year-class of 9 million fish at age 1, such as those for 2005 and 2006 (González-Troncoso and Vázquez 2011), a moderate cohort would weigh 315 tons at that time; but this is an upper figure because it is referred to July, at the end of more than 12 months period the fry was in the area and just before the recruitment weakness observation was done; a catch of roughly 150 tons along those 12 months would be equivalent to the 315 tons in July. Distribution of 150 tons of cod among 30.000 tons of shrimp catch would represent around 5 kg per ton, and even ten times more: 50 kg per ton, for vessels fishing between 140 and 200 fathoms depth, the only area where the fleet and young cod coincide. We concluded that it is unlikely that observers on board did not detect such by-catch if it occurred; instead, they detected some cod by-catch, but not enough to justify the spoil of an incoming cohort.

According to Icelandic report (Skúladóttir 2005), by-catch of American plaice occurred in 1999-2002 while cod only in 1999. American plaice had a similar distribution than juvenile cod, but it was no so restricted to shallowest strata; its abundance was less than cod, in general, however its by-catch was 40 times higher. Figure 4 illustrates abundance of juvenile cod and place; precise comparison in years 1999-2002 is not possible due to almost absolute lack of catches. Dominance of place by-catch on cod could be an indicator of cod escapement through cod-end meshes, which is easier for a fusiform body than for a flatfish, and consequently, also an indicator of escapement mortality: the mortality produced after damage suffered when fish escapes through narrow cod-end mesh size.

#### *Cod recruitment*

Figure 1 shows the evolution of the abundance of cod at age 1 in the EU survey (González-Troncoso and Vázquez 2011) and the fishing effort in the shrimp fishery. This last index was calculated as a quotient among catch and CPUE data as both reported by Casas (2011). Cod abundance at age 1 in January first is a VPA result, so its value is not only determined by age 1 abundance index in July survey, but by survivors of the same cohort at all later ages. It is related in Figure 1 to the shrimp fishing effort of the year when cod's cohort was age 1, because we understand that main effect of the fishery on young cod occurred at that age. Sudden changes in fishing effort did not occur along the period, so these two variables reflect the situation reasonable well.

The 1992 cohort was the first suffering the shrimp fishery when it was age 1, in 1993; it was the first weak year-class even SSB was not low (Figure 1). The same occurred with next three cohorts, those of 1993-1995, which were also weak while TEP remained noticeable. These four year-classes remain below main sequence in a stock-recruitment plot (Figure 5).

Recruitment of Flemish Cap cod has been quite irregular (Rice and Evans 1986, Vázquez 1991), but a low recruitment period of 13 consecutive years had never been observed. It is true that cod spawning biomass was at its lowest levels in years 1996-2004, but even a low SSB is able to produce higher recruitment than those observed as it finally occurred in 2004 onwards (Figure 5). Cod can be considered a leading species in the Flemish Cap ecosystem, taking into account its large biomass and its apical predator character. It means that cod is well adapted to survive in that zone with the natural variability of the environment.

### *Redfish*

Figure 6 shows the abundance of juvenile redfish in July, when the EU bottom-trawl survey took place. Modal length of this group is 11-14 cm, which mostly corresponds to age 3 (Saborido-Rey 1995). The scarce juvenile redfish in the 1994-2000 period indicate that the 1991-1997 year-classes were weak or they were decimated when age 2 (years 1993-1999). Like in the case for cod, the first redfish year-class suffering the shrimp fishery at age 2 was the first weak cohort. The occurrence of abundant juvenile redfish in 1993 didn't result in any increase of the adult stock: redfish, having less pressure from cod predation, suffered the by-catch of the shrimp fishery, particularly in 1993, when sorting grates had not been introduced yet. Figure 6 also indicates that the distribution of an abundant incoming redfish year-class survive in the shallowest area (less than 140 fathoms depth) three years before it could be possible in the deepest one, where the shrimp fishery took place (more than 140 fathoms depth).

The occurrence of abundant juvenile redfish in 2001 and 2002 was produced by the strong 1999 year-class which was the highest contributor to the biomass peak in 2006 (Vázquez 2012). Abundance of juvenile had been also observed in 1992 (the 1989 year-class: Saborido-Rey 1995), 1993 and 1994, but they have not contributed to any increase of the adult stock; it seems to indicate that a change in recruitment pattern occurred in 2000, the intermediate year. As in the case of cod, redfish recruitment had been quite irregular, and one of their main conditioning factors for survival has been cod predation. The 1999 year-class should have been quite abundant to survive in spite of by-catch in the shrimp fishery, even it didn't suffer cod predation.

### **Discussion**

Success of any annual recruitment of marine fish is the result of an abundant spawning and an adequate environment. Among relevant environment factors contributing to the recruitment process are the oceanographic conditions and currents, the occurrence and type of predators and, among other local circumstances, fishing activities. During the 13 years period when cod recruitment failed, an intense trawling fishery with small mesh size cod-end took place. The gears were provided with sorting grates that prevented the catch of large fish, but not fry. An expected negative effect of these gears on cod is the by-catch of small size cod, or even mortality produced to small fish crossing a small mesh size cod-end: escape mortality. Such fishery may be understood as a new component of the environment the cod supported.

Change is the norm in the ecosystem. That is the reason of the high dispersion of data from any stock-recruitment (S-R) theoretical relationship; however, such deviations around a predicted value do not invalidate our perception that such relationship exists, as a conceptual principle. However, although we have not a scale to quantify changes in the ecosystem, there should be a limit in change that implies that the current S/R relationship is out of functioning, particularly if the change occurs along several consecutive years. The question in those cases is not the  $r^2$  coefficient being high or low but the very effectiveness of such S/R relationship. Once again, there is not criterion to determine in what cases an S/R relationship is inappropriate and what years might be considered outliers. Anyway, such situations indicate that new factors are involved and are not considered.

Very deep changes occurred in the Flemish Cap ecosystem in the 13 years period from 1993 to 2005 in comparison with years before and after. Most clear changes were the cod and American plaice stocks collapse, a quick increase of the shrimp biomass, a later increase of redfish biomass, and a shift of Greenland halibut to shallower areas. These changes were partially reverted with the increase of the cod stock, the decrease in redfish stock, and the deep reduction of shrimp stock. These species, even they are the most visible reference, are only a small part of the whole system and, because of large variation in their abundance, they should also produce changes in the whole ecosystem, particularly on the pelagic region, dominated by shrimp and small redfish. The presence of a large fleet with an small mesh size cod-end never observed before was also characteristic of that period, and it should be considered an additional environment factor for species recruitment. If these changes are signals of a transitory change in the ecosystem is the matter of discussion, as well in what extent these change in abundance affected S/R parameters: if

they were modified, most recent recruitments should be considered episodic, outside the regular regime of new recruitment occurrences.

Changes in the Flemish Cap stocks were more complex than a simple replacement among dominant species. When cod collapsed in 1993 and the shrimp fishery started, age 5 shrimp was dominant in commercial catches (Parsons *et al.* 1998), which indicates that the 1988 cohort had survived much more than any previously observed. If the shrimp stock had been maintained in low levels by cod predation, this outbreak of shrimp was probably the result of a very abundant spawning, but also of reduced cod predation. The success of the 1988 shrimp year-class opened the scenario for the shrimp fishery in 1993. If that fishery really impeded cod recruitment, the maintenance of a shrimp resource would be favoured by its fishery; this would be a feed-back mechanism: the fishery maintained the resource by impeding cod predation on shrimp; when the intensity of the shrimp fishery was reduced the cod stock recovered and the shrimp stock declined.

Being shrimp and redfish main prey items of cod, the situation in 1993 and 1994 was quite favourable for cod stock development because these two species were abundant; however such opportunity was not seized. Cod recruitment of the 1992-1995 cohorts was below expected even spawning stock was still in medium size (Figure 5), and the shrimp fishery appears as a possible candidate to explain the failure in cod recruitment of those four cohorts. It is true that the fleet fishing for cod caught small size fish, contributing to stock depletion, but decreasing cod abundance observed in the surveys implied fishing mortalities higher than the ones estimated by VPA (Vázquez and Cerviño 1998).

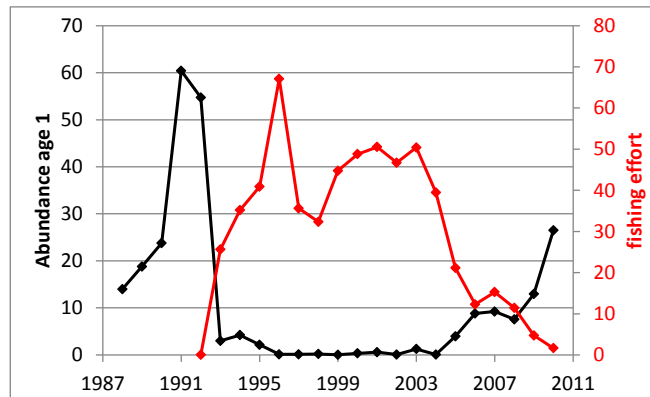
Cod stock was at a very low level after 1995, so any abundant recruitment should not be expected, but even in that period, recruitment could be reduced by the shrimp fishery. Survivor of age 1 cod improved in 2005-2008 when the shrimp fleet reduced its presence and became much higher later, when the fishery ceased.

Weak recruitment of cod cannot be attributed to competition with shrimp or redfish, such as cod being displaced by the intrusion of any or both of this species. It is unlikely that a prey displaces a predator, and besides, both redfish and shrimp return to their previous lower abundance when cod recovered; also Greenland halibut retracted to its common deep zone when cod recovered. In other words, when cod survived age 1 then survive to older ages. Cod survival in 2005 onwards was possible with an environment dominated by shrimp and redfish.

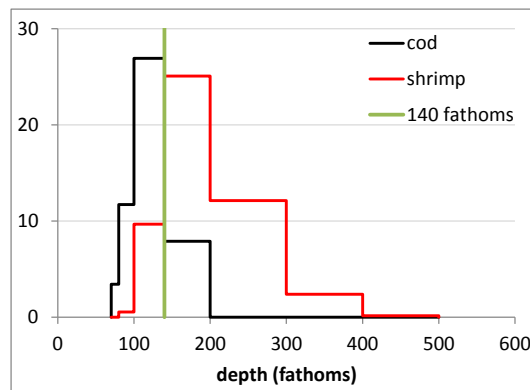
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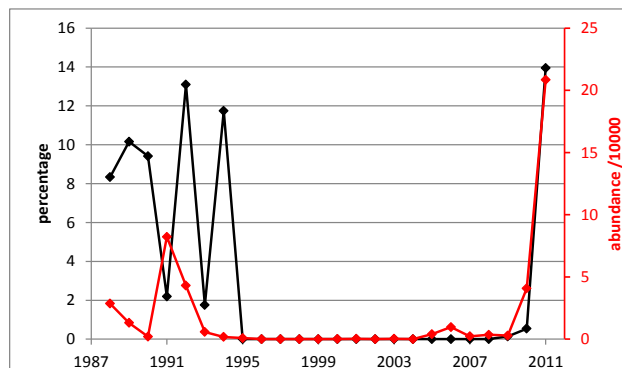
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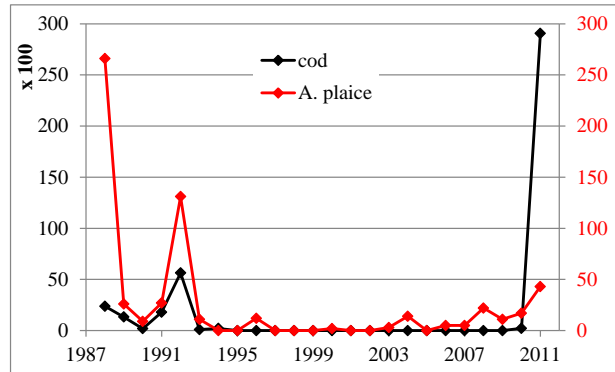
**Figure 1** – Abundance of cod at age 1 (millions) (González-Troncoso and Vázquez 2011) and fishing effort in the shrimp fishery (index: catch/CPUE) (Casas 2011).



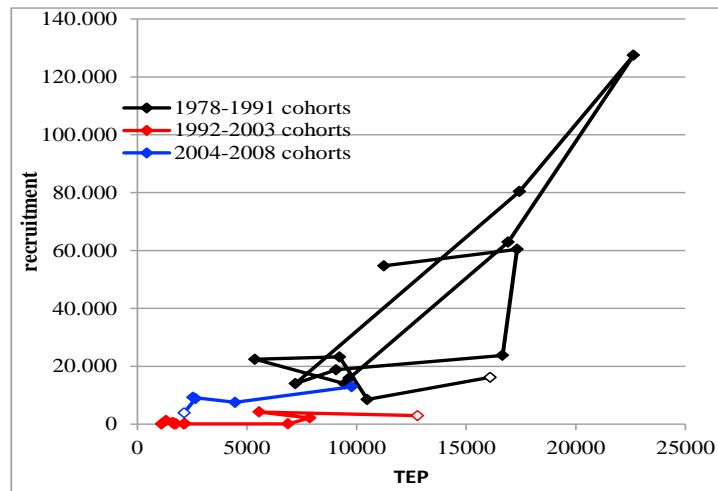
**Figure 2** – Percentage distribution of the cod abundance (age 1 dominates) and shrimp total biomass by depth ranges in the 1993-2005 period according to the July EU bottom trawl survey. The 140 fathoms depth limit is indicated with a green line.



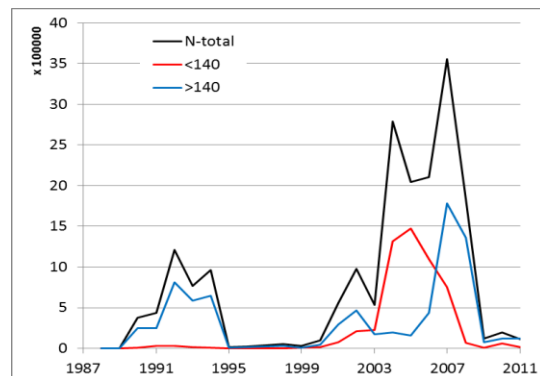
**Figure 3** – Less than 24 cm length (roughly age 1) cod according to the EU survey in July: total abundance and percentage of individuals distributed in areas deeper than 140 fathoms.



**Figure 4** – Abundance of juvenile cod (less than 24 cm length) and juvenile American plaice (less than 20 cm length) in strata deeper than 140 fathoms depth, according to EU bottom trawl survey results.



**Figure 5** – Stock-recruitment relationship. Stock measures as Total Egg Production (TEP) and recruitment measured at age 1. Data from Pérez-Rodríguez *et al.* (2011) updated with González-Troncoso and Vázquez (2011) results. The beginning of each series is pointed out with a white square.



**Figure 6** – Abundance of juvenile redfish in the Flemish Cap EU survey: total in the area and in less/more than 140 fathoms depth.