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# Assessing the status of demersal elasmobranchs in UK waters: a review

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Elasmobranch fish are susceptible to over-exploitation by commercial and recreational fisheries and an increasing focus of conservation initiatives. The lack of accurate species-specific landings data in many European fisheries and the paucity of biological data have restricted the types of stock assessment that can be undertaken. Hence, other methods of determining the overall status of elasmobranch fish are required. For demersal elasmobranchs around the British Isles, the most widely available biological data describe life histories and abundance from fishery-independent surveys. Here, we examine the length-distribution of demersal elasmobranchs caught during groundfish surveys, to determine which life history stages are sampled effectively. For these stages, we report trends in abundance and relate the trends to knowledge of the species' biology and fisheries, and to the decline criteria that are used to assess species' status by nature conservation agencies. The analyses show that many large demersal elasmobranchs have been severely depleted in UK waters but that groundfish surveys still provide a good source of data for monitoring changes in status of the more abundant species. For rare and highly depleted species, groundfish surveys often provide good retrospective descriptions of declines, but the surveys have limited power to detect recent changes in status.

## INTRODUCTION

The vulnerability of elasmobranch fish to fishing is well documented (Holden, 1973, 1974, 1977; Stevens et al., 2000) and the status of these fish is an increasing focus of many nature conservation organizations and conventions. Elasmobranch fish represent a minor but valuable component of marine fisheries in the north-east Atlantic, with some species targeted directly and others taken as by-catch of mixed fisheries. Because of their large size, many elasmobranchs are also targeted in recreational fisheries.

Traditionally, management of these species has had a low priority in Europe, and there are few directed management measures. In the North Sea, there is a total allowable catch (TAC) for 'skates and rays' and spurdog *Squalus acanthias*, and a TAC for some non-EU countries targeting porbeagle *Lamna nasus* in northern North Sea long-line fisheries. Within UK waters, several sea fisheries committees have bylaws stipulating a minimum landing size for skates and rays. It is widely recognized that improved management measures are required to ensure sustainable elasmobranch fisheries. In 1998 the FAO developed guidelines (FAO, 2000) to help improve management, through the International Plan of Action for Conservation and Management of Sharks (IPOA-Sharks). However, such an IPOA has not been implemented at either a European or national level.

To date, rigorous stock assessments of elasmobranchs have been problematic, primarily because of the lack of species-specific landings data and paucity of biological information, especially with regards to stock identity, age composition, reproductive biology and movements (e.g. Heessen, 2003; Pawson & Ellis, 2005). The recent EC-funded project 'Development of Elasmobranch Assessments' (DELASS) highlighted that, for most species, this lack of data precluded traditional age-based assessments, and that life-table, length-based and survey-only models would form the most useful approach for assessing the status of many elasmobranch stocks (Heessen, 2003).

Elasmobranchs are an increasing focus for nature conservation organizations and conventions. For example, basking shark *Cetorhinus maximus* were protected by the UK's Wildlife and Countryside Act in 1998, and both basking shark and common skate *Dipturus batis* are subject to UK Biodiversity Action Plans and listed as 'threatened and declining species' by OSPAR. One of the main categories used by conservation agencies for identifying species potentially in need of conservation measures is the decline criterion, which may be an inferred or observed decline in numbers or distribution.

We describe the size-distribution and relative abundance of elasmobranchs caught in the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) groundfish surveys. Twenty-six of the 50 species of chondrichthyans known to occur around the British Isles have been recorded in these surveys (Ellis et al., 2005), with the remaining species either deep-water, pelagic or vagrant species. We focus on those species that are caught most frequently on the continental shelf of the British Isles. We relate trends in abundance to knowledge of the species' biology and fisheries and to the decline criteria that are used to assess species' status by nature conservation agencies.



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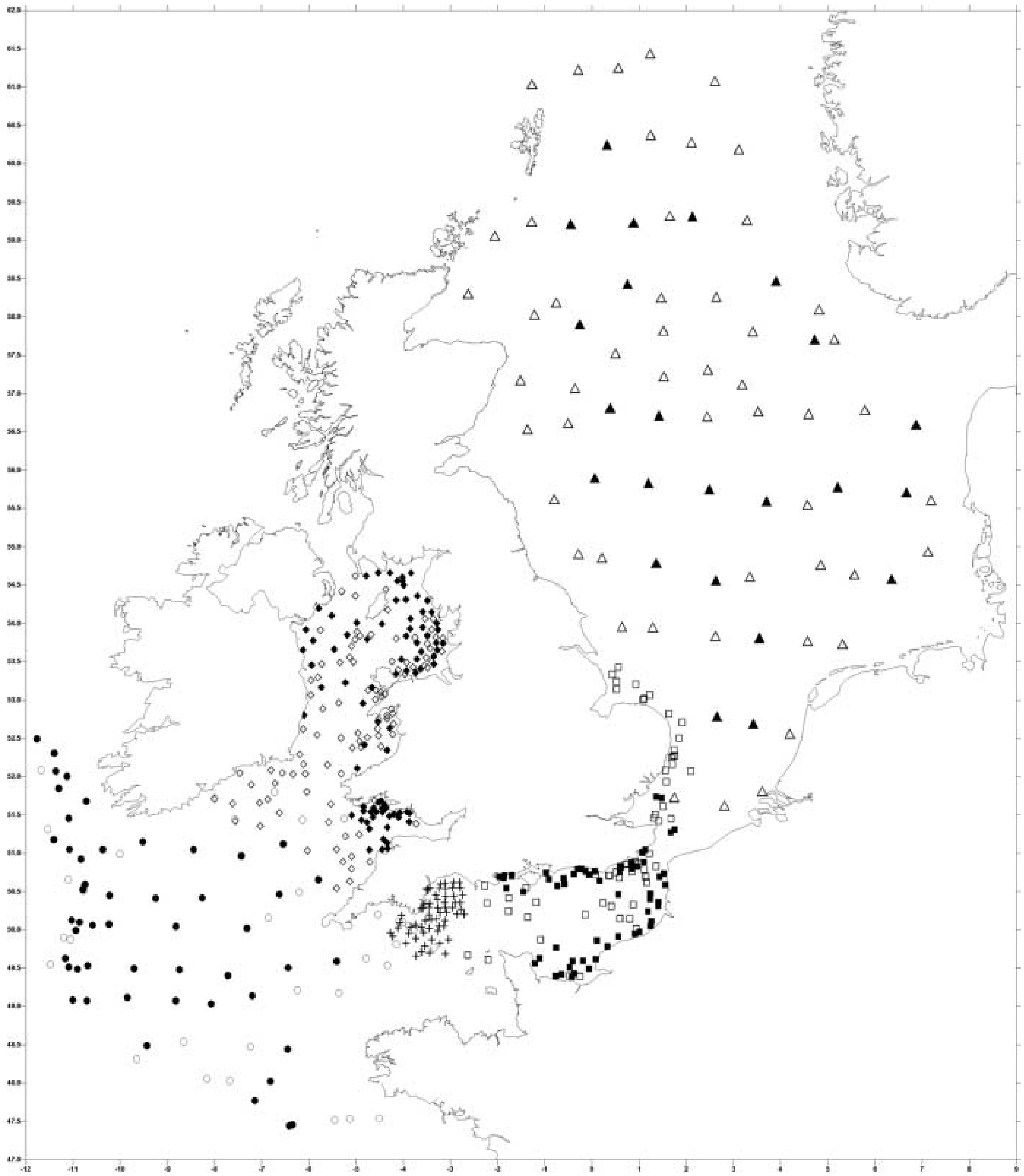

**Figure 1.** Map of the British Isles indicating stations fished and used in the analysis of length-distribution (filled and open symbols) and abundance trends (core stations only: filled symbols), for GOV surveys in the North Sea (△), PHHT surveys in the Celtic Sea (○), and during 4-m beam trawl in the Irish Sea and Bristol Channel (◇), eastern English Channel and southern North Sea (□) and western English Channel (+; length distributions only).

## MATERIALS AND METHODS

### *Surveys*

Annual groundfish surveys are undertaken in the North Sea, Celtic Sea, Irish Sea and English Channel, and these surveys use three different gears (see below). The surveys sample at fixed stations, though the number and location may vary between years, depending on factors such as weather and the presence of static fishing gear or fishing vessels.

*North Sea*

Currently, a total of 75 fixed stations (Figure 1) are fished throughout the North Sea each August with a *Grand Ouverture Verticale* (GOV) demersal trawl. The GOV trawl is fitted with a cod-end liner of 20 mm stretched mesh and is towed for 30 min at a speed of approximately 4 kn. All fish caught are identified and measured to the centimetre below. For further details of the survey gear and history of the survey, see Heessen et al. (2000) and ICES (1999) and for analyses of survey trends, see Nicholson & Jennings (2004) and Maxwell & Jennings (2005). Prior to 1992, the survey used a Granton trawl, which was towed for 60 minutes. Twenty-three of these 75 stations were fished each year for the period 1982–2002. Trends in the relative abundance of elasmobranchs at the 23 stations are described, so as to eliminate any potentially



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confounding space and time effects. All catch rates were standardized to numbers per hour.

Data from the English North Sea groundfish survey contribute to the International Bottom Trawl Survey (IBTS) database for the North Sea. Daan (2001) examined records of rare species in this database, and suggested that the database contained some errors (e.g. misidentification and mis-recording), especially in the early years. Daan (2001) identified the families Rajidae (skates) and Triakidae (tope and smoothhounds) as containing potential errors. We worked with only the English data because we were familiar with the history of the survey and the scientists who contributed to it, and could check all aspects of the survey history. We retrospectively screened data to identify potential errors, including the use of synonyms.

*Celtic Sea*

The Celtic Sea survey has operated since 1982, trawling at fixed stations each March with a Portuguese High Headline Trawl (PHHT). Between 1982 and 1988, the survey also operated in November–December. A tickler chain was used on fine grounds, but not on coarser grounds. The PHHT is fitted with a cod-end liner of 20 mm stretched mesh and is towed for 30–60 min at a speed of approximately 4 kn. For further details of the survey see Warnes & Jones (1995). Data from all stations fished were used to examine the size-frequency of the species sampled for the period 1982–2003. The survey grid was not finalized in the early years of the survey. To examine temporal trends in relative abundance we used a group of 50 stations (Figure 1) that were fished most consistently (14–16 times) between 1987 and 2002.

*Eastern English Channel*

The standard gear used in this survey was a 4-m beam trawl with a chain mat, flip up rope, and a 40 mm cod-end liner to retain small fish. The gear is towed at 4 kn (over the ground) for 30 min, averaging 2 nautical miles per tow. Fishing is only carried out in daylight hours. The numbers, biomass and length distribution of all fish species are recorded, with data for elasmobranchs recorded by sex. Further details of the gear and survey are given in Kaiser & Spencer (1994) and Kaiser et al. (1999), respectively. Surveys in the eastern English Channel and southern North Sea started in 1989, and a consistent survey grid has been sampled since 1993. This survey is conducted during July/August. Data for all stations and all years were used in the analysis of the length-distributions, whereas only data for the period 1993–2003 were used for the analysis of abundance trends. Since 1993, 61 stations have been fished every year, five in the southern North Sea, 29 in the north-eastern English Channel and 27 in the south-eastern English Channel.

*Irish Sea, Bristol Channel and western English Channel*

The same 4-m beam trawl is used in these surveys, as described above. Surveys in the Irish Sea and Bristol Channel started in 1988, and a consistent survey grid has been sampled every September since 1993. Equivalent spring surveys were also conducted between 1993 and 1998. Data for all stations and all years were used in the analysis of the length-distributions, whereas only data for the September surveys conducted between 1993–2003 were used to examine temporal trends in relative abundance. Since 1993, a total of 84 (out of approximately 100) stations have been fished each year, including 55 in the Irish Sea and St George's Channel and 29 in the Bristol Channel. For further details, see Ellis et al. (2000, 2002) and Parker-Humphreys (2004).

Beam trawl surveys in the western English Channel started in 1990 and are conducted annually in October. It was originally undertaken by the commercial beam trawler 'Carhelmar', but has been carried out by RV 'Corystes' since 2002. Data for all stations fished by the 'Carhelmar' were used in the analysis of the length-distributions.

*Data analysis*

Data for all surveys were converted to numbers caught per hour in subsequent analyses. Fish were always measured to the centimetre below, and all lengths refer to total length ($L_T$). Catch rates were standardized as $\ln(x+\alpha)$, where $\alpha$ was half the minimum non-zero abundance in the time series. Further details of this method were described in Maxwell & Jennings (2005). Smooth hound and starry smooth hound have been analysed separately, though it should be noted that there may be some misidentifications associated with these congeners.

## RESULTS

*Species recorded*

The relative abundance of the 17 elasmobranch species considered (Table 1, deep-water and vagrant species excluded) varied among regions (Table 2), reflecting differences in both distribution and gear selectivity. Fifteen species were recorded during North Sea surveys, including nine skates (Rajidae) and six sharks. Skates

**Table 1.** *Taxonomic list of elasmobranchs recorded regularly during CEFAS groundfish surveys around the British Isles.*

| Common name | Species |
|---|---|
| Spurdog | *Squalus acanthias* Linnaeus, 1758 |
| Blackmouthed dogfish | *Galeus melastomus* Rafinesque, 1810 |
| Lesser-spotted dogfish | *Scyliorhinus canicula* (Linnaeus, 1758) |
| Greater-spotted dogfish | *Scyliorhinus stellaris* (Linnaeus, 1758) |
| Tope | *Galeorhinus galeus* (Linnaeus, 1758) |
| Starry smooth hound | *Mustelus asterias* Cloquet, 1821 |
| Common smooth hound | *Mustelus mustelus* (Linnaeus, 1758) |
| Starry ray | *Amblyraja radiata* (Donovan, 1808) |
| Common skate | *Dipturus batis* (Linnaeus, 1758) |
| Sandy ray | *Leucoraja circularis* (Couch, 1838) |
| Shagreen ray | *Leucoraja fullonica* (Linnaeus, 1758) |
| Cuckoo ray | *Leucoraja naevus* (Müller & Henle, 1841) |
| Blonde ray | *Raja brachyura* Lafont, 1873 |
| Thornback ray | *Raja clavata* Linnaeus, 1758 |
| Painted ray | *Raja microocellata* Montagu, 1818 |
| Spotted ray | *Raja montagui* Fowler, 1910 |
| Undulate ray | *Raja undulata* Lacepede, 1802 |



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**Table 2.** Species composition of the 17 elasmobranchs by ICES division, as indicated by survey data (without corrections for potential differences in relative catchability by gear; GOV=Grand Ouverture Verticale trawl; PHHT=Portuguese High Headline Trawl; BT=4-m beam trawl).

| ICES Division | 4A | 4B | 4C | 7A | 7B | 7D | 7E | 7F | 7G | 7H | 7J |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Gear | GOV | GOV | GOV (BT) | BT | PHHT | BT | BT (PHHT) | BT (PHHT) | PHHT | PHHT | PHHT |
| *S. acanthias* | 4.7 | 26.0 | 1.0 | 0.6 | 59.3 | 0.2 | 0.9 | 3.1 | 48.7 | 43.0 | 41.6 |
| *G. melastomus* | 1.2 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 |
| *S. canicula* | 8.6 | 0.3 | 35.6 | 60.5 | 35.0 | 50.3 | 84.6 | 67.0 | 40.7 | 29.6 | 49.3 |
| *S. stellaris* | 0.0 | 0.0 | 0.6 | 0.8 | 0.0 | 0.9 | 0.2 | 0.4 | 0.1 | 0.0 | 0.0 |
| *G. galeus* | 0.0 | 0.7 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 3.2 | 0.1 |
| *M. asterias* | 0.0 | 0.1 | 6.3 | 0.5 | 0.1 | 3.8 | 1.0 | 2.7 | 0.3 | 2.1 | 0.3 |
| *M. mustelus* | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.8 | 0.2 |
| *A. radiata* | 78.7 | 67.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *D. batis* | 0.1 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.3 | 0.4 | 0.3 |
| *L. circularis* | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *L. fullonica* | 0.3 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.8 | 2.4 | 0.8 |
| *L. naevus* | 5.1 | 4.0 | 0.1 | 6.1 | 1.9 | 0.0 | 0.9 | 0.4 | 1.5 | 17.1 | 5.3 |
| *R. brachyura* | 0.0 | 0.0 | 0.5 | 1.9 | 0.1 | 1.4 | 0.7 | 1.4 | 0.1 | 0.1 | 0.0 |
| *R. clavata* | 0.2 | 0.2 | 40.3 | 18.7 | 0.7 | 33.6 | 5.8 | 11.5 | 3.3 | 0.4 | 1.5 |
| *R. microocellata* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.4 | 8.1 | 1.1 | 0.0 | 0.0 |
| *R. montagui* | 0.8 | 1.0 | 12.9 | 10.7 | 1.9 | 6.4 | 4.8 | 5.2 | 2.6 | 1.0 | 0.0 |
| *R. undulata* | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 2.3 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

**Table 3.** *Reported size at birth and maximum length of demersal elasmobranchs (data from Whitehead et al., 1984, unless otherwise specified), and the size range recorded during CEFAS groundfish surveys of the UK continental shelf ($L_T$ to the centimetre below).*

| | | | Size range observed | | | |
|---|---|---|---|---|---|---|
| Species | $L_{birth}$ | $L_{max}$ | North Sea | Celtic Sea | Irish Sea/ Western Channel | Eastern Channel |
| *S. acanthias* | 19–30 | 105 | 27–121 | 16–113 | *20–95* | |
| *G. melastomus* | 8 | 90 | 13–74 | 20–66 | — | — |
| *S. canicula* | 9–11 | 75 | 10–80 | 9–78 | 5–74 | 9–72 |
| *S. stellaris* | 16 | 162 | — | 20–125 | 18–115 | 13–112 |
| *G. galeus* | 30–40 | 200 | 31–165 | 48–160 | *24–80* | |
| *M. asterias* | 30 | 140 | 24–102 | 39–133 | 23–107 | 22–117 |
| *M. mustelus* | 35 | 150 | 28–102 | 45–124 | 26–81 | 31–93 |
| *A. radiata*[1] | 8–11 | 60 | 5–61 | — | — | — |
| *D. batis* | — | 250 | 57–196 | 20–156 | — | — |
| *L. circularis* | — | 120 | 17–102 | 44–79 | — | — |
| *L. fullonica* | — | 100 | 26–93[3] | 14–101 | — | — |
| *L. naevus* | 10 | 70 | 12–71[4] | 12–72 | 10–69 | — |
| *R. brachyura* | 16–19 | 120 | — | 34–110 | 11–102 | 15–72 |
| *R. clavata* | 11–12 | 90 | 9–98 | 10–112 | 10–103 | 10–93 |
| *R. microocellata* | 10 | 91[2] | — | 45–84 | 12–89 | 23–81 |
| *R. montagui* | 10 | 80 | 19–72[5] | 27–70 | 10–70 | 15–70 |
| *R. undulata* | — | 100 | — | — | 26–96 | 17–81 |

[1], Attain a larger size in the north-west Atlantic; [2], Ryland & Ajayi (1984); [3–5], exceptionally large recorded specimens of 128, 93 and 82 cm respectively omitted as possible misidentifications.

comprised approximately 77% of the numerical abundance of all elasmobranchs caught, and the most abundant species, over the period 1977–2003, were *Amblyraja radiata* (70%), *Squalus acanthias* (18%) and *Scyliorhinus canicula* (4%). Sixteen species (Table 2) were reported in the Celtic Sea. The dominant species were *Squalus acanthias*, *Scyliorhinus canicula* and *Leucoraja naevus*, which accounted for 43, 43 and 8% of the numerical abundance, respectively.

Twelve demersal elasmobranchs were recorded from beam trawl surveys in the eastern English Channel, and the dominant species, numerically, were *S. canicula* (47%),



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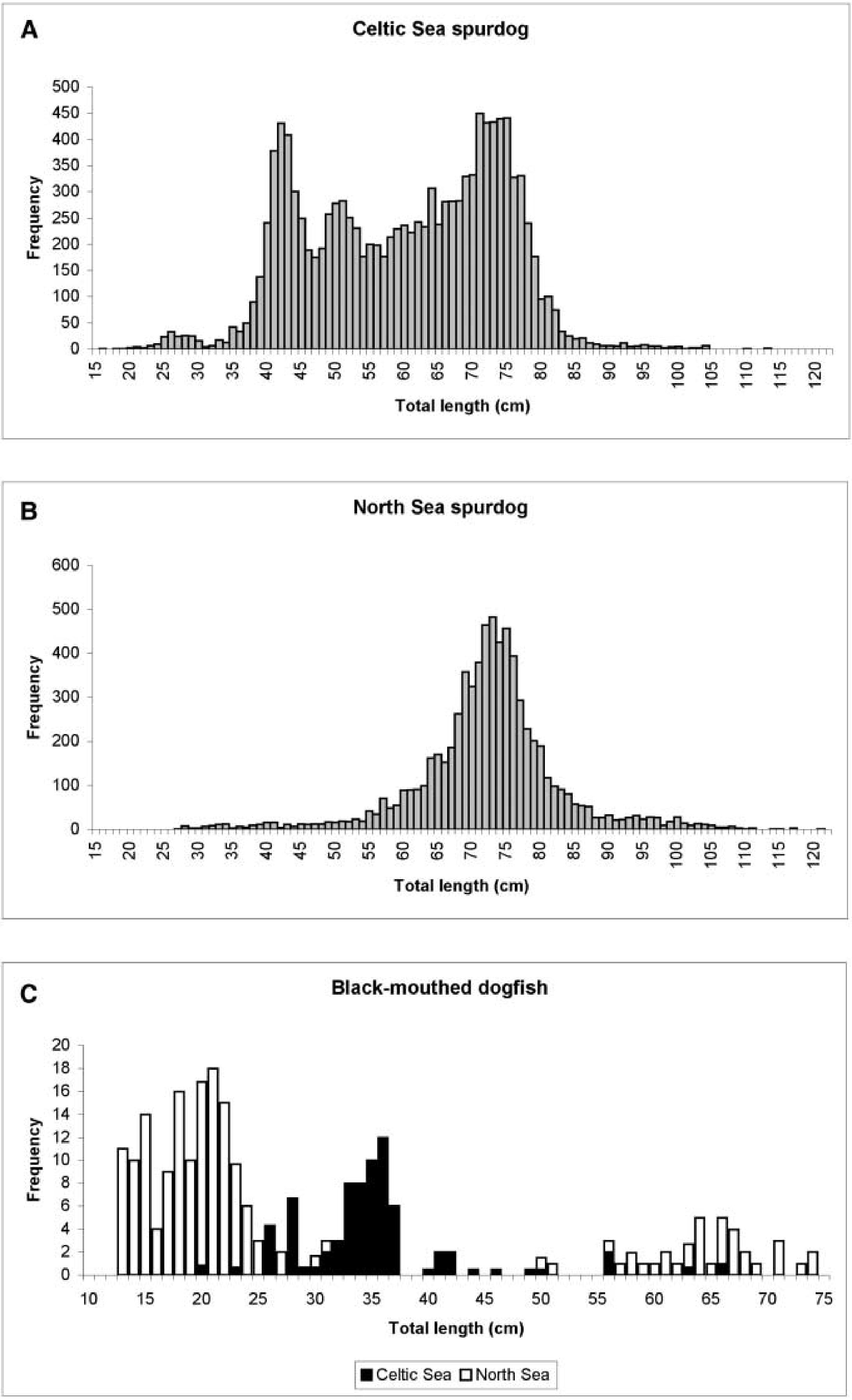


**Figure 2.** Length distribution of spurdog *Squalus acanthias* caught in (A) the Celtic Sea; and (B) the North Sea; and (C) black-mouth dogfish *Galeus melastomus* caught in the Celtic Sea and North Sea.

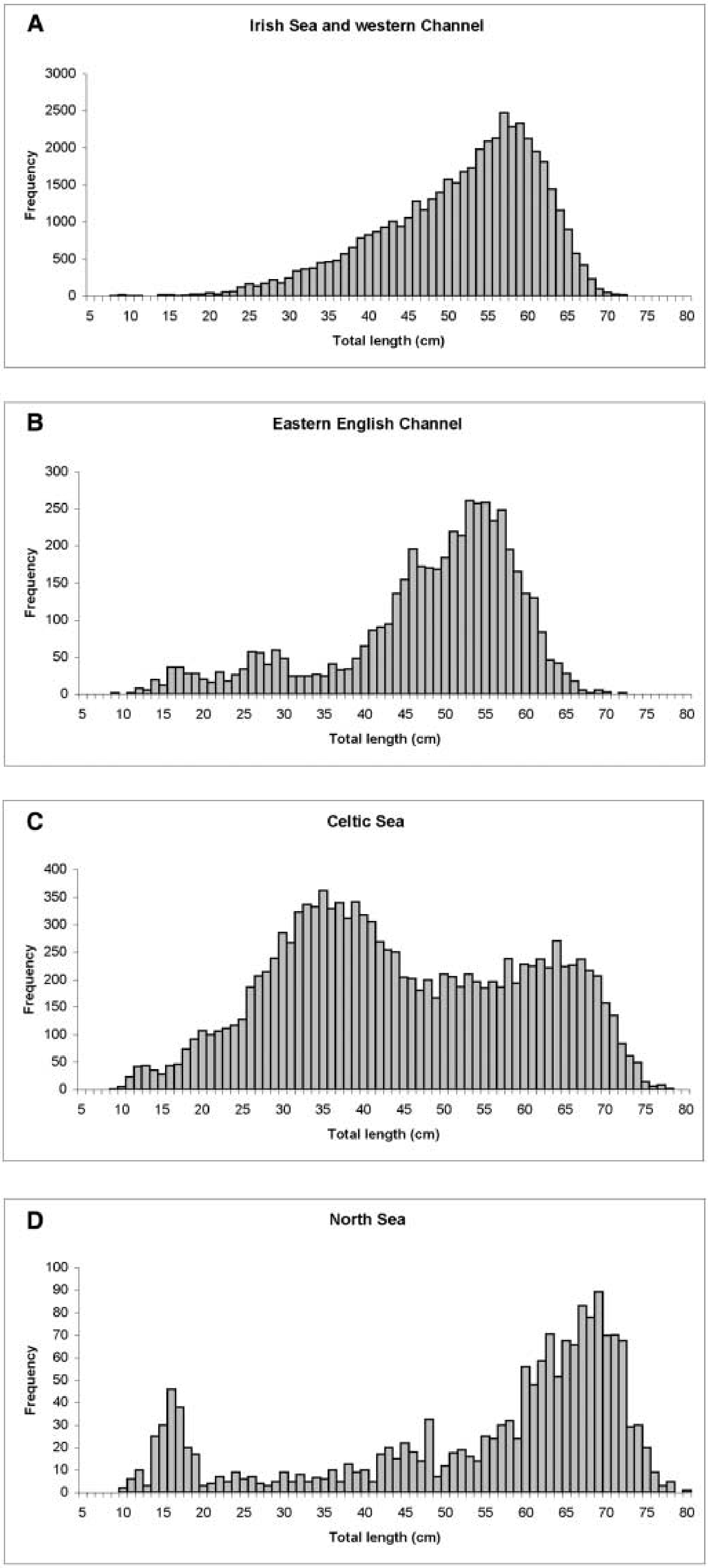


**Figure 3.** Length distributions of lesser-spotted dogfish *Scyliorhinus canicula* caught in (A) the Irish Sea and western English Channel; (B) eastern English Channel; (C) Celtic Sea; and (D) North Sea.



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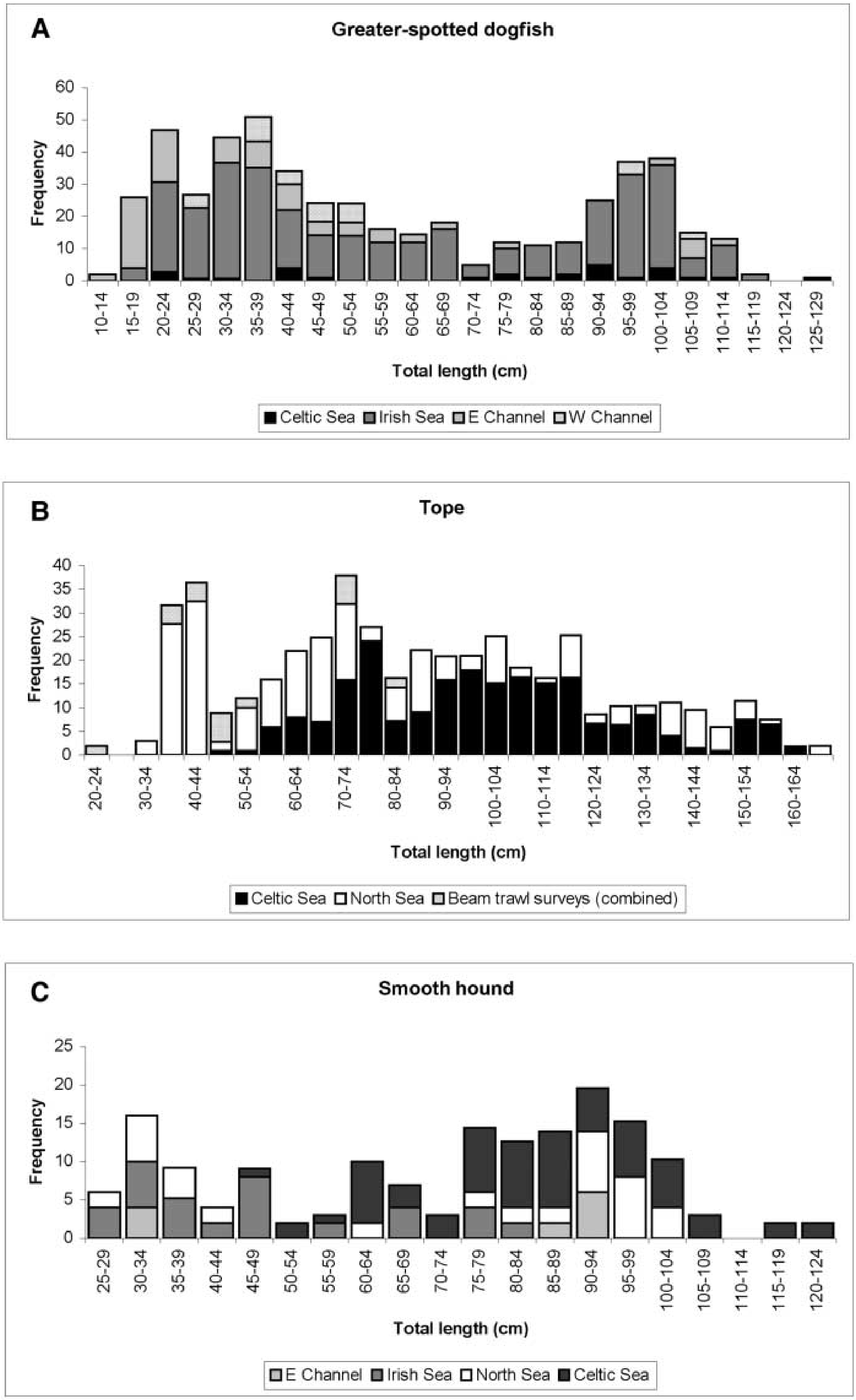


**Figure 4.** Length distributions of (A) greater-spotted dogfish *Scyliorhinus stellaris*; (B) tope *Galeorhinus galeus*; and (C) smooth hound *Mustelus mustelus* caught in the Irish Sea, English Channel, North Sea and Celtic Sea.

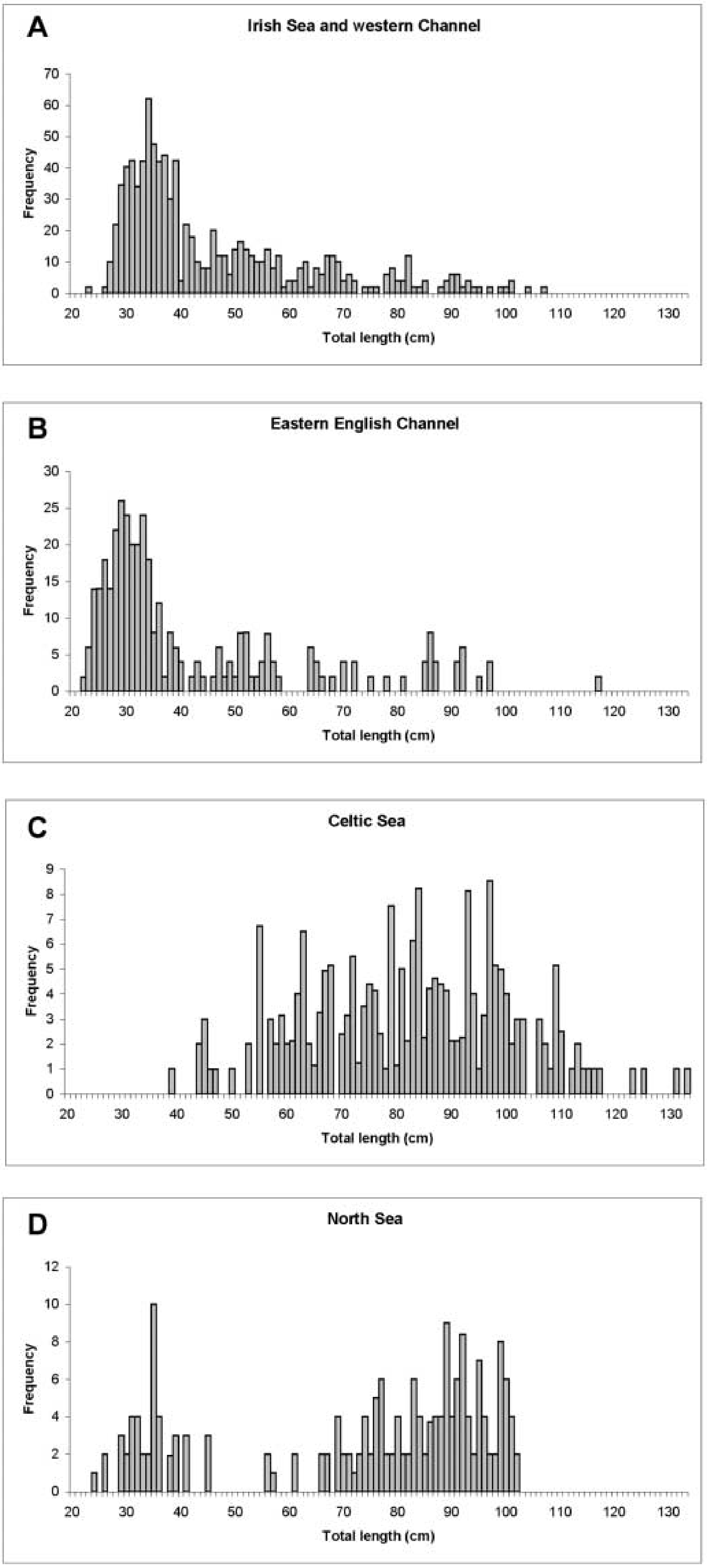


**Figure 5.** Length distributions of starry smooth hound *Mustelus asterias* caught in (A) the Irish Sea and western English Channel; (B) eastern English Channel; (C) Celtic Sea; and (D) North Sea.



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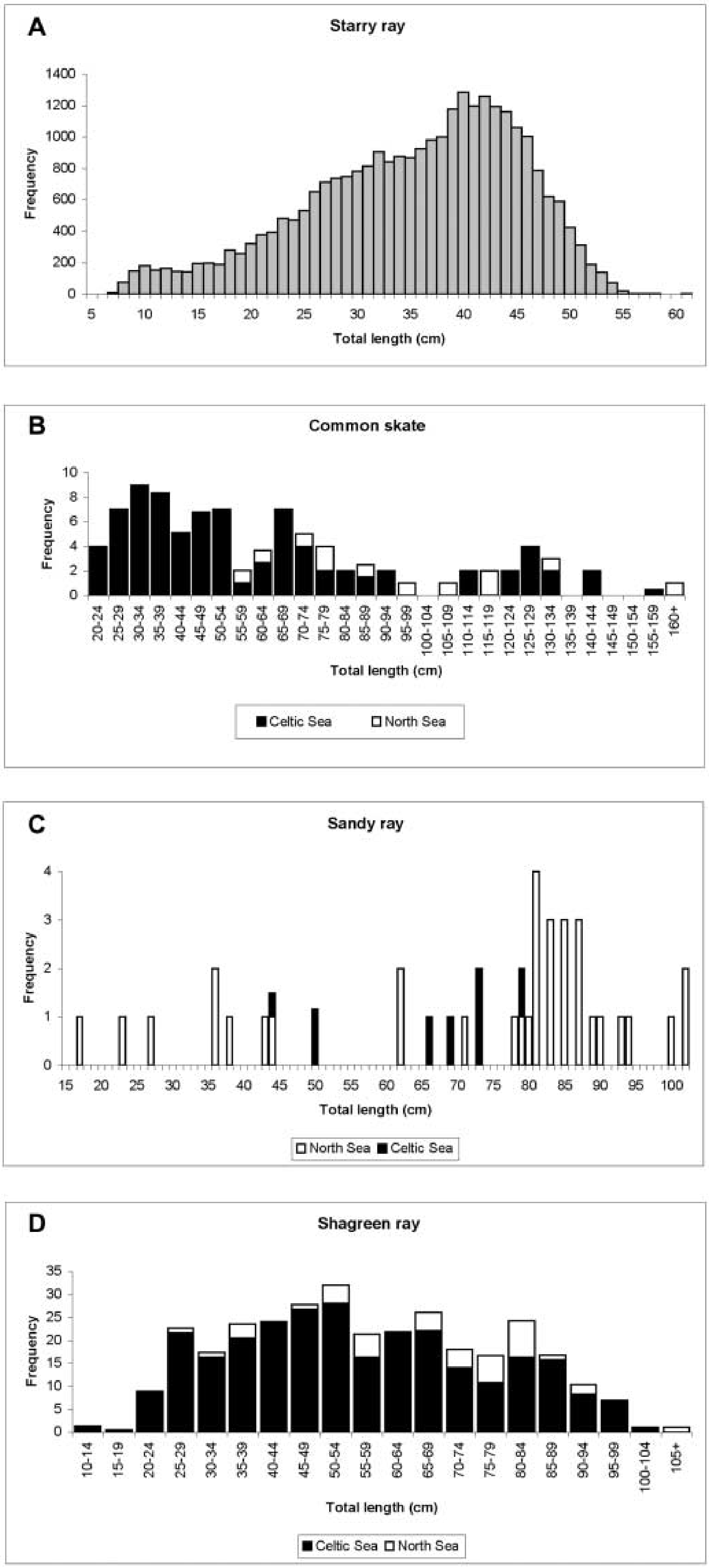


**Figure 6.** Length distributions of (A) starry ray *Amblyraja radiata* in the North Sea; and (B) common skate *Dipturus batis*; (C) sandy ray *Leucoraja circularis*; and (D) shagreen ray *Leucoraja fullonica* caught in the Celtic Sea and North Sea.

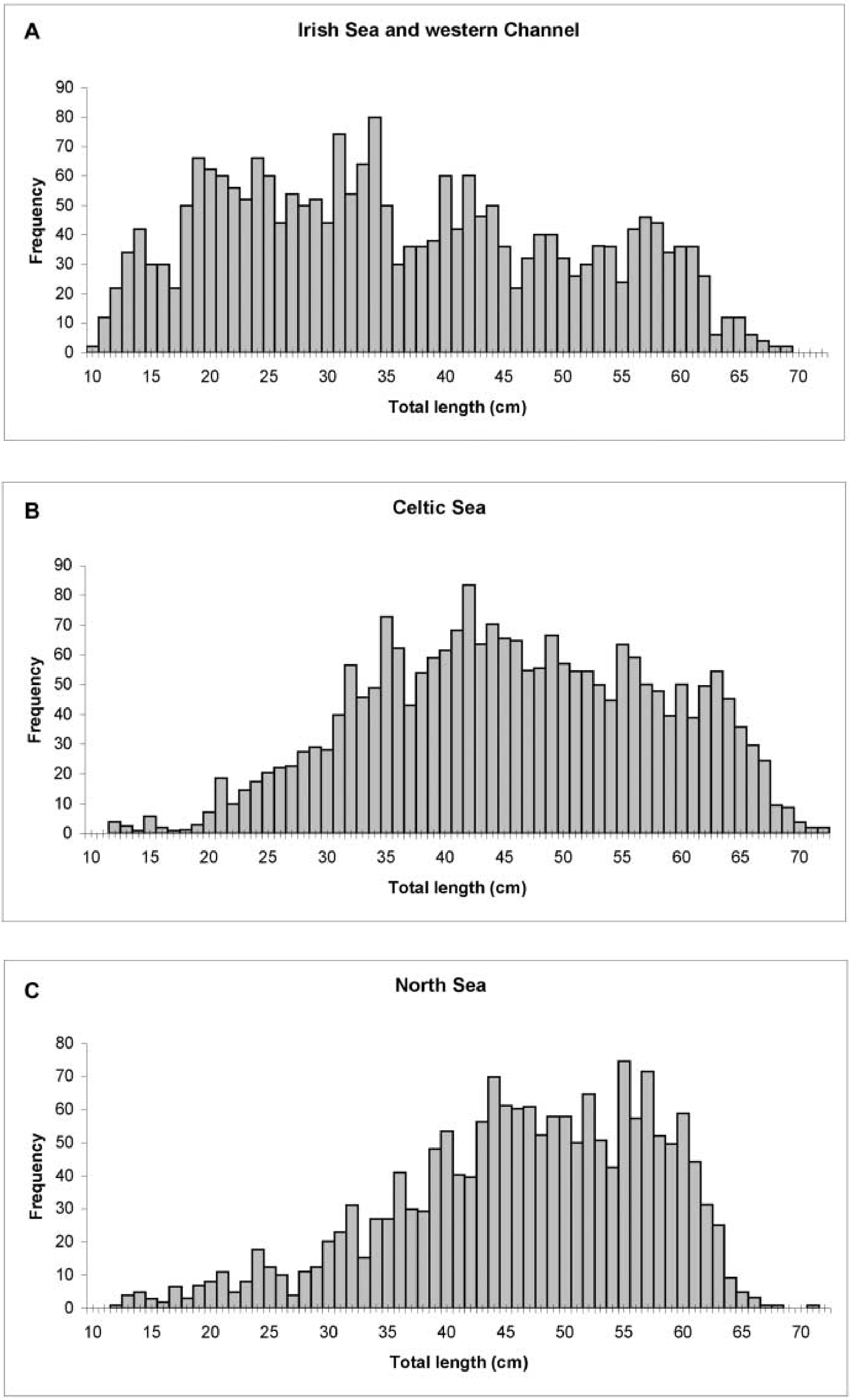


**Figure 7.** Length distribution of cuckoo ray *Leucoraja naevus* caught in (A) the Irish Sea and western English Channel; (B) Celtic Sea; and (C) North Sea.



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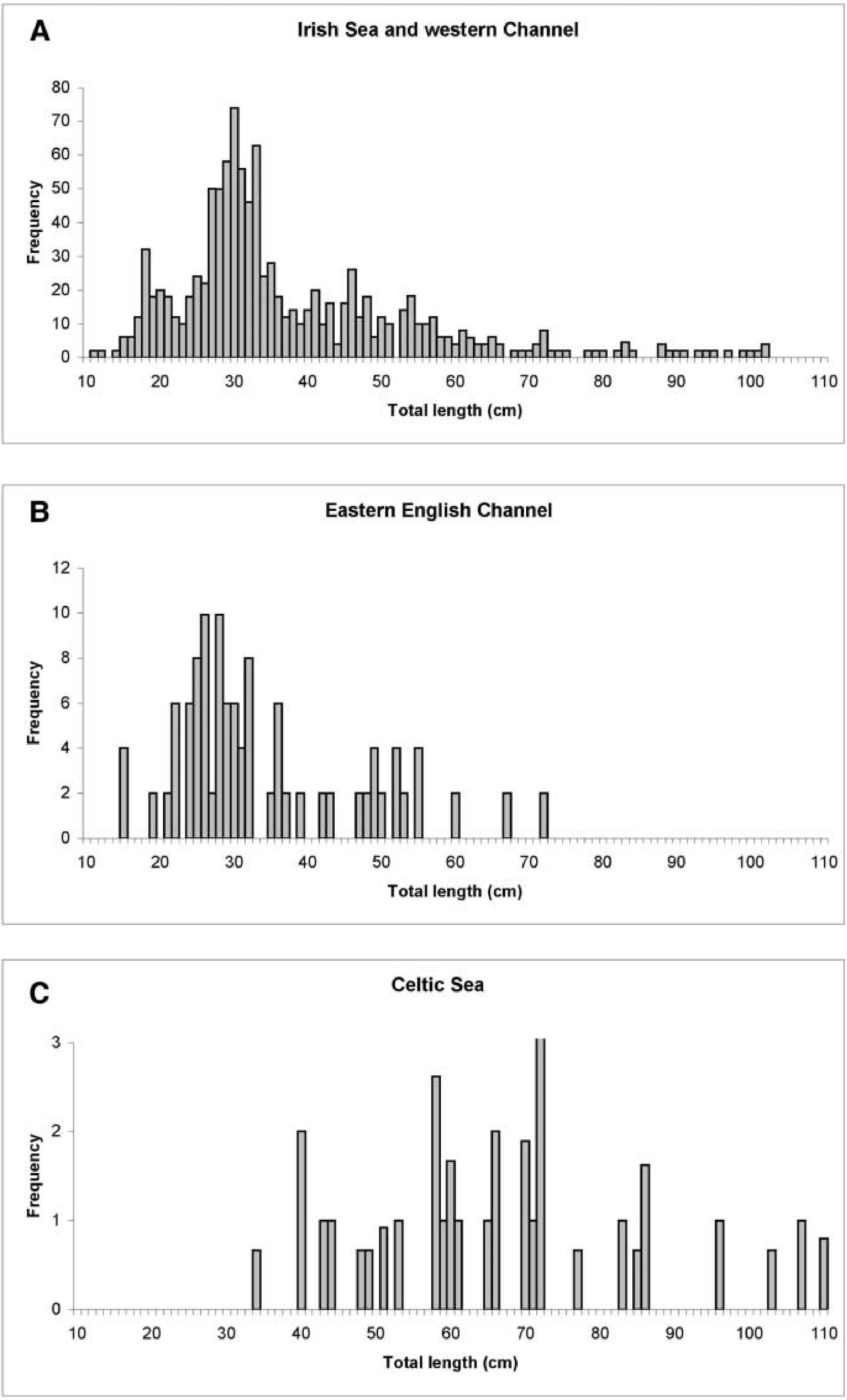


**Figure 8.** Length distribution of blonde ray *Raja brachyura* caught in (A) the Irish Sea and western English Channel; (B) eastern English Channel; and (C) Celtic Sea.

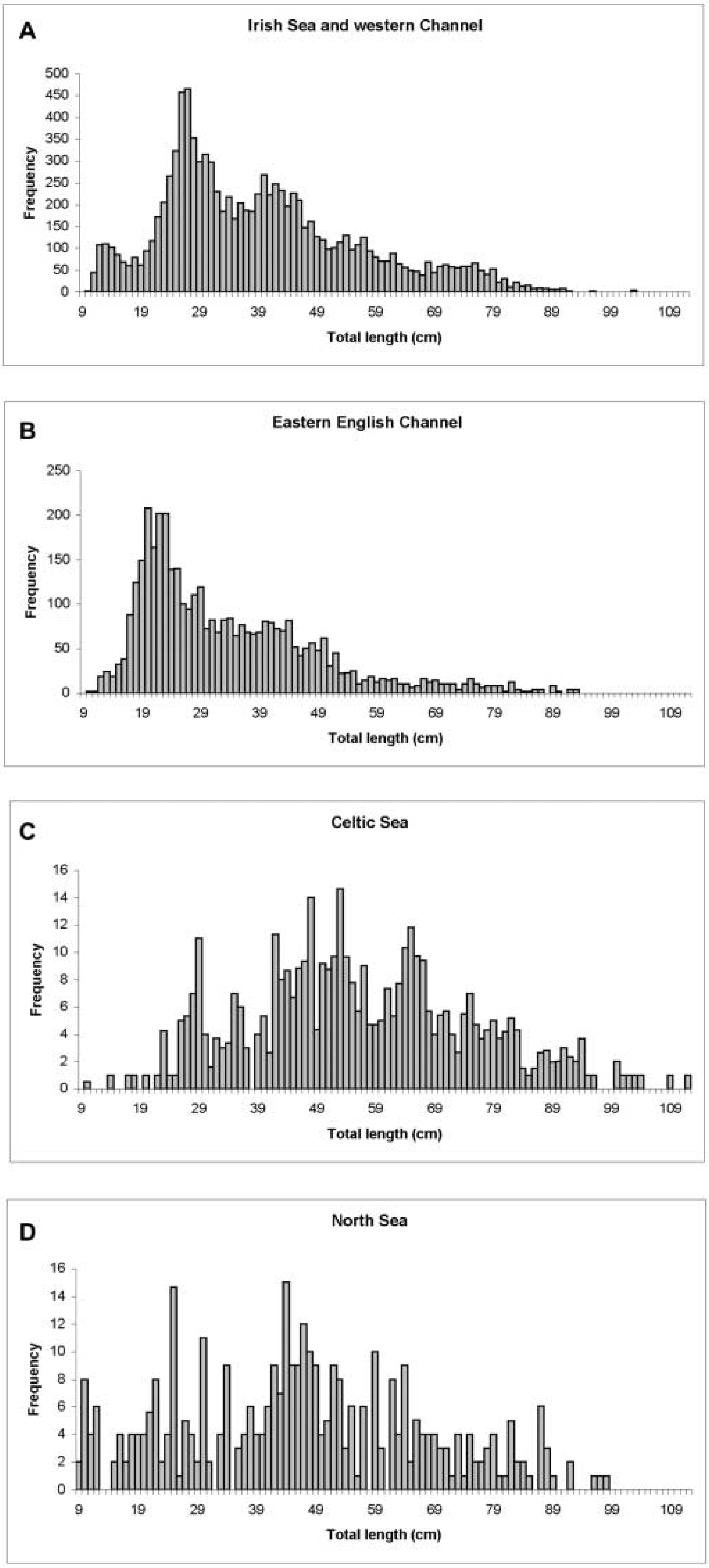


**Figure 9.** Length distribution of thornback ray *Raja clavata* caught in (A) the Irish Sea and western English Channel; (B) eastern English Channel; (C) Celtic Sea; and (D) North Sea.

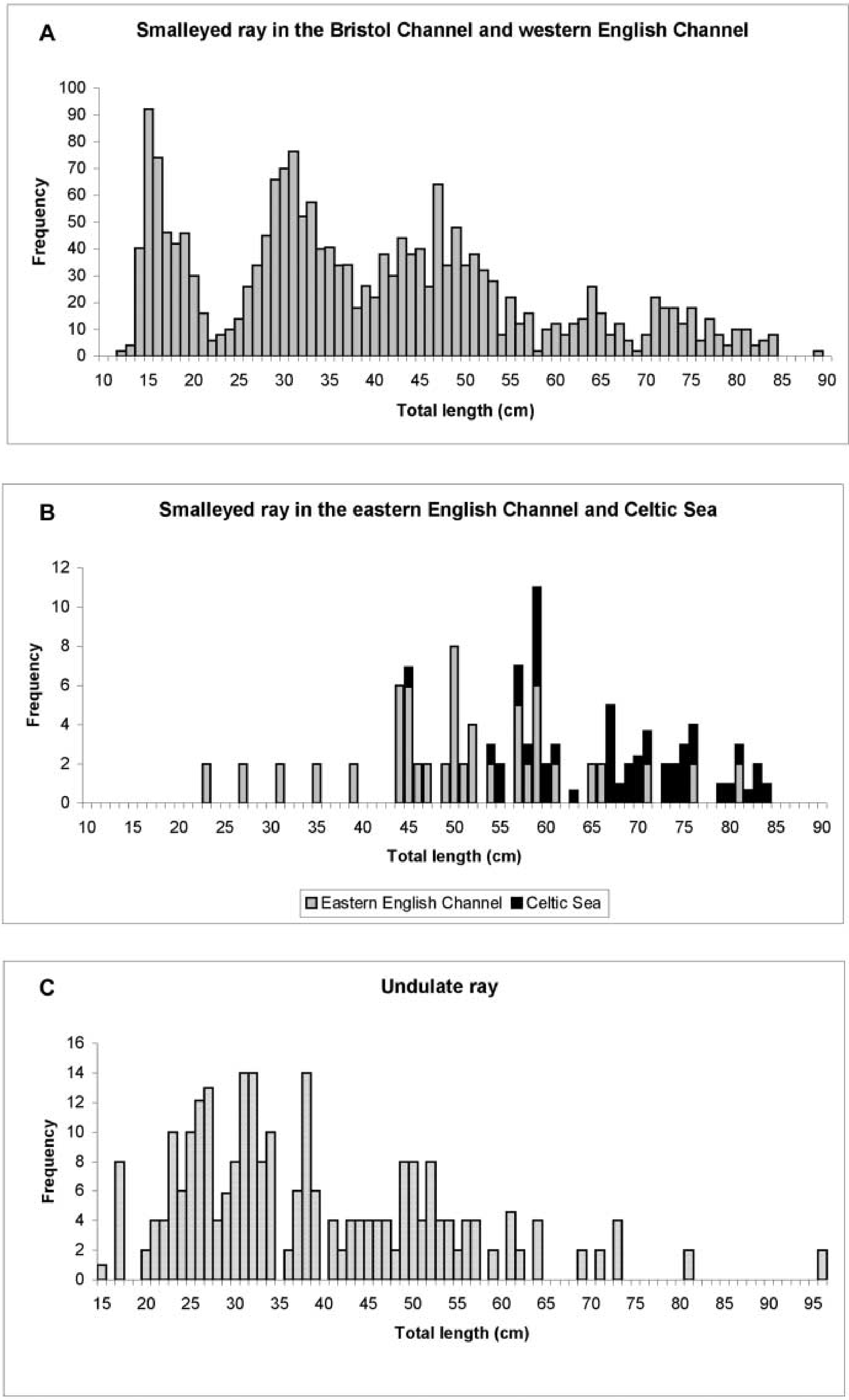


**Figure 10.** Length distribution of smalleyed ray *Raja microocellata* caught in (A) the Bristol Channel and western English Channel; and (B) eastern English Channel and Celtic Sea; and (C) undulate ray *Raja undulata* (all surveys combined).

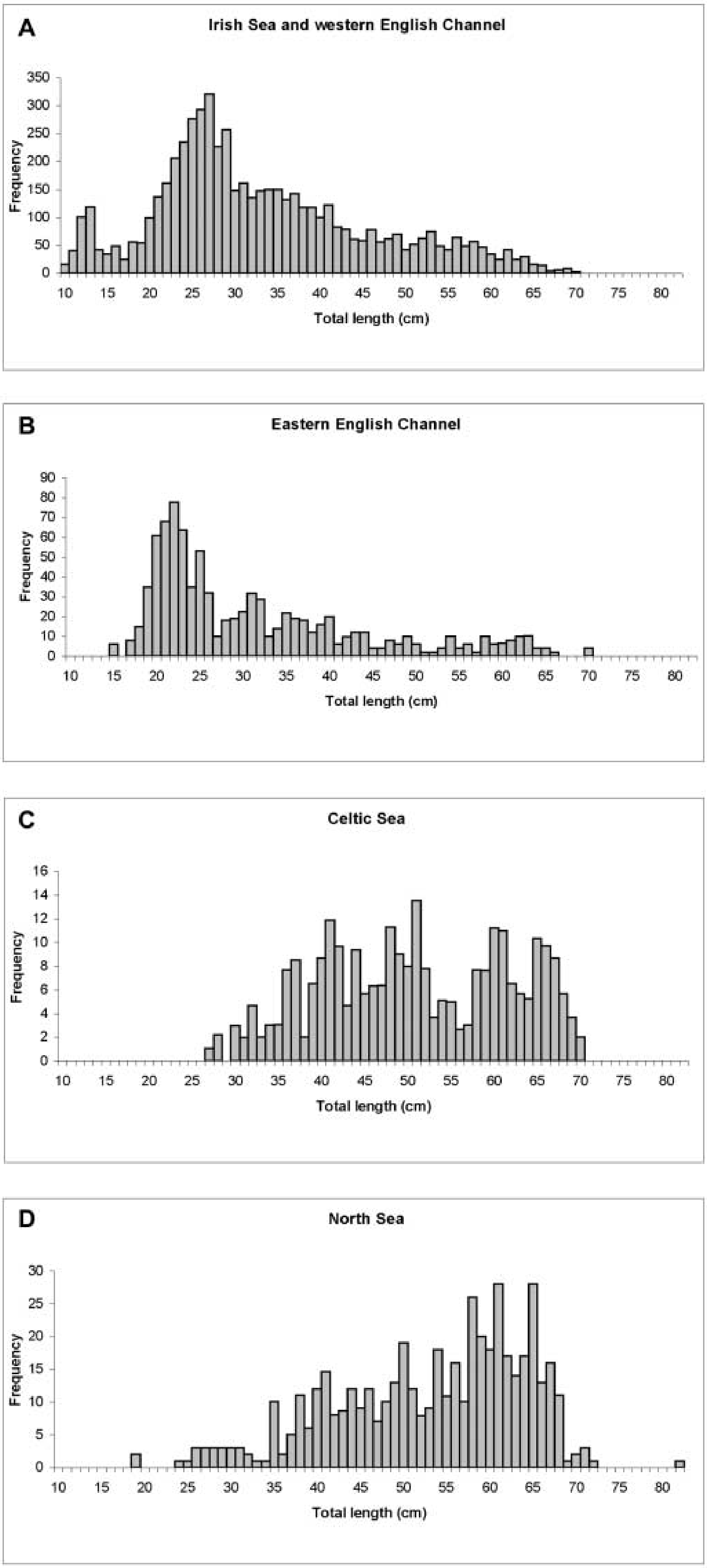


**Figure 11.** Length distribution of spotted ray *Raja montagui* caught in (A) the Irish Sea and western English Channel; (B) eastern English Channel; (C) Celtic Sea; and (D) North Sea.



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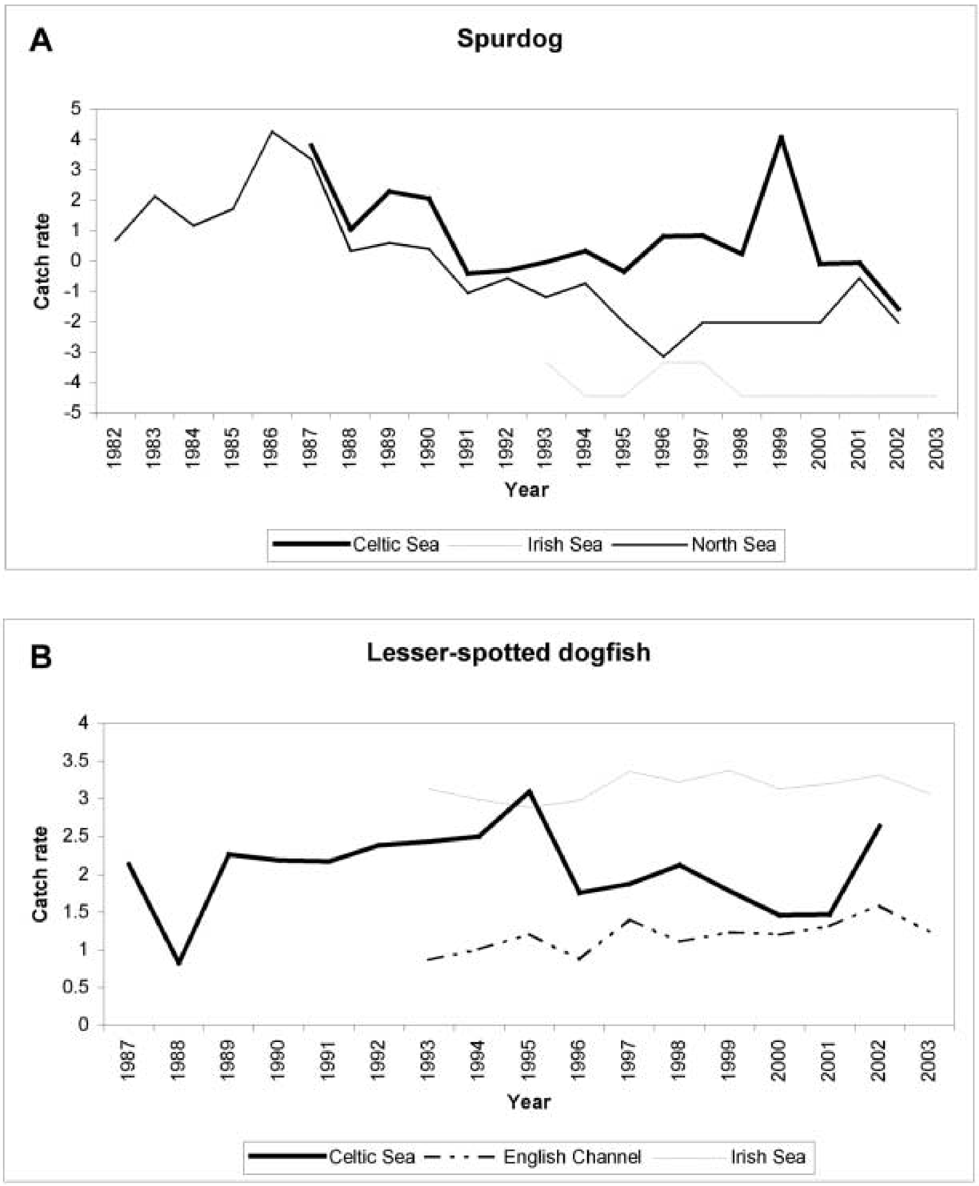


**Figure 12.** Trends in the relative abundance of (A) *Squalus acanthias* in the North Sea, Celtic Sea and Irish Sea; and (B) *Scyliorhinus canicula* in the Celtic Sea, Irish Sea and eastern English Channel.

*Raja clavata* (37%) and *R. montagui* (8%). Thirteen species were recorded in beam trawl surveys in the western English Channel and Irish Sea, and, once again, *S. canicula* (68%), *R. clavata* (14%) and *R. montagui* (8%) were the most abundant. *Leucoraja naevus* was one of the most abundant species on the coarse offshore grounds in the Irish Sea and St George's Channel, while *Raja microocellata* was one of the more abundant species in the Bristol Channel.

### *Length-frequency*

The length ranges sampled are summarized in Table 4, where they can be compared with the reported size at birth and maximum size.

*Squalus acanthias* were only caught regularly in the North Sea and Celtic Sea surveys, with occasional individuals (20–95 cm $L_T$) taken in beam trawls (Figure 2). Most individuals caught in the North Sea ranged from 55–90 cm, with >85% of individuals measuring 60–85 cm. Less than 3% of individuals were ⩽50 cm, indicating that the North Sea may not provide good information on the abundance of pre-recruits. Juveniles accounted for a greater proportion of the catch in the Celtic Sea, and approximately 30% were ⩽50 cm. A small peak in abundance at 20–30 cm corresponded with the size range of neonates, but their abundance was lower than would be expected given the abundance of larger juveniles (Figure 2).

*Galeus melastomus* were only caught in North and Celtic Sea surveys, and different size-classes predominated (Figure 2). In the North Sea, individuals were mostly 13–31 cm and 56–74 cm, while in the Celtic Sea fish of 26–42 cm were most abundant, with relatively few fish <25 cm and >50 cm. There were no contemporary records of this species in the Irish Sea. *Scyliorhinus canicula* were abundant in all surveys (Figure 3), and individuals ranged in size from 5 to 80 cm, with the smallest



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**Figure 13.** Trends in the relative abundance of (A) *Galeorhinus galeus* in the North Sea and Celtic Sea; (B) *Mustelus asterias* in the Celtic Sea, Irish Sea and eastern English Channel; and (C) *Amblyraja radiata* in the North Sea.

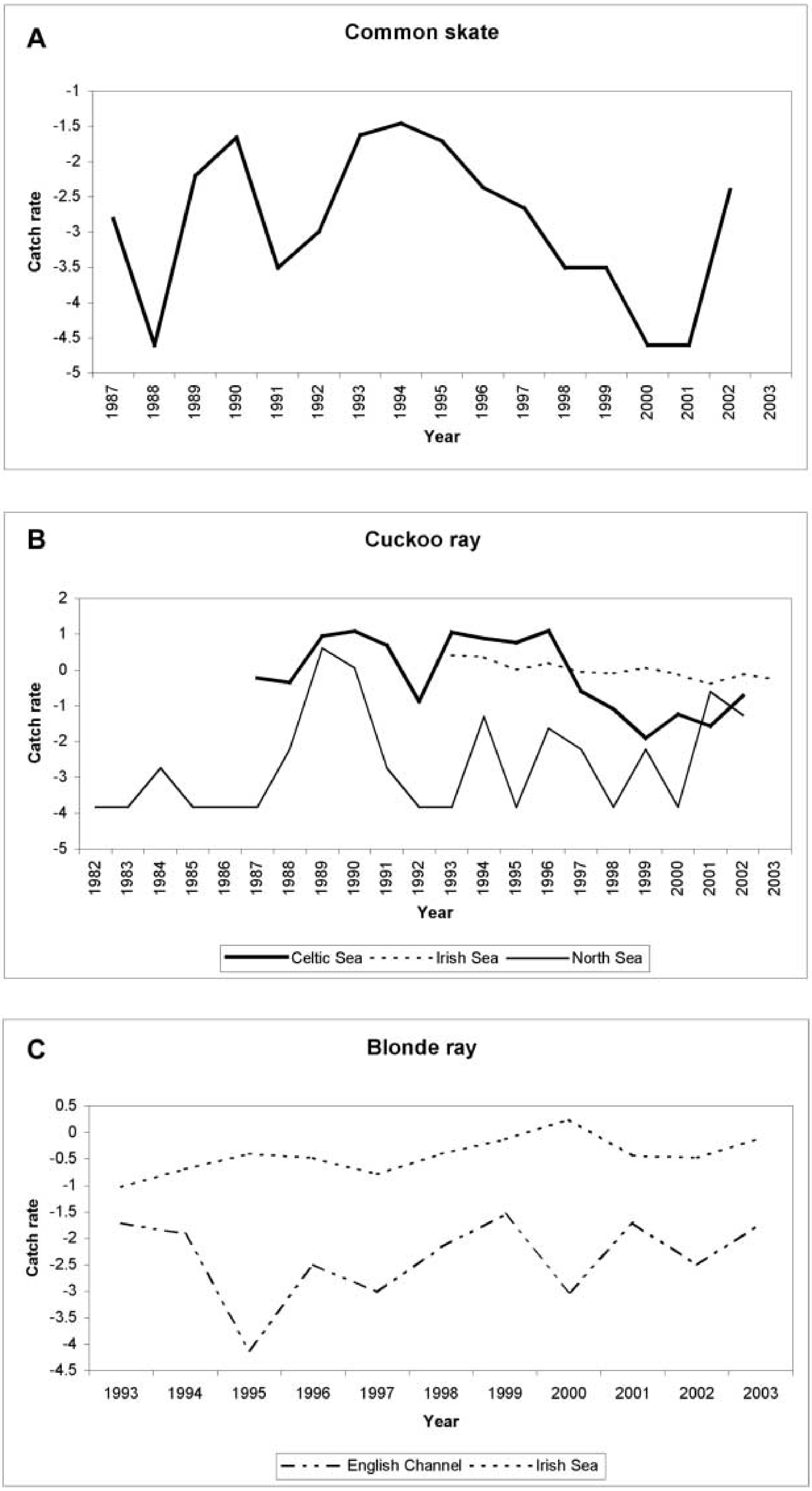


**Figure 14.** Trends in the relative abundance of (A) *Dipturus batis* in the Celtic Sea; (B) *Leucoraja naevus* in the North Sea, Celtic Sea and Irish Sea; and (C) *Raja brachyura* in the Irish Sea and eastern English Channel.

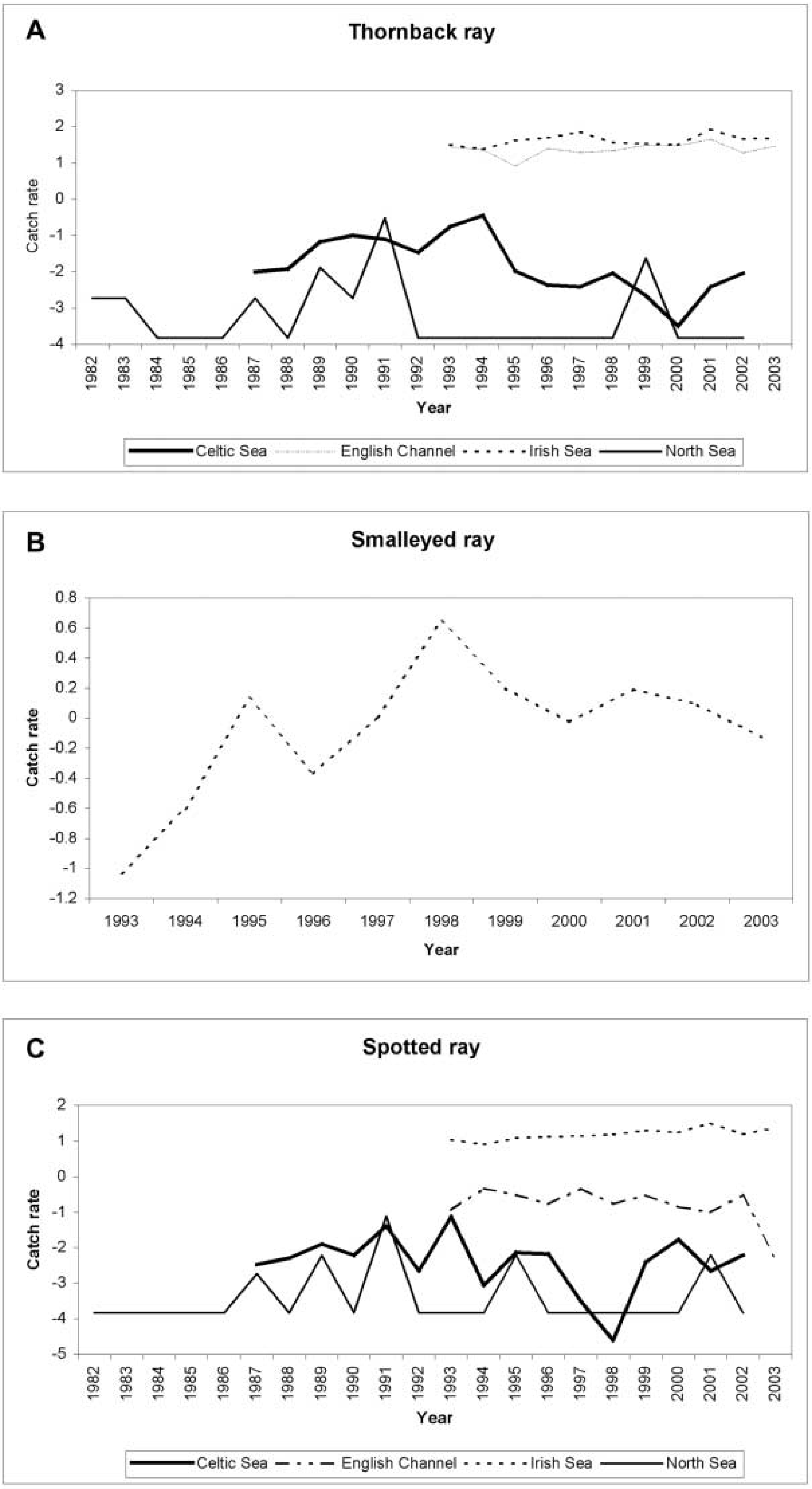


**Figure 15.** Trends in the relative abundance of (A) *Raja clavata* in the North Sea, Celtic Sea, Irish Sea and eastern English Channel; (B) *Raja microocellata* in the Bristol Channel; and (C) *Raja montagui* in the North Sea, Celtic Sea, Irish Sea and eastern English Channel.



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individuals recently hatched. Beam trawl surveys in the English Channel and Irish Sea caught comparatively few neonates and small juveniles, and most individuals were sub-adults and adults, with 87% of fish $\geqslant$40 cm. In the Celtic Sea, proportionately more juveniles were caught, with 42% <40 cm. North Sea surveys took predominantly adults (55–80 cm) and juveniles (10–20 cm). *Scyliorhinus stellaris* (13–125 cm) were caught in southerly and westerly surveys, and none were recorded in the North Sea. This species was only caught in appreciable numbers in the Irish Sea (Figure 4), with most being caught around Anglesey and the Lleyn Peninsula.

*Galeorhinus galeus* (24–165 cm) were often caught in the Celtic and North Sea. Few were caught in the beam trawl surveys, and these were $\leqslant$80 cm (Figure 4). Relatively large numbers of juveniles (31–45 cm) characterized North Sea catches, while these were generally absent from catches in the Celtic Sea. *Mustelus asterias* (22–133 cm) were caught in all surveys (Figure 5). Beam trawl surveys caught relatively large numbers of neonates and juveniles (22–45 cm), while catches of larger individuals were more sporadic. The North Sea survey routinely caught neonates and juveniles ($\leqslant$45 cm), as well as sub-adult and adult fish (56–102 cm). In the Celtic Sea, neonates were absent, with all fish >45 cm $L_T$. Fewer *M. mustelus* were reported (Figure 4), though the same general patterns were observed.

*Amblyraja radiata* (5–61 cm) were abundant in the North Sea (Figure 6), but smaller fish appear to be under-represented. *Dipturus batis* were only caught in North Sea and Celtic Sea surveys (Figure 6). Catches in the North Sea comprised individuals 57–196 cm, and no small juveniles were reported. In contrast, catches in the Celtic Sea comprised fish of 20–156 cm $L_T$, with most <75 cm.

*Leucoraja circularis* and *L. fullonica* were only caught in the North and Celtic Sea surveys. The former species was too rarely caught to allow a useful interpretation of the size distribution of captures (Figure 6), and *L. fullonica* was only caught in appreciable numbers in the Celtic Sea (Figure 6), where lengths ranged from 14–101 cm. *Leucoraja naevus* was abundant in the North Sea, Celtic Sea and Irish Sea surveys (Figure 7). Fish over the whole size range 10–72 cm were caught, but the Irish Sea beam trawl survey caught proportionately more recently hatched fish (10–15 cm $L_T$).

*Raja brachyura* were most frequently caught in the Irish Sea and eastern English Channel beam trawl surveys. Juveniles were most abundant, though adults were occasionally caught in the Irish Sea survey (Figure 8). The occasional captures in the Celtic Sea were typically of individuals >40 cm $L_T$. *Raja clavata* was one of the most abundant elasmobranchs caught, though catch rates tended to be greater at the inshore beam trawl surveys where juveniles dominated (Figure 9). *Raja microocellata* was caught predominantly in the Bristol Channel (Figure 10) while a few larger juveniles were caught in the eastern English Channel and adults were taken in the eastern Celtic Sea and outer Bristol Channel. Few recently hatched individuals were recorded.

*Raja montagui* was abundant in all surveys. Catch rates tended to be greatest in the inshore beam trawl surveys (Figure 11) where many juveniles were caught. In the Irish Sea neonatal fish (10–15 cm $L_T$) were reported, whereas in the Celtic and North Sea surveys individuals were typically >35 cm $L_T$. *Raja undulata* (15–96 cm $L_T$) were caught mostly in the English Channel. Once again, juveniles dominated catches (Figure 10), with few neonatal fish observed.

### *Abundance trends*

With low catch rates of many species over the duration of the surveys, annual catch data are not always sufficient to determine significant trends in relative abundance (e.g. *L. circularis* and *S. stellaris*). However, for some of the more abundant species, surveys can indicate trends in abundance. Catch rates of *Squalus acanthias* decreased in the North Sea from 1982–2002. Data from the Celtic Sea also indicated a general decline in abundance (Figure 12), with the peak in 1999 attributed to a large catch at a single station. In contrast, catch rates of *Scyliorhinus canicula* were relatively stable in the Irish and Celtic Seas, and showed a small increase in the eastern English Channel (Figure 12). Catch rates of *G. galeus* in the North Sea are insufficient to accurately identify trends, though catches in the Celtic Sea appear to have increased slightly (Figure 13). Data for the Irish Sea and Celtic Sea also suggest a slight increase in the numbers of *M. asterias* (Figure 13).

The relative abundance of *A. radiata* in the North Sea (Figure 13) showed a pronounced decrease in 1992, when the gear was changed from a Granton trawl to the GOV trawl. The Granton trawl has closer bottom contact than the GOV trawl, and catch rates of species living on the seabed are expected to be lower in the latter. Considering these two periods independently suggest an increase in relative abundance between 1982 and 1991, with catch rates not showing a consistent trend in subsequent years. *Dipturus batis* occurred sporadically in the North Sea during the 1980s, but none have been recorded in the surveys since 1991. *Dipturus batis* is still recorded occasionally in the Celtic Sea. Catches declined consistently from 1994 and 2001, but subsequent catch rates have increased slightly (Figure 14). Catch rates of *L. naevus* in the North Sea do not indicate a consistent trend. In the Irish and Celtic Seas, catch rates have declined slightly (Figure 14).

Catch rates of *R. brachyura* were low in the North and Celtic Sea surveys, and most specimens were caught in the coastal areas sampled in beam trawl surveys. Trends in the Irish Sea and eastern English Channel were similar (Figure 14), though these surveys cover a relatively short period. *Raja clavata* were caught regularly in the North Sea prior to 1992, but they have only been caught occasionally since the change of gear, possibly masking any overall trend. Data from other areas suggest a decrease in abundance in the offshore waters of the Celtic Sea, with more stable catches in the inshore waters of the Irish Sea and English Channel (Figure 15). Catch rates of *R. microocellata* increased in the Bristol Channel (Figure 15) since the first two early years of the survey, but have stabilized since 1995. *Raja montagui* were caught sporadically in the North Sea, and as with *A. radiata* and *R. clavata*, the lower catch rates since 1992 may reflect the change in gear. Catch rates in other surveys were generally stable, apart from a marked decline in the eastern English Channel in 2003 (Figure 15).

## DISCUSSION

Many of the demersal elasmobranchs of north-western Europe are caught in targeted and mixed fisheries (Heessen, 2003). Although landings of *Squalus acanthias* tend to be recorded on a species-specific basis, most nations have used more generic categories for reporting landings of other elasmobranch species (e.g. 'skates and rays' and 'dogfish and hounds'). In the absence of species-specific landings data, most traditional stock assessment methods cannot be used to determine their status.

Fisheries-independent surveys provide more detailed, species-specific information, though it is acknowledged that some historical data may include erroneous records for problematic taxa (e.g. certain rajids and *Mustelus*), and the quality of the data may be limited for some species or size-classes, especially as the gears and survey grids were selected to optimize sampling of commercial teleosts. Several studies have used survey data to report on trends in the abundance of elasmobranchs (Greenstreet & Hall, 1996; Heessen, 1996; Heessen & Daan, 1996; Walker & Heessen, 1996). For species that are reliably identified and well sampled by the surveys, the data can be used for a general assessment of the population status, including trends in relative abundance and distribution for some life history stages. Moreover, the data will help to highlight those species for which survey information is sufficient to be included in any stock assessment, and identify those species for which survey data are inadequate and that may require other methods for ascertaining contemporary population status.

Species and size compositions from the different surveys are not directly comparable, as different gears are used and different types of habitat are sampled. Additionally, the surveys take place at different times of year and in different sea areas, albeit with some spatial overlap between adjacent surveys.

*Squalus acanthias* is, or has been, the target of directed gill-net and long-line fisheries in many areas, and is also an important by-catch in otter trawl and other fisheries. Although not caught routinely in beam trawl surveys in the Irish Sea and English Channel, they occur in these areas, as indicated by landings data and other surveys (e.g. Ellis et al., 2002). The low catch rates in the beam trawl surveys are, therefore, likely to be a gear effect. Thus, in the North Sea and Celtic Sea surveys, where the GOV and PHHT otter trawls were used, more and larger spurdog were caught. Most of the spurdog caught in the North Sea survey were 55–90 cm long, and juveniles were less frequent. Juvenile spurdog are known to occur in the North Sea, including off northern Scotland (Ellis et al., 2005), so their apparent absence in this survey is possibly due to juveniles occurring outside of the survey area at this time of year. Spurdog declines in the North Sea were also reported in previous studies (e.g. Greenstreet & Hall, 1996; Heessen & Daan, 1996). Heessen & Daan (1996) reported low survey catch rates from 1970–1993, with a decline following peak catches in the years 1977–1980. There has also been an overall decline in the Celtic Sea, though the survey index shows a clear peak in 1999, which was associated with a large shoal ($>2800$ ind $h^{-1}$) being caught at one station. The shoaling behaviour of this species can result in a large variance in catch rates, which inevitably hampers analyses of survey trends. The population dynamics are, however, sufficiently well known to allow more detailed stock assessments to be conducted, and these also highlight the decline in spurdog (Hammond & Ellis, 2005).

*Scyliorhinus canicula* are caught occasionally as by-catch in commercial fisheries and are an important source of bait for whelk fisheries. Landings are normally recorded in generic categories, and species-specific landings data are limited. This species was taken regularly in surveys along the southern and western coasts of the UK, but was less abundant in the North Sea. Total catches in the North Sea are low, as the species' distribution is quite patchy in relation to the sites of survey stations. Earlier studies in the North Sea suggested that survey catch rates were relatively stable over the period 1970–1993 (Heessen, 1996). Beam trawl surveys caught proportionately more mature and maturing individuals ($>40$ cm), with juveniles proportionately more abundant in the Celtic Sea. Trends in catch rates were generally stable (Irish and Celtic Seas) or increased slightly (eastern English Channel). This species has a relatively fast, productive life history and has high post-discard survival, which may account for its stability and continued high abundance (Revill et al., 2005; Rodríguez-Cabello et al., 2005). Abundance data were limited for the other scyliorhinid species. *Galeus melastomus*, which is more abundant at the edge of the continental shelf, was recorded occasionally in the northern North Sea and Celtic Sea. Catches in the northern North Sea included juveniles (13–30 cm) and adults ($\sim$60–74 cm), whereas specimens in the Celtic Sea were of an intermediate size. Sexual and ontogenetic segregation in catsharks is often reported (e.g. Bullis, 1967), though whether such segregation is geographical or behavioural is unclear. *Scyliorhinus stellaris* was recorded from all surveys except the North Sea, but was only captured regularly in parts of the Irish Sea.

Triakid sharks are generally a by-catch in commercial fisheries, and are also targeted in recreational fisheries, with most released. Landings are usually recorded under a generic category, and species-specific landings data are limited. Three species of triakid shark occur in UK waters, though there is some taxonomic confusion regarding *Mustelus* spp. Both *Galeorhinus galeus* and *M. asterias* have increased in abundance slightly over the duration of the western surveys. *Galeorhinus galeus* was not sampled effectively in beam trawl surveys, though juvenile *M. asterias* were caught routinely in this gear. All these species occur in the North Sea, especially in the outer Thames Estuary and Southern Bight, especially during the summer (Ellis et al., 2005), and although surveys do not catch them in large numbers, there have tended to be more records since the early 1980s (Heessen, 1996).

About 15 species of skate (Rajidae) may occur on the continental shelf around the British Isles (Edwards & Davis, 1997), with some captured in targeted fisheries and many taken in mixed fisheries. Skate and ray landings are usually combined, though recent market sampling by EU countries has provided some data on the species composition. Several species have been reported as disappearing from UK waters, including *Dipturus batis* and white skate *Rostroraja alba* (Brander, 1981; Dulvy et al., 2000; Rogers & Ellis, 2000), and such events remain unnoticed from



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mixed landing statistics. Hence, survey data may be especially important for assessing retrospective declines and changes in the current status of rajids.

*Amblyraja radiata* showed a gradual increase in abundance during the 1980s, as also reported by Heessen & Daan (1996). Catch rates declined after the gear changed, and trends are harder to interpret since 1992. The decline in catch rate since 1992 is likely to be a gear effect since the GOV has much weaker bottom contact than the Granton trawl (ICES, 2004). North Sea surveys have historically recorded some of the lesser-known ray species, though *D. batis* has not been recorded in UK surveys since 1991, and *Leucoraja circularis* since 1996. The former species is still recorded regularly in the Celtic Sea, albeit in low numbers, and juveniles occur regularly. However, the main changes in the abundance of this species are likely to have occurred well before the survey began, given that Brander (1981) reported the loss of this formerly abundant species from the Irish Sea in the 1970s. Indeed, it is widely reported that *D. batis* was much more widespread at the beginning of the 20th Century (Walker, 1999; Dulvy et al., 2000; Rogers & Ellis, 2000).

The low numbers of offshore rays such as *L. circularis* and *L. fullonica* warrants further investigation, as it is unclear whether their low abundance and sporadic appearance in catches is due to the surveys being outside the main areas of their distribution, natural rarity or a decline. *Leucoraja naevus* is still abundant in the North, Irish and Celtic Seas, but spatial and temporal patterns in the catches are not consistent. Thus, data from the North Sea show low but stable catch rates, whereas catch rates in the Celtic Sea and Irish Seas have decreased slightly. Catch rates for the inshore skate species, such as *Raja brachyura*, *R. clavata*, *R. microocellata* and *R. montagui*, tended to be relatively stable, though catch rates of *R. clavata* had declined in the Celtic Sea.

Studies on rays in the North Sea have indicated that long-term survey data may not give a good indication of trends in abundance, due in part to misidentifications (Daan, 2001), that large inter-annual variation in catches cannot be driven by true changes in abundance (Maxwell & Jennings, 2005), and due to changes in the spatial coverage of surveys over time (Walker & Heessen, 1996). Furthermore, several ray species now have quite restricted distributions in the North Sea (Walker & Heessen, 1996; Ellis et al., 2005), and these species may have been more widely distributed earlier in the 20th Century (Walker & Heessen, 1996). The changes in distribution probably reflect distribution–abundance relationships, with populations contracting to core habitats with high suitability as abundance falls. The interrelationship between the location of sampling stations and the remaining centres of abundance will have a strong influence on the power of surveys to detect further trends in abundance.

Decreases in the abundance of larger demersal elasmobranches are primarily a fishing effect, since all species are expected to suffer high mortality as by-catch in mixed fisheries or as target species (e.g. ICES, 1998; Walker & Hislop, 1998; Walker, 1999). The role of fishing in the declines is consistent with the observation that larger and more vulnerable species have declined more than smaller species that can withstand higher rates of fishing mortality (Walker, 1999). In the Irish Sea, for example, Dulvy et al. (2000) demonstrated that smaller skate and ray species increased in abundance as larger species declined. Similarly, Jennings et al. (1999) compared abundance trends in phylogenetically related pairs of species in the North Sea and, from 1925–1996, larger-bodied elasmobranchs became increasingly scarce in comparison with their smaller-bodied relatives.

Commercial landings of many North Sea species, including spurdog and skates and rays, peaked in the late 1950s and 1960s, and there are few surveys that extend back to this time. A well-known exception is the groundfish survey that was conducted by the Marine Laboratory, Aberdeen in the central and northern North Sea from 1925 to 1996 (Greenstreet & Hall, 1996). When surveys have been highly intermittent, attempts have been made to compare historical survey data (early 1900s) with contemporary data (1990s) and the results have also demonstrated that some of the larger-bodied demersal elasmobranchs have declined (Rijnsdorp et al., 1996; Rogers & Ellis, 2000), including angel shark *Squatina squatina*. Such analyses, coupled with knowledge of landings data and fishermen's knowledge, suggest that contemporary surveys may not extend far enough back to fully ascertain the long-term trends in both the spatial distribution and relative abundance of elasmobranchs and, in particular, the extent of declines in many species due to fishing (Rogers & Ellis, 2000).

Analyses of contemporary survey data may, however, be one of the more pragmatic approaches for ascertaining their current status, especially in monitoring further decline or recovery in response to management. The time series data analysed here range from 11 years (beam trawl surveys) to more than 20 years (North Sea), and these surveys are ongoing. The Celtic Sea survey (1987–2002) is to be modified, and so this time series may be compromised. On a broader scale, groundfish surveys are undertaken by many other fisheries laboratories, including participation in internationally-coordinated surveys (Heessen et al., 2000), which in the future will permit more accurate assessments of the status of demersal elasmobranchs in many European seas.

Of the surveys analysed here, the Celtic Sea survey may be most appropriate for monitoring catch rates of *Squalus acanthias* (juveniles and adults), *Scyliorhinus canicula* (sub-adults), *G. galeus* and *M. asterias* (adults), and possibly *D. batis*, *L. fullonica* and *L. naevus*. Catches of rays in the North Sea, other than *A. radiata*, are generally low, though this survey does capture adult *Squalus acanthias* and *M. asterias*, albeit in low numbers. Beam trawl surveys in the Irish Sea, Bristol Channel and English Channel provide reasonable data for *Scyliorhinus canicula*, *M. asterias* (juveniles only), and rays (*L. naevus*, *R. brachyura*, *R. clavata, R. microocellata and R. montagui*), though catch rates for mature specimens of the larger species are low, which may reflect a gear effect.

Nature conservation bodies typically include 'decline' (whether in numbers or distribution) as one of criteria for categorizing whether a species is threatened or not. The decline criterion used by OSPAR (2003) has four categories (extirpated; severely declined; significantly declined; and with a high probability of a significant decline), and such declines can be in extent or abundance. The decline criterion used by the IUCN provides greater guidance, and state that declines (in either numbers or extent) ought to be assessed over periods of 'ten years or three generations, whichever is the longer' (IUCN, 2001). Although accurate data on the age and growth are not available for many of the species considered here, three generations is likely to be in the range of 20–30 years. Furthermore, IUCN (2001) states that changes in population sizes should be 'measured as numbers of mature individuals only'. Although more biological data have been collected in recent years, accurate maturity data are not available for all species and all areas, though length may be an appropriate surrogate. Assessing only mature individuals will reduce the potentially confounding effects of year-class strength, but also further reduces the power of survey data, which is already considered low for most elasmobranchs (e.g. Maxwell & Jennings, 2005).

When surveys are used to monitor trends in the abundance of relatively rare species, the noise to signal ratio in the time series is often high. Power analysis has been used to estimate the power of the North Sea survey to detect decreases in abundance that would lead to listing according to IUCN criteria and increases abundance that correspond with population growth at the intrinsic rate of increase. Decreases of $\geqslant 90\%$, $\geqslant 70\%$ or $\geqslant 50\%$ in adult abundance over the greater of ten years or three generations meet IUCN A1 criteria for 'Critically Endangered', 'Endangered' and 'Vulnerable'. The power of the North Sea survey to detect these trends in the adult abundance of large elasmobranchs was low, and even critically endangered species were unlikely to be detected. It was concluded that the low power partly resulted from the low contemporary abundance, which was a consequence of historic (pre-survey) depletion. Power to detect trends could be increased if a higher Type 1 error rate (falsely detecting a decline) was accepted. When the Type 1 error was set to 0.2 rather than 0.05, there was a high probability of detecting all trends consistent with 'Critically Endangered'. Since extinction of a population results in irreversible harm, it was argued that higher Type 1 error rates should be considered (Maxwell & Jennings, 2005). The general message from these studies of power is that many years of data are needed to discern real trends from noise, and even if surveys provide good long-term retrospective information on abundance trends they are unlikely to be informative about year to year changes in abundance.

We conclude that many large demersal elasmobranchs have been severely depleted by fishing in UK waters but that groundfish surveys still provide a good source of data for monitoring changes in status of the more abundant species. Groundfish surveys in the Celtic and North Sea should provide useful data for examining the relative abundance of several demersal dogfish. Beam trawl surveys in the English Channel and Irish Sea are most appropriate for monitoring the relative abundance of *S. canicula* and juvenile and sub-adult rays. Most other demersal elasmobranch species are caught less frequently in surveys, reflecting survey design and low abundance of these species in the study areas. For rare and highly depleted species, groundfish surveys often provide good retrospective descriptions of declines, but the surveys have limited power to detect recent changes in status.

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