# ICES WKSHARK4 REPORT 2018

ICES ADVISORY COMMITTEE

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# Report of the Workshop on Length-Based Indicators and Reference Points for Elasmobranchs (WKSHARK4)

6 - 9 February 2018

Ifremer, Nantes (France)

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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## Executive summary

The workshop WKSHARK4, Workshop on Length-Based Indicators and Refer-ence Points for Elasmobranchs, chaired by Pascal Lorance (France) and Jan Jaap Poos (Netherlands), was held in Nantes, France 6–9 February 2018. Twelve par-ticipants contributed by presence and six more attended daily video-conference and participated by correspondence.

The overall objective was to analyse the appropriateness of length-based indica-tors (LBIs) for assessment of the status of elasmobranch stocks. The concerns raised by WGEF in 2017 regarding the use of LBIs were investigated (Chapter for ToR a), a simulation approach based on a Leslie matrix was taken to investi-gate the possible values of LBIs in unexploited and exploited populations, this was mostly applied to the lesser-spotted dogfish, (Chapter for ToR b and c), and LBIs were applied to a few case studies (Chapter 4 Chapter for ToR d).

In the analyses of concerns raised by WGEF, it was shown that estimates of life-history parameters, in particular growth parameters, are uncertain. The asymp-totic length, $L_\infty$, is often estimated at higher value than the larger fish in age-at-length. The lack of old fish in data implies that the size where growth levels off is uncertain. When fitting growth models to data impacts both estimates of the growth, coefficient (K) and the asymptotic length ($L_\infty$). Because both are used in the calculation of reference points (RPs) for LBIs the impact of these uncertain-ties on the stock status derived from LBIs may be large. Investigations of the possible impact of the fishing gear selection and spatial distributions from a number of case studies did not reveal problems that would undermine the ap-propriateness of LBIs for the studied stocks. However, in one case, the undulate ray in ICES Division 9a, the very inshore distribution of the species implies that sampling should cover properly small-scale coastal fleet to derive representative estimate of the length-frequency distribution of the commercial catch. In con-trast, the four stocks investigated for constant recruitment, selection and fishing mortality in recent years were not in that situation and yearly variations in these stocks and fisheries parameters may lead to misinterpretation of LBIs (e.g. if larger recruitment is occurring in a stock, the first consequence will be a reduc-tion of the mean size observed in the catch, which could be interpreted as a de-cline of large fish). Extensive work was carried out with the Leslie matrix approach. This was mainly used to investigate the suitability of existing RPs. The model was further developed to simulate fisheries selectivity and calculate the expected values of LBIs in lesser-spotted dogfish stocks. LBIs were calculated from empirical data for 6 stocks exploited by UK fisheries, including spurdog, for which a quantitative assessment is available. These studies provided mixed results from the various LBIs. The LBIs based on length at first capture ($L_c$ and $L_{25\%}$) invariably highlighted that length at first capture (*i.e.* length 50% selected) is smaller than length at maturity, and therefore are always below their RPs val-ues. The LBIs representing exploitation at MSY ($L_{mean} = L_{F=M}$) were often above the corresponding RP. Therefore, contrasting diagnoses are obtained from the various LBIs, suggesting some inconsistencies in their RPs when applied to elas-mobranchs. It was suggested that trend-based metrics should be considered un-til appropriate reference points are validated.

Results from WKSHARK4 should be considered by WGEF and it is recom-mended that LBIs are calculated for more stocks and that the Leslie matrix model explored during WKSHARK4 is applied to several simulated elasmobranch stocks with varied life-

history traits to investigate the expected value of reference points for LBIs.

# 1 Terms of Reference

A **Workshop on Length-based Indicators and Reference Points for Elasmobranchs** (WKSHARK4), chaired by Pascal Lorance* (France) and Jan Jaap Poos* (Netherlands) will be established and will meet at Ifremer, Nantes, France 6–9 February 2018 to:

a) Address the concerns raised by WGEF regarding the use of these, or similar, Length Based Indicators to infer stock status and provide management advice for elasmobranchs, including:
   - The sensitivity of indicator values to life history parameters M/K, $L_{inf}$, and $L_{mat}$
   - The assumption of asymptotic fishing gear selection, which will not be appropriate for all elasmobranch stocks
   - The implicit assumption of homogeneous spatial distribution of the stock, i.e., that surveys consistently/adequately capture population size-distribution and important life history stages.
   - The assumption of constant recruitment, selection and fishing mortality; the violation of which could lead to a shift in population size distribution and affect indicator values and species status in relation to RP.

b) Further develop the provisional protocol which was developed at WGEF 2017 for deriving appropriate Reference Points and expected indicator ratio values based on specific life history parameters for lesser-spotted dogfish *Scyliorhinus canicula*;

c) Explore the use of the Leslie matrix approach as used at the WGEF 2017 meeting for identifying LBI 'expected values' based on the known life history characteristics of specific fish stocks;

d) Develop MSY proxy reference points for the stocks in need of new advice in 2018: skates in the Celtic Seas and Bay of Biscay and Iberian Coast ecoregions and test these proxies using stocks for which quantitative assessment and actual MSY reference points are available, including spurdog in the NE Atlantic;

Any new data on life-history parameters for species/stocks assessed by WGEF should be made available before the meeting. Possible unpublished archive data should be considered.

WKSHARK4 will report by 23 February 2018 for the attention of ACOM.

## 2 Summary of the agenda

### Tuesday 6 February

9:00-9:30 Arrival, housekeeping, connecting to internet, safety etc....

9:30-9:40 Round table (at least two new faces in addition to WGEF members)

9:40-10:10 Introduction what was done and issues found with length-based indicators at WGEF 2017 (slides - P. Lorance)

10:10-10:25 Terms of references of WKSHARK4 (P. Walker, P. Lorance)

10:30-11:00 LBI and expected values of the indicator for lesser spotted catsharks (Christopher Bird)

11:00-11:30 Coffee break

11:30-12:00: Outcome of WKLIFE VII relevant to length-based indicators applied to elasmobranchs (G Johnston)

12:30-13:00: Discussion

- - Data availability to WKSHARK4
- - Issues to work on
- - Other material prepared for the workshop (who came with a ppt?)
- - Organisation of the newt days
- - Distribution of report section writing
- - Questions to raise at the evening Webex (e.g. aspects of ToRs that members present in Nantes cannot address)

13:00-14:00 Lunch break

14:00-14:30 Uncertainty on Life history parameters, example for the Thornback ray (P. Lorance)

14:30-16:00 Working session, no plenary

16:00-16:30 Coffee break

17:00-18:00 Webex with WGEF members and length-based methods specialists (daily updates on the workshop progress and input from participants not physically attending)

### Wednesday- Thursday

9:00-9:30 - Plenary for planning presentations, subgroups, etc according to progress

Working sessions at 9:30-13:00 and 14:00-17:00

Webex with external at 17:00

### Friday

9:00-9:30 - Plenary: advancement of report writing, scheduling of finalisation, work to take home 9:30-12:00 - report writing

12:00-13:00 Final discussion and closure

# 3 ToR a) Address the concerns raised by WGEF regarding the use of these, or similar, Length Based Indicators to infer stock status and provide management advice for elasmobranchs

This Term of Reference is raised to highlight the fact that insufficient or inaccurate sampling of a stock will have consequences for assessments using length-based indicators (LBIs). The reasons for such concerns are discussed by theme. Case studies of different stocks and fishing methods are used, illustrating where issues with sample size, location or timing can cause errors in stock assessment using these methods. Conversely, examples are given where such concerns can be regarded as unnecessary, and where it is believed that catches are adequately sampled using existing methods.

## 3.1 The sensitivity of indicator values to life history parameters M/k, $L_{inf}$, and $L_{mat}$

Length-based indicator values are quite sensitive to the parameters $M/k$, $L_\infty$, $L_{max}$, and $L_{mat}$. An example for the thornback ray (*Raja clavata*) is presented to show the effect of different calculations of $L_\infty$ on calculations of $M/k$.

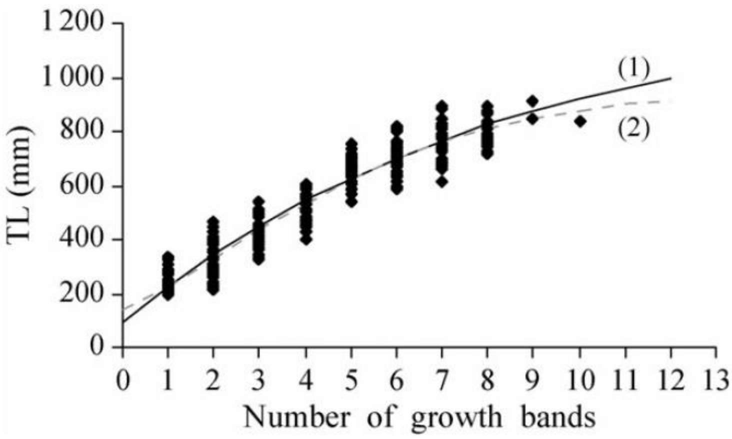



**Figure 3.1. Growth of *Raja clavata* in Portuguese waters. Source: Serra-Pereira *et al.*, (2008).**

The following growth parameters can be calculated from the growth curve for *Raja clavata* based on data from Serra-Pereira *et al*. (2008).

$L_\infty$ = 129.9 cm; k = 0.114 ; $t_0$= -0.662

The von Bertalanffy growth function (VBGF) assumes that the growth rate of fish tends to decrease linearly with size, as indicated by the equation (based on Fabens, 1965):

$$\frac{\mathrm{d}L}{\mathrm{d}t} = k_1(L_\infty - L)$$

where $k_1$ is a relative growth rate parameter (with units year$^{-1}$) and $L_\infty$ is the asymptotic length. The solution is generally calculated as follows:

$$L(t) = L_\infty\left(1 - \mathrm{e}^{-k_1(t-t_1)}\right)$$

where $t_1$ is the age when an individual fish would have been of zero length, assuming the equation to be valid at all ages.

$L_\infty$ is generally calculated from data from fish in much smaller size classes than the eventual value for $L_\infty$ , as can be seen for example in Figure 3.1. This can lead to high, and potentially overestimated, values of $L_\infty$ , which are associated with smaller *k*. By calculating *k* for different values of $L_\infty$ , the variation in *k* can be identified. See Figure 3.2. and Table 3.1

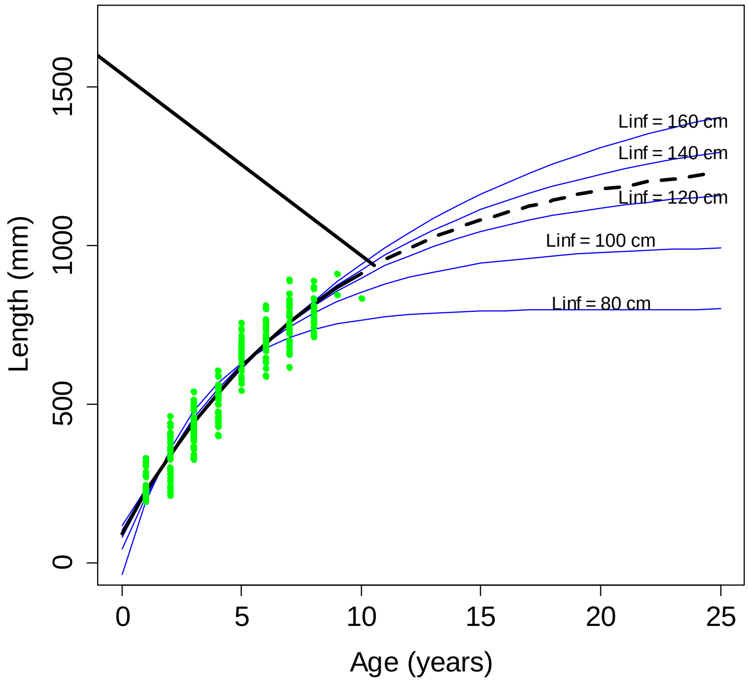



**Figure 3.2. Fit of von Bertalanffy growth curve (VBGF) with fixed $L_\infty$.**

**Table 3.1 Values of k calculated for different assumptions for $L_\infty$. The grey line shows the values calculated from the data from Serra-Pereira *et al.* (2008).**

| $L_\infty$ | k | t0 | BIC |
|---|---|---|---|
| 1299 | 0.114 | -0.662 | 2794 |
| 950 | 0.21 | -0.146 | 2812 |
| 1000 | 0.188 | -0.236 | 2803 |
| 1050 | 0.17 | -0.321 | 2797 |
| 1100 | 0.155 | -0.4 | 2793 |
| 1150 | 0.142 | -0.473 | 2791 |
| 1200 | 0.131 | -0.541 | 2789 |
| 1250 | 0.122 | -0.604 | 2789 |
| 1300 | 0.114 | -0.663 | 2789 |
| 1350 | 0.107 | -0.718 | 2789 |

The results in Table 3.1 show that the BIC value is not worse for fixed $L_\infty$ between 1050 and 1350 mm than for the estimated $L_\infty$ of 1299 cm.

Assuming $M = 0.2$

- $k = 0.114$ leads to $M/k = 1.75$
- $k = 0.17$ leads to $M/k = 1.18$

The estimates for $L_\infty$ used in the models are often taken from historical (10–20 year old) published data. They may represent overestimates of $L_\infty$ if based on catches of fish larger than those now caught. Taking $k$ from a model where $L_\infty$ is too high could be an underestimate of $k$ if based on age-at-length data where large fish (close to $L_\infty$) were missing. To get a reliable estimate of $L_\infty$, some individuals in the sample should be larger than $L_\infty$, which represent the average growth potential of individuals in a population. Exploited populations rarely include such individuals when they were sampled for age estimation. Underestimated $k$ leads to lower values of $M/k$ which is an important variable in the LBI as far as calculating $L_{opt}$ which is then used to estimate the role of large fish in the population.

## 3.2 The assumption of asymptotic fishing gear selection, which will not be appropriate for all elasmobranch stocks

The selectivity of fishing gear describes the vulnerability of age- or size- classes of fish to fishing. Gear selectivity can be either described as asymptotic or dome-shaped. Assuming asymptotic gear selectivity indicates an increase with age to a certain point at which the increase levels off. A dome-shaped selectivity shows increases to a maximum level followed by a decline. The selectivity-pattern can differ between fisheries depending on gear characteristics as well as the spatiotemporal dynamics of fishing activities (*i.e.* when and where to fish). In addition, the biology of the species in terms of behaviour (e.g. when encountering a fishing gear) as well as spatial and temporal distribution of different age- and size-classes may influence the selectivity. Due to the complexity of (interpreting) these factors it is difficult to define and estimate a reliable selectivity which is important as in assessment models, selectivity links the population's size and age composition to the size and age composition of the fish observed in a fishery or survey.

To analyse the assumption of asymptotic fishing gear selectivity the length distribution of several elasmobranch species in the commercial catch of French and Dutch demersal fisheries, as well as the IBTS survey are compared.

### France

Three case studies were considered to address the question of differing selectivity between nets and trawls: *Raja undulata* stock in ICES divisions 7.d-e, 8.a-b and *R. clavata* stock in ICES Subarea 8. These stocks were chosen based on the relative large size of datasets available and because they will be assessed in 2018.

Various data sources were used: French self-sampling data (2015 data collected according to a protocol described in Gadenne (2017) for *R. undulata*) and French on-board observer programme (2010–2017) for *R. clavata*. These data sets have the major interest of providing information on both the landed and the discarded portions of the catch. Data for the various mesh sizes were pooled.

In the next studies on length distributions of different stocks assessed, on-board observer data, data from scientific surveys and data from auction halls for the landed species could be used if they are sufficiently representative by stock, by gear, and by year. Within the French self-sampling programme for *R. undulata*, caught individuals were measured only for the year 2015.

- ***Raja clavata* in ICES Subarea 8**

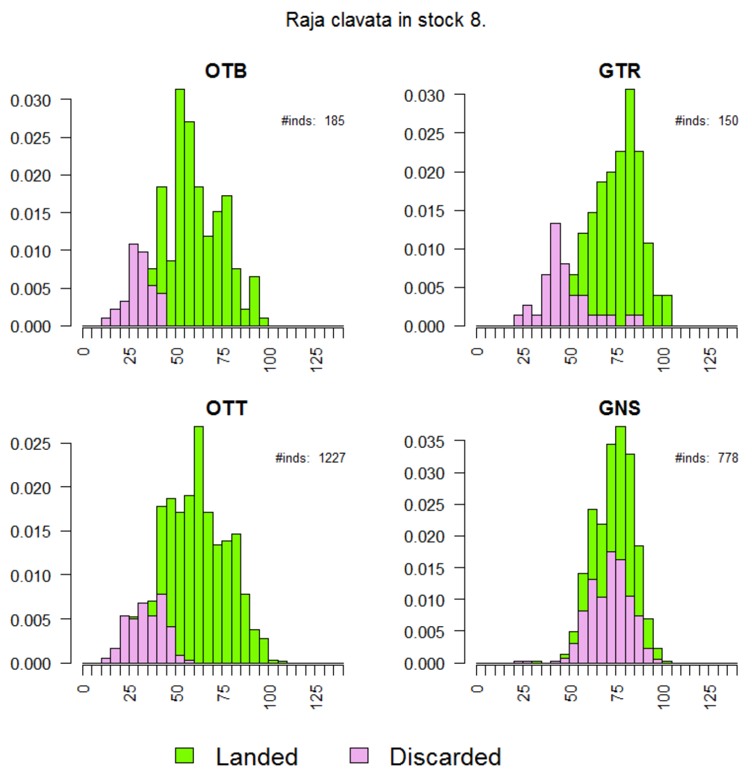



**Fig. 3.3 Length distribution of *R. clavata* catches (rjc.27.8) expressed in frequencies as a function of gear, distinguishing landed and discarded components, based on French on-board observer data 2010–2017.**

Though all mesh size were considered for bottom-set gillnet (GNS) catches, this gear displayed a more restricted length range of *R. clavata* (Figure 3.3). The other passive gear for which a substantial number of fishing operations (i.e. at least 50 operations with a catch of *R. clavata*), namely trammel net (GTR), displayed a wider range of sizes similar to those observed for bottom trawls (OTT and OTB) (despite the absence of catch below 20 cm TL). The mode of the length distribution of discarded individuals was quite different from the length distribution of landed individuals, except for gillnets (GNS), for which *R. clavata* seem to be discarded or landed irrespective of its size. A closer look at the data revealed that this species is partly discarded when caught in great amounts by GNS. It should also be noted that fishing operations for this gear mainly came from two vessels and so may not necessarily be representative of practices of the whole fleet. It entails that the distribution of size of landed individuals represents the higher portion of caught individual (except for gillnet).

The maximum lengths in the samples for the various gears (OTB: 99 cm, OTT: 107 cm, GTR: 101 cm, GNS: 102 cm) were all less than the value of $L_\infty$ (128 cm) reported by Serra-Pereira *et al*. (2008) for ICES Subarea 9. It thus can be asked whether the larger individuals of the stock are caught by the main gears of the fishery of *R. clavata* in ICES Subarea 8.

- ***Raja undulata* in ICES divisions 7.de and 8.abd**

The various gears concerned by the self-sampling programme for rju.27.7de presented similar modes in catch length distribution, at around 85 cm, but diverged regarding the size ranges of *R. undulata* (Figure 3.4). No differences between sexes were seen in the length distributions of the catch for any of the gears. The length distributions of the catch from these gears do not differ as to the larger individuals, which rarely exceeded 105 cm TL, with the exception of a few females measuring up to 109 cm TL and caught by bottom longlines (LLS). Catches from gillnets (GNS), trammel nets (GTR), and the combination of the two (GTN) were characterized by the absence of the smaller individuals (*i.e.* < 70 cm TL), unlike bottom longlines (LLS) and bottom trawls (OTB).

These gears seem to have similar selectivity regarding larger individuals. Note that landing data were limited by a maximum (97 cm) and minimum (78 cm) size authorisation in 2015 to land *R. undulata*.

The paucity of data in ICES Subarea 8 (due to the limited time frame available in 2015) renders the interpretation of the corresponding length distribution more difficult (Fig. 3.5). However, by considering the catch length distribution of gillnets GNS alone, for which a substantial amount of fishing operations were sampled, the absence of *R. undulata* larger than 95 cm TL can be noticed, as opposed to ICES divisions 7.d-e. Additional analyses showed differences in the length distributions of the two stocks considered. Individuals caught in the Channel were significantly larger (81.8 ± 13.9 cm) than individuals caught in 8.a (80.4 ± 11.5 cm), with 50% of individuals measuring more than 85 cm in divisions 7.d-e, compared to 83 cm in Division 8.a.

The maximum lengths in the samples for the various gears (GNS: 100 cm, GTN: 101 cm, GTR: 105 cm, LLF: 95 cm, LLS: 109 cm, OTB: 102 cm) differed slightly to the maximum size reported, which can reach at least 114 cm LT (Ellis *et al*. 2012), and possibly up to 120 cm (Wheeler, 1978; Bañon *et al*., 2008). It thus can be asked whether the larger individuals of the stock are caught by the main gears of the fishery of *R. undulata* in divisions 7.d-e and 8a.

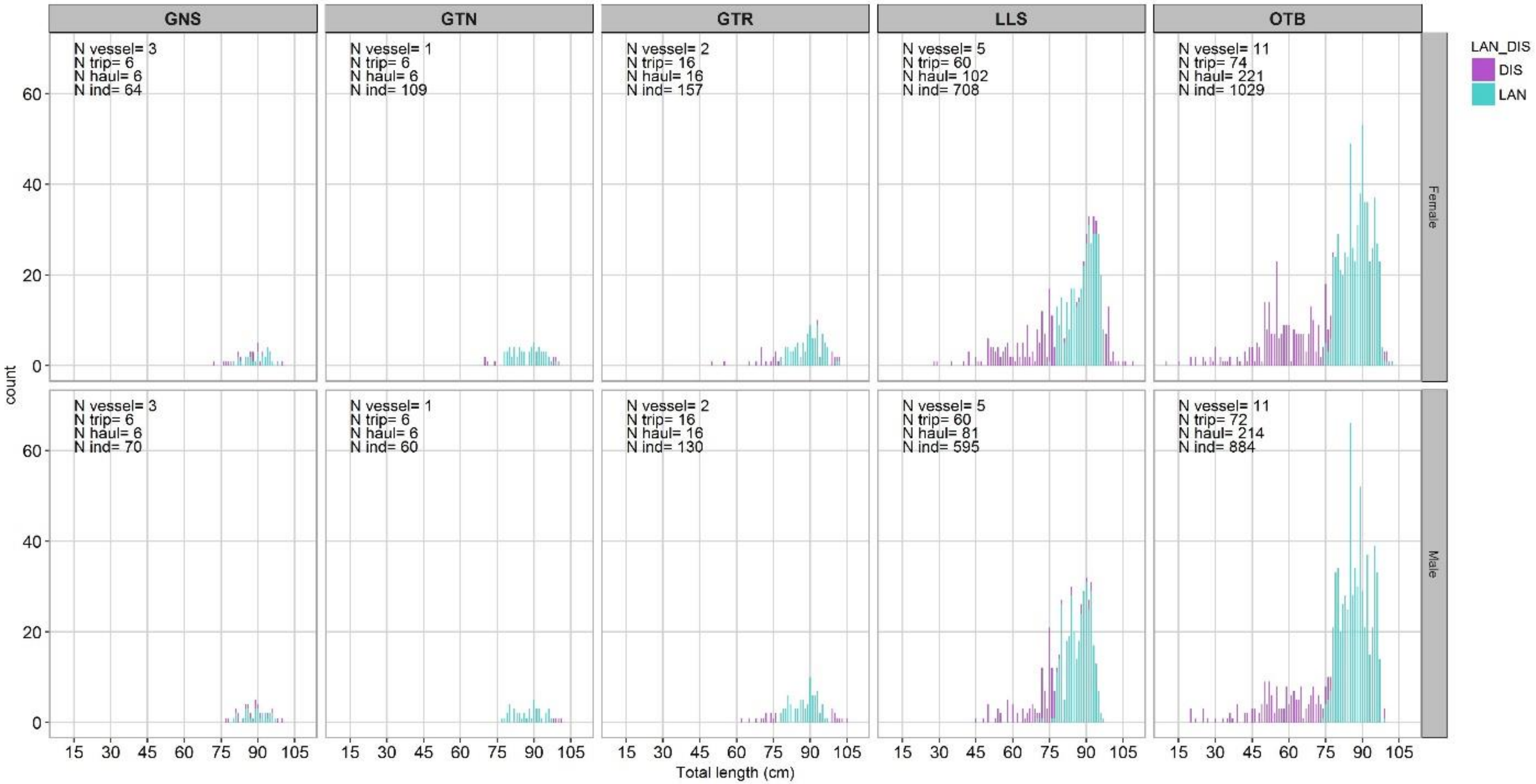



**Fig. 3.4. Length distribution of *R. undulata* catches in stock rju.27.7de by sex (females at the top, males at the bottom), expressed in numbers as a function of gear, distinguishing landed (LAN) and discarded (DIS) parts, based on the French self-sampling programme for *R. undulata* in 2015.**

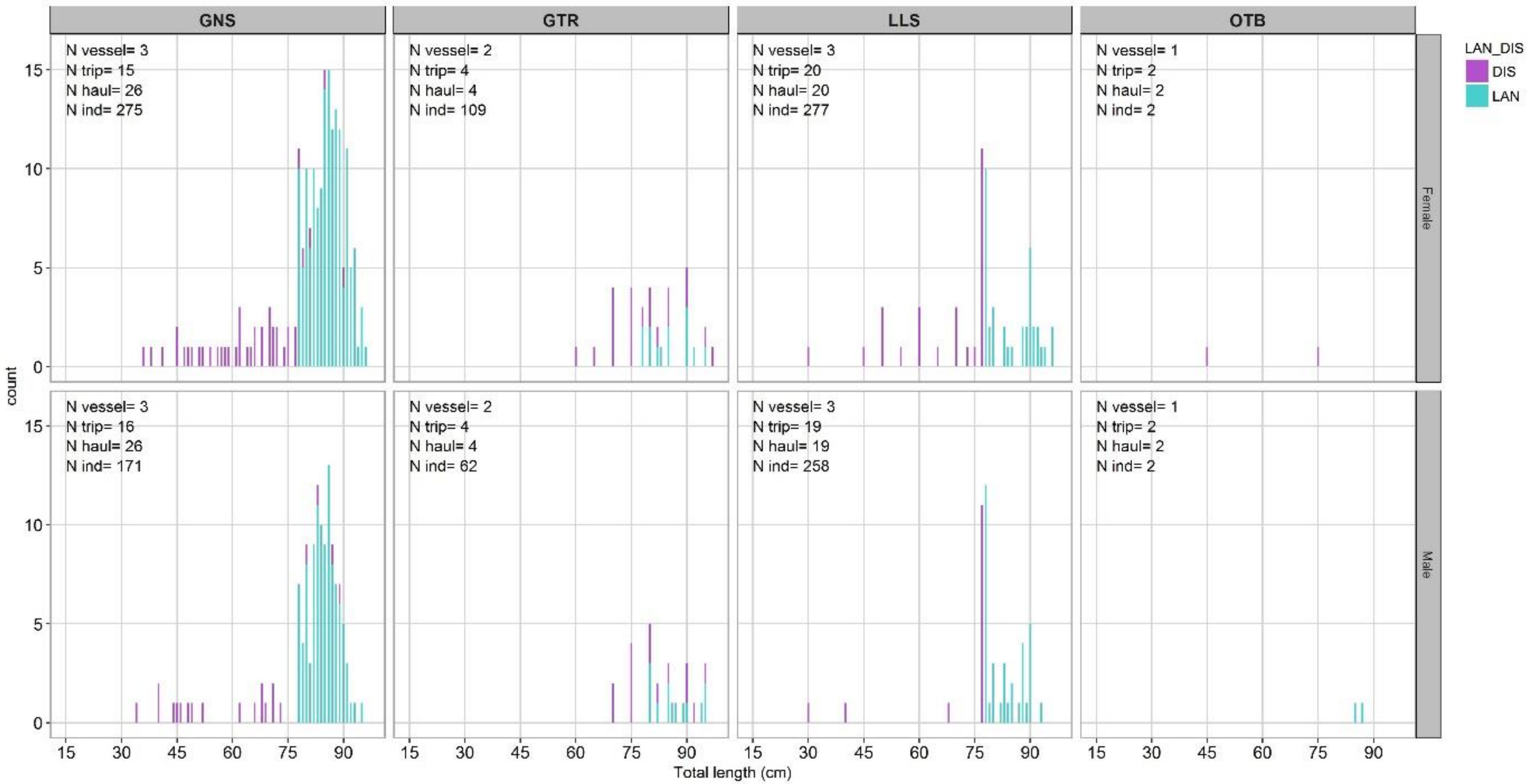



**Fig. 3.5. Length distribution of *R. undulata* catches in stock rju.27.8ab by sex (females at the top, males at the bottom), expressed in numbers as a function of gear, distinguishing landed (LAN) and discarded (DIS) parts, based on the French self-sampling programme for *R. undulata* in 2015.**

As a conclusion, no obvious cut in the length distribution of the catch of *R. clavata* or *R. undulata* for larger individuals can be inferred from the data sets considered here. Hence, the hypothesis that large individuals of these species are efficiently caught by commercial fisheries seems to be valid.

### Netherlands

To determine the fishery-specific selectivity in the Dutch demersal fishery, the length frequency distribution in the discards for six elasmobranch species (thornback ray (*Raja clavata*), blonde ray (*Raja brachyura*), spotted ray (*Raja montagui*), cuckoo ray (*Leucoraja naevus*), small-spotted catshark (*Scyliorhinus canicula*) and smooth-hounds (Triakidae)) caught in Subarea 4 were analysed. Discard data were available from the Dutch self-sampling programme for the period 2011–2016. Discard data were raised by year for three gear groups: beam-trawl, seines and one gear category combining several other bottom trawls (e.g. bottom and multi-rig otter trawl). For each gear group the mean number of individuals discarded per centimetre-class per year are shown in Figure 3.6.

With the exception of blonde ray in the seine fishery, all species were present in the discards. The beam-trawl clearly discarded a higher number of individuals for most of the species. Only cuckoo ray was more abundant in the seine fishery. This can be explained by overlap in the spatial distribution of the species (which is rare in the southern North Sea; Heessen *et al.,* 2015) with the distribution of fishing operations. When comparing the length frequency distributions between the gear groups, beam-trawls appeared to have a larger spectrum of length classes in their discards. For example, the size range of thornback ray in beam-trawls and seines were 13–81 cm and 22–57 cm, respectively. However, there was no clear difference between the gear groups when comparing the modes within each species. As such, a difference in the selectivity cannot be inferred from these data.

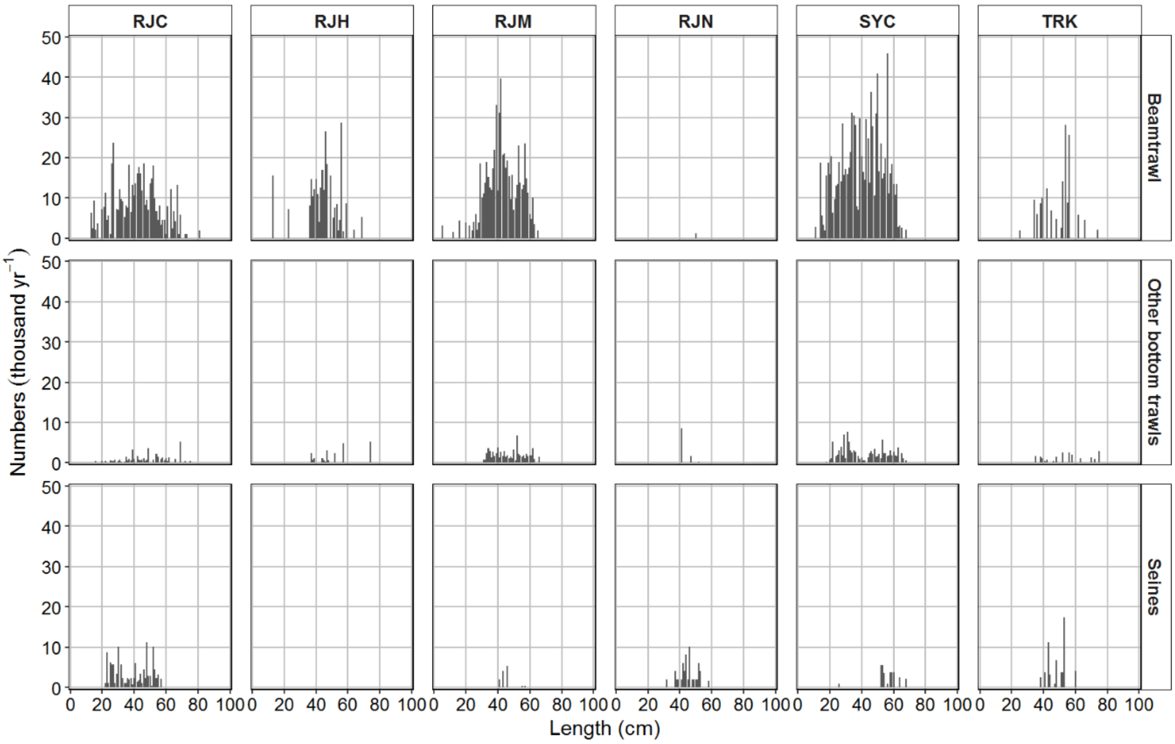



**Fig. 3.6. Length distribution of six elasmobranch species caught and discarded in 27.4, expressed in mean numbers (thousands) per year as a function of gear. RJC = thornback ray (*Raja clavata*), RJH = blonde ray (*Raja brachyura*), RJM = spotted ray (*Raja montagui*), RJN = cuckoo ray (*Leucoraja naevus*), SYC = small-spotted catshark (*Scyliorhinus canicula*) and TRK = smooth-hounds (*Triakidae*). Data are based on the Dutch self-sampling programme.**

It should be noted only discard data of the Dutch self-sampling programme were used for this analysis. These data could be biased towards the more smaller individuals in the discards (ICES, 2017a). A study on discards of the Dutch industry funded by the European Maritime and Fisheries Fund (2016–2018) demonstrated that up to 90% of the catches of rays in the pulse fishery were discarded, including large marketable individuals (19% of the discards were > 55 cm). In addition to the discards, it would be valuable to include landing data to obtain the full size spectrum of the catch. However, the amount of available quota is restrictive and the Dutch Producer Organisations have implemented a minimum landing size (>55 cm) as well as maximum to the amount of rays that can be landed per trip. The latter can range from 40–275 kg per trip. Due to these PO-measures, only the largest individuals of the most valuable species are landed, while the remainder of the catch is discarded. Including the landings in the analysis may thus induce a bias towards the larger individuals.

## 3.3 The implicit assumption of homogeneous spatial distribution of the stock, i.e., that surveys consistently/adequately capture population size-distribution and important life history stages.

If sampling of commercial fisheries is representative of fishing mortality at length, LBIs suitable to the life history of the studied population represent properly how the fishery is exploiting the population.

### 3.3.1 Survey Data

Length distribution from surveys are may vary from those measured in commercial catches as in many cases, surveys were designed to sample small fish. It should be kept in mind that, 3–4 decades ago, current survey time-series were initiated primarily to estimate the recruitment of the main exploited stocks. To this aim, surveys use small mesh size, smaller gear and shorter haul duration than commercial fisheries. The small mesh size implies better retention of small fish and the smaller gear and shorter hauls imply more avoidance by larger individuals. Importantly also, commercial fisheries involve preferential sampling where sampling locations and the process of interest are not independent, *i.e.* fisheries target areas with more valuable abundance, species and size composition (Diggle *et al*., 2010). Therefore length distribution sampled from survey and commercial catch should be dedicated to different uses.

Groundfish surveys such as the IBTS are the primary source of fisheries-independent data for elasmobranch stock assessment. Other surveys include long-line surveys (primarily off Iberia) and beam trawl surveys in the North Sea and Celtic Seas ecoregions. Whichever gear is used, it has been noted by the Working Group on Elasmobranch Fishes (ICES, 2017b) that these surveys were not designed primarily to inform on the populations of demersal elasmobranchs, and so the gears used, timing of the surveys and distribution of sampling stations may not be optimal for informing on some species and/or life-history stages.

Examples of stocks that are known to be inadequately sampled by surveys are outlined here. This is not an exhaustive list, but is intended to illustrate why a component of a stock may not be sufficiently sampled. It should also be noted, that despite inadequacies, these surveys provide the longest time-series of species-specific information for elasmobranchs for many parts of the relevant ecoregions.

**Blonde ray, *Raja brachyura*, in Subarea 6**

*Raja brachyura* has a patchy distribution in Subarea 6. It is not encountered in sufficient numbers in surveys to derive trends in abundance/biomass. For this reason it is currently classed as a Category 5 stock, with only landings used to assess stock status.

**Blonde ray *Raja brachyura* in divisions 7.a and 7.f-g**

While survey data are available from this region, it is not considered sufficiently reliable to assess the *R. brachyura* stock. Larger individuals are only encountered infrequently, which may be related to a low gear selectivity for larger fish in the survey gear and that adults may occur around sandbanks (ICES, 2012a).

**Small-eyed ray, *Raja microocellata* in Division 7.f**

Surveys for this stock have the opposite problem to those for *R. brachyura*, in that 0-groups are found in very shallow water and not sampled in the survey (ICES, 2012a).

**Greater-spotted dogfish, *Scyliorhinus stellaris* in divisions 4.c and 7.d**

This species tends to occur on rocky grounds which are not sampled extensively in the survey due to the possibility of severe gear damage (ICES, 2012a).

**Porbeagle, *Lamna nasus* in the North Atlantic**

This species was mainly caught be targeted longline fisheries and which only rarely appears as bycatch in other fisheries. As a consequence, current sampling from survey and on-board observation convey no information of this stock.

It has been noted by WGEF (ICES, 2014a) that some species have discrete areas in which they are abundant, and as such existing survey data may be limited. This is especially noteworthy for some of the more coastal species. More detailed studies of existing data are required to better inform on the status of:

- *Raja undulata* in Tralee Bay and southwest Ireland (27.7bj) and the middle of the English Channel (27.7de)
- *Raja brachyura* in areas of high local abundance.

In some instances, it may be that available survey data will not be appropriate to evaluate some of these species, and dedicated inshore surveys using an appropriate gear and census method may be required if these stocks are to be better evaluated.

### 3.3.2 Commercial Data

Length distribution from commercial catch, when sampling is representative, show what is extracted from the population and is suitable for applying length-based indicators with reference points based upon conservation, or MSY whereas depending on areas covered and sampling design, length distributions from surveys may be skewed towards larger, or more frequently, smaller individuals. Indicators based on length distributions from survey should generally be used in a different way as those from commercial catches and be used as indicators of e.g. the total population or the recruitment and mostly time-trends rather than indicators values in the last year only should be considered.

#### 3.3.2.1 Spatial distribution of commercial catch in French on-board observations

This investigation was carried out to clarify whether uneven spatial distribution of the stock is likely or not to violate underlying assumption of the LBIs. In other words, the point is not to analyse the spatial distribution, segregation by size, sex of life stage of stocks but to question whether aggregated length distribution collected from sampling for all fisheries catching the stock are appropriate to applying LBIs and if not describe why.

French on-board observations (2007–2017) were used to analyse the spatial aspect. The 11-years were aggregated to map the spatial distributions of all catch events by species. In order to assess spatial difference in the catch of juveniles and adults, catch events of individuals smaller than the length at maturity of females and half this length were identified. As presented in WKSHARK3 (ICES, 2017a), samples of rarer species are insufficient to derive population indicators and only dedicated sampling would allow collecting sufficient numbers of observations for species such as the white skate (*Rostroraja alba)* or the blue skate (*Dipturus batis*). Further, stocks with restrictive TACs, such as the undulate ray (*Raja undulata*) may be avoided by fisheries so that the number of observation in on-board observations would also be small.

**Table 3.2 Size-at-maturity of species and stock considered.**

| Species | ICES stock unit | Size of maturity | Comment |
|---|---|---|---|
| Spurdog (*Squalus acanthias*) | dgs.27.nea | 80 cm for females (stock annex) | French fisheries do not cover the full distribution of the stock |
| Smooth-hounds | sdv.27.nea | 81.9 cm for females (McCully and Ellis, 2015) | |
| Tope shark | gag.27.nea | 130 cm, smallest size for mature female | |
| Thornback ray | rjc.27.3a47d | 73 cm (McCully *et al.*, 2012) | Length at 50% maturity of females in the Greater North Sea |
| Thornback ray | rjc.27.7e | 78 cm (McCully *et al.*, 2012) | Length at 50% maturity of females in Celtic Seas |
| Thornback ray | rjc.27.8 | 78 cm (McCully *et al.*, 2012) | Length at 50% maturity of females in Celtic Seas |
| Undulate ray | rju.27.7de | 83 cm (Stéphan *et al.*, 2014) | |
| Spotted ray | all stocks | 62 cm (McCully *et al.*, 2012) | Length at 50% maturity of females |
| Undulate ray | English Channel and Biscay | 83 cm (McCully *et al.*, 2012) | Largest observed immature female. 50% maturity not estimated |
| Cuckoo ray | Celtic Sea and Bay of Biscay | 59 cm (McCully *et al.*, 2012) | |

## Spurdog

The species occurs at low frequency in French on-board observations. The spatial distribution of immature fish was not different from that of all individuals. Individuals smaller than half the size-at-maturity of females seem more concentrated in the Celtic Sea (Divisions 7.g-h; Figure 3.7). This was not considered to imply that the application of LBIs to the total catch of the species may convey misleading information about the stock status.

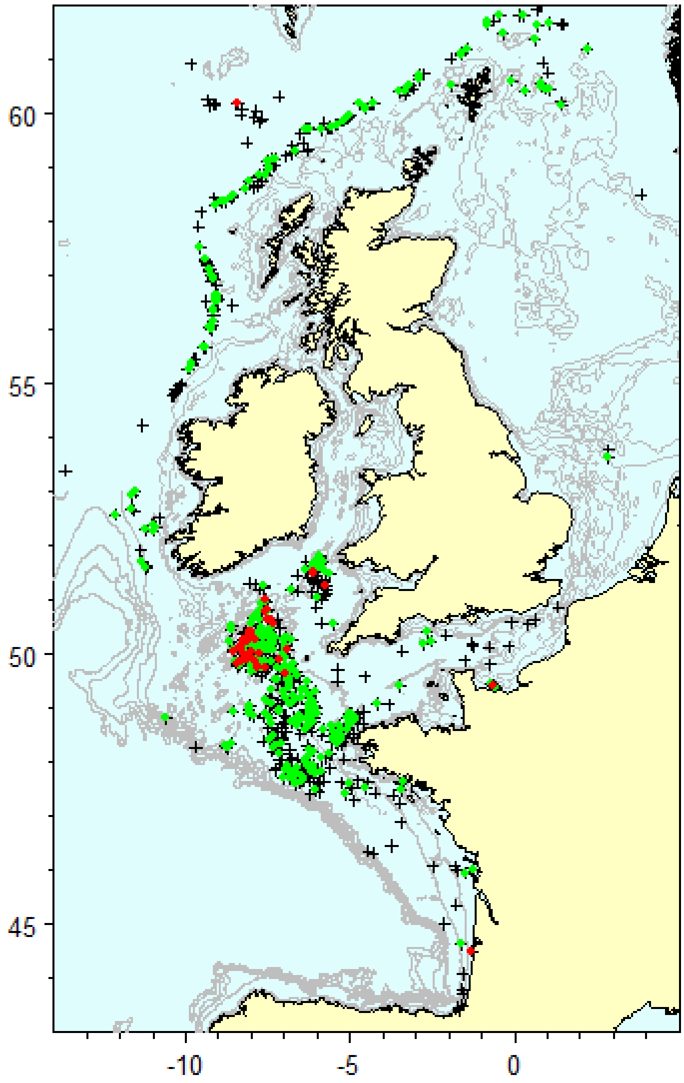



**Figure 3.7. Spatial distribution of spurdog in French on-board observations 2007–17. Black "+": fishing operations with catch of spurdog, green dots: fishing operation with catch of spurdog smaller than the size-at-maturity of females (80 cm), red dots: fishing operation with catch of spurdog smaller than half the size of maturity of females, taken to represent the distribution of juveniles.**

### Smooth-hounds (*Mustelus* sp.)

The species is frequently recorded in French on-board observations. The spatial distribution of immature fish (size smaller that size at 50% maturity of females) was not different from that of all fish. Individuals smaller than half the size-at-maturity of females seemed to be more concentrated in the Eastern Channel (Division 7.d; Figure 3.8). The occurrence of the species is however higher in this area. Occurrences of the species in French on-board observations, further north of the map area (cut at 54°N) were rare in 2007–17. The observed distribution, in waters visited by French vessels, was not considered to imply that the application of LBIs to the total catch of the species may convey misleading information about the stock status.

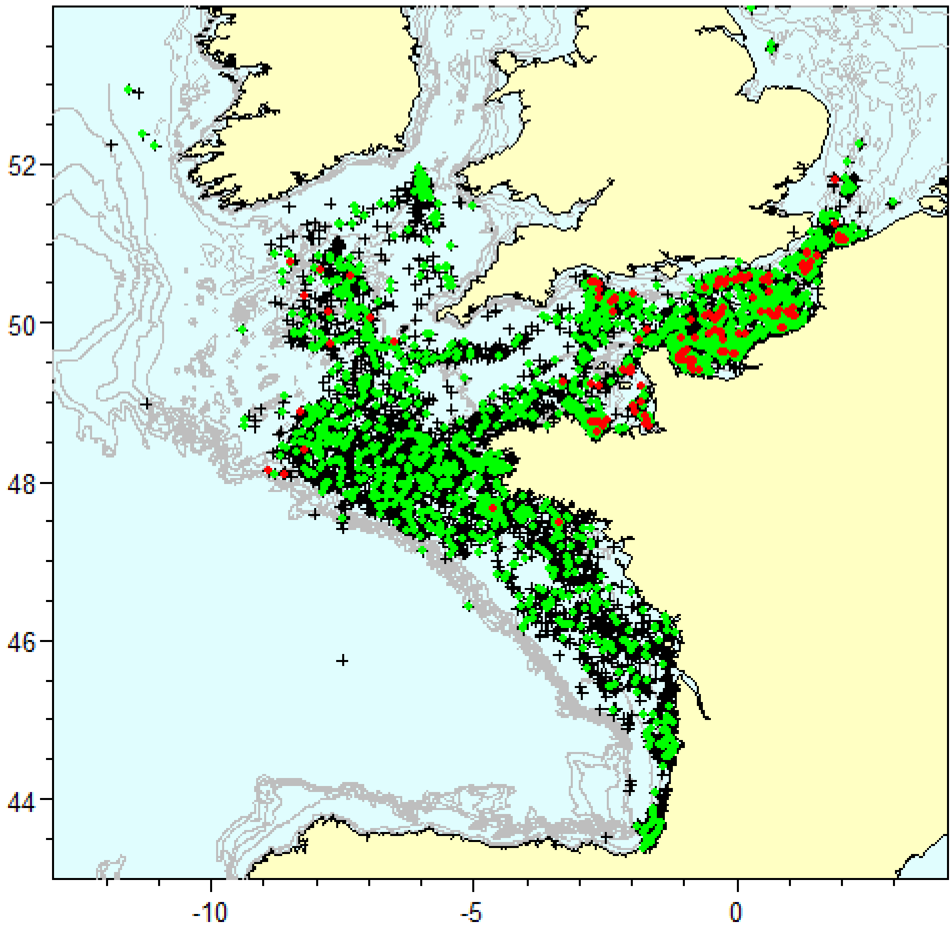



**Figure 3.8. Spatial distribution of smoothhounds in French on-board distribution. Black "+": fishing operations with catch of smoothhounds, green dots: fishing operation with catch of smoothhounds smaller than 81 cm, red dots: fishing operation with catch of smoothhounds smaller than 40 cm.**

### Tope (*Galeorhinus galeus*)

The species was occasionally recorded in French on-board observations 2007–2017. No published length-at-maturity in the Northeast Atlantic was found. Smaller observed mature females of 130 cm were reported (ICES, 2017b), and this size was used as a proxy for size-at-maturity. As the stock might be in a poor state as a consequence of overexploitation, the proportion of smaller individuals in the population is expected higher, then representing the spatial distribution of large and smaller individuals based upon a smaller cut-off length is suitable for the current population. The spatial distribution of those immature fish was not different from that of all fish (Figure 3.5). Individuals smaller than half the size of smallest mature females did not seem different either (Figure 3.9). Occurrences of the species in French on-board observations, further north of the map area (cut at 54°N) were rare in 2007–2017. The observed distribution, in waters visited by French vessels, was not considered to imply that the application of LBIs to the total catch of the species may convey misleading information about the stock status.

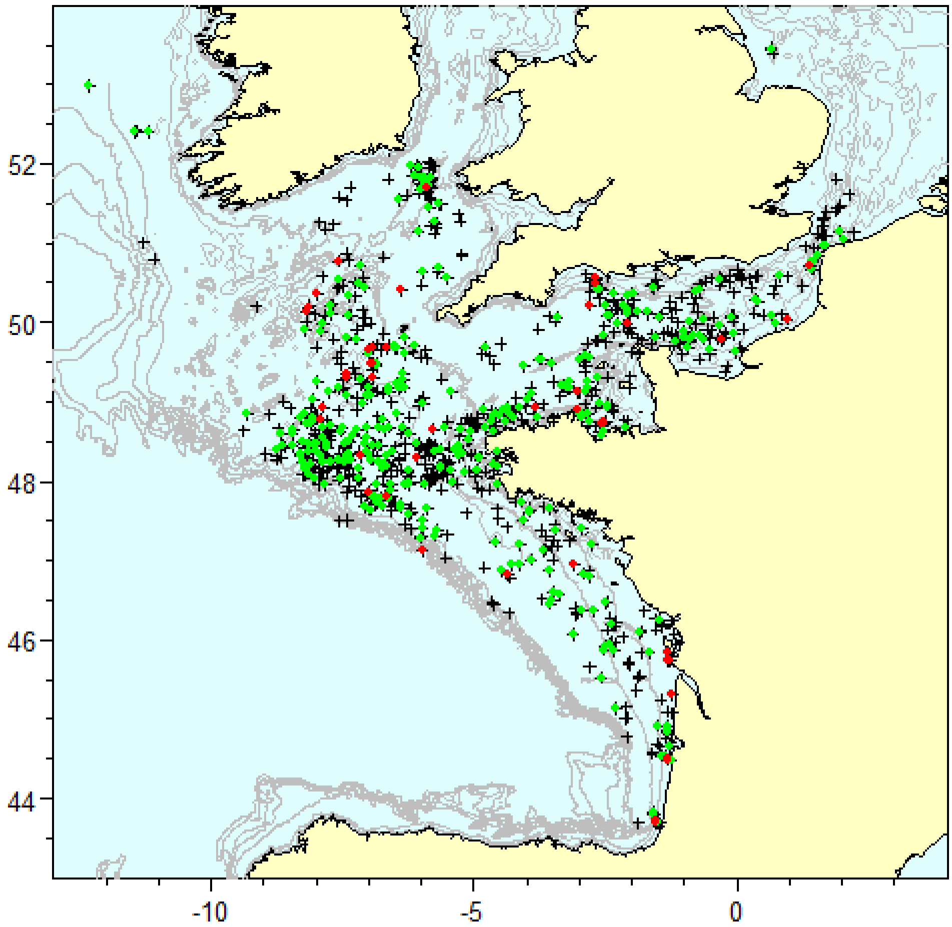



**Figure 3.9. Spatial distribution of tope in French on-board distribution. Black "+": fishing operations with catch of tope, green dots: fishing operation with catch of tope smaller than 81 cm, red dots: fishing operation with catch of tope smaller than 40 cm.**

### Thornback ray

### Subarea 4 and in divisions 3.a and 7.d

The species was observed mainly in the eastern Channel and southern North Sea, in the Outer Thames Estuary. Further north occurrences in French on-board observation were rare.

For this stock, the spatial distribution of adults and immatures (taken as individuals smaller than the size at maturity of females) did not seem different. Smaller individuals (smaller than half the size-at-maturity of female, *i.e.* 36 cm) were observed in larger abundance along the French coast (Figure 3.10). It may be that they also occur along the English coast, where no French fishing occurs. In the area, ontogenetic migrations are then well reflected by commercial catches. It implies that trends in size based indicators could be impacted by changes in spatial distribution of the fishing effort over year. However, no major change of the spatial distribution of the French fishing effort in the eastern Channel occurred in the past 10 years, so that length based indicators calculated from French commercial catch might be informative about stock trajectories.

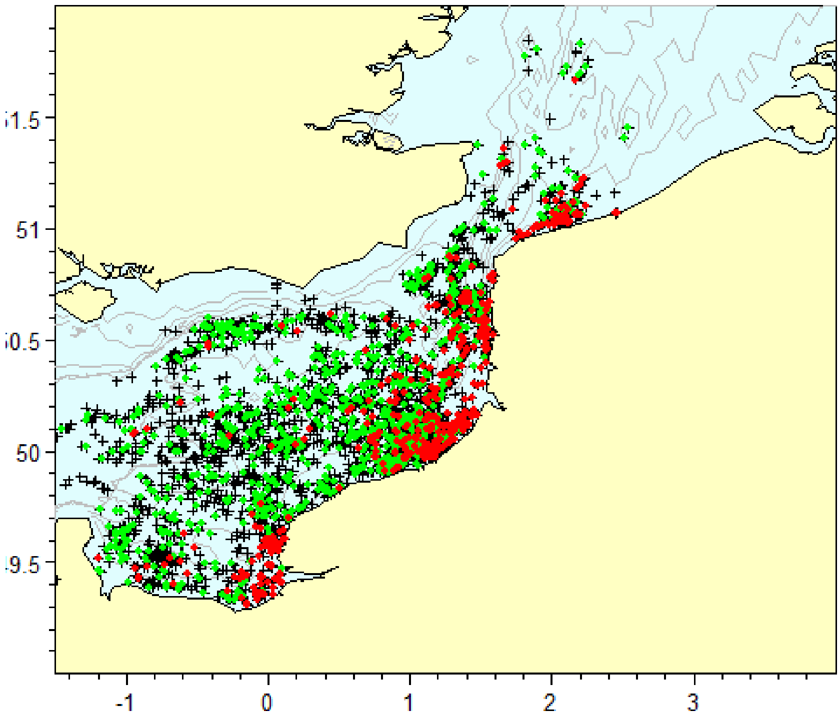



**Figure 3.10 Spatial distribution of thornback ray in French on-board observation in the eastern Channel and Southern North Sea. Black "+": fishing operations with catch of thornback ray, green dots: fishing operation with catch of thornback ray smaller than 73 cm, red dots: fishing operation with catch of thornback ray smaller than 36 cm.**

## Western Channel (rjc.27.7e)

This area is considered a separated stock by ICES. Occurrences of the species in French on-board observations are less numerous. Juveniles seemed to be concentrated along the coast (Figure 3.11).

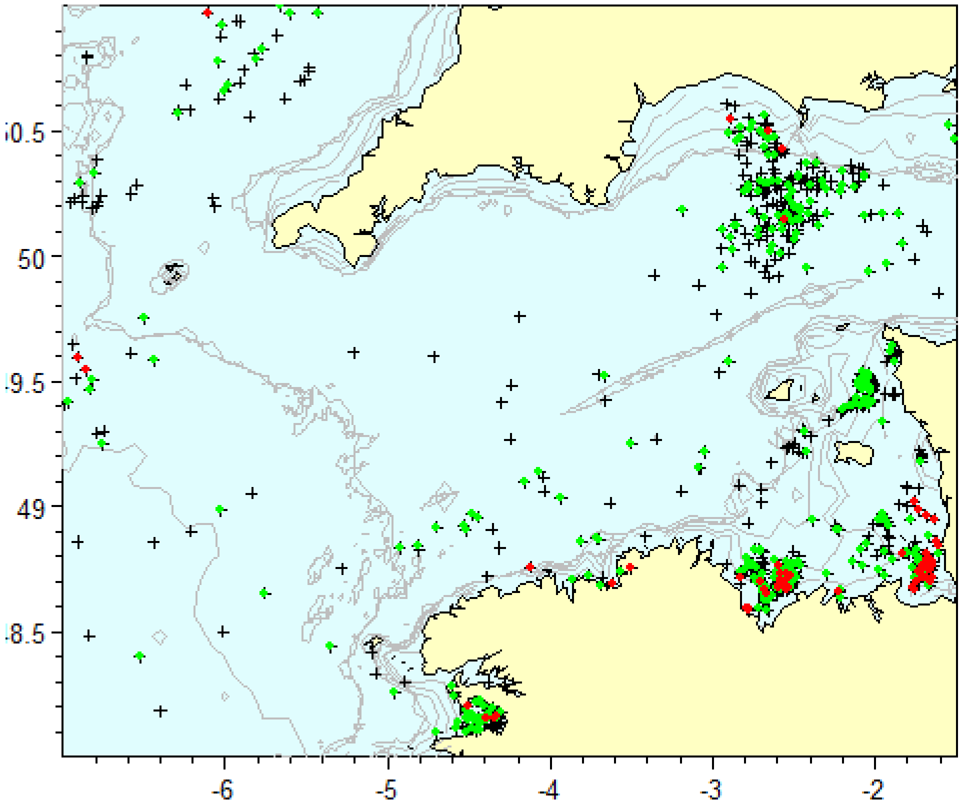



**Figure 3.11. Spatial distribution of thornback ray in French on-board observation in the Western Channel. Black "+": fishing operations with catch of thornback ray, green dots: fishing operation with catch of thornback ray smaller than 78 cm, red dots: fishing operation with catch of thornback ray smaller than 39 cm.**

### Subarea 8

The distribution of the catch was patchy with all areas including mature and immature fish. Larger individuals may spread more all over the shelf (Figure 3.12).

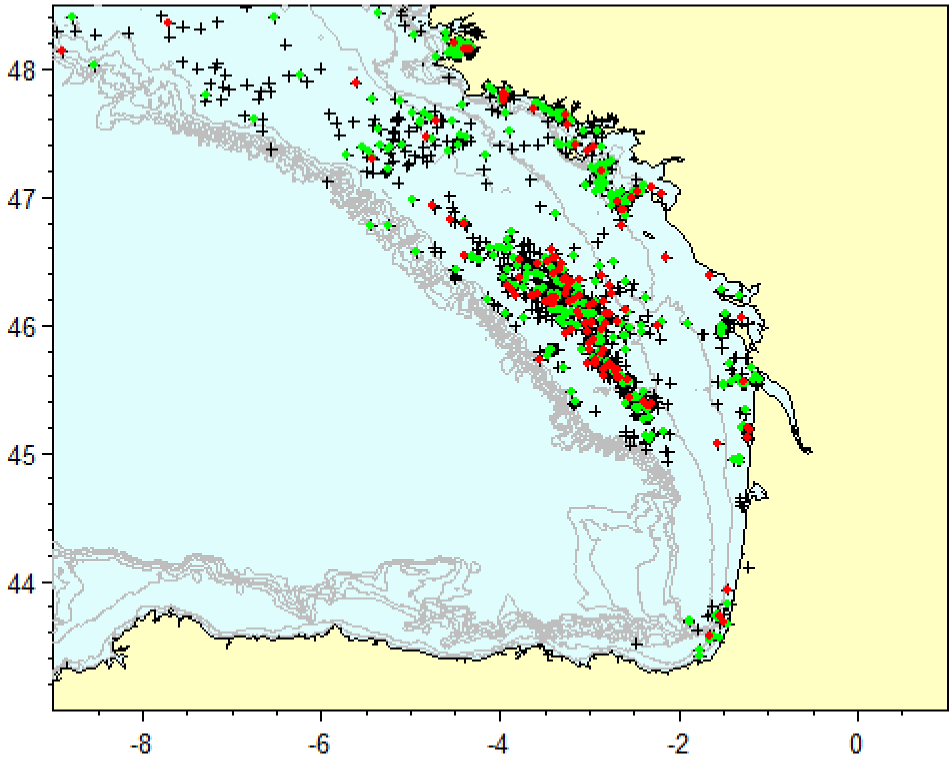



**Figure 3.12. Spatial distribution of thornback ray in French on-board observation in the Bay of Biscay. Black "+": fishing operations with catch of thornback ray, green dots: fishing operation with catch of thornback ray smaller than 78 cm, red dots: fishing operation with catch of thornback ray smaller than 39 cm.**

### Spotted ray.

The area where the species was caught during fishing operations sampled in the French on-board observations program covers parts of three stock areas for the species (rjm.27.3a47d, rjm.27.7aeh and rjm.27.8). Small and large individuals seem to have similar spatial distributions (Figure 3.13)

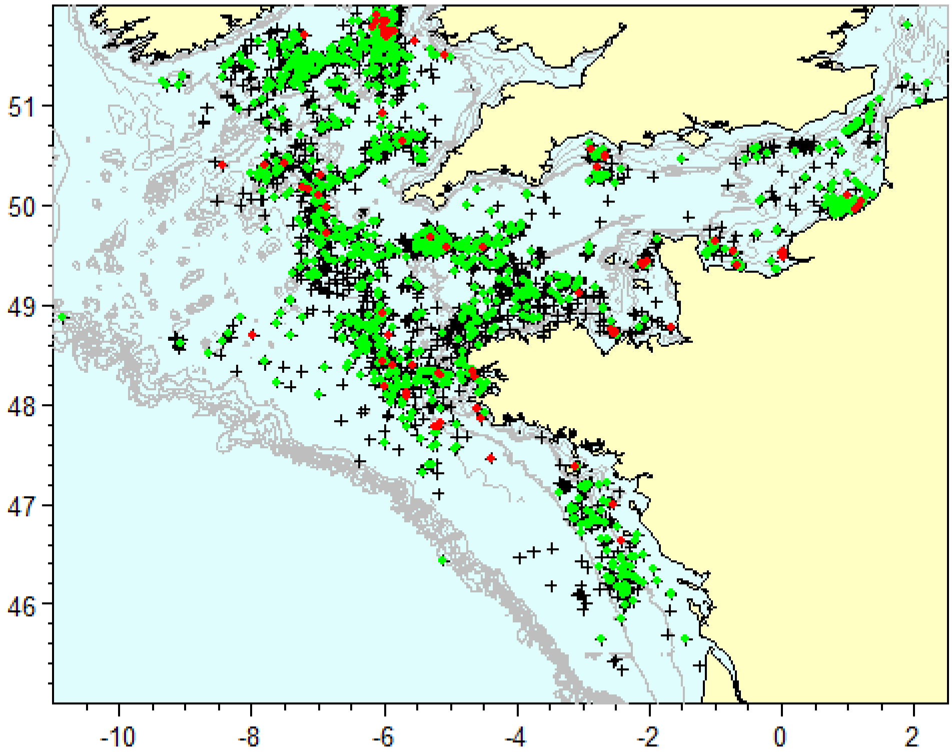



**Figure 3.13. Spatial distribution of spotted ray (*Raja montagui*) in French on-board distribution. Black "+": fishing operations with catch of spotted ray, green dots: fishing operation with catch of spotted ray smaller than 62 cm, red dots: fishing operation with catch of spotted ray smaller than 31 cm.**

## Undulate ray

Two stock units (rju.27.7de and rju.27.8ab) are considered in the area where French on-board observations are available. In both, there was a clear pattern were juveniles occurred in coastal waters  in the central Bay of Biscay, the Normano-Breton Gulf (Division 7.e) and parts of the eastern Channel (7.d), were they may be less coastal (Figure 3.14). Immature and adults were spread over the inner shelf.

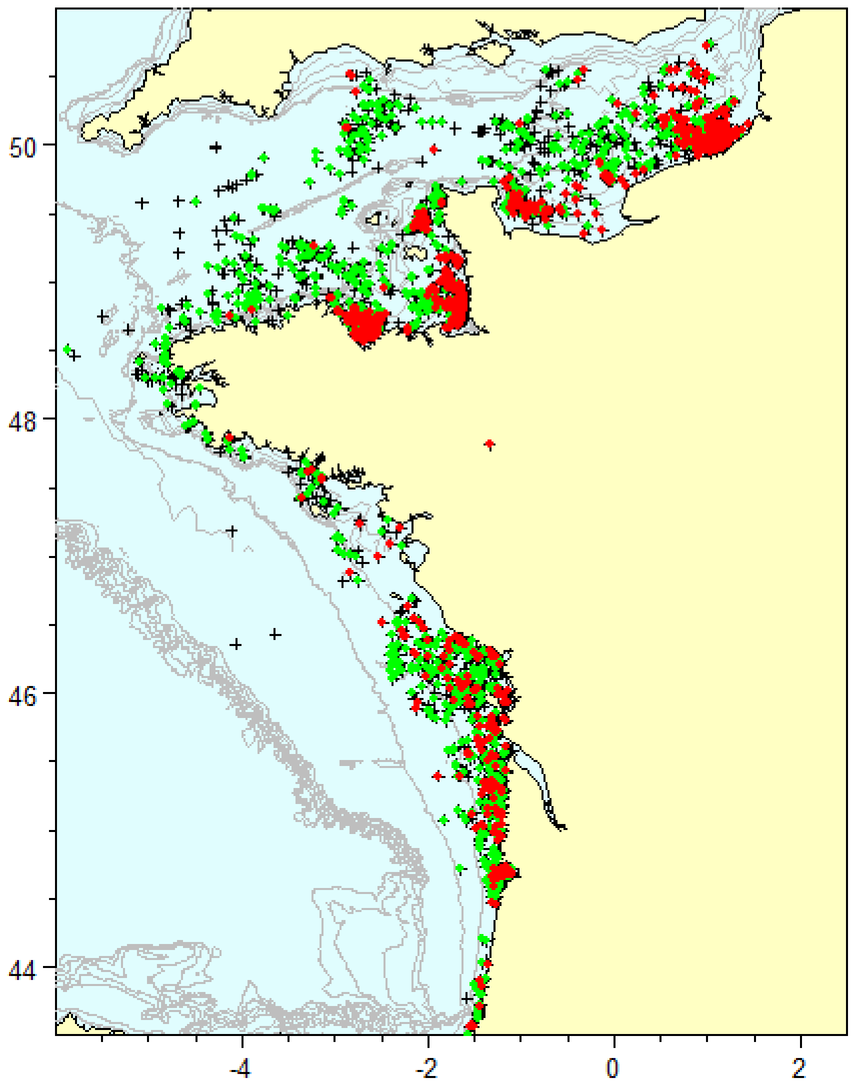



**Figure 3.14. Spatial distribution of undulate ray (*Raja undulata*) in French on-board distribution. Black "+": fishing operations with catch of undulate ray, green dots: fishing operation with catch of undulate ray smaller than 62 cm, red dots: fishing operation with catch of undulate ray smaller than 31 cm.**

### Cuckoo ray in the Celtic Sea and Bay of Biscay

All life stages seem to have similar distribution with juveniles occurring in the deeper range of the species, with records of larger individuals extending towards shallower waters (Figure 3.15).

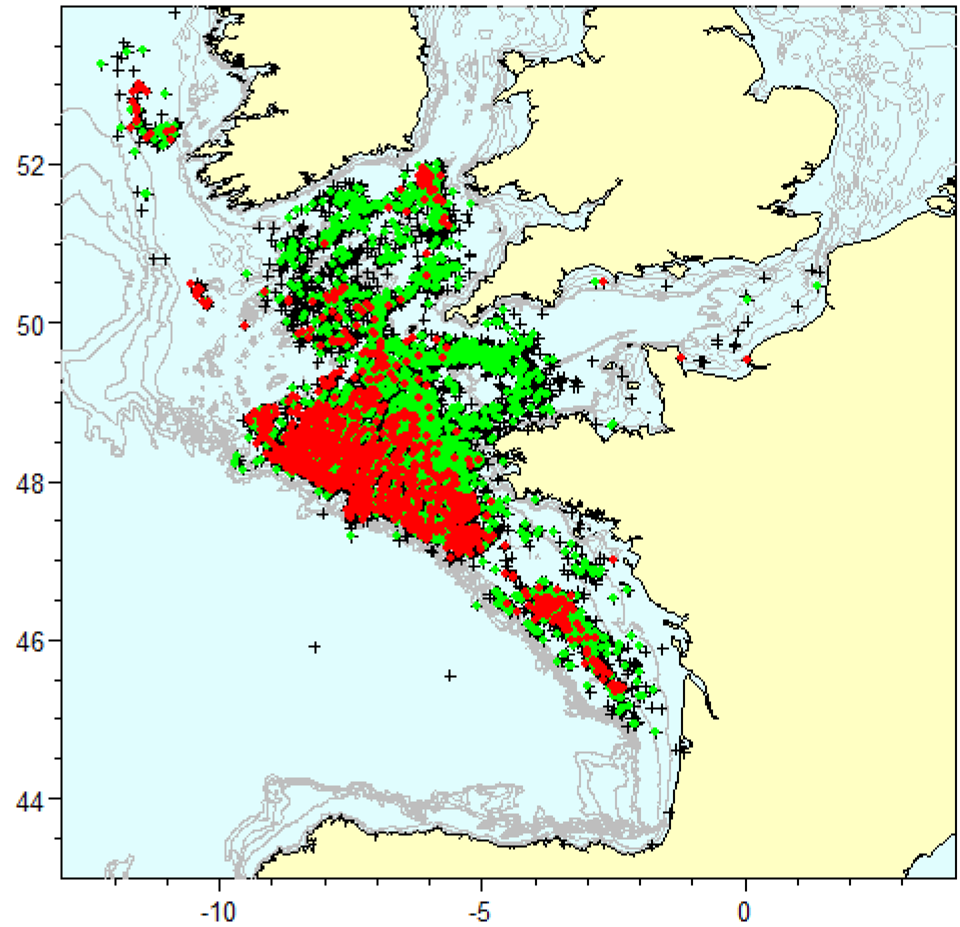



**Figure 3.15. Spatial distribution of cuckoo ray in French on-board distribution. Black "+": fishing operations with catch of cuckoo ray, green dots: fishing operation with catch of cuckoo ray smaller than 40 cm, red dots: fishing operation with catch of cuckoo ray smaller than 20 cm.**

Overall, for the studied species, distributions of French commercial catches do not display spatial structure susceptible to make length-based indicators meaningless. Nevertheless, adults have a wider distribution than juveniles in a number of cases, including thornback ray in the eastern Channel, undulate ray, where juveniles are more coastal, and cuckoo ray, where juveniles are concentrated offshore. In these cases, trends in length-based indicators could be impacted by changes in the spatial distribution of fishing effort or observed trips. Therefore it is recommended that when analysing temporal trends in indicators, fishing effort is considered and if there are change in the spatial distribution of fisheries those should be accounted for.

#### 3.3.2.2 Spatial distribution of the catch of undulate ray from Portuguese on-board observations

Under EU bycatch quota assigned to the rju.27.9a stock unit the stock has been monitored using fishery data regulated by Portuguese legislations (Portaria no 96/2016, Portaria no 27/2017). Results on the species abundance distribution show a clear spatial pattern of the species, with areas with higher density commonly associated to sandy bottoms and located inshore. Figure 3.16 shows regional limits defined in Portuguese waters together with habitats characteristics and figure 3.17 present the *R. undulata* predicted density for the Center, Southwest and southern areas off the Portuguese coast.

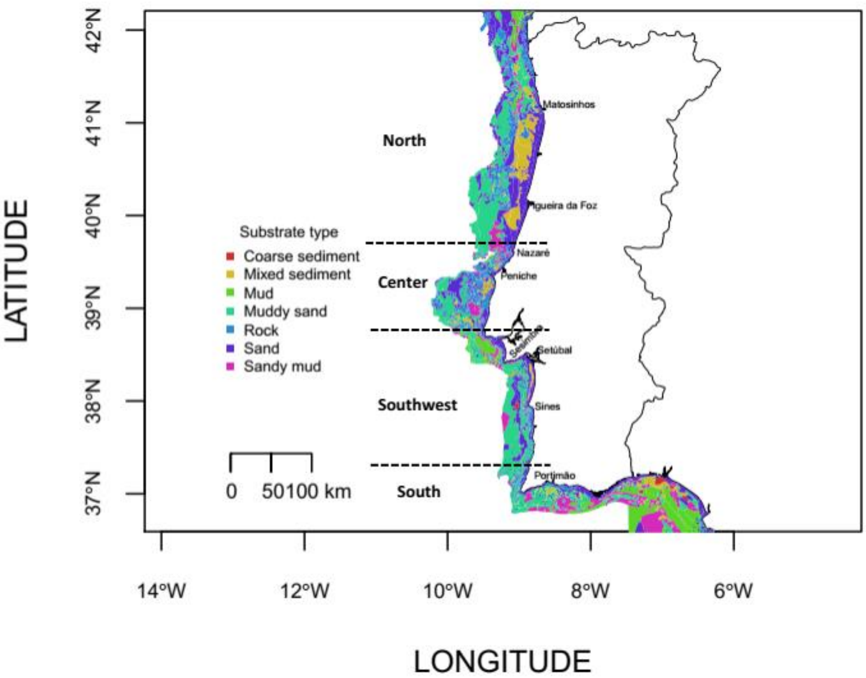



**Figure 3.16: Limits of regions defined along the Portuguese coast used to depict the distribution of *R. undulata* in figures 3.17-3.20.**

Overall the very coastal distribution of the catch of the species implies that representative sampling can only be obtained by sampling coastal small-scale fisheries.

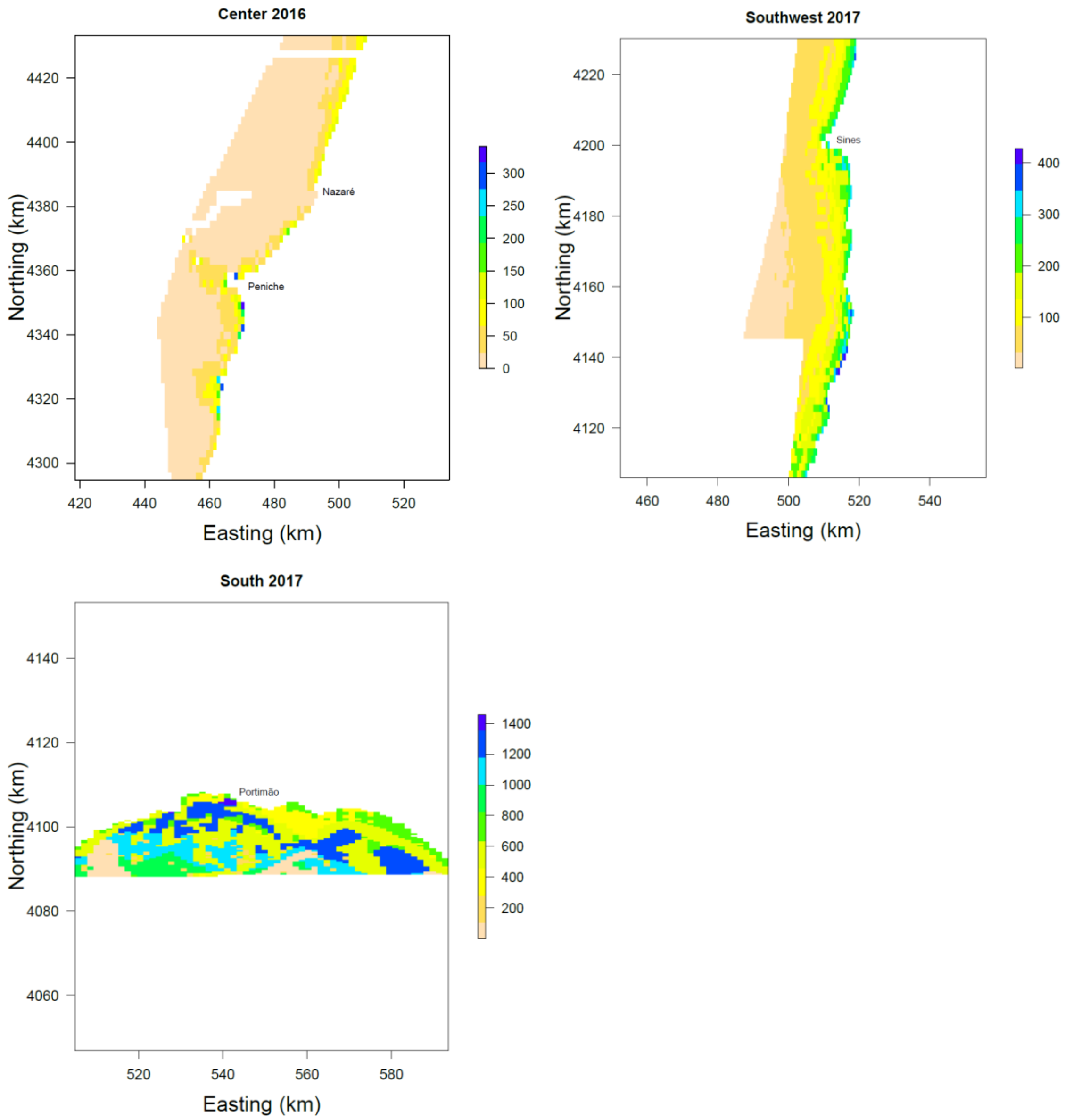



**Figure 3.17: Modelled spatial distribution of *R. undulata* in (top left) the Central, (top right) Southewest) and (bottom) South regions of the Portuguese coast based on the spatial distribution of commercial catch.**

#### 3.3.2.3 Spatial distribution of commercial catch in Irish on-board observations

A similar exercise to that carried out on French observer data was repeated for Irish observer data, collected under the Data Collection Framework from 2002–2017 (Johnston, 2018).

### Cuckoo Ray

Using the same size thresholds as were used by the French figures, Figure 3.18 below was plotted. This showed fewer juveniles caught along the shelf edge, although the proportions of juveniles and larger fish was similar in the Celtic Sea. This implies that the same conclusions can be drawn from these data**, *viz.*** all life stages seem to have similar distribution with juveniles occurring in the deeper range of the species and larger individuals being more spread towards shallower waters.

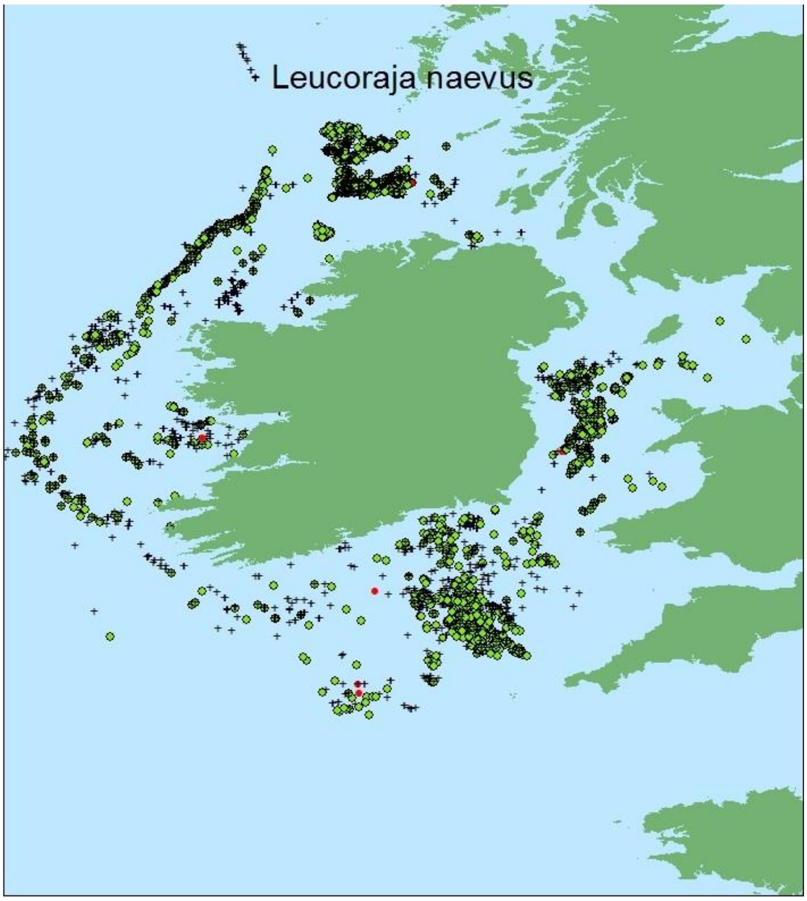



**Figure 3.18. Spatial distribution of cuckoo ray in Irish on-board distribution. Black "+": fishing operations with catch of cuckoo ray, green dots: fishing operation with catch of thornback ray smaller than 40 cm, red dots: fishing operation with catch of thornback ray smaller than 20 cm.**

### Thornback ray

These data (Figure 3.19) show that both juveniles and adults appear to be caught with similar frequencies with little spatial difference when looked at over a large scale. Smaller-scale stock assessment e.g., examining thornback ray within the Irish Sea only (7.a) shows that the eastern Irish Sea has a higher proportion of juveniles than the western Irish Sea. Therefore the scale of the area being assessed needs to be taken into consideration.

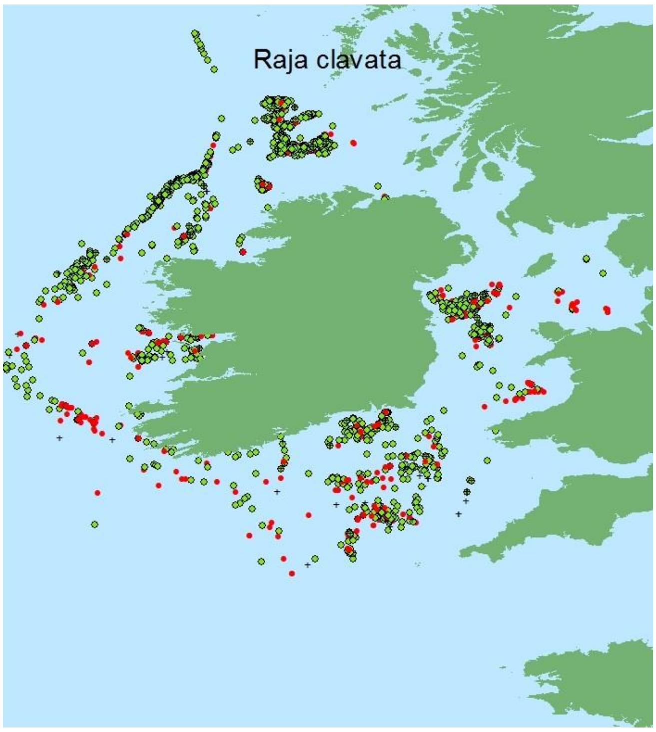



**Figure 3.19. Spatial distribution of thornback ray in Irish on-board observations. Black "+": fishing operations with catch of thornback ray, green dots: fishing operation with catch of thornback ray smaller than 78 cm, red dots: fishing operation with catch of thornback ray smaller than 39 cm.**

### Spotted ray

Spotted ray (Figure 3.20) showed a similar pattern to thornback ray (Figure 3.13), in that there are distinct areas such as the northern Irish Sea where there are higher proportions of juveniles than adult fish. This again shows that spatial variation needs to be taken into account when using length-based indicators for this stock.

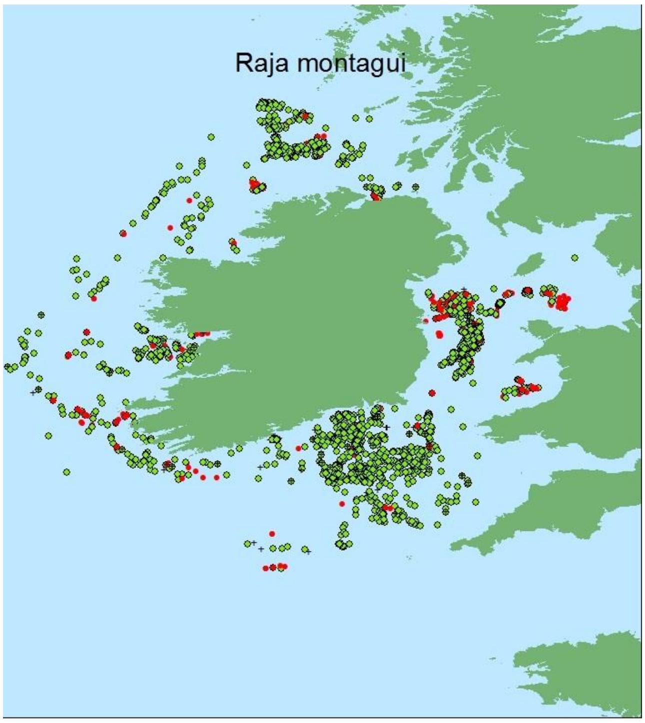



**Figure 3.20. Spatial distribution of spotted ray (*Raja montagui*) in Irish on-board distribution. Black "+": fishing operations with catch of spotted ray, green dots: fishing operation with catch of spotted ray smaller than 62 cm, red dots: fishing operation with catch of spotted ray smaller than 31 cm.**

#### 3.3.2.4 Spatial distribution of commercial catch Dutch on-board observations

An industry study (Dutch) funded by the European Maritime and Fisheries Fund carries out pilot trips to gain knowledge on the quantity, composition and spatial distribution of discards of quota regulated species. Participating fishing vessels in the pulse fishery (a subset of the beam trawl fleet) register and retain discards of all quota regulated species by haul on board. In the auction hall, discards are sorted by species, measured and weighed. As such, the composition and quantity for each fishing location is known. Plotting the weight of ray discards (not separated by species) by haul for eight trips showed there was variation between trips as well as within a trip (Fig 3.21). The catch rates of trips closer to the coast (e.g. blue line) were smaller compared to the trips further out at sea (e.g. purple line). Within a trip, catch rates can be a highly variable between hauls, even between succeeding hauls, indicating a patchy distribution of rays. Overall, the data show a difference in the distribution on both a larger as well as local scale.

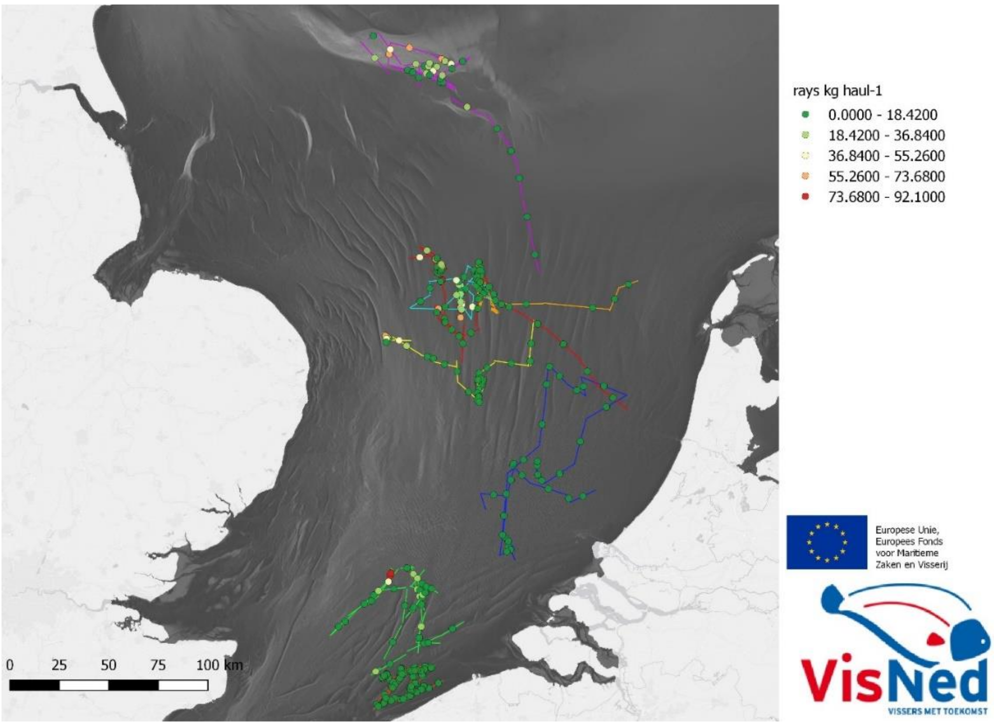



**Fig 3.21. Discard rates of eight industry pilot trips (lines) by haul over the period 2016–2017. The points are plotted on the midpoint of the haul. The colour of the points denotes the height of the discard rates going from 0kg (green) to 92 kg (red) by haul.**

### Comparison of Dutch Commercial data with IBTS-survey

Standardised length-distribution of two species was compared between Dutch commercial beam-trawl data and the IBTS (Figure 3.22). These showed considerable differences, illustrating the potential issues of choosing between datasets. In both species, the IBTS-survey showed a wider size-spectrum in the samples. Also, the survey showed a larger proportion of larger fish in the samples. The lower size-range found in the commercial discard data may be caused by the sampling bias towards the lower size-classes in the self-sampling programme (ICES, 2017a).

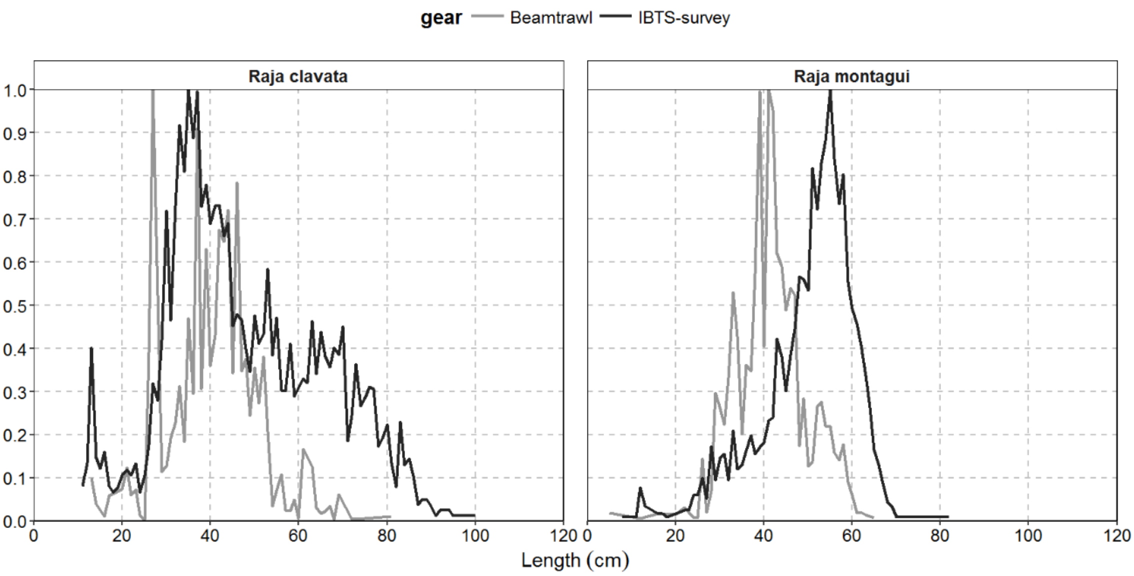



**Fig. 3.22. Standardized length distribution for *Raja clavata* and *Raja montagui* in the IBTS-survey (Q1 and Q3) and the discards of the beam-trawl derived from the Dutch self-sampling programme. In both species the IBTS-survey shows a large size-spectrum in the samples. Also, the survey shows a larger proportion of larger fish in the samples. The lower size-range found in the commercial discard data may be caused by the sampling bias towards the lower size-classes in the self-sampling programme (ICES, 2017a).**

## 3.4 The assumption of constant recruitment, selection and fishing mortality; the violation of which could lead to a shift in population size distribution and affect indicator values and species status in relation to RP

Length distribution from surveys may be used in several ways depending on available data. In addition to trends in survey biomass used for advice, information on the stocks dynamics can be extracted. Here, a few examples of length distributions from surveys were used to evaluate the assumption of constant recruitment in elasmobranch populations

### 3.4.1 Constant recruitment

Swept area numbers-at-length (*i.e.* number caught raised to the total area sampled) from surveys were aggregated in three larger size groups of (1) individuals smaller than half the size-at-maturity of females, (2) individuals of size between half the size-at-maturity and the size-at-maturity of females and (3) individuals larger than the size-at-maturity of females. These three groups are denoted below as recruiting, sub-adult and mature fish. It is worth noting that the length chosen to split sub-adults from mature fish was the length at 50% maturity of females (Table 3.2).

This size grouping was applied to thornback ray, undulate ray, lesser-spotted dogfish and starry smooth-hound in the French otter trawl survey in the Eastern Channel (FR-CGFS) and for lesser-spotted dogfish from the English BTS in the Irish Sea and Bristol Channel. These estimates have large variance, which are not shown here, however, bar-plots of the estimated swept area abundance and relative abundance (percent of size groups per year) were drawn.

## Thornback ray

The average recruitment in the last 10 years was higher than in the 20 first years of the time-series and in recent years the absolute number and proportion of mature rays increased (Figure 3.23 left). In proportions, although total number were much higher in early years, the contribution of recruiting thornback rays (individuals smaller than 36 cm, corresponding roughly to the two first years of life) was similar in early years and in recent years (Figure 3.23 right).

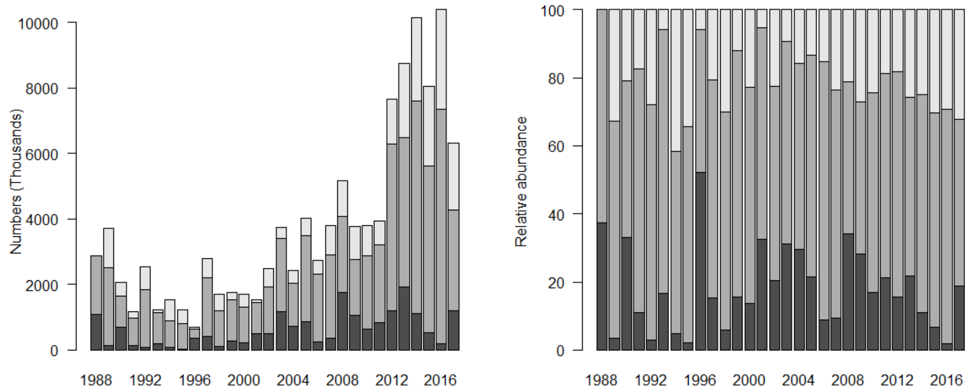



**Figure 3.23. Swept-area estimates of numbers of thornback ray in FR-CGFS, left: swept area estimates, right: percent per year. Black: recruitment (individuals smaller than half the size-at-maturity of females); dark grey sub-adults (individuals between half the size-at-maturity of females and the size-at-maturity of females); light grey: mature fish (larger than the size-at-maturity of females).**

## Undulate ray

Number of all size groups increased from 2012 (Figure 3.24). The recruitment of this species is not be well sampled by the survey because is it distributed in too shallow coastal waters for the R/V. Numbers of the three size groups have increased almost at the same time, all being several time higher in the 2010s than previously.

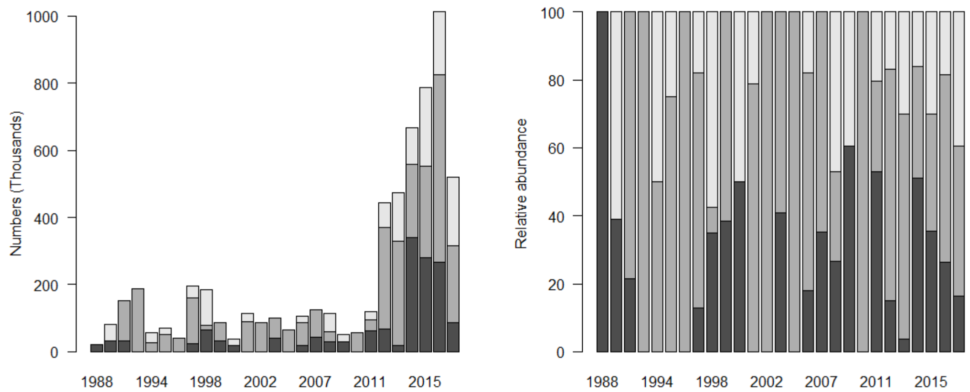



**Figure 3.24. Swept-area estimates of numbers of undulate ray in FR-CGFS, left: swept area estimates, right: percent per year Black: recruitment (individuals smaller than half the size-at-maturity of females); dark grey sub-adults (individuals between half the size-at-maturity of females and the size-at-maturity of females); light grey: mature fish (larger than the size-at-maturity of females).**

## Lesser-spotted dogfish

In the eastern Channel, the species is presumed properly sampled by the survey with high numbers caught annually; however, the recruitment is hardly caught by the survey, probably as a consequence of low catchability of lesser-spotted dogfish smaller than 28 cm TL. Pre-adult and mature fish have been caught in constant proportion of about 60 and 40% respectively during the time-series. With the exception of year 1989, there was an increase in abundance of both sub-adults and adults in the 1990 and this was not preceded by higher recruitment.

Similarly, the recruitment is not caught in the English BTS in the Irish Sea and Bristol Channel. However, increasing number of pre-adults in the 2000 suggest that increasing recruitment came in (Figure 3.25).

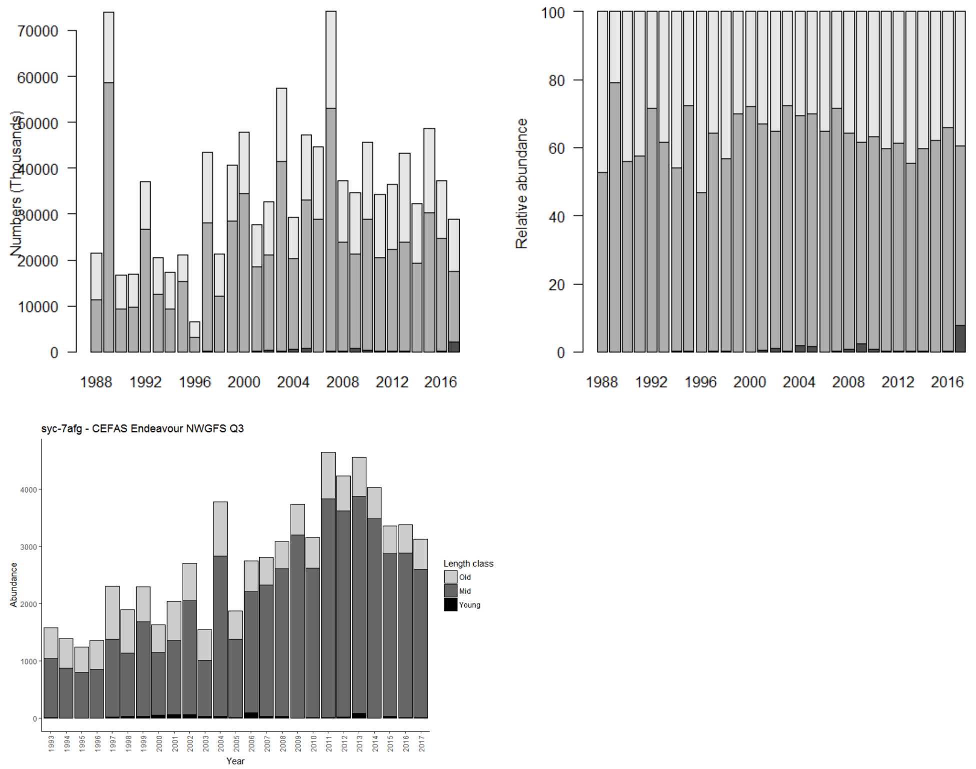



**Figure 3.25. Swept-area estimates of numbers of lesser-spotted dogfish in (top) FR-CGFS, left: swept area estimates, right: percent per year and (bottom) raw caught in the English BTS survey in the Irish Sea and Bristol Channel (7.a.f-g). Black: recruitment (individuals smaller than half the size-at-maturity of females); dark grey sub-adults (individuals between half the size-at-maturity of females and the size-at-maturity of females); light grey: mature fish (larger than the size-at-maturity of females)**

### Starry smooth-hound

Like for lesser-spotted dogfish, the recruit stage does not seem to be well sampled. The abundance of sub-adult fish increased gradually from the mid-1990s. There was a clear increase in the abundance of mature fish in recent years. In proportions, the recruitment seems stable over time and the proportion of adults increased (Figure 3.26).

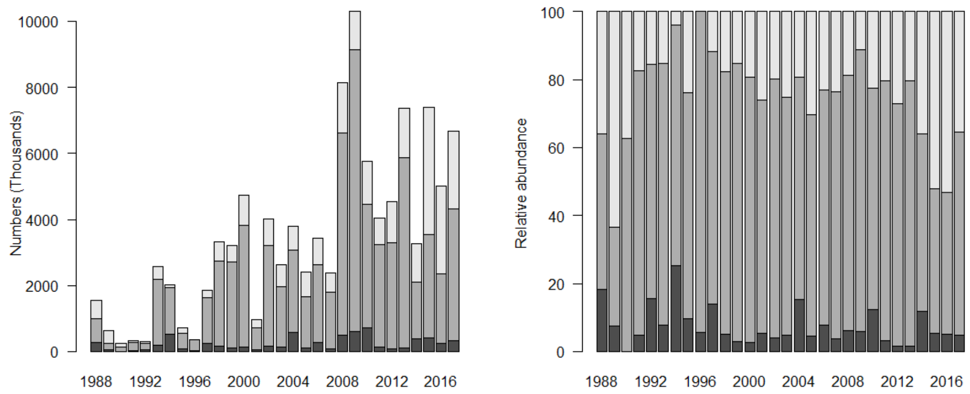



**Figure 3.26. Swept-area estimates of numbers of starry smooth-hound in FR-CGFS, left: swept area estimates, right: percent per year. Black: recruitment (individuals smaller than half the size-at-maturity of females); dark grey sub-adults (individuals between half the size-at-maturity of females and the size-at-maturity of females); light grey: mature fish (larger than the size-at-maturity of females)**

### Conclusion

None of the four stocks studied for the eastern Channel have been stable of the time-series, large increases in total number are observed in 3 of the 4 stocks examined. Only for the lesser-spotted dogfish the change in total number was lesser, with possibly an increase followed by a decrease. Changes in recruitment numbers were detected for the two rays. For smooth-hounds an increased proportion of adult fish occurred in recent years. Lesser spotted dogfish in 7.a.f-g also showed a phase of increasing numbers of pre-adult fish, reflecting a non-equilibrium situation. It is unclear whether the observed changes were driven by changes in fishing pressure or recruitment but the change observed reflect non steady state situations. Overall using Reference Points based on an equilibrium assumption could be misleading for these stocks.

### 3.4.2 Constant selection

The issue of constant selection was not examined in detail at this Workshop. It was noted that vessels of different nationalities targeting rays in the Irish Sea have preferential species (*L. naevus* vs. *R. brachyura*). Although fishing in the same area, some discard adults of these species that are retained by other vessels. Discard survival may be relatively high for these species (Depestele *et al.*, 2014; Saygu and Deval, 2014; Morfin *et al.*, 2017; Knotek *et al.*, 2018). Given that some of these vessels may only be in particular areas on a semi-regular or opportunistic basis, selection to the fishery may vary annually on a seasonal or annual basis. Further work is required to determine where similar or related issues may apply to other stocks.

### 3.4.3 Constant fishing mortality

This term of reference was addressed under Term of Reference C, where fishing mortality was varied under different model scenarios. It is not further discussed here.

# 4 ToR b) Further develop the provisional protocol which was developed at WGEF 2017 for deriving appropriate Reference Points and expected indicator ratio values based on specific life history parameters for lesser-spotted dogfish *Scyliorhinus canicula* and ToR c) Explore the use of the Leslie matrix approach as used at the WGEF 2017 meeting for identifying LBI 'expected values' based on the known life history characteristics of specific fish stocks

Due to the high amount of overlap between ToR b and ToR c, the results and discussions from both have been combined into a single section.

During WGEF 2017, methods for applying length-based indicators (LBIs) to data limited elasmobranch species were developed and applied to commercial landings and discard data from three elasmobranch stocks (syc.27.8abd, sdv.27.nea, rjc.27.3a47d). The WKLIFE LBI (Table 4.1) can be calculated easily from the length-frequency distribution of survey or catch data. For assessment purposes, selected indicators are considered relative to specified life history reference points (RP), *i.e.*, as a ratio of indicator/reference point (Table 4.1). RP are estimates of the von Bertalanffy asymptotic length $L_\infty$, length at maturity $L_{mat}$, optimal harvest length $L_{opt}$ (2/3 $L_\infty$ when M/k = 1.5), and the mean length at which fishing- and natural mortality are equal $L_{F=M}$ ($0.75L_c + 0.25L_\infty$ when M/k = 1.5). Each ratio has a defined 'Expected value' at which relevant conservation, yield and MSY 'Properties' are considered achieved.

It was found that length-based methods were quite sensitive to life history parameters and that several LBI RP (i.e. $L_c/L_{mat}$ and the definition of 'mega-spawner' for the $P_{mega}$ indicator) would need further evaluation (ICES, 2017b). Concerns were also raised with regard to how the length-based proxy methods dealt with multi-modal length-frequency distributions; something which may be quite common in elasmobranch species that segregate by age and maturity. Lastly, preliminary generation of a Leslie matrix Model (LMM) to determine the "Expected values" of LBIs in a pristine *Scyliorhinus canicula* stock highlighted some potential issues with RP and combinations of life history parameters.

The aim of this chapter is to build on the work from WGEF 2017 and further explore the application of LBI to elasmobranch fishes. This will include (1) discussing the suitability of LBI to elasmobranch populations, (2) exploring the sensitivity of the Leslie matrix to the life history parameters, (3) developing a refined LMM to assess the expected values of the LBIs, (4) providing a preliminary protocol that would be suitable to further refine expected LBI values for a sustainably fished population.

For a full description of LBI methods and associated RP, indicator ratios and Leslie matrix approaches please refer to WGEF 2017 and Walker *et al.* (2018 WD02).

**Table 4.1. Indicators, indicator ratios and expected values selected by WKLIFE V for screening of length composition data. The equations for $L_{opt}$ and $L_{F=M}$ reported here assume $M/k$ = 1.5, but the indicators can be calculated for any $M/k$ (Beverton, 1992; Jardim *et al.*, 2015).**

| Indicator | Calculation | Reference Point | Indicator ratio | Expected value |
|---|---|---|---|---|
| $L_{max5\%}$ | Mean length of largest 5% | $L_{\infty}$ | $L_{max5\%} / L_{\infty}$ | >0.8 |
| $L_{95\%}$ | 95th percentile of length | $L_{\infty}$ | $L_{95\%} / L_{\infty}$ | >0.8 |
| $P_{mega}$ | Proportion of individuals above $L_{opt}$ + 10% | 0.3-0.4 | $P_{mega}$ | >0.3 |
| $L_{25\%}$ | 25th percentile of length distribution | $L_{mat}$ | $L_{25\%} / L_{mat}$ | >1 |
| $L_C$ | Length at first catch (length at 50% of mode) | $L_{mat}$ | $L_C / L_{mat}$ | >1 |
| $L_{mean}$ | Mean length of individuals larger than $L_c$ | $L_{opt} = 2/3\ L_{inf}$ | $L_{mean} / L_{opt}$ | ≈1 |
| $L_{maxy}$ | Length class with maximum biomass in catch | $L_{opt} = 2/3\ L_{inf}$ | $L_{maxy} / L_{opt}$ | ≈1 |
| $L_{mean}$ | Mean length of individuals larger than $Lc$ | $L_{F=M} = 0.75L_c + 0.25L_{inf}$ | $L_{mean}/L_{F=M}$ | ≥1 =MSY |

## 4.1 Exploring the suitability of LBI and RP

### 4.1.1 Length at first capture ($L_C$)

One important component of assessing the status of fish stocks is the status of the immature individuals (Froese, 2004). To explore the "Conservation of immatures" within a stock, the indicator length at first capture ($L_C$) is used in the calculation of several LBI (e.g. $L_c/L_{mat}$). The indicator $L_{mean}$ and reference point $L_{F=M}$ are also dependent of $L_C$ (Table 4.1). The calculation of $L_C$ can therefore have broader implications on LBIs $L_{mean}$ /$L_{opt}$ and $L_{mean}/L_{F=M}$.

In previous working groups, $L_C$ was stated as the "length at 50% of the mode". During preliminary applications of LBIs to data from the English and Welsh Observer at Sea Program, the calculation of $L_C$ was highly variable across those data examined (Walker *et al.*, 2018 WD). Additionally, the absolute value of $L_C$ was also very low. Accordingly, $L_C/L_{mat}$ would consistently indicate a poor status to all stocks, with values typically <0.5 (Walker *et al.*, 2018 WD).

There may be several reasons why this LBI consistently failed. One scenario is that all those stocks assessed were indeed in poor condition with relation to the "conservation of immatures". Alternatively, the calculation of $L_C$ could have been inappropriate for the length-frequency distributions observed. Lastly, the "Expected value" for the LBI "$L_C/L_{mat}$" could be inappropriate for elasmobranch fishes. After further examination of the underlying R-code used to calculate LBIs and further consideration of the life histories of many elasmobranchs, it was concluded that a combination of the latter two points was most likely the reason for the poor performance of this LBI.

In the initial code, $L_C$ was calculated as the length at 50% of the first mode. After consultation with other applications of this metric (e.g. ICES, 2012b), $L_C$ has now been defined as the length corresponding to 50% of the frequency of the overall mode. This will revise the associated LBIs using $L_{mean}$, and $L_{mean}/L_{opt}$ and $L_{mean}/L_{F=M}$. Furthermore, due to the later age of maturation of many elasmobranch species, most fisheries are expected to catch a relatively high proportion of fish smaller than $L_{mat}$ when compared to teleosts. Likewise, the lower mortality rates of early size classes (*i.e.* age 0 and 1) are expected to improve recruitment efficiencies, which may also violate some of the assumptions underpinning the ecological theories behind the LBIs for immature fish (Froese, 2004; Myers and Mertz, 1998). It is therefore highly likely that most elasmobranch fisheries will always fail on these LBIs and it may be necessary to adjust the "Expected value" for these metrics.

Moving forward it is advised that $L_C$ be taken as the length corresponding to 50% of the frequency of the overall mode and that a more relevant "Expected value" is calculated (see section 4.1.1).

### 4.1.2 Optimal fishing length ($L_{opt}$)

The indicator ratio $L_{mean}/L_{opt}$ gives a measure of overfishing in relation to optimal yield, and is expected to be ≈1. $L_{opt}$ is calculated:

$$L_{opt} = \frac{3}{3 + {}^{M}/_{k}} L_{\infty}$$

Where $M$ is natural mortality, $k$ is the von Bertalanffy rate coefficient and $L_{\infty}$ is the asymptotic length from the von Bertalanffy growth model. These parameters themselves are associated with large amounts of uncertainty, and any calculation of $L_{opt}$ could likewise be very uncertain (see section 3.1 in file chapter for Tor a). The ratio $M/k$ is thought to be more stable than either of the parameters separately, and is estimated at 1.5 for teleost fishes. The ICES approximation of $L_{opt}$ therefore simplifies to 2/3 $L_{\infty}$. It is unclear at this stage whether this is suitable for elasmobranch fishes as it has been suggested that $M/k$ may be lower (Frisk *et al.*, 2001; Prince, 2015). Allowing $M/k$ to vary would provide a more accurate calculation but by taking this approach it is necessary to have stock-specific growth parameters and $M$ values, which are not always available.

There was also some discussion regarding the relationship between $L_{mat}$ and $L_{opt}$. Froese (2004) suggested that $L_{mat}$ should typically be lower than $L_{opt}$, due to the fact that a proportion of the mature population have been able to contribute offspring before capture. From those examples run in WD WKSHARK4, it was clear that this was often not the case in many of the studies. Where elasmobranch fishes mature relatively late in comparison to teleost fishes, the assumption of $L_{mat} < L_{opt}$ from Froese (2004) may not be applicable to elasmobranch fishes. Indeed, Prince (2015) suggested that fisheries concentrating on a few year classes of pups, juveniles or sub-adults may be a more robust management strategy, and therefore $L_{opt}$ being less than $L_{mat}$ may not necessarily be detrimental. This relationship may warrant further investigation however.

It has also been suggested that $P_{mega}$ may need further evaluation for elasmobranch fishes (ICES, 2017a). $P_{mega}$ is defined as those fish which are mega-spawners ($L_{opt}$ + 10%), and is considered an LBI for "Conservation of spawners". In addition to the uncertainty surrounding the calculation of $L_{opt}$, using $P_{mega}$ for determining the health of large spawning elasmobranchs may be not be appropriate. For this indicator to be accurate, it would be necessary to be able to separate the length-frequency data into separate sexes. In many elasmobranch species, it is the females that attain a larger size and later age at maturity than the males (Ellis and Shackley, 1997) and any calculation of $P_{mega}$ would need to consider this. Senescence (the cessation of offspring production in older size classes) has also been suggested in a few elasmobranch species (Figueiredo *et al.*, 2008 and references within). It is unclear if senescence affects those elasmobranchs assessed here, but if LBI were going to be applied to species that do stop producing eggs in older size classes, this would need to be considered. The expectation that $P_{mega} > 0.3$ assumes asymptotic selection. If selection is dome-shaped then lower values of $P_{mega}$ are desirable, following the fishing strategy that no mega-spawners are caught (see Section 3.2 in file chapter for Tor a).

## 4.2 Refining the Leslie matrix for a pristine *Scyliorhinus canicula* stock

The application of LBIs to elasmobranch fishes may require the development of elasmobranch specific indicator ratios due to intrinsic differences in the life history between teleosts and elasmobranchs (e.g. elasmobranchs typically mature later, are less fecund, have slower growth rates etc.). One approach to evaluate the suitability of expected values of LBIs for elasmobranch stocks, is to calculate LBIs from a simulated pristine and sustainably exploited populations in an age-structured model in discrete time (Leslie matrix approach) using published life history parameters for that species (WGEF, 2017b).

### 4.2.1 Methods for refining the Leslie matrix

The methods in the current exploration of this approach followed the same as those outlined in WGEF 2017 but with further testing of some of the assumptions made in earlier iterations.

The results from initial simulations of a Leslie matrix for *S. canicula* highlighted some of the challenges of establishing a population at equilibrium (ICES, 2017). It was found that achieving a population at equilibrium (*i.e.* an eigenvalue $\lambda \approx 1$) was challenging based on the combination of $k$, $M$ and $L_\infty$. Subsequently, using this model to test the indicator ratios for an unexploited stock would be associated with high levels of uncertainty and difficult to provide robust stock assessments. To further attempt to refine the Leslie matrix for *S. canicula*, $L_\infty$ and $k$ were fixed to those values for females from Ivory *et al.* (2005), and the sensitivity to some of the other assumptions were tested (Table 4.2). These assumptions included constant mortality $M$ for all ages, a mean fecundity of two pups for each individual, specific length at maturity, and varying maturity slopes. Furthermore, the application of an intermediate traffic light system was also trialled. For full details of the Leslie matrix, please see ICES (2017) and Walker *et al.* (2018 WD).

**Table 4.2: Life history parameters of female *S. canicula* used to constrain the Leslie matrix model. Those parameters with multiple values were those that were tested in current analyses where $L_\infty$, $k$ and $t_0$ are von Bertalanffy growth parameters, $A_{max}$ is the maximum age, $L_{mat}$ is the length at 50% maturity, $L_C$ is the length at first capture (assuming knife edge selection), $M_{(A1)}$ is the mortality at age 1 using the Gislason *et al.*, 2010 age varying mortality equation, $M$ is**

**the average mortality across all ages, $K_{mat}$ is the maturity slope and *Fec* is the number of individuals from each female expected to reach age 1 per year (fecundity).**

| Parameter | Value | Reference |
|---|---|---|
| $L_\infty$ | 75.14 | Ivory *et al.*, 2005 |
| $k$ | 0.15 | Ivory *et al.*, 2005 |
| $t_0$ | -0.96 | Ivory *et al.*, 2005 |
| $A_{max}$ | 15 | ICES, 2017 |
| $L_C$ | 15 | ICES, 201b7 |
| $L_{mat}$ | 45, 57*, 65 | *Ivory *et al.*, 2005 |
| $M_{(A1)}$ | 0.7, 0.9 | Arbitrary |
| $M$ | 0.28, 0.3 | Mean across all ages (varying mortality) |
| $K_{mat}$ | 0.5 | ICES, 2017 |
| *Fec* | 2,4,6,8,10 | Arbitrary |

### 4.2.2 Age varying mortality

Instead of constant mortality across the age groups (as in ICES, 2017), an age varying mortality was applied based on Equation 2 from Gislason *et al.* (2010):

$$\ln(M_a) = 0.55 - 1.61\ln(L_a) + 1.44\ln(L_\infty) + \ln(k)$$

$M_a$ being the mortality at age $a$, $L_a$ being length at age $a$, $L_\infty$ being the asymptotic length from the von Bertalanffy growth parameters (VBGP), with $k$ being the slope from the VBGP.

When using the life history parameters for *S. canicula* the resultant age varying mortality curve was unrealistic for early age classes (Figure 4.1). This mortality model was derived from teleosts, and therefore predicts high mortality (>1) for age 0 and 1 when using the VBGP for *S. canicula* (Figure 4.1). These predictions may be different in elasmobranchs where growth is typically slower and the production of well-developed offspring increases survivorship in year one. To overcome this issue, mortality at age 1 was replaced by two hypothetical values; 0.7 was used arbitrarily but subsequently produced results that agreed with the mean mortality of 0.28 calculated by Rodríguez-Cabello *et al.* (2018 WD), and 0.9 was applied to constrain the mortality curve closer to more realistic mortality rates (<1). To calculate $M/k$ for the population, the mean mortality across all age classes was used, and the $k$ value from the von Bertalanffy growth parameters from Ivory *et al*., 2005. The empirical relationship from Gislason et al. (2010) is an attempt to quantify the well understood fact that mortality of juvenile fish undergo higher predation mortality than large adults, this is especially true for teleosts eggs and larvae. Most fisheries science models have used a single natural mortality coefficient at all ages; this "overall mortality" definitely did not accounted for the high mortality of the early life. To be consistent with this, the natural mortality used to calculate M/K could be the mean over exploited ages (age 2 or 3 and older for lesser spotted dogfish, see below).

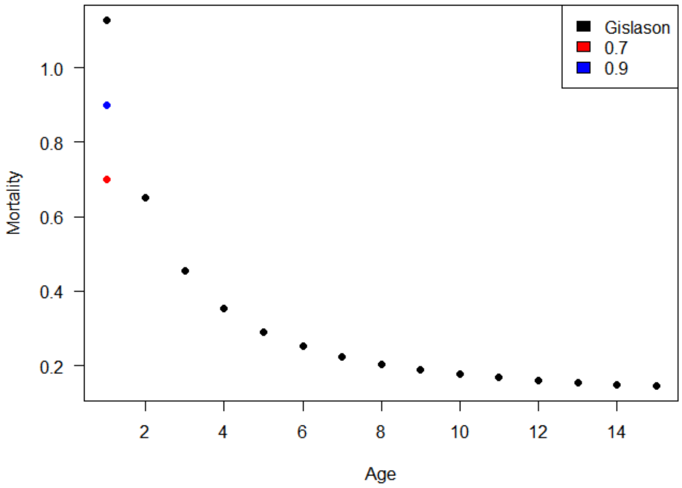



**Figure 4.1: Mortality curve for *S. canicula* calculated from Gislason *et al.* (2010) equation 2, using life history parameters from Table 4.2. The calculated mortality of age 1 from the original equation (black points) were unrealistically high (>1). Arbitrary mortality at age 1 were set to 0.7 (red point) and 0.9 (blue).**

### 4.2.3 Fecundity

There was some uncertainty about the appropriate level of "fecundity" to apply within the model. It was suggested that a range between 1–10 would be appropriate; *i.e.* 1–10 individuals survive gestation (in egg) and reach age 1. For both simulations of age varying mortality ($M_{(A1)}$ = 0.7 and 0.9), the various simulations of fecundity were applied from 2 to 10, in increments of two.

### 4.2.4 Length at 50% maturity ($L_{mat}$)

In previous Leslie matrices, $L_{mat}$ was set to 54.2 cm based on Rodríguez-Cabello *et al.* (1998). Life history parameters can however vary between regions (Ellis and Shackley, 1997 and references within). Accordingly, $L_{mat}$ was set at 57 cm in accordance with the other life history parameters used from Ivory *et al.* (2005). The Leslie matrix was then generated with arbitrary smaller and larger sizes at maturity to test the sensitivity of the model to this parameter (45 and 65 cm).

### 4.2.5 Length-based indicator expected ratios

LBI, RP and indicator ratios were then calculated from the length structure of the simulated pristine exploitable population and input life history parameters to assess the appropriateness of the ICES expected values (Table 4.1) for elasmobranch species. $L_{opt}$ and $L_{F=M}$ were calculated:

$$L_{opt} = \frac{3}{3 + {}^{M}/_{k}} L_{\infty}$$

Where $M$ is mean natural mortality across all age ranges, $k$ is the von Bertalanffy rate coefficient and $L_{\infty}$ is the asymptotic length from the von Bertalanffy growth model.

*MSY*: *F=M* is a proxy for MSY. The length at which *F=M* ($L_{F=M}$) is rearranged from Beverton and Holts equation for mean length in the catch as a function of the von Bertalanffy growth parameters, length at first capture and natural and fishing mortality:

$$L_{F=M} = (1 - a)L_c + aL_{\infty}$$

$$a = \frac{1}{2\left({}^{M}/_{k}\right) + 1}$$

Where $L_C$ is the length at first capture (15 cm), $L_\infty$ and $k$ are the von Bertalanffy growth parameters and $M$ is the average mortality across all age classes. All other LBI were calculated from ratios in Table 4.1.

## 4.3 Applying LBIs to simulated length-frequency distribution of commercial catch

Further explorations were made using *Lc* values that were visually estimated from length distribution plots of lesser spotted dogfish (*S. canicula*) in ICES (2017 a,b) and applying indicators from Table 4.1 to the length-frequency of commercial catch instead of to that of the population. These *Lc* values were based on either the length distribution of the catch (landings and discards) or landings data only. For example, in the length distribution from the Basque Country fleet in the Bay of Biscay (8abd), the overall mode of the landings was about 55 cm and *Lc* "length corresponding to 50% of the frequency of the overall mode" was about 50 cm (Figure 4.2). Using landings and discards combined, the overall mode was 36 cm and *Lc* is 26 cm (Figure 4.2). The same was done for several other fleets to derive multiple *Lc* values (Table 4.3). In the North Sea ecoregion, data from otter trawl fleets only were used, based on this gear being the dominant one used in this area. To estimate the actual *Lc* of the total commercial catch in the North Sea, an appropriate combination of catch from all fleet should be done in the future.

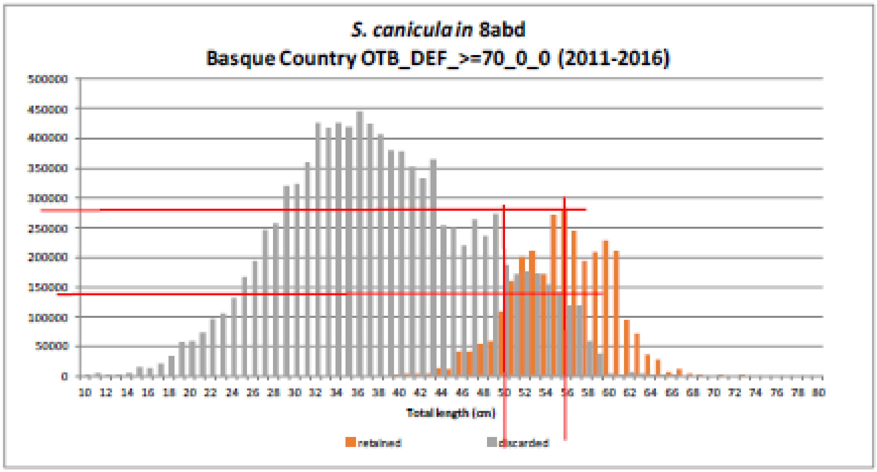
Furthermore, in section 2.1, *Lc* is applied as a knife-edge selectivity of the fishery, which is not consistent with the definition above, where individuals fully recruited are those longer or equal to the overall mode. Applying *Lc* as a knife-edge selectivity size generated a length-frequency distribution of the catch where the highest frequency occurs at *Lc*. Therefore, the simulated length distribution of the catch from the unexploited population generated by the LMM was created as follows:

1. A LMM was used to simulate a North Sea population based on Ivory *et al.*, (2005) and a Bay of Biscay/Iberia population based on Rodríguez-Cabello *et al.*, (2018 WD01),
2. To calculate indicators for exploited populations, length distributions were truncated at the length of the smallest length-class, referred to as $L_i$ (initial length), in the fishery catch (e.g. 40 cm for landings only and 15 cm for landings and discards for the Basque Country fleet, Figure 4.2),
3. A linear selectivity between $L_i$ and the overall mode was assumed (green line in Figure 4.2 bottom),
4. The simulated catch of a fishery fishing the unexploited population (in the real world this corresponds to the onset of a fishery on a virgin stock) was created by multiplying the length distribution from (1) by a sequence of selectivity coefficients from 0 at $L_i$-1 to 1 at the overall mode.

To apply an *M*/*k* ratio representative of exploited age classes, *M* was taken as the mean natural mortality over ages where mean length-at-age was >= *Lc.* The correction of *M* at age 1 (section 4.2.2) was therefore not applied.

**Table 4.3. Overall mode, *Lc* and length of smallest individuals (*Li*) in length distributions of *S. canicula* from different fleets and areas.**

| Overall mode (cm) | Lc (cm) | Li (cm) | Type of catch | Fleet | Source |
|---|---|---|---|---|---|
| 55 | 50 | 44 | L | Basque country 8abd | ICES, 2017a |
| 36 | 26 | 15 | L+D | Basque country 8abd | ICES, 2017a |
| 50 | 45 | 40 | L | Portuguese landings | ICES, 2017a |
| 56 | 52 | 40 | L+D | UK otter trawl North Sea | ICES, 2017b (fig. 5.22) |
| 57 | 53 | 45 | L+D | FR otter trawl 47d | ICES 2017b (fig. 5.23) |



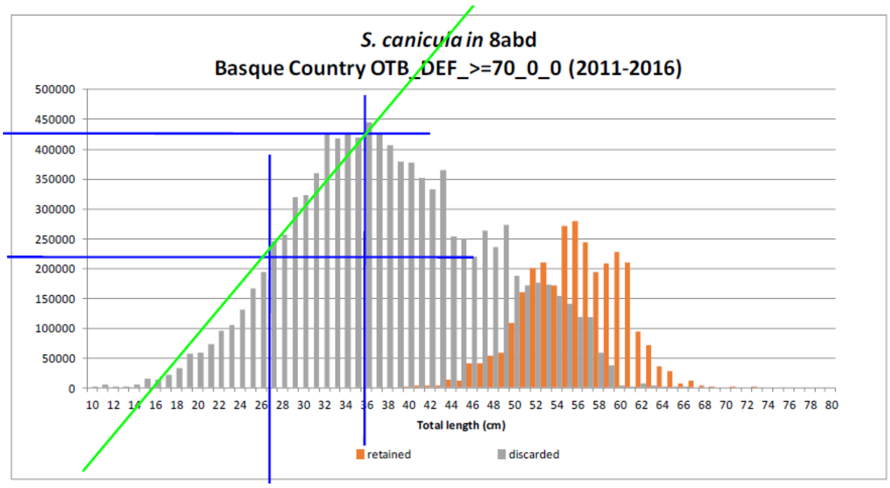




**Figure 4.2. Length distribution of *S. canicula* retained (orange) and discarded (grey) in catch of the Basque country trawlers from 2011 to 2016 in 8abd (redrawn from ICES, 2017a) Top panel: (red lines) visual estimates of the overall mode and *Lc* for the landed fraction. Bottom panel (blue lines) overall mode and *Lc*, (green line) assumed linear selectivity.**

## 4.4 A preliminary protocol for defining suitable LBIs for elasmobranch stocks

The Leslie matrix models have been further refined here to include a sustainable fishing mortality, so that the resulting LBI can inform on expected values that are suitable to assess the status of *S. canicula*.

### 4.4.1 Parameters and further refinement

Natural mortality was fixed at $M_{(A1)} = 0.7$, giving a mean natural morality rate of $M = 0.28$ across all ages. Length at 50% maturity was taken as that reported by Ivory *et al.* (2005), $L_{mat} = 57$ cm, and the slope of the maturity function $k_{mat}$ increased from 0.5 to 1 to better match that reported in Ivory *et al.* (2005). A larger range of fecundities were trialled to balance the fishing mortality entering the model ($Fec = 2–30$). Aside from the length at first capture ($L_c$; described below) all other parameters are as reported in Table 4.2. The LBI $L_{95}/L_\infty$ was additionally included in the output of the model, having been missing from previous LMM code.

### 4.4.2 Length at first capture $L_c$

In the initial applications of the LMM, it was not possible to accurately calculate $L_c$ from the simulated data because the mode of the length-frequency distribution would always be the smallest size class; hence the length at first capture was set to 15 cm following discussions from WGEF 2017. WKSHARK4 viewed this value too low and an $L_C$ value of 25 cm was determined to be more realistic to the length at which *S. canicula* recruit into fisheries. The following models use $L_C = 25$ cm in the calculation of LBI for consistency with the application of knife-edged fishery selection.

### 4.4.3 Fishing mortality

In the absence of a defined $F_{MSY}$ for *S. canicula*, the MSY proxy $F=M$ was chosen as a sustainable level of fishing mortality in the Leslie matrices. Two levels of fishing mortality were chosen: $F = 0.1$ as the approximate level of natural mortality sustained by adult fish (Figure 4.1), and $F = 0.05$ as a precautionary value. Within the matrices, $F$ was applied only to age groups larger than $L_c$ after applying the von Bertalanffy equation ($L_{(A2)} = 26.9$ cm).

### 4.4.4 First row of the Leslie matrix

Leslie matrices for pristine populations were constructed using the *leslie.row1* function in R package demogR (Jones, 2007), which assumes birth-flow populations. This was updated here to assume birth-pulse fertility, more consistent with fish life history. The fertilities ($F_a$) in the first row of the Leslie matrix were calculated:

$$F_a = \frac{P_a m_a}{2}$$

where $P_a$ is survivorship at age and $m_a$ fecundity at age (ICES, 2017b; Caswell, 1989).

## 4.5 Results

### 4.5.1 LBIs applied to a simulated whole population from the LMM.

The Leslie matrix produced a length-frequency distribution considered an appropriate simulation of a *S. canicula* population, with a high number of small (young) individuals and decreasing numbers of larger older individuals (Figure 4.3).

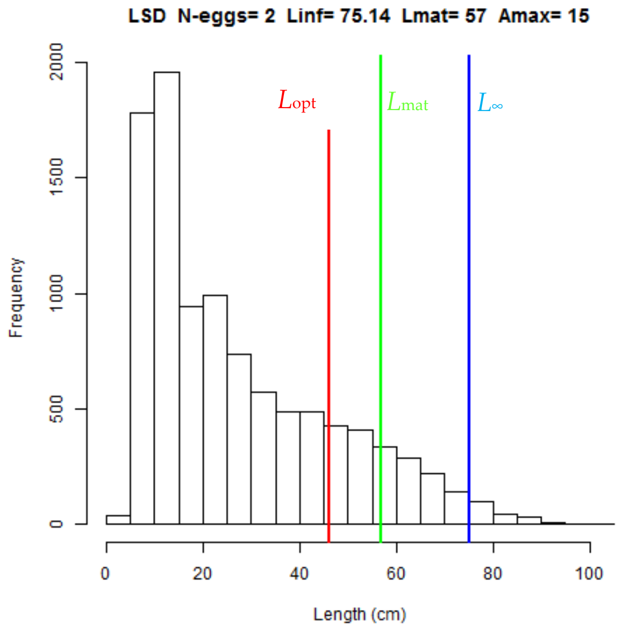



**Figure 4.3. Length-frequency distribution of a simulated *S. canicula* population with simulated parameters from Ivory *et al.* (2005, Table 4.2). Vertical lines correspond to $L_{opt}$ (red), $L_{mat}$ (green) and $L_\infty$ (blue).**

Owing to the stochasticity of individual sizes simulated by a Gaussian distribution from the length of individuals at each age class, a fraction of the population had lengths larger than $L_\infty$. Note that with the set of parameters used in Figure 3, $L_{opt}$ is less than $L_{mat}$.

Applying a varying age mortality and different values for fecundity changed the absolute values produced from the Leslie matrix ($\lambda$ and $\varrho$), but had little impact on the overall status of the LBI (*i.e.* most still failed) (Table 4.3). Increasing the fecundity decreased the status of all of the LBI. This is somewhat counterintuitive but may be an effect of high mortality rates imposed on young age classes using the Gislason equation and/or skewing the length-frequency distribution towards smaller size classes.

Using the life history parameters from Ivory *et al.* (2005), $\lambda$ values close to 1 were achieved at fecundity 4, where mortality at age 1 ($M_{(A1)}$) was 0.7 ($M$ = 0.28) and at fecundity of about 5 when $M_{(A1)}$ was 0.9 ($M$ = 0.30). Interestingly, the mean mortality $M$ of 0.28 across the varying mortality ages was the same as those predicted from Rodríguez-Cabello *et al.*, (2018 WD). This may corroborate some of the life history parameters used here to generate a *S. canicula* population of $\lambda$ = 1 (*i.e.* in equilibrium).

Using an $M_{(A1)}$ of 0.7 ($M$ = 0.28), the length of 50% maturity was also tested. The lower length at maturity (45 cm) generated Leslie matrix *S. canicula* populations that were generally increasing in size ($\lambda$>1), whereas the higher length of maturity (65 cm) generated Leslie matrices where populations were moving towards extinction ($\lambda$<1). This may suggest that for the combination of life history parameters used here, the value for $L_{mat}$ (57 cm) is likely appropriate. While the lower $L_{mat}$ across all fecundities had almost no effect on the LBI statuses, there were some improvements on the LBIs for the larger $L_{mat}$ (Table 4.3). $P_{mega}$ was greater than 0.3 for fecundities of 2–6 and for a $L_{mat}$ of 65 cm, and in one instance ($L_{mat}$ = 65 cm, *Fec* = 2) $L_{mean}/L_{opt}$ was within 10% of 1 which indicated a “good” status. However, these optimal yield indicator values are based on current knife-edge selectivity and would need changing to further determine the appropriateness of the expected values.

Using an intermediate traffic light system of +/- 10% had little impact on the LBI observed. There were several parameter combinations that lead to $L_{mean}/L_{opt}$ that were with within 10% of the acceptable range (0.9–1.1). It may be beneficial moving forward to explore acceptable LBI ranges to allow for stochasticity between years. Providing there is long enough time series data (~5 years, which is now available for a number of elasmobranch stocks), it is advised that an individual year LBI assessment is considered in conjunction with annual LBI trends and general trends in other survey indices. It may also be beneficial to indicate how far the reference point is from the desired indicator ratio. It may be useful to discuss these more during WGEF 2018, when this protocol is further refined.

**Table 4.3: Parameter combinations and output from the Leslie matrix models. $M_{(A1)}$ is the mortality at age one using the Gislason *et al.*, (2010) age varying mortality equation (see section 4.2.2), $M$ is the average mortality across all ages, $L_{mat}$ is the length at 50% maturity, *Fec* is the number of individuals from each female expected to reach age 1 per year (fecundity), $L_{\infty}$ and $k$ are von Bertalanffy growth parameters, $L_C$ is the length at first capture (assuming knife edge selection), $A_{mat}$ is the von Bertalanffy calculated age of $L_{mat}$, $\lambda$ is the growth parameter of the population (1 being a stable population, <1 being decreasing population and >1 expanding population), $\varrho$ is the damping ratio of the matrix (a parameter of the matrix itself which is not considered further here), and $P_{mat}$ the proportion of individuals in the population greater than the $L_{mat}$. For descriptions of remaining indicators see Table 4.1. $\lambda$=1 indicates that the corresponding Leslie matrix generates a stable population, for $\lambda$>1 the population is increasing over time and for $\lambda$<1 it is decreasing.**

| $M_{A1}$ | $M$ (mean) | $L_{mat}$(cm) | Fec | $k$ | $L_{\infty}$ | $M/k$ | $A_{mat}$ | $\lambda$ | $\rho$ | $P_{mat}$ | $L_c/L_{mat}$ | $L_{25}/L_{mat}$ | $L_{max5}/L_{\infty}$ | $P_{mega}$ | $L_{mean}/L_{opt}$ | $L_{mean}/L_{F=M}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Original application of LBI from ICES (2017) | | | | | | | | | | | | | | | | |
| - | 0.22 | 54.2 | 2 | 0.15 | 75.14 | 1.47 | 8.52 | 1.14 | 0.37 | | 0.28 | 0.41 | 0.92 | 0.14 | 0.67 | 1.12 |
| | | | | | | | | Expected value | | | >1 | >1 | >0.8 | >0.3 | ~1 | ≥1 |
| | | | | | | | | Thresholds | | | 0.1 | 0.1 | 0.08 | 0.03 | 0.8-0.9 & 1.1-1.2 | 0.1 |
| Varying mortality and fecundity | | | | | | | | | | | | | | | | |
| 0.7 | 0.28 | 57 | 2 | 0.15 | 75.14 | 1.9 | 9.47 | 0.94 | 0.23 | 0.16 | 0.26 | 0.4 | 1.05 | 0.31 | 0.82 | 1.38 |
| 0.7 | 0.28 | 57 | 4 | 0.15 | 75.14 | 1.9 | 9.47 | 1 | 0.26 | 0.12 | 0.26 | 0.38 | 0.99 | 0.23 | 0.75 | 1.25 |
| 0.7 | 0.28 | 57 | 6 | 0.15 | 75.14 | 1.9 | 9.47 | 1.05 | 0.28 | 0.08 | 0.26 | 0.37 | 0.95 | 0.18 | 0.71 | 1.18 |
| 0.7 | 0.28 | 57 | 8 | 0.15 | 75.14 | 1.9 | 9.47 | 1.08 | 0.29 | 0.07 | 0.26 | 0.36 | 0.93 | 0.16 | 0.69 | 1.15 |
| 0.7 | 0.28 | 57 | 10 | 0.15 | 75.14 | 1.9 | 9.47 | 1.11 | 0.31 | 0.06 | 0.26 | 0.36 | 0.89 | 0.14 | 0.66 | 1.11 |
| | | | | | | | | | | | | | | | | |
| 0.9 | 0.3 | 57 | 2 | 0.15 | 75.14 | 1.98 | 9.47 | 0.91 | 0.22 | 0.19 | 0.26 | 0.41 | 1.07 | 0.35 | 0.87 | 1.46 |
| 0.9 | 0.3 | 57 | 4 | 0.15 | 75.14 | 1.98 | 9.47 | 0.97 | 0.24 | 0.13 | 0.26 | 0.39 | 1.02 | 0.26 | 0.79 | 1.32 |
| 0.9 | 0.3 | 57 | 6 | 0.15 | 75.14 | 1.98 | 9.47 | 1.02 | 0.26 | 0.1 | 0.26 | 0.37 | 0.99 | 0.23 | 0.75 | 1.25 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9 | 0.3 | 57 | 8 | 0.15 | 75.14 | 1.98 | 9.47 | 1.05 | 0.28 | 0.09 | 0.26 | 0.37 | 0.97 | 0.19 | 0.72 | 1.21 |
| 0.9 | 0.3 | 57 | 10 | 0.15 | 75.14 | 1.98 | 9.47 | 1.07 | 0.29 | 0.07 | 0.26 | 0.36 | 0.94 | 0.18 | 0.7 | 1.17 |
| Varying L50 and fecundity with M(A1) = 0.7 | | | | | | | | | | | | | | | | |
| 0.7 | 0.28 | 45 | 2 | 0.15 | 75.14 | 1.9 | 6.09 | 1.01 | 0.34 | 0.15 | 0.33 | 0.48 | 0.98 | 0.22 | 0.74 | 1.23 |
| 0.7 | 0.28 | 45 | 4 | 0.15 | 75.14 | 1.9 | 6.09 | 1.11 | 0.4 | 0.09 | 0.33 | 0.45 | 0.91 | 0.14 | 0.67 | 1.12 |
| 0.7 | 0.28 | 45 | 6 | 0.15 | 75.14 | 1.9 | 6.09 | 1.17 | 0.44 | 0.06 | 0.33 | 0.44 | 0.88 | 0.11 | 0.63 | 1.06 |
| 0.7 | 0.28 | 45 | 8 | 0.15 | 75.14 | 1.9 | 6.09 | 1.22 | 0.48 | 0.05 | 0.33 | 0.44 | 0.82 | 0.09 | 0.61 | 1.03 |
| 0.7 | 0.28 | 45 | 10 | 0.15 | 75.14 | 1.9 | 6.09 | 1.27 | 2.18 | 0.04 | 0.33 | 0.43 | 0.8 | 0.08 | 0.6 | 1 |
| | | | | | | | | | | | | | | | | |
| 0.7 | 0.28 | 65 | 2 | 0.15 | 75.14 | 1.9 | 13.35 | 0.85 | 0.16 | 0.11 | 0.23 | 0.41 | 1.09 | 0.44 | 0.94 | 1.58 |
| 0.7 | 0.28 | 65 | 4 | 0.15 | 75.14 | 1.9 | 13.35 | 0.91 | 0.17 | 0.06 | 0.23 | 0.37 | 1.08 | 0.35 | 0.87 | 1.45 |
| 0.7 | 0.28 | 65 | 6 | 0.15 | 75.14 | 1.9 | 13.35 | 0.94 | 0.18 | 0.05 | 0.23 | 0.35 | 1.05 | 0.31 | 0.82 | 1.37 |
| 0.7 | 0.28 | 65 | 8 | 0.15 | 75.14 | 1.9 | 13.35 | 0.96 | 0.19 | 0.04 | 0.23 | 0.34 | 1.01 | 0.28 | 0.79 | 1.32 |
| 0.7 | 0.28 | 65 | 10 | 0.15 | 75.14 | 1.9 | 13.35 | 0.98 | 0.19 | 0.03 | 0.23 | 0.34 | 1 | 0.25 | 0.77 | 1.29 |

### 4.5.2 LBIs from simulated length-frequency distribution of the commercial catch

Populations in the North Sea ecoregion and in the Bay of Biscay and Iberia Ecoregion were simulated using life history parameters from Ivory *et al.* (2005) and Rodríguez-Cabello *et al.* (2018 WD) respectively. The simulated fecundity producing the most stable populations were used for results (6 and 8 offspring per year, respectively). The length distribution of the catch of the fishery fishing for an unexploited population was simulated as described in section 2.3 (Table 4.4). In this setting, $P_{mega}$ is high for all fisheries, $L_{25\%}$ and $L_C$ are generally smaller than $L_{mat}$, and $L_{mean}$ is close to $L_{opt}$ and $L_{F=M}$. These results suggest that there are some inconsistencies in the interpretation of indicators in several cases. It could be inferred from instances where $P_{mega}$ was high but $L_{mean}$ was low, that the reference points for $P_{mega}$ and LBIs $L_{mean}/L_{opt}$ and $L_{mean}/L_{F=M}$ should be adapted for elasmobranchs. Alternatively, the life history parameters used could be incorrect. However, simulating a stable unexploited population and applying the selectivity observed in an existing fishery resulted in indicator values closer to or above reference points for unexploited populations. For a given population, the natural mortality ($M$) used to calculate reference points is not the same for all fisheries considered because it is the mean of exploited ages (i.e. it is highly influenced by the size-varying mortality) and subsequently, larger $M$ are calculated for fisheries where smaller fish are exploited. In this instance, all $M/K$ values would be low. Overall the simulations for a few fisheries suggest that the results are sensitive to the life history parameters. Fisheries that are more selective towards larger individuals would as a result produce LBI ratios indicating more sustainable fisheries.

**Table 4.4: Parameter combinations and output from the LMM applying *Lc* and selectivity estimated from commercial catch. Life history parameters from Ivory et al. (2005) for the North Sea Ecoregion and from Rodríguez-Cabello *et al.* (2018 WD) for the Bay of Biscay and Iberia. Results are shown for the simulated fecundity which gave the more stable population λ≈1 (6 offspring per adult per year for the Bay of Biscay and Iberia, 8 for the North Sea)**

| Fishery | $K$ | $L_\infty$ | $M$ | $MK$ | $A_{50}$ | $L_{25}/L_{mat}$ | $L_{max5}/L_\infty$ | $P_{mega}$ | $L_C$ | $L_C/L_{mat}$ | $L_{mean}/L_{opt}$ | $L_{mean}/L_{F=M}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Basque country 8abd -L | 0.21 | 69.3 | 0.21 | 1.00 | 7.26 | 0.96 | 1.21 | 0.74 | 55 | 1.01 | 1.14 | 0.99 |
| Basque country 8abd –L+D | 0.21 | 69.3 | 0.26 | 1.22 | 7.26 | 0.49 | 1.09 | 0.23 | 36 | 0.66 | 0.77 | 0.83 |
| Portuguese landings | 0.21 | 69.3 | 0.22 | 1.03 | 7.26 | 0.93 | 1.22 | 0.69 | 50 | 0.92 | 1.13 | 1.03 |
| UK otter trawl North Sea L+D | 0.15 | 75.14 | 0.17 | 1.16 | 9.47 | 0.91 | 1.13 | 0.65 | 52 | 0.91 | 1.10 | 1.01 |
| FR otter trawl 47d L+D | 0.15 | 75.14 | 0.17 | 1.12 | 9.47 | 0.96 | 1.13 | 0.75 | 53 | 0.93 | 1.13 | 1.03 |

### 4.5.3 Preliminary protocol for defining suitable LBIs for elasmobranch stocks

When including fishing mortality in the Leslie matrices, larger values of fecundity were required to obtain $\lambda$ values closer to 1 (Table 4.5). When considering a fishing mortality of $F = 0.1$, the highest fecundity tested ($Fec = 30$) resulted in a slightly decreasing population ($\lambda = 0.98$). When considering a fishing mortality of $F = 0.05$, a $\lambda$ value of 1 was achieved assuming a fecundity of 25; much higher than the fecundity value of 4 in the equivalent pristine matrix (although this may be due in part to the refinements listed above).

Only considering those matrices that are in equilibrium (i.e. the population remains stable given sustainable fishing; $0.95 \le \lambda \le 1.05$), the indicator ratios relating to mega-spawners and the conservation of immatures consistently fail to meet the ICES expected values. This preliminary analysis suggests that when *S. canicula* is fished sustainably, expected values of around 0.2 for mega-spawners and 0.5 for immatures could be suitable.

**Table 4.5: Parameter combinations and output from the Leslie matrix models. $M_{(A1)}$ is the mortality at age one using the Gislason *et al.*, 2010 age varying mortality equation, $M$ is the average mortality across all ages, $L_{mat}$ is the length at 50% maturity, *Fec* is the number of individuals from each female expected to reach age 1 per year (fecundity), $L_\infty$ and $k$ are von Bertalanffy growth parameters, $L_C$ is the length at first capture (assuming knife edge selection), $A_{mat}$ is the von Bertalanffy calculated age of $L_{mat}$, λ is the growth parameter of the population (1 being a stable population, <1 being decreasing population and >1 expanding population), ϱ is the damping ratio of the matrix (a parameter of the matrix itself which is not considered further here), and $P_{mat}$ the proportion of individuals in the population greater than the $L_{mat}$. For descriptions of remaining indicators see Table 4.1. λ=1 indicates that the corresponding Leslie matrix generates a stable population, for λ>1 the population is increasing over time and for λ<1 it is decreasing.**

| Fec | k | $L_\infty$ | M/K | $Age_{50}$ | λ | ρ | $L_{95}/L_{inf}$ | $L_{max5}/L_\infty$ | $P_{mega}$ | $L_{25}/L_{mat}$ | $L_C/L_{mat}$ | $L_{mean}/L_{opt}$ | $L_{mean}/L_{F=M}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Expected value | | >0.8 | >0.8 | >0.3 | >1 | >1 | ~1 | ≥1 |
| | | | | | Thresholds | | 0.08 | 0.08 | 0.03 | 0.10 | 0.10 | 0.8-0.9 & 1.1-1.2 | 0.10 |
| Fishing mortality $F = 0.1$ | | | | | | | | | | | | | |
| 2 | 0.15 | 75.14 | 1.90 | 9.47 | 0.77 | 0.17 | 1.04 | 1.13 | 0.48 | 0.65 | 0.44 | 1.10 | 1.43 |
| 4 | 0.15 | 75.14 | 1.90 | 9.47 | 0.82 | 0.18 | 1.00 | 1.10 | 0.39 | 0.59 | 0.44 | 1.03 | 1.33 |
| 6 | 0.15 | 75.14 | 1.90 | 9.47 | 0.85 | 0.19 | 0.98 | 1.07 | 0.36 | 0.59 | 0.44 | 1.00 | 1.30 |
| 8 | 0.15 | 75.14 | 1.90 | 9.47 | 0.87 | 0.20 | 0.98 | 1.07 | 0.34 | 0.57 | 0.44 | 0.98 | 1.28 |
| 10 | 0.15 | 75.14 | 1.90 | 9.47 | 0.88 | 0.20 | 0.95 | 1.05 | 0.30 | 0.56 | 0.44 | 0.96 | 1.24 |
| 15 | 0.15 | 75.14 | 1.90 | 9.47 | 0.92 | 0.21 | 0.94 | 1.04 | 0.27 | 0.55 | 0.44 | 0.93 | 1.21 |
| 20 | 0.15 | 75.14 | 1.90 | 9.47 | 0.94 | 0.22 | 0.93 | 1.03 | 0.25 | 0.54 | 0.44 | 0.91 | 1.18 |
| 25 | 0.15 | 75.14 | 1.90 | 9.47 | 0.96 | 0.22 | 0.91 | 1.00 | 0.22 | 0.53 | 0.44 | 0.89 | 1.16 |
| 30 | 0.15 | 75.14 | 1.90 | 9.47 | 0.98 | 0.23 | 0.89 | 1.00 | 0.21 | 0.53 | 0.44 | 0.88 | 1.15 |
| Fishing mortality $F = 0.05$ | | | | | | | | | | | | | |
| 2 | 0.15 | 75.14 | 1.90 | 9.47 | 0.81 | 0.17 | 1.05 | 1.14 | 0.47 | 0.65 | 0.44 | 1.10 | 1.43 |
| 4 | 0.15 | 75.14 | 1.90 | 9.47 | 0.86 | 0.18 | 1.02 | 1.11 | 0.41 | 0.61 | 0.44 | 1.04 | 1.35 |
| 6 | 0.15 | 75.14 | 1.90 | 9.47 | 0.89 | 0.19 | 0.99 | 1.09 | 0.36 | 0.58 | 0.44 | 1.01 | 1.31 |
| 8 | 0.15 | 75.14 | 1.90 | 9.47 | 0.91 | 0.20 | 0.97 | 1.08 | 0.33 | 0.57 | 0.44 | 0.98 | 1.27 |
| 10 | 0.15 | 75.14 | 1.90 | 9.47 | 0.93 | 0.20 | 0.96 | 1.06 | 0.31 | 0.56 | 0.44 | 0.97 | 1.25 |
| 15 | 0.15 | 75.14 | 1.90 | 9.47 | 0.96 | 0.21 | 0.94 | 1.05 | 0.27 | 0.55 | 0.44 | 0.93 | 1.21 |
| 20 | 0.15 | 75.14 | 1.90 | 9.47 | 0.98 | 0.22 | 0.91 | 1.01 | 0.23 | 0.54 | 0.44 | 0.90 | 1.17 |
| 25 | 0.15 | 75.14 | 1.90 | 9.47 | 1.00 | 0.22 | 0.91 | 1.01 | 0.23 | 0.53 | 0.44 | 0.89 | 1.16 |
| 30 | 0.15 | 75.14 | 1.90 | 9.47 | 1.02 | 0.23 | 0.90 | 1.01 | 0.21 | 0.53 | 0.44 | 0.89 | 1.15 |

## 4.6 Discussion

### 4.6.1 Refining the Leslie matrix for a pristine stock

Most LBI values from the "pristine" simulated population were below the Reference Points (RPs). LBIs were designed to assess whether the length-frequency distribution of commercial catch correspond to sustainable exploitation or not. Applying LBIs to the whole population is may be used to e.g. analyse the change in length composition between a (simulated) pristine and an exploited population, but the RPs and their expected values (Table 4.1) are not meaningful to the length-frequency distribution of whole populations.

The low values of LBIs for the whole population also imply that RPs applicable to commercial catch are not applicable to e.g. survey data, which normally, without being representative of the whole population, include a higher proportion of small fish than commercial catch.

It is currently unclear how the performance of the Leslie matrix using life history parameters from other *S. canicula* stocks, or for other species with different reproductive modes (*i.e.* viviparity), may affect the performance of the Leslie matrix, and the associated LBI values. Moving forward it would be beneficial to apply similar Leslie matrix models to a ray species (e.g. *Raja clavata)* and a viviparous shark species (e.g. *Mustelus asterias*).

### 4.6.2 Simulating the length-frequency distribution of catch from a 'pristine' stock.

Applying LBI to a simulated pristine population gives an indication of the suitability of expected values for elasmobranch stocks.

Values of LBI resulting from inclusion of a sustainable amount of fishing mortality in the population model give an indication of the threshold values that could be used to assess fished populations of elasmobranchs.

The main difference between elasmobranchs and (most) teleosts is the numbers and sizes of offspring between the different reproductive strategies and subsequent recruitment processes. Given that elasmobranchs produce larger offspring with lower initial mortality, reference points may be different between these two groups. Lower expected values of indicator ratios relating to the conservation of immatures could be considered. The preliminary analysis presented here suggests that values of 0.5 could be considered for *S. canicula*.

Simulations showed that the proportion of large adults, corresponding to the indicator ratio $P_{mega}$ is small in a complete population, because adults are less abundant that juveniles. This is true in any fish population. In elasmobranch populations, the proportion of adult fish in the whole population might be higher than in teleost populations however because they produce fewer (but larger) offspring. As a consequence, $P_{mega}$ values calculated on a pristine elasmobranch population (Table 4.3) might be higher than for teleost populations.

To investigate the suitability of indicator values on the length-frequency distribution of catch data, the selectivity from current fisheries was applied to simulated pristine populations of *S. canicula*. Some indicators calculated in this setting were above reference points (e.g. $P_{mega}$), but some were below ($L_{25}$) and some were close to or slightly greater than the reference point ($L_{mean}/L_{opt}$ and $L_{mean}/L_{F=M}$). This suggests that reference points may need to be adjusted in accordance with the life history of elasmobranchs. For example, the low level of $L_{25}$, might reflect the larger sizes of maturation when compared to teleosts ($L_{mat}/L_{\infty}$ larger from elasmobranchs than for teleosts). Consequently, there is a need to simulate additional populations of more species, both in a pristine state and cumulating fishing (*F*) and natural mortality (*M*), to appraise suitable reference points for LBIs. These explorations are achievable with the simulation code provided to WKSHARK4 (ICES, 2017) and further developed.

#### 4.6.3 Protocol for defining suitable LBIs for elasmobranch stocks

The analysis presented here is a preliminary example of a protocol that could be followed to define appropriate expected values of indicator ratios when assessing elasmobranch stocks. The higher fecundity values that produced a stable population under application of a fishing mortality, can be considered as representing the density-dependent recruitment (i.e. a higher proportion of offspring survive when the density of the whole population is lower). However, there may be some circularity at simulating stable populations in order to assess LBIs because an excessive fishing mortality would generate a declining population.

Further work is also needed to apply the simulated fishing mortality together with a suitable selectivity as developed in section 3.2. Additionally, in the example protocol, most life history values were taken from a single study (Ivory *et al.* 2005),although there are other studies available from other ecoregions (*i.e.* Rodriguez-Cabello *et al.* 1998). The reliability of these values, and the life history parameters subsequently derived from them (e.g. $M/k$ and $A_{50}$) as well as the parameterisation of the Leslie matrix should be carefully evaluated. Where there is uncertainty about the life history parameters, it would be desirable to evaluate this within the protocol before using the outputs to inform management advice.

### 4.7 Overall conclusion

WHSHARK4 first applied knife-edge fishery selection to sample the population through the lens of a fishery. Additional simulations applied an increasing selectivity between smaller size and the mode of the length distributions observed in commercial fisheries. These approximations were performed using the overall mode of the catch, which assumed the size of 100% selectivity and that selectivity was linear between the smallest fish caught and the overall mode. Careful consideration should be given to an appropriate selectivity pattern to inform appropriate expected values of LBI. Finally, the protocol should be applied to a representative sample of elasmobranch species with differing life histories (i.e. oviparous skates, oviparous sharks, viviparous sharks) to define expected values appropriate for the overall elasmobranch group.

# 5 ToR d) Develop MSY proxy reference points for the stocks in need of new advice in 2018: skates in the Celtic Seas and Bay of Biscay and Iberian Coast ecoregions and test these proxies using stocks for which quantitative assessment and actual MSY reference points are available, including spurdog in the NE Atlantic

Length-based indicators were applied to five elasmobranch stocks (blonde ray, thornback ray, cuckoo ray, starry smooth-hound and lesser-spotted dogfish) in Walker *et al.* (2018 WD02). This work found the length at first catch $L_c$ to be extremely low and variable across the data examined. Accordingly, the indicator ratio $L_c/L_{mat}$ would consistently indicate 'poor' status with regards to the conservation of immatures, with values typically <0.5.

In this initial application, $L_c$ was calculated as the length at 50% of the first mode. After consultation with other applications of this metric, $L_c$ has now been defined as the length at 50% of the overall mode, although other calculation methods exist (e.g. ICES, 2018). Given that the indicator $L_{mean}$ and reference point $L_{F=M}$ depend on the calculation of $L_c$, this update will have implications for other LBI. The first part of this chapter reapplies LBI to the five elasmobranch stocks considered in Walker *et al.* (2018 WD02): blonde ray in divisions 7.a and 7.f-g, cuckoo ray in subareas 6, 7, and 8, thornback ray in Subarea 4 and Division 7.d, starry smooth-hound in the Northeast Atlantic and lesser-spotted dogfish in divisions 7.a and 7.f-g.

The second part of this chapter applies the same length-based indicators to survey data for spurdog in the Northeast Atlantic. As the only elasmobranch stock with a category 1 assessment, this allows status as predicted by the length-based indicators to be compared to that from a full quantitative assessment model.

## 5.1 Exploratory applications of LBI to elasmobranch stocks

### 5.1.1 Data

Length-frequency data for blonde, cuckoo and thornback rays and starry smooth-hound came from the UK England and Wales Observer at Sea program. For each trip, numbers-at-length were raised to the haul based on an estimated proportion of the total catch sampled, then to the trip based on the proportion of sampled hauls. Trip-raised estimates were summed for sampled vessels in each stratum (ICES division x gear class (otter trawls, beam trawls, netters and other gears) x quarter x year). They were then raised to the fleet using a ratio between the total number of trips and the number of trips sampled in the same stratum.

Length-frequency data for species attaining <90 cm $L_T$ (e.g. cuckoo ray and lesser-spotted dogfish) were analysed in 1 cm length intervals, whilst species reaching a maximum size of ca. 90–120 cm (e.g. thornback ray) were analysed in 2 cm length intervals, and fish attaining ≥120 cm (e.g. blonde ray and starry smooth-hound) were analysed in 5 cm length intervals.

Analysis for cuckoo ray, thornback ray and starry smooth-hound looked at length-frequencies for all gears and both otter trawls and netters separately, while analyses for blonde ray looked at data from otter trawls only. Due to a low sample size, blonde ray data for 2013–2016 were aggregated.

Data for lesser-spotted dogfish were downloaded from the Cefas Fishing Survey System (FSS) for the Irish Sea and Bristol Channel beam trawl survey in 7.a, f-g for the years 1993–2017 (ICES, 2009). This survey uses a commercially rigged 4 m steel beam trawl with chain mat, flip-up ropes, and a 40 mm codend liner that is typically towed for 30 minutes at four knots. Data were restricted to surveys in quarter 3. Length-frequency data for each year were collected in 1 cm length intervals.

The LBIs require estimates of length at 50% maturity ($L_{mat}$), von Bertalanffy asymptotic length ($L_{\infty}$) and weights-at-length, obtained here using the allometric relationship $w = aL^b$. We also report maximum length ($L_{max}$) as a check on the value of $L_{\infty}$. Life history parameters for the species considered here are given in Table 1.

**Table 5.1: Input parameters for LBI. $L_{max}$ (literature) from Heesen *et al.* (2015).**

| Stock | Species | $L_{\infty}$ | $L_{max}$ (literature) | $L_{max}$ (in data) | $L_{mat}$ | *a* | *b* |
|---|---|---|---|---|---|---|---|
| BLR7afg | Blonde ray | 118.4 | 120 | 104 | 83.4 | 0.0028 | 3.2495 |
| CUR678 | Cuckoo ray | 73.1 | 72 | 96 | 59.8 | 0.0036 | 3.1396 |
| THR47d | Thornback ray | 118 | 115 (130) | 102 | 73.7 | 0.0045 | 3.0686 |
| Mustelus | Starry smooth-hound | 123.5 | 124 | 162 | 81.9 | 0.0014 | 3.1000 |
| LSD7afg | Lesser-spotted dogfish | 75.14 | 80 | 74 | 57.0 | 0.0022 | 3.1194 |

### 5.1.2 LBI

*Conservation of large individuals*: Comparing indicators characterising the upper portion of the length frequency distribution to the RP $L_{\infty}$ provides an indication of the degree of truncation of the population size structure that may be caused by fishing. Indicators chosen to characterise the upper portion are the mean length of the largest 5% ($L_{max5\%}$) and the 95th percentile ($L_{95\%}$) of the length frequency distribution, both of which are considered more stable than the maximum length in the catch (Probst *et al.*, 2013; ICES, 2014b). The ratio of indicator to RP $L_{\infty}$ is expected to be above 0.8, based on a simulation study (Miethe and Dobby, 2015).

The proportion of mega-spawners (fish larger than the optimum length plus 10%) in the stock ($P_{mega}$) follows the principle of '*Let the mega-spawners live*' (Froese, 2004). Old, large fish play several important roles in the long-term survival of a population, as they may produce more eggs (increased fecundity), larger eggs or young (which may have better survival) and may have a greater spawning success. Consequently, $P_{mega}$ can be viewed as a simple proxy for the resilience of a stock. The principle is to implement a fishing strategy where no mega-spawners are caught. However, if the catch reflects the size structure of the population, values above 0.3 are considered healthy (Froese, 2004; ICES, 2015).

*Conservation of immatures*: LBI relating to small individuals follow the principle '*Let them spawn*' (Froese, 2004). Overfishing is theoretically impossible if every spawner produces at least one replacement spawner (Myers and Mertz, 1998); therefore, if the indicator length at first capture ($L_c$; estimated as the length at 50% of the first mode) is above the RP $L_{mat}$ biomass is likely to be above that which produces MSY (ICES, 2014b). A simulation study found the 25th percentile ($L_{25\%}$) of the length frequency distribution to be a suitable proxy when $L_c$ is difficult to estimate (Miethe and Dobby, 2015). Based on theory, the ratio of indicator to RP $L_{mat}$ is expected to be greater than 1.

*Optimal yield*: LBI relating to optimal yield follow the principle '*Let them grow*' (Froese, 2004) which states that all fish caught should be within 10% of the RP optimum harvest length ($L_{opt}$). $L_{opt}$ represents the length where cohort biomass and egg production are maximal in an unexploited state and where catch is maximal for a given fishing mortality (*F*), or *F* minimal for a given catch (Cope and Punt, 2009). $L_{opt}$ is calculated:

$$L_{opt} = \frac{3}{3 + {}^{M}/_{k}} L_{\infty}$$

Where *M* is natural mortality and *k* is the von Bertalanffy rate coefficient. The ratio M/k is thought to be more stable than either of the parameters separately, and is estimated at 1.5 for teleost fishes. The ICES approximation of $L_{opt}$ therefore simplifies to $2/3L_{\infty}$. If the central indicators mean length of individuals larger than $L_c$ ($L_{mean}$) or length class with maximal biomass ($L_{maxy}$) are close to the RP $L_{opt}$ then either the stock is lightly exploited or the fishery is operating with a target length that is sustainable and close to MSY (ICES, 2014b). Given the requirement that fish caught are within 10% of $L_{opt}$, the ratio of indicator to RP should be 0.9–1.1.

*MSY*: *F*=*M* is a proxy for MSY. The length at which *F*=*M* ($L_{F=M}$) is rearranged from Beverton and Holts equation for mean length in the catch as a function of the von Bertalanffy growth parameters, length at first capture and natural and fishing mortality:

$$L_{F=M} = (1 - a)L_c + aL_{\infty}$$

$$a = \frac{1}{2\left({}^{M}/_{k}\right) + 1}$$

Assuming M/k = 1.5, this simplifies to $0.75L_c + 0.25L_{\infty}$. This RP gives the mean length in the catch expected from fishing at F=M in the long term; hence a suitable indicator is $L_{mean}$. If $L_{mean}$ is less than $L_{F=M}$ then fishing mortality is likely to be larger than *M* and hence $F_{MSY}$ (ICES, 2014). The ratio of indicator to RP should therefore be greater than or equal to 1.

**Table 5.2: Summary of length-based indicators (LBI) with corresponding reference points and indicator ratios (* = simplified equations resulting from substituting M/k = 1.5; an assumption based on the life history of teleost fish).**

| Indicator | Calculation | Reference point | Indicator ratio | Expected value |
|---|---|---|---|---|
| $L_{max5\%}$ | Mean length of largest 5% | $L_{\infty}$ | $L_{max5\%}/L_{\infty}$ | > 0.8 |
| $L_{95\%}$ | 95th percentile | $L_{\infty}$ | $L_{95\%}/L_{\infty}$ | > 0.8 |
| $P_{mega}$ | Proportion of individuals above $L_{opt}$ + 10% | 0.3-0.4 | $P_{mega}$ | > 0.3 |
| $L_{25\%}$ | 25th percentile | $L_{mat}$ | $L_{25\%}/L_{mat}$ | > 1 |
| $L_c$ | Length at first catch (length at 50% of mode) | $L_{mat}$ | $L_c/L_{mat}$ | > 1 |
| $L_{mean}$ | Mean length of individuals > $L_c$ | $L_{opt}=2/3L_{\infty}$ * | $L_{mean}/L_{opt}$ | ≈ 1 |
| $L_{maxy}$ | Length class with maximum biomass in catch | $L_{opt}=2/3L_{\infty}$ * | $L_{maxy}/L_{opt}$ | ≈ 1 |
| $L_{mean}$ | Mean length of individuals > $L_c$ | $L_{F=M}=(0.75L_c+0.25L_{\infty})$ * | $L_{mean}/L_{F=M}$ | ≥ 1 |

### 5.1.3 Results

*Blonde ray in divisions 7.a and 7.f–g:* LBI suggested the stock to be in a "poor" state with regards to the conservation of both large and small individuals, with the MSY indicator ratio close to the expected value of 1.

The length-frequency distributions showed $L_\infty$ to fall far beyond the right tail of the distribution (Figure 5.1), so indicators calculated from the upper portion failed to meet expectations. $L_{mat}$ fell towards the right tail of the distribution, whereas indicators examining the smaller component of the catch usually fall to the left. $L_{maxy}$ indicated that fishing is targeted optimally, while $L_{mean}$ suggested targeting below the optimum length, which is consistent with the conservation LBI. The MSY condition was satisfied 2011–2012, despite the failure of the other LBIs to meet their expected values.

**Table 5.3: LBI for blonde ray in divisions 7.a and 7.f-g. Cells in green indicate those indicators that meet expectations (see Table 5.2) and theoretically represent 'good' status.**

**Blonde ray**

| Year | $L_{max5}$_$L_{inf}$ | $L_{95}$_$L_{inf}$ | $P_{mega}$ | $L_{25}$_$L_{mat}$ | $L_c$_$L_{mat}$ | $L_{mean}$_$L_{opt}$ | $L_{maxy}$_$L_{opt}$ | $L_{mean}$_LFeM |
|---|---|---|---|---|---|---|---|---|
| 2010 | 0.72 | 0.7 | 0.02 | 0.57 | 0.63 | 0.83 | 0.98 | 0.95 |
| 2011 | 0.72 | 0.7 | 0.02 | 0.51 | 0.45 | 0.74 | 1.05 | 1.01 |
| 2012 | 0.74 | 0.7 | 0.03 | 0.51 | 0.45 | 0.73 | 0.98 | 1 |
| 2013–2016 | 0.72 | 0.7 | 0.02 | 0.33 | 0.51 | 0.7 | 0.98 | 0.9 |

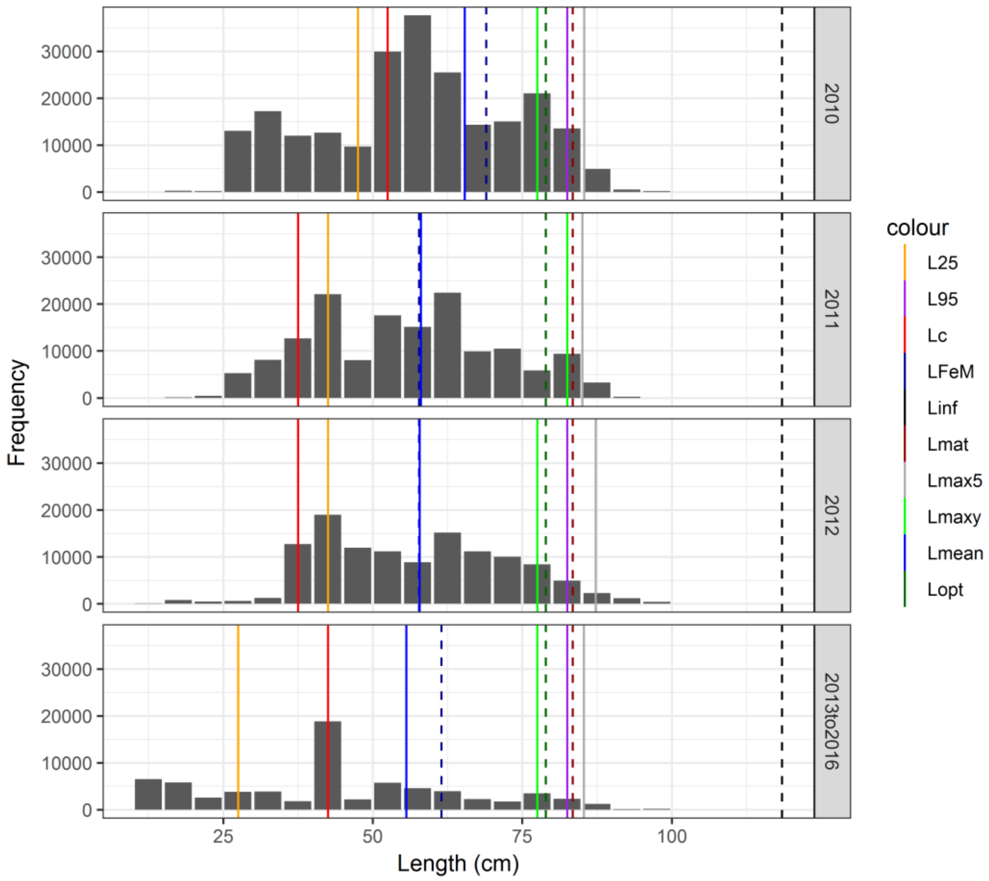



**Figure 5.1: Length frequency of blonde ray in divisions 7.a and 7.f-g with indicators (solid vertical line) and reference points (dashed vertical lines).**

*Cuckoo ray in subareas 6, 7 and 8:* LBIs for cuckoo ray were calculated for all gears combined. When analysed separately for both netters and otter trawls only, there was general agreement in relation to MSY expectations, but differences in status when looking at separate properties of the stock, with data from netters providing a more optimistic assessment in terms of conservation than data from otter trawls.

$L_\infty$ fell within the right tail of the length frequency distributions (not shown) with both indicator ratios characterising the upper portion meeting expected values for all gear combinations. The indicator ratios relating to optimal yield indicated that netters selected larger individuals than otter trawls. This was also apparent from $P_{mega}$ and $L_{25\%}$. The conditions that $P_{mega} > 0.3$ and $L_{25\%} > L_{mat}$ were met each year (bar one) when considering data from netters, but failed to hold for most of the otter trawl data. Data for all gears combined were dominated by the otter trawl data, causing $L_{25\%}$ to fall below $L_{mat}$. $P_{mega}$ conditions were met because netter $P_{mega}$ was close to 1, and otter $P_{mega}$ close to 0.3 in some years.

**Table 5.4: LBI for cuckoo ray in subareas 6, 7 and 8. Cells in green indicate those indicators that meet expectations (see Table 2) and theoretically represent 'good' status.**

**Cuckoo ray all gears**

| Year | $L_{max5}$_$L_{inf}$ | $L_{95}$_$L_{inf}$ | $P_{mega}$ | $L_{25}$_$L_{mat}$ | $L_c$_$L_{mat}$ | $L_{mean}$_$L_{opt}$ | $L_{maxy}$_$L_{opt}$ | $L_{mean}$_$L_{FeM}$ |
|---|---|---|---|---|---|---|---|---|
| 2010 | 0.93 | 0.91 | 0.32 | 0.58 | 0.39 | 1.01 | 1.04 | 1.37 |
| 2011 | 0.96 | 0.94 | 0.51 | 0.63 | 0.88 | 1.28 | 1.3 | 1.08 |
| 2012 | 0.96 | 0.94 | 0.34 | 0.56 | 0.34 | 0.95 | 1.39 | 1.38 |
| 2013 | 0.96 | 0.94 | 0.38 | 0.53 | 0.41 | 1 | 1.36 | 1.32 |
| 2014 | 0.92 | 0.9 | 0.16 | 0.48 | 0.43 | 0.83 | 1.34 | 1.08 |
| 2015 | 0.96 | 0.92 | 0.38 | 0.59 | 0.56 | 1.06 | 1.32 | 1.2 |
| 2016 | 0.95 | 0.94 | 0.37 | 0.68 | 0.69 | 1.12 | 1.41 | 1.1 |

**Cuckoo ray netters**

| Year | $L_{max5}$_$L_{inf}$ | $L_{95}$_$L_{inf}$ | $P_{mega}$ | $L_{25}$_$L_{mat}$ | $L_c$_$L_{mat}$ | $L_{mean}$_$L_{opt}$ | $L_{maxy}$_$L_{opt}$ | $L_{mean}$_$L_{FeM}$ |
|---|---|---|---|---|---|---|---|---|
| 2010 | 0.95 | 0.94 | 0.92 | 0.98 | 0.94 | 1.31 | 1.39 | 1.05 |
| 2011 | 0.97 | 0.95 | 0.95 | 1.05 | 1.06 | 1.37 | 1.3 | 1.01 |
| 2012 | 0.99 | 0.98 | 0.96 | 1.05 | 1.08 | 1.39 | 1.39 | 1.02 |
| 2013 | 0.98 | 0.96 | 0.97 | 1.06 | 1.08 | 1.38 | 1.36 | 1.01 |
| 2014 | 0.94 | 0.94 | 0.99 | 1.05 | 1.1 | 1.37 | 1.34 | 0.99 |
| 2015 | 0.98 | 0.96 | 0.97 | 1.05 | 1.05 | 1.35 | 1.32 | 1.01 |
| 2016 | 0.97 | 0.95 | 0.98 | 1.05 | 1.08 | 1.38 | 1.41 | 1.01 |

**Cuckoo ray otter trawls**

| Year | $L_{max5}$_$L_{inf}$ | $L_{95}$_$L_{inf}$ | $P_{mega}$ | $L_{25}$_$L_{mat}$ | $L_c$_$L_{mat}$ | $L_{mean}$_$L_{opt}$ | $L_{maxy}$_$L_{opt}$ | $L_{mean}$_$L_{FeM}$ |
|---|---|---|---|---|---|---|---|---|
| 2010 | 0.89 | 0.84 | 0.24 | 0.74 | 0.84 | 1.13 | 1.04 | 0.98 |
| 2011 | 0.94 | 0.92 | 0.49 | 0.74 | 0.73 | 1.15 | 1.3 | 1.1 |
| 2012 | 0.94 | 0.91 | 0.28 | 0.58 | 0.46 | 0.96 | 1.34 | 1.2 |
| 2013 | 0.91 | 0.88 | 0.15 | 0.58 | 0.49 | 0.9 | 1.32 | 1.09 |
| 2014 | 0.9 | 0.85 | 0.16 | 0.54 | 0.48 | 0.89 | 0.85 | 1.09 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2015 | 0.94 | 0.92 | 0.32 | 0.73 | 0.61 | 1.04 | 1.39 | 1.12 |
| 2016 | 0.9 | 0.84 | 0.1 | 0.69 | 0.69 | 0.94 | 0.87 | 0.93 |

*Thornback ray in subarea 4 and division 7.d:* LBI for thornback ray applied to data for all gears, netters only and otter trawls only showed general agreement in that all indicator ratios relating to the conservation of large and small individuals failed to meet the expected values. The conditions for optimal yield and MSY were met in some years only. Length frequency distributions (not shown) showed $L_\infty$ to lie far beyond the right tail, while time-series of indicators and reference points showed indicators describing the larger portion of the catch to be around the level of $L_{mat}$ with indicators describing smaller fish falling far below (Figure 5.2). Indicator ratios for optimal yield suggest fishing at or below optimal length, with $L_{maxy}$ higher than $L_{mean}$ and both indicators typically higher for netters than otter trawls. Although values were often below suggested indicator ratios, there were improving trends in some LBIs.

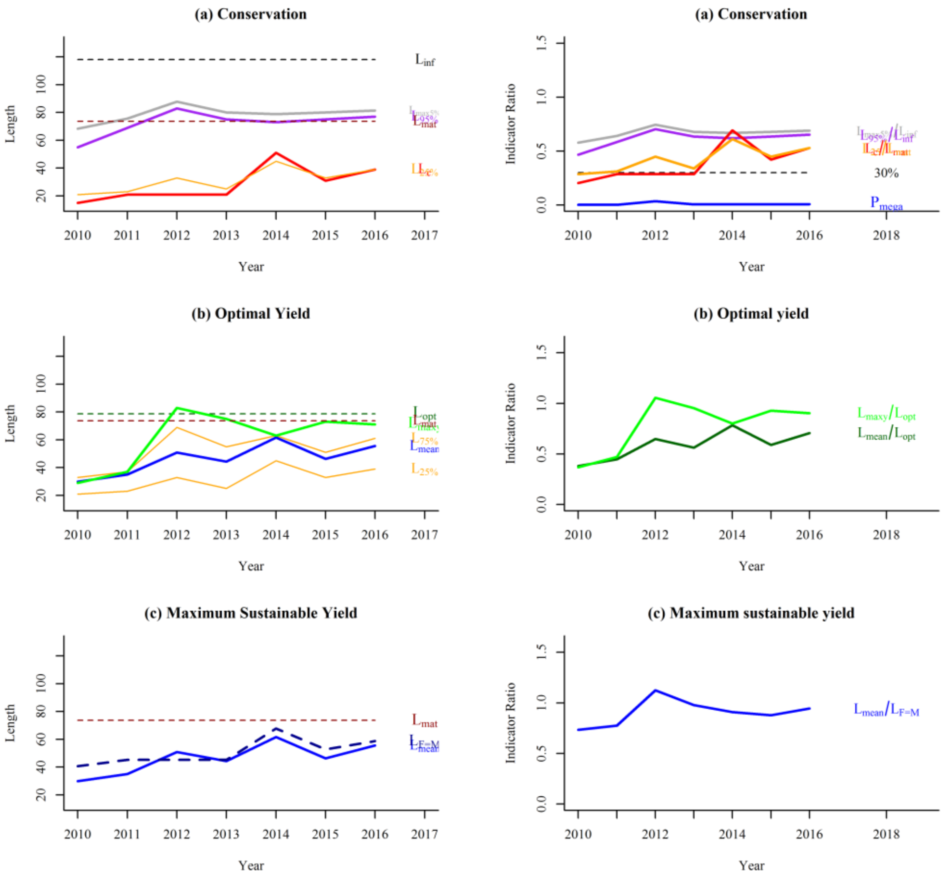



**Figure 5. 2: Indicators, reference points and indicator ratios for thornback ray caught by all gears in subarea 4 and division 7.d.**

*Starry smooth-hound in the Northeast Atlantic:* LBI for starry smooth-hound using data from netters and otter trawls showed differences in status for all components of the stock.

The optimal yield ratio $L_{mean}/L_{opt}$ indicated that netters generally fished at the optimal length, while otter trawlers fished below. This shift towards smaller individuals by otter trawls was confirmed by the values of indicator ratios for the conservation of large and small individuals, and a shift of length distributions to the left (Figures 5.3–5.4). The differing selectivities of the fleets cause netters to ostensibly meet conditions for 'conservation' and 'sustainability', where otter trawls failed to do so. LBIs applied to all gears were influenced by data from both otter trawls and netters, and therefore gave an intermediate perception of status.

**Table 5.5: LBI for starry smooth-hound in the Northeast Atlantic. Cells in green indicate those indicators that meet expectations (see Table 5.2) and theoretically represent 'good' status.**

**Starry smooth-hound all gears**

| Year | $L_{max5}$_$L_{inf}$ | $L_{95}$_$L_{inf}$ | $P_{mega}$ | $L_{25}$_$L_{mat}$ | $L_c$_$L_{mat}$ | $L_{mean}$_$L_{opt}$ | $L_{maxy}$_$L_{opt}$ | $L_{mean}$_LFeM |
|---|---|---|---|---|---|---|---|---|
| 2010 | 0.87 | 0.83 | 0.17 | 0.58 | 0.52 | 0.85 | 1.06 | 1.12 |
| 2011 | 0.88 | 0.79 | 0.11 | 0.52 | 0.52 | 0.76 | 1 | 1 |
| 2012 | 0.85 | 0.75 | 0.13 | 0.64 | 0.52 | 0.84 | 1 | 1.1 |
| 2013 | 0.85 | 0.79 | 0.11 | 0.64 | 0.52 | 0.8 | 1 | 1.05 |
| 2014 | 0.81 | 0.75 | 0.07 | 0.58 | 0.52 | 0.79 | 1.06 | 1.03 |
| 2015 | 0.85 | 0.79 | 0.1 | 0.7 | 0.7 | 0.9 | 0.88 | 1 |
| 2016 | 0.93 | 0.87 | 0.26 | 0.89 | 0.89 | 1.06 | 1 | 1.02 |

**Starry smooth-hound netters**

| Year | $L_{max5}$_$L_{inf}$ | $L_{95}$_$L_{inf}$ | $P_{mega}$ | $L_{25}$_$L_{mat}$ | $L_c$_$L_{mat}$ | $L_{mean}$_$L_{opt}$ | $L_{maxy}$_$L_{opt}$ | $L_{mean}$_LFeM |
|---|---|---|---|---|---|---|---|---|
| 2010 | 0.89 | 0.87 | 0.33 | 0.95 | 0.95 | 1.07 | 1 | 0.99 |
| 2011 | 0.94 | 0.91 | 0.3 | 0.89 | 0.82 | 1.04 | 1 | 1.05 |
| 2012 | 0.91 | 0.87 | 0.33 | 0.95 | 1.07 | 1.14 | 1.06 | 0.97 |
| 2013 | 0.9 | 0.87 | 0.34 | 0.89 | 1.01 | 1.13 | 1.06 | 1 |
| 2014 | 0.87 | 0.83 | 0.14 | 0.7 | 0.89 | 1.02 | 0.94 | 0.98 |
| 2015 | 0.93 | 0.91 | 0.36 | 0.82 | 0.76 | 1.05 | 1.18 | 1.11 |
| 2016 | 0.97 | 0.91 | 0.41 | 0.95 | 0.95 | 1.12 | 1.12 | 1.04 |

**Starry smooth-hound otter trawls**

| Year | $L_{max5}$_$L_{inf}$ | $L_{95}$_$L_{inf}$ | $P_{mega}$ | $L_{25}$_$L_{mat}$ | $L_c$_$L_{mat}$ | $L_{mean}$_$L_{opt}$ | $L_{maxy}$_$L_{opt}$ | $L_{mean}$_LFeM |
|---|---|---|---|---|---|---|---|---|
| 2010 | 0.86 | 0.79 | 0.13 | 0.52 | 0.52 | 0.79 | 1.06 | 1.03 |
| 2011 | 0.78 | 0.71 | 0.04 | 0.46 | 0.52 | 0.65 | 0.64 | 0.85 |
| 2012 | 0.84 | 0.75 | 0.12 | 0.64 | 0.52 | 0.83 | 1 | 1.09 |
| 2013 | 0.79 | 0.71 | 0.05 | 0.58 | 0.52 | 0.74 | 1 | 0.97 |
| 2014 | 0.76 | 0.71 | 0.04 | 0.52 | 0.52 | 0.74 | 1.06 | 0.97 |
| 2015 | 0.76 | 0.71 | 0.04 | 0.7 | 0.7 | 0.86 | 0.88 | 0.96 |
| 2016 | 0.82 | 0.75 | 0.09 | 0.76 | 0.89 | 1 | 1 | 0.96 |

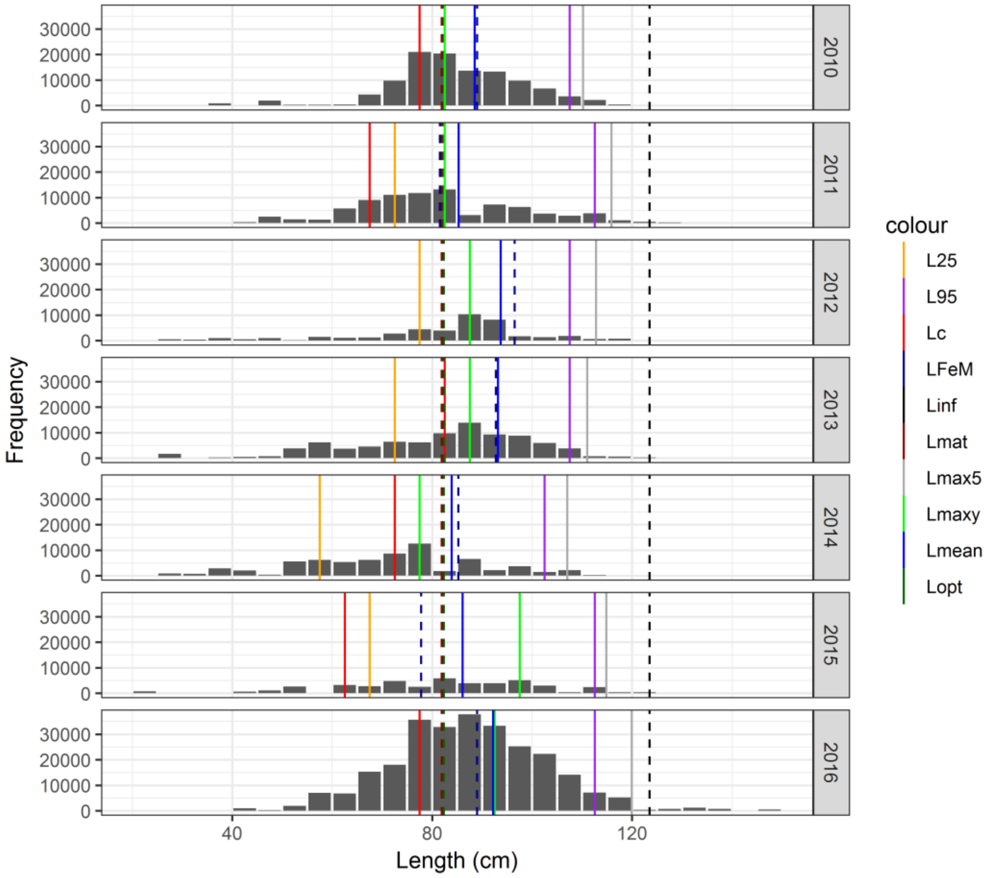



**Figure 5.3: Length frequency of starry smooth-hound in the Northeast Atlantic caught by netters, with indicators (solid vertical lines) and reference points (dashed vertical lines).**

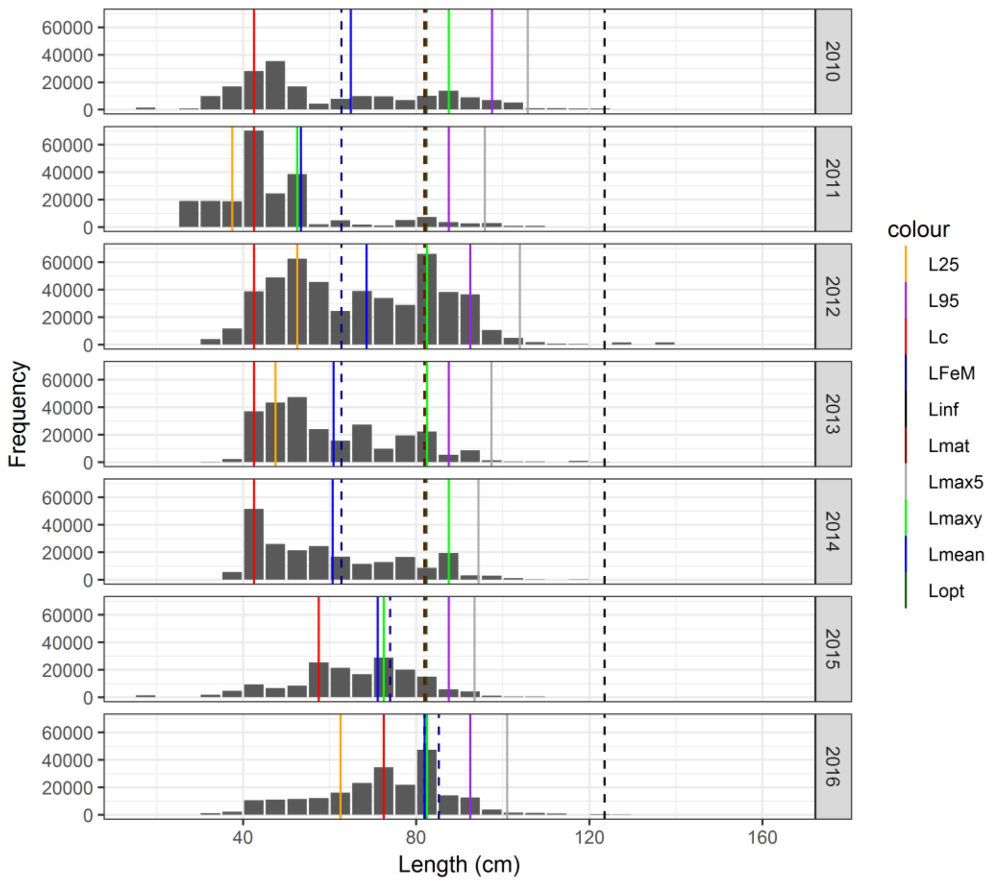



**Figure 5.4: Length frequency of starry smooth-hound in the Northeast Atlantic caught by otter trawl, with indicators (solid vertical lines) and reference points (dashed vertical lines).**

*Lesser-spotted dogfish in divisions 7.a and 7.f–g:* LBI show the stock to be in a "poor" state with regards to the conservation of small individuals but meeting MSY expectations. LBI for other components of the stock have conflicting views of status.

LBI charactering the upper portion of the length-frequency distributions in comparison to $L_\infty$ showed a healthy presence of larger individuals throughout the entire time-series. $P_{mega}$ and the optimal yield LBI showed a slight shift towards smaller individuals, with $P_{mega}$ falling below the expected value of 0.3 from 2006 onwards. Interestingly, as $P_{mega}$ fell to 'unhealthy' levels, the optimal yield LBI indicated a shift from targeting individuals that were too large to targeting at the optimal length. This conflict between $P_{mega}$ and the optimal yield LBI is unlikely to be related to gear selectivity, as data were from a standardised trawl survey. Time-series plots revealed all indicators (apart from the estimated $L_c$ in the mid-2000s) to be relatively stable over the 25-year time series (Figure 5). The reference point $L_{F=M}$ was variable in the mid-2000s; a consequence of calculating $L_{F=M}$ from $L_c$.

**Table 5.6: LBI for lesser-spotted dogfish in divisions 7.a and 7.f-g. Cells in green indicate those indicators that meet expectations (see Table 2) and theoretically represent ‘good’ status.**

**Lesser spotted dogfish**

| Year | $L_{max5}$_$L_{inf}$ | $L_{95}$_$L_{inf}$ | $P_{mega}$ | $L_{25}$_$L_{mat}$ | $L_c$_$L_{mat}$ | $L_{mean}$_$L_{opt}$ | $L_{maxy}$_$L_{opt}$ | $L_{mean}$_LFeM |
|---|---|---|---|---|---|---|---|---|
| 1993 | 0.88 | 0.86 | 0.45 | 0.85 | 0.85 | 1.12 | 1.17 | 1.03 |
| 1994 | 0.9 | 0.87 | 0.48 | 0.83 | 0.89 | 1.15 | 1.17 | 1.03 |
| 1995 | 0.91 | 0.89 | 0.43 | 0.78 | 0.71 | 1.07 | 1.21 | 1.1 |
| 1996 | 0.9 | 0.87 | 0.46 | 0.85 | 0.85 | 1.13 | 1.17 | 1.04 |
| 1997 | 0.9 | 0.87 | 0.51 | 0.87 | 0.87 | 1.14 | 1.23 | 1.04 |
| 1998 | 0.9 | 0.89 | 0.48 | 0.89 | 0.87 | 1.14 | 1.21 | 1.03 |
| 1999 | 0.89 | 0.85 | 0.37 | 0.85 | 0.85 | 1.1 | 1.13 | 1.01 |
| 2000 | 0.89 | 0.86 | 0.4 | 0.78 | 0.85 | 1.12 | 1.13 | 1.03 |
| 2001 | 0.89 | 0.87 | 0.44 | 0.78 | 0.87 | 1.14 | 1.17 | 1.03 |
| 2002 | 0.87 | 0.85 | 0.33 | 0.68 | 0.55 | 0.98 | 1.15 | 1.17 |
| 2003 | 0.88 | 0.86 | 0.46 | 0.78 | 0.96 | 1.17 | 1.17 | 0.99 |
| 2004 | 0.88 | 0.86 | 0.35 | 0.78 | 0.78 | 1.08 | 1.13 | 1.05 |
| 2005 | 0.87 | 0.86 | 0.36 | 0.69 | 0.57 | 1.01 | 1.19 | 1.17 |
| 2006 | 0.87 | 0.83 | 0.26 | 0.71 | 0.59 | 0.99 | 1.15 | 1.13 |
| 2007 | 0.85 | 0.83 | 0.24 | 0.69 | 0.61 | 0.97 | 1.15 | 1.1 |
| 2008 | 0.85 | 0.82 | 0.23 | 0.73 | 0.64 | 0.98 | 1.13 | 1.08 |
| 2009 | 0.87 | 0.83 | 0.2 | 0.71 | 0.64 | 0.97 | 1.09 | 1.06 |
| 2010 | 0.86 | 0.83 | 0.26 | 0.73 | 0.69 | 1.01 | 1.11 | 1.06 |
| 2011 | 0.86 | 0.83 | 0.26 | 0.75 | 0.66 | 1.01 | 1.07 | 1.08 |
| 2012 | 0.85 | 0.82 | 0.23 | 0.76 | 0.68 | 1 | 1.11 | 1.06 |
| 2013 | 0.85 | 0.82 | 0.23 | 0.76 | 0.71 | 1.02 | 1.09 | 1.04 |
| 2014 | 0.84 | 0.81 | 0.21 | 0.78 | 0.71 | 1 | 1.09 | 1.03 |
| 2015 | 0.85 | 0.82 | 0.24 | 0.8 | 0.75 | 1.03 | 1.03 | 1.03 |
| 2016 | 0.85 | 0.82 | 0.25 | 0.83 | 0.85 | 1.07 | 1.03 | 0.99 |
| 2017 | 0.85 | 0.82 | 0.26 | 0.85 | 0.83 | 1.07 | 1.07 | 1 |

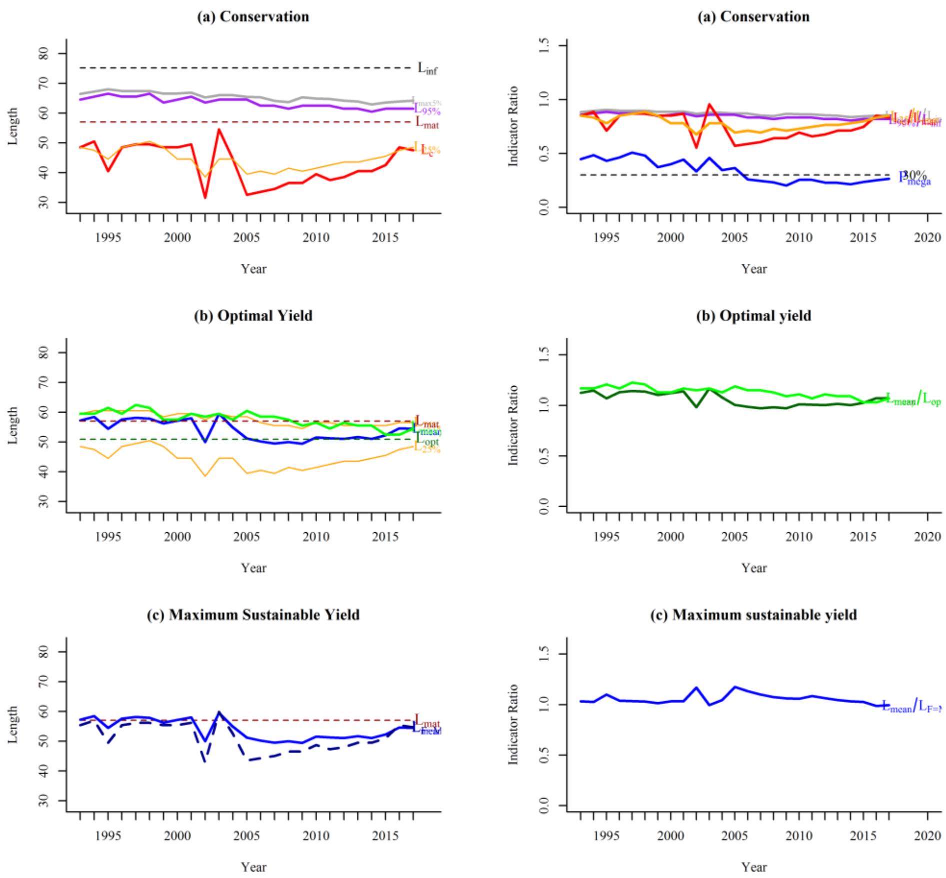



**Figure 5.5: Indicators, reference points and indicator ratios for lesser-spotted dogfish in divisions 7.a and 7.f-g.**

### 5.1.4 Discussion

As with all models, the quality of the input data will influence the quality of the results. Using the data from the UK England and Wales Observer at Sea program, it is likely that there may have been some issues regarding the raising factors. There appeared to be several cases within the available data where certain length classes may have been over represented (See Figure 5.1 – years 2013–2016, where the size class 40–45 cm seems over-represented). This becomes particularly problematic when calculating LBI's that are reliant on such length frequency data.

There were also some issues relating to having sufficient data with which to draw robust conclusions. For several species sampled in the UK England and Wales Observer at Sea program, it was necessary to combine the results from gears, or collate data across several years to apply the model. In doing so, using trends in LBIs to draw conclusions on the effect of fishing will be problematic, unless this collation of data is applied consistently over longer time periods (e.g. every two years over a period of 10 years or more).

In addition to issues of raising factors from variable sample sizes, there are potential issues in relation to the spatial, temporal variability and range of vessels that have been sampled over time. This is particularly relevant to elasmobranchs, which often show sex- and size-based aggregations and segregation. Future studies could usefully examine the raw data to determine whether a more consistent subset of the data (e.g. in terms of fleet, fishing ground and seasonal coverage) can give a more reliable temporal source of standardised data with which to examine temporal change (*i.e.* minimising potential bias from spatial, temporal and gear related differences in the data). If the development of LBIs requires a more consistent data set (at least for some species), then there may need to be consideration of a "reference fleet" to allow for the collection of more standardised data.

The current ICES assessments for the case study species are generally based on survey trends (Category 3), and so the utility of LBIs to provide additional demographic information when evaluating stock status is a potentially useful tool for managers. It should also be noted, however, that spatial metrics for such stocks may also be informative. Further analyses of spatial information may also inform on the most reliable sources of observer data for the better refinements of input data for LBIs.

For larger bodied fish, $L_C$ and $L_{25\%}$ will invariably be at a smaller size than $L_{mat}$ and therefore the LBI relating to the conservation of immatures often suggested 'poor' status in the current case studies. Consequently, the expected indicator ratio value of 1 may not be appropriate for elasmobranchs and other large bodied fish.

The estimation of $L_c$ will impact MSY status, as RP $L_{F=M}$ is calculated from $L_c$ (Table 5.2). This can be seen in the LBI of lesser-spotted dogfish where the variable nature of $L_c$ mid-time series is reflected in $L_{F=M}$ (Figure 5.5). Low estimations of $L_c$ will lower the value of $L_{F=M}$ which will in turn increase the ratio $L_{mean}$/ $L_{F=M}$, potentially giving over-optimistic MSY status. This appeared to be evident to some extent for both blonde and thornback rays, where MSY status was considered 'good', despite the failure of other LBIs to meet the expectations of a 'healthy' stock. $L_{25\%}$ could be considered a proxy for length at first capture in the calculation of $L_{F=M}$ when $L_c$ is considered unreliable.

Application of the LBIs revealed inconsistencies in status between indicators describing the same properties when applied to the same data. There was a tendency for $L_{maxy}$ to be higher than $L_{mean}$, often giving conflicting status when describing optimal yield in the traffic light assessment. Differences in status also occurred when looking at indicators describing the conservation of large individuals (e.g., starry smooth-hound caught by all gears). Consideration should be given to which indicator is most appropriate for the species (and fishery).

There were some cases where the traffic light assessment revealed too low a proportion of mega spawners, even when indicators compared to $L_\infty$ revealed a healthy presence of large individuals. For lesser-spotted dogfish $P_{mega}$ fell below the expected value of 0.3 while other indicators relating to large individuals remained at expected levels and the optimal yield LBI indicated targeting at the optimal length. This contradiction in status requires further study. The expectation that $P_{mega} > 0.3$ assumes asymptotic selection. If selection is dome-shaped then lower values of $P_{mega}$ are desirable, following the fishing strategy where no mega-spawners are caught. Hence, due consideration should be given to fishery selection when defining appropriate reference points.

Given the large size of elasmobranchs and the late age at maturity, LBI based on length at first capture ($L_c$ and $L_{25\%}$) invariably highlight that this occurs before fish mature. It is considered unlikely to have a mixed fishery that captures elasmobranchs to meet these indicators, and a simulation study suggests targeting a few year classes of immatures to be a more robust strategy for elasmobranchs (Prince, 2005). The RPs adopted by ICES were derived primarily for teleost and shellfish stocks (Froese, 2004; Miethe and Dobby, 2015). It is likely that these RPs will need to be adjusted for fishes with contrasting life history (e.g., Shephard *et al.*, 2018).

The current case studies often provided mixed results from the various LBIs, and so there could be consideration of having more categories than red/green, and consideration of trend-based metrics until appropriate reference points are validated.

## 5.2 LBI applied to spurdog in the Northeast Atlantic

### 5.2.1 Data

Length-frequency distributions were reconstructed for the years 2000–2015 from the Scottish survey sample numbers and proportions used in the stock assessment. For consistency with the application of LBI to the five elasmobranch stocks considered above, the length-frequency data were analysed in 2 cm length intervals, as the $L_\infty$ values indicate a maximum size of ca. 90–120 cm.

No commercial data has been available for spurdog since 2004.

Life history parameters were taken from the stock assessment (Table 5.7). The LBI analysis was run using the life history parameters for females. The stock assessment assumes a variable natural mortality at age. Here the constant value of 0.1 applied to the adult portion of the stock aged 4–30 was used to calculate an $M/k$ ratio of 1.16, based on the female value of $k$. Sensitivity runs were performed assuming $M/k$ ratios of 0.59 and 1.5, based on the ratios of male spurdog and teleosts respectively.

**Table 5.7: Life history parameters used in the stock assessment of Northeast Atlantic spurdog.**

| Parameter | Definition | Males | Females | Combined |
|---|---|---|---|---|
| $L_\infty$ | Asymptotic length | 81.36 | 110.66 | |
| $k$ | Growth rate coefficient | 0.17 | 0.086 | |
| a | Length-weight parameter | 0.00576 | 0.00108 | |
| b | Length-weight parameter | 2.89 | 3.301 | |
| $L_{mat}$ | Length at 50% maturity | | 80 | |
| $M_{adult}$ | Natural mortality | | | 0.1 |

### 5.2.2 Results

LBI characterising the conservation of large individuals show the two indicators relating to the upper portion of the length-frequency distribution to be relatively stable but fluctuate around the expected value of $0.8L_\infty$, so that the condition for 'good' status is met in some years but not others. $L_{max5\%}$ was generally higher than $L_{95\%}$ and therefore gave a slightly more optimistic picture. Given that the $L_\infty$ for females is much higher than that of males, running the analysis using the female $L_\infty$ represents the precautionary option in terms of large individuals. However, plots of reference points against length-frequency distributions show this value to be appropriate (Figure 5.6).

Like most elasmobranch stocks considered above, and consistent with the results of the Leslie matrix analysis, the LBI relating to mega-spawners and the conservation of immatures consistently failed to meet the expected values corresponding to the theoretical "desirable" status.

Length-based indicators reflect size-selective fishing pressure and are therefore representative of exploitation pattern and status, rather than biomass. Hence, results of the LBI analysis can be compared to the fishing pressure status of the latest stock assessment, which was classified as below $F_{MSY}$, but not the stock size status, which was classified as below MSY $B_{trigger}$ (ICES, 2016).

**Table 9.3.17.1** Spurdog in the Northeast Atlantic. State of the stock and fishery relative to reference points.

| | | Fishing pressure | | | | Stock size | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2013 | 2014 | 2015 | | 2014 | 2015 | 2016 | |
| Maximum sustainable yield | $F_{MSY}$ | | | | Appropriate | MSY $B_{trigger}$ | | | Below trigger |
| Precautionary approach | $F_{pa}$, $F_{lim}$ | | | | Undefined | $B_{pa}$, $B_{lim}$ | | | Undefined |
| Management plan | $F_{MGT}$ | - | - | - | Not applicable | $SSB_{MGT}$ | - | - | Not applicable |

LBI that are comparable to $F_{MSY}$ are the MSY indicator $L_{mean}/L_{F=M}$ and to some extent the optimal yield LBI, both of which are sensitive to the assumed value of $M/k$, where lower $M/k$ will result in a more pessimistic assessment. Assuming the $M/k$ ratio for female spurdog, the MSY LBI somewhat matches the trend of the assessment; the indicator ratio is mostly 'bad' prior to 2006 and 'good' from then onwards (Table 5.8), corresponding to the assessment $F$ dropping below $F_{MSY}$ from 2006 onwards, although the time-series of the MSY indicator ratio fails to capture the large drop in $F$ that is apparent from the assessment (Figure 5.7). Assuming the more pessimistic $M/k$ ratio of 0.59 results in a 'bad' status across the time-series, in direct opposition to the latest assessment, while assuming the more optimistic $M/k$ ratio results in mostly 'good' status, which agrees with the assessment.

**Table 5.8: LBI for spurdog in the Northeast Atlantic. Cells in green indicate those indicators that meet expectations (see Table 2) and theoretically represent 'good' status.**

***M/k* = 1.16**

| Year | $L_{max5}$_$L_{inf}$ | $L_{95}$_$L_{inf}$ | $P_{mega}$ | $L_{25}$_$L_{mat}$ | $L_c$_$L_{mat}$ | $L_{mean}$_$L_{opt}$ | $L_{maxy}$_$L_{opt}$ | $L_{mean}$_LFeM |
|---|---|---|---|---|---|---|---|---|
| 2000 | 0.86 | 0.77 | 0.05 | 0.51 | 0.36 | 0.74 | 0.94 | 1.11 |
| 2001 | 0.84 | 0.82 | 0.07 | 0.64 | 0.66 | 0.91 | 0.92 | 1.03 |
| 2002 | 0.83 | 0.8 | 0.05 | 0.71 | 0.79 | 0.94 | 0.94 | 0.97 |
| 2003 | 0.82 | 0.75 | 0.02 | 0.69 | 0.91 | 1 | 1.04 | 0.94 |
| 2004 | 0.88 | 0.75 | 0.03 | 0.64 | 0.86 | 0.95 | 0.94 | 0.93 |
| 2005 | 0.77 | 0.73 | 0 | 0.69 | 0.86 | 0.94 | 0.97 | 0.92 |
| 2006 | 0.78 | 0.71 | 0.01 | 0.59 | 0.66 | 0.87 | 0.94 | 0.98 |
| 2007 | 0.86 | 0.82 | 0.06 | 0.61 | 0.51 | 0.81 | 1.19 | 1.04 |
| 2008 | 0.86 | 0.82 | 0.05 | 0.46 | 0.89 | 0.97 | 0.94 | 0.93 |
| 2009 | 0.83 | 0.75 | 0.03 | 0.61 | 0.74 | 0.9 | 0.92 | 0.96 |
| 2010 | 0.69 | 0.68 | 0 | 0.49 | 0.34 | 0.63 | 0.94 | 0.97 |
| 2011 | 0.84 | 0.77 | 0.04 | 0.64 | 0.61 | 0.89 | 0.94 | 1.05 |
| 2012 | 0.87 | 0.86 | 0.07 | 0.51 | 0.49 | 0.83 | 1.19 | 1.09 |
| 2013 | 0.88 | 0.8 | 0.14 | 0.54 | 0.36 | 0.76 | 1.12 | 1.14 |
| 2014 | 0.85 | 0.75 | 0.03 | 0.56 | 0.91 | 0.99 | 0.97 | 0.94 |
| 2015 | 0.91 | 0.91 | 0.07 | 0.59 | 0.36 | 0.79 | 1.27 | 1.17 |

***M/k* = 0.59**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2011 | 0.84 | 0.77 | 0 | 0.64 | 0.61 | 0.76 | 0.81 | 0.92 |
| 2012 | 0.87 | 0.86 | 0 | 0.51 | 0.49 | 0.71 | 1.03 | 0.92 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2013 | 0.88 | 0.8 | 0.01 | 0.54 | 0.36 | 0.66 | 0.96 | 0.92 |
| 2014 | 0.85 | 0.75 | 0.01 | 0.56 | 0.91 | 0.86 | 0.83 | 0.88 |
| 2015 | 0.91 | 0.91 | 0 | 0.59 | 0.36 | 0.68 | 1.09 | 0.94 |

***M/k* = 1.5**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2011 | 0.84 | 0.77 | 0.11 | 0.64 | 0.61 | 0.96 | 1.02 | 1.1 |
| 2012 | 0.87 | 0.86 | 0.1 | 0.51 | 0.49 | 0.9 | 1.29 | 1.16 |
| 2013 | 0.88 | 0.8 | 0.18 | 0.54 | 0.36 | 0.83 | 1.21 | 1.23 |
| 2014 | 0.85 | 0.75 | 0.07 | 0.56 | 0.91 | 1.07 | 1.04 | 0.96 |
| 2015 | 0.91 | 0.91 | 0.15 | 0.59 | 0.36 | 0.85 | 1.37 | 1.27 |

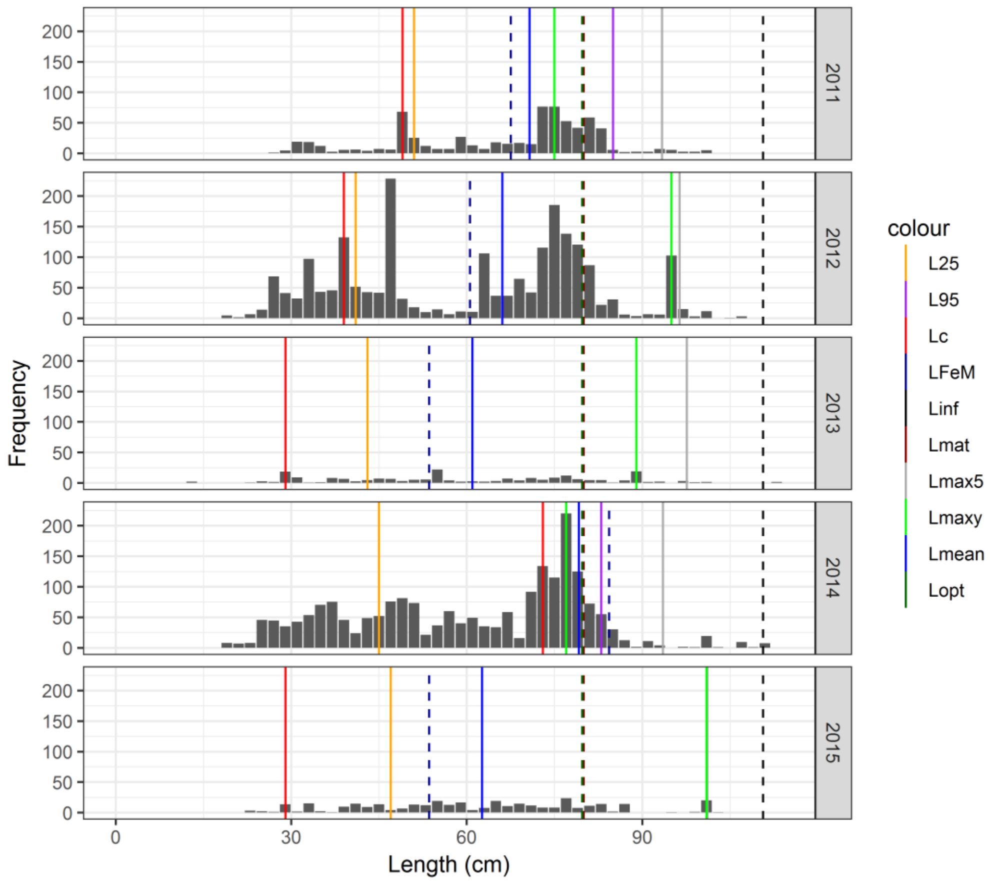



**Figure 5.6: Length frequency distributions of spurdog in the Northeast Atlantic for the last five years of Scottish survey data used in the assessment, with indicators (solid vertical lines) and reference points (dashed vertical lines).**

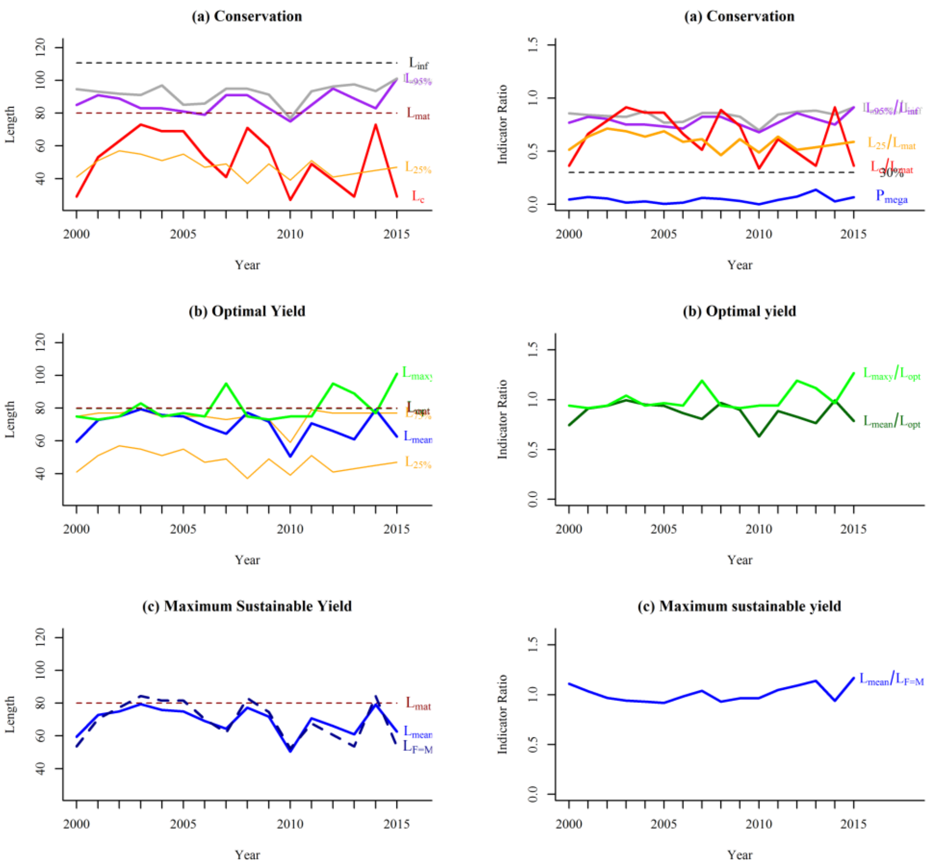



**Figure 5.7: Indicators, reference points and indicator ratios for spurdog in the Northeast Atlantic.**

### 5.2.3 Discussion

The MSY LBI shows some correspondence to the results of the most recent assessment of spurdog, although this is sensitive to the value of *M*/*k* assumed. In the absence of recent commercial data, the LBI were applied to the Scottish survey data used in the assessment. While this can give some insight into the performance of the LBI, it is not ideal. $L_c$ calculated from survey data will typically be smaller than that calculated from commercial catch data, and will therefore impact the LBI that are calculated from this indicator, including both parts of the MSY indicator ratio. Optimal yield LBI describe the targeting of the fishery, which will typically be skewed to the left when considering survey data. It is therefore recommended that the LBI are applied to commercial data for spurdog for a more accurate comparison to the stock assessment results.

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## Annex 2: Working documents

- **WD1.** Review of some life-history parameters of lesser-spotted dogfish (*Scyliorhinus canicula*) in the Cantabrian Sea (ICES area 8c)
- **WD2**. Length-based indicators to assess the status of elasmobranch stocks: applications and caveats
- **WD3**. Spatial distribution of commercial catch in Irish on-board observations

**WORKING DOCUMENT 01**

Working Document presented to the Workshop on Length-Based Indicators and Reference Points for Elasmobranchs. ICES WKSHARK4 – IFREMER, Nantes 6-9 February 2018.

**Review of some life-history parameters of lesser-spotted dogfish (*Scyliorhinus canicula*) in the Cantabrian Sea (ICES area 8c)**

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**Abstract**

A review of the tag-recapture data base of *S. canicula* in the Cantabrian Sea (N of Spain) has been performed to study some life-history parameters of this species. In this document we present the results obtained for parameters such as longevity, mortality, survival and recovery rates obtained from tag-recapture data. A total of 14107 *S. canicula* were tagged and released from 1993 to 2017, with a total of 478 recaptures up to date. The maximum time at liberty recorded has been 14.6 years. Maximum and mean length obtained from the historical series of bottom trawl surveys (1990-2017) is also presented. Both parameters remain fairly constant along the time series. Recovery models for multiyear tagging studies were applied using the program Mark. The best model fit was achieved considering constant survival and recovery rates. The outputs were a survival rate (S) 0.72 and a recovery rate (r) 0.038. The total finite mortality estimated was therefore Z=0.28.

**Introduction**

In the last two decades there has been a global increase in interest in elasmobranchs, particularly related with the need for management advice (ICES, 1997) and conservation (STECF, 2002). Since 2005, ICES has been asked by the European Commission to provide advice of certain elasmobranch species.

Stock assessments for many elasmobranchs are particularly difficult due to incomplete (or lack of) species-specific catch data, the highly migratory nature of some of these stocks (especially deep-water and pelagic sharks), and that internationally-coordinated fishery-independent surveys only sample a small number of demersal elasmobranchs with any degree of effective-ness (ICES, 2017).

Several methods have been developed in an attempt to provide advice for this type of stocks with limited information (ICES, 2016 WKLIFE V) known as Data Limited Stocks. Under this framework, members of the ICES WGEF considered important to carefully evaluate the use of Length Base Indicators (LBI) and Reference points (RP) for elasmobranchs assessments.

Tagging studies have been proved to be an important tool in estimating population variables such as abundance, migration, growth and mortality rates (e.g. Jones, 1976; Thorsteinsson, 2002). In the Spanish Institute of Oceanography (IEO) a tagging program on some demersal elasmobranchs species has been carried out since 1993. The instantaneous mortality rate (M) is an important parameter in elasmobranch management and conservation, but is difficult to estimate directly. Thus, in this WD we present some estimates based on tag recapture data.

**Material and Methods**

The Spanish Institute of Oceanography (IEO) carries out annual bottom trawl surveys along the continental shelf of the Cantabrian Sea (N of Spain; ICES areas 9.a and 8.c) to estimate abundance indices of the commercially important demersal and benthic species (Sánchez *et al.*, 2002). Since 1993 a tagging program, mainly focused on *S. canicula,* has been carried during these surveys which continue up-to-date. In the last years other species have also been included in the tagging program. Elasmobranchs were tagged with T-bar anchor tags using a Mark II regular tagging gun. For each individual, the tag number, date, sex, total length (TL), latitude, longitude and depth (m) were recorded. The TL was measured from the snout to the caudal tip, to the lower cm. Length frequency data were also obtained from these surveys and used to evaluate the maximum and the mean length of the time series.

Mortality estimates were obtained from tag-recapture data using the period from 1993 to 2005. The classical approach of multi-year tagging models (Seber, 1970; Brownie *et al.*, 1985) aimed at estimating survival and recovery rates of animals tagged over successive years was applied. The reduced parameterisation first described by Seber (1970) and later by Anderson *et al.* (1985) and Catchpole *et al.* (1995) was applied. Four different models were compared considering survival (S) and recovery rate (r) constant or time-specific. The analysis were done using program Mark (Cooch&White, 1998) v4 Besides mortality estimates were obtained indirectly from empirical equations and compare to previous results. Some indirect methods to estimate mortality were also examined.

**Results**

<u>Longevity or Maximum age</u>

Results from tag-recapture data reveals that the maximum time at liberty achieved for a *S. canicula* was 14.6 years. Other four specimens were recovered after 10 years (Fig. 1). However according to the tagging length of these specimens (Table 1a) the estimated age or life expectancy of this species could be at least 20 years. Growth models derived from tagging data were firstly used and provided von Bertalanffy parameters (Rodriguez-Cabello *et al.*, 2005). In general all the models underestimated the asymptotic length ($L\infty$) when compared to observed lengths. The most plausible estimates of von Bertalanffy growth parameters for sexes combined according to these models were $L\infty$= 69.3 cm and K=0.21. A revision of other growth models incorporating new tag-recapture data will be carried out in a next future.

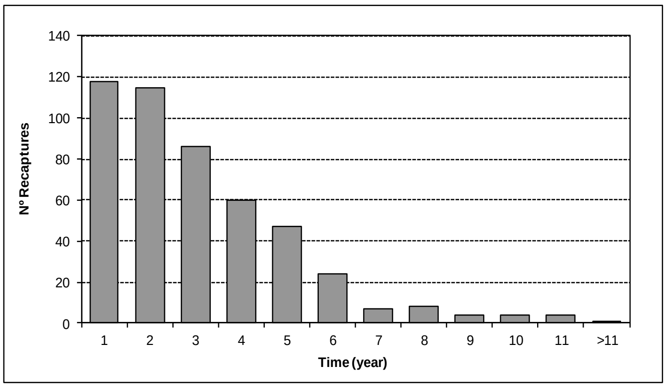


Fig. 1. Recaptures of *Scyliorhinus canicula* according to the time at liberty.

On table 1b the largest specimens tagged are shown. As it can be seen there is data on a *S. canicula* tagged with 72 cm and recaptured after 8 years which did not growth. Thus indicates that probably it attained the asymptotic length.

Table 1. Summary data of a) the longest (time) specimens recorded and b) largest (size).

| Tagging Data | | | | Recapture Data | | Time at liberty | | Growth | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Length | Sex | Tag Nº | Date | Length | Days | Year | (cm) | Miles |
| 25/10/2001 | 50 | 1 | R1823 | 03/06/2016 | 0 | 5331 | 14.6 | 0 | 3.0 |
| 25/09/1993 | 43 | 1 | B3618 | 27/05/2004 | 64 | 3895 | 10.7 | 21 | 7.5 |
| 14/10/2001 | 39 | 2 | G0277 | 17/04/2012 | 0 | 3835 | 10.5 | 0 | 0.0 |
| 24/10/1999 | 59 | 1 | Y2954 | 15/03/2010 | 0 | 3793 | 10.4 | 0 | 85.7 |
| 20/10/2003 | 51 | 1 | Y3707 | 30/01/2014 | 0 | 3751 | 10.3 | 0 | 0.0 |

a)

b)

| Tagging Data | | | | Recapture Data | | Time at liberty | | Growth | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Length | Sex | Tag Nº | Date | Length | Days | Year | (cm) | Miles |
| 28/10/2000 | 66 | 1 | G0029 | 21/04/2006 | 67 | 2000 | 5.479 | 1 | 1.2 |
| 19/10/1995 | 67 | 1 | Y0367 | 27/10/1999 | 68 | 1468 | 4.022 | 1 | 0.6 |
| 18/10/1996 | 72 | 1 | Y1304 | 01/07/2005 | 72 | 3176 | 8.701 | 0 | --- |

## Maximum length

Mean and maximum lengths by sex obtained from trawl surveys (1990-2017) are shown on Fig. 2. Although the length distributions do not come from the commercial fleet the fact that these surveys cover the whole trawl area and depths where this species mainly occurs it could be a good indicator of the demographic composition of the population. Besides the trawl gear used in the surveys is assumed to retain all sizes both small and large individuals thus it can provide information on the trends of the population structure.  As it shows on Fig 2, males always attain largest size. Although there are fluctuations among years mean and maximum sizes remained more or less constant. Length at first capture it is also very stable (10-12 cm) coinciding with length at birth. Maximum length observed in the surveys was 75 cm.

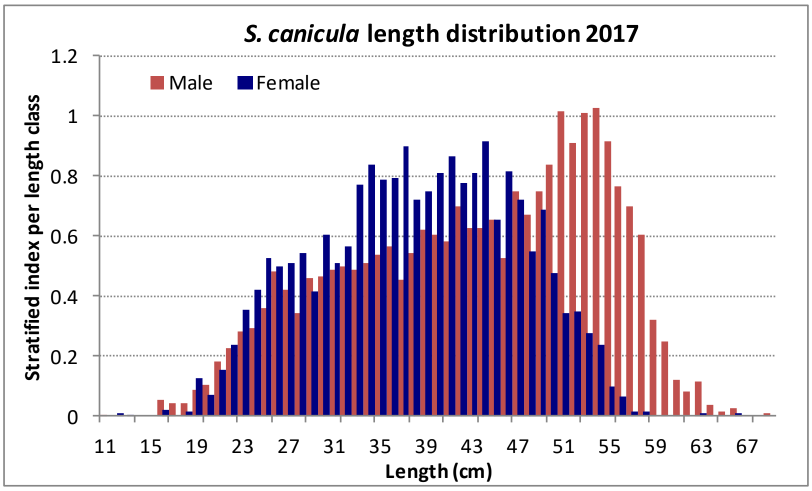


Fig. 2. Example of length distribution obtained in the bottom trawl survey 2017.

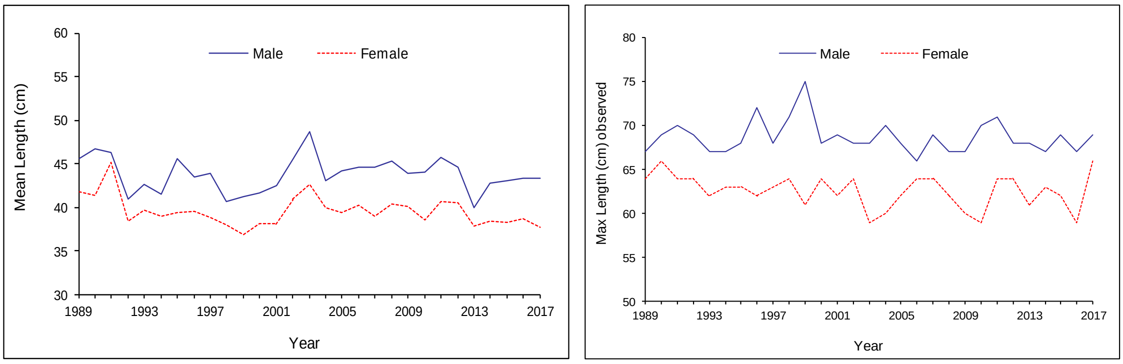


Fig. 3.  Mean and maximum length by sex obtained from bottom trawl surveys during the time series (1989-2017).

Mortality

Although tagging has been conducted since 1993, some yearly gaps after 2005 advice using only this period 1993-2005 to avoid the likely effect of using non successive tagging periods. Thus from 1993 to 2005 a total of 12137 *Scyliorhinus canicula* were tagged and 351 recaptures were obtained during this period (Table 2).

Table 2. Number of *S. canicula* tagged and recaptured during the study period (1993-2005) used in the analysis.

| Year Tagged | Number Tagged | Number of recaptures 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1993 | 903 | 6 | 4 | 2 | 6 | 2 | 2 | 1 | 1 | 1 | 0 | 1 | 0 | 0 |
| 1994 | 783 | | 3 | 6 | 8 | 3 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 1995 | 466 | | | 8 | 5 | 3 | 4 | 2 | 2 | 1 | 0 | 0 | 0 | 0 |
| 1996 | 829 | | | | 8 | 13 | 5 | 1 | 3 | 1 | 0 | 0 | 1 | 0 |
| 1997 | 1250 | | | | | 8 | 11 | 11 | 4 | 4 | 1 | 0 | 0 | 0 |
| 1998 | 784 | | | | | | 8 | 3 | 3 | 4 | 0 | 1 | 0 | 1 |
| 1999 | 523 | | | | | | | 8 | 6 | 5 | 2 | 3 | 2 | 2 |
| 2000 | 1081 | | | | | | | | 15 | 2 | 9 | 5 | 4 | 4 |
| 2001 | 1022 | | | | | | | | | 8 | 9 | 11 | 7 | 9 |
| 2002 | 675 | | | | | | | | | | 7 | 5 | 3 | 4 |
| 2003 | 980 | | | | | | | | | | | 9 | 9 | 9 |
| 2004 | 1225 | | | | | | | | | | | | 9 | 11 |
| 2005 | 1616 | | | | | | | | | | | | | 10 |
| | 12137 | 6 | 7 | 16 | 27 | 29 | 31 | 26 | 35 | 26 | 28 | 35 | 35 | 50 |

Four different models were compared considering survival (S) and recovery rate (r) constant or time-specific (Table 3). The results indicate that although it appears to be some evidence for variation in survival and recapture rates over years there was no significant annual variation.

Table 3. Models tested in the analysis considering S and r constant (.) or time-specific (t) and quasi Akaike's information criterion (QAIC) values, number of parameters and deviance for each model.

| MODEL | Model description | QAIC | NUMPAR | DEVIANCE |
|---|---|---|---|---|
| S(.) r(.) | Survival and recovery rate constant | 4267.76 | 2.00 | 112.12 |
| S(.) r(t) | Constant survival and recovery rate independent of year | 4278.71 | 14.00 | 99.04 |
| S(t) r(.) | Survival independent of year and constant recovery rate | 4275.22 | 14.00 | 95.55 |
| S(t) r(t) | Survival and recovery rate independent of the year | 4266.72 | 24.00 | 66.98 |

The lowest deviance value 66.98 was obtained with the most parameterized model S(t) r (t). In terms of model deviance this model fits the data better but not so much so as to compensate for the fact that it takes more parameters to achieve this better fit, 24 against 2. Based on Akaike information criteria (AIC), the model that has survival and recovery rate independent of the year performs a somewhat better (4266.72 vs 4267.75) than the one with constant survival and recovery rate. According to these results it is not possible to distinguish among the alterna-tive models, so it is reasonable to use the simplest model (time invariant survival and recovery rates). Nevertheless other tests should be performed to check differences among models. Results of the model which accounts for survival and recovery rate constant S(.) and r (.) is shown on table 4.

Table 4. Estimated parameters for the model S(.) r(.) survival and recovery rate constant.

| Parameter | Estimate | Stand. Error | 95% Confid. Interval Lower | Upper |
|---|---|---|---|---|
| 1: S | 0.7224263 | 0.0192823 | 0.6831008 | 0.7585963 |
| 2: r | 0.0382886 | 0.0022195 | 0.0341679 | 0.0428842 |

Annual survival rates were transformed to finite mortality rates, according to Krebs (1989), resulting in Z=0.28.

Indirect estimation of mortality

Several empirical equations are used to infer mortality. Many of these are based on observed relationships between direct M estimates and various life-history parameters (e.g. Pauly 1980, Hoenig 1983, Jensen 1996, Charnov et al. 2013). One of the most popular indirect method in elasmobranch literature is that of Hoenig (1983). Hoenig (1983) used maximum observed age (tmax) to develop four relationships for estimating M. The most widely used of the three relationships was developed from 84 fish stocks, 80 of which were teleosts:

$\ln(M) = 1.46 - 1.01\ln(T_{max})$ ,

where, $t_{max}$ is the oldest observed age. Due to the over representation of teleosts, this relationship may cause bias when applied to elasmobranchs. Therefore another Hoenig's equation is developed from the combined data of fish, cetaceans, and mollusks:

$\ln(M) = 1.44 - 0.982\ln(T_{max})$.

Using the previous estimates of maximum age ($T_{max}$=20 y) we obtained a Z=0.215 in the first case and Z= 0.223 respectively.

Brander, (1981) developed other method to estimate mortality on elasmobranchs based on the number of eggs or recruits produced each year. He applied to the skate *D. batis*. This method allows to estimate the threshold upon which the population would collapse. It is based on Holden`s (1974) equation. For a population to remain in equilibrium, the mortality rate of mature fish ($Z_m$) must equal the net rate of recruitment of mature fish ($R_m$), thus. $Z_m = R_m$. The net recruitment is given by the number of eggs laid per female per year (X/2), because only eggs developing into females are included) multiplied by the survival from egg laying to maturity, thats is: $Rm= (X/2)*e^{(-Zi.tm)}$, wher X is the fecundity rate expressed as number of eggs per female each year(divided by two considered that half of the new born would be females), $Z_i$ is the mortality rate of the immature fraction which is assumed constant along the period considered and $t_m$ is the number of years to attain maturity.

The results applying Brander equation are shown in Fig. 3. Since there is some uncertainty about the fecundity of this species, three different scenarios were used: a) 60 eggs per year, b) 100 or c) 150. Age at maturity was estimated in from length at maturity obtained for this species in this area 54.2 cm (Rodriguez-Cabello *et al.*, 1998) and using the von Bertalanffy growth equation derived from tag-recapture data (Rodríguez-Cabello *et al*., 2005) which results 7 years.

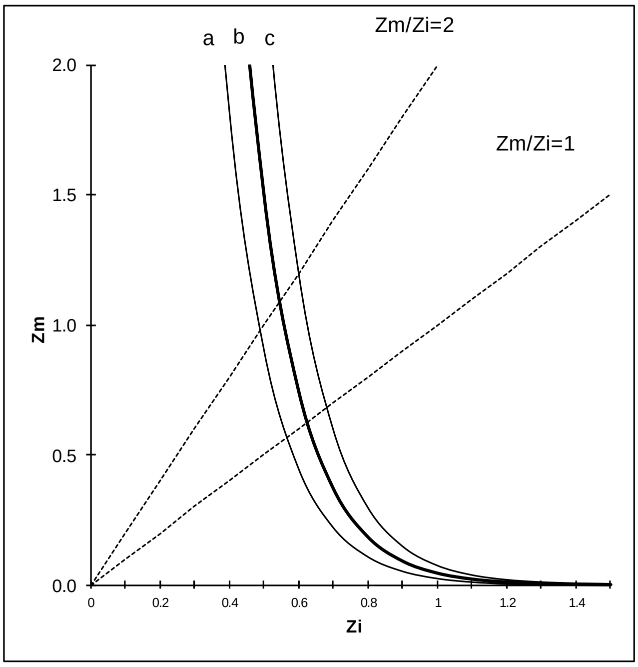


Fig. 3. Values of Zm (mortality rate on mature fish) and Zi (mortality rate on immature fish) to maintain the population in equilibrium. a) Fecundity 60 eggs per year (30 h); b) Fecundity 100 eggs per year (50 h); c) Fecundity 160 eggs per year (80 h).

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**WORKING DOCUMENT 02**

Working Document to the ICES Workshop on Length-Based Indicators and Reference Points for Elasmobranchs (WKSHARK4), Nantes, 6–9 February 2018

# Length-based indicators to assess the status of elasmobranch stocks: applications and caveats

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## SUMMARY

Exploratory studies applying length based indicators (LBI) to five demersal elasmobranch stocks were undertaken.

## INTRODUCTION

Many elasmobranch species are data-limited owing to incomplete species-specific catch data, inaccurate species identification, poor knowledge of life-history and that fishery independent surveys only sample a few species with any degree of effectiveness (ICES, 2017). This precludes the formal stock assessment process that is used for many commercial teleost stocks, with only one elasmobranch species (spurdog) within ICES assessed using analytical models.

Recently, the need to provide management advice, especially in relation to maximum sustainable yield (MSY), for an increasing number of fish species taken in commercial fisheries has led to a proliferation of data-limited assessment methodologies, reflecting differing data availabilities and intended use of assessment. These include methods based on time-series of catch (Martell and Froese, 2013; Zhou *et al.*, 2017), catch-based methods that use additional information on life histories (MacCall, 2009; Dick and MacCall, 2011) or size structure (Gedamke and Hoenig, 2006; Hordyk *et al.*, 2015a, 2015b) and process-based models that require additional indices of biomass or abundance (Pedersen and Berg, 2017).

Many biological and fishery processes are related to size (e.g. fecundity, fishery selection and natural mortality). Length data can therefore contain substantial information on stocks and the fisheries impacting them (ICES, 2014). Given that length data are relatively cheap and straightforward to obtain, and that length-frequency data are the primary data collected under the data collection framework (DCF), length-based assessments may be suitable for various data-limited stocks.

Length-based indicators (LBI) are assumed to reflect size-selective fishing pressure. Indicators of status are calculated from length-frequency distributions and compared to reference points (RP) derived from life-history parameters and ecological theory or empirical observation, providing a snapshot assessment of status under steady state assumptions. The ICES workshop on the ‘Development of Quantitative Assessment Methodologies based on Life-history Traits, Exploitation Characteristics and other Relevant Parameters for Data-limited Stocks’ (WKLIFE V) selected a set of LBIs characterising conservation of large and small individuals, yield optimisation and maximum sustainable yield (ICES, 2015). A traffic light approach is used to compare ratios of indicators and reference points to expected values where conservation, yield or MSY properties are considered achieved. This suite of LBI outputs is considered to provide an overall perception of stock status.

Here we apply length-based indicators to five elasmobranch stocks; blonde ray, thornback ray, cuckoo ray, starry smooth-hound and lesser spotted dogfish.

**METHODS**

**Data**

Length-frequency data for blonde, cuckoo and thornback rays and starry smooth-hound came from the UK England and Wales Observer at Sea program. For each trip, numbers-at-length were raised to the haul based on an estimated proportion of the total catch sampled, then to the trip based on the proportion of sampled hauls. Trip-raised estimates were summed for sampled vessels in each stratum (ICES division x gear class (otter trawls, beam trawls, netters and other gears) x quarter x year). They were then raised to the fleet using a ratio between the total number of trips and the number of trips sampled in the same stratum.

Length-frequency data for species attaining <90 cm $L_T$ (e.g. cuckoo ray and lesser-spotted dogfish) were analysed in 1 cm length intervals, whilst species reaching a maximum size of ca. 90–120 cm (e.g. thornback ray) were analysed in 2 cm length intervals, and fish attaining ≥120 cm (e.g. blonde ray and starry smooth-hound) were analysed in 5 cm length intervals.

Analysis for cuckoo ray, thornback ray and starry smooth-hound looked at length-frequencies for all gears and both otter trawls and netters separately, while analyses for blonde ray looked at data from otter trawls only. Due to a low sample size, blonde ray data for 2013–2016 were aggregated.

Data for lesser-spotted dogfish were downloaded from the Cefas Fishing Survey System (FSS) for the Irish Sea and Bristol Channel beam trawl survey in 7.a, f-g for the years 1993–2017 (ICES, 2009). This survey uses a commercially rigged 4m steel beam trawl with chain mat, flip-up ropes, and a 40mm codend liner that is typically towed for 30 minutes at four knots. Data were restricted to surveys in quarter 3. Length-frequency data for each year were collected in 1 cm length intervals.

The LBIs require estimates of length at 50% maturity ($L_{mat}$), von Bertalanffy asymptotic length ($L_\infty$) and weights-at-length, obtained here using the allometric relationship $w = aL^b$. We also report maximum length ($L_{max}$) as a check on the value of $L_\infty$. Life history parameters for the species considered here are given in Table 1.

**Table 9:** Input parameters for LBI. $L_{max}$ (literature) from Heesen *et al.* (2015).

| Stock | Species | $L_\infty$ | $L_{max}$ (literature) | $L_{max}$ (in data) | $L_{mat}$ | a | b |
|---|---|---|---|---|---|---|---|
| BLR7afg | Blonde ray | 118.4 | 120 | 104 | 83.4 | 0.0028 | 3.2495 |
| CUR678 | Cuckoo ray | 73.1 | 72 | 96 | 59.8 | 0.0036 | 3.1396 |
| THR47d | Thornback ray | 118 | 115 (130) | 102 | 73.7 | 0.0045 | 3.0686 |
| Mustelus | Starry smooth-hound | 123.5 | 124 | 162 | 81.9 | 0.0014 | 3.1000 |
| LSD7afg | Lesser-spotted dogfish | 75.14 | 80 | 74 | 57.0 | 0.0022 | 3.1194 |

**LBI**

*Conservation of large individuals*: Comparing indicators characterising the upper portion of the length frequency distribution to the RP $L_\infty$ provides an indication of the degree of truncation of the population size structure that may be caused by fishing. Indicators chosen to characterise the upper portion are the mean length of the largest 5% ($L_{max5\%}$) and the 95th percentile ($L_{95\%}$) of the length frequency distribution, both of which are considered more stable than the maximum length in the catch (Probst *et al.*, 2013; ICES, 2014). The ratio of indicator to RP $L_\infty$ is expected to be above 0.8, based on a simulation study (Miethe and Dobby, 2015).

The proportion of mega-spawners (fish larger than the optimum length plus 10%) in the stock ($P_{mega}$) follows the principle of '*Let the mega-spawners live*' (Froese, 2004). Old, large fish play several important roles in the long-term survival of a population, as they may produce more eggs (increased fecundity), larger eggs or young (which may have better survival) and may have a greater spawning success. Consequently, $P_{mega}$ can be viewed as a simple proxy for the resilience of a stock. The principle is to implement a fishing strategy where no mega-spawners are caught. However, if the catch reflects the size structure of the population, values above 0.3 are considered healthy (Froese, 2004; ICES, 2015).

*Conservation of immatures*: LBI relating to small individuals follow the principle '*Let them spawn*' (Froese, 2004). Overfishing is theoretically impossible if every spawner produces at least one replacement spawner (Myers and Mertz, 1998); therefore, if the indicator length at first capture ($L_c$; estimated as the length at 50% of the first mode) is above the RP $L_{mat}$ biomass is likely to be above that which produces MSY (ICES, 2014). A simulation study found the 25th percentile ($L_{25\%}$) of the length frequency distribution to be a suitable proxy when $L_c$ is difficult to estimate (Miethe and Dobby, 2015). Based on theory, the ratio of indicator to RP $L_{mat}$ is expected to be greater than 1.

*Optimal yield*: LBI relating to optimal yield follow the principle '*Let them grow*' (Froese, 2004) which states that all fish caught should be within 10% of the RP optimum harvest length ($L_{opt}$). $L_{opt}$ represents the length where cohort biomass and egg production are maximal in an unexploited state and where catch is maximal for a given fishing mortality ($F$), or $F$ minimal for a given catch (Cope and Punt, 2009). $L_{opt}$ is calculated:

$$L_{opt} = \frac{3}{3 + M/_k} L_\infty$$

Where $M$ is natural mortality and $k$ is the von Bertalanffy rate coefficient. The ratio M/k is thought to be more stable than either of the parameters separately, and is estimated at 1.5 for teleost fishes. The ICES approximation of $L_{opt}$ therefore simplifies to $2/3L_\infty$. If the central indicators mean length of individuals larger than $L_c$ ($L_{mean}$) or length class with maximal biomass ($L_{maxy}$) are close to the RP $L_{opt}$ then either the stock is lightly exploited or the fishery is operating with a target length that is sustainable and close to MSY (ICES, 2014). Given the requirement that fish caught are within 10% of $L_{opt}$, the ratio of indicator to RP should be 0.9–1.1.

*MSY*: $F=M$ is a proxy for MSY. The length at which $F=M$ ($L_{F=M}$) is rearranged from Beverton and Holts equation for mean length in the catch as a function of the von Bertalanffy growth parameters, length at first capture and natural and fishing mortality:

$$L_{F=M} = (1 - a)L_c + aL_\infty$$

$$a = \frac{1}{2\left(M/_k\right) + 1}$$

Assuming M/k = 1.5, this simplifies to $0.75L_c + 0.25L_\infty$. This RP gives the mean length in the catch expected from fishing at F=M in the long term; hence a suitable indicator is $L_{mean}$. If $L_{mean}$ is less than $L_{F=M}$ then fishing mortality is likely to be larger than $M$ and hence $F_{MSY}$ (ICES, 2014). The ratio of indicator to RP should therefore be greater than or equal to 1.

**Table 10:** Summary of length-based indicators (LBI) with corresponding reference points and indicator ratios (* = simplified equations resulting from substituting M/k = 1.5; an assumption based on the life history of teleost fish).

| Indicator | Calculation | Reference point | Indicator ratio | Expected value |
|---|---|---|---|---|
| $L_{max5\%}$ | Mean length of largest 5% | $L_\infty$ | $L_{max5\%}/L_\infty$ | > 0.8 |
| $L_{95\%}$ | 95th percentile | $L_\infty$ | $L_{95\%}/L_\infty$ | > 0.8 |
| $P_{mega}$ | Proportion of individuals above $L_{opt}$ + 10% | 0.3-0.4 | $P_{mega}$ | > 0.3 |
| $L_{25\%}$ | 25th percentile | $L_{mat}$ | $L_{25\%}/L_{mat}$ | > 1 |
| $L_c$ | Length at first catch (length at 50% of mode) | $L_{mat}$ | $L_c/L_{mat}$ | > 1 |
| $L_{mean}$ | Mean length of individuals > $L_c$ | $L_{opt}=2/3L_\infty$ * | $L_{mean}/L_{opt}$ | ≈ 1 |
| $L_{maxy}$ | Length class with maximum biomass in catch | $L_{opt}=2/3L_\infty$ * | $L_{maxy}/L_{opt}$ | ≈ 1 |
| $L_{mean}$ | Mean length of individuals > $L_c$ | $L_{F=M}=(0.75L_c+0.25L_\infty)$ * | $L_{mean}/L_{F=M}$ | ≥ 1 |

**RESULTS**

**Blonde ray in divisions 7.a and 7.f–g:** LBI suggested the stock to be in a “poor” state with regards to the conservation of both large and small individuals, but meeting MSY expectations.

The length-frequency distributions showed $L_\infty$ to fall far beyond the right tail of the distribution (Figure 1), so indicators calculated from the upper portion failed to meet expectations. $L_{mat}$ fell towards the right tail of the distribution, whereas indicators examining the smaller component of the catch usually fell to the left. $L_{maxy}$ indicated that fishing is targeted optimally, while $L_{mean}$ suggested targeting below the optimum length, which is consistent with the conservation LBI. The MSY condition was satisfied, despite the failure of the other LBIs to meet their expected values. This could be a consequence of calculating $L_{F=M}$ from low values of $L_c$.

**Table 11:** LBI for blonde ray in divisions 7.a and 7.f-g. Cells in green indicate those indicators that meet expectations (see Table 2) and theoretically represent ‘good’ status.

| **Blonde ray** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Lmax5_Linf | L95_Linf | Pmega | L25_Lmat | Lc_Lmat | Lmean_Lopt | Lmaxy_Lopt | Lmean_LFeM |
| 2010 | 0.72 | 0.7 | 0.02 | 0.57 | 0.21 | 0.72 | 0.98 | 1.34 |
| 2011 | 0.72 | 0.7 | 0.02 | 0.51 | 0.45 | 0.74 | 1.05 | 1.01 |
| 2012 | 0.74 | 0.7 | 0.03 | 0.51 | 0.21 | 0.72 | 0.98 | 1.33 |
| 2013to2016 | 0.72 | 0.7 | 0.02 | 0.33 | 0.15 | 0.56 | 0.98 | 1.13 |

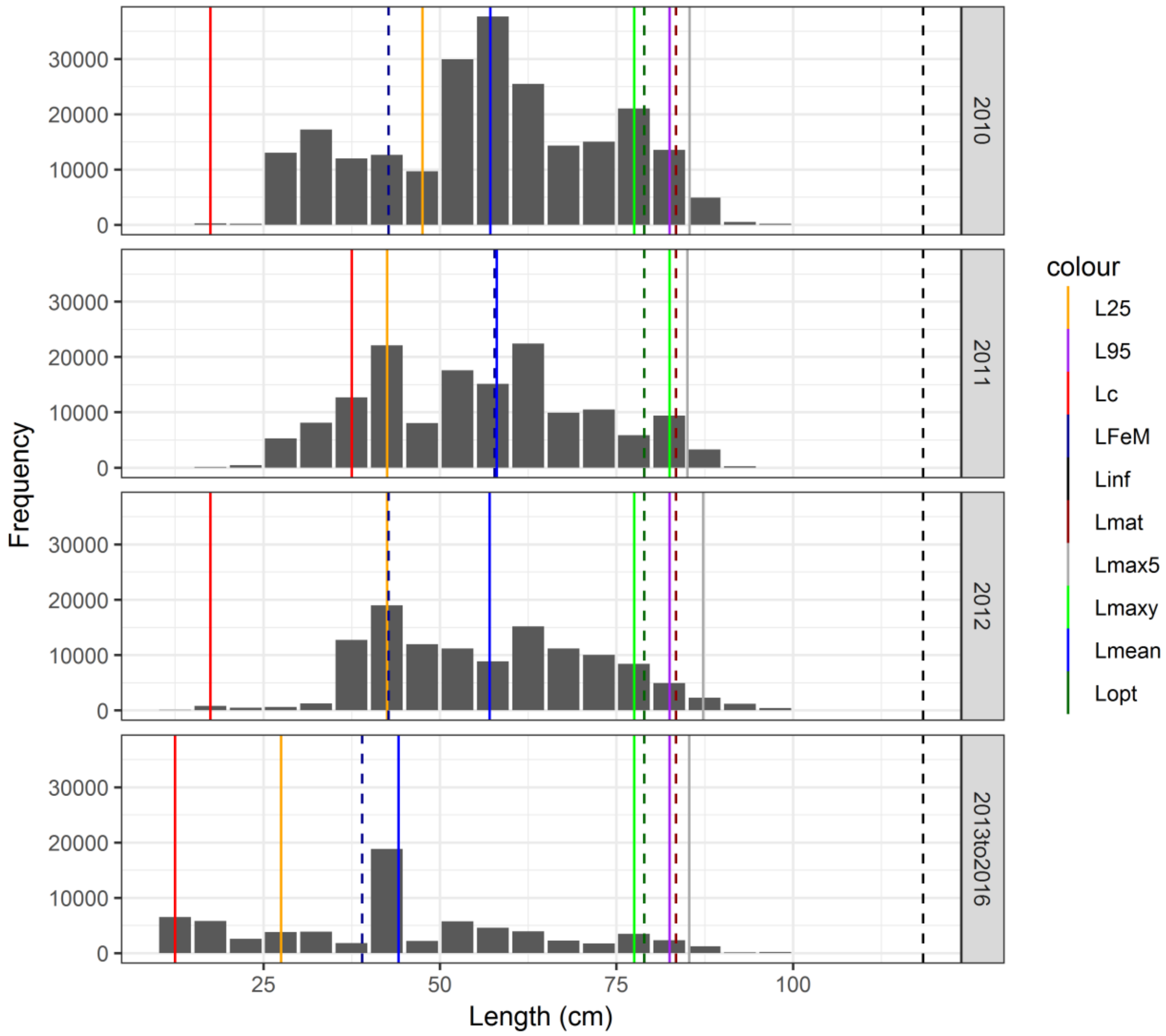



**Figure 8**: Length frequency of blonde ray in divisions 7.a and 7.f-g with indicators (solid vertical line) and reference points (dashed vertical lines).

**Cuckoo ray in subareas 6, 7 and 8:** LBIs for cuckoo ray were calculated for all gears combined. When analysed separately for both netters and otter trawls only, there was agreement in relation to MSY expectations, but differences in status when looking at separate properties of the stock, with data from netters providing a more optimistic assessment than data from otter trawls.

$L_\infty$ fell within the right tail of the length frequency distributions (not shown) with both indicator ratios characterising the upper portion meeting expected values for all gear combinations. The indicator ratios relating to optimal yield indicated that netters selected larger individuals than otter trawls. This was also apparent from $P_{mega}$ and $L_{25\%}$. The conditions that $P_{mega} > 0.3$ and $L_{25\%} > L_{mat}$ were met each year (bar one) when considering data from netters, but failed to hold for most of the otter trawl data. Data for all gears combined were dominated by the otter trawl data, causing $L_{25\%}$ to fall below $L_{mat}$. $P_{mega}$ conditions were met because netter $P_{mega}$ was close to 1, and otter $P_{mega}$ close to 0.3 in some years.

**Table 12**: LBI for cuckoo ray in subareas 6, 7 and 8. Cells in green indicate those indicators that meet expectations (see Table 2) and theoretically represent 'good' status.

**Cuckoo ray all gears**

| Year | Lmax5_Linf | L95_Linf | Pmega | L25_Lmat | Lc_Lmat | Lmean_Lopt | Lmaxy_Lopt | Lmean_LFeM |
|---|---|---|---|---|---|---|---|---|
| 2010 | 0.93 | 0.91 | 0.32 | 0.58 | 0.31 | 0.95 | 1.04 | 1.45 |
| 2011 | 0.96 | 0.94 | 0.51 | 0.63 | 0.23 | 1.03 | 1.3 | 1.78 |
| 2012 | 0.96 | 0.94 | 0.34 | 0.56 | 0.19 | 0.94 | 1.39 | 1.7 |
| 2013 | 0.96 | 0.94 | 0.38 | 0.53 | 0.24 | 0.95 | 1.36 | 1.58 |
| 2014 | 0.92 | 0.9 | 0.16 | 0.48 | 0.28 | 0.78 | 1.34 | 1.25 |
| 2015 | 0.96 | 0.92 | 0.38 | 0.59 | 0.19 | 0.98 | 1.32 | 1.77 |
| 2016 | 0.95 | 0.94 | 0.37 | 0.68 | 0.21 | 0.99 | 1.41 | 1.75 |

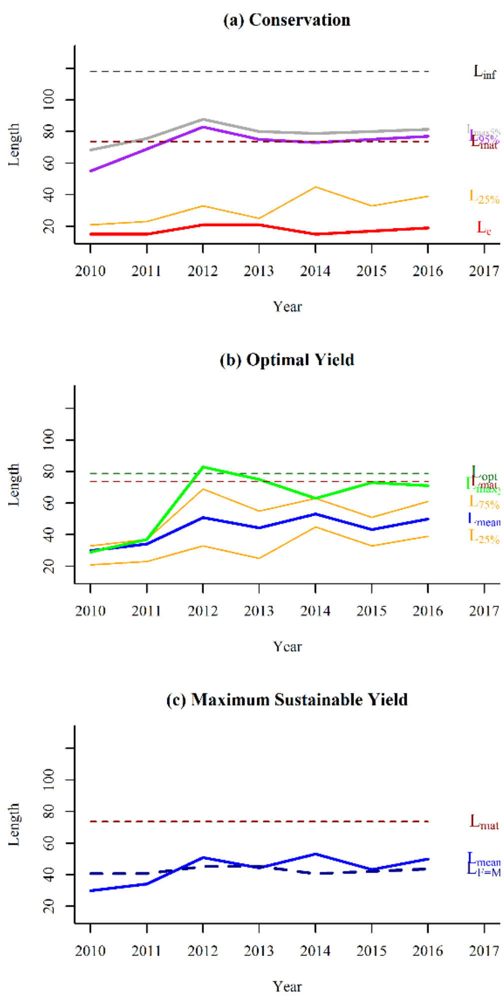
**Cuckoo ray netters**

| Year | Lmax5_Linf | L95_Linf | Pmega | L25_Lmat | Lc_Lmat | Lmean_Lopt | Lmaxy_Lopt | Lmean_LFeM |
|---|---|---|---|---|---|---|---|---|
| 2010 | 0.95 | 0.94 | 0.92 | 0.98 | 0.79 | 1.28 | 1.39 | 1.15 |
| 2011 | 0.97 | 0.95 | 0.95 | 1.05 | 0.54 | 1.32 | 1.3 | 1.51 |
| 2012 | 0.99 | 0.98 | 0.96 | 1.05 | 0.79 | 1.33 | 1.39 | 1.21 |
| 2013 | 0.98 | 0.96 | 0.97 | 1.06 | 0.73 | 1.34 | 1.36 | 1.28 |
| 2014 | 0.94 | 0.94 | 0.99 | 1.05 | 0.83 | 1.32 | 1.34 | 1.16 |
| 2015 | 0.98 | 0.96 | 0.97 | 1.05 | 0.78 | 1.33 | 1.32 | 1.22 |
| 2016 | 0.97 | 0.95 | 0.98 | 1.05 | 0.81 | 1.32 | 1.41 | 1.18 |

**Cuckoo ray otter trawls**

| Year | Lmax5_Linf | L95_Linf | Pmega | L25_Lmat | Lc_Lmat | Lmean_Lopt | Lmaxy_Lopt | Lmean_LFeM |
|---|---|---|---|---|---|---|---|---|
| 2010 | 0.89 | 0.84 | 0.24 | 0.74 | 0.33 | 0.98 | 1.04 | 1.45 |
| 2011 | 0.94 | 0.92 | 0.49 | 0.74 | 0.38 | 1.08 | 1.3 | 1.49 |
| 2012 | 0.94 | 0.91 | 0.28 | 0.58 | 0.19 | 0.93 | 1.34 | 1.69 |
| 2013 | 0.91 | 0.88 | 0.15 | 0.58 | 0.23 | 0.87 | 1.32 | 1.5 |
| 2014 | 0.9 | 0.85 | 0.16 | 0.54 | 0.36 | 0.86 | 0.85 | 1.21 |
| 2015 | 0.94 | 0.92 | 0.32 | 0.73 | 0.51 | 1.03 | 1.39 | 1.22 |
| 2016 | 0.9 | 0.84 | 0.1 | 0.69 | 0.59 | 0.92 | 0.87 | 1 |

**Thornback ray in subarea 4 and division 7.d:** LBI for thornback ray applied to data for all gears, netters only and otter trawls only showed general agreement in that all indicators relating to the conservation of large and small individuals failed to meet the expected values. The conditions for optimal yield and MSY were met in some years only. Length frequency distributions (not shown) showed $L_\infty$ to lie far beyond the right tail, while time-series of indicators and reference points showed indicators describing the larger portion of the catch to be around the level of $L_{mat}$ with indicators describing smaller fish falling far below (Figure 2). Indicator ratios for optimal yield suggest fishing at or below optimal length, with $L_{maxy}$ higher than $L_{mean}$ and both indicators higher for netters than otter trawls. Although values were often below suggested indicator ratios, there were improving trends in some LBIs.


(a) Conservation
Length
Year
(b) Optimal Yield
Length
Year
(c) Maximum Sustainable Yield
Length
Year

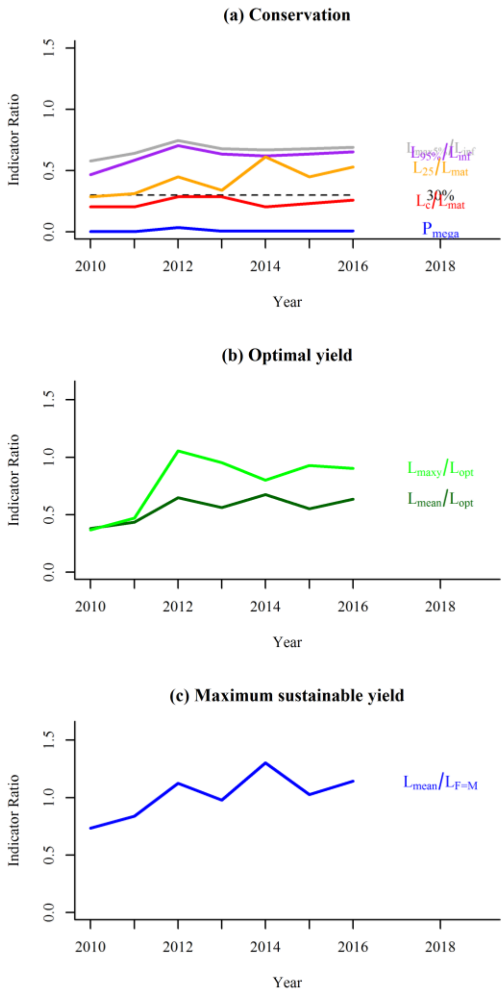



**Figure 9**: Indicators, reference points and indicator ratios for thornback ray caught by all gears in subarea 4 and division 7.d.

**Starry smooth-hound in the Northeast Atlantic:** LBI for starry smooth-hound using data from netters and otter trawls showed differences in status for all components of the stock except small individuals, where both indicator ratios failed to meet expected values.

**Table 13**: LBI for starry smooth-hound in the Northeast Atlantic. Cells in green indicate those indicators that meet expectations (see Table 2) and theoretically represent 'good' status.

**Starry smooth-hound_all gears**

| Year | Lmax5_Linf | L95_Linf | Pmega | L25_Lmat | Lc_Lmat | Lmean_Lopt | Lmaxy_Lopt | Lmean_LFeM |
|---|---|---|---|---|---|---|---|---|
| 2010 | 0.87 | 0.83 | 0.17 | 0.58 | 0.21 | 0.81 | 1.06 | 1.51 |
| 2011 | 0.88 | 0.79 | 0.11 | 0.52 | 0.34 | 0.7 | 1 | 1.11 |
| 2012 | 0.85 | 0.75 | 0.13 | 0.64 | 0.15 | 0.82 | 1 | 1.68 |
| 2013 | 0.85 | 0.79 | 0.11 | 0.64 | 0.34 | 0.79 | 1 | 1.26 |
| 2014 | 0.81 | 0.75 | 0.07 | 0.58 | 0.27 | 0.77 | 1.06 | 1.33 |
| 2015 | 0.85 | 0.79 | 0.1 | 0.7 | 0.21 | 0.84 | 0.88 | 1.57 |
| 2016 | 0.93 | 0.87 | 0.26 | 0.89 | 0.89 | 1.06 | 1 | 1.02 |

**Starry smooth-hound_netters**

| Year | Lmax5_Linf | L95_Linf | Pmega | L25_Lmat | Lc_Lmat | Lmean_Lopt | Lmaxy_Lopt | Lmean_LFeM |
|---|---|---|---|---|---|---|---|---|
| 2010 | 0.89 | 0.87 | 0.33 | 0.95 | 0.46 | 1.03 | 1 | 1.44 |
| 2011 | 0.94 | 0.91 | 0.3 | 0.89 | 0.58 | 0.99 | 1 | 1.23 |
| 2012 | 0.91 | 0.87 | 0.33 | 0.95 | 0.34 | 1 | 1.06 | 1.6 |
| 2013 | 0.9 | 0.87 | 0.34 | 0.89 | 0.34 | 0.99 | 1.06 | 1.58 |
| 2014 | 0.87 | 0.83 | 0.14 | 0.7 | 0.34 | 0.87 | 0.94 | 1.38 |
| 2015 | 0.93 | 0.91 | 0.36 | 0.82 | 0.27 | 0.99 | 1.18 | 1.71 |
| 2016 | 0.97 | 0.91 | 0.41 | 0.95 | 0.52 | 1.06 | 1.12 | 1.39 |

**Starry smooth-hound_otter trawls**

| Year | Lmax5_Linf | L95_Linf | Pmega | L25_Lmat | Lc_Lmat | Lmean_Lopt | Lmaxy_Lopt | Lmean_LFeM |
|---|---|---|---|---|---|---|---|---|
| 2010 | 0.86 | 0.79 | 0.13 | 0.52 | 0.21 | 0.73 | 1.06 | 1.37 |
| 2011 | 0.78 | 0.71 | 0.04 | 0.46 | 0.34 | 0.58 | 0.64 | 0.93 |
| 2012 | 0.84 | 0.75 | 0.12 | 0.64 | 0.52 | 0.83 | 1 | 1.09 |
| 2013 | 0.79 | 0.71 | 0.05 | 0.58 | 0.52 | 0.74 | 1 | 0.97 |
| 2014 | 0.76 | 0.71 | 0.04 | 0.52 | 0.52 | 0.74 | 1.06 | 0.97 |
| 2015 | 0.76 | 0.71 | 0.04 | 0.7 | 0.21 | 0.8 | 0.88 | 1.5 |
| 2016 | 0.82 | 0.75 | 0.09 | 0.76 | 0.82 | 0.97 | 1 | 0.98 |

The optimal yield ratio $L_{mean}/L_{opt}$ indicated that netters generally fished at the optimal length, while otter trawlers fished below. This shift towards smaller individuals by otter trawls was confirmed by the values of indicator ratios for the conservation of large and small individuals, and a shift of length distributions to the left (Figures 3–4). The differing selectivities of the fleets cause netters to ostensibly meet conditions for 'conservation' and 'sustainability', where otter trawls failed to do so. LBIs applied to all gears were influenced by data from both otter trawls and netters, and therefore gave an intermediate perception of status.

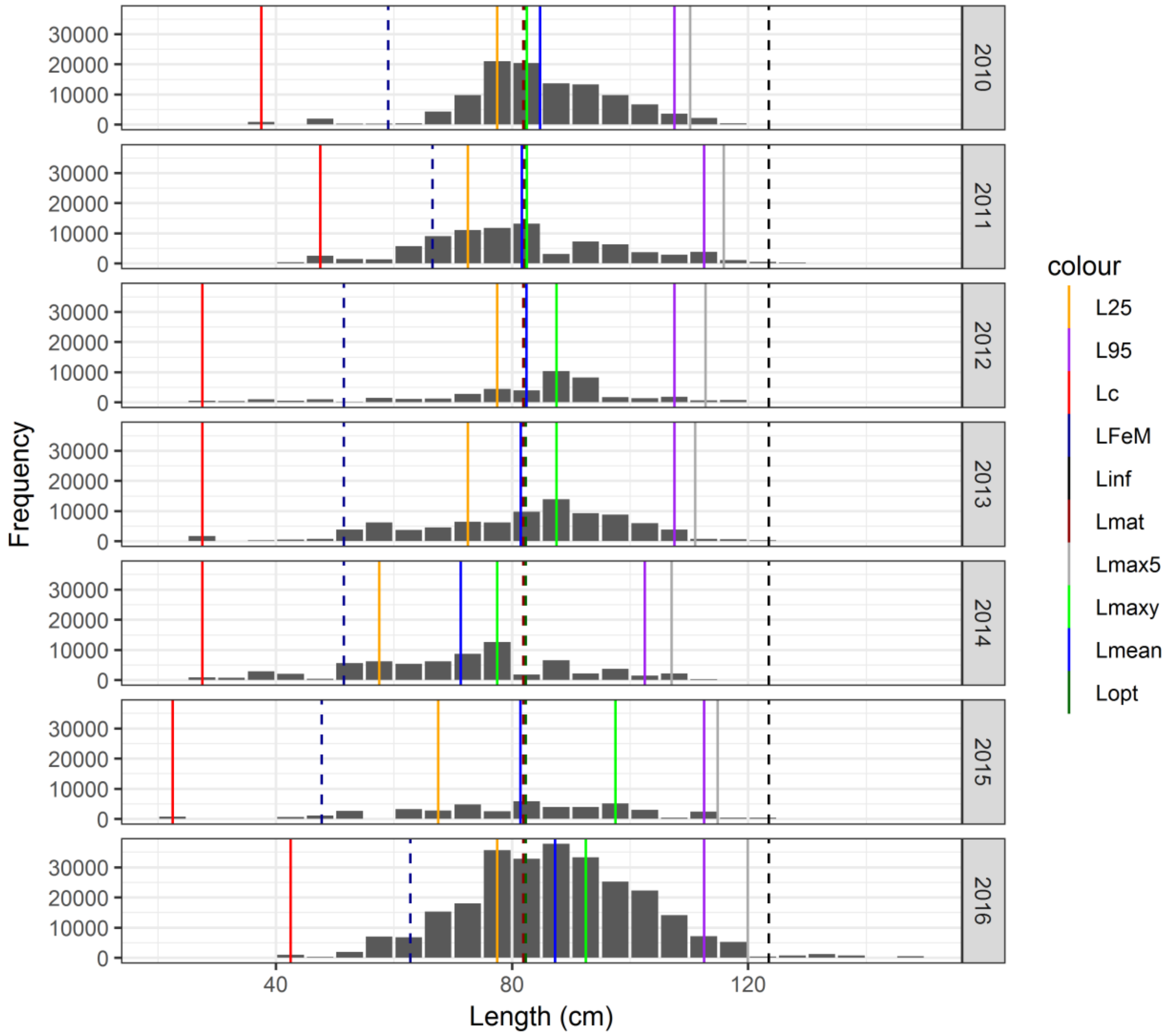



**Figure 10**: Length frequency of starry smooth-hound in the Northeast Atlantic caught by netters, with indicators (solid vertical line) and reference points (dashed vertical lines).

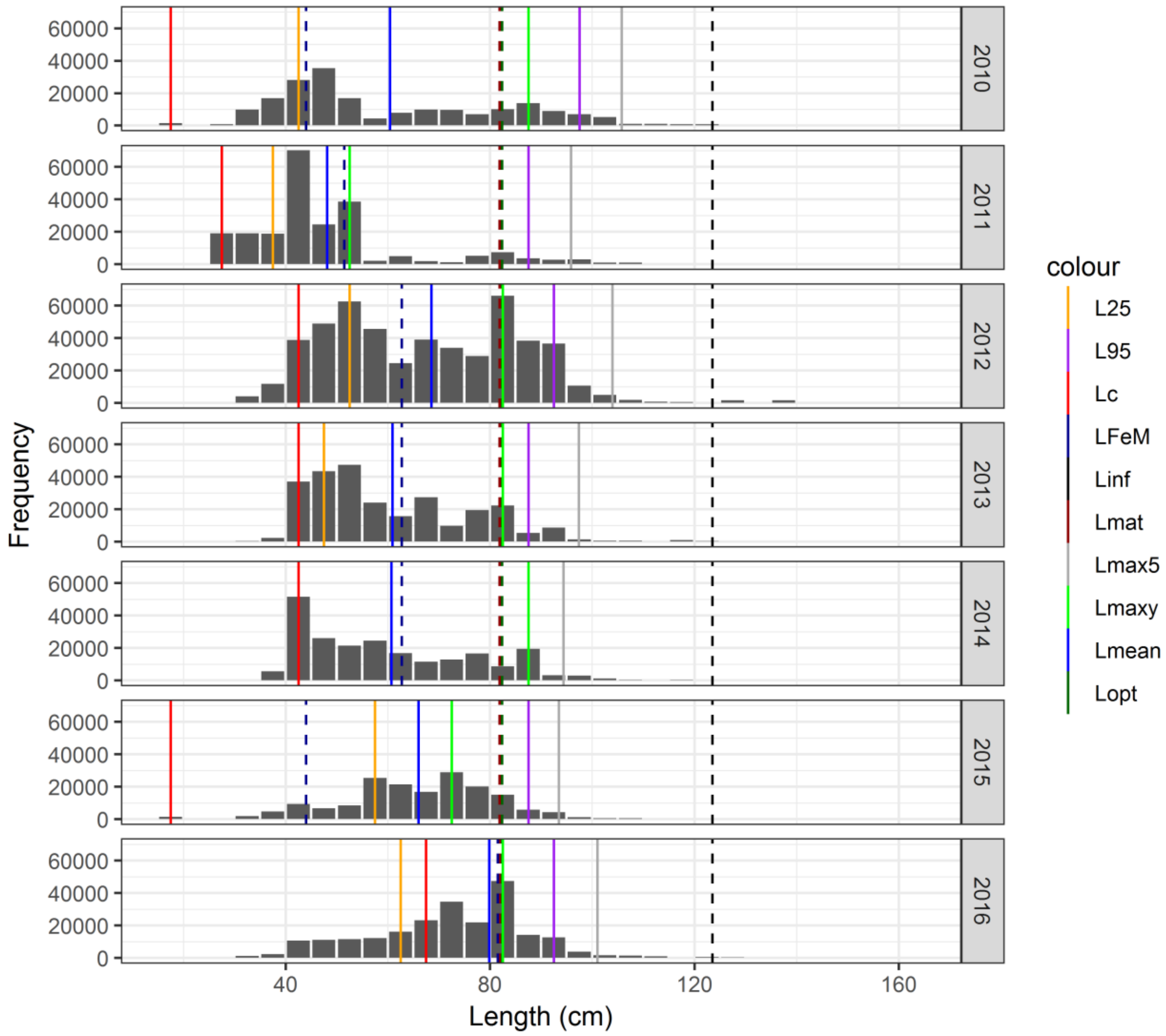



**Figure 11**: Length frequency of starry smooth-hound in the Northeast Atlantic caught by otter trawl, with indicators (solid vertical line) and reference points (dashed vertical lines).

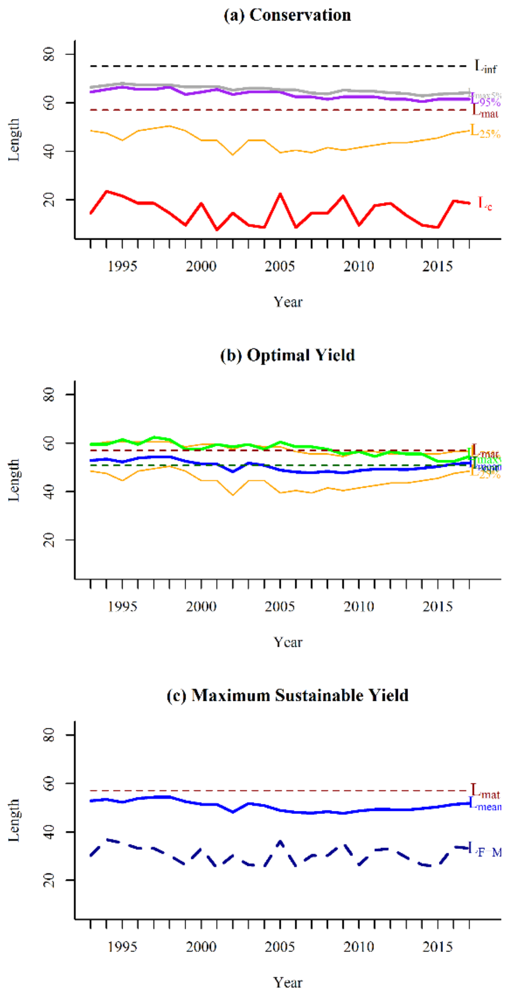
**Lesser-spotted dogfish in divisions 7.a and 7.f–g:** LBI show the stock to be in a "poor" state with regards to the conservation of small individuals but meeting MSY expectations. LBI for other components of the stock have conflicting views of status.

**Table 14**: LBI for lesser-spotted dogfish in divisions 7.a and 7.f-g. Cells in green indicate those indicators that meet expectations (see Table 2) and theoretically represent 'good' status.

| **Lesser spotted dogfish** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Lmax5_Linf | L95_Linf | Pmega | L25_Lmat | Lc_Lmat | Lmean_Lopt | Lmaxy_Lopt | Lmean_LFeM |
| 1993 | 0.88 | 0.86 | 0.45 | 0.85 | 0.25 | 1.04 | 1.17 | 1.75 |
| 1994 | 0.9 | 0.87 | 0.48 | 0.83 | 0.41 | 1.05 | 1.17 | 1.45 |
| 1995 | 0.91 | 0.89 | 0.43 | 0.78 | 0.38 | 1.03 | 1.21 | 1.48 |
| 1996 | 0.9 | 0.87 | 0.46 | 0.85 | 0.32 | 1.06 | 1.17 | 1.62 |
| 1997 | 0.9 | 0.87 | 0.51 | 0.87 | 0.32 | 1.07 | 1.23 | 1.64 |
| 1998 | 0.9 | 0.89 | 0.48 | 0.89 | 0.25 | 1.07 | 1.21 | 1.8 |
| 1999 | 0.89 | 0.85 | 0.37 | 0.85 | 0.17 | 1.03 | 1.13 | 1.98 |
| 2000 | 0.89 | 0.86 | 0.4 | 0.78 | 0.32 | 1.01 | 1.13 | 1.55 |
| 2001 | 0.89 | 0.87 | 0.44 | 0.78 | 0.13 | 1.01 | 1.17 | 2.05 |
| 2002 | 0.87 | 0.85 | 0.33 | 0.68 | 0.25 | 0.95 | 1.15 | 1.6 |
| 2003 | 0.88 | 0.86 | 0.46 | 0.78 | 0.17 | 1.02 | 1.17 | 1.95 |
| 2004 | 0.88 | 0.86 | 0.35 | 0.78 | 0.15 | 1 | 1.13 | 1.97 |
| 2005 | 0.87 | 0.86 | 0.36 | 0.69 | 0.39 | 0.96 | 1.19 | 1.35 |
| 2006 | 0.87 | 0.83 | 0.26 | 0.71 | 0.15 | 0.95 | 1.15 | 1.87 |
| 2007 | 0.85 | 0.83 | 0.24 | 0.69 | 0.25 | 0.94 | 1.15 | 1.58 |
| 2008 | 0.85 | 0.82 | 0.23 | 0.73 | 0.25 | 0.95 | 1.13 | 1.6 |
| 2009 | 0.87 | 0.83 | 0.2 | 0.71 | 0.38 | 0.94 | 1.09 | 1.35 |
| 2010 | 0.86 | 0.83 | 0.26 | 0.73 | 0.17 | 0.96 | 1.11 | 1.84 |
| 2011 | 0.86 | 0.83 | 0.26 | 0.75 | 0.31 | 0.97 | 1.07 | 1.52 |
| 2012 | 0.85 | 0.82 | 0.23 | 0.76 | 0.32 | 0.97 | 1.11 | 1.48 |
| 2013 | 0.85 | 0.82 | 0.23 | 0.76 | 0.24 | 0.96 | 1.09 | 1.66 |
| 2014 | 0.84 | 0.81 | 0.21 | 0.78 | 0.17 | 0.98 | 1.09 | 1.87 |
| 2015 | 0.85 | 0.82 | 0.24 | 0.8 | 0.15 | 0.99 | 1.03 | 1.95 |
| 2016 | 0.85 | 0.82 | 0.25 | 0.83 | 0.34 | 1.01 | 1.03 | 1.51 |
| 2017 | 0.85 | 0.82 | 0.26 | 0.85 | 0.32 | 1.02 | 1.07 | 1.56 |

LBI charactering the upper portion of the length-frequency distributions in comparison to $L_\infty$ showed a healthy presence of larger individuals throughout the entire time-series. $P_{mega}$ and the optimal yield LBI showed a slight shift towards smaller individuals, with $P_{mega}$ falling below the expected value of 0.3 from 2006 onwards. Interestingly, as $P_{mega}$ fell to 'unhealthy' levels, $L_{maxy}/L_{opt}$ indicated a shift from targeting individuals that were too large to targeting at the optimal length, while $L_{mean}/L_{opt}$ indicated targeting at the optimal length throughout the time series. This conflict between $P_{mega}$ and $L_{maxy}/L_{opt}$ is unlikely to be related to gear selectivity, as data were from a standardised trawl survey. Time-series plots revealed all indicators (apart from the estimated $L_c$) to be relatively stable over the

25-year time series (Figure 5). The reference point $L_{F=M}$ was highly variable and fell well below indicator $L_{mean}$; a consequence of calculating $L_{F=M}$ from $L_c$.


(a) Conservation
Length
Year
(b) Optimal Yield
Length
Year
(c) Maximum Sustainable Yield
Length
Year

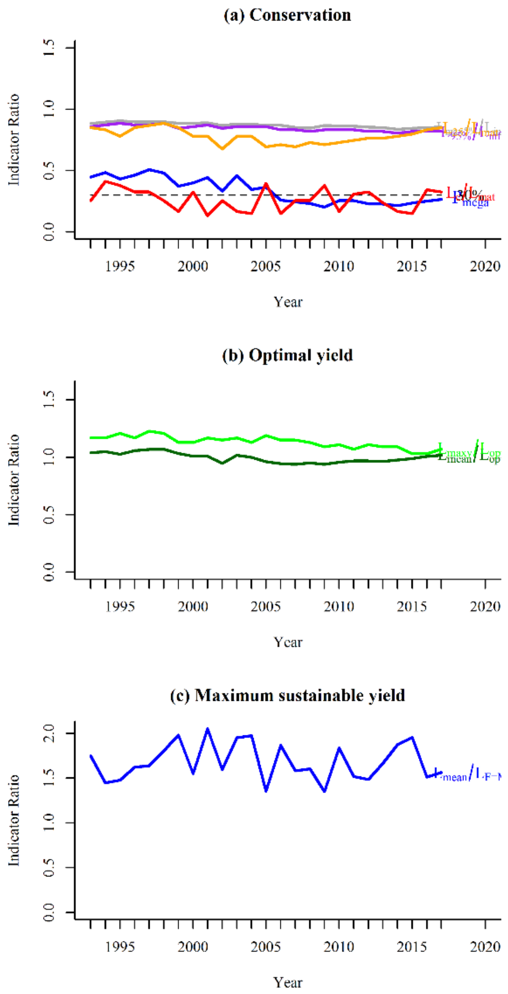



**Figure 12**: Indicators, reference points and indicator ratios for lesser-spotted dogfish in divisions 7.a and 7.f-g.

## DISCUSSION

As with all models, the quality of the input data will influence the quality of the results. Using the data from the UK England and Wales Observer at Sea program, it is likely that there may have been some issues regarding the raising factors. There appeared to be several cases within the available data where certain length classes may have been over represented (See Figure A1 – year 2013). This becomes particularly problematic when calculating LBI's that are reliant on such length frequency data.

There were also some issues relating to having sufficient data with which to draw robust conclusions. For several species sampled in the UK England and Wales Observer at Sea program, it was necessary to combine the results from gears, or collate data across several years in order to apply the model. In doing so, using trends in LBIs to draw conclusions on the effect of fishing will be problematic, unless this collation of data is applied consistently over longer time periods (e.g. every two years over a period of 10 years or more).

In addition to issues of raising factors from variable sample sizes, there are potential issues in relation to the spatial, temporal variability and range of vessels that have been sampled over time. This is particularly relevant to elasmobranchs, which often show sex- and size-based aggregations and segregation. Future studies could usefully examine the raw data to determine whether a more consistent subset of the data (e.g. in terms of fleet, fishing ground and seasonal coverage) can give a more reliable temporal source of standardised data with which to examine temporal change (i.e. minimising potential bias from spatial, temporal and gear related differences in the data). If the development of LBIs requires a more consistent data set (at least for some species), then there may need to be consideration of a "reference fleet" to allow for the collection of more standardised data.

The current ICES assessments for the case study species are generally based on survey trends (Category 3), and so the utility of LBIs to provide additional demographic information when evaluating stock status is a potentially useful tool for managers. It should also be noted, however, that spatial metrics for such stocks may also be informative. Further analyses of spatial information may also inform on the most reliable sources of observer data for the better refinements of input data for LBIs.

For larger bodied fish, the current model approach to estimating $L_C$ will invariably be at a smaller size than $L_{mat}$ and therefore the estimation of $L_C$, which was also highly variable, always suggested 'poor' status in the current case studies. Consequently, this metric may not be appropriate for elasmobranchs and other large bodied fish. There should be consideration for adopting a different approach to estimating first capture, or basing reference points and indicator ratios on more consistent metrics, possibly the $L_{25\%}$ for smaller fish.

The estimation of $L_c$ will impact MSY status, as RP $L_{F=M}$ is calculated from $L_c$ (Table 2). This can be seen in the LBI of lesser-spotted dogfish where the low, variable nature of $L_c$ is reflected in $L_{F=M}$ (Figure 5). Low estimations of $L_c$ will lower the value of $L_{F=M}$ which will in turn increase the ratio $L_{mean}$/ $L_{F=M}$, potentially giving over-optimistic MSY status. This appeared to be evident for both blonde and thornback rays, where MSY status was considered 'good', despite the failure of other LBIs to meet the expectations of a 'healthy' stock. $L_{25\%}$ seemed a more stable indicator for small individuals, and could therefore be considered a proxy for length at first capture in the calculation of $L_{F=M.}$

Application of the LBIs revealed inconsistencies in status between indicators describing the same properties when applied to the same data. There was a tendency for $L_{maxy}$ to be higher than $L_{mean}$, often giving conflicting status when describing optimal yield in the traffic light assessment. Differences in status also occurred when looking at indicators describing the conservation of large (e.g., starry smooth-hound caught by all gears) and small (e.g., cuckoo ray caught by netters) individuals. Consideration should be given to which indicator is most appropriate for the species (and fishery).

There were some cases where the traffic light assessment revealed too low a proportion of mega spawners, even when indicators compared to $L_\infty$ revealed a healthy presence of large individuals. For lesser-spotted dogfish $P_{mega}$ fell below the expected value of 0.3 while other indicators relating to large individuals remained at expected levels and $L_{maxy}$/$L_{opt}$ shifts indicated targeting at the optimal length. This contradiction in status requires further study. The expectation that $P_{mega}$ > 0.3 assumes asymptotic selection. If selection is dome-shaped then lower values of $P_{mega}$ are desirable, following the fishing strategy where no mega-spawners are caught. Hence, due consideration should be given to fishery selection when defining appropriate reference points.

Given the large size of elasmobranchs and the late age at maturity, LBI based on length at first capture ($L_c$ and $L_{25\%}$) invariably highlight that this occurs before fish mature. It is considered unlikely to have a mixed fishery that captures elasmobranchs to meet these indicators, and a simulation study suggests targeting a few year classes of immatures to be a more robust strategy for elasmobranchs (Prince, 2005). The RPs adopted by ICES were derived primarily for teleost and shellfish stocks (Froese, 2004; Miethe and Dobby, 2015). It is likely that these RPs will need to be adjusted for fishes with contrasting life history (e.g., Shephard *et al.*, 2018).

The current case studies often provided mixed results from the various LBIs, and so there could be consideration of having more categories than red/green, and also consideration of trend-based metrics until appropriate reference points are validated.

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## Appendix – raw length frequency plots

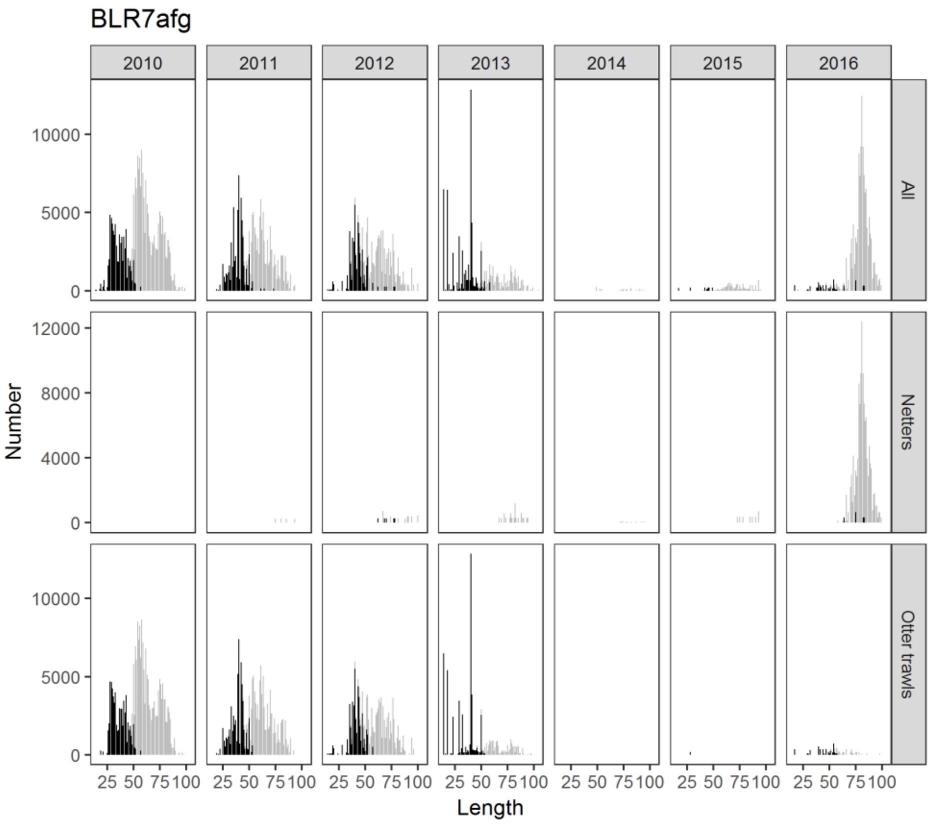


**Figure A1**: Raw length-frequency plots for blonde ray in divisions 7.a and 7.f-g showing landings (grey) and discards (black).

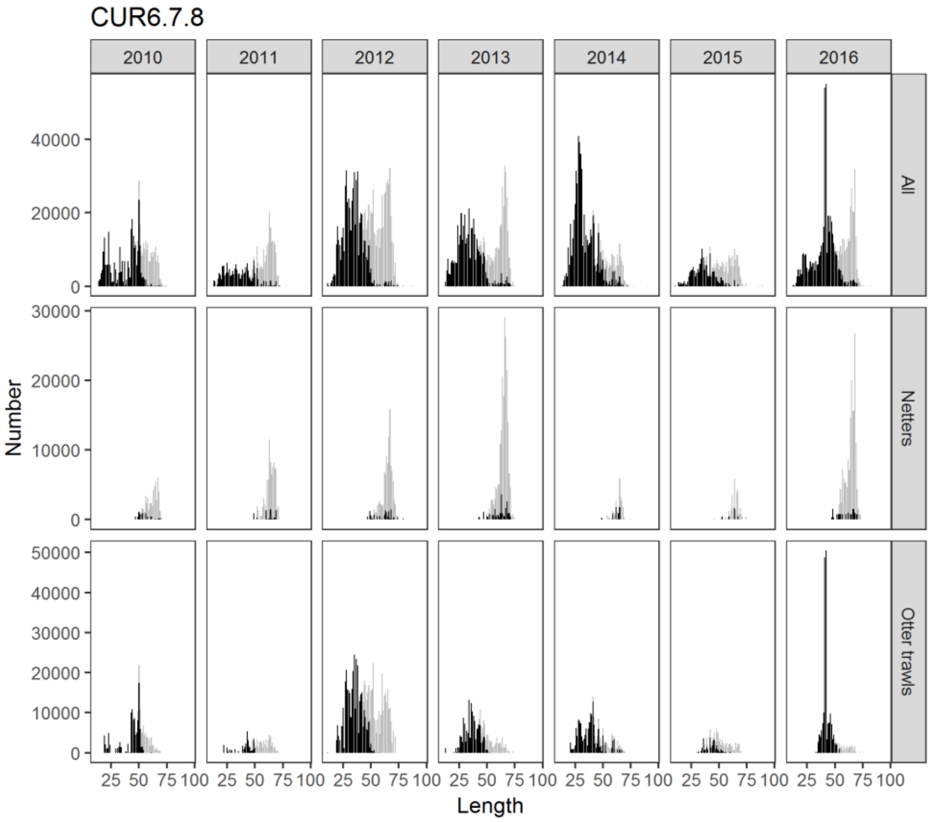


**Figure A2**: Raw length-frequency plots for cuckoo ray in subareas 6, 7 and 8 showing landings (grey) and discards (black).

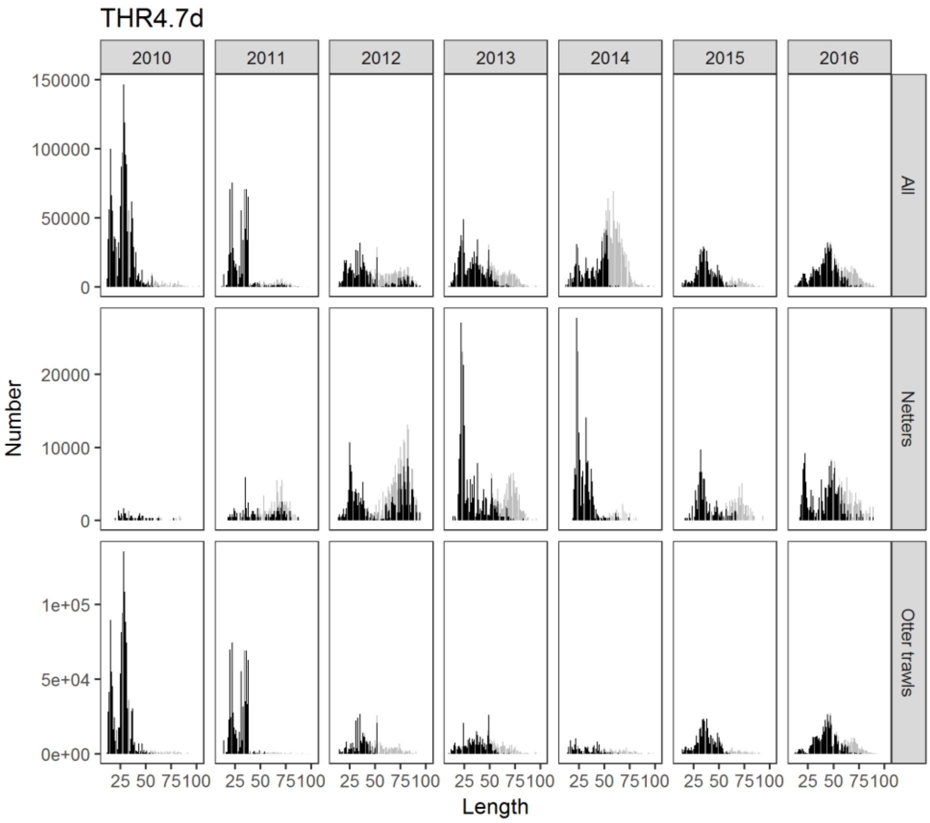


**Figure A3**: Raw length-frequency plots for thornback ray in subarea 4 division and 7.d showing landings (grey) and discards (black).

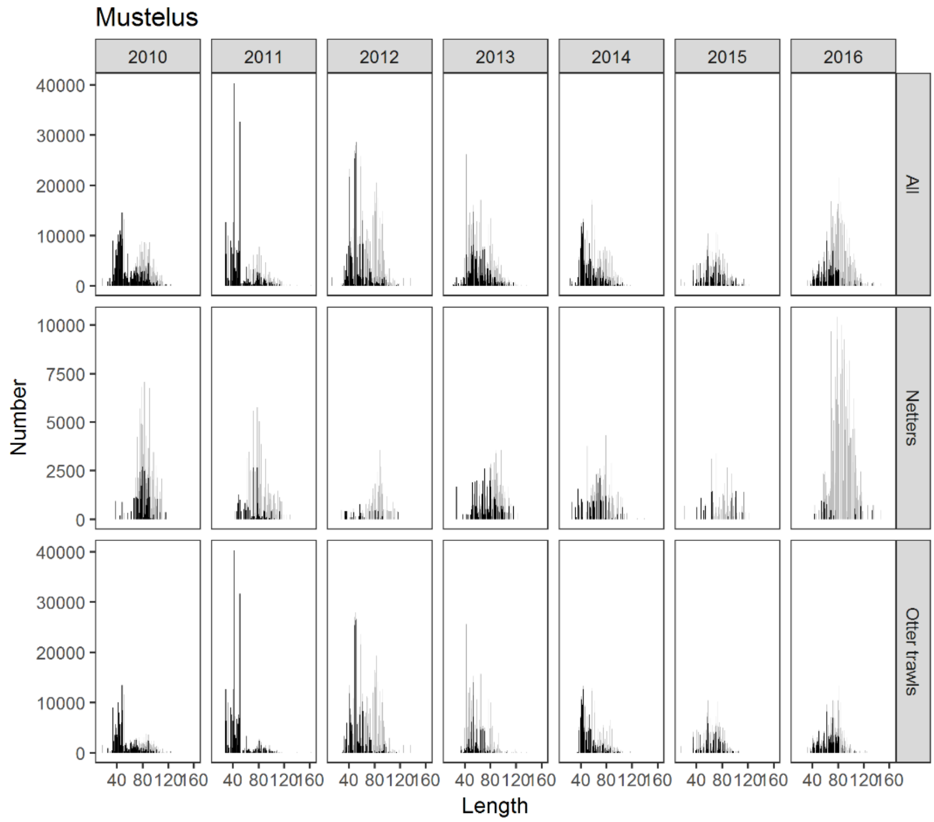


**Figure A4**: Raw length-frequency plots for starry smooth-hound in the Northeast Atlantic showing landings (grey) and discards (black).

**WORKING DOCUMENT 03**

Spatial distribution of commercial catch in Irish on-board observations.

Graham Johnston, Marine Institute, Ireland.

**Working Document to the Workshop on Length-Based Indicators and Reference Points for Elasmobranchs (WKSHARKS4). 06 February 2018**

Irish on-board observer data was collected from 2002-2017 under the Data Collection Regulation. These data have been analysed using the same methodology, and using the same length thresholds as Lorrance 2018. It is intended that using similar methodology will allow similar conclusions to be drawn across fleets by WKSHARKS.

Data for three species, *Leucoraja naevus,* cuckoo ray*, Raja montagui,* spotted ray, and *Raja clavata,* thornback ray are presented here. It was determined that there was insufficient observations of Raja brachyura, blonde ray, to infer differences in spatial distribution of juveniles and adults.

**Cuckoo Ray**

Using the same size thresholds as were used by the French figures, Figure 1 below was plotted. This showed fewer juveniles caught along the shelf edge, although the proportions of juveniles and larger fish was similar in the Celtic Sea. This implies that the same conclusions can be drawn from these data***, viz.*** all life stages seem to have similar distribution with juveniles occurring in the deeper range of the species and larger individuals being more spread towards shallower waters.

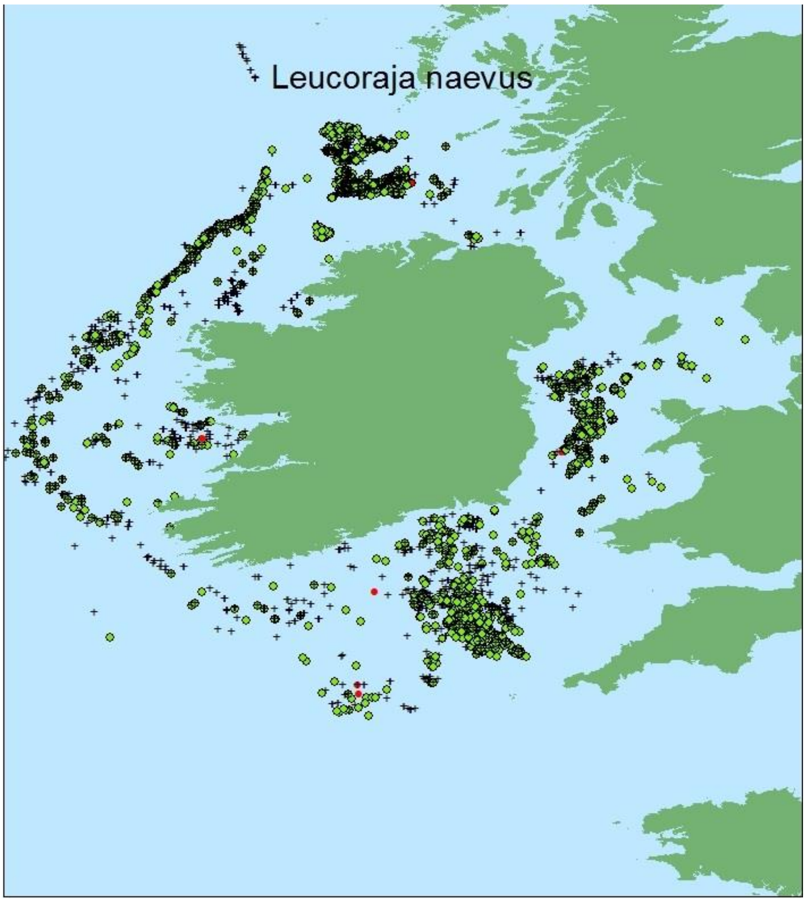


**Figure 1**. Spatial distribution of cuckoo ray in Irish on-board distribution. Black "+": fishing operations with catch of cuckoo ray, green dots: fishing operation with catch of thornback ray smaller than 40 cm, red dots: fishing operation with catch of thornback ray smaller than 20 cm.

**Thornback ray**

These data (2). show that both juveniles and adults appear to be caught with similar frequencies with little spatial difference when looked at over a large scale. Smaller-scale stock assessment e.g., examining thornback ray within the Irish Sea only (7a) shows that the eastern Irish Sea has a higher proportion of juveniles than the western Irish Sea. Therefore the scale of the area being assessed needs to be taken into consideration.

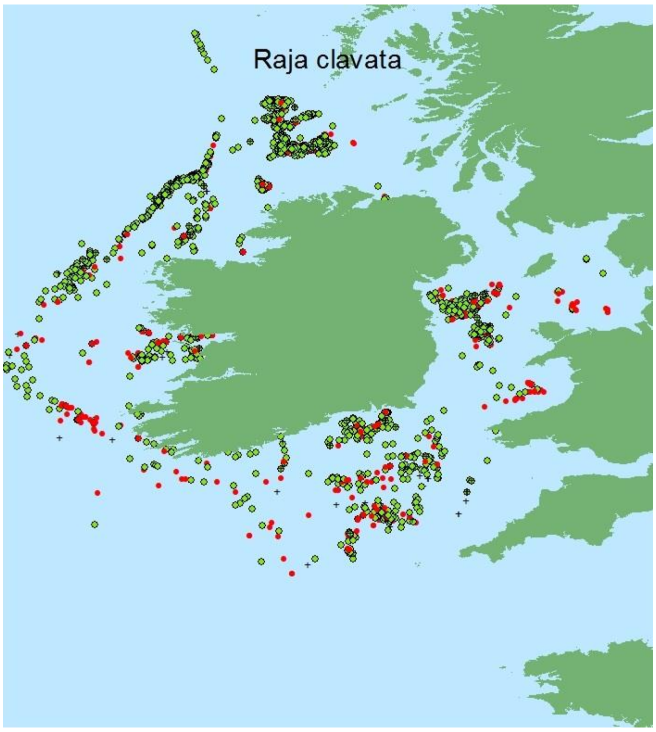


**Figure 2** Spatial distribution of thornback ray in Irish on-board observations. Black "+": fishing operations with catch of thornback ray, green dots: fishing operation with catch of thornback ray smaller than 78 cm, red dots: fishing operation with catch of thornback ray smaller than 39 cm.

**Spotted ray**

Spotted ray (Figure 3) shows a similar pattern to thornback ray (Figure 3.13), in that there are distinct areas such as the northern Irish Sea where there are higher proportions of juveniles than adult fish. This again shows that spatial variation needs to be taken into account when using length-based indicators for this stock.

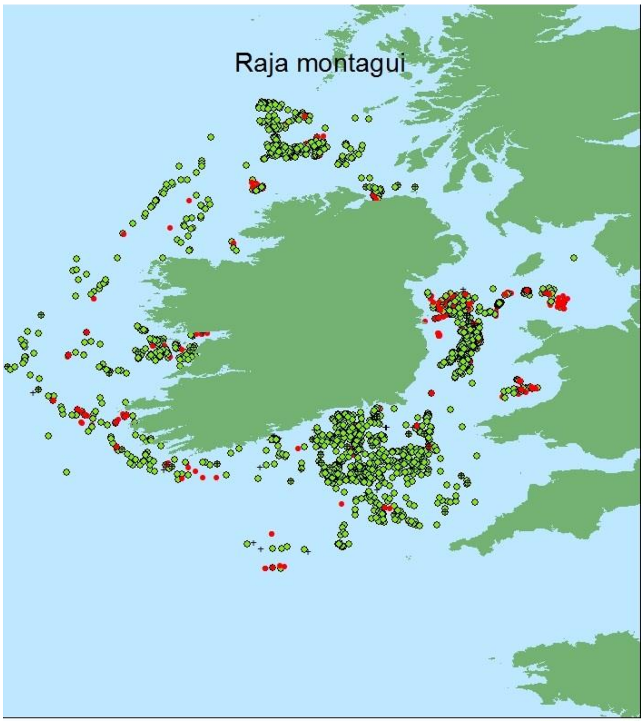


**Figure 3.** Spatial distribution of spotted ray (Raja montagui) in Irish on-board distribution. Black "+": fishing operations with catch of spotted ray, green dots: fishing operation with catch of spotted ray smaller than 62 cm, red dots: fishing operation with catch of spotted ray smaller than 31 cm.

**Reference:**

Lorrance, P. 2018. Spatial distribution of commercial catch in French on-board observations. Working Document to the Workshop on Length-Based Indicators and Reference Points for Elasmobranchs (WKSHARKS4). 06-10 February 2018. Nantes, France. 12pp