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Stock Assessments of Elasmobranchs in the North-East Atlantic: Making the Most of the Data

(Elasmobranch Fisheries – Oral)

by

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Abstract

Elasmobranch species in the North-East Atlantic have rarely been assessed over the past decades. A European research project (DELASS) has been initiated in 2000 to remedy this deficiency. A number of case study species were chosen from the rays, the coastal sharks, the deepwater sharks and the pelagic sharks. With the available data that could be collected from the partners in the project stock assessment models of very different scope and complexity have been applied. Initial results of the assessments are summarized in the paper. Implications for further research and for the management of elasmobranch species are discussed.

Introduction

Management of elasmobranch species is difficult because many elasmobranchs are taken in multispecies fisheries as by-catch (Hoenig, 1990). However, elasmobranch species are increasingly in the centre of attention in management plans concerning biodiversity (e.g. OSPAR, FAO). In spite of the lack of knowledge on the precise abundance of these species, it is recognized in many instances they are highly vulnerable to fishing operations and may run the risk of extinction once a directed fishery develops on that species. The need to acquire sufficient biological data and to develop appropriate assessment techniques is therefore of paramount importance.

It has been generally accepted that stock assessments of elasmobranch species are difficult to obtain. This is due to several reasons, e.g. life history characteristics of elasmobranchs, relatively low production, lack of biological data, lack of fisheries data, lack of validated age estimates and lack of suitable models. Often we are faced with data-poor situations which the assessment models at hand cannot handle. However, the number of papers on the issue of stock assessment for elasmobranch species appears to be increasing in the last decade. Stock assessment models can be distinguished according to either the type of data they require or the level of biological realism they attain (Table 1).

A subdivision of stock assessment models based on the type of data required could be:

- Life history models
- Survey-only models
- Commercial catch data models
- Mark-recapture models

When subdivided into the level of biological realism:

- Life history models
- Total abundance based models
- Length structured models

- Age structured models

In this paper I explore the possibilities of applying stock assessment models to a selected number of elasmobranch species, predominantly in the North-East Atlantic. This work is part of an international research project Development of Elasmobranch Assessments (DELASS, CFP 99/055) in which 15 European research institutes collaborate. The arguments for the selection of the case study species will be presented and the general process of matching the models to the data for each case study species. Although this paper is written by only one person, it relies on the work of many colleagues in the DELASS project.

Material and Methods

Stock assessment data for elasmobranch species in the North East Atlantic is generally scarce. This is due to incomplete sampling, divergent practices at sea and – historically – a lack of interest when compared to commercially exploited teleost species. However, in this study, the scarcity of the data is at the same time a barrier and an opportunity. The DELASS project aims to explore the possibilities of assessing the state of elasmobranch stocks irrespective of the amount of detail in the available data. In other words, it aims to say the most with the data at hand.

Nine case study species were selected for analysis. The choice for these species was based on a number of criteria (Table 2):

- spatial extent of distribution (local - North-east Atlantic)
- production types (oviparous-viviparous)
- data availability (poor-good)
- commercial importance (medium-high)
- habitat type (pelagic - shelf - deep)

The final list of case study species consisted of the following species:

species group	**species**	**english name**	**area**
pelagic sharks	*Prionace glauca*	Blue shark	N Atl.
coastal dogfish & catsharks	*Squalus acanthias* *Scyliorhinus canicula*	Spurdog Lesser spotted dogfish	NE Atl. Cantabrian Sea
skates and rays	*Raja clavata* *Leucoraja naevus*	Thornback ray Cuckoo ray	North Sea Celtic Sea
deepwater sharks	*Centroscymnus coelolepis* *Centrophorus squamosus* *Dalatias licha* *Galeus melastomus*	Portugese dogfish Leaf-scale gulper shark Kitefin shark Blackmouth catshark	N Atl. N Atl. N Atl. Azores

In this paper the stock assessments of the kitefin shark and blackmouth catshark will not be considered because the analysis have not been completed.

The intention within the DELASS project (2000-2002) was to apply assessment models to the data that was available within different research institutes. However, for a number of stocks there has been a limited amount of market sampling, for example when it was unclear what the species composition in the landings was. Also, an inventory was written of the available assessment methods and some applications to elasmobranch stocks all over the globe (Pastoors *et al*., 2000). The assessment methods were summarized in terms of input requirement and output deliverables. The stage of actually applying the methods to the data collated within the DELASS project was carried out within the ICES Study Group on Elasmobranch Fishes, which met in May 2002 in Copenhagen (ICES, 2002a).

Results

Blue shark (Prionace glauca) in the North Atlantic

Blue shark represents a case study on a pelagic, wide ranging, life-bearing species, with uncertain data availability, high commercial importance. Blue shark is a by-catch in many fisheries for tunas and billfishes. There is no large-scale directed fishery for blue shark. Available landings data may not indicative of stock trends because a variable part of the catch is discarded. ICCAT collects and collates catch and landings statistics from these commercial fisheries. These data are not complete at present. There are recreational fisheries for the species in the USA, Ireland and the UK. Blue sharks are also caught incidentally in the Canadian porbeagle fishery (Bonfil, 1994).

The data available for the assessment of blue shark would, in theory, consist of the following categories: life history data, landings and discards data, CPUE data and tagging data. However, the tagging data from the USA were not yet available to the DELASS group and the Irish tagging data for blue sharks (Fitzmaurice and Green, 2000) will only be compiled in 2002. Also the landings and discards data are not yet available. In principle the following analysis were foreseen for blue shark: life table model, catch curve analysis and Petersen estimates from tagging studies. Because of the limited data availability only the life table model could be parameterized at present.

Results of the life table model indicate that the values of **r** ranges from 0.03 to 0.24 while the most likely value, given the present knowledge, is 0.18. The results suggested that accurate estimates of survival are relatively more important than accurate estimates of fecundity for evaluating this species using demographic techniques. Life span (maximum age) and its effect on estimates of natural mortality also have a relatively large effect on the estimated demographic parameters. The values found are considerably lower than the estimates reported by Cortes (in prep) who used a stochastic life table analysis.

Spurdog (Squalus acanthias) in Sub-areas IV, VI and VII

Spurdog represents a case study on a shelf species that is wide ranging (Northeast Atlantic) and life bearing, with good data availability and high commercial importance. Spurdog is a relatively small (<130 cm length) squaliform shark that is target of one of the most important directed fisheries for elasmobranchs in the North-east Atlantic. During the 1950s and 1960s, landings of spurdog in the North Sea increased rapidly and total annual landings rose to 58 000 tons during the 1960s. During the 1980s, long-line fisheries for spurdog became relatively important in the Irish Sea, with boats targeting shoals of large females. This fishery subsequently declined. Spurdog are currently taken in mixed demersal fisheries (e.g. otter trawls) and also in gill nets, where they may be the target species. Since the late-1980s, total landings of spurdog have declined and more recent catches (1997-1999) have been around 15 000 tons per year.

Spurdog is a relatively well known species and there is a considerable quantity of published information on its biology. The reproductive biology is well documented and there are many estimates of size at maturity, gestation period, fecundity, size at birth and sex ratio of pups. Age and growth data are available, although validation of ages using dorsal fin spines is uncertain and published results should be used with caution. Several thousands spurdog have been tagged in the late-1950s and 1960s, and these data have been used to interpret the stock structure and could be used to provide supporting evidence for growth models or total levels of mortality.

The available landing statistics for "dogfish" over the period 1905-1960 are likely to be composed primarily of spurdog and, though data prior to 1932 do not include landings from Norway or France, these statistics are probably representative of spurdog landings during that period. After 1961, landings of spurdog were identified separately. The UK has an extensive data set of length-frequency data (by sex) from commercial fisheries. Discards information is available for some recent areas. Several survey data series are available for spurdog from 1970 onwards. Survey data consists of CPUE (numbers and biomass by sex) and length-frequencies (by sex).

Although for this species, the available data would allow a wide spectrum of assessment models, the following approaches have been explored so far:

- Trends in length-frequency of commercial landings
- Trends in survey CPUE

- Slicing of the length distributions using growth parameters derived from the literature and they applying catch-curves or separable VPA
- Catch at length analysis
- Bayesian assessment using a stock production model, with a prior for the intrinsic rate of increase set by demographic methods.

Analysis of the length frequency data from UK (England and Wales) commercial sampling showed that the length range of the frequency distributions has not changed substantially over the period 1983-2001. There appears to have been no reduction in the prevalence of larger, older, females in the landings. Under the assumption of constant selection at length, an analysis of the time series of mean length in the catch and survey data was carried out to examine trends that might indicate whether the level of exploitation has altered the structure of the length distributions. For each sex, the analyses showed an increasing mean length in the commercial catch distributions whereas in the surveys this was only observed for the oldest ages. The differences between the survey and commercial length distributions at the youngest ages may result from spatial effects and more detailed analysis is required to resolve them.

Trends in CPUE from eight research survey series were plotted. The majority of the CPUE series exhibited a decline over the time series although a more northern survey indicated the opposite. The data is useful for assessment purposes but needs more analysis.

Under the assumption that the UK (E&W) length distribution data are representative of the composition of the total international landings from the spurdog fishery in ICES Sub-areas IV, VI and VII, the Von-Bertalanffy growth parameters derived from published parameters (Holden and Meadows, 1962; Holden and Meadows, 1964; Nammack *et al*., 1985; Fahy, 1988; Fahy, 1989), were used to slice the length distributions into age distributions. Catch curve analysis was used to estimate average F for the fully recruited ages, for each year of the time series and each sex. Both sexes show a reduction in total mortality (Z) throughout the time period. The results also illustrated the estimated rates of mortality were highly dependent on the growth parameters used for slicing. It was found that the published values of L_∞ lies well within the upper range of the length frequency distributions, so that substantial accumulations can occur in the plus group. A Separable VPA model (Pope and Shepherd, 1982) was fitted to the catch at age data set, assuming a value of 0.1 for M, a terminal age selection of 1.0 and a range of terminal F values (F = 0.5*M, M, 2M, 3M). The estimated fishing mortality rates indicated that the level of fishing mortality is low throughout the time series and that the mature population has declined.

The possibility of applying an entirely length-based method (Sullivan *et al*., 1990) was explored. This method uses a size-transition matrix approach to project the population length distribution forwards in time. The size-transition matrix is obtained from a stochastic growth model with known Von Bertalanffy growth parameters. Problems were encountered in the application of this method, again due to the fact that a large number of individuals in the catch were larger than the values of L_∞ obtained from the literature. The CASA model assumes that as length increases towards L_∞, the mean growth increment decreases to zero, which implies that growth beyond this length is impossible.

The methods of McAllister *et al*. (2001) were applied to spurdog, using demographic techniques to convert prior distributions for age-specific fecundity and natural mortality to prior distributions for r. The priors for **r** were then used in a Bayesian Schaefer stock production model fitted to research vessel survey data (CPUE) from England, Scotland and Northern Ireland. Given the relatively low catch levels prior to 1946 it was assumed that the population started from near carrying capacity K. In fitting the model it was assumed that each index *i* had its own catchability q_i and its own dispersion parameter s_i^2. These parameters were assigned non-informative priors, uniform in log space. The same prior was also used for Schaefer model parameter K. The Bayesian Schaeffer model indicated that landings since 1946 were above the maximum sustainable yield (MSY) and that there is a high probability (i.e. 73%) that less than 100 000 tons of spurdog are left at present. Thus the method, although dependent on a number of model assumptions, is able to provide probability statements about the state of the stock and trends in exploitation.

In conclusion: the analysis of the spurdog data by the method of slicing has established that the methodology can and should be taken forward to provide estimates of mortality rates and stock dynamics for the species. If the sensitivity of the results to the growth equations cannot be resolved by additional analysis (using tagging data, etc.), then the model will allow an evaluation of recent trends, but not absolute levels of those dynamics. The Bayesian approach seems to be a promising way to address the uncertainty in the underlying data and to transform that into estimates of uncertainty at the population level.

Lesser spotted dogfish (Scyliorhinus canicula) in the Cantabrian Sea (Division VIIIc)

Lesser spotted dogfish represents a case study on a shelf species that is local (Cantabrian Sea) and oviparous, with good data availability and medium commercial importance. It is taken in the demersal fishery along the north and north-west coasts of Spain (Cantabrian Sea) is a multispecies and multigear fishery where many species are caught with a great variety of gears. Most of the elasmobranchs species are taken as a by-catch of which the lesser spotted dogfish (*Scyliorhinus canicula*) is the most prominent. A study carried out in 1994 in the Cantabrian Sea revealed that almost the 90% of the total catch of lesser spotted dogfish were discarded. Landing statistics of lesser spotted dogfish have been compiled for the period 1996 to 2001, while for years before 1996, data are only available for some ports. For some fleet segments effort data is also available. Length compositions on board of commercial trawlers are only available for 2000 and 2001. For these years the length distributions from commercial vessels was very similar to the length distributions in the bottom trawl surveys. However, since most of the catch is discarded. Previous studies demonstrated that in the trawl fleet the discards of this specie can reach the 92% of the total catch. The length distribution of the surveys has therefore been used instead.. The mean size from the trawl surveys series shows a relatively constant pattern.

Bottom trawl survey data is available for the period 1991-2001 and shows that lesser spotted dogfish is quite abundant in the continental shelf and is one of the most important species in biomass terms after the commercial teleost species (blue whiting, horse mackerel, megrim, hake). A dogfish tagging program has been carried out since 1993. A total of 6 619 specimens have been tagged of which 162 have been recaptured to date

With the given availability of data, the following assessment approaches have been explored: surplus production model, separable VPA and survey-only separable model.

The available commercial fisheries and research vessel data on catch, effort and CPUE were used to carry out a dynamic (non-equilibrium) Schaefer surplus production model (Hilborn and Walters, 1992). The model was fitted to two datasets: one using only landings data and the other including dead discards (i.e. total removals). Observer estimates of discards for the years 1994, 1999 and 2000 indicated that between 77 and 93% of the catch was discarded (Perez *et al*., 1996). The estimates of discards at sea were translated to dead discards using experimentally obtained data on the survival of this species during research surveys which indicated that 70% of the fish survive for up to 6 hrs or more on deck (Rodriguez-Cabello *et al*., 2001). The CPUE calculated by the Schaefer model was fitted to the three available CPUE series (two commercial and one research survey). The model was implemented in a spreadsheet and the non-linear algorithm 'solver' was used to find the best parameter values for **K**, **r**, **q** and the initial biomass in 1991 (**B0**). The Schaefer model had a relatively good fit to the CPUE series when only landings data were considered. The Schaefer model predicted an increasing stock trend and the estimated model parameters were considered plausible (B0 = 226,146, r = 0.3832, K = 535,067). Although the estimates may appear reasonable, there is considerable uncertainty about the true values because a large combination of r and K values could predict equally well the various CPUE series. This is a function of the lack of contrast in the data (Hilborn and Walters, 1992). The inclusion of estimated dead discards only raised the estimates of **K** and **B0** but did not affect the dynamics.

Age based assessment methods were explored on catch-at-length data which was 'sliced' into age groups. The growth parameters were derived from (so far unpublished) tag-recapture data. Age 4 was adopted as reference age and the selectivity at age was dome shaped in all trials. Results from these initial explorations indicated a very low fishing mortality on this stock.

The last assessment method considered was the age based survey-only method (Cook, 1997). Age disaggregated abundance indices were obtained by slicing the length distributions from the Spanish bottom trawl survey. The model assumes that fishing mortality is separable into an age and year effect, and that the population size of a cohort at a given age can be expressed as the product of its initial cohort strength and its cumulative mortality. These parameters can then be used to obtain estimates of relative number at age, stock biomass and yield. An important assumption of this model is that the ratio between the survey catchabilities at age is known. Cook (1997) suggests that catchability (q) is assumed constant above a certain age and to adjust q on the youngest age by trial and error to give selectivity on the youngest age similar to that obtained from the conventional assessment. In the case of this stock, however, there is no conventional assessment and therefore difficulties arise in making choices about the validity of the estimated selectivity pattern and consequently the assumed catchabilities. Results from initial runs of this model with various values of catchability at the youngest age gave either unrealistically high selectivity for this age class or very low mean estimated fishing mortality. A closer consideration of the survey indices appeared to indicate that the assumption of constant catchability at older ages may not be valid as increasing numbers of individuals from the same year class were caught through time.

Thornback ray (Raja clavata) in the North Sea

Thornback ray represents a case study on a shelf species that is local (North Sea) and oviparous, with medium data availability and medium commercial importance. Although there have been directed fisheries for skates and rays in the North Sea, mainly using hook and line, these have almost completely disappeared in the course of the last century. Only a small scale directed fishery with tangle nets still exists off the English south-east coast. Skates and rays are predominantly taken as by-catch in demersal mixed fisheries. In the North Sea they have therefore been subjected to intensive exploitation for many years.

In most countries, skates and rays are landed together, most often sorted in particular size categories, rather than by species. With the exception of France, catch statistics are therefore only available for all species of skates and rays combined. Data on total international landings of North Sea skates and rays are available since 1903. There are no effort data specifically for North Sea rays and skates. Starting in 2000, some exploratory market sampling programmes for North Sea skates and rays were carried out under the DELASS project in England, Scotland, Denmark, Netherlands and Belgium although only preliminary results are available up till now. The main survey data for North Sea skates and rays is the ICES coordinated International Bottom Trawl Survey (IBTS). Data from this survey were available for the period 1965-2002. The IBTS data include surveys from quarter 1 in the years 1967-1990, surveys in all quarters in the period 1991-1997, and surveys in quarters 1 and 3 for 1998 onwards. For the early-1900s some survey data were available for the English RV 'Huxley' and the Dutch vessel 'Wodan' (Rijnsdorp *et al*., 1996).

Survey data are the major historical data source for thornback ray in the North Sea. However, catching thornback ray in the IBTS is a relatively rare event. Only 605 hauls out of a total of 13 923 hauls had a non-zero catch. The high frequency of zero catches in combination with a few, in some cases, high catches were analyzed statistically by use of a two-stage model approach. First, the probability of getting a catch with at least one thornback ray was calculated using a Generalized Linear model with a binomial distribution and a logit link function. Secondly, non-zero catches were modelled using a Gamma distribution and a log link function. Both models included a season, an area and a period effect. In the first model, the parameters *area* and *period* were highly significant (Pr <0.0001) for all length groups. The *season* effect was highly significant for some length groups. The probability of having a haul with at least one thornback ray was estimated to be 16 times higher in the period 1967-1976 compared to the most recent years, 1993-2002. The results for the second model (non-zero catches) did not show such a consistent pattern. Bringing the results of the two models together, there has been a steep decline in the number of fishing positions with a catch of thornback ray since 1967. For fishing positions with a catch of thornback ray, the average catch in number seems, however, to have increased slightly. These remaining patches might have been less attractive for the commercial fleet, due to factors such as bottom type and low abundance of commercially important fish.

Cuckoo ray (Leucoraja naevus) in the Celtic Sea

Cuckoo ray represents a case study on a shelf species that is local (Celtic Sea) and oviparous, with good data availability and medium commercial importance. Cuckoo ray are – like thornback ray – often landed together, most often sorted in particular size categories, rather than by species. However, the landings in France are discriminated between species. France takes on average 55 % of the international landings (1980-1998) in the Celtic Sea and the proportion of Cuckoo ray in the French landings has fluctuated between 26 and 53%. None of the French fleets are targetting cuckoo ray, although it is an important by-catch. The main fishing gears are otter trawl and, increasingly, twin trawl. Discarding of cuckoo ray is likely to be important. Estimates of discard levels are in the order of 50% in numbers (1974 estimate) or between 13 and 35% in weight (1997 estimate).

The data available for stock assessments of the Cuckoo ray in the Celtic Sea are the following:

- Total landings of rays per ICES sub-area (1973-1998)
- Total landings of French cuckoo ray (kg and sale value) and effort (hours) by rectangle, fleet, gear and month (1986-1998)
- Ray species composition of the French landings per ICES sub-area (1988-1998)
- Evhoe survey data (weight and number) by station and sex (1987-2000).
- Length composition of the French cuckoo ray landings for areas combined (1989-1997)
- Length composition of the French cuckoo ray discards for areas combined (1997)

The assessment methods explored for this stock are:

- General Linear Modelling of commercial CPUE data and survey data
- Surplus production model
- Catch curve analysis

GLM analysis have been carried out on both the commercial CPUE data and the EVHOE survey data. The GLM's give estimate of the spatial distribution of the CPUE of French trawlers. This indicates a continuous distribution of cuckoo ray catches from North of Scotland to the Bay of Biscay. Highest CPUE is observed in the Celtic Sea and the Irish Sea. The interaction term (year*fleet*gear) could be used to standardize the fishing effort, but this has not been pursued further at present.

A second GLM gives an estimate of the seasonal changes in CPUE in relation to the area. It was shown that seasonal differences in CPUE exist between summer and winter in the area north of 50°N with higher CPUE in the winter period.

The other GLM's on commercial CPUE and survey data give estimates of trends in abundance over time where consistent signals are derived from both data sources.

The Aspic surplus production software (Prager, 2000) was used to assess the trends in the stock, based on the total international landings of cuckoo ray and the CPUE series of the two French fleets with the highest overall landings of cuckoo ray. The ASPIC program fits a non-equilibrium logistic (Schaefer) production model to the catch and effort data (Prager, 1994; Quinn and Deriso, 1999; Prager, 2000). The errors in the model were assumed to be conditional on effort. Results are shown as the ratio of fishing mortality against F_{msy} and Biomass against B_{msy}. Results indicate that the fishing mortality is above F_{msy} for this stock and the stock below B_{msy}.

A catch curve analysis was carried out on the catch at age matrix that was constructed from the length data and the growth parameters. Results suggest, in contrast to the ASPIC model, that total mortality is around 0.3. Given that the assumed natural mortality is around 0.15 (Biseau, 1999) the estimated fishing mortality would be around 0.15 and thus substantially lower than the estimates from the biomass model.

There appears to be a general agreement between the methods applied that the stock experienced a low abundance in the early-1990s, followed by a recovery in the later part of the 1990s. The stock trends in the most recent years are unclear as there was no data available from the commercial fishery. The survey suggests that the stock may be decreasing since the late-1990s.

The estimates of fishing mortality from the production model and the catch curve analysis do not seem to be consistent.

Portugese dogfish (Centroscymnus coelolepis) in the North-East Atlantic and Leaf-scale gulper shark (Centrophorus squamosus) in the North-East Atlantic

Portugese dogfish and leaf-scale gulper shark represent a case study on a deepwater species that are wide ranging (North Atlantic) and life bearing species, with medium data availability and high commercial importance. Portugese dogfish and leaf-scale gulper shark are taken in several mixed trawl and longline fisheries in the northeast Atlantic.

The two species are often landed together as so-called ‘siki’. Landings of Siki commenced in 1989(ICES, 2002b). Discarding is not considered to be a feature of fisheries for this species that is marketed for its flesh, liver and sometimes fins and skin.

There are few data to assess the stock status of portugese dogfish and leaf-scale gulper shark. Stock structure is poorly understood, and specimen under 70 cm are very rarely encountered in ICES sub-areas V, VI, VII, VIII and IX. However, in the absence of information, a single assessment unit of the northeast Atlantic was chosen for this species. A particular problem is the lack of species specific landings data.

Short time series of length frequencies by species and year are available from Irish research surveys, Norwegian longline surveys and Spanish commercial fishing on Hatton Bank. Reproductive parameters are well described (Girard and Du Buit, 1999) but there are no published age estimates for these species.

The assessment was carried out for the two species combined. Two methods were explored:

- Schaeffer production model
- Leslie depletion model

The Schaeffer production model was explored using the CEDA implementation (Holden *et al*., 1995). It was assumed that growth rather than recruitment was the main contributor to biomass production. The available time-series data of CPUE comprise a gradual decline across the time period studied, for most of the time period. Given this sort of pattern caution is needed because of the “one-way trip” (Hilborn and Walters, 1992) resulting in highly unreliable estimates of the model parameters. The ratio of initial stock to virgin stock was chosen as 0.7, based on a sensitivity analysis. The fit of the model was very poor when all years, except 1990 were included. When the years 1991-1993 (because the fishery was not fully developed) and 2000-2001 (because there was no supporting evidence of an upward trend in stock abundance in these years) were excluded the fit of the model was better. However, the intrinsic rate of population increase (r) and maximum sustainable yield (MSY) were still poorly estimated, and did not have meaningful confidence intervals.

In addition a Leslie Depletion method, for closed populations was applied (Hilborn and Walters, 1992). This is based on the assumption that the population gains no new recruits or immigrants and loses no animals to natural mortality or emigration. The Leslie method can be conceptualized as a linear regression of relative abundance and cumulative catch and examining the trend to investigate what cumulative catch would result in the relative abundance dropping to zero. The Leslie depletion models gave consistent results for different CPUE series that were explored. Also, there was a good degree of agreement between the 1993 biomass estimated from the Leslie method and the carrying capacity estimated from the Schaeffer production model.

Discussion

In this section, the main findings of the explorations towards stock assessment of the case study species presented above will be discussed.

Landings data

The collection of landings data for elasmobranch species is still considered to be problematic. In particular, landings need to be separated to the species level and, in most fisheries, this is not the case. There has been some improvement in, e.g. the identification of deepwater sharks to the species level. Also, exploratory market sampling programs have been carried out, aimed estimating the species and length composition of landings (e.g. for rays).

Some elasmobranch species may be subject to intense discarding (e.g. lesser spotted dogfish). In these cases, the collection of discard data is of great importance if we are to give reliable estimates of the stock size in the future.

Figure 1 shows the general evolution of all elasmobranch landings as officially reported to ICES since 1973. The overall level appears to have remained relatively constant, but the distribution over areas has changed. Landings from the North Sea have decreased, whereas landings in Sub-areas IX, X and XII have an increased.

Life table models

Life table models use the demographic characteristics of a population in the form of a schedule of the *survivorship* and *fertility*[1] at each age for the entire (female) population. These methods allow the calculation of reference parameters of population growth, such as the generation time (G), net reproductive rate (R_0), population doubling time (t_{x2}), and the observed rate of increase of the population (r). This last parameter can be used as an input parameter for stock assessment methods such as surplus production models.

The observed rate of increase of the population is an estimate of the intrinsic rate of increase of the logistic population growth model. Thus, r can be used to define likely values of the intrinsic rate of increase. Recent approaches have used estimates of r using life tables to define the prior probability distribution of the intrinsic rate of increase for use in a Bayesian Surplus production model (McAllister *et al*., 2001).

Another application of life table analysis is the ranking of species in a relative scale of 'productivity' or capacity to grow. If we perform life tables analyses for a suite of species, we can have an idea of their relative capacity for population growth (and, by analogy, of their capacity to withstand exploitation) by comparing the values of r for each species. Species with higher r should be able to recover faster from the effects of exploitation.

A recent modification of life table approaches developed by (Smith *et al*., 1998) allows for estimation of the 'rebound potential' of a population, a relative measure of the capacity of populations to return to their normal size after decreases in abundance due to fishing, which includes density-dependent responses.

In order to be able to use life table models, biological parameters for the species are required. In this paper, life table models have been applied to blue shark with some success. However, it was found that the biological basis for the application of life table models is often relatively weak. Therefore, it is important that more ageing and growth studies are carried out, and also that estimates of maturity and fecundity at age and at length become available. Since the life table models are heavily dependent on the calculated survivorship, the estimates of natural mortality also need to improve.

Surplus production models

For many elasmobranch species, length- or age-based data are either limited or not available. In these cases, surplus production models may provide a suitable alternative. These models are generally applicable when historical series of catch are available and CPUE series from either fisheries or surveys.

CPUE data from the commercial fisheries can, in principle, be the cause of pitfalls. In order to be able to use CPUE as an indicator of stock size (as is done in a surplus production model), the catchability should be constant. If catchability is not constant during the history of the fishery (e.g. due to technological improvements or to specific targeting of certain species), CPUE may just as well be an indicator of the technological success of the fishery, rather than of the size of the stock.

In order to be able to run surplus production models, it is not strictly necessary to have data at the species level. In this paper, an example is provided for two combined deepwater sharks (Siki). However, this approach runs the risk of missing the separate trends in the species, as opposite trends could be hidden. For that reason, species-specific data are urgently needed.

Growth models

Growth models like the Von Bertalanffy equation and the associated parameters appear to play an important role when direct age compositions of catches or surveys are not available. Growth parameters are essential for the life table models and for the slicing of length distributions into age compositions (both from the commercial fishery or from research surveys). Growth parameters are also important for purely length-based models, such as the catch at size method (Sullivan *et al*., 1990).

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[1] Fertility at age is the standard terminology used in life table analysis to express the number of females born to each female per year.

For many of the stocks considered, several studies with growth data were available. However, the estimated growth parameters were often found to be dependent on the method or the data used to estimate growth, and thus cannot be generically applied. There is clearly a need to evaluate the sensitivity of the assessment models to the growth parameters used.

A problem that was identified for a number of stocks was that the L_∞ from the growth model was substantially lower than the maximum length found in the length compositions of the commercial or survey catches. This created problems in slicing the length information and also in applying the catch at size method.

It should be noted that reliable growth data will be difficult to collect when age information is only scarce and is seldom validated. Tagging data could be an important remedy for this deficiency.

Length-based methods

The catch at size method was explored for spurdog and lesser spotted dogfish. This method uses a size-transition matrix approach to project the population length distribution forwards in time. The size-transition matrix is obtained from a stochastic growth model with known von Bertalanffy growth parameters. All population dynamics processes, such as recruitment and fishing mortality, are assumed to be dependent on length rather than age. Estimates of yearly recruitment, length distribution of recruits, selectivity and temporal fishing mortality are then obtained by fitting the annual catch-at-length predicted by the model to the observed data. Problems were encountered with this method due to the fact that a large number of individuals occurring in the catch are significantly larger than the values of L_∞ obtained from the literature. The model assumes that, as length increases towards L_∞, the mean growth increment decreases to zero, which implies that growth beyond this length is impossible. The model is, therefore, unable to predict that a proportion of large individuals appearing in the catch. Further work on this method is encouraged, and the method is considered to be potentially very useful.

Catch at age analysis

Catch at age analysis of elasmobranchs has so far only been based on length-converted age compositions, as there are no direct estimates of frequencies at age available from the landings.

A separable VPA may be used to explore the consistency of the catch at age matrix (however that is derived) and the sensitivity of the model to different assumptions of terminal fishing mortality at age and terminal selection at the oldest true age. A separable VPA was explored for spurdog and lesser spotted dogfish.

When age-based information is available from surveys, a separable model of survey catches only could be applied (Cook, 1997). This model assumes that F is separable into an age and year effect, and that the population size of a cohort at a given age can be expressed as the product of its initial cohort strength and its cumulative mortality. Assuming that age disaggregated survey indices are related to abundance at age by age-dependent catchabilities, then the model estimates of these values can be fitted to the observations to obtain estimates of age, year and year-class effects. These parameters can then be used to obtain estimates of relative number at age, stock biomass and yield.

Results from initial runs of this model applied to lesser spotted dogfish with various values of catchability at the youngest age gave either unrealistically high selectivity for this age class or very low mean estimated F. A closer consideration of the survey indices indicated that the assumption of constant catchability at older ages may not be valid, as increasing numbers of individuals from the same year class were caught through time. This would explain the very low estimates of F obtained in these initial runs. Other assumptions about the relative catchabilities at age may, therefore, be more appropriate and these should be further explored.

General Linear Models (GLM) analysis

Although not formally listed as a ‘stock assessment method’, it was found that the application of GLM could provide a very useful insight into the development of some stocks. This method was mainly applied to the two ray species. In the example of thornback ray in the North Sea, GLM analysis enabled the modelling of CPUE indices from the IBTS survey. This gave insight in structure of the catches, first in terms of the number of hauls where thornback rays were caught, and second in the number of individuals in hauls where they were caught. This led to the conclusion that the number of successful hauls had decreased, but that the number of fish per successful haul was more or less constant. Further work in this direction is to be encouraged as survey data of relatively high quality and readily available.

Bayesian methods

The Bayesian methods, such as that applied to spurdog, are a general class of statistical methods that could be applied to evaluate the contribution of uncertainty in a wide range of input data (e.g. growth, CPUE, catch) on the stock assessment results. Although there is a computation burden on Bayesian analysis (may take a long time to compute), there are also major advantages. The possibility to define prior distributions of parameters from comparable species or species groups, for example, allows the application of these methods even when estimates of certain parameters for the stock considered are not available.

Overall is can be concluded that considerable progress has been made in making input data for stock assessment of elasmobranch species available. The application of several stock assessment models to the case study species proved to be fruitful and can direct future research in this area.

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Table 1. Overview of assessment methods in relation to data requirements and biological realism of the models.

		9 Date requirements			
		Life history data	**Survey data**	**Commercial catch data**	**Mark recapture data**
Biological realism	**Life history model**	• Life table model			• Estimates of growth rate
	9.1 Total abundance	• provide r for stock production model	• Swept area estimates	• Stock production • Depletion model • Delay difference model	• Estimates of total Z
	Length structured		• GLM survey indices	• Catch at size analysis • Length converted catch curve	
	Age structured		• GLM survey indices • Separable stock trend analysis	• Catch curve • (separable) VPA • tuned VPA	

Table 2. Overview of selected case study species and the criteria for selecting these species.

species group	**species**	**english name**	**spatial extent**	**life bearing**	**data quality**	**commercial importance**	**ecotype**
pelagic sharks	Prionace glauca	Blue shark	N Atl.	yes	uncertain	high	pelagic
coastal dogfish & catsharks	Squalus acanthias	Spurdog	NE Atl.	yes	good	high	shelf
	Scyliorhinus canicula	Lesser spotted dogfish	local	no	good	medium	shelf
skates and rays	Raja clavata	Thornback ray	local	no	medium	medium	shelf
	Leucoraja naevus	Cuckoo ray	local	no	good	medium	shelf
deepwater sharks	Centroscymnus coelolepis	Portugese dogfish	N Atl.	yes	medium	high	deep
	Centrophorus squamosus	Leaf-scale gulper shark	N Atl.	yes	medium	high	deep
	Dalatias licha	Kitefin shark	N Atl.	yes	good	high	deep
	Galeus melastomus	Blackmouth catshark	local	no	medium	medium	deep

Abbreviations: N Atl.: North Atlantic, NE Atl.: North-East Atlantic.

Table 3. Overview of data availability by species.

species group	species	english name	Life history	Survey	Commercial	Mark recapture
pelagic sharks	Prionace glauca	Blue shark	Several estimates of LH parameters available	Very limited	Incomplete landings data at ICCAT	Substantial data available but not to the group
coastal dogfish	Squalus acanthias	Spurdog	Several estimates of LH parameters available	Survey data since 1970: CPUE and length frequency (by sex)	STATLANT landing statistics since 1932. UK timeseries on length frequency	Substantial data available
	Scyliorhinus canicula	Lesser spotted dogfish	Some estimates of LH parameters available	Survey data since 1991: CPUE and length frequency.	Spanish landings data since 1996, for one fleet since 1991. CPUE data available since 1991. Length distributions for 2000/2001 only	Data available since 1993. Limited recaptures.
skates and rays	Raja clavata	Thornback ray	Several estimates of LH parameters available	Survey data since 1967: CPUE and length frequency. Some survey data from the early 1900s available.	No separate statistics by species (except for 2000/2001).	Substantial data available but not to the group
	Leucoraja naevus	Cuckoo ray	Several estimates of LH parameters available	Survey data since 1987: CPUE	French landings data by species 1988-98: weight and length composition. CPUE data available 1988-1998. Some discard data available	Substantial data available but not to the group
deepwater sharks	Centroscymnus coelolepis	Portugese dogfish	Some estimates of LH parameters available	Some survey data available: length frequency.	Landings data of combined species (SiKi) available 1990-2001. CPUE data available in short timeseries.	no
	Centrophorus squamosus	Leaf-scale gulper shark	Some estimates of LH parameters available	Some survey data available: length frequency.	Landings data of combined species (SiKi) available 1990-2001. CPUE data available in short timeseries.	no
	Dalatias licha	Kitefin shark	Some estimates of LH parameters available	Survey data 1993-2000	CPUE data 1987-1988. Possibly some catch data and length frequency data	no
	Galeus melastomus	Blackmouth catshark	Some estimates of LH parameters available	Some survey data available: length frequency.	Portugese landings data 1991-2001	no

Table 4. Overview of assessment methods applied to each species.

species group	species	english name	Life history	Total abundance	Length structured	Age structured
pelagic sharks	*Prionace glauca*	Blue shark	Life table analysis			
coastal dogfish	*Squalus acanthias*	Spurdog	Bayesian estimates of LH parameters	Trend in survey indices Bayesian Schaefer production model.	Trend in length freq. in catch data	After length slicing: catch curve analysis and separable VPA.
	Scyliorhinus canicula	Lesser spotted dogfish	none	Schaefer production model	none	After length slicing: separable VPA and survey-only separable model.
skates and rays	*Raja clavata*	Thornback ray	none	none	Analysis of length frequency in surveys. Analysis of frequency and occurrence in surveys by length-class.	none
	Leucoraja naevus	Cuckoo ray	none	GLM analysis on CPUE and survey data Schaeffer production model.	none	After length slicing: catch curve analysis and VPA.
deepwater sharks	*Centroscymnus coelolepis*	Portugese dogfish	none	Trend in CPUE, Schaefer production model and Leslie depletion model on SiKi	none	none
	Centrophorus squamosus	Leaf-scale gulper shark	none	see Portugese dogfish	none	none
	Dalatias licha	Kitefin shark	none	none	none	none
	Galeus melastomus	Blackmouth catshark	none	none	none	none

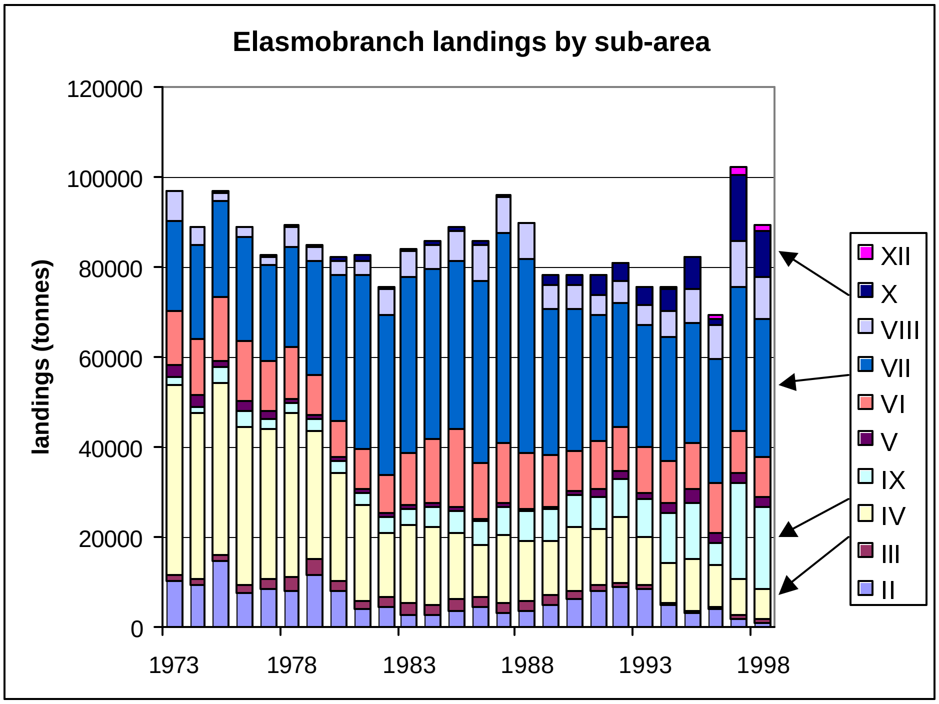

Fig. 1. Elasmobranch landings by ICES Sub-area as officially reported to ICES.