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North Sea Elasmobranchs: distribution, abundance and biodiversity

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Abstract
Based on data from various international and national surveys, an overview is given of the fine-scale distribution (resolution of 20'longitude * 10' latitude; ≈ 10*10 nm) and trends in abundance of elasmobranch species reported from the North Sea. Presence-absence maps are produced based on 4 surveys, which help to delineate distribution limits of the less common species, while maps in terms of catch rates (International Bottom Trawl Survey data only) are given for the seven most common shark and ray species. While the results largely confirm published information, the higher resolution helps to delineate actual concentrations, which should prove useful when trying to relate abundance to habitat requirements. Trends in abundance do not reveal a consistent pattern across species. Some have markedly increased over the last 30 years, some have markedly decreased and some have remained remarkably stable. In a separate analysis, the information on number of species is integrated in a spatial biodiversity index for the elasmobranch community, by applying a novel method of correcting for differences in sampling effort. Although there are conceptual scientific problems in applying such biodiversity indices because of arbitrary choices of the level of effort for which the index is calculated, a highly consistent pattern emerges: a strong east-west gradient, with the species-richest elasmobranch community being largely restricted to the area off the British coast from the Channel to the Shetlands and virtually no elasmobranch species along the continental coast. This has clear implications for management, because any measure aimed at their conservation should take these spatial effects into account.

Keywords: North Sea, Elasmobranchs, distribution, abundance, diversity.

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Introduction

Although much is known about North Sea fish and fisheries, up to recent years the elasmobranch component of the fish community has received relatively little attention. Holden (1974, 1977) discussed general management problems in elasmobranch fisheries and ICES established a Study Group on Elasmobranch Fisheries (ICES, 1989), but it was not before the late nineties that the interest in these species increased worldwide because of their alleged susceptibility to overfishing (Stevens *et al*., 2000). Walker (1999) made a thorough study of the life history of North Sea rays, while Ellis *et al*. (2004) provide a comprehensive study of the distribution of elasmobranchs caught in UK research vessel surveys around the British Isles, highlighting important nursery areas. Specific management advice on skates and rays was first formulated by ICES in 1997 (ICES 1998; page 171), indicating that the common skate was almost extirpated and that stocks of thornback rays and spotted rays were outside safe biological limits. Because these species are landed as a bycatch in mixed fisheries targeting teleost species, the view was expressed that conservation measures should in some way be limiting the impact of these fisheries in those areas where the most vulnerable ray species still occur. Although this hints at establishing marine protected areas (MPA) for these species, so far EC management measures have been restricted to an overall TAC for all rays caught in EU waters of ICES areas IIa and IV. Because a large part of the ray catch is discarded and a global TAC does not restrain catches of individual species in any mixed fishery, this measure cannot be expected to provide any protection. Therefore, more effective management is required, which takes into account the spatial distribution of the various stocks or of the elasmobranchs as a whole.

We use international and national surveys carried out over the past 30 years to describe the distribution of all elasmobranch species caught, based on presence-absence and at a high spatial resolution. Many of these species are caught only infrequently and therefore it is sensible to use all information on locations where they have been caught. Presence-absence maps have the advantage that we don't have to worry about different catchabilities and thus in principle all survey information can be used. However, for the more common species, distribution maps based on catch rates are more informative, because they indicate the concentrations. The drawback is that it is problematic to integrate the information obtained from different surveys because of different gears and associated catchabilities. In this case, we only use information from the most comprehensive survey available. This also applies to the analysis of temporal trends in relative abundance. Finally, we use the information to estimate spatial variation in biodiversity within the elasmobranch community to provide guidance for potential conservation measures in terms of MPA.

Materials and Methods

Presence-absence

Qualitative distribution maps aimed at delineating the maximum distribution of all individual species identified were based on four different surveys to identify, whether a species had at least been observed once in any of these surveys: International Bottom Trawl Survey 1970-2004 (IBTS), Beam Trawl Survey 1985-2004 (BTS), Demersal Fish Survey 1970-2004 (DFS), and Sole Net Survey 1970-2004 (SNS). The resolution chosen was one/ninth of an ICES statistical rectangle (20' longitude by 10' latitude; ≈10*10 nm).

The IBTS constitutes the most comprehensive survey data set available for the North Sea. The survey annually covers the entire shelf area <200m, including Skagerrak and Kattegat, during February, but additional surveys in other quarters have been carried out since 1991 (see for details Heessen *et al.*, 1997). Data for the years 1983-2005 were extracted from the DATRAS Database and for earlier years from the former IBTS Database at the ICES Secretariat. Because not all countries have systematically collected information on all bycatch species during the initial years, some of the earlier data had to be excluded. The gear used during the survey is a French-designed bottom-trawl with a high vertical net opening (chalut à Grande Ouverture Verticale or GOV-trawl). The mesh size in the cod-end is 20 mm stretched mesh. The horizontal opening of the trawl is approximately 20 m and the vertical opening 5 to 6 m. The groundrope is relatively light, although bobbins have been used on rough grounds to prevent damage to the gear.

The other surveys are more restricted (Van Beek, 1997). Although there is some international coordination in some cases, only the Dutch data were readily available. During the BTS in August/September, an 8m beam trawl with 4 chains is used and up to 1996 only the southern North Sea was covered. From that year onwards, the survey has been extended to cover most of the North Sea. The DFS is a continental inshore survey in September/October, during which a 6m or 3m shrimp (beam) trawl is used depending on vessel size. During the SNS (also in autumn), a 6m beam trawl with 3 chains is used to sample fixed stations along some transects near the Dutch and German coasts.

Each haul was assigned to a sub-rectangle according to the shooting position and a species was considered present, if it was caught at least once during any of the hauls made during any survey (some 17000 hauls distributed over 1390 sub-rectangles). The resolution chosen ensured that almost all sub-rectangles have been fished at least once. Also, a finer resolution would not seem appropriate given the distance covered during a haul (standard 2 nm for the IBTS, but up to 4 nm for some vessels) and the accuracy of survey positions (especially during the earlier years).

Quantitative analyses

The species-specific quantitative analyses were based entirely upon IBTS data, but data collected before 1977 were excluded, because some countries may not have reported all species caught in these years. Distribution maps in terms of average number per hour were restricted to the seven most abundant species based on data from all quarters.

Trends in annual catch rates are presented for all species for the 1st quarter only to avoid bias owing to seasonal differences in abundance, with three-year running averages calculated only for those caught in at least 50% of the years. Annual catch rates were calculated by first averaging the catches for all length classes combined within one ICES rectangle and then taking the average over all rectangles fished within one survey over the entire North Sea, Skagerrak and Kattegat.

Biodiversity index

The number of species recorded by sub-rectangle may be used as a spatial biodiversity index for the elasmobranch community. However, these figures are heavily influenced by the effort exercised and because the number of hauls varied widely across sub-rectangles (Figure 1), the effort must be taken into account. Taking the average number of species per haul does not resolve this problem, because the probability of a rare species having been observed depends on the total number of hauls. Therefore, we established a data set, which represented all elasmobranch species by haul by sub-rectangle and then randomly selected a sequence of hauls to get rid of the potential temporal component in biodiversity trends, and calculated the number of species after n=1 to N hauls, where N refers to the total number of hauls made within each sub-rectangle. This random selection was repeated 20 times and the results were averaged. Figure 2 shows the resulting patterns for a selection of the most frequently fished rectangles. Although the number of species caught appears to stabilize on a linear scale after some 40 hauls, the index keeps in fact almost linearly increasing on a log-scale, reflecting that ever more rare species are being caught after ever more hauls. Secondly, the lines may cross each other at any point, which means any relative measure of biodiversity among sub-rectangles in terms of number of species depends on which number of hauls is selected. Choosing a higher value seems preferable in terms of resolution, but of course we would be loosing information for squares, where effort has been less than the effort level selected. To overcome this problem, we estimated the linear regression for all sub-rectangles with $3 \leq N < 20$ and estimated the expected number of species caught after 20 hauls accordingly. In addition, we used the number of species 'observed' after 20 hauls according to the average of the Monte-Carlo simulations for sub-rectangles with $N \geq 20$, and the actual number of species observed for $N < 3$. The choice of biodiversity being measured after 20 hauls remains arbitrary.

Identification problems

So far 23 species of elasmobranchs have been recorded in the surveys. However, problems have been encountered in the identification of Rajid rays, even among the more common ones, which we have not been able to resolve systematically and satisfactorily (Daan, 2001). Starry ray *Amblyraja radiata* and thornback ray *Raja clavata* particularly may have been mixed up in the earlier years, but also the results for common skate *Dipturus batis* appear somewhat doubtful. As a consequence, the results for this group may be somewhat distorted. Furthermore, we have sincere doubts about the existence of two *Mustelus* species in the North Sea. Smoothhounds with and without white spots (supposedly *M. mustelus* and *M. asterias*, respectively) are often caught in the same hauls, but their distinguishing features are vague and the annual numbers reported among individual vessels are often inconsistent. Even recently and aware of the problems, R.V. Tridens made a good catch of juvenile smoothounds, which we were not able to identify satisfactorily to the species level, because they exhibited all kind of transitions between clear white spots and none at all, while other clues given in the literature (Whitehead *at all*, 1984) indicated that they all belonged to a single species (*Mustelus mustelus*). Therefore, these two species have been taken together as *Mustelus* sp.

Results

Presence-absence

Figure 3 shows the presence/absence of all elasmobranch species recorded during any of the four surveys by sub-rectangle. Among the sharks, the spurdog *Squalus acanthias* may be encountered in the entire North Sea, although few have been observed along the continental coast. The lesser spotted dogfish *Scyliorhinus canicula* and smoothhounds are more restricted to the western part, although they may sometimes rach the Skagerrak and Kattegat. The tope *Galeorhinus galeus* has a much more southerly distribution, entering the North Sea through the Channel during the summer. The nursehound *Scyliorhinus stellaris* is extremely rare, apparently entering the North Sea through the Channel and around Scotland. The blackmouth dogfish *Galeus melastomus* and velvet-belly *Etmopterus spinax* are deep-water species that may largely be found along the Norwegian Deep and the remaining shelf edge. Two greenland sharks *Somniosus microcephalus* have been caught in the Kattegat and two porbeagles *Lamna nasus* in the central/northern North Sea. The catch of a porbeagle in a bottom trawl is a chance hit and the species is probably more common than these data suggest.

Among the skates, the starry ray is present throughout the central and northern North Sea and the distribution extends into the Kattegat. Some of the southerly data points may actually reflect contaminated data owing to misidentifications. The thornback ray is also widely spread, but in this case especially some of the easterly observations may refer to starry rays. The spotted ray *Raja montagui* and blonde ray *Raja brachyura* show similar distributions, with two concentrations around southern England and around Scotland, but although very different from other rays, these two species may have been confounded. The easily recognizable cuckoo ray *Leucoraja naevus* is largely restricted to Scottish waters with a southerly extension along the English coast. The distribution of common skate suggests four rather isolated areas, where this species might still be encountered. However, it seems quite possible that these data also have been contaminated by misidentifications. Also the reports of long-nose skate *Dipturus lintea* come somewhat as a surprise, because they have not been reported by Wheeler (1978). Records of sandy ray *Leucoraja circularis* and shagreen ray *Leucoraja fullonica* have remained largely restricted to waters around the Shetlands and there is one catch record of two juvenile undulated rays *Leucoraja undulata* from the Norfolk coast. The long-nosed skate *Dipturus oxyrhinchus* and round skate *Rajella fyllae* are deep-water species that occasionally are caught along the Norwegian Deeps. The few observations of the common stingray *Dasyatis pastinaca* are restricted to Shetland waters and the southern North Sea, where they are occasionally caught in inshore surveys.

Catches of rabbitfish *Chimaera monstrosa* follow closely the 200m depth contour delineating the survey area.

Quantitative distribution maps

The distribution maps in terms of catch rates for the more common elasmobranch species are shown in Figure 4. The three shark species (Figure 4a; spurdog, lesser spotted dogfish and smoothhounds) are clearly concentrated in the western part of the North Sea. None of these probably reflect the existence of true North Sea stocks. While spurdogs seem to enter the North Sea around Scotland and smoothhounds through the Channel, lesser spotted dogfish show concentrations in both the Orkney-Shetland area and in the western part of the Southern Bight. Remarkably, all concentrations seem to fall within the 100m depth contour, but at least spurdog and smoothhounds may occur also pelagically and it may be that the maps are biased by their habitat in surface waters extending only to 100m depth.

Among rays (Figure 4b), the densest concentrations of starry ray are clearly found offshore in the central North Sea within the 50-100m depth range, extending along the

200m line of the Norwegian Deeps. The thornback ray shows a continuous distribution along the English east coast, with secondary concentrations in the central North Sea and less clearly in the northern part. The cuckoo ray is largely restricted to the 50-100m depth range, but only off Scotland, while the spotted ray is mostly found within 50m depth off southern England (somewhat further offshore than thornback rays) and around the Orkneys.

Trends in catch rates

Table 1 provides the average number per hour fishing for all species caught in the quarter 1 IBTS surveys and figure 5 gives the variation over time (1977-2004). Long-nose skate and round skate do not appear here because they were only caught during other parts of the year. Among the sharks, spurdog and velvet-belly's have clearly declined markedly over time, whereas lesser spotted dogfish, tope and smoothhounds have increased markedly. The remaining shark species are caught only infrequently and no trend can be detected.

Among the rays, trends are less clear. Starry rays appear to have increased from the late seventies to the early eighties, possibly followed by a decline. The same pattern also seems to apply to the cuckoo ray and spotted ray. Common skate shows an overall decline, while sandy ray and shagreen ray appear to have somewhat increased in abundance, but interannual variability is high due to many years with zero observations. The thornback ray has largely remained stable, with one outlier in 1991 owing to a single exceptionally large catch. Also the blonde ray does not show a specific trend.

Little can be said about the rabbitfish. They were not seen during the first 5 years, but of course the survey is not well suited to sample this deep-water species.

Biodiversity

Figure 6 provides the spatial pattern in species richness of the elasmobranch community, based on the estimated average number of species caught after 20 hauls over the entire period. There appears to be a clear east-west gradient, with highest biodiversity off the British coast and the lowest ones along the Danish coast. Some hotspots appear along the shelf edge owing to intermittent catches of deep-water species.

Discussion

Survey information on fish communities always suffers from species-specific differences in catchability (Daan *et al*., 2005). This hampers the interpretation of relative abundances among species, but also affects any community metrics. Strictly, all information must be interpreted in terms of the typical assemblage sampled by the survey gear. The GOV used in the IBTS is not the most effective gear for catching rays. A comparison between GOV hauls and beam trawl hauls within the same rectangle suggests that the catches per unit of swept area of rays and lesser spotted dogfish may be a factor of 4 (other rays) to 8 (starry ray) higher in the latter, while catches of Carcharinid sharks may be by a factor 5 higher in the former (ICES, 2004). This indicates that the absolute abundance of rays is considerably underestimated relative to the sharks in the IBTS data set. Thus, although the data should reflect relative changes in abundance within species and differences in distribution among species, the relative abundances among species may deviate considerably from the 'true' situation.

Our results on species-composition and distribution largely confirm the results presented by Ellis *et al.* (2004) for the North Sea part of the extensive area around the British Isles covered by their data set. However, the larger number of hauls and the higher resolution used help to delineate the distribution areas of the different species more precisely. It would be worthwhile to try and combine all data sets for NE Atlantic waters using cherent methods of analysis, because such extended coverage may help to resolve the important issue of identifying appropriate stock units for management. Among the sharks, tagging experiments of spurdog have shown migrations between southern Ireland and the North Sea, indicating there is one single stock in the waters around the British Isles. This probably applies also to tope and smoothhounds, because these species are more frequently seen in the North Sea during summer than during winter. Rays are supposed to be rather more limited in their migrations (Walker, 1999; Hunter *et al*., 2005) and are more likely to constitute local unit stocks even within the North Sea. This view is supported by the clear gaps in between areas of high concentrations.

The trends in catch rates vary markedly among the various elasmobranch species and no coherent pattern is emerging. The conclusion that elasmobranchs are in general decline would certainly not be justified. Nevertheless, the low catch rates of all species (<1 per hour) compared to many teleost species are certainly reason for concern.

Species richness as an indicator of biodiversity on the basis of research surveys proves a difficult concept because a correction has to be made for the amount of effort exercised. Moreover, the indices depend markedly on the number of hauls for which the number of species recorded is calculated, because the trajectories of changes in species richness for individual sub-rectangles with increasing number of hauls cross each other at different levels: both slopes and intercepts vary. Although the index selected is somewhat arbitrary, it would seem best to select a large number of hauls for the calculation, because this yields both a higher resolution and a more stable pattern among sub-rectangles. However, it also involves larger extrapolations (and thus potential bias) for areas, in which only a restricted number of hauls has been made.

To give some idea of the potential bias in our pragmatic approach of arbitrary selecting an effort level of 20 hauls, we estimated for all sub-rectangles with N≥20 (for which we thus have an 'observed' average number of species) the regression based on the first 10 data points and then estimated the expected number observed after 20 hauls. The frequency distribution of the deviations between observed and estimated values (Figure 7) indicates that for 81% of the rectangles the difference was ≤±0.5, whereas in 8% of the cases the difference was >±1. The distribution was a little bit skewed to the negative side, indicating that species richness is slightly underestimated. The bias of course should increase for lower effort. Although this may have influenced some individual values in figure 6, it should not have distorted the general pattern, because the IBTS is essentially stratified by ICES rectangles and there are no systematic differences in effort across the North Sea. Moreover, an extrapolation leading to underestimates of species richness would seem preferable to overestimates.

There is another type of bias that is more problematic and that is the one caused by misidentifications of species. Each misidentification affects two species and therefore has a double effect. But, there is not much that can be done about it after the data have been entered in the data base and the original specimens have been lost. Trying to find inconsistencies in the reporting (Daan, 2001) is of course important in evaluating the analysis, but the problem can only be solved at the origin: proper identification should receive the highest priority in survey design!

Ellis *et al*. (2004; Figure 9) provide information on the number of species caught by statistical rectangle in the North Sea during English groundfish surveys, but did not correct for the large differences in effort from which these were obtained (differences between rectangles ranging from 1 to over 60). These data do not show the marked east-west gradient observed here and instead there are two hotspots: in the Southern Bight and in Scottish waters, with very few species recorded in between. We deduce that the correction is extremely important when dealing with biodiversity issues.

We conclude that measures aimed at alleviating fishing pressure on the elasmobranch community in the North Sea necessarily have to take into account the clear east-west gradient in biodiversity. Because there is a clear continuity in the presence of a relatively large number of elasmobranch species along the British coast, it seems likely that these use this route for migration. Thus, if they are the object of conservation, bottom trawling should be prohibited over a vast area coinciding with the area of high richness.

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Table 1. Average catch rate (number per hour, 1977-2004) for all species of elasmobranchs caught during the quarter 1 IBTS in the North Sea, Skagerrak and Kattegat.

Starry ray	*Amblyraja radiata*	*4.1321*
Thornback ray	*Raja clavata*	*1.8511*
Spurdog	*Squalus acanthias*	*1.1554*
Lesser spotted dogfish	*Scyliorhinus canicula*	*0.6167*
Cuckoo ray	*Leucoraja naevus*	*0.3233*
Spotted ray	*Raja montagui*	*0.2554*
Smoothhound	*Mustelus sp.*	*0.2128*
Rabbitfish	*Chimaera monstrosa*	*0.0272*
Common skate	*Dipturus batis*	*0.0151*
Blonde ray	*Raja brachyura*	*0.0107*
Velvet-belly	*Etmopterus spinax*	*0.0062*
Tope	*Galeorhinus galeus*	*0.0038*
Shagreen ray	*Leucoraja fullonica*	*0.0025*
Nursehound	*Scyliorhinus stellaris*	*0.0020*
Sandy ray	*Leucoraja circularis*	*0.0012*
Undulated ray	*Leucoraja undulata*	*0.0007*
Common stingray	*Dasyatis pastinaca*	*0.0006*
Long-nosed skate	*Dipturus lintea*	*0.0006*
Greenland shark	*Somniosus microcephalus*	*0.0005*
Blackmouth dogfish	*Galeus melastomus*	*0.0003*
Porbeagle	*Lamna nasus*	*0.0002*

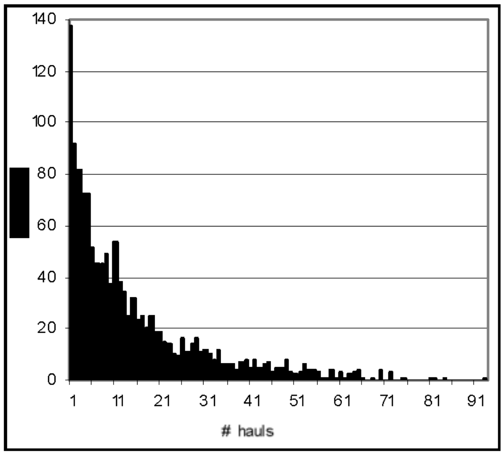


Figure 1. Frequency distribution of sub-rectangles characterized by the number of hauls.

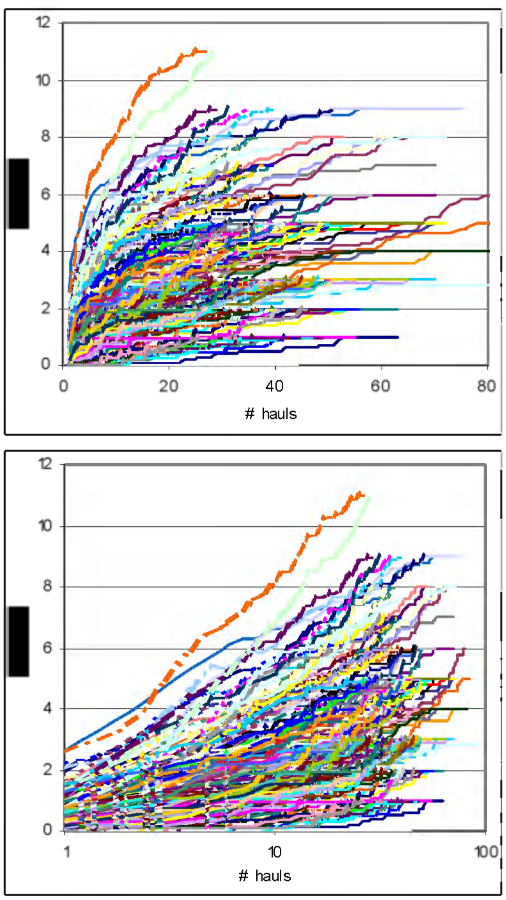


Figure 2. Average number of species observed after a varying number of hauls, based on 20 Monte-Carlo simulations for a selection of rectangles with high numbers of hauls: a) arithmetic scale; b) effort log-transformed.

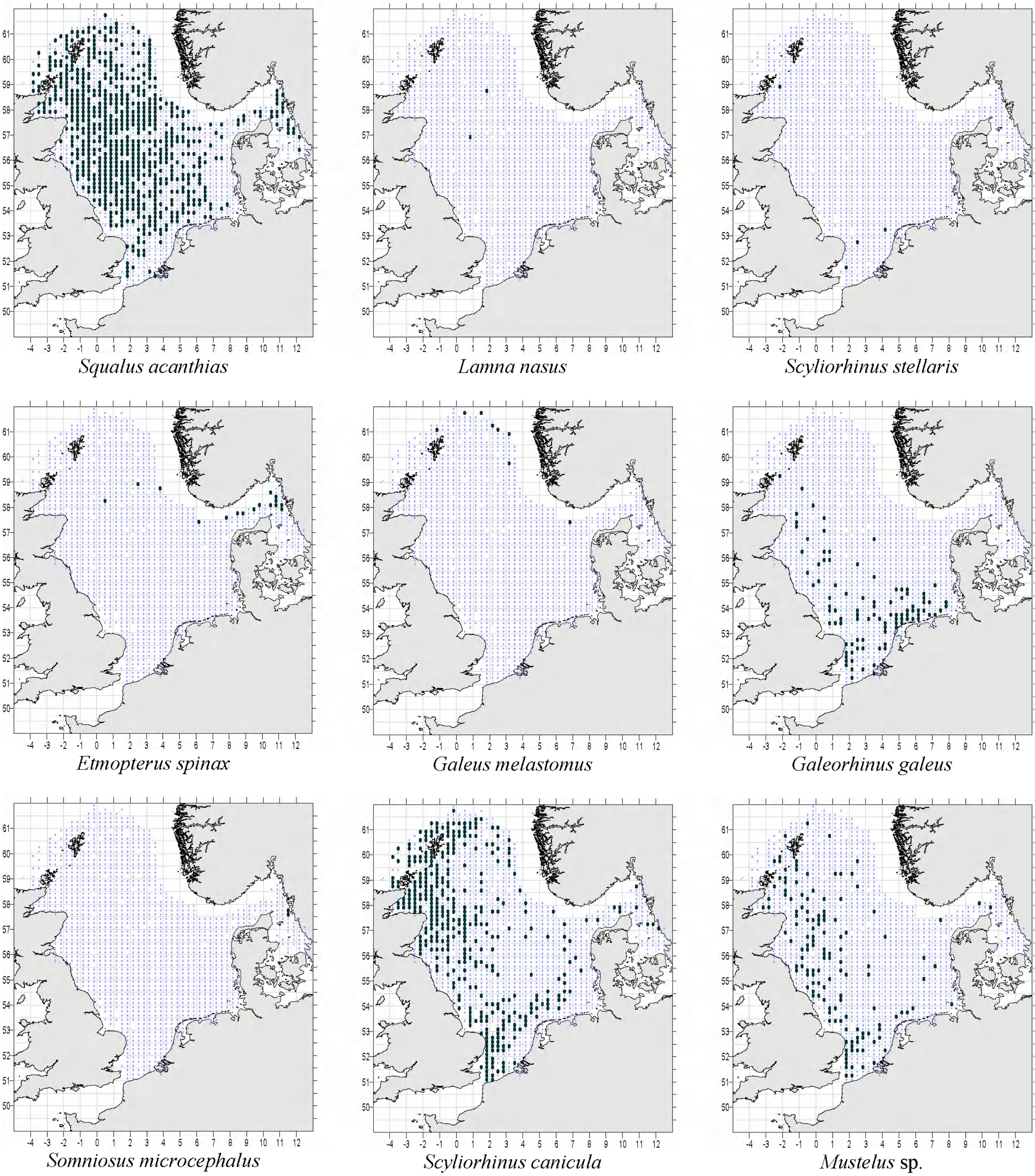


Figure 3. Distribution of elasmobranchs expressed as presence-absence, based on catches during four research vessel surveys, 1965-2005.

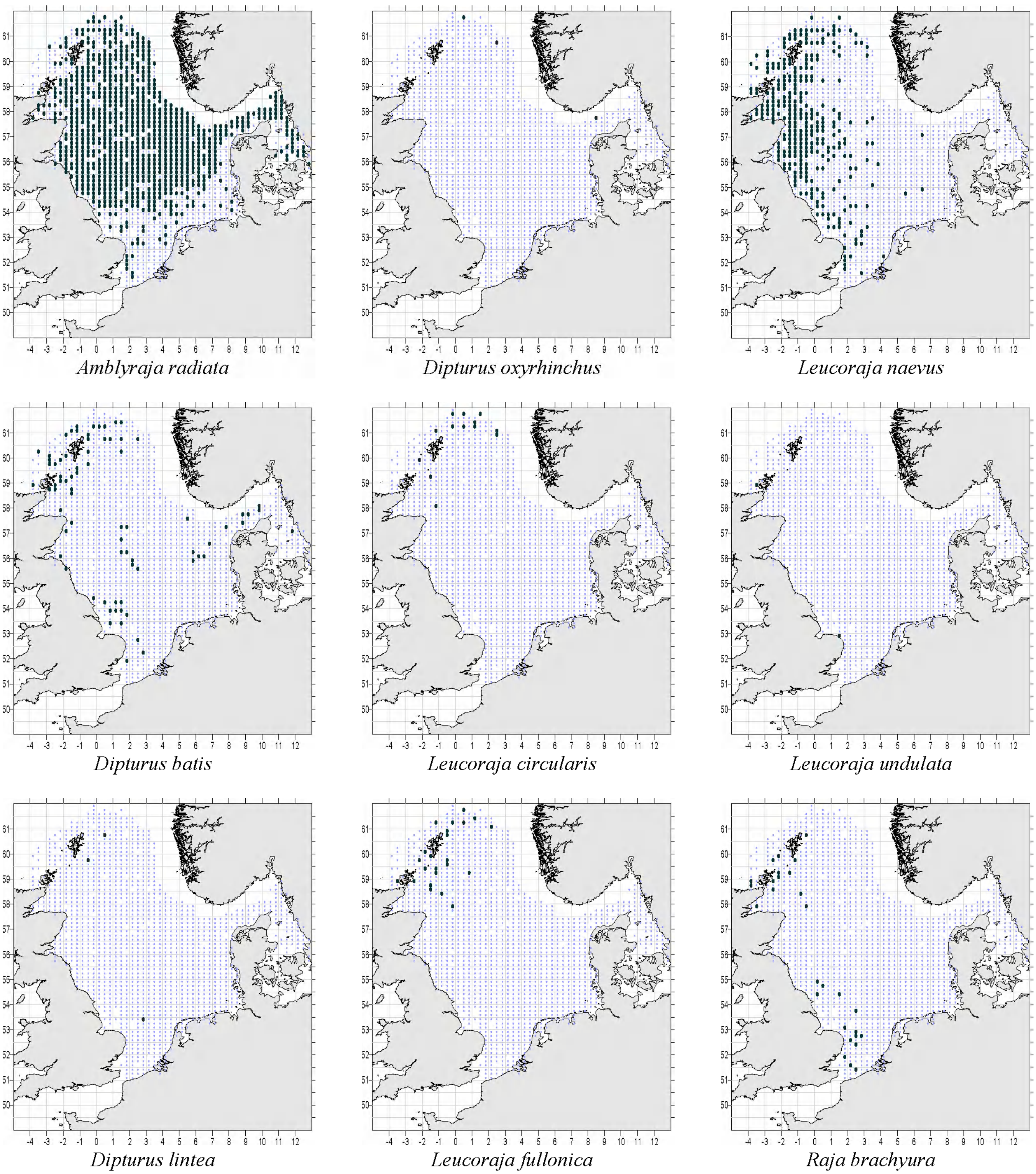
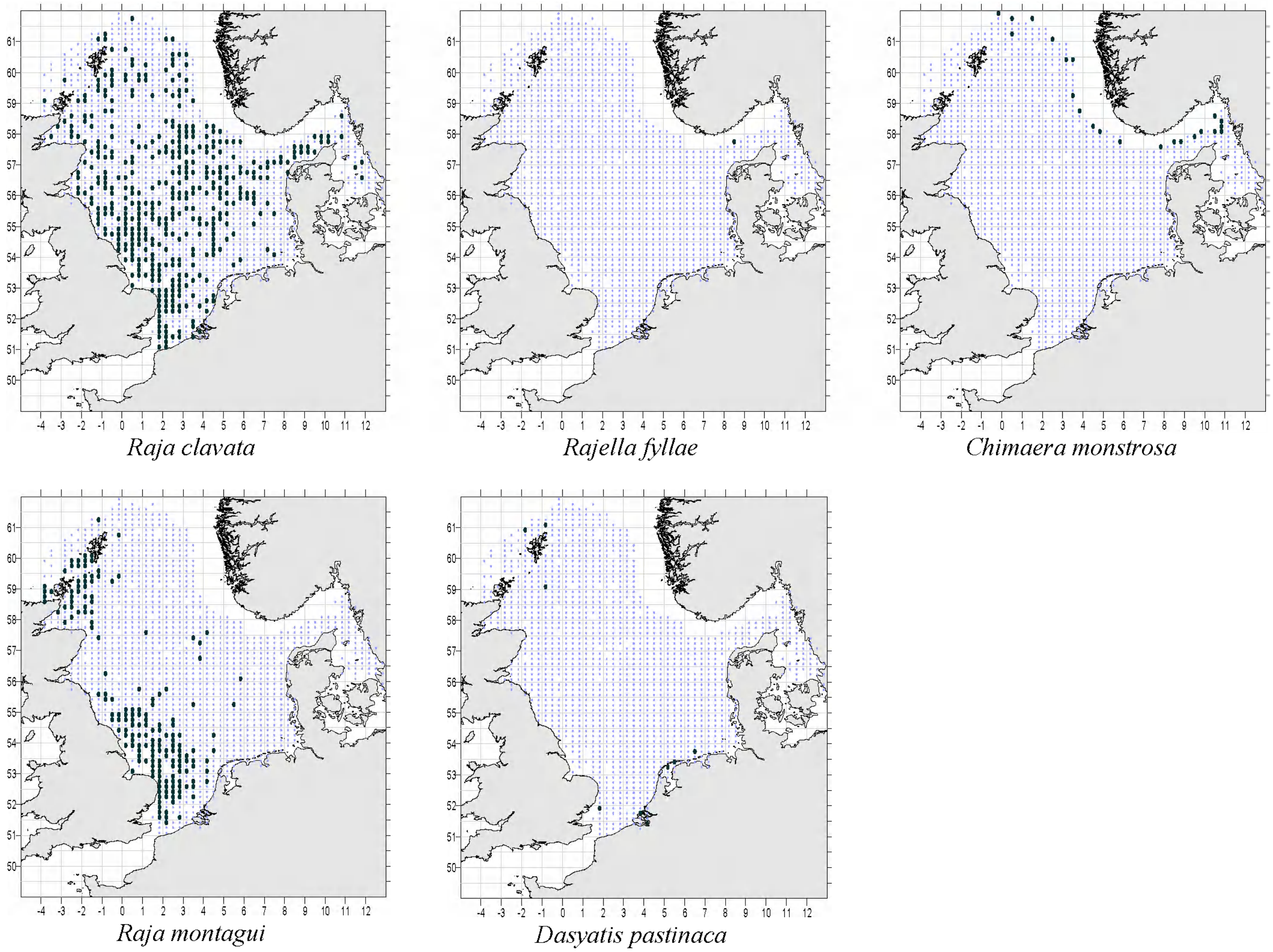


Figure 3. Continued.



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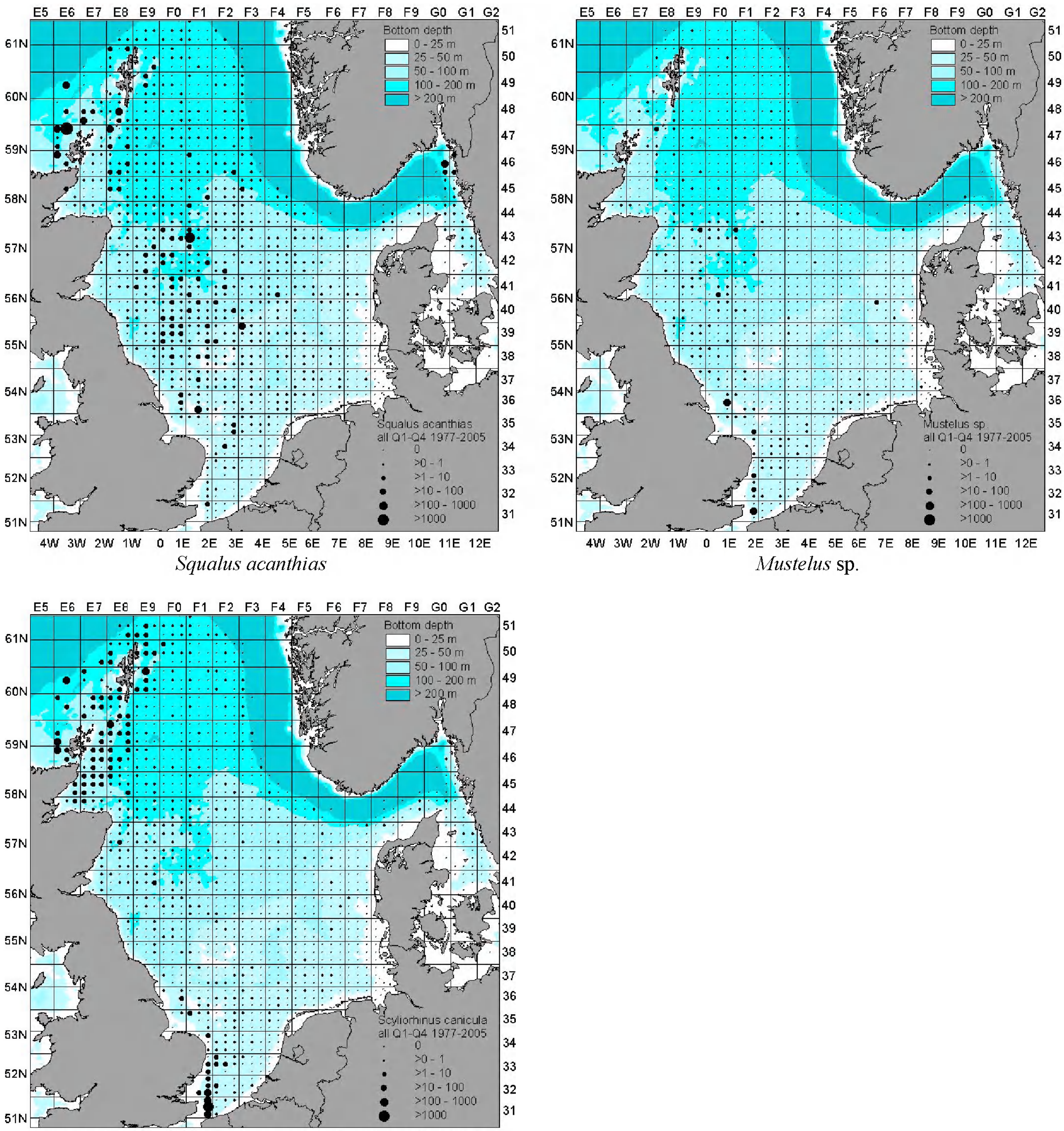

Squalus acanthias

Mustelus sp.

Scyliorhinus canicula

Figure 4a. Average catch rate in N per hour for all length classes combined, IBTS 1977-2005: sharks.

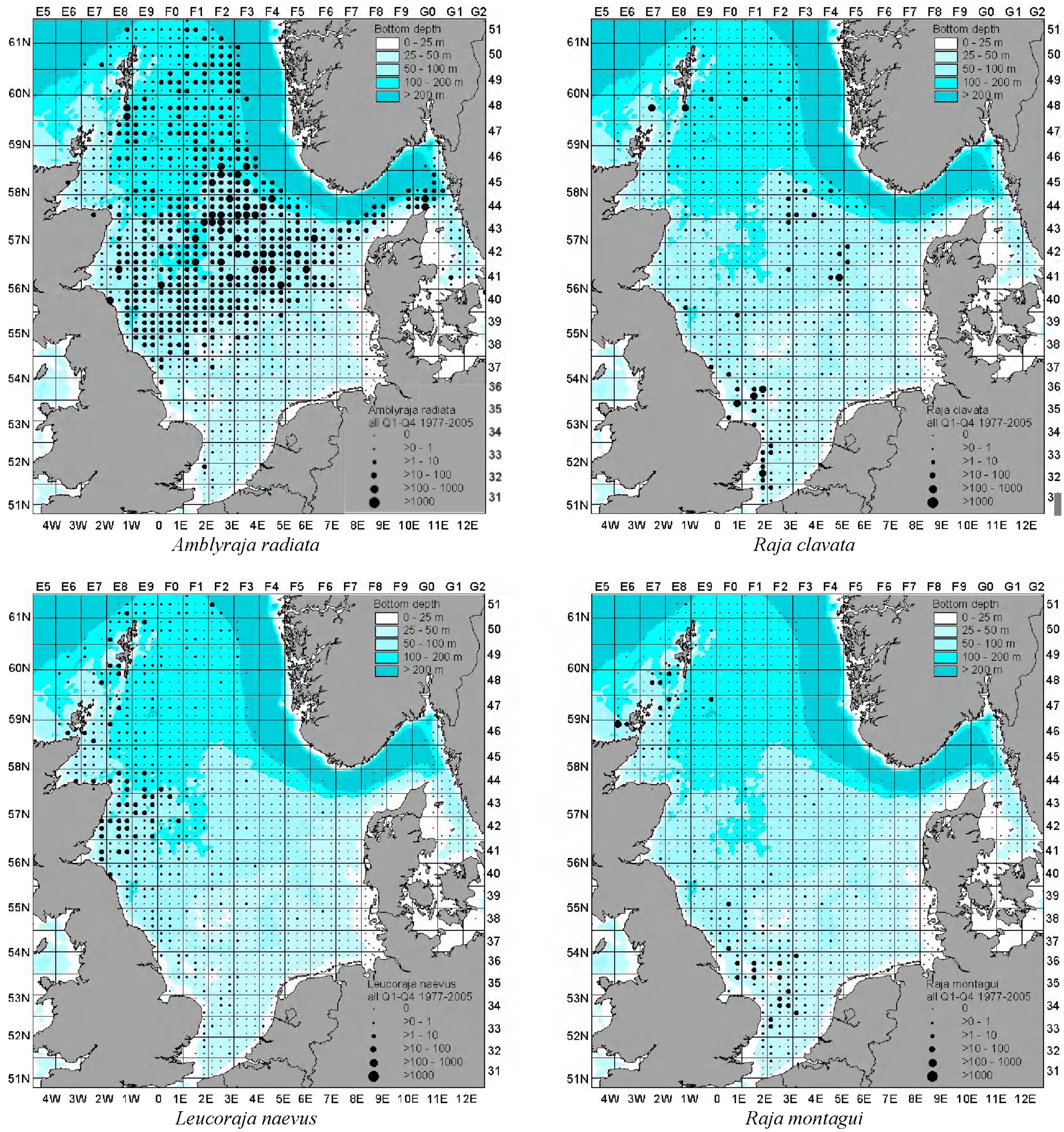

Figure 4b. Average catch rate in N per hour for all length classes combined, IBTS 1977-2005: rays.

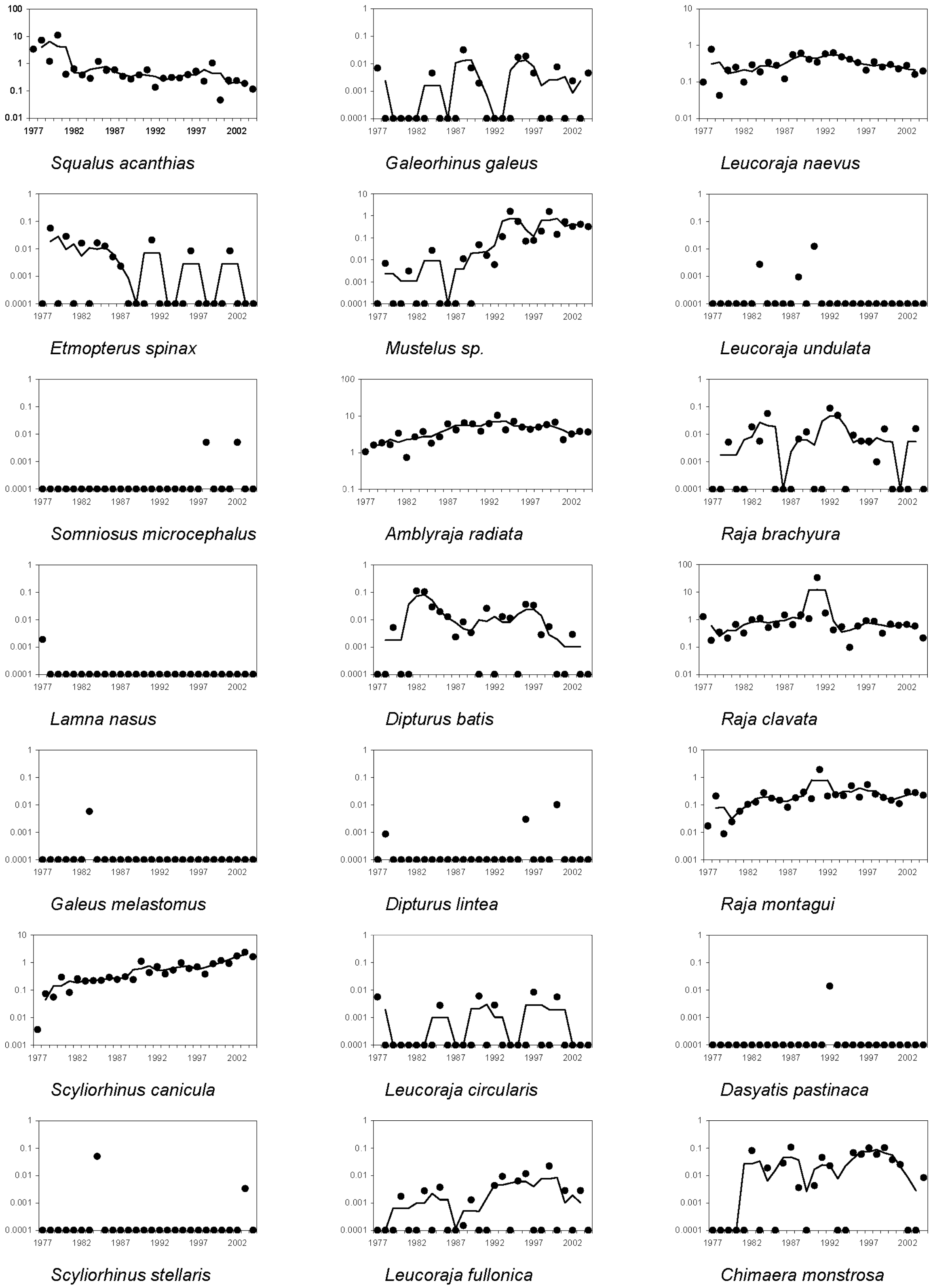

Figure 5. Annual catch rates and 3-year moving average of elasmobranch species during the quarter 1 IBTS, 1977-2004.

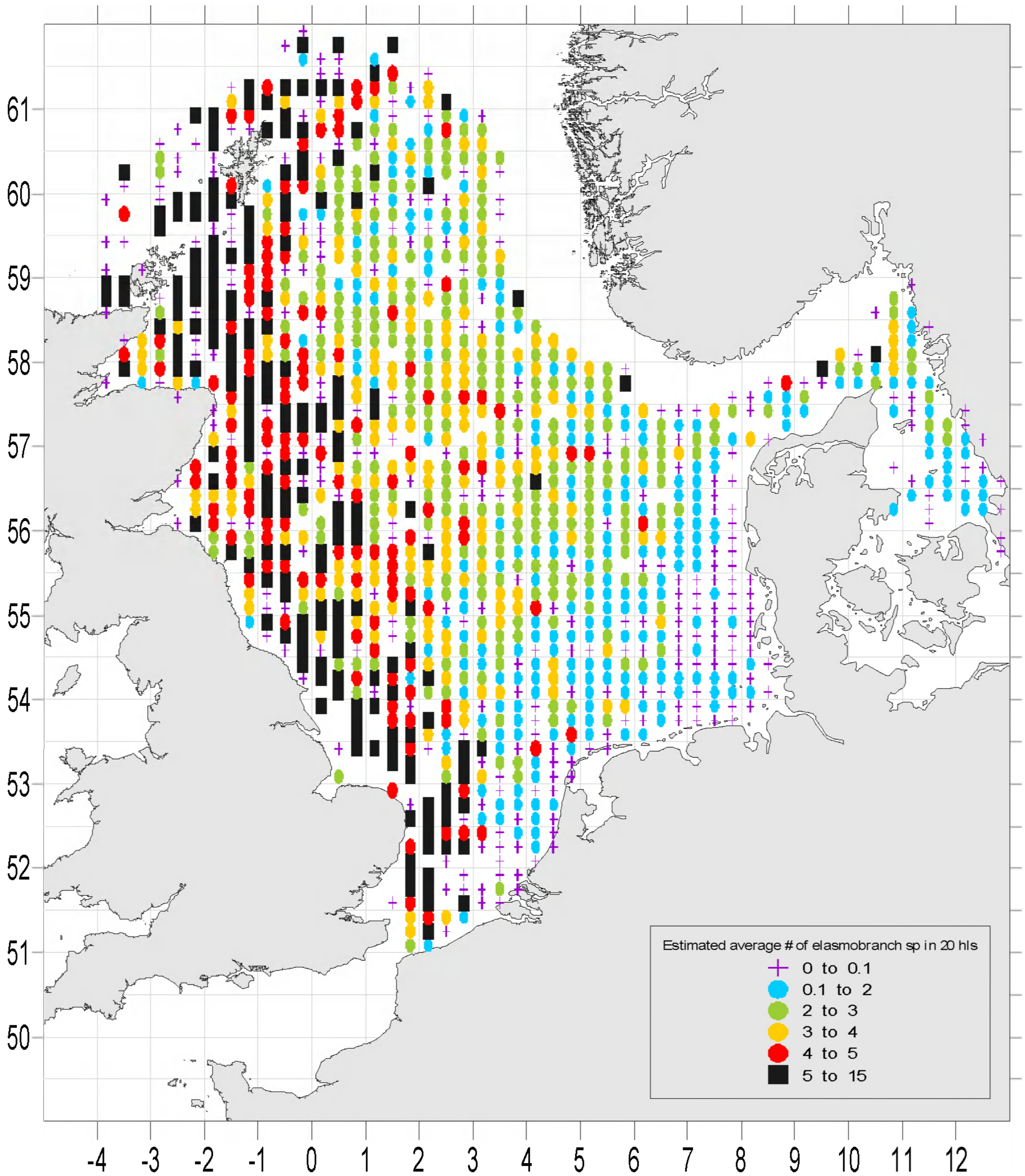

Figure 6. Estimated average number of elasmobranch species caught after 20 hauls during IBTS (all quarters), based on 20 Monte-Carlo simulations and fitted regression lines of nr of species vs nr of hauls (1977-2004).

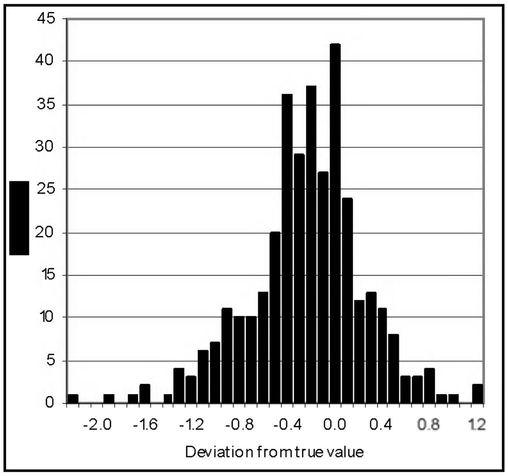

Figure 7. Frequency distribution of deviations between estimated number of species caught after 20 hauls based on the estimated regression for the first 10 data points and the ‘observed’ average number after 20 hauls (343 sub-rectangles with N $\geq$ 20).