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Stock Annex: Boarfish (*Capros aper*) in subareas 6–8 (Celtic Seas, English Channel, and Bay of Biscay)

Stock specific documentation of standard assessment procedures used by ICES.

Stock: Boarfish

Working Group: Working Group on Widely Distributed Stocks (WGWIDE)

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A. General

A.1. Stock definition

The boarfish (*Capros aper*, Linnaeus) is a deep bodied, laterally compressed, pelagic shoaling species distributed from Norway to Senegal, including the Mediterranean, Azores, Canaries, Madeira and Great Meteor Seamount (Blanchard and Vandermeirsch, 2005). An analysis of IBTS data suggests a continuity of distribution spanning Subareas 4, 6, 7 and 8 (Figure A.1.1). Isolated small occurrences appear in the North Sea in some years and an isolated landing in area 5.b 2 indicates spill-over into these areas (Figure A.1.2). A hiatus in distribution is apparent between Divisions 8.c and 9.a south. Boarfish are considered very rare in northern Portuguese waters but are abundant further south (Cardador and Chaves, 2010) however it is unclear if this suggested hiatus represents a true stock separation. Based on these data, a single stock is considered to exist in Subareas 4, 5, 6, 7, 8 and the northern part of 9.a. This distribution is broader than the current EC TAC area: 6, 7, and 8.

A dedicated study on the genetic population structure of boarfish within the Northeast Atlantic and Mediterranean Sea commenced in October 2013 in order to resolve outstanding questions regarding the stock structure of boarfish and the suitability of assessment data. Novel genetic methods utilising next generation sequencing were developed to identify species-specific polymorphic microsatellite loci and to screen samples following a genotyping-by-sequencing approach (Farrell *et al.*, 2015; Farrell *et al.*, submitted; Vartia et al., 2016). Results (Farrell *et al.*, submitted) based on the genotyping of 839 samples at forty microsatellite loci indicated strong population structure across the distribution range of boarfish with 7-8 genetic populations identified (Figure A.1.3).

The eastern Mediterranean (*MED*) samples comprised a single population and were distinct from all other samples. Similarly the Azorean (*AZA*), Western Saharan (*MOR*) and Alboran (*ALM*) samples were distinct from all others. Of particular relevance to the assessment and management of the boarfish fishery is the identification and delineation of the population structure between southern Portuguese waters (*PTN2B-PTS*) and waters to the geographic north. A distinct and temporally stable mixing zone was evident in the waters around Cabo da Roca. The *PTN2A* sample appeared to be significantly different from all other samples however this sample was relatively small and was considered to represent a mixed sample rather than a true population.

No significant spatial or temporal population structure was found within the samples comprising the *NEA* population (Figure A.1.3). A statistically significant but comparatively low level of genetic differentiation was found between this population and the northern Spanish shelf/northern Portuguese samples (*NSA-PTN1*). However a high level of migration was revealed between these two populations and no barriers to gene flow were detected between them. Therefore for the purposes of assessment and management these areas can be considered as one unit.

Whilst the current assessment and management area constitutes the majority of the most northern population it should be extended into Northern Portuguese waters and repeated genetic monitoring of the stock in this region should be conducted to ensure the validity of this delineation. Based on analyses of IBTS data (see ICES, 2013) the biomass in this area is suspected to be small relative to the overall biomass in the TAC area.

A.2. Fishery

Previous to the development of the fishery, boarfish was a discarded bycatch in pelagic fisheries for mackerel in Subareas 7 and 8. A study by Borges *et al*. (2008) found that boarfish may account for as much as 5% of the total catch of Dutch pelagic freezer trawlers.

The first targeting of boarfish began in 2001. Landings fluctuated between 100 and 700 t per year (Table A.2.1). In 2006 the landings began to increase considerably, and cumulative landings since 2001 are now in excess of 580 000 t. The expansion of the fishery in the mid-2000s was associated with developments in the pumping technology for boarfish catches. These changes made it easier to pump boarfish ashore. The fishery targets dense shoals of boarfish. Catches are generally free from bycatch from September to February. From March onwards a bycatch of mackerel is found in the catches. Information on the bycatch of other species in the boarfish fishery is sparse, though thought to be minimal. The fishery uses typical pelagic pair trawl nets with mesh sizes ranging from of 32 to 54 mm. Preliminary information suggests that only the smallest boarfish escape this gear. From 2001 to 2006 only Ireland participated in the fishery. In 2007 UK-Scotland also participated, landing less than 750 t. In all years the vast majority of catches have come from Subarea 7.j and 7.h (Figure A.2.1 and Table A.2.2).

Since 2013, the TAC has not been caught. This is thought to be partly due to lesser availability of fishable aggregations, and partly due to economic and administrative reasons. According to the industry, fishable aggregations were not always available during the fishery. The season coincides with the mackerel and horse mackerel fisheries. Also, the Irish quota was allocated to individual boats, with non-specialist vessels receiving allocations that were not used. In 2016 Q3 and Q4 individual boat quotas have been removed in Ireland, in an attempt to allow the specialist 6-7 vessels to target the stock without 7(what the industry considers to be unnecessary) constraints. In 2015 there was a significant decrease in catches with 17 766 t reported, well under the TAC of 53 296 t. Ireland continued to be the main participant in the fishery (16 325 t).

A TAC was set for this species for the first time in 2011, covering ICES Subareas 6, 7 and 8. This TAC was set at 33 000 t. Before 2010, the fishery was unregulated. In October 2010, the European Commission notified national authorities that under the terms of Annex 1 of Regulation 850/1998, industrial fisheries for this species should not proceed with mesh sizes of less than 100 mm. In 2011, the European Parliament voted to change Regulation 850/1998 to allow fishing using mesh sizes ranging from 32 to 54 mm.

In 2011, 31 295 t were caught. Ireland continued to be the main participant (20 685 t), with Denmark taking 7 797 t and Scotland 2 813 t. Due to the 2010 net regulation and extended negotiations over quota allocations the Irish target fishery commenced in late Q3 and as such landings in Q1 and Q2 may be considered as bycatch. Twenty-nine Irish registered fishing vessels reported landings of boarfish. Only 2 Scottish vessels reported landings of boarfish, which were in Q3 and Q4. The number of Danish vessels participating in the fishery is unknown.

For 2012, ICES advised that catches of boarfish should not increase, based on precautionary considerations. As supporting information, ICES noted that it would be cautious that landings did not increase above 82 000 t, the average over the period 2008-2010, during which the stock did not appear to be overexploited. In 2012 the TAC was set at 82 000 t by the Council of the European Union.

In August 2012 the executive committee of the Pelagic RAC approved a long term management plan for boarfish. The management plan has not yet been evaluated by ICES. However, in 2013, ICES advised that Tier 1 of the plan can be considered precautionary if a Category 1 assessment is available.

For 2013, ICES advised that catches of boarfish should not be more than 82,000 t. This was based on applying a harvest ratio of 12.2% ($F_{0.1}$, as an F_{msy} proxy). For 2013, the TAC was set at 82 000 t by the Council of the European Union.

For 2014, ICES advised that, based on F_{MSY} (0.23), catches of boarfish should not be more than 133 957t. ICES also stated that if discard rates do not change from the average of the last ten years this implies landings of 127 509t. For 2014 the TAC was set at 127 509t by the Council of the European Union. The assessment was considered to be category 1 conducted using a Baysean-Schaefer surplus production model.

The advice given for 2015 was based on the data-limited approach and stated that catch should be no more than 53 296 t. The assessment conducted was now a category 3 assessment indicative of trends using an exploratory Bayesian Schaefer surplus production model.

The 2016 advice was based on the precautionary approach and stated that catches in 2016 should be no more than 42 637 t. ICES considers the current basis for the advice on this stock to be an interim measure prior to development of an age-based assessment.

Since 2011, there has been a provision for by-catch of boarfish (also whiting, haddock and mackerel) to be taken from the western and North Sea horse mackerel EC quotas. These provisions are shown in the text table below. The effect of this is that a quantity not exceeding the value indicated of these 4 species combined may be landed legally and subtracted from quotas for horse mackerel.

Year	North Sea (t)	Western (t)
2011	2031	7779
2012	2148	7829
2013	1702	7799
2014	1392	5736
2015	583	4202

2016	760	5443

A.3. Ecosystem aspects

The ecological role and significance of boarfish in the NE Atlantic is largely unknown. However, in the south-east North Atlantic, in Portuguese waters, they are considered to have an important position in the marine food web (Lopes *et al.*, 2006). The diet has been investigated in the eastern Mediterranean, Portuguese waters and at Great Meteor Seamount and consists primarily of copepods, specifically *Calanus helgolandicus*, with some mysid shrimp and euphausiids (MacPherson, 1979; Fock *et al.*, 2002; Lopes *et al.*, 2006). This contrasted with the morphologically similar species, the slender snipefish, *Macroramphosus gracilis* and the longspine snipefish, *M. scolopax*, whose diet comprised *Temora* spp., copepods and mysid shrimps, respectively (Lopes *et al.*, 2006). Despite the obvious potential for these species to feed on fish eggs and larvae, there was no evidence to support this conclusion in Portuguese waters and they were not considered predators of commercial fishes and thus their increase in abundance was unlikely to affect recruitment of commercial fish species (Lopes *et al.*, 2006). If the NE Atlantic population of boarfish is sufficiently large then there exists the possibility of competition for food with other widely distributed planktivorous species.

Both seasonal and diurnal variations were observed in the diet of boarfish in all three regions. In the eastern Mediterranean and Portuguese waters, mysids become an important component of the diet in autumn, which correlates with their increased abundance in these regions at this time (MacPherson, 1979; Lopes *et al*., 2006). Fock *et al*. (2002) found that boarfish at Great Meteor Seamount fed mainly on copepods and euphausiids diurnally and on decapods nocturnally, indicating habitat dependent resource utilisation.

Boarfish appear an unlikely target of predation given their array of strong dorsal and anal fin spines and covering of ctenoid scales. However, there is evidence to suggest that they may be an important component of some species' diets. Most studies have focused in the Azores and few have mentioned the NE Atlantic, probably due to the relatively low abundance in the region until recent years. In the Azores, boarfish was found to be one of the most important prey items for tope (*Galeorhinus galeus*), thornback ray (*Raja clavata*), conger eel (*Conger conger*), forkbeard (*Phycis phycis*), bigeye tuna (*Thunnus obesus*), yellowmouth barracuda (*Sphyraena viridensis*), swordfish (*Xiphias gladius*), blackspot seabream (*Pagellus bogaraveo)*, axillary seabream (*Pagellus acarne*) and blacktail comber (*Serranus atricauda*) (Clarke *et al*., 1995; Morato *et al*., 1999; Morato *et al*., 2000; Morato *et al*., 2001; Barreiros *et al*., 2002; Morato *et al*., 2003; Arrizabalaga *et al*., 2008). Many of these species also occur in the NE Atlantic shelf waters although it is unknown whether boarfish represent a significant component of the diet in this region.

In the NE Atlantic boarfish have not previously been recorded in the diets of tope or thornback ray (Holden and Tucker, 1974; Ellis *et al*., 1996,). However, this does not prove that they are currently not a prey item. A study of conger eel diet in Irish waters from 1998-1999 failed to find boarfish in the diet (O'Sullivan *et al*., 2004). However, in Portuguese waters a recent study has found boarfish to be the most numerous species in the diet of conger eels (Xavier *et al*., 2010). It has been suggested that boarfish are an important component of the diet of hake (*Merluccius merluccius*), as they are sometimes caught together. However, a recent study of the diet of hake in the

Celtic Sea and Bay of Biscay did not report any boarfish in the stomachs of hake caught during the 2001 EVHOE survey (Mahe *et al.*, 2007).

The conspicuous presence of boarfish in the diet of so many fish species in the Azores is perhaps more related to the lack of other available food sources than to the palatability of boarfish themselves. Given the large abundance in NE Atlantic shelf waters it is likely that they would have been recorded more frequently if they were a significant and important prey item.

Boarfish are also an important component of the diet a number of sea birds in the Azores, most notably the common tern (*Sterna hirundo*) and Cory's shearwater (*Calonectris diomedea*) (Granadeiro *et al*., 1998; Granadeiro *et al*., 2002). This is surprising given that in the Mediterranean discarded boarfish were rejected by seabirds whereas in the Azores they were actively preyed on (Oro and Ruiz, 1997). Cory's shearwaters are capable of diving up to 15 m whilst the common tern is a plunge-diver and may only reach 2-3 m. It is therefore surprising that boarfish are such a significant component of their diet given that it is generally considered a deeper water fish. In the Azores boarfish shoals are sometimes driven to the surface by horse mackerel and barracuda where they are also attacked by diving sea birds (J. Hart, CW Azores, pers. comm.). Anecdotal reports from the Irish fishery indicate that boarfish are rarely found in waters shallower than 40 m. This may suggest that they are outside the range of shearwaters and gannets, the latter having a mean diving depth of 19.7±7.5 m (Brierley and Fernandes, 2001). However, the upper depth range of boarfish is within maximum diving depth recorded for auks (50 m) as recorded by Barrett and Furness (1990). Given their frequency in the diets of marine and bird life in the Azores, boarfish appear to be an important component of the marine ecosystem in that region. There is currently insufficient evidence to draw similar conclusions in the NE Atlantic.

The length-frequency distribution of boarfish may be important to consider. IBTS data shows an increase in mean total length with latitude and perhaps the smaller boarfish in the southern regions are more easily preyed upon. Length-frequency data of boarfish from stomach contents studies of both fish and sea birds in the Azores indicate that the boarfish found are generally < 10 cm (Granadeiro *et al*., 1998; Granadeiro *et al*., 2002).

B. Data

B.1. Historical

In the Northeast Atlantic region boarfish have historically been characterised by apparent fluctuations in abundance. A literature review of historical sources suggests peaks in abundance in the following periods:

- 1840s to 1880s
- 1950s
- Mid-1980s to 1990s

From the 1840s to 1880s large abundances were periodically observed in the western English Channel (Day, 1880–1884; Couch, 1844; Cunningham, 1888). Gatcombe, writing in 1879, stated that they had become an extreme nuisance in trawl fisheries. In the early 1900s boarfish were noted for their sporadic occurrence in the English Channel and were scarce or absent for many years in the area around Plymouth where they had previously been abundant (Cooper, 1952). In the mid-1900s there was another apparent increase in abundance, which Cooper (1952) hypothesised was caused by a 'submarine eagre' that swept shoals of boarfish from submarine canyons in the southern edge of the Celtic Sea onto the continental shelf. It should be noted that these apparent peaks in abundance occurred during periods when fisheries and sampling were less widespread that the present day. The primary distribution area of boarfish, along the shelf edge, was rarely, if ever sampled during this time. Therefore, the observations of peaks in abundance are only related to inshore areas. There is no evidence that boarfish were not also abundant offshore throughout these periods.

Increases in abundance were observed in the Bay of Biscay, Galician continental shelf waters and the Celtic Sea between the 1980s and 2000 (Farina *et al.*, 1997; Pinnegar *et al.*, 2002; Blanchard and Vandermeirsch, 2005). The relative abundance in the Bay of Biscay increased from 0.3% in 1973 to 16% in 2000 resulting in boarfish becoming one of the dominant species in the fish community in this region (Blanchard and Vandermeirsch, 2005).

Based on the above information the external reviewers in 2012 noted the possibility that boarfish was a deep-water species that had undergone a shoreward range extension onto the shelf in the late 1980's. They suggested that this was consistent with the large proportion of older fish in the stock and stated "If the increased abundance during the early 1990s was due to increasing recruitment on the continental shelf, then it seems unlikely that so many old fish would be observed". On this basis the reviewers made two recommendations: one was to extend the acoustic survey tracks into deeper water off shelf waters. This is already part of the standard protocol of the acoustic survey and since 2011 all westward transects extend until no boarfish shoals have been recorded for 15 nm (O'Donnell *et al.*, 2013). No boarfish shoals have been detected off the shelf from 2011 to 2013 and anecdotal evidence from the fishing industry also suggests that boarfish is a shelf species and does not occur off the shelf. The second recommendation was to use an integrated analysis model capable of simultaneously examining the age composition data, the catch time series, and the survey index time series to compare the movement hypothesis to the increased recruitment on the shelf hypothesis. Whilst it would be an interesting exercise this second point is deemed unnecessary as there is no evidence for boarfish being a deep water off-shelf species. It is also unclear why the reviewers considered that the increasing abundance during the early 1990's could not be due to increased recruitment on the shelf as these fish would now be in the 20+ age group and thus increased recruitment on the shelf could be the source of these fish.

Preliminary GAM modelling of the IBTS data also lends supports to the fact that boarfish are a shelf species. There is no evidence of a spread of boarfish from oceanic waters onto the shelf. Furthermore the GAM models highlight where the theories such as this likely arose. The periodic increases in abundance in the western English Channel may simply have been an incursion of boarfish from shelf waters. Such incursions are evident from the GAM model in 1999 and 2002 (Figure B.4.3). The reasons for these incursions are unknown but may be related to annual hydrographic conditions. They do not occur in all years and as such likely result in a perceived local increase in abundance.

B.2. Commercial catch

For years prior to 2011, a proxy catch-at-age matrix was constructed using the age-length key from a combination of fisheries-independent and dependent data (Table B.2.1). Length-frequencies of commercial catches are available from 2007 onwards (Table B.2.2). Ageing is based on the method that has been validated for ages 0-7 by

Hüssy *et al*. (2012). These age samples were collected mainly during 2010. The age range is similar to the published growth information presented by White *et al*. (2011).

ALKs were applied to commercial length-frequency data available for the years 2007-2015 to produce a proxy catch numbers-at-age (Figure B.2.1 and Table B.2.3). It can be seen that many older fish are still present in catches, with a high proportion in the plus group (15+) each year. The main ages in recent years are 7,8,9 and 10. There is poor cohort tracking with the same ages dominant each year. In 2015 a high proportion of age 2 boarfish can been seen. These were not picked up at age 1 in the 2014 fishery.

Since 2011, catch number-at-age were prepared for Irish, Danish and Scottish landings using the ALKs in table B.2.1. The same ALK was also applied to the IBTS data (Table B.4.1) There were a number of unsampled metiers and allocations were made appropriately. Ireland is the main participant in the fishery and therefore collects the most samples. Only Irish collected samples were deemed reliable enough for length frequency and length weight analyses. The sampling intensity of commercial catches is presented in Table B.2.4.

B.3. Biological data

The boarfish are classified in the order Perciformes. They are a small (max 23cm TL), thin, laterally compressed pelagic shoaling species. They have a red to orange colour and are sexually dimorphic. They are widely distributed at depths from the surface to 600m.

Kaya and Özaydin (1995) conducted a study on boarfish in the Mediterranean (Turkish waters) and estimated a maximum age of 4 years and age at maturity 2 years. These results conflicted with the results of White et *al*., (2011) who attained a maximum age of 26 years and age at maturity of 5.25 and 4.6 years for males and females respectively, based on samples from the NE Atlantic. Neither study included a validation of the ageing method used or information on methods used for maturity determination.

In 2010, a biological study of boarfish commenced based on both fishery dependent and independent samples (n=3376). Samples were collected from ICES Divisions 6.a, 7.b, 7.h, 7.j and 8.a from September 2009 to December 2010 (excluding August). TL ranged from 26 to 180 mm, with one additional fish reaching 233mm. Based on 232 of these samples Hüssy *et al*. (2012) carried out an age validation study. Subsequently an ALK was produced and used for preliminary growth investigations. Farrell *et al*. (2012) also investigated the reproductive biology of the species based on 2015 of these samples. From these 2 studies the following biological background information has been gathered:

Boarfish reach a maximum age of 31 years. An ALK based on 407 age readings, from 0 to 28 years, of males and females combined was applied to a combination of length-only fishery independent and dependant data (n=1633). The von Bertalanffy growth curve was constructed based on the typical parameterisation of the von Bertalanffy growth equation (Table B.3.1 and Figure B.3.1):

$TL_{age} = L_{inf}*(1-exp(-K*(age-t0)))$

The growth curve and ALK were used to investigate length-at-age, age distribution and maturity at age/length. Growth is fastest in the first 2-3 years then levels off and energy is allocated to other processes such as reproduction. The age distribution (Figure B.3.2) is uni-modal with a peak at 7 years (corresponding to approx. 12 cm).

Length classes were continuous up to 18 cm after which only one individual fish was present in the 23 cm length class. The abundance of females peaked in the 12 cm length class, while the highest number of males was observed in the 11 cm length class.

The length and age at 50 % maturity were 9.7 cm TL and 3.5 years, respectively (Figure B.3.3). The reproductive cycle commenced between February and April and finished between October and December, when fish entered the resting phase. Oocyte development was asynchronous and all oocytes stages were present concurrently in spawning fish. There was no hiatus between pre-vitellogenic and vitellogenic oocytes. Spawning occurred in June and July with a notable peak in July (Figure B.3.4). No samples were available from August. The boarfish is a batch spawner. In September there was a generalised atresia and remaining oocytes were observed to be resorbed. Aquarium observations of spawning fish indicated that males spawned daily whilst females spawned every 2–3 days. In the controlled aquarium environment spawning lasted approximately 9 months. All indications are that the boarfish has indeterminate fecundity.

B.4. Surveys

B.4.1. IBTS

The western IBTS data and CEFAS English Celtic Sea Groundfish Survey were investigated for their utility as abundance indices. An index of abundance was constructed from the following surveys:

- EVHOE, French Celtic Sea and Biscay Survey, (Q4) 1997 to 2015
- IGFS, Irish Groundfish Survey, (Q4) 2003 to 2015
- WCSGFS, West of Scotland, (Q1 and Q4) 1986 to 2015 (no Q4 survey in 2010)
- SPPGFS, Spanish Porcupine Bank Survey, (Q3) 2001 to 2015
- SPNGFS, Spanish North Coast Survey, (Q3/Q4) 1991 to 2015
- ECSGFS, CEFAS English Celtic Sea Groundfish Survey, (Q4) 1982 to 2003

The time series for each survey with the exception of the CEFAS groundfish survey were updated and used in the 2016 exploratory assessment.

From the IBTS data CPUE was computed as the number of boarfish per 30 minute haul. The abundance of boarfish per year per ICES Rectangle was then calculated by summing the boarfish in a given rectangle and dividing by the total number of hauls in that rectangle. The complete area was sampled from 2003–2015.

The shoaling nature of the species results in occasional large hauls. This is evidenced in the 2014 data which appears to indicate a peak in abundance. Therefore, the number of hauls sampled was compared with the number of hauls in which boarfish were caught (Figure B.4.1). The number of hauls containing boarfish increased slightly in 2004 and since then has levelled off while the total number of hauls shows greater fluctuations.

The IBTS appears to give a relative index of abundance, with good resolution between periods of high and low abundance. The main centres of abundance in the survey (Figure A.1.1 and A.1.2) correspond to the main fishing grounds (Figure A.2.1). Figure B.4.2 shows the signal in abundance, increasing in the 1990s and reached a small peak in 2000. A decrease can be seen until another peak is reached in

2008. A fluctuating trend can be seen in more recent years with 2015 being the highest number of boarfish in the time series. Similar trends have been reported by (Farina *et al.*, 1997; Pinnegar *et al.*, 2002; Blanchard and Vandermeirsch, 2005). These authors used IBTS and other trawl survey data to show the increased abundance of the species in this area.

Anecdotal evidence from the fisheries indicates that from September to March boarfish are found on the shelf in dense shoals often in close proximity to the bottom. These shoals are particularly abundant around the banks in ICES Division 7.j in the Celtic Sea. Therefore boarfish are likely effectively sampled by the demersal gear of the IBTS despite being a pelagic species. However the shoaling nature of the species results in occasional large hauls.

The preliminary results of a GAM modelling project of the IBTS data up to 2011, including the Portuguese data, are presented to illustrate the temporal and spatial distribution of boarfish in the ICES Area. A GAM based on the probability of occurrence of boarfish in a surveyed area was developed based on presence absence data from over 13,000 individual fishing hauls in 7 groundfish surveys over a 30 year period (Figures B.4.3 and B.4.4). The GAM models clearly illustrate that boarfish are distributed on the shelf and have a wide area of distribution. In recent years (2003 onwards) there has been an increase in the northerly distribution of boarfish. The depth distribution profile of boarfish within these hauls was also calculated, which shows that boarfish have a depth distribution preference of approximately 100–300m and the probability of occurrence in deeper water decreases sharply (Figure B.4.3). The proportion of each region over which boarfish were distributed per year was also investigated and shows an increasing trend over time (Figure B.4.4). This indicates that the area of spread of boarfish within the surveyed area has increased during the period.

For subsequent surplus production modelling, biomass indices were extracted from each of the IBTS surveys using a delta-lognormal model (Stefánsson, 1996). Many of the surveys exhibited a large proportion of zero tows (Figure B.4.7) with occasionally very large tows, hence the decision to explicitly model the probability of a non-zero tow and the mean of the positive tows. A delta-lognormal fit comprises fitting two generalized linear models (GLMs). The first model (binomial GLM) is used to obtain the proportion of non-zero tows and is fit to the data coded as 1 or 0 if the tow contained a positive or zero CPUE, respectively. The second model is fit to the positive only CPUE data using a lognormal GLM. Both GLMs were fit using ICES rectangle and year as explanatory factor variables. Where the number of tows per rectangle was less than 5 over the entire series, they are grouped into an “others” rectangle. An index per rectangle and year is constructed, according to Stefánsson (1996), by the product of the estimated probability of a positive tow times the mean of the positive tows. The station indices are aggregated by taking estimated average across all rectangles within a year. To propagate the uncertainty, all survey index analyses were conducted in a Bayesian framework using MCMC sampling in WinBUGS (Spiegelhalter *et al.*, 2004).

B.4.2. Acoustic Survey

The Boarfish Acoustic Survey (BFAS) series was initiated in July 2011 and is now in its sixth year. The 2011 survey, the first in the series, was conducted by Marine Institute scientists aboard the Irish pelagic RSW vessel FV ‘’Felucca’’ with a towed body system with a calibrated 38 kHz split beam transducer (O’Donnell *et al.*, 2012a). The survey was designed to extend the Malin Shelf Herring Acoustic Survey (MSHAS) conducted aboard the RV “Celtic Explorer” to the south, which increased the range of continuous coverage from approximately 58.5°N to 47.5°N (Figure B.4.2.1). The 2011 BFAS operated on a 24 hour basis as it was an exploratory survey and the distribution and behaviour of boarfish during this time of year were unknown prior to the survey. The combined surveys resulted in a continuous coverage over 33 days, 90 000 nmi^2 and transect coverage over 4 500 nmi. 24 trawls were sampled and lengths, weights, maturity data, and otoliths of boarfish were collected. In 2011 the total biomass of boarfish in the survey area was estimated at 670 176 t. Biomass estimates of boarfish biomass by year are presented in Table B.4.2 and the spatial distribution of the echotraces attributed to boarfish in each year can be seen in Figure B.4.2.1. Significant fluctuations can be seen between years.

The text table below explains the categories used to report estimated biomass from all BFASs. Following standard acoustic survey protocols the Total Biomass estimate includes the '*Definitely*', '*Probably*' and '*Mixture*' categories but excludes the '*Possibly*' category.

Category	Definition
Definite	"Definitely" echotraces were identified on the basis of captures of boarfish from the fishing trawls which were sampled directly. Based on the directly sampled schools echotraces were also characterised as definitely boarfish which appeared very similar on the echogram i.e. large marks which showed as very high intensity (red), located high in the water column(day) and as strong circular schools.
Probably	"Probably" was attributed to smaller echotraces that had not been fished but which had similar characteristics to "definite" boarfish traces.
Mixture	"Mixture" was attributed to NASC values arising from all fish traces in which boarfish were contained, based on the presence of a proportion of boarfish in the catch or within the nearest trawl haul. Boarfish were often taken during trawling in mixed species layers during the hours of darkness.
Possibly	"Possibly" was attributed to small echotraces outside areas where fishing was carried out, but which had the characteristics of definite boarfish traces.

In 2012 the survey methodology was refined by switching to daylight only (04:00-00:00) surveying. This change in protocol was a result of the observation during the 2011 BFAS that boarfish shoals were observed to break up during the night (00:00-04:00) and could not be acoustically detected or quantified. The 2012 total biomass estimate was 863 446 t (O' Donnell *et al.*, 2012b; Table B.4.4), with the increase partially attributable to the protocol change.

In July 2013 the BFAS series was continued, with the survey being conducted again aboard the FV "Felucca" (O'Donnell *et al.*, 2013). The survey used the same equipment and followed the same protocol as the 2012 survey and the survey track was broadly similar (Figure B.4.2.1). In total 4,295nmi (nautical miles) of cruise track was undertaken by both vessels over 53 transects relating to a total area coverage of 57,020nmi^2. Transect spacing was set at 15nmi for the *Felucca* and 15 and 7.5nmi for the *Explorer* component. Coverage extended in coastal areas from the c.50m contour to the shelf slope (250m). The survey was carried out from 04:00–00:00 each day. In 2013 thirty three hauls were carried out during the survey, 19 of which contained boarfish. A total of 1,074 boarfish echotraces were identified during the survey. Of this 98% were categorised as '*Definitely*' boarfish, 1.6% as '*Probably*' and 0.3% '*Boarfish in a mixture*'. The total estimated biomass of the survey area was 439 890 t (Table B.4.2).

As no species-specific target strength (TS) previously existed for boarfish, an industry funded project was conducted to model boarfish TS. Samples were collected during the 2011 survey and MRI scans were taken of the swim bladders from the observed size range of boarfish. 3D swimbladder dimensions of each fish sample were used as input to a KRM model. An estimated TS-L relationship of -65.98dB was derived based on model calculations. This TS was used in 2012 to produce biomass estimates for the 2012 and 2011 survey. In 2013 this TS was reviewed and revised to -66.2dB (Fässler *et al.*, 2013; O'Donnell, 2013). This new TS (-66.2dB) was applied to the 2013 survey data and retrospectively to the 2012 and 2011 BFAS survey data for use in the boarfish assessment.

The July 2014 BFAS again comprised acoustic and trawl data recorded from the FV "Felucca" and RV "Celtic Explorer". Temporal and spatially coverage were almost identical to 2013 and the revised TS was used in the biomass calculation. Twenty one hauls were carried out during the survey, 11 of which contained boarfish. A total of 3 160 boarfish lengths, 1 102 length/weight measurements and 397 otoliths were collected during the survey. The total estimated biomass was 187 779 t, 57% less than the 2013 BFAS estimate. Of this total estimate 71% were categorised as 'definitely' boarfish, 27% as 'probably' and 1.4% 'boarfish in a mixture'. It should be noted that the higher percentage of '*Probably*' boarfish this year was mainly due to technical difficulties with the trawl gear that prevented sampling of some schools that had all the characteristics of '*Definitely*' boarfish. A full breakdown of school categorisation, abundance and biomass by ICES statistical rectangle is available in O'Donnell and Nolan (2014).

The 2015 BFAS was conducted on board the FV "Felucca" (O Donnell and Nolan 2015). Twenty hauls were carried out by the *Felucca* during the survey, 14 of which contained boarfish. An additional 4 carried out by the *C. Explorer* were used in the analysis. In total, 4,168 lengths and 1,500 length/weight measurements were taken in addition to 695 individual boarfish otoliths collected for aging. The total biomass estimate from this survey was 232 634 t.There was concern that the low estimate in 2014 could have been an outlier and it did cause some problems for the Bayesian assessment model but the 2015 acoustic biomass estimate supports the validity of the 2014 estimate.

In 2015, the 2011 survey data were reworked to exclude the data collected between 00:00 and 04:00. This allowed the inclusion of the 2011 survey estimate in the assessment.

In 2016 this survey was carried out on the RV *Celtic Explorer* and run in conjunction the Malin Shelf herring survey. These surveys are collectively known as the Western European Shelf Pelagic Acoustic Survey (WESPAS). The WESPAS survey in 2016 was carried out over a 42 day period beginning on the 16 June in the north (59°N) and working south to 47°N ending on 30 July. The 2016 estimate of total biomass is 69 690 t and is 70% lower than observed in 2015. Significant annual variation is a feature of the time series although an overall downward trend is evident. No strong evidence exists for removing any of the survey points from the time series.

It should be noted that the survey does not contain the stock fully, given that concentrations of boarfish are likely to be found southward of the survey area as evidenced by both IBTS data and information from the PELACUS survey on the northern Spanish Shelf (Carrera *et al.*, 2013).

C. Assessment: data and method

A number of exploratory assessment runs for boarfish were carried out in 2013.

Model used: Bayesian Schaefer state space surplus production model (BSP) (Meyer and Millar 1999)

Model Options chosen:

- Run priors:
- r ~ U(0.001,2)
- ln K ~ U(ln max(C), ln 10xsum C) = U(ln 144,047t, ln 4,450,407t)
- a ~ U(0.001, 1.0)
- *ln* q_i *~ U(-16,0) (for IBTS)*
- $\frac{1}{\sigma_u^2} \sim Gamma(0.001,0.001)$

***Model Outputs*:**

Full run estimates:

- r (intrinsic rate of population growth)
- K (carrying capacity)
- a (proportion of K in 1982)
- q_i (catchabilities, 6 IBTS and 1 acoustic survey)
- B_t (biomass states, 33 years)

Errors:

- Single biomass process error encompassing recruitment and growth variability
- Measurement errors come directly from variance of delta-lognormal indices

Prior assumptions on the parameter distributions were:

- Intrinsic rate of population growth: r ~ U(0.001,2)
- Natural logarithm of the carrying capacity ln K ~ U(ln max(C), ln 10xsum C)=U(ln 144,047t, ln 4,450,407t)
- Proportion of carrying capacity in first year of assessment: a ~ U(0.001, 1.0)
- Natural logarithm of the survey-specific catchabilities ln qi ~ U(-16,0) (for IBTS only). Acoustic survey is discussed below when separate runs are described.
- Process error precision ~Gamma(0.001,0.001)

Eight initial runs were performed. The four base runs are explained in the table below:

Run	qacoustic	Iacoustic,2012 (t)	Iacoustic,2013 (t)
1	Fixed at 1	Total (863,446)	Total (439,897)
2	Free (strong prior)	Total	Total
3	Fixed at 1	Definitely (708,019)	Definitely (431,571)
4	Free (strong prior)	Definitely	Definitely

$q_{acoustic}$ is the catchability of the acoustic survey, $I_{acoustic}$ is the acoustic index value used for the specified years.

Runs 1 and 3 assume that the acoustic survey surveys the entire stock and is an absolute index of abundance. Runs 2 and 4 assumes a strong prior ln $q_{acoustic}$ ~ N(1,1/4) (standard deviation of 1/4), which has 95% of the density between 0.5 and 2. Given the short acoustic series (2 years) it is not possible to estimate this parameter freely (using an uninformative prior) but assuming a strong prior removes the assumption of an absolute index from the acoustic survey and will be continually updated as data accrue.

Following concerns regarding the quality of the recording of boarfish from the early part of the ECSGFS survey and the fact that the WCSGFS survey is distant from the center of abundance and unlikely to provide an index for the complete stock, sensitivity runs were performed on Runs 1-4 that completely omitted the ECSGFS and WCSGFS surveys. These are referred to as runs 1.1, 2.1, 3.1, and 4.1 with the same settings as the corresponding runs 1 through 4 respectively with the omission of these two surveys.

Following plenary discussion of the sensitivity runs, it was decided that the final run be based on a run that includes all surveys with the omission of the first 5 years of the WCSGFS and first 9 years of the ECSGFS. The reasons for this decision was

- -It is unclear whether boarfish were consistently recorded in the early part of the ECSGFS
- -The WCSGFS is thought to be at the northern extreme of the distribution and may not be an appropriate index for the whole stock.
- -The SPNGFS commences in 1991 such that running the assessment from 1991 onwards includes at least three surveys without relying solely on the ECSGFS and WCSGFS.
- -Surveys are internally weighted such that highly uncertain values receive lower weight.

Run 2.2. is therefore the final run. The specifications are that for run 2 with the omission of the early parts of the WCSGFS and ECSGFS, as detailed above.

Run convergence

Parameters for runs 1-4, sensitivity runs 1.1, 2.1, 3.1, 4.1 and final run 2.2 converged with good mixing of the chains and R_{hat} values lower than 1.1 indicating convergence (Figures C.1, C.2, C.3). MCMC chain autocorrelation was also low indicating good sampling of the parameter posteriors (Figures C.4 and C.5).

Diagnostic plots for these runs are provided in Figures C.6 and C.7, showing residuals about the model fit. There is relatively little difference between any of the runs in the fitting of the trawl surveys, and a fairly balanced residual pattern is in evidence. In some cases outliers are apparent, for instance in the English survey in the final year (2003). However, these points are down-weighted according to the inverse of their variance and hence to not contribute much to the model fit. For this reason, no indices were removed from the analyses. The west of Scotland IBTS survey, located at the northern extreme of the stock distribution underestimates the stock in the early period (years) and overestimates it in the recent period from all fits. This could be indicative of stock expansion into this area at higher stock sizes and suggests that this index is not representative of the whole stock. Figures C.8, C.9 and C.10 show the prior and posterior distributions of the parameters of the biomass dynamic model.

The estimate of q in runs 2, 2.1, 4 and 4.1 is less than 1.0, leading to higher estimates of final stock biomass than the acoustic survey.

Trajectories of observed and expected indices are shown in Figures C.11, C.12 and C.13, along with the stock size over time and a harvest ratio (total catch divided by estimated biomass). It can be seen that runs 2, 2.1, 2.2, 4 and 4.1 lead to larger stock sizes given the non-absolute assumption on the acoustic survey catchability. Parameter estimates from the four preliminary runs (1-4), four sensitivity runs (1.1, 2.1, 3.1, 4.1) and the final run (run 2.2) are summarized in Table C.1.1. It can be seen that the precision of the estimates of stock size are higher (more certain) for the runs where q is set at 1.0 for the acoustic surveys (Runs 1, 3, 1.1, 3.1). As the acoustic survey does not span the entire range of the stock, assuming the catchability of the acoustic survey is likely incorrect, hence the decision to use a strong prior on the acoustic survey catchability. Consequently the group considers run 2.2 as the final run for the purposes of stock assessment and forecasting catch options for 2013.

2014 – 2016 Assessments

In 2014 the Bayesian state space surplus production model was again fit using the catch data, delta-lognormal estimated IBTS survey indices, and the acoustic survey estimates. However, the inclusion of the low 2014 acoustic biomass estimate changed the perception on the stock, which raised concerns over the sensitivity and process error of the model. The stock was moved from a category 1 assessment to a category 3 with the results of the surplus production model being used to calculate an index for the data limited stock approach.

In 2015 the model was again run using the same procedure as last year with updated catch and survey data. Details of this exploratory run, which will again be used to calculate the DLS index, are described below. In 2016 the same procedure as 2015 was followed.

Further model development work was also undertaken in 2015 and 2016.

In the Bayesian state space surplus production model the biomass dynamics are given by a difference form of a Schaefer biomass dynamic model:

$$B_t = B_{t-1} + rB_{t-1}\left(1 - \frac{B_{t-1}}{K}\right) - C_{t-1}$$

where B_t is the biomass at time t, r is the intrinsic rate of population growth, K is the carrying capacity, and C_t is the catch, assumed known exactly. To assist the estimation the biomass is scaled by the carrying capacity, denoting the scaled biomass $P_t = B_t/K$. Lognormal error structure is assumed giving the scaled biomass dynamics (process) model:

$$P_t = \left(P_{t-1} + rP_{t-1}(1 - P_{t-1}) - \frac{C_{t-1}}{K}\right)e^{u_t}$$

where the logarithm of process deviations are assumed normal $u_t{\sim}N(0, \sigma_u^2)$; with σ_u^2 the process error variance .

The starting year biomass is given by aK, where a is the proportion of the carrying capacity in the first year. The biomass dynamics process is related to the observations on the indices through the measurement error equation:

$$I_{j,t} = q_j P_t K e^{\varepsilon_{j,t}}$$

where $I_{j,t}$ is the value of abundance index j in year t, q_j is survey-specific catchability, $B_t = P_t K$, and the measurement errors are assumed lognormally distributed with

$\varepsilon_t \sim N(0, \sigma^2_{\varepsilon,j,t})$ where $\sigma^2_{\epsilon,j,t}$ is the index-specific measurement error variance. Var($I_{j,t}$) is obtained from the delta-lognormal survey fits. That is, the variance of the mean annual estimate per survey is inputted directly from the delta-lognormal fits (Figure 3.6.2.2) as opposed to estimating a measurement error within the assessment. The measurement error is obtained from:

$$\sigma^2_{\epsilon,j,t} = ln\left(1 + \frac{Var(I_{j,t})}{\left(I_{j,t}\right)^2}\right)$$

For the acoustic survey, the CV of the survey was transformed into a lognormal variance via

$$\sigma^2_{\varepsilon,acoustic,t} = \ln(CV^2_{acoustic,t} + 1)$$

Prior assumptions on the parameter distributions were:

- Intrinsic rate of population growth: $r \sim U(0.001,2)$
- Natural logarithm of the carrying capacity: $\ln(K) \sim U(\ln(\max(C), \ln(10.sum(C)) = U(\ln(144047), \ln(4450407))$
- Proportion of carrying capacity in first year of assessment: $a \sim U(0.001,1.0)$
- Natural logarithm of the survey-specific catchabilities $\ln(q_i) \sim U(-16,0)$ (for IBTS only). The acoustic survey prior is discussed below.
- Process error precision $\frac{1}{\sigma^2_u} \sim Gamma(0.001,0.001)$

Specifications

During the 2013 WGWIDE meeting a number of different iterations of the model were run to discern the best parameters for the assessment. After four initial runs and four sensitivity runs the settings for the final run (run 2.2) were chosen. These settings are shown below and were used for the assessment model in 2014, 2015 and 2016. (More details of the trial runs in 2013 can be found in the stock annex.)

The specifications for the final 2013, 2014, 2015 and 2016 boarfish assessment model runs are:; $q_{acoustic}$ is the catchability of the acoustic survey:

Acoustic survey

Years: 2011-2016

Index value ($I_{acoustic,y}$): 'Total' in tonnes (*i.e.* Definitely Boarfish + Probably Boarfish + Boarfish in a Mix)

Catchability ($q_{acoustic}$): A free, but strong prior (*i.e.* the acoustic survey is treated as a relative index but is strongly informed, this allows the survey to cover <100% of the stock).

IBTS surveys

6 delta log normal indices (WCSGFS, SPPGFS, IGFS, ECSGFS, SPNGFS, EVHOE)

First 5 years omitted from WCSGFS

First 9 years omitted from ECSGFS

Discards

Average of 2004-2015 (5158t)

The final run assumes a strong prior $\ln(q_{acoustic}) \sim N(1,1/4)$ (mean 1, standard deviation 0.25), which has 95% of the density between 0.5 and 2. Given the short acoustic series (6 years) it is not possible to estimate this parameter freely (*i.e.* using an uninformative prior). The prescription of a strong prior removes the assumption of an absolute index from the acoustic survey. This assumption will be continually updated as additional data accrue.

Following plenary discussion of the sensitivity runs in 2013, it was decided that the final run be based on a run that includes all surveys with the omission of the first 5 years of the WCSGFS and first 9 years of the ECSGFS. The reasons for this decision were:

- It is unclear whether boarfish were consistently recorded in the early part of the ECSGFS
- The WCSGFS is thought to be at the northern extreme of the distribution and may not be an appropriate index for the whole stock.
- The SPNGFS commences in 1991 such that running the assessment from 1991 onwards includes at least three surveys without relying solely on the ECSGFS and WCSGFS.
- Surveys are internally weighted such that highly uncertain values receive lower weight.

Pseudo-cohort Analysis

Pseudo-cohort analysis is a procedure where mortality is calculated by means of catch curves derived from catch-at-age from a single year. This is in contrast to cohort analysis, which is the basis of VPA-type assessments. In cohort analysis, mortality is calculated across the ages of a year class, not within a single year. Because only seven years of sampling data were available and owing to the large age range currently in the catches a cohort analysis would only yield information for a very limited age and year range. Therefore, pseudo-cohort analysis was performed to supplement the Bayesian state space model.

Pseudo-cohort Z estimates increased with the rapid expansion of the fishery but decreased in 2011 due to the introduction of the first boarfish TAC (Table C.1.2). By subtracting M (=0.16), an estimate of F was obtained for each year (ages 7-14). This series was revised to represent ages 7-14, rather than 6-14 as in previous years, because in 2013 age 6 boarfish were not fully selected, i.e. age 7 had higher abundance at age.

It can be seen from the table C.1.2 that $Z \approx M$ in 2007, the initial year of the expanded fishery, while F is negligible. F increased to a high of 0.26 in 2012 and has reduced to 0.18 in 2014 and 2015. There was a weak correlation between catches and pseudo-cohort F ($r^2 = 0.40$). Recent F estimated in this way is above F_{MSY} (0.14) and $F_{0.1}$ (0.13).

D. Short-Term Projection

As the assessment is exploratory and indicative of trends, no short term projections were conducted.

E. Medium-Term Projections

A yield per recruit analysis was conducted in 2011 (Minto *et al.* WD 2011) and $F_{0.1}$ was estimated to be 0.13 whilst F_{max} was estimated as in the range 0.23 to 0.33. (Figure E.1 and E.2). The estimation of $F_{0.1}$ was considered to be quite good.

F. Long-Term Projections

G. Biological Reference Points

It does not appear that boarfish is an important prey species in the NE Atlantic. ICES (1997) considered that precautionary F targets (F_{pa}) should be consistent with F<M for prey species, and F = M for non-prey species. This approach would ensure that fishing does not out-compete natural predators for their prey. This would suggest that a good candidate precautionary F_{pa} is F = M = $0.16y^{-1}$. This is considered appropriate because boarfish is not an important prey in the NE Atlantic. B_{lim} may be defined from the stock size estimates available from the stock assessment and set at 0.2*K, (131 063 t), based on the exploratory assessment in 2016.

Yield based reference points

An estimate of F_{msy} is available from the stock assessment model as 0.138.

An estimate of B_{msy} is available from stock assessment model (327 657 t). This is proposed as a conservative basis for MSY $B_{trigger}$.

It should be noted that these values have changed slightly since 2015 and are based on the revised the perception of the stock after the inclusion of the latest data in the exploratory assessment described above.

H. Other Issues

H.1 Management and ICES advice

In 2010, an interim management plan was proposed by Ireland for boarfish in ICES Divisions 6, 7 and 8. The plan was as follows:

1) Until a long term management plan has been developed, and evaluated, the following interim TAC setting rule shall apply.

2) The TAC for 2011 (hereinafter referred to as the Reference TAC) shall be set in the range 22,000-33,000 t, 50%-75% of the Recent Average Yield 2007-2009.

3) The TAC for 2012 shall be based on the Reference TAC, adapted by the rule, below, based on the Exploitation Indicator (E) and Reproductive Capacity Indicator (R)*:

a) If the average of either E or R in the past two years is 20% or more lower than in the preceding three years, a 15% TAC decrease applies.

b) If the average of either E or R in the past two years is 20% or more higher than in the preceding three years, a 15% TAC increase applies.

c) If the average of either E or R in the past two years is less than 20% different than in the preceding three years, no TAC change applies.

d) Notwithstanding 3.b above, in no case shall the TAC for a given year exceed the Reference TAC.

1) A precautionary closed season shall operate between the 15th March and the 31st August. This is because it is known that mackerel and boarfish are caught in mixed aggregations at these times.

2) A closed area shall be implemented in 7.g from 1st September to 31st October, in order to prevent catches of Celtic Sea herring, known to form feeding aggregations in this region at these times.

3) If catches of species covered by TAC, other than boarfish amount to more than 5% of the total catch by day by ICES statistical rectangle, then fishing must cease in that rectangle.

4) Vessels participating in the fishery for boarfish shall only land in designated ports.

5) Participating vessels already facilitate scientific studies, and observer coverage, and this cooperation shall be further developed.

***Indicator Definitions**

Exploitation Indicator E is defined as follows:

The mean length of fish of size greater than length at maturity as estimated in 2007 in the ICES western IBTS.

Reproductive Indicator R is defined as follows:

The total abundance of mature boarfish as estimated per year by the ICES western IBTS survey.

In 2011, ICES was asked by the European Commission to provide advice for boarfish in 2012 for the Celtic Sea and in the Bay of Biscay and the Iberian Coast. Data analysis suggests that a single management area exists in Subareas IV, V, VI, VII and VIII. This differs from the request made by the EC to ICES and also differs to the TAC area (VI, VII and VIII).

In 2012 a management plan was proposed by the Pelagic RAC. This management plan has not yet been fully evaluated by ICES. However, ICES identifies that Tier 1 of the proposed plan coincides with the ICES generic approach to giving advice for data-rich situations. Given that a Category 1 assessment is now being used for advice, ICES recommends that Tier 1.1 of the plan be considered consistent with the PA and MSY approaches for as long as a Category 1 assessment is available (ICES, 2013). This plan is presented below.

1) The TAC setting rules 1.1-1.6 shall apply. Precedence is in decreasing order from Rule 1.1. These are shown in the table below. The decision year for TAC setting is the last year in the assessment, and not the TAC year.

Rule	Assessment	Uncertainty	Condition	Procedure
1.1.a	SSB and F	Low	SSB > Btrigger	Ftarget
1.1.b			SSB < Btrigger	SSB * (Ftarget / Btrigger)
1.2.a	SSB and F	Higher	SSB > Btrigger	Ftarget
1.2.b			SSB < Btrigger	SSB * (Ftarget / Btrigger) * G
1.3.a	F	Any	F < Ftarget	Reference TAC * G

1.3.b			F > Ftarget,	RTAC + (-RTAC / Flim-Fpa)*(F-Fpa) * G
1.4.a	U	Any	U > Upa, TAC =	Reference TAC * G
1.4.b			U < Upa, TAC =	U * (Reference TAC / Upa) * G
1.5.	Survey biomass	Any	TAC y,q3,4 = TACy+1, q1 =	ASB * 1-exp-F0.1_ * G * 0.62 ASB * 1-exp-F0.1_ * G * 0.38
1.6	None		No information on stock status and no risk of recruitment impairment	TAC = 33,000 t (interim management plan TAC)

2) Notwithstanding Paragraph 1, if in the opinion of ICES, the stock is at risk of recruitment impairment, a TAC shall be based on advice given by ICES, and at a lower level than provided for in Paragraph 1, rules 1.1 to 1.6.

3) Closed seasons, closed areas and moving on procedures shall apply to all directed boarfish fisheries as follows:

i A closed season shall operate from 15th March to the 31st August. This is because it is known that herring and mackerel are present in these areas and may be caught with boarfish.

ii A closed area shall be implemented inside the Irish 12 mile limit south of 52°30 from 12th February to 31st October, in order to prevent catches of Celtic Sea herring, known to form aggregations at these times.

iii If catches of other species covered by TAC, amount to more than 5% of the total catch by day by ICES statistical rectangle, then all fishing must cease in that rectangle for 5 consecutive days.

In 2015 the Pelagic Advisory Council submitted a revised draft management strategy for Northeast Atlantic boarfish. The EU has requested ICES to evaluate the following management plan:

This management strategy aims to achieve sustainable exploitation of boarfish in line with the precautionary approach to fisheries management, FAO guidelines for new and developing fisheries, and the ICES form of advice.

1) The TAC shall be set in accordance with the following procedure, depending on the ICES advice

a) If category 1 advice (stocks with quantitative assessments) is given based on a benchmarked assessment, the TAC shall be set following that advice.

b) If category 1 or 2 (qualitative assessments and forecasts) advice is given based on a non-benchmarked assessment the TAC shall be set following this advice.

c) Categories 3-6 are described below as follows:

i) Category 3: stocks for which survey-based assessments indicate trends.

This category includes stocks with quantitative assessments and forecasts which for a variety of reasons are considered indicative of trends in fishing mortality, recruitment, and biomass.

ii) Category 4: stocks for which only reliable catch data are available.

This category includes stocks for which a time series of catch can be used to approximate MSY.

iii) Category 5: landings only stocks.

This category includes stocks for which only landings data are available.

iv) Category 6: Category 6 – negligible landings stocks and stocks caught in minor amounts as bycatch

2) Notwithstanding paragraph 1, if, in the opinion of ICES, the stock is at risk of recruitment impairment, a TAC may be set at a lower level.

3) If the stock, estimated in the either of the 2 years before the TAC is to be set, is at or below

B_{lim} *or any suitable proxy thereof, the TAC shall be set at 0 t.*

4) The TAC shall not exceed 75,000 t in any year.

5) The TAC shall not be allowed to increase by more than 25% per year. However, there shall be no limit on the decrease in TAC.

6) Closed seasons, closed areas, and moving on procedures shall apply to all directed boarfish fisheries as follows:

a) A closed season shall operate from 31st March to 31st August. This is because it is known that herring and mackerel are present in these areas and may be caught with boarfish.

b) A closed area shall be implemented inside the Irish 12-mile limit south of 52°30 from 12th February to 31st October, in order to prevent catches of Celtic Sea herring, known to form aggregations at these times.

c) If catches of other species covered by a TAC amount to more than 5% of the total catch by day by ICES statistical rectangle, then all fishing must cease in that rectangle for 5 consecutive days.

H.2 Review

This assessment was peer-reviewed by two independent experts on behalf of ICES in 2012. . In 2013, a new assessment was provided, that was based on last previous year's work and took into account the reviewers' comments, which are detailed below.

The reviewers suggested that an age based model would be most appropriate. An age based model, however, is not attainable in the short term because:

- Insufficient age samples are available per year to derive representative CNAA.
- The age range of the species is wide and the year range of the fishery is narrow, making it impossible to populate the age-matrices of any such model in the short term.

The impediments to having an age based assessment can be overcome with time. The reviewers recommend the development of an age-based assessment in a 3-year timeframe. A cost-benefit analysis is required on whether to pursue an age based approach. At present there are insufficient resources for a full ageing programme. The reviewers suggested that more samples with fewer fish per sample and to refine the age length relationship for older fish. Perhaps the most expedient approach is to collect a large amount of samples, but only age a sub-set of these to maintain the indicator pseudo-cohort F estimates. If better resources are considered to be warranted, then the back-log of samples could be aged to produce CNAA over several years.

Given the problems with an age-based assessment, it was necessary to develop the biomass dynamic model further, whilst paying attention to the reviews conducted in 2012. The main points of the reviews on the biomass dynamic model are presented in the text table below, along with notes on how they were addressed.

Reviewer comment	How addressed
Provide indication of steepness of stock recruitment relationship	The model does not provide modelled recruitment, so this is not relevant to current model specification.
Better description of weighting of individual surveys	Surveys are weighted based on the survey index variability. A highly uncertain survey is therefore down-weighted within the assessment as detailed below. Apart from the index uncertainties, no a-priori weights are given to the indices although sensitivities to the exclusion of certain surveys were conducted and described below.
Clarification of rationale for model(run) selection	We now include a full clarification on final run selection.
Provide sensityivity analysis of prior assumptions	We include a sensitivity analysis to prior assumptions based on a "low resilience" assumption of WKLIFE (ICES, 2012) based on the maximum age for the species.
Need to describe process error to observation error	The process error and observation errors are described in full below.
Better description of Monte Carlo Markov Chain simulations	We now include traceplots of MCMC chains for the all runs to illustrate convergence accompanied by the Rhat statistic (ratio of between-chain to within-chain variance) with Rhat =1 indicating perfect convergence and Rhat < 1.1 indicative of acceptable convergence (Kéry, 2010). We also present autocorrelation functions of the final run to indicate MCMC sample independence.
Better description of catch used as inputs, including discards	Discards are described in Section 6.1.6.
Sensitivity analysis required on model results to assumptions on error variances	Measurement error variances come directly from the survey index analyses. The estimated process error variance is very strongly updated from a gamma prior on the precision so we don't think a sensitivity analysis is warranted for the error variances.
Show correlation among abundance indices	Now presented in Figures 6.6.2.5 and 6.6.2.6.
Include sensitivity analysis for including indices with zero or negative correlations with other indices	Again, the survey indices are internally weighted by their measurement error uncertainty and we do not a priori exclude series. Our sensitivity analyses remove the WCSGFS and ECGFS. The ECGFS survey displays negative correlation with the EVHOE and SPNGFS.

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Table A.2.1. Boarfish in Subareas 6, 7, 8 Landings by year (t), 2001–2015. (Data provided by Working Group members). These figures may not in all cases correspond to the official statistics and cannot be used for management purposes.

	Ireland	Denmark	Scotland	The Netherlands	UK England	Germany	Unallocated	Discards	Total	TAC
2001	120	0	0				NA	NA	120	-
2002	91	0	0				NA	NA	91	-
2003	458	0	0				NA	10929	11387	-
2004	675	0	0				NA	4476	5151	-
2005	165	0	0				NA	5795	5959	-
2006	2772	0	0				NA	4365	7137	-
2007	17615	0	772				NA	3189	21576	-
2008	21585	3098	0.45				NA	10068	34751	-
2009	68629	15059	0				NA	6682	90370	-
2010	88457	39805	9241				NA	6544	144047	-
2011	20685	7797	2813				NA	5802	37096	33000
2012	55949	19888	4884				NA	6634	87355	82000
2013	52250	13182	4380				NA	5598	75409	82000
2014	34622	8758	38				NA	1813	45231	133957
2015	16325	29	0	375	104	4	NA	929	17766	53296

Table A.2.2 Boarfish in ICES Subareas 6, 7, 8. Landings by year (t), 2001–2015 and area where available. (Data provided by Working Group members). These figures may not in all cases correspond to the official statistics and cannot be used for management purposes.

Year	Denmark	Ireland	Scotland	The Netherlands	Germany	UKE	Total
2001		**120**					120
2002		**91**					91
2003		**458**					**458**
6.a		65					65
7.b		214					214
7.j		179					179
2004		**675**					**675**
6.a		292					292
7.b		224					224
8.d		38					38
7.j		122					122
2005		**165**					**165**
6.a		10					10
7.b		105					105
8.a		38					38
7.j		12					12
2006		**2772**					**2772**
6.a		21					21
7.b		15					15
7.g		375					375
8.a		1					1
7.j		2360					2360
2007		**17615**	**772**				**18386**
5.b.2		6					6
6.a		93					93
7.b		1259					1259
7.g		120					120
8.a		5					5
7.j		16131	772				16903
2008		**21584**	**0**				**21585**
6.a		28	0				28
7.b		3					3
7.g		184					184
7.j		21370					21370
2009		**68629**					**68629**
6.a		45					45
7.b		73					73
7.c		1					1
7.g		4912					4912
7.h		18225					18225
7j		45372					45372
2010	**39805**	**88457**	**9241**				**137503**
6a		1349	10				1359
6.a.S		7					7
7.b		2258					2258
7.c		35	4				39
7.e	2						2
7.g	672	3649					4321
7.h	1465	8453	1712				11629

Year	Denmark	Ireland	Scotland	The Netherlands	Germany	UKE	Total
7.j	37667	72707	7515				117889
2011	**7797**	**20685**	**2813**				**31295**
6.a		26					26
7.b		274					274
7.c		9					9
7.g		811					811
7.h	4155	8540	2813				15508
8.a	18						18
7.j	3624	11025					14648
2012	**19888**	**55949**	**4884**				**80720**
6.a		125					125
7.b	80	4501	838				5419
7.c		108	907				1015
7.g		616					616
7.h	5837	10579	3139				19554
8.a	1604	93					1697
7.j	12366	39928					52294
2013	**13182**	**52250**	**4380**				**69811**
6.a		538	15				553
7.b		10405	100				10505
7.e			883				883
7.g		1808					1808
7.h	955	11355	1728				14038
8.a	1354	870					2224
8.d		270					270
7.j	10873	27003	1653				39529
2014	**8758**	**34622**	**38**				**43418**
6.a		182	30				212
7.b	12	3262					3274
7.g		135					135
7.h	4808	18389					23196
8.a		119					119
7.j	3886	12536	8				16429
7.k	53						53
2015	**29**	**16325**		**375**	**5**	**104**	**16837**
6.a	10	116				9	134
7.b	8	2609			4	85	2706
7.c		220					220
7.g		547					547
7.h	5	8506					8510
8.a	6	682			1		688
7.j		3646			0	10	3655
6				128			128
7				33			33
8				214			214
Total	**89458**	**380395.92**	**22128**	**375**	**5**	**104**	**492465**

Table B.2.1. Boarfish in ICES Subareas 6, 7, 8. Boarfish age length key produced from 2011 commercial samples. Figures highlighted in grey are estimated.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
7	1	1													
7.5	1	1													
8		1													
8.5		1	1												
9		1	1												
9.5			1												
10			1												
10.5			2	10	3										
11			1	29	14	2	2								
11.5				9	21	21	18	2	2	1					
12				4	17	22	38	12	8						1
12.5					5	9	42	37	14	6	2		1	1	1
13					2	4	31	28	24	12	6	2	3	1	5
13.5					1	3	25	22	21	14	6	5	4	2	11
14							6	8	18	22	8	3	7	1	20
14.5						1	1	2	3	8	1	6	6	6	30
15							1	1		2	2	2	5	2	19
15.5										2				2	19
16															8
16.5															1
17															1
17.5															1
18															1
18.5															1

Table B.2.2. Boarfish in ICES Subareas 6, 7, 8. Length-frequency distributions of the international catches (raised numbers in '000s) for the years 2007-2015.

TL (cm)	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
4.5	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	14	14
5	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	878	878
5.5	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	515	515
6	0	0	0	156	0	0	0	0	810	965
6.5	0	0	0	439	0	0	0	0	14	453
7	0	0	0	1090	522	56	52	0	513	2232
7.5	0	0	1354	1574	0	0	551	0	10598	14077
8	0	0	677	375	1345	185	1419	0	80716	84716
8.5	0	0	0	1082	0	555	3592	1064	49508	55801
9	0	0	677	5382	851	555	7263	327	10219	25272
9.5	0	7473	17367	7883	7012	641	47509	4916	213	93014
10	9609	11209	54130	29410	33243	2791	94702	31649	1211	267954
10.5	0	52308	174796	130889	15848	6132	59833	71344	3865	515016
11	84555	63517	343283	361774	70615	24571	18359	108261	12226	1087162
11.5	0	59781	321637	655875	93487	81928	20938	82470	28142	1344258
12	44199	119561	297737	739025	189434	264888	98564	84288	41613	1879309
12.5	0	70990	207739	564347	114904	398772	204868	112826	42461	1716906
13	82633	52308	147965	353484	133539	419060	315063	172416	59990	1736459
13.5	0	29890	149314	246146	51235	307533	285688	153742	52625	1276174
14	117224	22418	105782	224611	50857	176710	210137	138549	50139	1096428
14.5	0	14945	71273	127711	25309	89726	105571	74059	28771	537364
15	65338	33627	47816	125463	25569	52791	62175	43347	16087	472212
15.5	0	11209	13082	81386	5473	25065	31122	22629	8572	198539
16	13452	11209	19397	24256	4181	13149	14990	7672	4331	112638
16.5	0	3736	4061	6209	2280	2738	4918	2134	2081	28156
17	0	3736	677	1913	456	827	1109	1361	289	10368
17.5	0	0	0	0	0	0	407	0	23	430
18	0	0	0	283	0	0	296	0	0	579
18.5	**0**	**0**	**0**	**0**	**0**	**0**	592	0	0	592

Table B.2.3. Boarfish in ICES Subareas 6, 7, 8. Proxy catch numbers-at-age of the international catches (raised numbers in '000s) for the years 2007-2015.

	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	0	0	1575	2415	0	28	301	0	5556
2	352	5488	15043	11229	2894	893	7148	695	116135
3	2114	21140	65744	72709	41913	5467	156680	49503	32248
4	40851	105575	338931	294382	28148	41278	58522	127520	16588
5	48915	141300	475619	567689	30116	110272	59797	93705	24564
6	62713	195339	543707	878363	175696	146582	68949	67275	26566
7	26132	104031	307333	522703	143967	492078	302967	193061	74115
8	29766	66570	172783	293719	107126	365840	250341	139124	52052
9	56075	53159	155477	276672	77861	271916	212318	121042	44615
10	44875	46893	130148	232122	60022	173486	160137	94225	34264
11	14019	15289	42521	78588	46079	69396	63025	36078	12999
12	32359	21178	61350	114600	40468	40968	41490	24895	9114

13	4848	11854	39609	59932	24352	58888	59380	36309	13362
14	16837	13570	31569	59060	19724	30277	30355	19064	7152
15+	109481	112947	196967	349320	157707	217260	239366	150688	59139

Table B.2.4. Boarfish in ICES Subareas 6, 7, 8. Sampling intensity by country of commercial catches

			DK			IRL			SCT		
YEAR	Q	AREA	LANDINGS	SAMPLES	MEASURED	LANDINGS	SAMPLES	MEASURED	LANDINGS	SAMPLES	MEASURED
2007	1	6.a				12	0	0			
	1	8.a				5	0	0			
	1	7.j				5253	0	0	772	0	0
	2	7.g				120	0	0			
	2	7.j				4130	2	197			
	3	7.b				0	0	0			
	4	5.b.2				6	0	0			
	4	6.a				82	1	20			
	4	7.b				1259	0	0			
	4	7.j				6748	0	0			
	Total		0	0	0	17615	3	217	772	0	0
2008	1	6.a				5	0	0			
	1	7.g				184	0	0			
	1	7.j				5041	0	0			
	2	7.j				46	0	0			
	3	7.j				4067	0	0			
	4	6.a				23	0	0	0.5	0	0
	4	7.b				3	0	0			
	4	7.j				12216	1	152			
	Total		3098	0	0	21584	1	152	0.5	0	0
2009	1	7.b				55	0	0			
	1	7.g				2979	0	0			
	1	7.h				1971	0	0			
	1	7.j				10901	2	359			
	2	7.g				1933	0	0			
	2	7.h				3169	0	0			
	2	7.j				2727	0	0			
	3	7.h				10378	0	0			
	3	7.j				11423	1	175			
	4	6.a				45	0	0			
	4	7.b				18	0	0			
	4	7.h				2707	0	0			
	4	7.j				20321	6	941			
	Total		15059	0	0	68629	9	1475	0	0	0

Table B.2.4. Boarfish in ICES Subareas 6, 7, 8. Sampling intensity by country of commercial catches continued

			DK			IRL			SCT		
Year	Q	Area	Landings	Samples	Measured	Landings	Samples	Measured	Landings	Samples	Measured
2010	1	6.a							10	0	0
	1	7.b				1069	1	102			
	1	7.g	577	1	77	2392	0	0			
	1	7.h	1079	0	0	326	1	94			
	1	7.j	32422	2	193	34466	12	1447	2504	0	0
	2	7.h				102	0	0			
	2	7.j	344	0	0						
	3	7.g				338	0	0			
	3	7.h	377	0	0	5540	8	1316	548	0	0
	3	7.j	2660	0	0	11531	31	3275	2171	0	0
	4	6.a				1355	1	117			
	4	7.b				1189	0	0			
	4	7.c				35	0	0	4	0	0
	4	7.e	2	0	0						
	4	7.g	94	0	0	920	0	0			
	4	7.h	9	3	384	2484	6	715	1165	0	0
	4	7.j	2241	2	217	26710	27	2738	2840	0	0
	Total		39805	8	871	88457	87	9804	9241	0	0
2011	1	7.b				39	0	0			
	1	7.h	32	0	0						
	1	8.a	18	0	0						
	1	7.j	1	0	0	38	0	0			
	2	7.b				1	0	0			
	3	7.h				820	0	0	434	0	0
	3	7.j				1092	0	0			
	4	6.a				26	0	0			
	4	7.b				235	0	0			
	4	7.c				9	0	0			
	4	7.g				811	0	0			
	4	7.h	4123	11	1347	7720	3	319	2379	0	0
	4	7.j	3623	5	611	9894	8	1789			
	Total		7797	16	1958	20685	11	2108	2813	0	0

Table B.2.4. Boarfish in ICES Subareas 6, 7, 8. Sampling intensity by country of commercial catches continued

			DK			IRL			SCT		
Year	Q	Area	Landings	Samples	Measured	Landings	Samples	Measured	Landings	Samples	Measured
2012	1	7.b				4365	3	339			
	1	7.g				616	0	0			
	1	7.h	3789	1	150	1005	0	0			
	1	7.j	11403	3	102	27812	42	4987			
	1	8.a	1330	2	214						
	2	7.h	208	0	0						
	3	7.b				49	0	0			
	3	7.h				3176	5	682	1537	0	0
	3	7.j				834	2	341			
	4	6.a				125	1	96			
	4	7.b	80	0	0	87	0	0	838	0	0
	4	7.c				108	0	0	907	0	0
	4	7.h	1840	4	445	6398	7	945	1602	0	0
	4	8.a	274	0	0	93	0	0			
	4	7.j	963	2	180	11281	8	1175			
Total			19888	12	1091	55949	68	8565	4884	0	0
2013	1	6.a				370	0	0	15	0	0
	1	7.b				8314	15	2037	100	0	0
	1	7..e							883	0	0
	1	7.g				1443	0	0			
	1	7.h	955	0	0	1319	1	113	828	0	0
	1	8.a	1354	3	369	100	1	147			
	1	7.j	10873	11	852	14338	21	2984	721	0	0
	3	7.b				11	0	0			
	3	7.g				46	0	0			
	3	7.h				2307	3	480			
	3	8.a				770	0	0			
	3	7.j				3892	2	436	468	0	0
	4	6.a				167.262	1	123			
	4	7.b				2080	2	198			
	4	7.g				320	0	0			
	4	7.h				7729	10	1467	901	0	0
	4	8.d				270	0	0			
	4	7.j				8773	6	833	464	0	0
Total			13182	14	1221	52250	62	8818	4380	0	0

Table B.2.2. Boarfish in ICES Subareas 6, 7, 8. Sampling intensity by country of commercial catches continued

			DK			IRL			SCT		
Year	Q	Area	Landings	Samples	Measured	Landings	Samples	Measured	Landings	Samples	Measured
2014	1	6.a				14	0	0	30	0	0
	1	7.b				808	0	0			
	1	7.h	2259	0	0	2409	5	550			
	1	7.j	2992	0	0	6062	11	871	8	0	0
	2	7.j				10	0	0			
	3	7.b				31	0	0			
	3	7.h				2183	8	727			
	3	7.j				1547	4	416			
	4	8.a				119					
	4	6.a				167.8	0	0			
	4	7.b	12	0	0	2424	1	44			
	4	7.g				135	0	0			
	4	7.h	2549	11	1936	13797	19	1914			
	4	7.k	53	0	0						
	4	7.j	894	0	0	4916	6	550			
Total			8758	11	1936	34622	54	5072	38	0	0
2015	1	7.h	5	0	0	4606	14	1380			
	1	7.b				2123	3	263			
	1	7.j				306	2	175			
	1	6.a	4	0	0	42	0	0			
	1	7.g				547	0	0			
	1	8.a	6	0	0	460	0	0			
	3	7.j				2753	3	344			
	4	7.h				3900	7	934			
	4	7.j				587	1	115			
	4	7.c				220	1	145			
	4	6.a	6	0	0	74	0	0			
	4	7.b	8	0	0	486	0	0			
	4	8.a				222	0	0			
			29			16325	31	3356			

Table B.3.1 Boarfish in ICES Subareas 6, 7, 8. Parameter estimates of the von Bertalanffy growth equation

	Estimate	Std. error	t value	Pr(>|t|)
Linf	15.563073	0.134828	115.43	<2e-16 ***
K	0.190592	0.006698	28.45	<2e-16 ***
t0	-1.662997	0.109091	-15.24	<2e-16 ***
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1				
Residual standard error: 0.8982 on 404 degrees of freedom				

Table B.4.1. Boarfish in area 6, 7 and 8. IBTS length-frequency data converted to age-structured index by application of the common ALK.

All	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1997	9186	11460	5356	4603	4209	7331	6050	4331	4970	4375	1498	2491	1741	1248	635	1242	161	676	635	3814
1998	17475	19641	6886	6423	5693	7515	5791	3814	4860	4439	1481	2883	1654	1644	685	1240	236	917	685	4965
1999	11838	33029	20031	8826	3580	3421	2837	1990	2911	2552	804	1716	1045	1010	320	705	80	539	320	2435
2000	19340	29071	12974	18627	16220	19669	14950	10117	11553	9928	3345	5427	3955	2717	1310	2709	265	1470	1310	7757
2001	20344	44451	20694	25753	22184	16593	9665	4839	5137	4484	1492	2471	1545	1362	643	1109	175	824	643	4482
2002	10040	33131	18597	13158	9120	9171	6846	4380	6006	5313	1699	3476	2053	2046	696	1430	202	1115	696	5313
2003	840	4714	8356	20850	19443	18478	13092	7863	10801	10051	3279	7063	3662	4270	1598	2792	629	2439	1598	12890
2004	5958	5660	2092	2537	3567	8255	7560	5288	8479	8618	2871	6954	2968	4378	1924	2576	866	2794	1924	16191
2005	4201	4323	2012	2784	3836	9869	9393	6931	10296	9875	3269	7332	3684	4419	1814	2913	759	2642	1814	14728
2006	44120	35631	8054	7238	6703	8802	9417	6528	14774	15648	4994	14441	5398	9659	3847	4781	1967	6478	3847	37015
2007	24531	128029	67188	19124	7326	8707	7376	4824	8405	8454	2739	7014	2967	4520	1748	2495	799	2784	1748	15325
2008	43985	262478	172674	148047	91323	53729	31280	15702	23250	22959	7433	17778	7213	11602	5022	6177	2310	7992	5022	45589
2009	18107	42788	14748	10829	12257	14366	9760	5252	7847	7656	2476	5816	2443	3766	1259	2049	642	2128	1259	11324
2010	58552	98227	37475	25665	30828	52503	37174	21833	27440	24593	8035	15093	8215	8983	3253	6110	1257	4997	3253	25820
2011	8615	17617	17110	34003	34910	52378	39952	26259	31789	27728	9181	16113	10503	8764	3850	7350	1012	5048	3850	26631
2012	32050	40410	12771	13406	14205	27201	28554	21680	36693	35756	11588	28599	13608	17833	7714	10766	2944	11650	7714	64807
2013	6803	7520	5505	13956	13771	24883	28094	22103	38364	35844	11307	27931	14497	17316	6137	10616	2170	10230	6137	51394
2014	2155	3114	4766	15071	20583	38743	39077	28420	50052	46327	14393	35894	18343	22637	6791	13256	2562	12503	6791	59768
2015	24429	181549	110000	36872	19083	38724	34780	23628	40224	38192	12069	29568	13858	18906	7249	10662	2826	12061	7249	64472
EVHOE	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20+**
1997	1876	6003	3741	3911	3938	7065	5867	4218	4832	4259	1461	2428	1699	1214	623	1215	159	659	623	3737
1998	12977	15997	6248	6247	5591	7435	5732	3777	4806	4386	1463	2843	1635	1619	676	1224	232	904	676	4888
1999	7576	31223	19915	8732	3499	3308	2715	1905	2720	2357	743	1540	975	893	285	647	62	474	285	2102
2000	17676	27730	12586	17986	15525	18740	14297	9737	11041	9490	3208	5160	3797	2556	1266	2604	253	1384	1266	7385
2001	14389	41313	20357	25467	21921	16211	9247	4525	4543	3951	1332	2057	1322	1098	578	959	153	684	578	3884
2002	6719	31728	18455	12784	8389	7115	4767	2851	3429	3018	994	1806	1123	1009	421	796	117	573	421	2964
2003	509	3993	7348	18371	17276	16113	10798	6270	7620	6852	2267	4294	2501	2456	1009	1838	326	1387	1009	7340
2004	1265	1976	1261	1722	2227	4124	3228	2061	2871	3058	1066	2426	939	1509	901	917	382	1142	901	7311
2005	2102	2603	1497	2098	3015	7160	5992	4177	5301	4873	1642	3144	1796	1776	833	1368	285	1065	833	6107
2006	35834	26593	4803	2199	1386	1489	1332	947	1521	1484	485	1170	557	725	311	445	125	464	311	2596
2007	16818	122140	65369	16986	4919	4316	2967	1715	2452	2392	788	1802	820	1124	484	678	204	715	484	4049
2008	41611	258758	168378	134061	77106	37738	18750	8277	9132	8183	2660	4868	2458	2992	1226	1876	492	1919	1226	10417
2009	13338	36829	12194	5626	5982	7788	5443	3054	4443	4230	1364	3079	1382	1965	618	1114	309	1064	618	5485
2010	33601	83903	35048	21678	23503	34210	23037	12643	16303	14519	4647	9008	4716	5551	1689	3457	690	2957	1689	14298
2011	2212	12471	14982	28729	26114	31844	23915	15535	19473	16964	5542	10176	6534	5663	2262	4513	597	3197	2262	16235
2012	20089	34348	11535	11098	10795	14979	13308	9004	15662	14714	4598	11467	5540	7325	2325	4142	920	4164	2325	20439
2013	1647	3695.1	3805.3	10388	9207	11385	11271	8299	14485	13797	4374	10961	5364	6893	2550	4068	981	4205	2550	21823
2014	1524	2365.1	3804.7	12988	17315	27692	24954	17460	27410	25016	7911	18266	9918	11160	3465	7107	1227	5977	3465	28811
2015	19233	175572	108367	35891	17618	33196	26770	17433	25562	22840	7208	15396	8396	9445	3078	5952	1033	5325	3078	25978
IGFS+WCSGFS+EVHOE	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20+**
2003	636	4552	8306	20803	19406	18414	13013	7804	10668	9916	3237	6942	3612	4190	1573	2752	617	2393	1573	12654
2004	1685	3414	1912	2444	3481	8017	7255	5037	8031	8189	2735	6610	2796	4164	1860	2446	838	2683	1860	15644
2005	2930	3604	1895	2694	3773	9738	9200	6777	9949	9514	3154	7004	3553	4203	1731	2801	721	2505	1731	13978
2006	36687	28176	6830	7100	6633	8714	9277	6421	14479	15337	4898	14144	5288	9457	3779	4686	1933	6356	3779	36365
2007	17873	124020	66810	18929	7205	8648	7322	4790	8309	8353	2708	6917	2932	4453	1729	2464	788	2746	1729	15126
2008	42240	260577	172031	147113	90691	53328	31023	15587	22918	22641	7344	17496	7113	11395	4967	6101	2285	7861	4967	44972
2009	13607	37705	13658	10616	12063	14060	9426	5030	7283	7072	2296	5275	2243	3396	1141	1878	582	1909	1141	10185
2010	33976	84649	35967	24858	30441	52245	36921	21671	26982	23992	7828	14456	8055	8546	3060	5910	1145	4712	3060	24053
2011	2884	13954	16666	33742	34724	52174	39716	26089	31387	27290	9039	15699	10356	8486	3752	7213	958	4882	3752	25707
2012	20395	35049	12386	13340	14140	26984	28191	21406	35924	34955	11342	27840	13323	17314	7548	10525	2861	11338	7548	63197
2013	2021	4557.2	5053.5	13515	13490	24723	27933	21993	38084	35555	11218	27662	14393	17133	6074	10529	2140	10116	6074	50796
2014	1608	2472.2	3961.5	13920	19658	37649	37854	27659	47709	43766	13598	33366	17513	20876	6103	12489	2234	11310	6103	53097
2015	20221	179118	109751	36408	18564	38073	34281	23340	39684	37587	11866	29018	13680	18538	7082	10480	2733	11805	7082	62919
SPNGFS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20+**
1997	7306	5446	1609	681	249	203	121	67	69	56	18	22	18	11	4	11	0	6	4	23
1998	4493	3640	638	175	101	79	58	37	54	53	17	40	19	25	9	15	4	14	9	77
1999	4258	1802	116	93	80	112	121	85	191	195	61	175	70	117	35	58	18	65	35	333
2000	1661	1325	347	518	553	750	537	315	443	379	116	237	139	146	37	91	10	78	37	325
2001	5952	3099	308	205	161	197	190	148	199	175	58	114	77	62	25	53	6	34	25	169
2002	3315	1395	104	54	43	55	63	47	98	88	26	71	37	46	10	25	3	24	10	97
2003	203	155	38	26	16	14	10	5	9	9	3	7	3	4	2	2	1	3	2	15
2004	4267	2243	177	82	68	171	219	186	303	279	89	209	118	124	37	85	14	63	37	294
2005	1253	701	108	78	46	50	60	51	84	78	25	59	33	35	15	24	4	22	15	116
2006	7297	7378	1191	85	34	36	56	44	116	112	33	100	43	68	14	32	8	35	14	154
2007	6646	3990	367	180	106	37	30	18	55	54	16	50	20	35	8	15	4	20	8	92
2008	1736	1886	629	908	597	329	178	62	202	183	47	158	53	122	28	36	10	81	28	352
2009	4487	5077	1085	168	104	79	71	26	174	155	37	147	56	113	9	34	6	58	9	194
2010	24558	13572	1504	792	346	101	85	41	222	365	132	436	76	306	146	130	91	206	146	1347
2011	5730	3656	432	244	163	94	77	38	140	182	61	198	48	140	50	59	33	84	50	493
2012	11653	5359	383	62	55	160	276	202	620	657	201	638	228	441	140	198	73	266	140	1382
2013	4763	2947	446	439	276	110	59	30	44	49	17	44	16	28	15	16	7	21	15	132
2014	542	611	767	1131	910	875	626	323	711	914	317	926	228	635	271	291	168	402	271	2512
2015	4207	2430	248	463	516	616	432	233	403	463	158	419	125	281	130	138	74	193	130	1195

Table B.4.2 Boarfish in ICES Subareas 6, 7, 8. Boarfish acoustic survey results.

	Abundance					
Age (Yrs)	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
0	-	-	-	-	-	-
1	4.97	21.49	-	-	198.49	4.58
2	11.61	*10.776*	78	-	319.2	35.746
3	57.84	174.05	1842.9	15	16.64	45.46
4	187.42	64.828	696	98	34.34	43.6
5	436.71	94.966	381.6	102.3	80.04	5.96
6	1165.94	736.06	253.8	104.9	111.98	10
7	1184.16	973.77	1056.6	414.6	437.37	169.001
8	703.59	758.9	879.4	343.8	362.91	112.6
9	1094.46	848.63	800.9	341.9	353.53	117.62
10	1031.49	955.85	703.8	332.3	360	96.608
11	332.94	650.85	263.7	129.9	131.73	16.96
12	653.31	1099.7	202.9	104.9	112.96	31.951
13	336	857.17	296.6	166.4	174	48.688
14	385	655.75	169.8	88.5	108	18.28
15+	3519	6353.7	1464.251	855.1	1195	400.07

TSN ('000)	11104	14256.56	9091	3098	3996	1157
TSB (t)	670176	863446	439890	187779	232634	69690
SSB (t)	669392	861544	423158	187654	226659	69103
CV	21	11	18	15	17	19

Table C 1.1. Boarfish in ICES Subareas 6, 7, 8. Key parameter estimates from all runs. CV(TSB_{2013}) is the coefficient of variation of the estimated total stock biomass in 2013.

Run	*r*	*K*	F_{MSY}	B_{MSY}	TSB_{2013}	CV(TSB_{2013})
1	0.481	731549	0.241	365775	500945	0.156
2	0.493	835581	0.247	417791	633617	0.44
3	0.467	634469	0.233	317234	472169	0.153
4	0.466	865294	0.233	432647	665705	0.555
1.1	0.552	768400	0.276	384200	493886	0.161
2.1	0.551	898583	0.275	449292	604780	0.444
3.1	0.528	660356	0.264	330178	470985	0.157
4.1	0.517	828299	0.259	414150	607527	0.434
2.2	0.459	911209	0.229	455605	653668	0.436

Table C1.2. Boarfish in ICES Subareas 6, 7, 8. Pseudo-cohort derived estimates of fishing mortality (F) and total mortality (Z), in comparison with total landings per year. Pearson correlation coefficient of F vs. landings (tonnes) indicated.

Age	2007	2008	2009	2010	2011	2012	2013	2014	2015	2007	2008	2009	2010	2011	2012	2013	2014	2015
	Raised numbers									ln (raised numbers)								
1	0	0	1575	2415	0	28	301	0	5559	0	0	7	8	0	3	6	0	9
2	352	5488	15043	11229	2894	893	7148	695	116185	6	9	10	9	8	7	9	7	12
3	2114	21140	65744	72709	41913	5467	156680	49503	32263	8	10	11	11	11	9	12	11	10
4	40851	105575	338931	294382	28148	41278	58522	127520	16502	11	12	13	13	10	11	11	12	10
5	48915	141300	475619	567689	30116	110272	59797	93705	24507	11	12	13	13	10	12	11	11	10
6	62713	195339	543707	878363	175696	146582	68949	67275	26544	11	12	13	14	12	12	11	11	10
7	26132	104031	307333	522703	143967	492078	302967	193061	74188	10	12	13	13	12	13	13	12	11
8	29766	66570	172783	293719	107126	365840	250341	139124	52142	10	11	12	13	12	13	12	12	11
9	56075	53159	155477	276672	77861	271916	212318	121042	44677	11	11	12	13	11	13	12	12	11
10	44875	46893	130148	232122	60022	173486	160137	94225	34287	11	11	12	12	11	12	12	11	10
11	14019	15289	42521	78588	46079	69396	63025	36078	13012	10	10	11	11	11	11	11	10	9
12	32359	21178	61350	114600	40468	40968	41490	24895	9116	10	10	11	12	11	11	11	10	9
13	4848	11854	39609	59932	24352	58888	59380	36309	13361	8	9	11	11	10	11	11	10	10
14	16837	13570	31569	59060	19724	30277	30355	19064	7147	10	10	10	11	10	10	10	10	9
15+	109481	112947	196967	349320	157707	217260	239366	150688	59047	12	12	12	13	12	12	12	12	11
Z (age 7-14)										0.18	0.32	0.32	0.32	0.28	0.42	0.35	0.34	0.34
F (Z-M), where M = 0.16										0.02	0.16	0.16	0.16	0.12	0.26	0.19	0.18	0.18
Catches (t)										21576	34751	90370	144047	36937	86414	75409	45231	17765
Correllation coefficient landings vs. F										0.39								

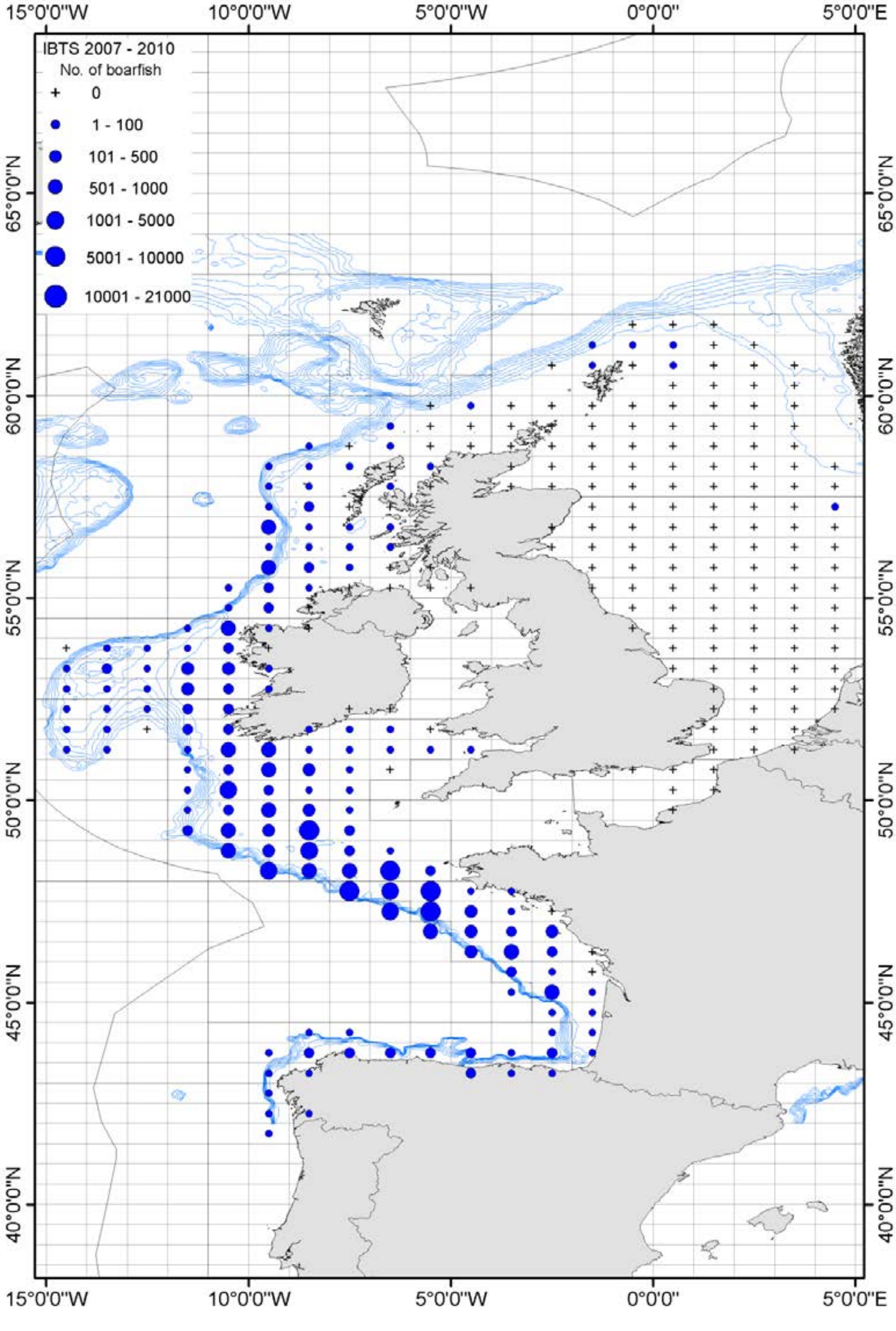

Figure A.1.1 Boarfish in ICES Subareas 5, 6, 7, 8. Distribution of boarfish from IBTS surveys in the NE Atlantic showing proposed management area.

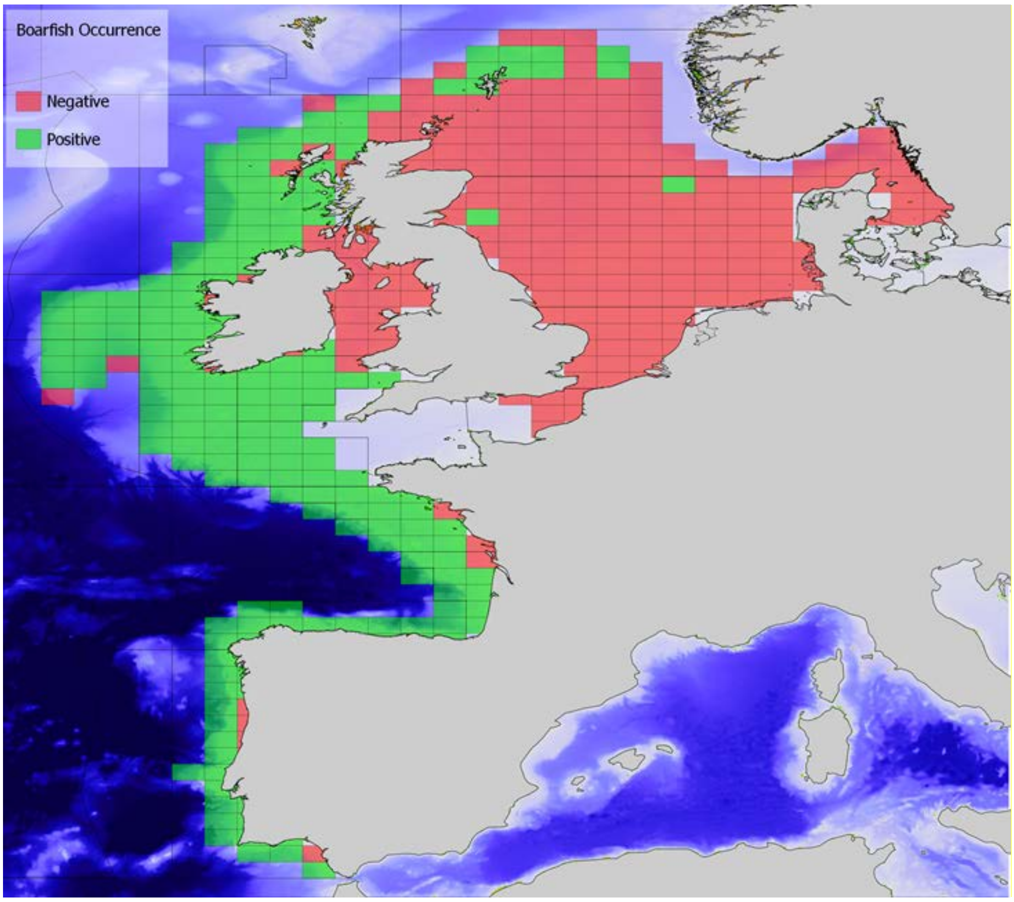

Figure A.1.2. Boarfish in ICES Subareas 6, 7, 8. Distribution of boarfish in the NE Atlantic area based on presence and absence in IBTS surveys.

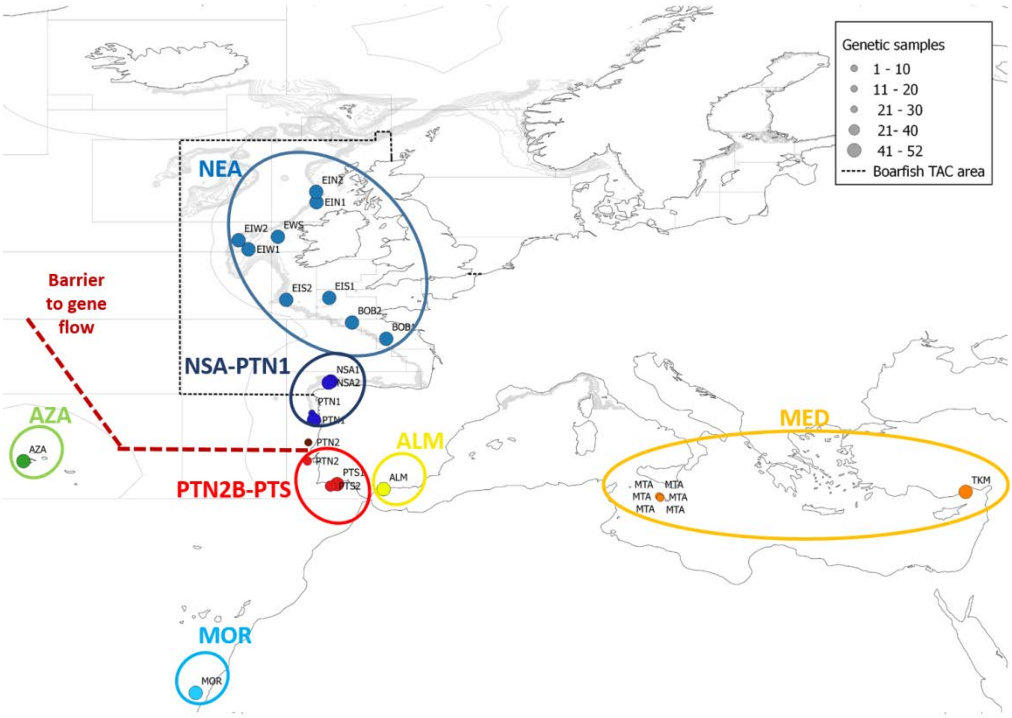

Figure A.1.3. Boarfish samples included in the genetic stock identification. Population clusters identified by multiple analyses are indicated by colour coded markers and circles.

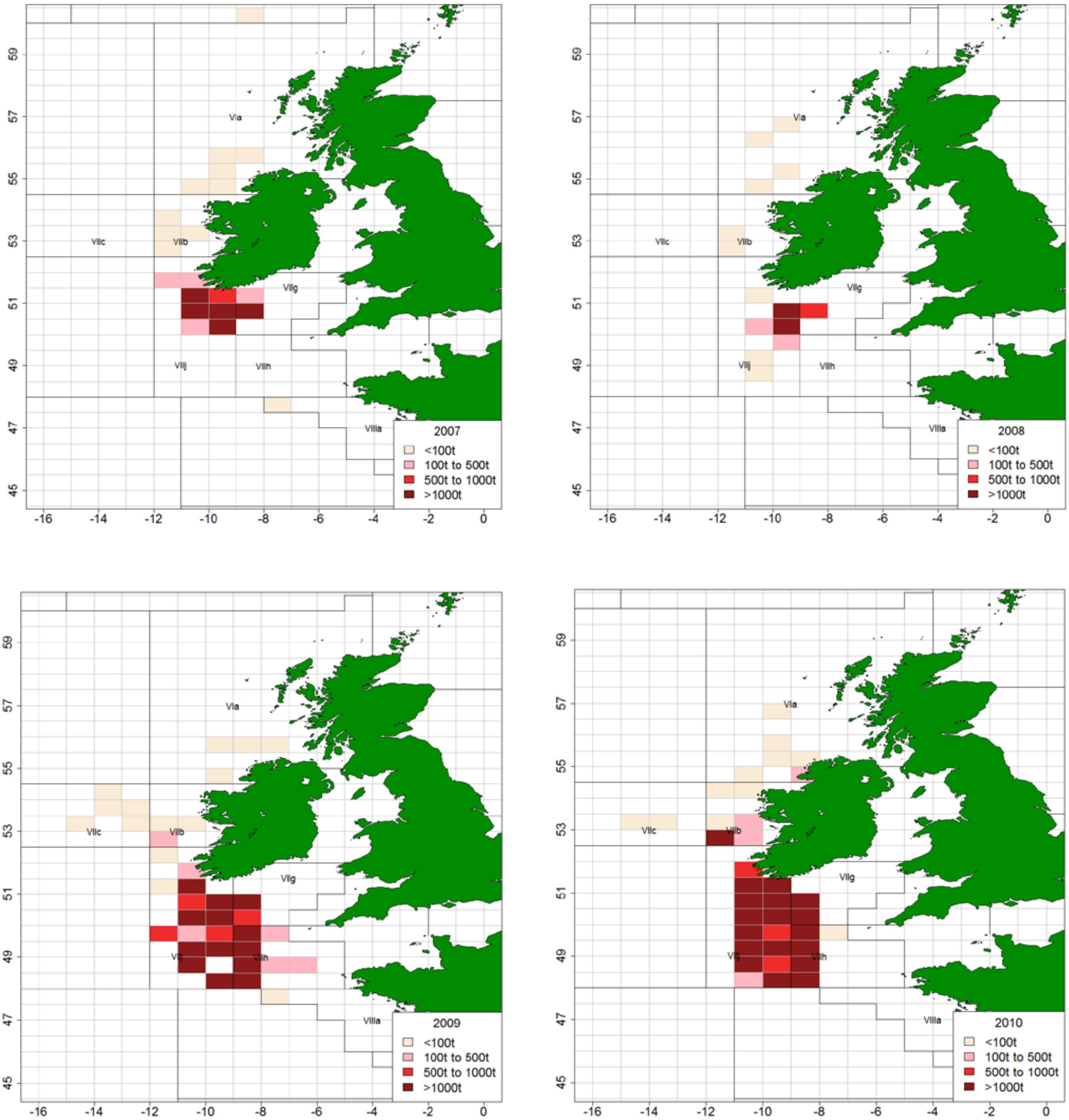

Figure A.2.1. Boarfish in ICES Subareas 6, 7, 8. Irish catches by rectangle and year 2007-2010 Need to update

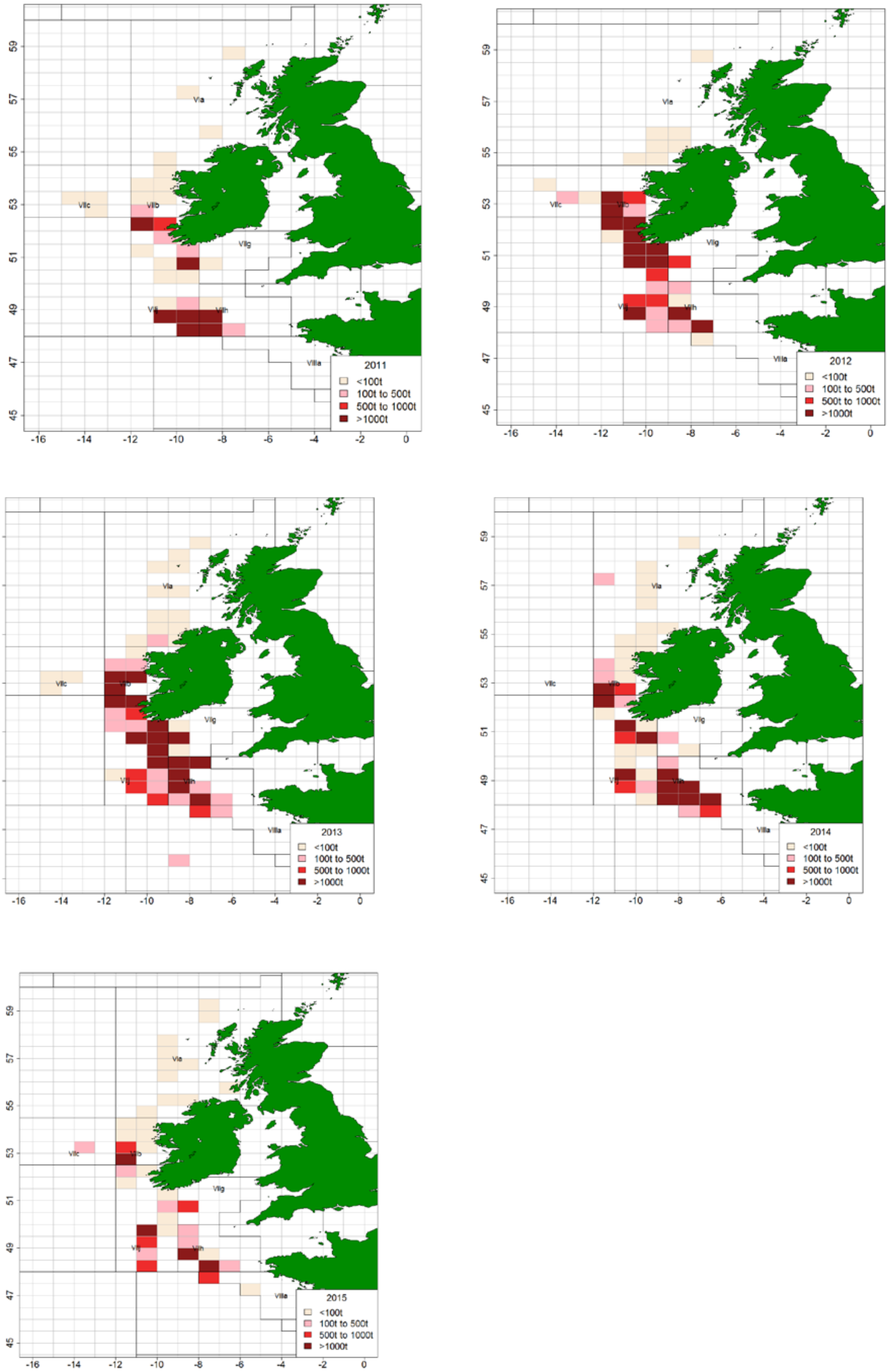

Figure A.2.1. continued Boarfish in ICES Subareas 6, 7, 8. Irish catches by rectangle and year 2011-2015.

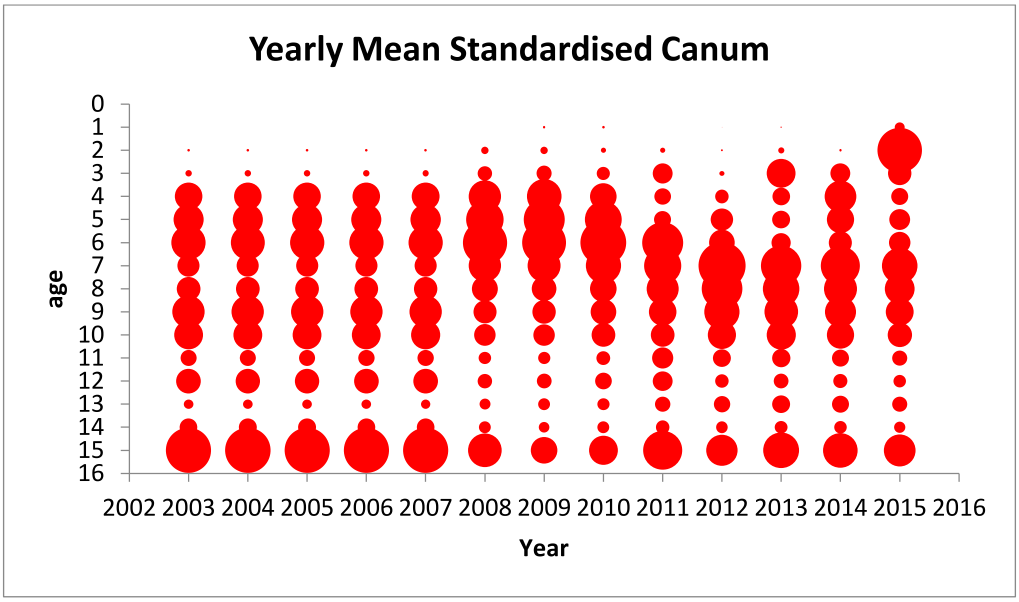

Figure B.2.1. Boarfish in ICES Subareas 6, 7, 8. Catch numbers-at-age standardised by early mean. 15+ is the plus group.

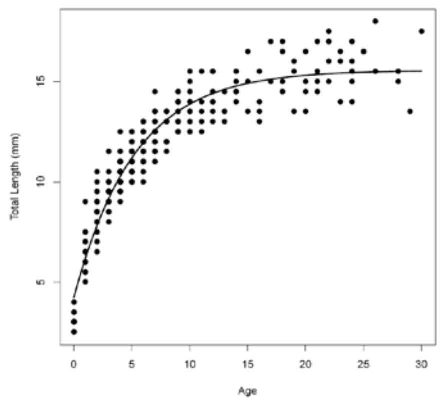

Figure B.3.1 Boarfish in ICES Subareas 6, 7, 8. Von Bertalanffy growth curve; see Table B.3.1 for parameter estimates

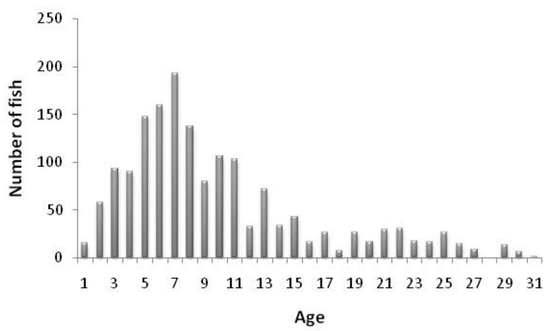

Figure B.3.2 Boarfish in ICES Subareas 6, 7, 8. Age distribution for n=1633 fish sampled

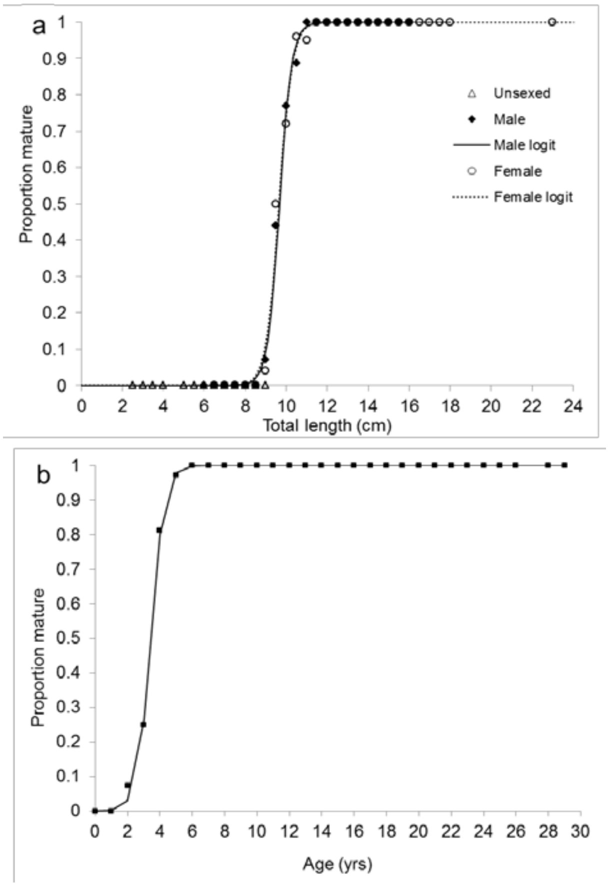

Figure B.3.3 Boarfish in ICES Subareas 6, 7, 8. Maturity ogives for (a) total length and (b) age for boarfish

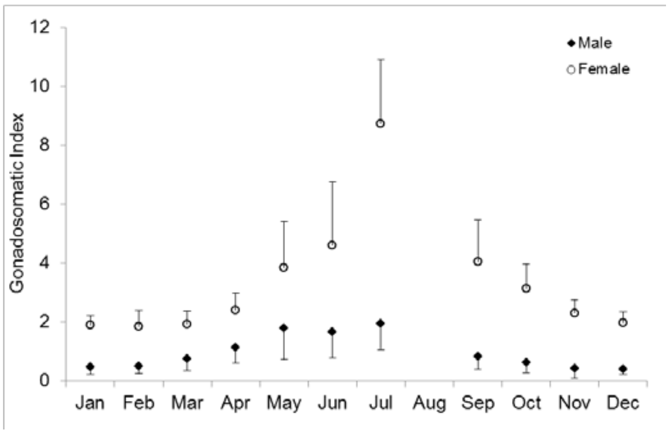

Figure B.3.4 Boarfish in ICES Subareas 6, 7, 8. Gonadosomatic index for male and female boarfish

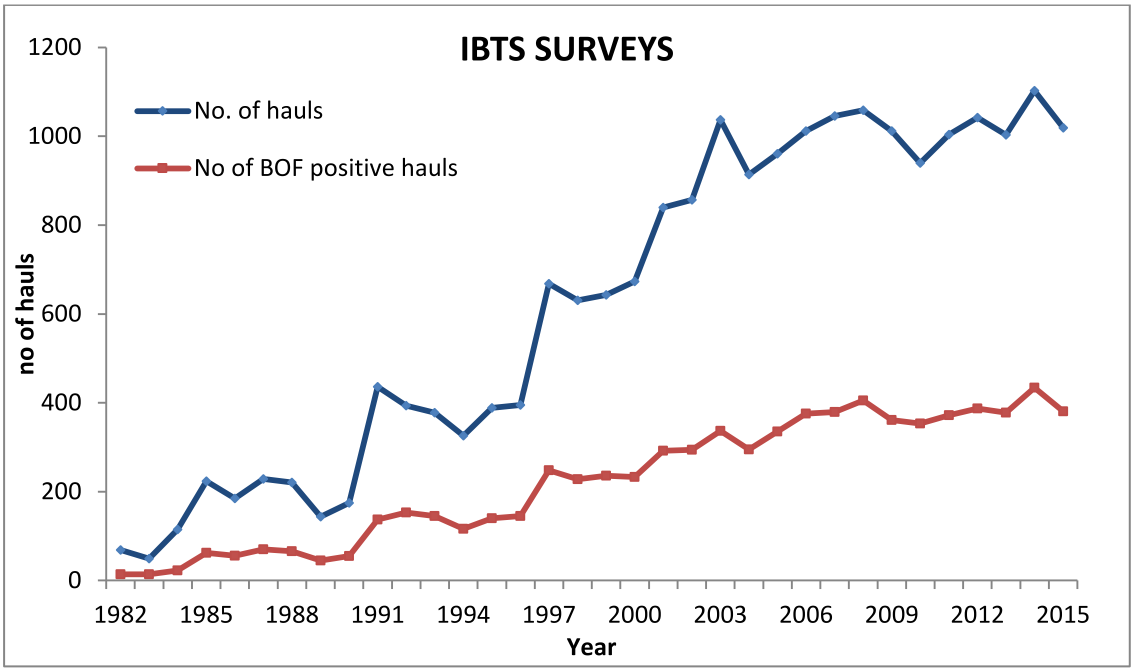

Figure B.4.1 Boarfish in ICES Subareas 6, 7, 8. Occurrence of boarfish in ICES Rectangles sampled during the IBTS 1985 – 2015.

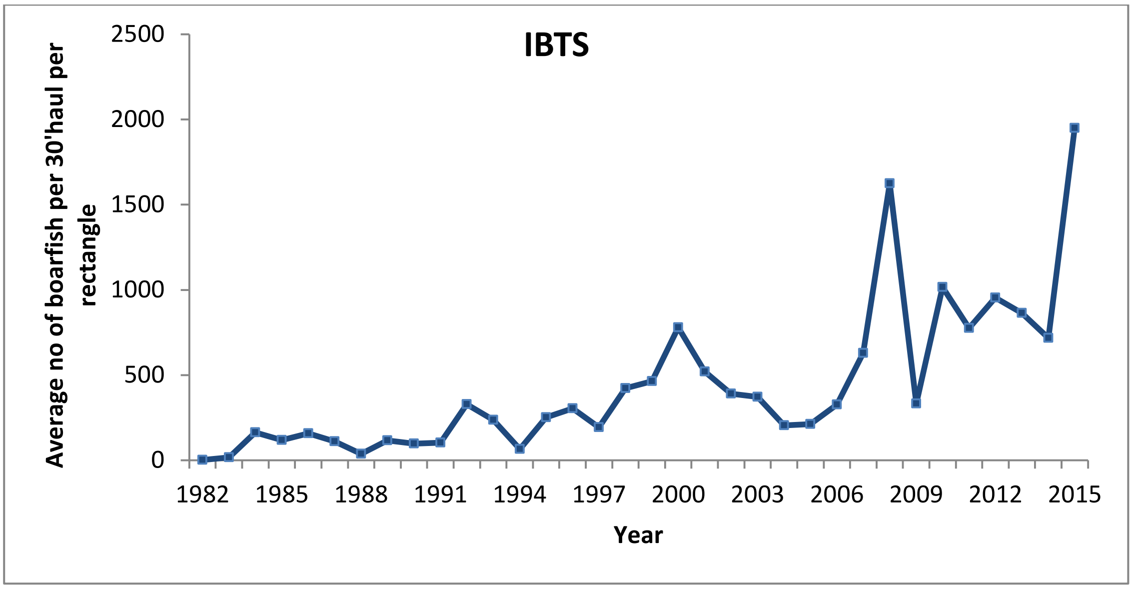

Figure B.4.2 Boarfish in ICES Subareas 6, 7, 8. CPUE in number per 30 minute haul of boarfish per rectangle in the western IBTS survey 1985 to 2015.

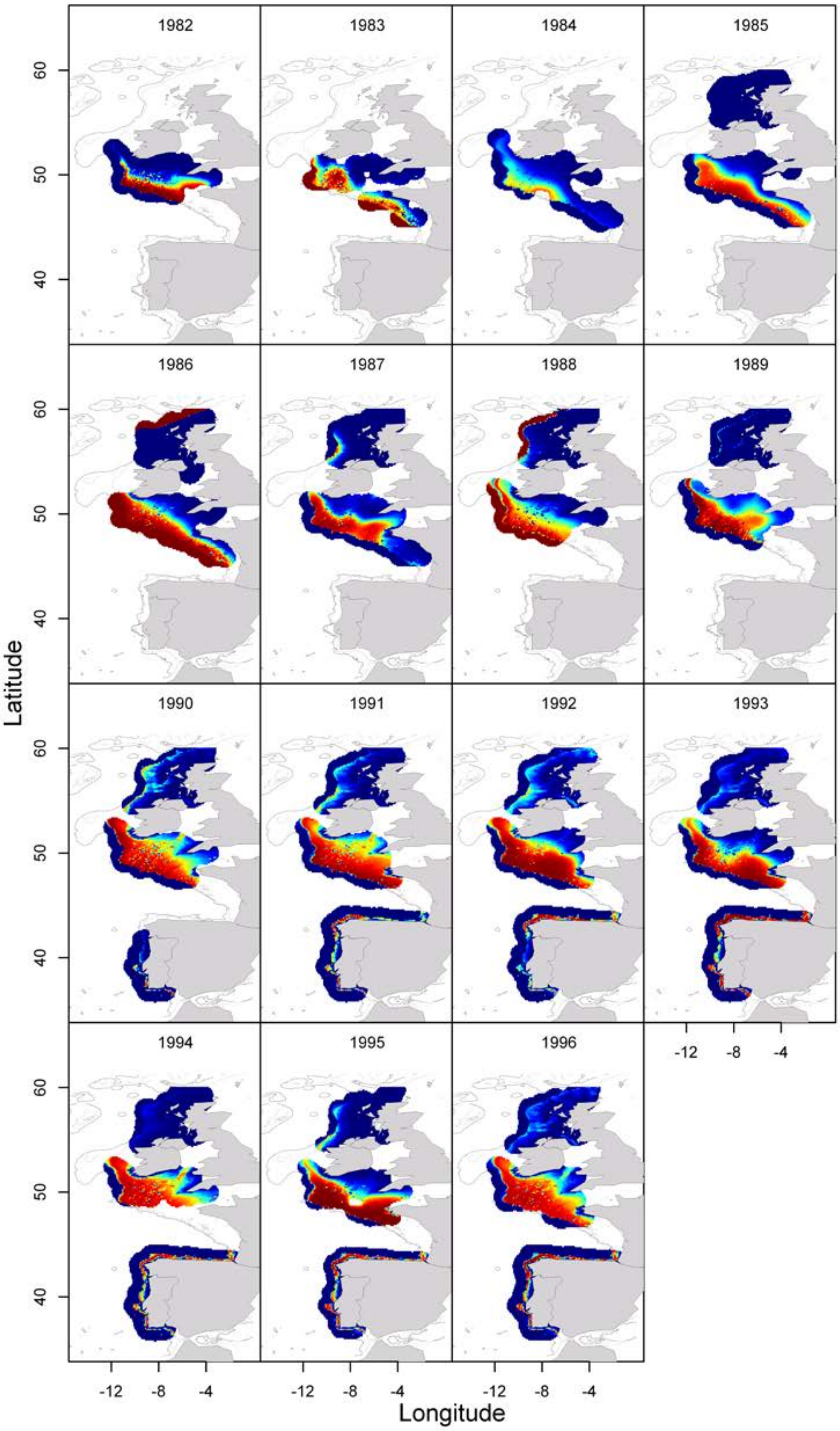

Figure B.4.3. Boarfish in ICES Subareas 6, 7, 8. The occurrence GAM of the probability of occurrence of boarfish in a survey area 1982 – 1996. Red indicates definite occurrence and blue indicates absence.

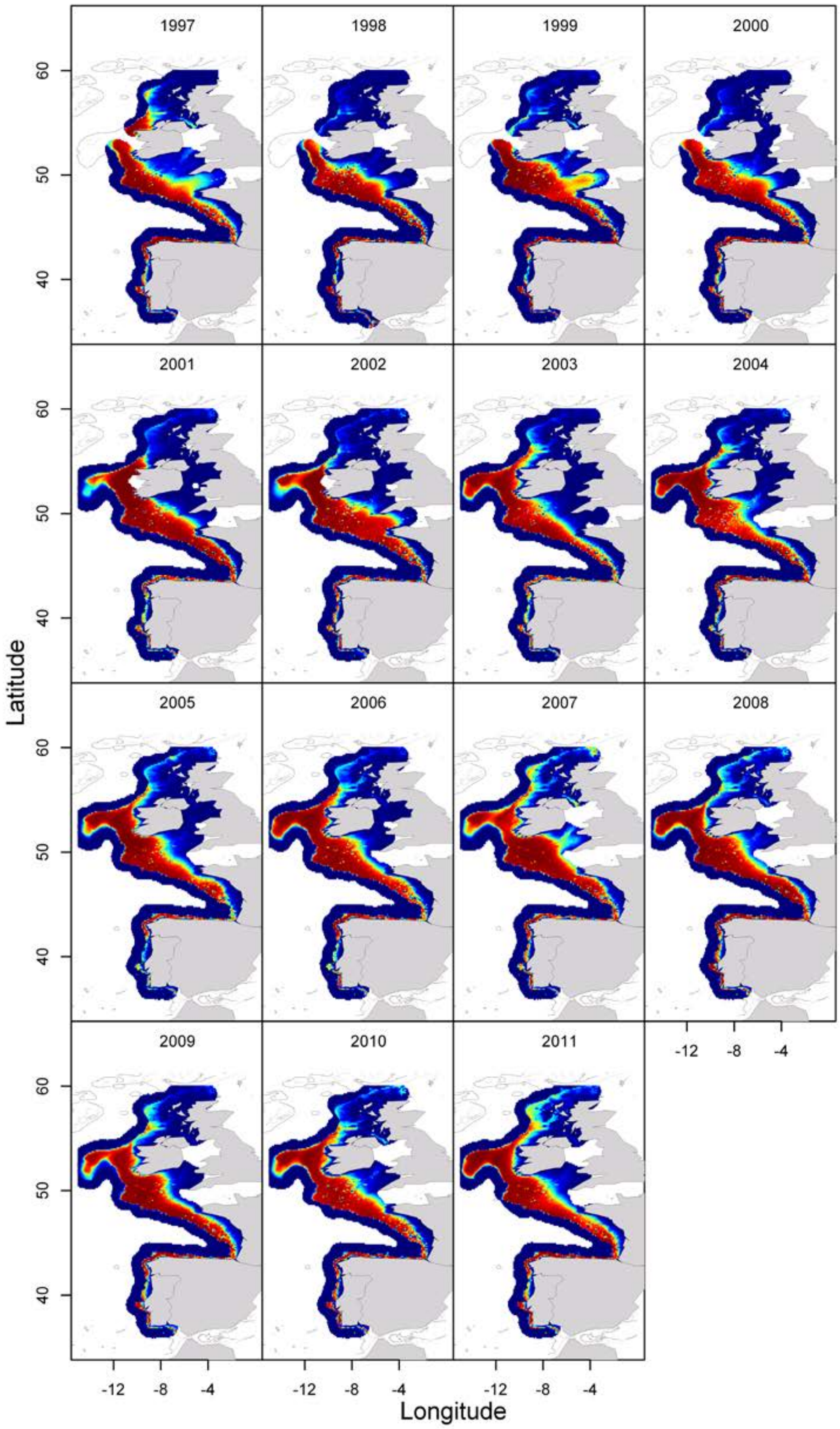

Figure B.4.3. Boarfish in ICES Subareas 6, 7, 8. The occurrence GAM of the probability of occurrence of boarfish in a survey area 1997 – 2011. Red indicates definite occurrence and blue indicates absence.

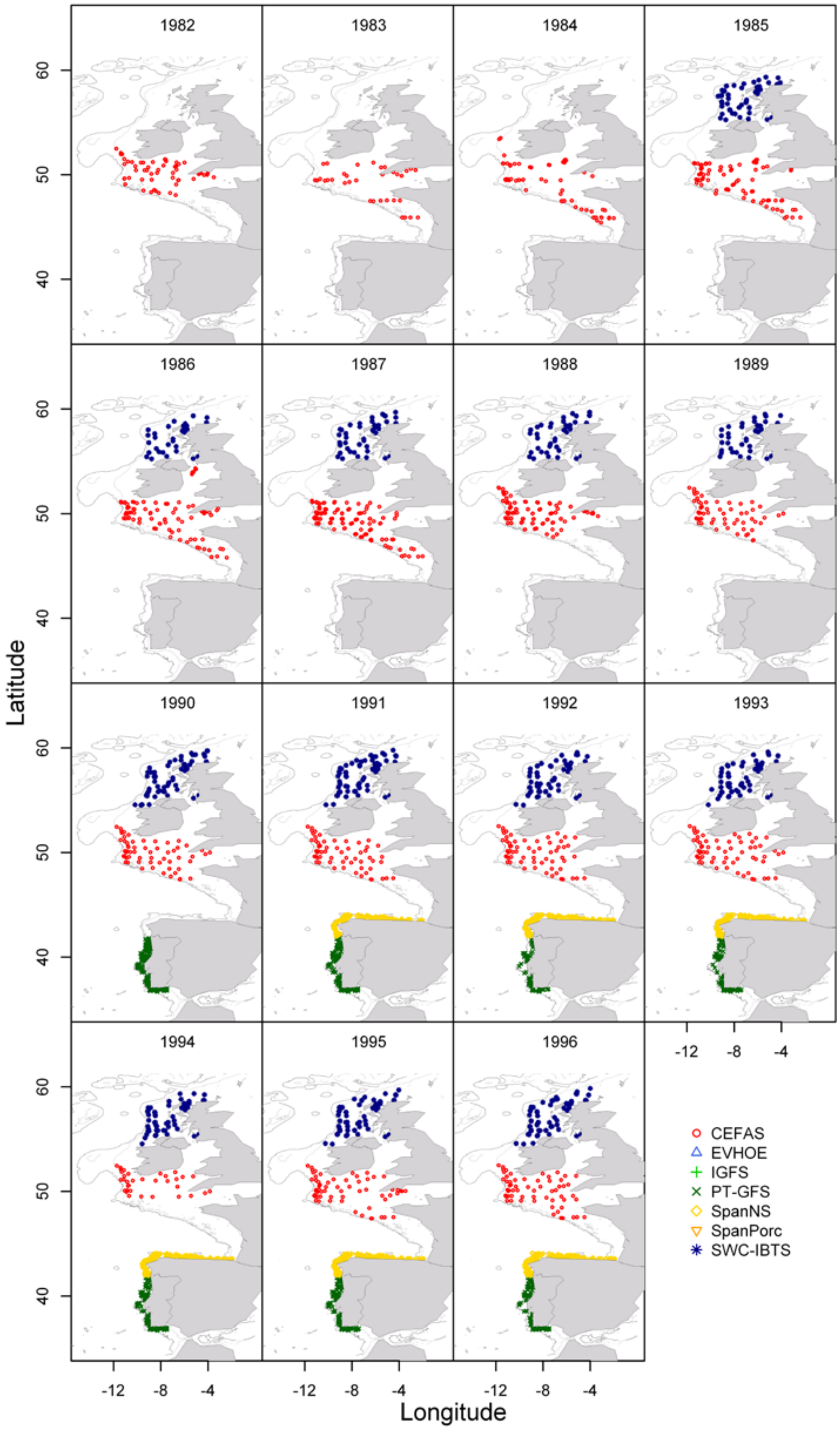

Figure B.4.4 Boarfish in ICES Subareas 6, 7, 8. The haul positions of bottom trawl surveys by year (1982-1996) analysed as part of the GAM modelling.

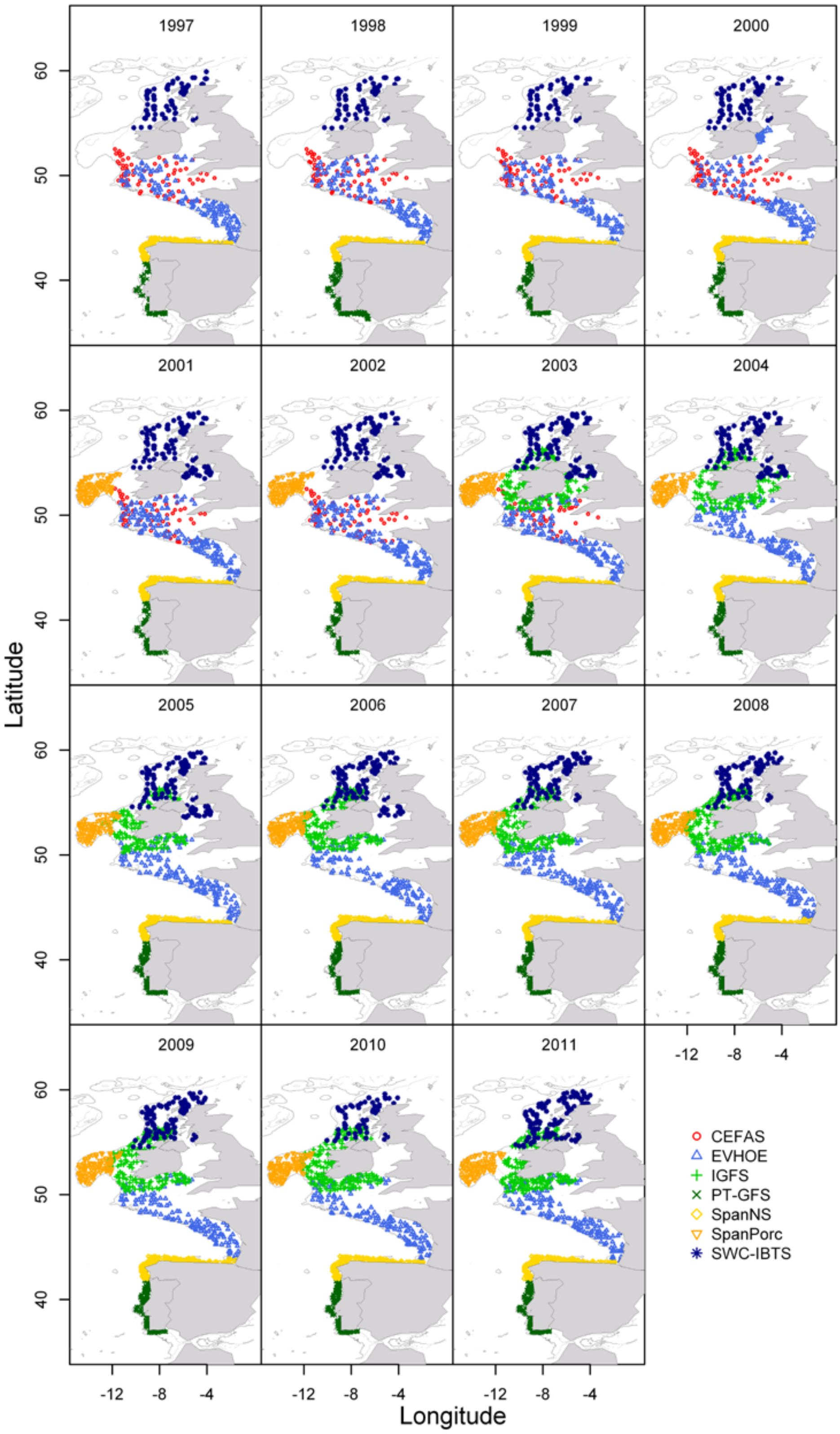

Figure B.4.4 continued Boarfish in ICES Subareas 6, 7, 8. The haul positions of bottom trawl surveys by year (1997-2011) analysed as part of the GAM modellin

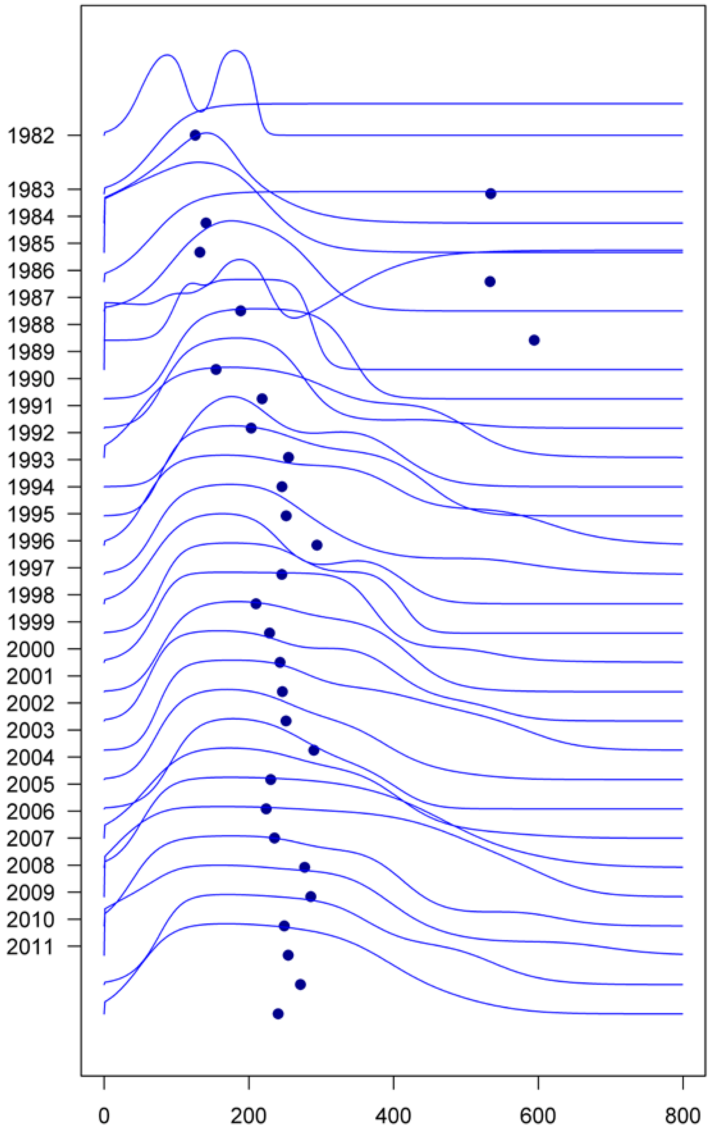

Figure B.4.5. Boarfish in ICES Subareas 6, 7, 8. The depth distribution profile of boarfish within the IBTS surveys.

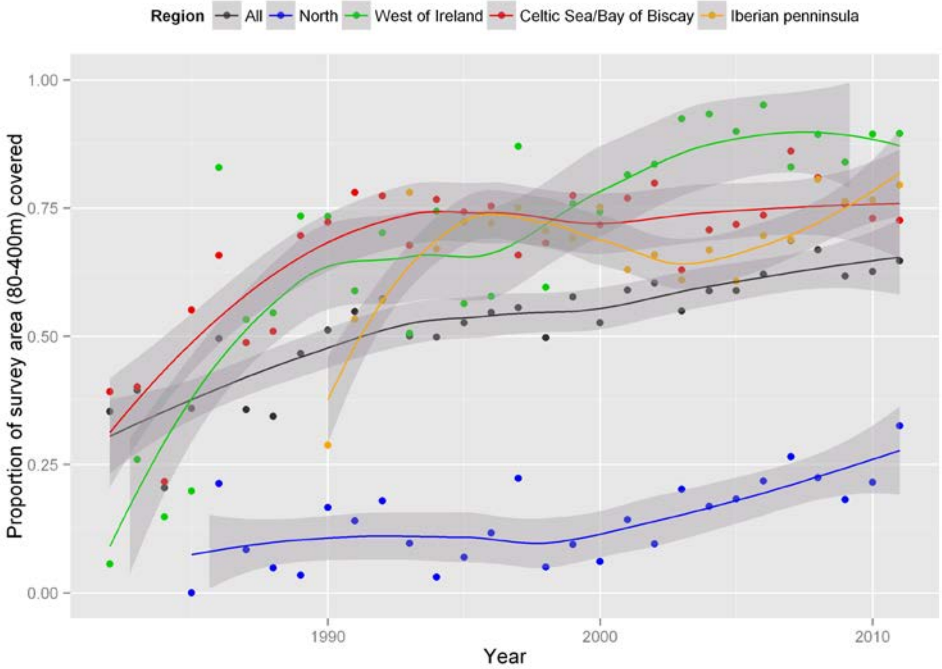

Figure B.4.6. Boarfish in ICES Subareas 6, 7, 8. The proportion of survey area covered by boarfish per region and per year.

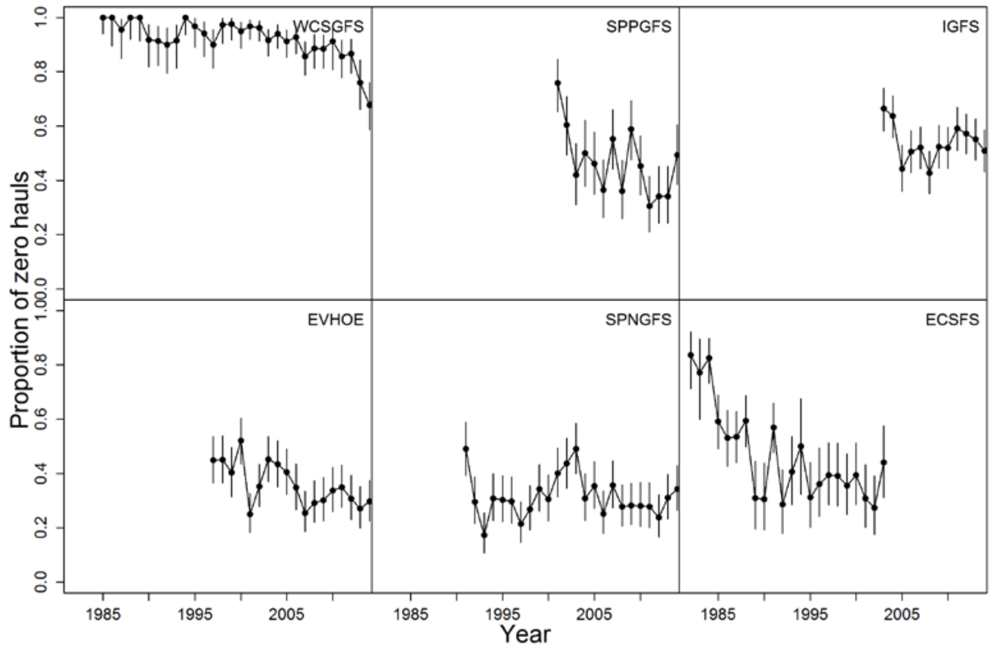

Figure B.4.7. Boarfish in ICES Subareas 6, 7, 8. The proportion of zero hauls per IBTS survey.

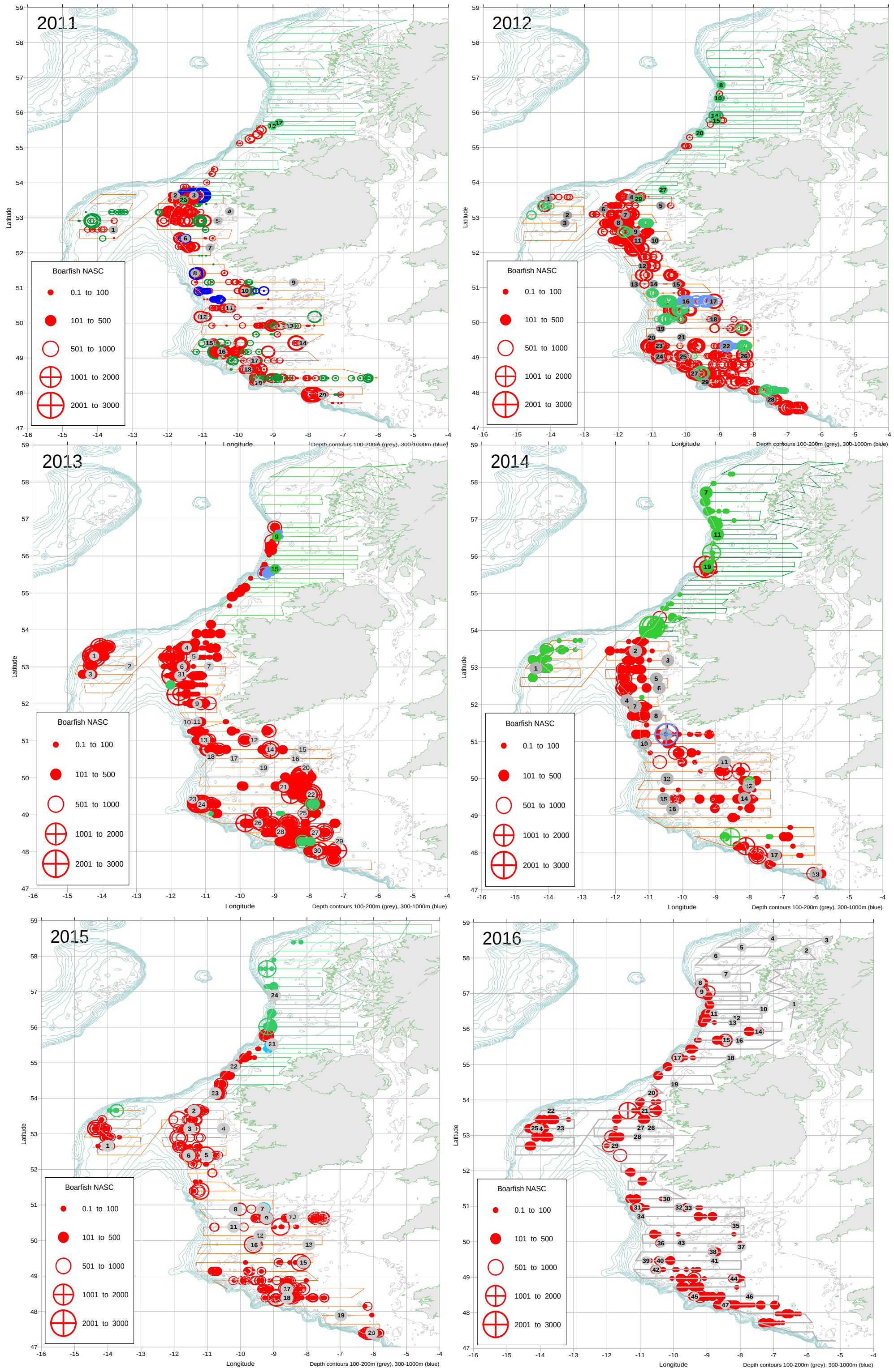

Figure B.4.2.1. Boarfish in ICES Subareas 6, 7, 8. Boarfish acoustic survey track and haul positions from acoustic survey 2011-2016. Red circles represent 'definitely' boarfish, green: 'probably boarfish', blue: 'boarfish mix' (all included in the biomass estimate).

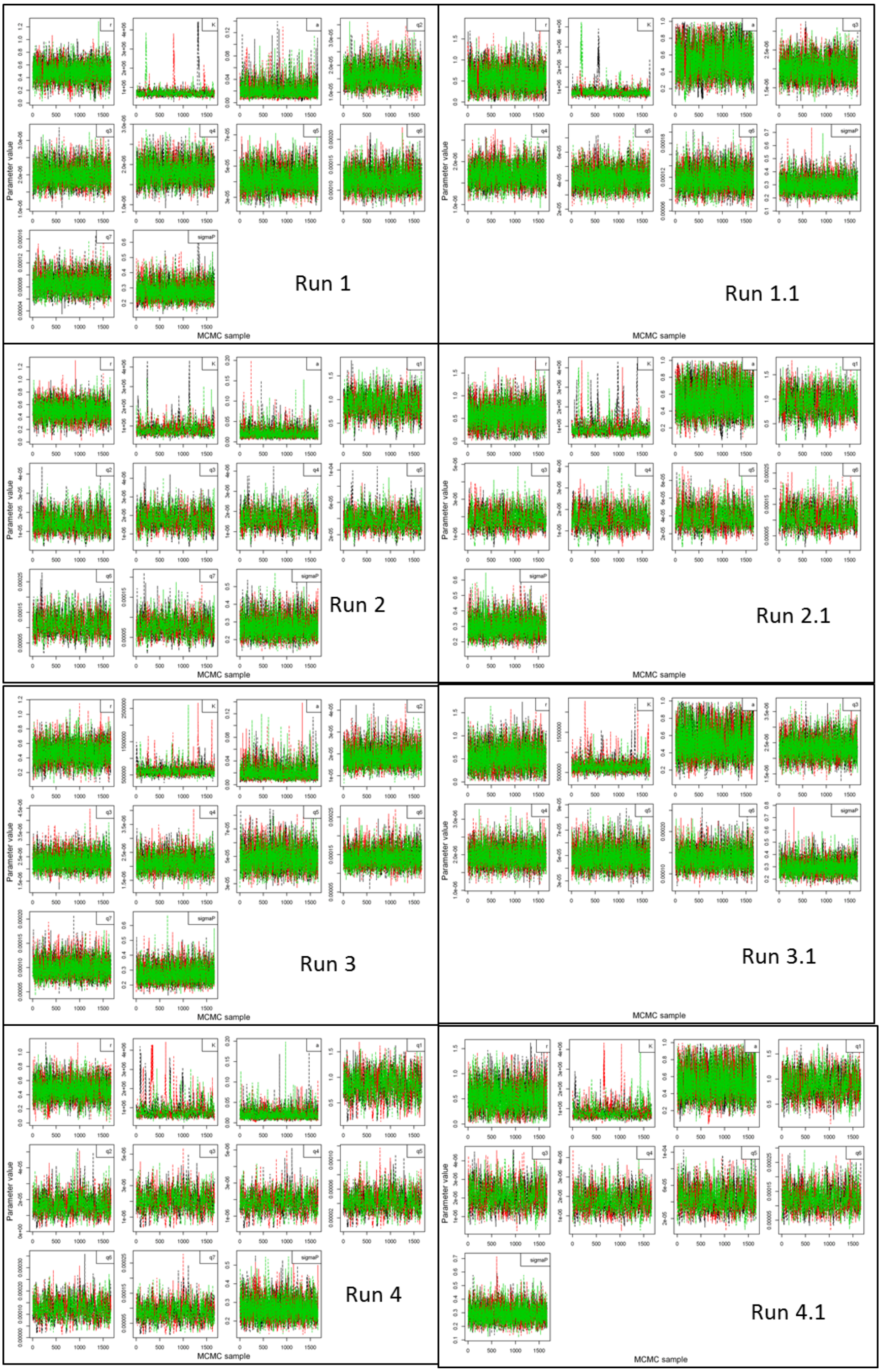

Figure C.1. Boarfish in ICES Subareas 6, 7, 8. Parameters for runs 1-4 and sensitivity runs 1.1, 2.1, 3.1, 4.1 converged with good mixing of the chains.

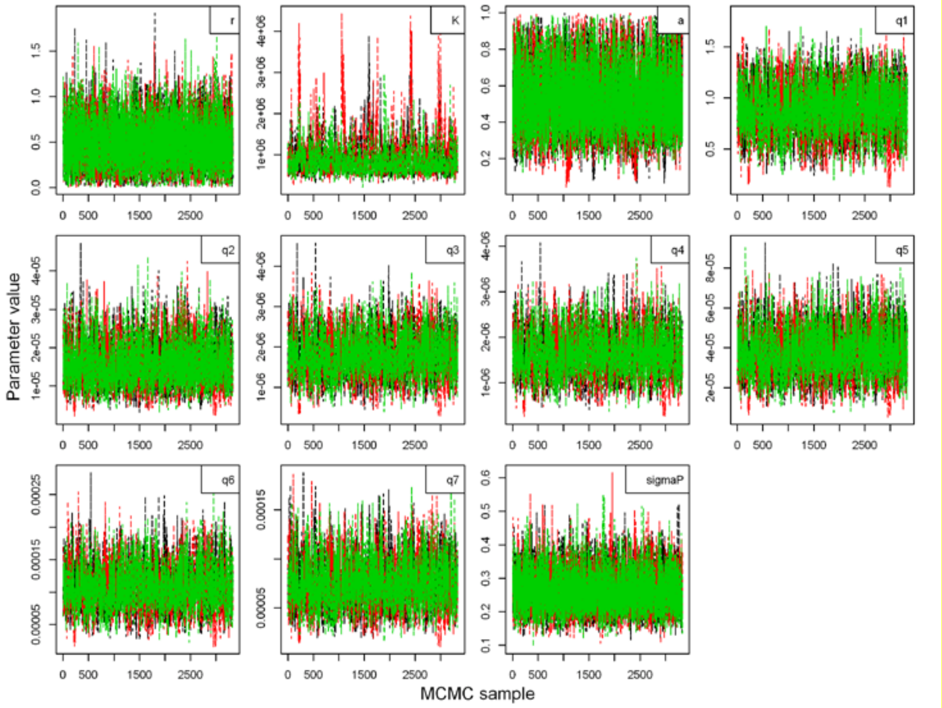

Figure C.2. Boarfish in ICES Subareas 6, 7, 8. Parameters for run 2.2 converged with good mixing of the chains.

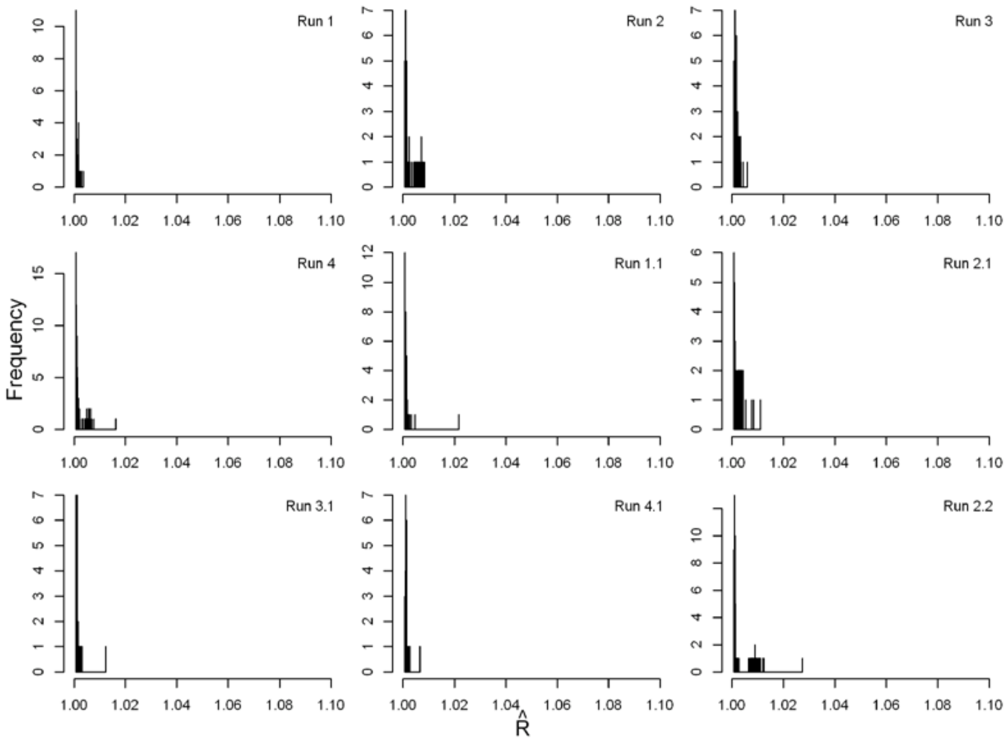

Figure C.3. Boarfish in ICES Subareas 6, 7, 8. Rhat values lower than 1.1 indicating convergence.

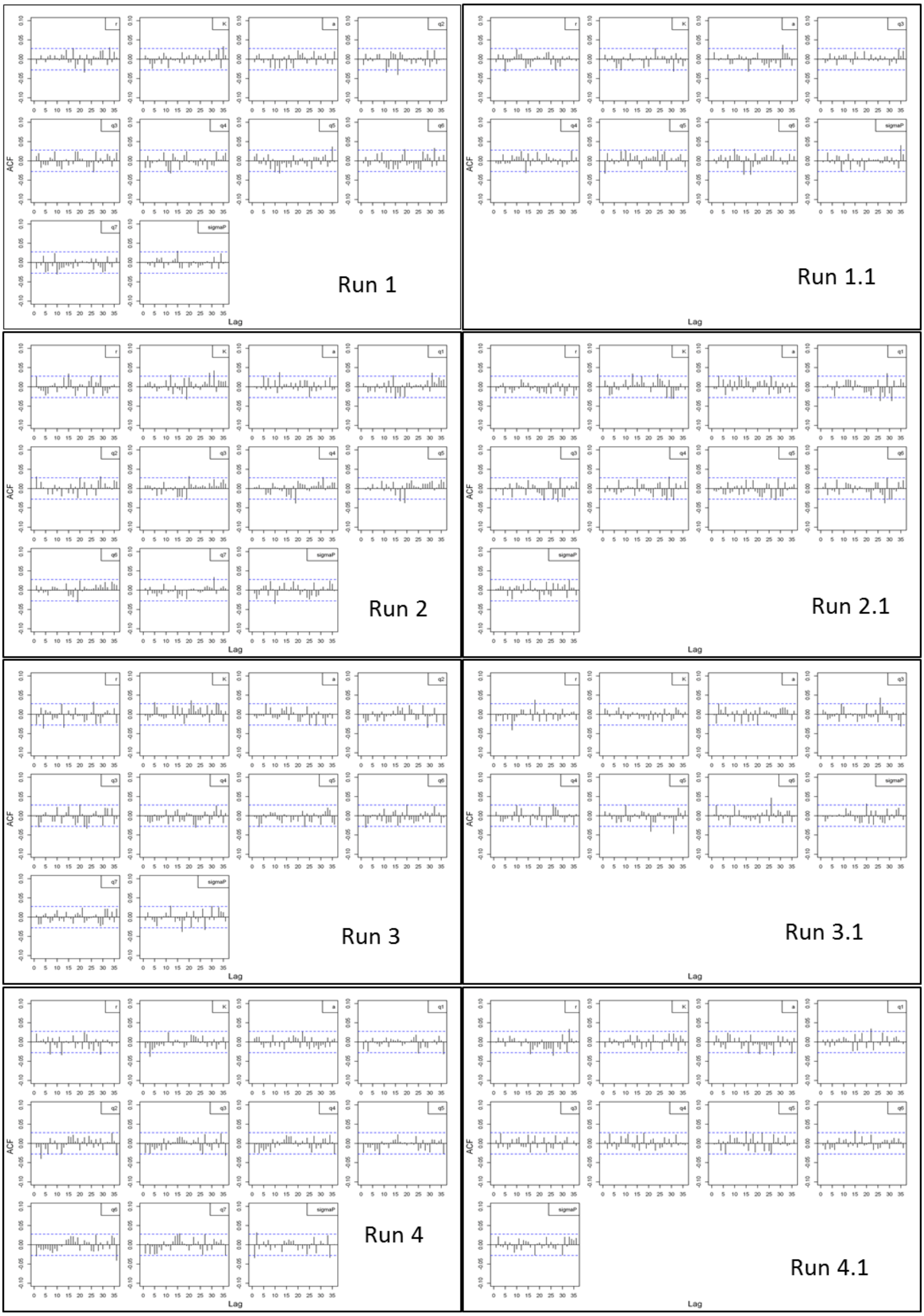

Figure C.4. Boarfish in ICES Subareas 6, 7, 8. MCMC chain autocorrelation for runs 1-4, sensitivity runs 1.1, 2.1, 3.1, 4.1.

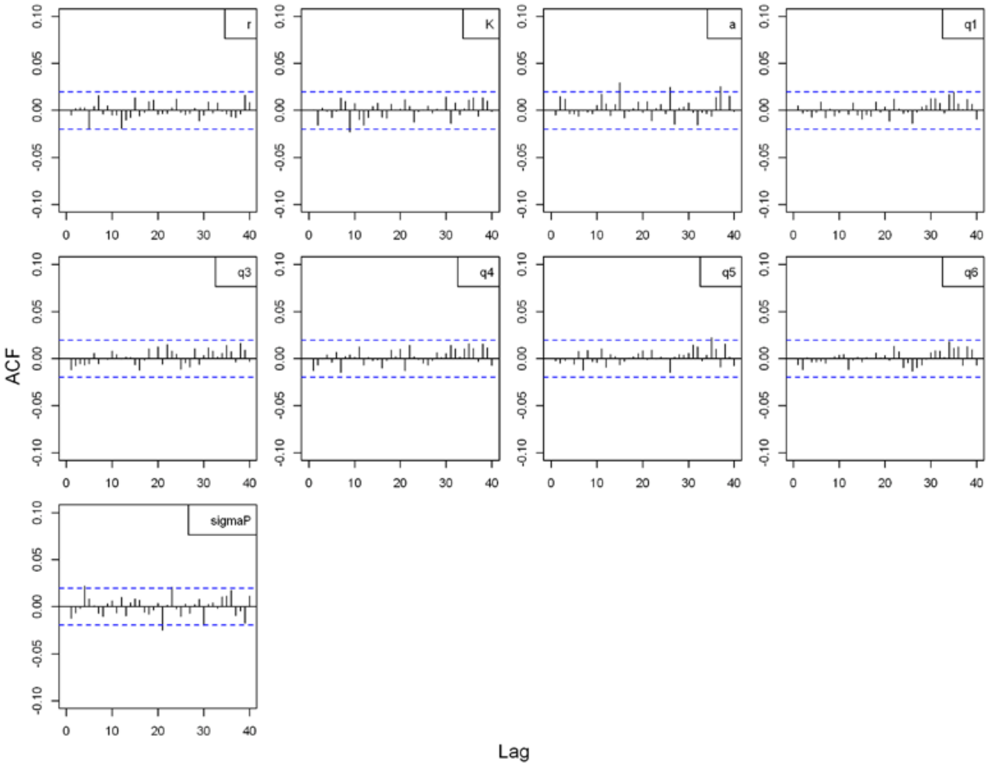

Figure C.5. Boarfish in ICES Subareas 6, 7, 8. MCMC chain autocorrelation for run 2.2.

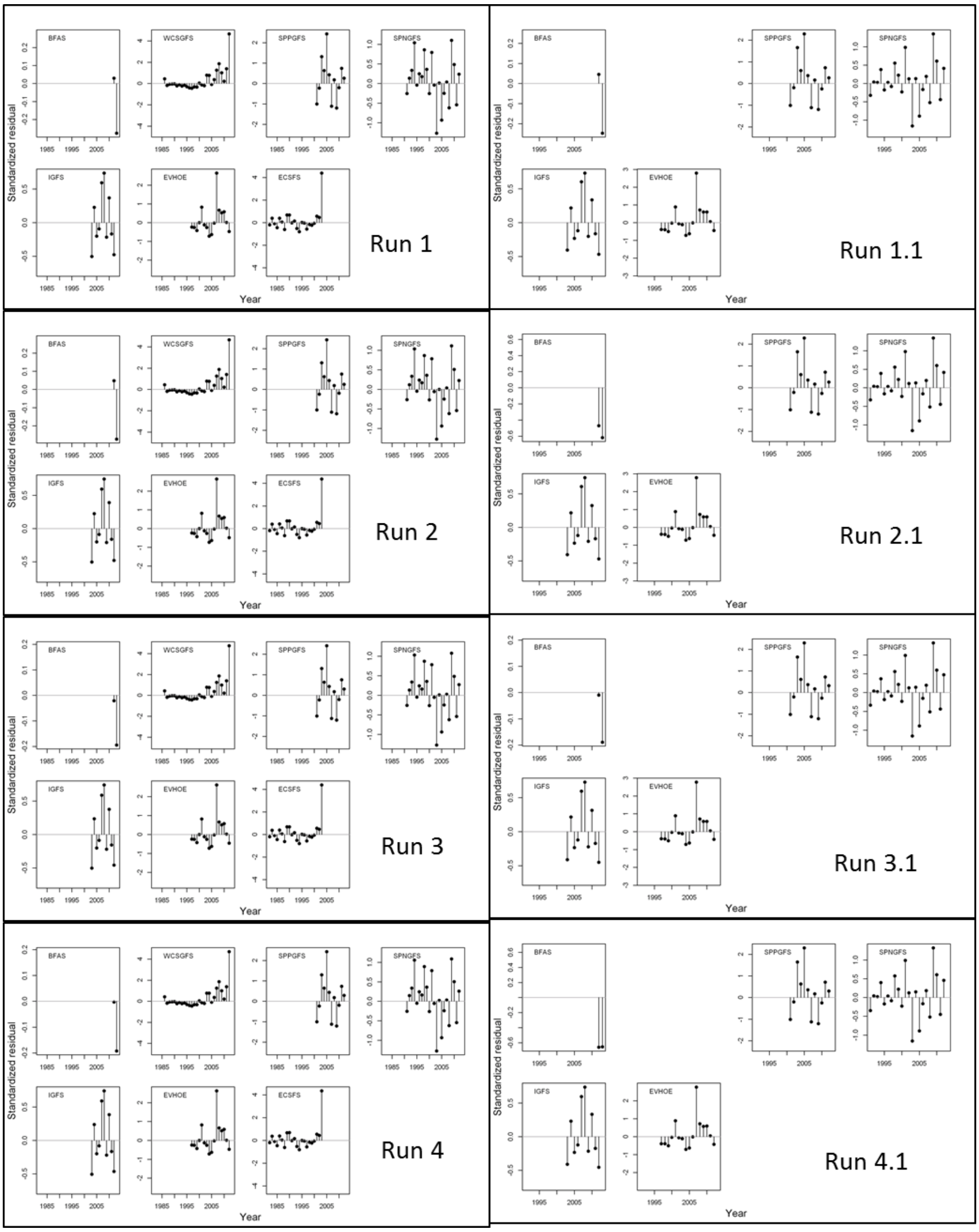

Figure C.6. Boarfish in ICES Subareas 6, 7, 8. Residuals around the model fits for runs 1-4, sensitivity runs 1.1, 2.1, 3.1, 4.1.

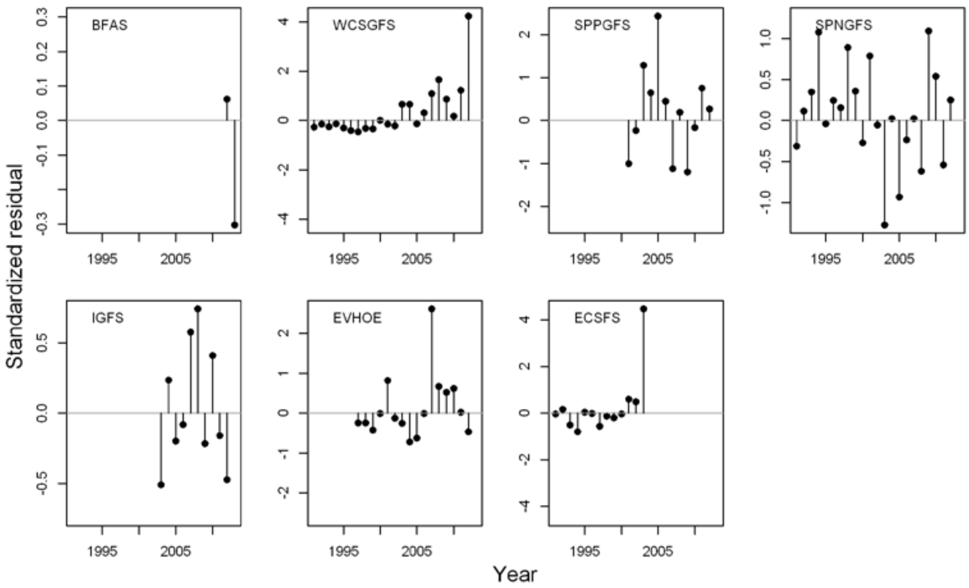

Figure C.7. Boarfish in ICES Subareas 6, 7, 8. Residuals around the model fit for run 2.2.

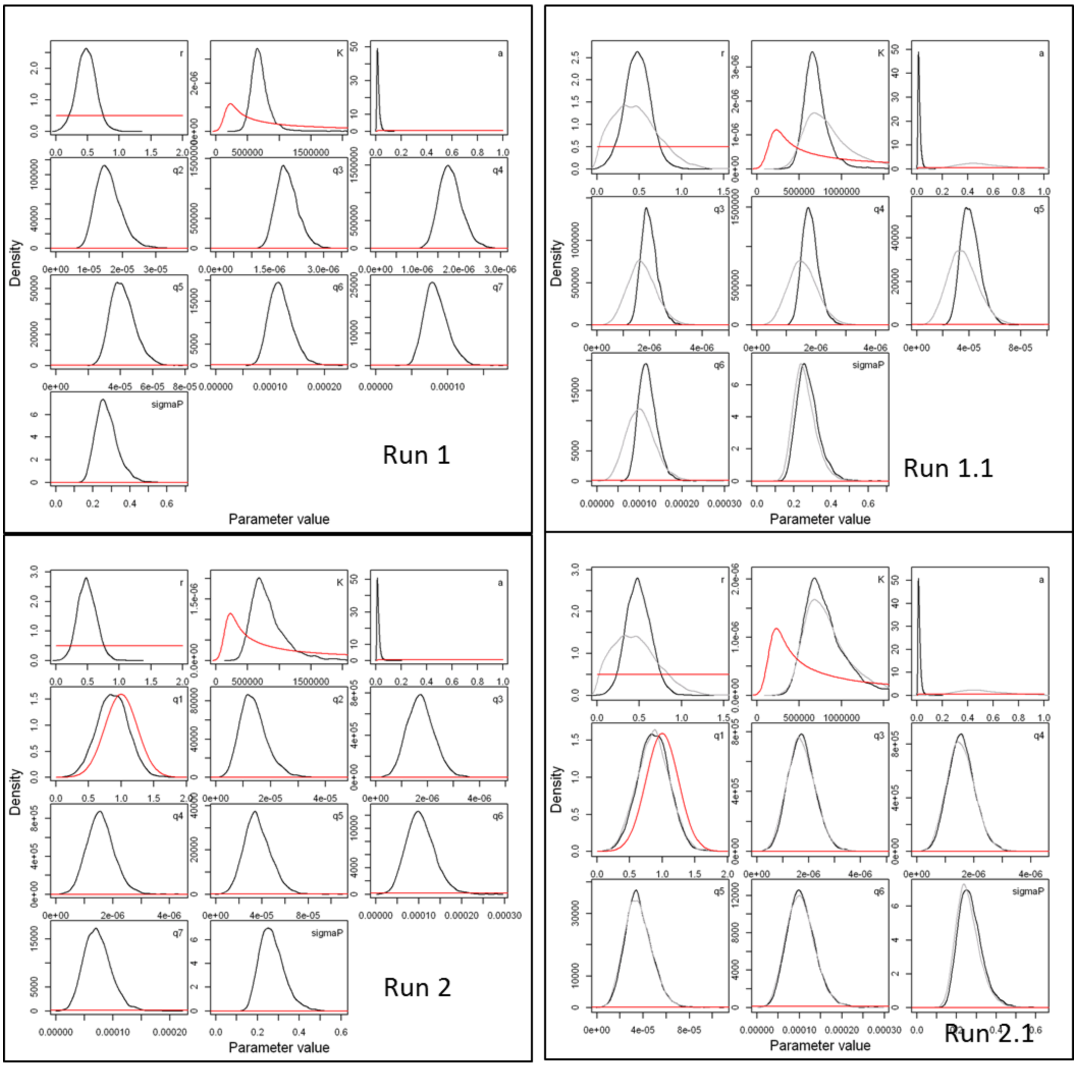

Figure C.8. Boarfish in ICES Subareas 6, 7, 8. prior and posterior distributions of the parameters of the biomass dynamic model. Runs 1, 1.1, 2 and 2.1.

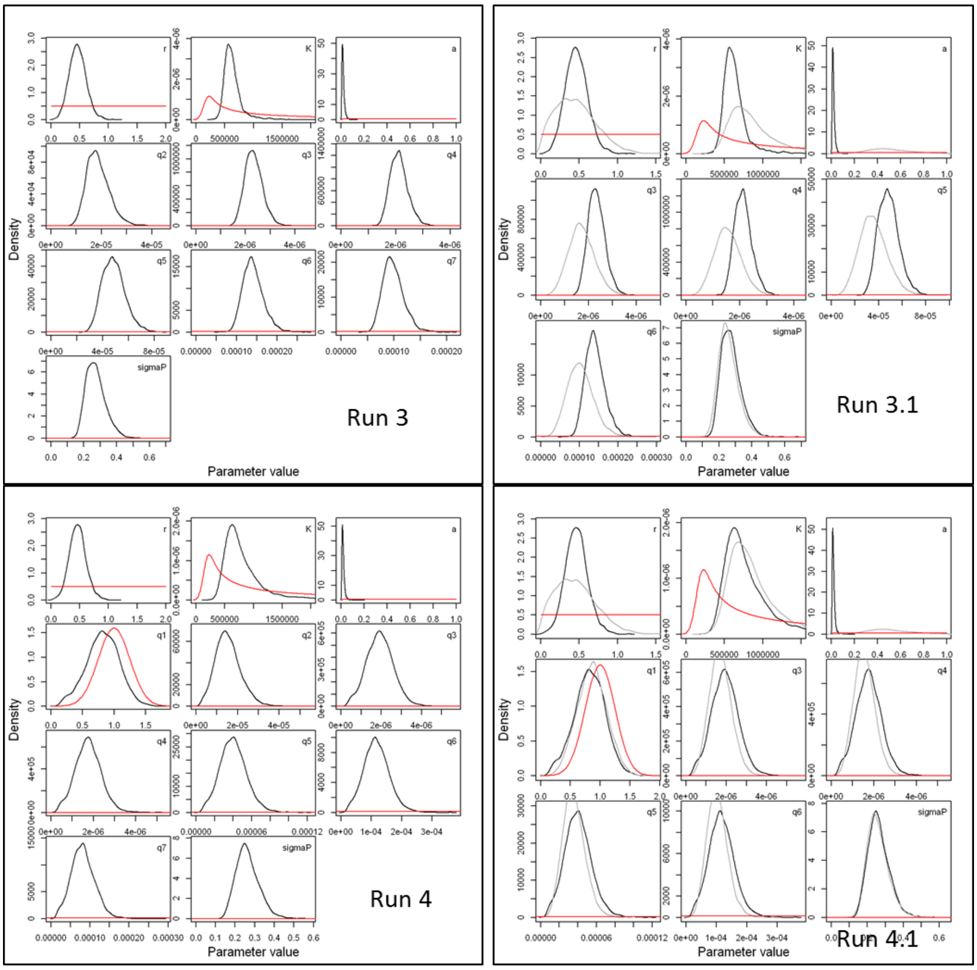

Figure C.9. Boarfish in ICES Subareas 6, 7, 8. prior and posterior distributions of the parameters of the biomass dynamic model. Runs 3, 3.1, 4 and 4.1.

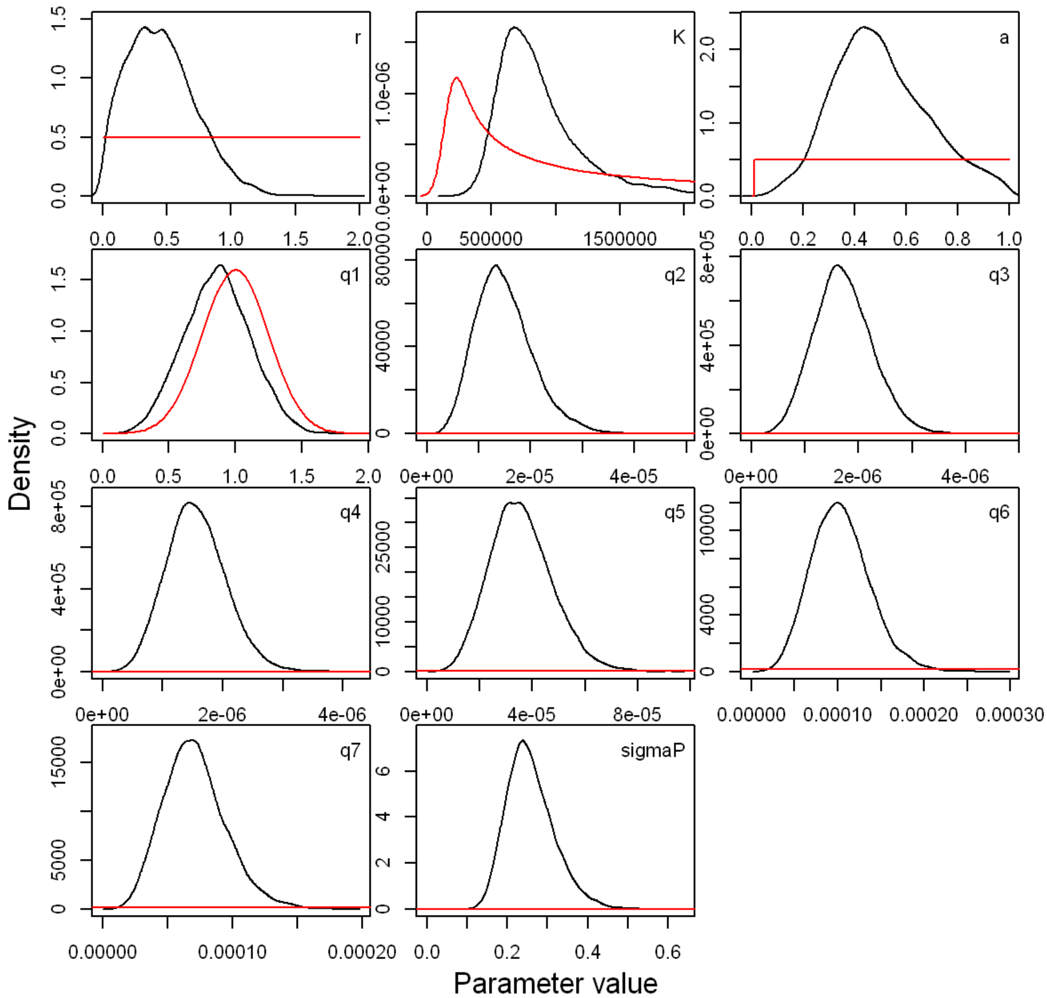

Figure C.10. Boarfish in ICES Subareas 6, 7, 8 prior and posterior distributions of the parameters of the biomass dynamic model. Run 2.2.

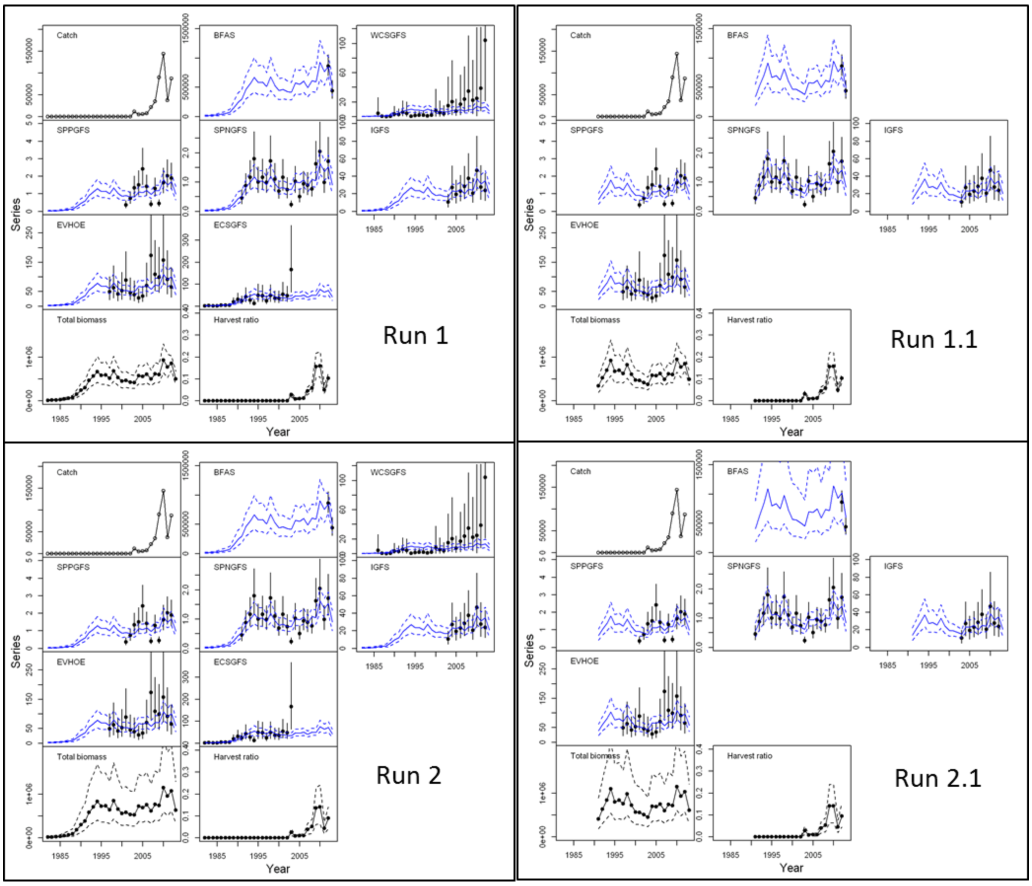

Figure C.11. Boarfish in ICES Subareas 6, 7, 8. Trajectories of observed and expected indices for runs 1, 1.1, 2 and 2.1. The stock size over time and a harvest ratio (total catch divided by estimated biomass) are also shown.

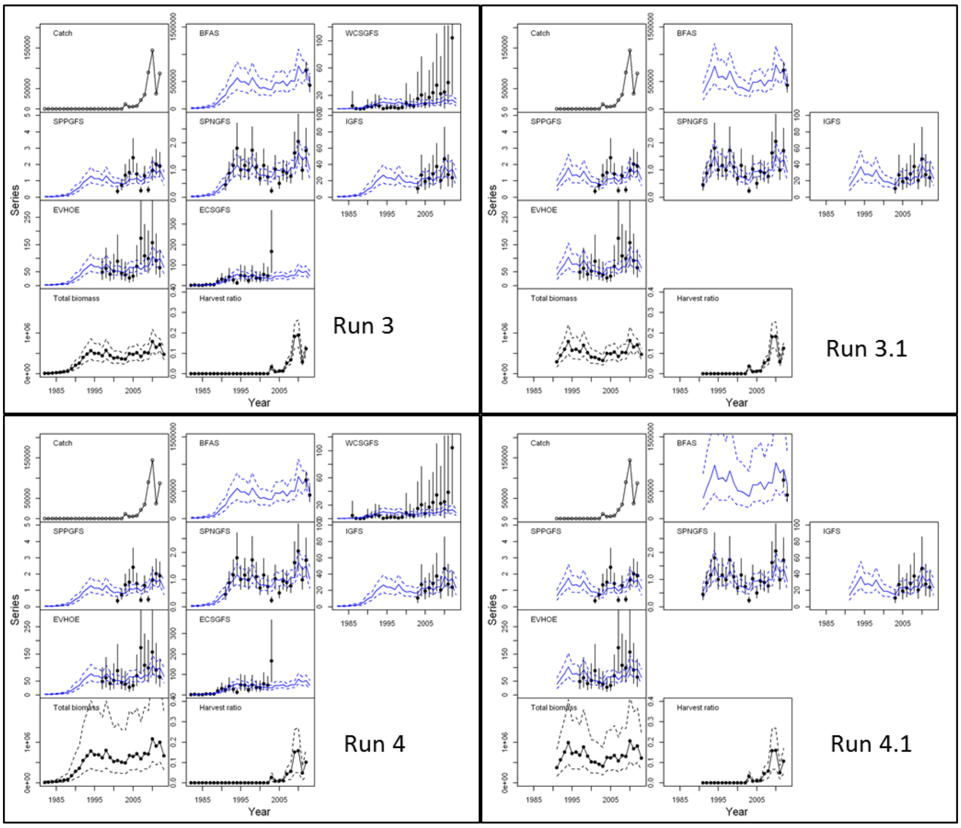

Figure C.12. Boarfish in ICES Subareas 6, 7, 8. Trajectories of observed and expected indices for runs 3, 3.1, 4 and 4.1. The stock size over time and a harvest ratio (total catch divided by estimated biomass) are also shown.

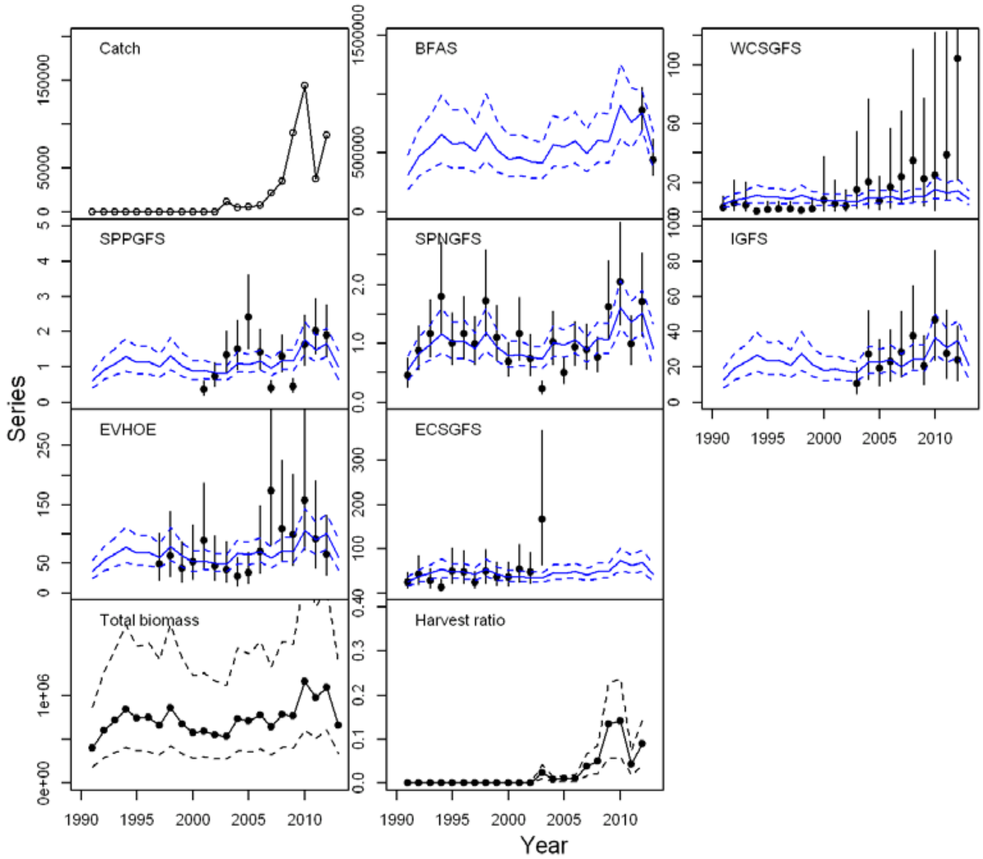

Figure C.13. Boarfish in ICES Subareas 6, 7, 8. Trajectories of observed and expected indices for run 2.2. The stock size over time and a harvest ratio (total catch divided by estimated biomass) are also shown.

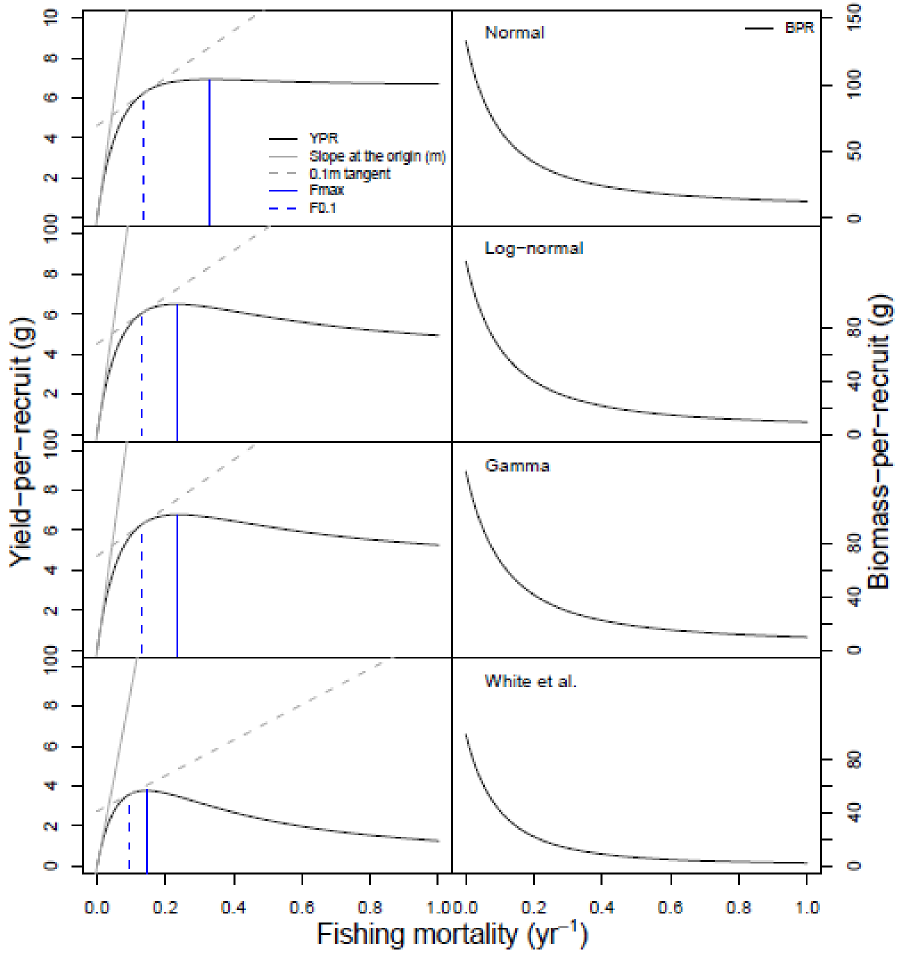

Figure E.1 Boarfish in ICES Subareas 6, 7, 8. Results of exploratory yield per recruit analysis. Beverton and Holt model applied to various fits of the VBGF and for comparison with the VBGF parameters provided by White et al. 2011.

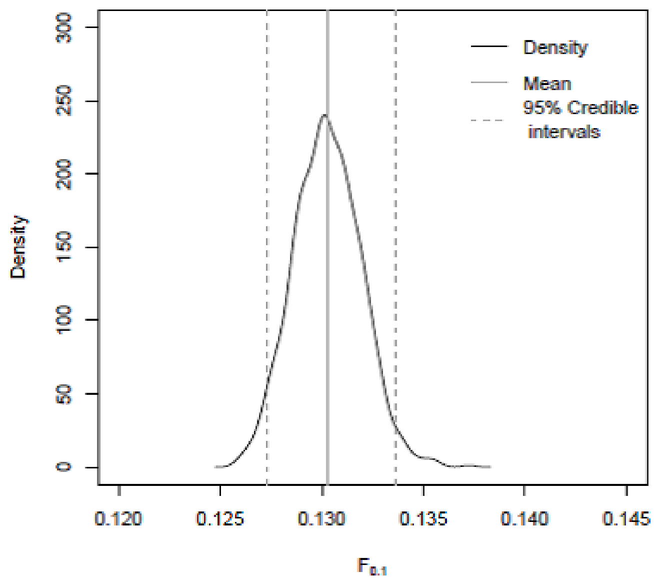

Figure E.2 Boarfish in ICES Subareas 6, 7, 8. Sensitivity of estimation of $F_{0.1}$.