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Crab and Lobster Fisheries in Scotland:

Results of Stock Assessments 2016-2019

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Abstract

The Scottish creel fisheries are long established and tend to be mixed species fisheries with brown crab, velvet crab and lobster as the main target species. The importance of each species varies regionally and in relation to season and market demand. The landings of the combined fishery into Scotland in 2020 were 9,000 tonnes with a first-sale value of £31M. This report presents the results of Scottish regional brown crab (*Cancer pagurus*), velvet crab (*Necora puber*) and lobster (*Homarus gammarus*) stock assessments carried out by Marine Scotland Science (MSS) based on length cohort analyses (LCAs) applied to commercial length frequency data for the period 2016-19. The stock assessments presented are conducted on a regional basis for the crab and lobster management areas in Scottish waters, with males and females assessed separately. The methodologies used include length-based methods, size indicators and analysis of survey data, providing stock status for stocks with available data. Analysis of trawl and dredge survey data for brown crab in the east and west coast indicates that abundance and recruitment (the number of young crabs entering the adult population annually) show a general increase from 2008 until the 2013-2016 period and a decline in recent years. The decline in survey catch rates coincides with a period a declining brown crab landings from 2016. There are no survey data available for velvet crab and European lobsters. The stock assessment results in this report for the three species are based on estimates of fishing mortality in relation to a reference point for each stock, to infer whether or not a stock is fished above the level that would in theory result in maximum sustainable yield (in the long term). The results of assessments for the period 2016-19 indicated that in the majority of the assessment areas, brown crab, velvet crab and lobster in Scotland were fished close to or above fishery reference points. To ensure sustainability of these fisheries, it is recommended that effort/fishing mortality should be reduced in those stocks for which fishing mortality is estimated to be above the sustainable fishing mortality (F_{MSY}).

Executive summary

This report presents the results of Scottish regional brown crab (*Cancer pagurus*), velvet crab (*Necora puber*) and lobster (*Homarus gammarus*) stock assessments carried out by Marine Scotland Science (MSS) based on length cohort analyses (LCAs) applied to commercial length frequency data, for the period 2016-19.

The Fisheries

The Scottish creel fisheries are long established and tend to be mixed species fisheries, with brown crab, velvet crab and lobster as the main target species. The importance of each species varies regionally and in relation to season and market demand. The landings of the combined fishery into Scotland in 2020 were 9,000 tonnes with a first-sale value of £31M.

Brown crab:
The most important crab species, in terms of weight and value, landed in Scotland is the brown crab which is found all around the Scottish coast. In recent years, reported landings of brown crab have decreased and were under 7,000 tonnes in 2020. The principal fishing areas for brown crab in Scotland are the Hebrides, Orkney, East Coast and South Minch; landings from these areas accounted for over 60% of the total brown crab in recent years.

Velvet crab:
Velvet crabs are caught in the inshore creel fishery with lobster and brown crab, although few fishermen fish solely for velvet crab. In recent years, landings for velvet crab have fluctuated around 1,600 tonnes. Most landings were taken from inshore areas.

Lobster:
The total tonnage of lobster landed in Scotland has always been much less than that of crab, but the average value per tonne is much higher. Lobster landings have increased substantially over the last 20 years to about 1,100 tonnes in 2020. Historically, the majority of landings of lobster in Scotland have been from the Hebrides, Orkney, and South Minch, but these areas have been overtaken in recent years by landings from the South East and East Coast areas.

Assessments and stock status

Temporal trends in landings were explored using several size-based indicators for the period over which sampling data are available for each species, by sex and assessment area. The size at first capture, the mean size in the landings of individuals above the size at first capture and the mean size of the largest 5% of individuals were compared to the respective reference points. In several of the well sampled areas it was possible to relate variations of the mean size and mean size of largest animals to trends in fishing mortality. In most cases, results were in agreement with the LCA results and showed similar exploitation level relative to F_{MSY} reference points.

Length based assessments (LCAs) and length based indicators (LBIs) were used for assessing Scottish crab and lobster stocks. LCAs use commercial catch size composition data and estimates of growth parameters and natural mortality to estimate fishing mortality at length. LBIs were used to explore trends in the sampled landings for each of the three species. Assessments are conducted on a regional basis, with males and females assessed separately.

LCAs were conducted for each species with sufficient data (2016-1019), by assessment area. There was a change in the minimum landing size (MLS) for the three species in 2018 but it is not expected that this has resulted in a major selectivity change. Nevertheless, F_{MSY} reference points were re-estimated for all stocks with available data, using the most recent LCA input data (2016-2019). A summary of stock status in terms of fishing mortality in relation to reference points is provided for each stock.

Brown crab:
Brown crab fishing mortality for both males and females was estimated to be above F_{MSY} in the East Coast, Hebrides, North Coast, South East, South Minch and Sule areas. In the Clyde, Orkney and Ullapool, fishing mortality for females was at F_{MSY} while males were fished above F_{MSY}. In the Papa area, fishing mortality was below F_{MSY} for both males and females. In Shetland, the fishing mortality was deemed to be inconclusive due to a lack of consistency between alternative assessment parameters. No assessments were performed for the Mallaig area. In the latest stock assessments, fewer stocks are being fished above F_{MSY} than in the 2013-2015 assessments.

Analysis of trawl and dredge survey data for brown crab indicates that recruitment and abundance are declining in recent years. Similar trends are apparent in the brown crab survey abundance estimates for the east and west coast.

Velvet crab:

Velvet crab in the Clyde, East Coast, Orkney and South Minch were estimated to be fished at levels above F_{MSY} (both males and females). In the Hebrides and South East, recent fishing mortality for males was at F_{MSY} while females were fished above F_{MSY}. In Shetland, fishing mortality estimates were inconclusive. No assessments were performed for the Mallaig, North Coast, Papa, Sule and Ullapool areas.

Lobster:

Fishing mortality was estimated to be above F_{MSY} for both males and females in the Clyde, South East, Shetland and South Minch areas. In the East Coast, Hebrides, Orkney and Papa, the fishing mortality estimated for females was at or below F_{MSY} while males were fished above F_{MSY}. No assessments were performed for the Mallaig, North Coast, Sule and Ullapool areas as the sampling data collected were considered insufficient to run LCAs.

Management considerations

The results of assessments for the period 2016-19 indicated that in the majority of the assessment areas, brown crab, velvet crab and lobster were fished close to or above F_{MSY}. It is recommended that effort/fishing mortality should be reduced in those crab and lobster stocks where fishing mortality is estimated to be above F_{MSY}.

Data and recommendations

With the exception of Shetland, only limited effort data (number of pots fished) have been collected from creel fisheries. Recent changes in the FISH1 form for vessels under 10 m provide additional data which may be useful for deriving estimates of fishing effort. For larger offshore vessels (over 12 m), Vessel Monitoring System (VMS) data integrated with logbook landings could be used to derive a time series of landings-per-unit-effort which could potentially be used as an indicator of trends in stock size.

Discards in crab and lobster fisheries are sampled only on an irregular basis. More regular sampling and information on catches of undersized animals could provide an indication of inter-annual variation in recruitment.

The population structure and some aspects of the biology of crab and lobster are not well understood and some of the assessment areas as currently defined may be inappropriate. Brown crab tagging studies are currently underway in Orkney and these may shed light on potential links between the offshore stock at Sule and inshore Orkney stock.
Given the sensitivity of LCAs/LBIs to the input growth parameters, further work in this area is required. Field studies based on tagging methods and subsequent evaluation of parameters would be desirable.

Information on factors affecting catchability could also be collected by engaging with fishers and the fishing industry. Work being conducted within the RIFGs, for example through the inshore fisheries pilots, ought to provide an improved understanding of the drivers of fishing behaviour.

Contents

1. Introduction

1.1. Overview of Scotland’s Crab and Lobster Fisheries

Crabs and lobsters are important species for the Scottish fishing industry. Although the total weight landed is small relative to finfish landings, crab and lobster attain high prices. In 2020, the combined crab and lobster species landings of approximately 9,000 tonnes had a value at first-sale of over £31M (Scottish Sea Fisheries Statistics, 2021). The fishery is long established and was traditionally an inshore mixed species creel fishery, prosecuted by small vessels. However, improved technology and the ability to store and transport live animals in the 1980s led to the development of an offshore fishery for brown crab. This, and the demand from new markets, resulted in a substantial increase in the Scottish landings.

Creel fishing in Scotland continues today as an inshore fishery around most of the Scottish coast, with vessels setting their gear within a few miles of the shore. The fishery is typically a mixed species fishery with both crab and lobster being targeted, albeit with some seasonal and regional variation. Most creel vessels are small, less than 10 m in length and with only one or two crew, and make short day trips to haul creels. However, a number of larger vessels take part in an offshore fishery to the north and west of Scotland. These vessels, which are up to 25 m in length and have a crew of four or five, mainly target brown crab and carry vivier ponds on board to keep the catch alive. The size and power of these vessels enables fishing on offshore grounds such as the Papa and Sule Banks, with boats landing catch into ports such as Scrabster on a weekly basis. These ‘vivier vessels’ or ‘super-crabbers’ are fewer in number than the small day vessels, but their catches represent over 50% of brown crab landings in some regions. Local processors were the preferred market until the overseas market emerged in the 1990s. By this time, technology had developed to enable the transport of live animals by vivier lorries (specially adapted vehicles containing cooled ponds for the transport of live shellfish), within a day of landing. It is common for crabs and lobsters fished in UK waters to be transported live to the continent, particularly France, Spain and Portugal, where there is a good market. After Brexit, despite changes in trading arrangements, the majority of crabs and lobsters are still exported to the European Union, with the region accounting for 84% of total UK exports. More recently, brown crab have also been exported to emergent Asian markets including China, where “dry transport” of live animals is the preferred method. Exports of crab and lobster from the UK to China rose steadily in the period 2017-2019, from around £18M in 2017 to £31M in 2019. However, since 2019 exports to China have reduced sharply, with only £7M exported in 2020.

The most important crab species, in terms of weight and value, landed in Scotland is the edible or brown crab (*Cancer pagurus*) which is found all around the Scottish coast. The second most important by landed weight is the velvet swimmer crab (*Necora puber*). Velvet crabs are often caught in the inshore creel fishery with lobster and brown crab and were once considered to be a ‘pest’ species. Very few fishermen fish solely for velvet crab, although some target the species at certain times of the year. The Scottish fishery expanded in the early 1980s following the collapse of the Spanish fishery (MacMullen, 1983), to become the largest in Europe (Tallack, 2002). Other crabs landed include deep-water crabs (*Chaceon* sp.), the northern stone crab (*Lithodes maja*) and the shore or green crab (*Carcinus maenas*), but these species only comprise a small proportion of the total landings (**Table 1**).

European lobster (*Homarus gammarus*) is a valuable species for which seasonal prices can be as high as £20 per kg at first sale. Other lobsters landed include the spiny lobster or crawfish (*Palinurus elephas*), squat lobsters (family: *Galatheidae*) and the Norway lobster (*Nephrops norvegicus*), also known as langoustine or *Nephrops*. In Scottish waters *P. elephas* is caught mainly on the west coast and along the north coast to Orkney and Shetland. Landings of *P. elephas* into Scotland up to 1998 were consistently over 30 tonnes dropping to an average of around 5 tonnes over the last 10 years. The *Nephrops* fishery is one of the most economically important Scottish fisheries with vessels targeting this species operating mostly trawl gears, although a smaller scale *Nephrops* creel fishery also takes place in the west coast of Scotland. *Nephrops* stocks are assessed by ICES (International Council for the Exploration of the Sea) working groups and managed under a Total Allowable Catch (TAC) system. They are therefore not considered further in this report.

1.2. Management and Regulations

In Scotland, vessels fishing for brown crab, velvet crab, spider crab, green crab, lobster or crawfish must have a licence with a shellfish entitlement. The quantities that are permitted to be landed are not restricted. Owners of vessels of length up to 10 m with a shellfish entitlement are required to complete the FISH1 form for all landings of lobsters and crabs and submit it on a weekly basis to the Fishery Office at which the vessel is administered. In July 2016, the Scottish Government introduced a number of changes to reporting on the FISH1 form as part of vessel licensing requirements. Since then, fishermen have been required to report (1) the position where fishing activity starts on any fishing day (for creel vessels this corresponds to the first position where creels are hauled); and (2) the number of creels hauled associated with the declared landings quantity. For vessels between 10 m and 12 m, data on fishing activity by trip must be recorded in a paper logbook and submitted to the Fishery Office within 48 hours of landing. Vessels over 12 m must use electronic logbook systems to record their activity. Licensed fishing vessels, which do not hold a shellfish entitlement, are allowed to land a maximum of 5 lobsters and 25 crabs per day. Regulations effective from April 2017, restrict the numbers of certain shellfish species that can be taken by unlicensed fishing boats on a daily basis. The restrictions are set daily per vessel as: 1 lobster, 5 crabs (any combination of the following species: brown crab, velvet crab, green crab and spider crab), 10 *Nephrops* and 6 scallops (The Shellfish (Restrictions on Taking by Unlicensed Fishing Boats) (Scotland) Order, 2017).

There is currently a restrictive licensing system, whereby no new licenses or entitlements are being granted. There are, however, non-active (latent) licence entitlements, which mean that there is the potential for the number of vessels actively fishing for crab and lobster to increase. In 2014, participants in the European project ACRUNET (A Transnational Approach to Competitiveness and Innovation in the Brown Crab Industry) produced an analysis of latent capacity and the implications for the management of the brown crab fisheries. It became clear that in the UK and Ireland there is significant latent capacity (part of the fleet that is currently inactive but continues to hold fishing entitlements) that could potentially target brown crab, but the likelihood of currently unused shellfish entitlements becoming active could not be estimated at the time (Mesquita et al., 2015).

Crab and lobster fisheries are not subject to international TAC regulations or national quotas although there are measures to restrict fishing effort in the west of Scotland. After Brexit, the maximum annual fishing effort for UK vessels over 15 m participating in the brown crab fishery was maintained at the level set by previous EU Regulations (702,292 KW days in ICES Areas 5 and 6 and 543,946 KW days in ICES Area 7 (EC, 2004; MMO, 2022).

MLS regulations designed to protect juvenile animals apply to the main commercial crab and lobster species. These are summarised in **Table 2**. In 2017, Marine Scotland introduced a number of new management measures. These include: increases in MLS in some areas (**Table 2**), the prohibition of landing berried velvet crab and a decrease in the maximum landing size of female lobster (from 155 mm to 145 mm CL, except Orkney and Shetland) (The Specified Crustaceans Order, 2017). Other extant regulations in the crab and lobster fishery are described in detail in previous assessment reports (Mesquita et al., 2011; Mesquita et al., 2017; Mill et al., 2009).

This report presents summaries of historical and recent landings data and the results of stock assessments for brown crab, velvet crab and lobster, updated with data collected between 2016 and 2019. A description of the biology, habitat and life history of these species is provided in Mill et al. (2009).

2. Data Collection and Methods

2.1. Assessment Areas

For assessment purposes, the Scottish creel fishing grounds are divided into 12 assessment areas as shown in **Figure 1**. These areas are based on the historical system for reporting Scottish landings data (Thomas, 1958), subsequently revised to include two offshore areas – Papa, which lies to the west of Shetland, and Sule, which is to the north and west of Orkney and includes the Rona, Sulisker and Sule-Skerry banks. Some Scottish assessment areas extend outside Scottish Territorial Waters. On the east of Scotland, the South East assessment area extends beyond the Scottish EEZ border, while on the west coast, the Clyde assessment area stops short of the Irish EEZ border. There is some fishing on grounds outside the assessment areas. Currently these areas support only small fisheries and landings data are monitored for any change in importance.

2.2. Landings Data

The assessments use official landings data, which provide location of capture (by ICES rectangle), the species and the weight landed into ports in Scotland. These data are collated by Marine Scotland Compliance from sales notes, logbooks and FISH1 forms. The UK iFISH database was used to extract landings data for all crab and lobster species mentioned in this report. Marine Scotland's FIN database was used for inspecting and performing corrections in landings from rectangle 40E4 (see below). Data for brown crab landings from the Republic of Ireland (collected by the Irish Sea-Fisheries Protection Authority – SFPA) were compiled and provided by the Irish Marine Institute. These data were not used in the assessments but have been included to illustrate brown crab landings by nation on a statistical rectangle basis to the west coast of Scotland.

ICES rectangle 40E4 straddles two assessment areas: the Clyde and the South Minch. Officially, reported landings data are available only for the whole rectangle. Exploratory data analysis was performed with the aim of developing a working method to split landings in rectangle 40E4 between the two areas.
FISH1 form data (2017-2020), which contain positional information on where fishing activities take place, were used to make a comparison between fishing location and the subsequent landing port. Results of the analysis indicated that the location of the landing port, either East (Clyde) or West (South Minch) of the Kintyre peninsula, was a good proxy for fishing location. Therefore, the E/W location of the landing port

was used to allocate landings from rectangle 40E4 to either the Clyde or the South Minch areas for all trips.

2.3. Catch-at-length Data

2.3.1. Landings-at-length

Landings length-frequency data were collected by MSS as part of its market sampling programme with data extractions carried out from MSS' Fisheries Management Database (FMD). Historical Shetland sampling data were provided by Shetland UHI (formerly the North Atlantic Fisheries College (NAFC) Marine Centre) with the permission of the Shetland Shellfish Management Organisation. Since 2010, data from fisheries in Shetland have been collected and provided by staff at Shetland UHI under the Memorandum of Understanding (MoU) between Shetland UHI and MSS. From 2012, landings length-frequency data collected by Orkney Sustainable Fisheries (OSF), mostly from the Orkney assessment area (but also from Papa and Sule), have been shared with MSS. These additional data have been used in combination with data collected by MSS from the same areas. All the sampling data are held in the MSS Fisheries Management Database (FMD).

Sampling measurements are taken as carapace length (CL) for lobsters, measured from the eye-socket to the centre of the base of the thorax carapace, and carapace width (CW) for brown and velvet crabs, measured across the widest part of the body, not including any spines.

In general, sampling effort is focused in those areas where fisheries are most important. However, the timing of landings is rather unpredictable and sampling is to some extent opportunistic, which explains the variability in numbers sampled and the occurrence of zeros for certain species in some areas. Brown crabs and lobsters may be retained for a period of time in holding tanks after being landed, which makes them easier to access for sampling. In contrast, velvet crabs are often landed in remote harbours and promptly dispatched to fishing processors or shipped abroad. This makes it more difficult to get samples, particularly in the Inner Hebrides (South Minch) in the west of Scotland.

MSS aims to conduct crab and lobster stock assessments every three years using length-frequency data from the most recent three years. However, due to delays in staffing to conduct this work, this report uses four years of sampling data (2016-2019). Before the report was concluded, landings information for 2020 became available and therefore the most recent landings data are also presented for the three species although the assessments were conducted for 2016-2019. The numbers of animals measured, number of trips and percentage of sampled fishing trips (quotient between the number of trips sampled and the total number of trips extracted from iFISH) by assessment area are shown for each species in **Table 3**, **Table 4** and **Table 5**.

2.3.2. Discards

Discard data are not regularly collected for the crab and lobster fisheries in Scotland, and any mortality due to discarding practices is not taken into account in these assessments. Anecdotal information and recent *ad hoc* unpublished studies suggest that crab and lobster discard rates in the target creel fisheries are variable and occasionally high (>50% by number). Discards typically comprise those animals that do not meet landing regulations such as undersized individuals, post-moult animals with soft shells, v-notched female lobsters or berried female crabs. Discard survival rates are likely to be high (Rodrigues et al., 2021), and for assessment purposes landings are assumed equal to catch.

2.3.3. Raising and Data Quality

Length frequency data obtained from market sampling and official landings data were combined to provide a raised annual landings-at-length distribution. Data were averaged over four years (2016-19) and aggregated into 5 mm size classes for brown crab and lobster, and 3 mm size classes for velvet crab for use in the Length Cohort Analysis (LCA).

Landings-at-length data were not available for the three species in all assessment areas. The decision-making process to select which areas had sufficient data to run stock assessments is presented in Annex A. Four parameters were used to categorise the quality of the sampling data: number of trips/animals sampled; number of years for which data are available (maximum four years – 2016-19); sampling seasonality; and the shape of the length frequency distribution (LFD). For each species/area combination, these parameters were classified in one of three categories ("poor"/"ok"/"good"). Stock assessments were not run for areas where one or more of the parameters was classified as "poor" (see Annex A).

2.4. Biological Data

Information about the growth of British crabs and lobsters used in the LCA comes mainly from tagging studies carried out in the 1960s and 70s (Hancock and

Edwards, 1966; Hancock and Edwards, 1967) (**Table 6**). Estimates of the von Bertalanffy growth parameters: asymptotic length (L_∞) and instantaneous growth rate (*K*) have been estimated using Ford-Walford plots (Chapman, 1994; Tallack, 2002; Mouat et al., 2006) (**Table 6**). Length-weight relationships (parameters *a* and *b* shown in **Table 6**) are from MSS (unpublished) market sampling measurements of length and weight. Different, area specific, biological parameters were applied in Shetland assessments as these are available from research on these species conducted in Shetland (see Leslie et al., 2010 for data sources).

2.5. Size-based Indicators and Sex Ratio

1

In theory, size-based indicators or length-based indicators (LBI) can provide information about the effects of fishing pressure on a stock. Fishing mortality affects the abundance of populations but also their age and size distribution. As cohorts age and grow, the effects of mortality accumulate over time. With increasing mortality, fewer older and larger individuals can be expected in a stock and associated catches. Life history processes such as maturation and fecundity depend on size, such that the size structure of the stock affects the reproductive potential and capacity for recovery (Trippel, 1998; Moland et al., 2010).

In this report, several size-based indicators were explored for the period over which sampling data are available (brown crab and lobster – from 1981; velvet crab – from 1987) for each species, by sex and assessment area. Any years in which the number of animals sampled was less than 50 and species from assessment areas sampled only once (Sule for lobster, Mallaig for brown crab, and North Coast, Papa, Sule for velvet crab) were excluded.

Size at first capture (L_c), the mean size in the landings of individuals above L_c, and the mean size of the largest 5% of individuals in the landings ($L_{max5\%}$) were examined and plotted. The size at first capture, L_c, was calculated as the size at half the maximum frequency in the ascending part of a size frequency distribution (ICES, 2014b). Ideally, the size at first capture, L_c, should be above the size at first maturity, L_{mat}, to allow for reproduction before being caught by the fishery (Myers and Mertz, 1998).

As a reference point for the mean size, we plotted the F_{MSY} proxy $L_{F=M}$ (the expected length in the landings when fishing mortality is equal to natural mortality). The proxy depends on the ratio of natural mortality *M* and the growth rate *K* from the von Bertalanffy equation. A ratio of 1.5 is assumed in standard data-limited cases where *K* and *M* are uncertain (Prince et al., 2015). Other crab and lobster species have been characterized as having an M/K ratio around 1.5, with unexploited stocks dominated in numbers by juveniles (Prince et al., 2015). Species with lower M/K ratios, such as *Nephrops*, exhibit an adult modal size (Prince et al., 2015). Given that the parameter values for M and K as used in the LCA (**Table 6**) are not recent (originating from Chapman (1994)) and additionally, that natural mortality is difficult to estimate, we use the default ratio of 1.5 for the calculation of reference point $L_{F=M}$, such that $L_{F=M}$ =0.75L_c+0.25L_∞ (ICES, 2014b). L_∞ refers to the asymptotic size parameter from the von Bertalanffy growth equation (ICES, 2014b). As for M and K, L_∞ estimates were also obtained from historical data (Chapman, 1994) with the exception of those applied to the Shetland area (**Table 6**).

A decrease in mean size may be due to a reduction in the number of large individuals in the population due to fishing pressure but may also be as a result of good recruitment, which causes an increase in the number of small individuals. To mitigate the effects of variable recruitment, the mean size of the largest 5% of landed individuals $L_{max5\%}$ was examined (ICES, 2014b; Probst et al., 2013). The mean size of the largest 5% was compared to the reference point 0.9 L_∞ which is considered to be a better F_{MSY} proxy than the precautionary reference point of 0.95 L_∞ (Miethe and Dobby, 2016). A declining trend in the mean size of largest animals can be associated with a reduction in the abundance of large individuals due to the effects of fishing mortality. Due to data-limitation, we used available values of life history parameters derived for particular regions such as Shetland, Hebrides and Firth of Forth for other areas (**Table 6**, **Table 7**).

Trends in the average annual sex ratio in the sampled landings were explored for each of the three species, again excluding years in which fewer than 50 animals were sampled.

2.6. Survey Data

The habitat preferences and spatial distribution of Scottish crustacean stocks are poorly understood and the stocks are often described as data-limited for stock assessment purposes. By using fishery-independent surveys in the form of scallop trawl and dredge surveys, estimates of abundance and recruitment of more commonly caught by-catch species (such as brown crab) can be assessed. In this report, the spatial distribution of brown crab was described for three study areas East Coast (**Figure 18**), West Coast (**Figure 19**) and Shetland (**Figure 20**), and abundance and recruitment indices for each area developed using methodologies outlined by Mesquita et al., 2021. While these study areas do not directly match the assessment areas outlined in the other assessment methods in this report, they do cover larger regional areas of Scotland and give an indication of abundance and recruitment trends given the data available. Data was provided by fishery-independent dredge and trawl surveys carried out by Marine Scotland Science research vessels between 2008 and 2020, bathymetry data from the UK Hydrographic Office by OceanWise Ltd and sediment layers from the British Geological Survey (BGS) (Cooper et al., 2013; OceanWise, 2015). Survey data for Shetland was limited to dredge only data due to the low number of trawl survey stations sampled in the inshore waters of the islands. Additionally, the dredge survey was not completed in Shetland in 2008, 2012, 2014 or 2015 due to poor weather.

2.6.1. Spatial Distribution

Geostatistics were used to explore the spatial distribution of brown crabs using catch rates from dredge and trawl surveys. For each study area, analysis was performed separately for males, females and juveniles under 100mm carapace width (CW). Due to fluctuations in crab catch rates, including the presence of zeros (no crabs caught), the data was logarithmically transformed as follows:

$$\mathrm{C_{ij}} = \log\left(\frac{\mathrm{r_{ij}}}{\bar{r}_{\mathrm{j}}} + 1\right),$$

where Cij is the log-transformed catch rate (response variable), r_{ij} is the catch rate in station i and year j, and $\bar{r}_j$ is the mean catch rate in year j.

Variogram models were then fitted to the transformed dredge and trawl surveys in each year using the estimator:

$$\gamma(\mathrm{h}) = \frac{1}{2\mathrm{N(h)}} \sum_{\mathrm{i}\,=\,1}^{\mathrm{N(h)}} [\mathrm{Z(x_i)} - \mathrm{Z(x_i + h)}]^2,$$

where γ is the calculated semi-variance for each dataset, $\mathrm{Z(x_i)}$ is the catch rate of brown crabs at sampled station $\mathrm{x_i}$, $\mathrm{Z(x_i + h)}$ is the catch rate value separated from $\mathrm{x_i}$ by a lag distance h (measured as a straight line, in km) and $\mathrm{N}(h)$ is the number of observation pairs separated by h. A distance h of 10 km was used for the dredge survey and 25 km for the trawl survey (number of lags = 15) (Mesquita et al., 2021). Following the approach proposed by Rivoirard et al., 2000, the variograms for each survey per year were combined to obtain a mean variogram standardized by the yearly sample variance. The mean variograms were then visually inspected and used to fit either spherical or nested linear models to the data (Mesquita et al., 2021). Kriging was then applied using the predictor variables distance to coast, depth and BGS sediment type.

2.6.2. Abundance and Recruitment Indices

An abundance estimate of brown crab in each study area was estimated using generalized additive models (GAMs). Two sets of GAMs (one for dredge surveys and one for trawl surveys) were created using the catch rate per haul (numbers of crabs caught per square meter) as the response variable, using the Tweedie distribution to account for zero observations and skewed data distribution.

Recruitment indices were also calculated using GAMs in a two-part hurdle model as described by Mesquita et al. (2021), with the response variable of the catch rate of crabs (N m^{-2}) under 100 mm CW. As very few crabs below 100 mm CW are caught in the trawl surveys, only dredge survey data is used in the calculation of recruitment indices. Explanatory variables for the abundance models and the recruitment models were sediment type (BGS data, categorical variable with four levels), depth, distance to coast, year (2008–2020), and geographical position (latitude and longitude plus an interaction term between these) at each sampling station. Models were selected using a backward stepwise selection based on the analysis of deviance of fitted models.

2.7. Length Cohort Analysis (LCA)

Age determination is generally not possible for animals that moult, and therefore the application of age-structured assessment methods to crustacean stocks is problematic (Smith and Addison, 2003). Length Cohort Analysis (LCA) (Jones, 1984) is a commonly used method of assessing stocks for which commercial catch length frequency distribution data are available. LCA was used by MSS in previous assessments of the Scottish crab and lobster stocks (Mill et al., 2009; Mesquita et al., 2011; Mesquita et al., 2016), by Shetland UHI to assess crustacean stocks around Shetland (Leslie et al., 2007; Leslie et al., 2010) and also by Cefas (Centre for Environment, Fisheries and Aquaculture Science) to assess crab and lobster stocks in England (CEFAS, 2020a; CEFAS, 2020b).

The LCA method uses the commercial catch size composition data (length frequency data) and estimates of growth parameters and natural mortality to estimate fishing mortality at length. The key assumption of the approach is that the length distribution is representative of a typical cohort over its lifespan. However, this is only true of length frequency data from a single year if the population is in equilibrium, therefore, LCA is usually applied to data averaged over a number of years during which it is assumed that there were no major systematic changes in the stock (e.g. in recruitment and exploitation rates). LCA also assumes uniform growth among animals. The results of LCA can be used to predict changes in the long-term (equilibrium) stock biomass and yield-per-recruit (YPR) based on changes in mortality, potentially resulting from fishing effort reductions or changes to minimum landing size regulations. The approach gives an indication of the exploitation of the stock in terms of growth overfishing, but not recruitment overfishing.

LCAs were applied to all stocks where sampling data were collected and considered to be sufficient (Annex A). To account for the differences in growth and length-weight relationships (**Table 6**), males and females were assessed separately. For the Shetland stocks of brown crab and velvet crab, two assessments were conducted using the two alternative sets of biological parameters (**Table 6**). The LCA provides estimates of fishing mortality (F) for each length class which are averaged over a fixed length range for each species and sex to give an estimate of average fishing mortality (F_{bar}) for each stock. Using a fixed length range in the calculation of F_{bar} enables comparisons of the recent F value (2016-19) with those calculated in previous assessments (2006-08 and 2009-12, 2013-15) and offers the potential to detect trends in F.

2.8. Reference Points

The results of LCA were used to calculate yield-per-recruit and biomass-per-recruit (BPR) relative to changes in fishing mortality, which provide an indication of stock status in terms of growth overfishing. The relationship between YPR and F is typically dome-shaped – low levels of F result in low landings as few individuals are caught, whilst high levels of F may also result in a reduction in yield (and biomass) from a particular cohort as animals are caught before they have had time to grow to a size that would contribute much weight to the yield (growth overfishing). In between these lies F_{MAX}, the fishing mortality rate that maximizes YPR for a particular selection pattern. For data-limited stocks such as crabs and lobsters it is not possible to directly estimate the maximum sustainable yield (MSY) and hence, in line with previous assessments, F_{MAX} was used as a proxy for F_{MSY}. This approach has been widely used by ICES (ICES, 2010) for other crustaceans such as *Nephrops* (e.g. ICES, 2014a). F_{MSY} proxy values for the majority of the stocks were estimated from the most recent per-recruit analysis, based on the results of the LCA of 2016-2019 landings-at-length data. For lobster stocks in two areas (North Coast and Ullapool), 2016-19 sampling data were not available and so for these stocks, reference points were retained from previous round of assessments. All F_{MSY} proxy values remain preliminary and may be modified following further data exploration and analysis. A summary of stock status in terms of fishing mortality in relation to F_{MSY} was provided for each stock. A stock was classified as being fished “at F_{MSY}” when the estimated F was within 10% of F_{MSY}.

3. Results and Discussion by Species

3.1 Brown Crab

3.1.1. The Fishery

The brown crab fishery is long established and landings, although variable, have increased significantly over the last 40 years (**Figure 2a**). Reported landings averaged around 2,000 tonnes in the late 1970s, increased to a maximum of about 12,000 tonnes in 2007 and fluctuated between 11,000 tonnes and 12,000 tonnes until 2015. In recent years, landings of brown crab into Scotland have decreased to around 7,000 tonnes. In 2020, a reduction of over 30% was recorded in relation to 2019. It is difficult to establish how accurate the pre 2006 data are, as landings are thought to have been under-recorded before the introduction of the UK ‘buyers and sellers’ legislation. The value of landings has increased in line with the tonnage landed. However, the price per kilogram changed little until the recent ~5 years when there has been a significant increase. (**Figure 2b** and **Figure 2c**). One kilogram of brown crab was sold for an average of £2 at first sale during the period 2016 to 2020, up from the average of £1.3 seen in the period 2013-2015.

The annual brown crab landings by assessment area are shown in **Figure 3**. The principal fishing areas for brown crab in Scotland are the Hebrides, Orkney, East Coast and South Minch; landings from these areas accounted for over 60% of the total in recent years (**Table 8**). Landings from the offshore areas of Sule and Papa increased sharply in the 1990s when the fishery expanded, but seem to have decreased in both areas during the last 5-10 years. Substantial declines in landings in recent years are also apparent in the Hebrides, North Coast and Orkney assessment areas. Landings from both the East Coast and South East have shown an increasing trend since the early 2000’s. The spatial distribution of brown crab landings by ICES statistical rectangle (including Irish landings) from 2016 to 2020 is shown in **Figure 6**. There were no major changes in relation to the most important rectangles for brown crab landings, compared to the previous assessments. Landings by non-UK vessels taken from the Scottish assessment areas were relatively low (mostly by Irish vessels) and usually confined to the South Minch (rectangle 40E3). The Irish fishery in Scottish waters has contracted in recent years with previously fished grounds in the Hebrides, Sule and North Coast not currently fished by Irish vessels. There is an important fishery for brown crab on the Malin shelf (Irish assessment area) that is exploited by Irish vessels, with most landings being taken from the Donegal region (rectangles 40E2, 39E2 and 39E1). There were no other regions of importance for brown crab landings around Scotland outside the Scottish assessment areas.

3.1.2. Sampling Levels

The number of sampled brown crabs, number of trips and percentage of sampled fishing trips are shown in **Table 3**. Good sampling coverage was achieved for the most important (in terms of landings) assessment areas, with samples being obtained throughout the year in the period 2016-19. A decline in the number of sampling trips was noted in North Coast with no samples collected in 2018, before sampling again in 2019 although at a low level. The percentage of trips sampled was generally less than 3% in assessment areas where daily inshore trips are common. In the Orkney (where OSF has been sharing considerable amounts of data with MSS) and Papa assessment areas, which include offshore grounds, sampling percentages were higher (**Table 3**) as the fishery is dominated by larger vessels, which tend to make fewer but longer trips. Sampling data from Ullapool (which was not included in the previous round of assessments) for 2016-19 was sufficient to conduct an assessment. Sampling data were considered to be insufficient (low numbers and infrequent sampling) to conduct an assessment in the Mallaig area (Annex A). Amongst the assessed areas, the South Minch, East Coast, South East and the Ullapool areas had the lowest sampling levels with less than 1% of fishing trips sampled in the period 2016-19. However, data included samples from all quarters and the averaged length frequency (Annex B) were similar to those in other adjacent areas and therefore assumed to be representative, despite the low sampling levels.

3.1.3. Size-based Indicators and Sex Ratio

Size-based indicators of brown crab in the landings from each assessment area are shown for males in **Figure 9** and for females in **Figure 10**. The data are typically noisy. In recent years (2016-19), the mean size of males was above the respective reference point in the Hebrides and Papa (**Table 11**). For females, the mean size was above the reference point in Hebrides, Orkney, Papa and Sule. In several areas, the mean size in the landings appears to have increased (both sexes), which is driven mainly by an increase in size at first capture following the implementation of a MLS in 1998. The MLS for brown crab increased again in 2017 from 140 mm to 150 mm in all areas except Shetland (The Specified Crustaceans Order, 2017) but any potential effect of this change is not visible in any of the size based indicators. In 2016-19, the mean sizes of the largest 5% of males and females were above the reference point in Papa (**Table 11**). For males, the mean sizes for the largest 5%

was also above the reference point in the Hebrides. There is some evidence of a positive trend in the mean size of the largest individuals throughout the time series in Shetland and the Clyde. In Shetland, the mean size of the largest females was close to the reference point in 2018. In all areas, the size at first capture of males was well above the size at first maturity L_{mat} throughout the time series. For females, in recent years size at first capture was above size at first maturity. In the SE, SH, EC and CL the size at first capture was fluctuating around L_{mat} prior to the year 2000.

The sex ratio in landings of brown crab varied greatly between assessment areas but in most cases shows no trend over time (**Figure 15**). Consistently higher percentages of females in landings over the time series are evident in areas, which include offshore fishing grounds such as the Hebrides (70%), Papa (90%), Sule (90%) and North Coast (90%). The only inshore area with a clear predominance of females in landings is the South Minch (55%). The South East is a male dominated fishery (70% males). Orkney has shown a decrease in the male percentage in landings from over 70% in the 1980s to around 40% in recent years, whereas the sex ratio in Shetland and East Coast displayed the opposite trend.

3.1.4. Survey Data Analysis

3.1.4.1. East Coast

The spatial distribution of brown crabs in the East Coast indicated that catch rates for both sexes and all sizes in the dredge survey were higher in coastal areas particularly in the Moray Firth and the Firth of Forth (**Figure 21**). Towards the south east coast areas of the Tay and the Firth of Forth, high catch rates were also predicted further offshore. Trawl survey catch rates were similar in distribution to the dredge surveys, however, trawl surveys did identify a region of medium density catch rates in Orkney. Male and female brown crabs were similarly distributed in the dredge survey data with juveniles of <100mm CW showing an inshore distribution. An abundance index for East Coast brown crabs was derived from the dredge model and compared to the index from the trawl model. The abundance index estimated from the dredge model increased gradually from 2008 and peaked in 2015 followed by a decline up to 2019 (**Figure 24a**). The trawl catch rate for the same period followed a similar pattern with an increasing trend until 2017 and a subsequent decline.

The GAMs used to derive the recruitment index showed that recruitment was found to be dependent on year, distance to coast and geographical position which were all significant ($p<0.05$) (Mesquita et al., 2021). The recruitment index shows an increase in the catch rate of juvenile crabs until reaching a peak in 2014. This is then followed by a decline in recruitment until 2019 (**Figure 25a**).

The mean length distributions of crabs captured in the East coast surveys are shown in **Figure 26**. The dredge survey (median=135 mm, mean=136.6 mm) captured generally smaller crabs than the trawl survey (median=162 mm, mean=158.5 mm). The median size per year (for those years where both dredge and trawl surveys were available: 2008-2019) was found to be significantly correlated (Pearson correlation=0.84, $p<0.001$) in the two surveys but fluctuated with no trend throughout the study period.

3.1.4.2. West Coast

Spatial distribution in the West Coast showed that catch rates in the dredge survey were higher in inshore areas (**Figure 22**). Male brown crabs had the highest catch rates close into shore particularly in the area of Mull, the Small Isles and around the south east of Barra. Female distribution was more widespread, with moderate to high density catch rates throughout the full dredge survey area in the West Coast. Juveniles showed an inshore distribution similar to that of males. Trawl survey data indicated a consistent moderate density catch rate throughout the whole West Coast, however the trawl survey covers a larger area with lower station density than the dredge survey.

The abundance index estimated for the west coast dredge survey increased gradually from 2008 to 2016 and declined in recent years. The abundance index derived from the trawl survey data is only available since 2011 and shows a fluctuating trend until 2014 and a decline in the last six years (**Figure 24b**).

The estimated recruitment index for the West Coast displays a steady trend between 2008 and 2013. Recruitment then rose to a peak in 2015 at near 30 crabs per km^2 before declining in recent years to just below 10 crabs per km^2 in 2019 (**Figure 25b**).

The mean length distributions of crabs captured in the west coast surveys are shown in **Figure 27**. The dredge survey (median=127 mm, mean=130 mm) captured generally smaller crabs than the trawl survey (median=170 mm, mean=165.3 mm). The mean size of crabs captured in the west coast was lower than that on the east coast for the dredge survey, however, an opposite trend was found when comparing the mean size of crabs caught in the trawl survey. The median size per year (for those years where both dredge and trawl surveys were available: 2011-2019) was found to be significantly correlated (Pearson correlation=0.74, $p=0.02$) in the two surveys but fluctuated with no trend throughout the study period.

3.1.4.3. Shetland

Despite the limited spatial coverage of the data (dredge only), there was still a clear propensity for higher catch rates of brown crabs in the most inshore waters around Shetland (**Figure 23**). Higher catch rates were observed around Yell and Unst and to the southern point of the mainland off Sumburgh. Despite some missing data between 2012 and 2015, the Shetland abundance index appears lower in the most recent 5 years than in 2011 and 2013. (**Figure 24c**).

A trawl abundance index was not calculated for Shetland given the low number of trawl stations available close to Shetland. Additionally, a recruitment index was not derived for Shetland due to the very low catch rates of juveniles in the dredge survey.

The mean length distributions of crabs captured in the Shetland surveys are shown in **Figure 28**. The median size of crabs caught in the dredge survey was 120 mm and the mean size was 120.3 mm. There were very few animals caught in the trawl surveys around Shetland (typically less than three animals, except in 2011, 2012 and 2020) which explains the missing length data in **Figure 28**. The median and mean size per year in the dredge survey fluctuated with no trend throughout the study period.

3.1.5. Length Cohort Analysis

Results of assessments based on LCAs and per recruit analysis, summarising estimates of fishing mortality in relation to F_{MSY}, are shown below. Estimated fishing mortalities in relation to previous assessments are presented in **Figure 29** (males) and **Figure 30** (females). Brown crab biomass and yield-per-recruit plots for each assessment area are shown in **Figure 35** (males) and **Figure 36** (females).

Brown crab stock status, relationship between F and F_{MSY} for 2006-08, 2009-12, 2013-15 and 2016-2019.

Assessment period		F (Fishing Mortality) 2006-2008	2009-2012	2013-2015	2016-19
Clyde	Males	✗	?	✗	✗ Above
	Females	✗	?	✗	O At F_{MSY}
Hebrides	Males	✗	✓	O	✗ Above
	Females	✗	✗	✗	✗ Above
North Coast	Males	✗	✓	✗	✗ Above
	Females	✗	✓	✗	✗ Above
Papa	Males	?	✓	✓	✓ Below
	Females	?	✓	O	✓ Below
Shetland	Males	?	?	✗	? Unknown
	Females	?	?	?	? Unknown
Sule	Males	✗	O	✗	✗ Above
	Females	O	✗	✗	✗ Above

Assessment period		F (Fishing Mortality) 2006-2008	2009-2012	2013-2015	2016-19
East Coast	Males	✗	✗	✗	✗ Above
	Females	✗	✗	✗	✗ Above
Mallaig	Males	?	?	?	? Unknown
	Females	?	?	?	? Unknown
Orkney	Males	✗	✗	✗	✗ Above
	Females	✗	✗	✗	O At F_{MSY}
South East	Males	✗	✗	✗	✗ Above
	Females	✗	✗	✗	✗ Above
South Minch	Males	✗	✗	✗	✗ Above
	Females	✗	✗	✗	✗ Above
Ullapool	Males	?	?	?	✗ Above
	Females	?	?	?	O At F_{MSY}

In the most recent assessments, nine of the eleven assessed areas were fished above F_{MSY} to some extent (**Table 14**). Fishing mortality for both males and females was estimated to be above F_{MSY} in the East Coast, Hebrides, North Coast, South East, South Minch and Sule. In the Clyde, Orkney and Ullapool, fishing mortality for females was at F_{MSY} while males were fished above F_{MSY}. In Papa, recent fishing mortality was below F_{MSY}. Fishing mortality assessment results for Shetland were deemed inconclusive for both males and females due to contradictory results obtained when using the two alternate sets of biological parameters (see section below and discussion). No assessments were performed for the Mallaig area as the sampling data collected were considered insufficient to run LCAs.

3.1.6. Comparison with Previous Assessments

The current assessment uses a fixed length range to calculate an average fishing mortality and can be compared with previous assessments which used the same range (Mesquita et al., 2011; Mesquita et al., 2016; Mesquita et al., 2017; Mill et al., 2009). Estimated F has decreased in relation to the last assessment in all areas except for females in the East Coast. (**Figure 29** and **Figure 30**). The main changes in status in relation to F_{MSY} are evident in the Clyde and Orkney females, which were both above F_{MSY} and are now fished at F_{MSY} while males in Hebrides were previously at F_{MSY} and are now fished above F_{MSY}.

Estimates of F for Shetland (using Shetland parameters) are higher than those estimated elsewhere (**Table 14**, **Figure 29** and **Figure 30**). This is due to the use of different growth rate (*K*) and natural mortality (*M*) parameters specific to Shetland (**Table 6**). To examine what underlies these differences, LCAs were run for all areas using both the Shetland and the rest of Scotland biological parameters and results compared (Annex C). Shetland's high natural mortality rate results in flat-topped YPR curves with both higher estimates of current F and F_{MAX} (the F_{MSY} proxy) compared with other areas, particularly for female brown crab (**Figure 30** and **Table 14**). This is further discussed in section 4.3.

3.2 Velvet Crab

3.2.1. The Fishery

Velvet crab landings increased gradually until the mid-1990s followed by a slight decline up to 2005 and a sharp increase in 2006. It is not clear, however, whether this increase in landings reflects the introduction of the UK 'buyers and sellers' legislation or an expansion of the fishery at this time. In recent years, landings have decreased and were around 1,600 tonnes in 2020. The value per unit weight of velvet crab remains higher than that of brown crab and is currently approximately £2.5 per kilogram (**Figure 2b**). The three areas that have historically had significant velvet crab fisheries are the Hebrides, Orkney and South Minch, although the fisheries in the two latter areas have shown a marked decrease over the last ten years (**Figure 4**). Landings in the East Coast increased sharply in 2005 and have been fluctuating ever since but this area remains one of the more important areas for the velvet crab fishery. These four areas accounted for about 80% of velvet crab landings in Scotland in the period 2016-19 (**Table 9**). **Figure 7** shows the spatial distribution of velvet crab landings 2016-19. Most landings were taken from inshore areas; only very small amounts were reported from offshore grounds in Papa and Sule. There were small landings of velvet crab from around Scotland reported from outside the assessment areas including north of the Hebrides and in ICES rectangles 44E9 and 45E8 in 2017.

3.2.2. Sampling Levels

The numbers of sampled velvet crabs, number of trips and percentage of sampled fishing trips are shown in **Table 4**. The percentage of trips sampled was generally lower than that achieved for other species. In the Clyde, Hebrides and Orkney, temporal coverage was good with samples generally being obtained throughout the year in the period 2016-19. The South Minch is one of the important areas for the velvet crab fishery where the number of samples has been relatively low in the past, although this improved in 2016-19 compared to 2013-15 (Mesquita et al., 2017). Assessments were conducted for the Clyde, Hebrides, Orkney, South Minch, East Coast and South East. Sampling data were considered to be insufficient (low numbers and infrequent sampling) to conduct assessments in the Mallaig and Ullapool areas (Annex A) while there is no fishery for velvet crabs in the offshore areas of Papa, Sule and North Coast. An LCA analysis was attempted for the Shetland area but the results were not conclusive (see section 4.2).

3.2.3. Size indicators and Sex Ratio

Size-based indicators for velvet crab by assessment area are shown for males in **Figure 11** and for females in **Figure 12**. The time series of sampled landings is shorter than for brown crab. The mean sizes of individuals in landings were relatively stable. In 2016-19, the mean size and the mean size of the largest 5% of both males and females were on average below the reference points in all assessment areas (**Table 12**). However, there is a weak positive trend in the mean size of the largest 5% since 2000 in the Hebrides and in Orkney. A decrease in the mean size and the mean size of the largest 5% of individuals was noted in the East Coast since 2008, before a slight rise in both males and females in 2019. A decrease in the mean size and the size of the largest 5% of males was noted in South Minch and Clyde since 2016. The size at first capture was generally above maturation size L_{mat} (**Figure 11**, **Figure 12**).

The sex ratio for velvet crab showed little evidence of a trend with males dominating in the landings, representing around 60% to 80% (by number) in the well-sampled areas (**Figure 16**).

3.2.4. Length Cohort Analysis

The results of assessments based on LCAs and per recruit analysis, summarising estimates of fishing mortality in relation to F_{MSY} are shown below. Estimates of fishing mortality in relation to previous assessments are presented in **Figure 31** (males) and **Figure 32** (females). Velvet crab biomass and yield-per-recruit plots for each assessment area are shown in **Figure 37** (males) and **Figure 38** (females).

Velvet crab in the Clyde, East Coast, and Orkney, were fished at levels above F_{MSY} (both males and females) in the most recent assessments. In the Hebrides and South East, males were fished at F_{MSY} while females were fished above F_{MSY} (**Table 15**). Assessment results for Shetland were deemed inconclusive due to contradictory results in the estimated fishing mortality when using the two alternate sets of biological parameters (see section below and discussion). No assessments were performed for the Mallaig, North Coast, Papa, Sule and Ullapool as the sampling data collected were considered insufficient to run LCAs.

Velvet crab stock status, relationship between F and F_{MSY} for 2006-08, 2009-12, 2013-15 and 2016-2019.

Assessment period		F (Fishing Mortality) 2006-2008	2009-2012	2013-2015	2016-19	
Clyde	Males	✗	✗	✗	✗	Above
	Females	✗	✗	✗	✗	Above
Hebrides	Males	✓	✓	✓	o	At F_{MSY}
	Females	✗	✗	✗	✗	Above
North Coast	Males	?	?	?	?	Unknown
	Females	?	?	?	?	Unknown
Papa	Males	?	?	?	?	Unknown
	Females	?	?	?	?	Unknown
Shetland	Males	?	?	?	?	Unknown
	Females	?	?	?	?	Unknown
Sule	Males	?	?	?	?	Unknown
	Females	?	?	?	?	Unknown

Assessment period		F (Fishing Mortality) 2006-2008	2009-2012	2013-2015	2016-19	
East Coast	Males	o	✗	✗	✗	Above
	Females	o	✗	✗	✗	Above
Mallaig	Males	?	?	?	?	Unknown
	Females	?	?	?	?	Unknown
Orkney	Males	✗	✗	✗	✗	Above
	Females	✗	✗	✗	✗	Above
South East	Males	o	?	o	o	At F_{MSY}
	Females	✗	?	✗	✗	Above
South Minch	Males	✗	✗	✗	✗	Above
	Females	✗	✓	✗	✗	Above
Ullapool	Males	?	?	?	?	Unknown
	Females	?	?	?	?	Unknown

3.2.5. Comparison with Previous Assessments

The current assessment uses a fixed length range to calculate an average fishing mortality and can be compared with previous assessments which used the same range (Mesquita et al., 2011; Mesquita et al., 2016; Mesquita et al., 2017; Mill et al., 2009). In the Hebrides, male fishing mortality increased to be at F_{MSY} (previously below F_{MSY}) in the most recent assessment while in the other areas the position of F relative to F_{MSY} remains unchanged. The estimated F for velvet crab has been found to be relatively stable over the time series in the Hebrides and Orkney areas (**Figure 31** and **Figure 32**). Velvet crab F estimates for Shetland (using Shetland parameters) are much higher than those estimated elsewhere (**Table 15**, **Figure 31** and **Figure 32**). This is due to the use of different growth rate (*K*) and natural mortality (*M*) parameters specific to Shetland (**Table 6**). To examine what underlies these differences, LCAs were run for all areas using both the Shetland and the rest of Scotland biological parameters and results compared (Annex C). Shetland's higher natural mortality rate results in flat-topped YPR curves with both higher estimates of current F (F_{male}=2.3; F_{female}=2.6) and F_{MAX} (the F_{MSY} proxy) for both sexes compared with other areas (**Figure 31**, **Figure 32** and **Table 15**). This is further discussed in section 4.3.

3.3 Lobster

3.3.1. The Fishery

The total tonnage of lobster landed in Scotland has consistently been much lower than that of crabs. However, reported lobster landings have increased substantially over the last 20 years, from 410 tonnes in 2000 to about 1,100 tonnes in 2020 (**Figure 2a**). The average price per kilogram of lobster was stable at just over £10 per kilogram for a long period of time but has seen a significant increase since 2016 with an average price per kilo of £13.7 for the period 2016-20 (**Figure 2c**). Between 2016 and 2020, the total value of the lobster fishery was around 80% that of the brown crab fishery (**Figure 2b**). The annual lobster landings by assessment area are shown in **Figure 5**. Historically, the majority of landings of lobster in Scotland have been from the Hebrides, Orkney and South Minch, but these areas have been overtaken in recent years by landings from the South East and East Coast areas. The period between 1999 and 2004 was characterised by lower landings from all areas. This can be related to an increase in minimum landing size to 87 mm in 1999, with the effect on landings being evident for the following years. The same effect is not evident following the staged increase in the minimum landing size from 87 mm to 90 mm in 2018 for the west coast of Scotland (except the Solway Firth), although landings by area in this report are only presented up to 2019. Landings in 2006 do not seem to be comparable with those in the preceding years (particularly in the South East and East Coast) which could be due to the introduction of UK 'buyers and sellers' regulations, before which landings may have been under-reported. Landings from the South East and the East Coast increased continuously from 2006 to 2014 and accounted for almost 60% of landings into Scotland over the last four years (**Table 10**). **Figure 8** shows the spatial distribution of lobster landings around Scotland in the period 2016-19. ICES rectangles 41E7 in the South East and 42E7 in the East Coast consistently have the largest landings. Small quantities of lobster were landed from grounds outside the assessment areas, including ICES rectangles to the west of Sule and the Hebrides; west of South Minch, to the south of the Clyde; and just outside the South East and East Coast areas.

3.3.2. Sampling Levels

The numbers of sampled lobsters, number of trips and percentage of sampled fishing trips are shown in **Table 5**. The percentage of trips sampled was generally less than 5% in most assessment areas, where daily inshore trips are common. The best sampled areas were the South Minch, South East, Hebrides, Orkney and Shetland. The number of sampling trips carried out in the Clyde and Papa areas remains lower than elsewhere. The overall number of fishing vessels exploiting the Papa Bank is low throughout the year – this implies a relatively high percentage of trips sampled compared with other areas such as the East Coast, which has a high number of animals measured but a low percentage of trips sampled. Length frequencies derived for these areas typically show a similar distribution to those from better sampled, adjacent areas and are therefore assumed to be representative, despite the low sampling levels. Sampling data were considered to be insufficient (low numbers and infrequent sampling) to run assessments in the Mallaig, North Coast, Sule and Ullapool areas (Annex A). These four areas represent only a small percentage of the total Scottish landings.

3.3.3. Size-based indicators and Sex Ratio

Size-based indicators for lobster landings by assessment area are shown in **Figure 13** for males and in **Figure 14** for females. The data are very noisy, and although males and females appeared to generally follow the same pattern of variation, there is little evidence of trends in any of the areas. Lobsters in the Clyde, South East and East Coast were noticeably smaller than in other areas over the full time series. A decline in the mean size of larger individuals can be observed in Shetland over the most recent eight years for both sexes. For males only, there has been a slight decreasing trend in the mean size of larger individuals in the East Coast since 2010, which has levelled out over the last three years. In Orkney, there is a decline in the mean size of larger male individuals in the past three years, while the mean size of large females increased. In the Hebrides, there has been a decreasing trend in males over the last fifteen years. Between 2016 and 2019, the overall mean size and the mean size of the largest 5% of males were generally below the reference points (**Table 13**). In the same time period, only the mean length of the largest females in Orkney was above the reference point. In the East Coast and South East, the size at first capture was above the size at first maturity L_{mat} for both sexes. In the other assessment areas, maturation size is estimated to be larger and size at first capture was below size at maturity L_{mat}. The sex ratio in landings for lobsters was close to 50% in all areas and showed no trends (**Figure 17**).

3.3.4. Length Cohort Analysis

The results of assessments based on LCAs and per recruit analysis summarising estimates of fishing mortality in relation to F_{MSY} are shown below. Estimates of fishing mortality in relation to previous assessments are presented in **Figure 33** (males) and **Figure 34** (females). Lobster biomass and yield-per-recruit plots for each assessment area are shown in **Figure 39** (males) and **Figure 40** (females).

In the most recent assessments, lobsters in all the areas were fished above F_{MSY} to some extent, particularly males. Fishing mortality was estimated to be above F_{MSY} for both males and females in the Clyde, South East, Shetland and South Minch. In the East Coast, Hebrides, Orkney, and Papa, fishing mortality for females was at or below F_{MSY} while males were fished above F_{MSY} (**Table 16**). No assessments were performed for Mallaig, North Coast, Sule and Ullapool, as the sampling data collected were considered insufficient to run LCAs.

Lobster stock status, relationship between F and F_{MSY} for 2006-08, 2009-12, 2013-15 and 2016-2019.

Assessment period		F (Fishing Mortality) 2006-2008	2009-2012	2013-2015	**2016-19**
Clyde	Males	✗	✗	✗	✗ Above
	Females	✗	✗	✗	✗ Above
Hebrides	Males	✗	✗	✗	✗ Above
	Females	✓	✓	✓	✓ Below
North Coast	Males	✗	?	?	? Unknown
	Females	✓	?	?	? Unknown
Papa	Males	?	✗	✗	✗ Above
	Females	?	✓	✓	✓ Below
Shetland	Males	?	✓	✗	✗ Above
	Females	?	✗	✗	✗ Above
Sule	Males	?	?	?	? Unknown
	Females	?	?	?	? Unknown
East Coast	Males	✗	✗	✗	✗ Above
	Females	✗	✗	✗	O At F_{MSY}
Mallaig	Males	?	?	?	? Unknown
	Females	?	?	?	? Unknown
Orkney	Males	✗	✗	✗	✗ Above
	Females	✓	O	O	✓ Below
South East	Males	✓	✗	✗	✗ Above
	Females	✗	✗	✗	✗ Above
South Minch	Males	?	✗	✗	✗ Above
	Females	?	✗	✗	✗ Above
Ullapool	Males	✗	?	?	? Unknown
	Females	✓	?	?	? Unknown

3.3.5. Comparison with Previous Assessments

The current assessment uses a fixed length range to calculate an average fishing mortality and can be compared with previous assessments which used the same range (Mesquita et al., 2011; Mesquita et al., 2016; Mesquita et al., 2017; Mill et al., 2009). Shetland's lobster results are only presented from 2009 onwards. The MoU between MSS and Shetland UHI for data provision means that recent data (sampled landings) are not directly comparable with data provided prior to 2009 (raised catch data including discards).

In the South East and Shetland, estimated F for both males and females increased and remained above F_{MSY} in the latest assessment. An increase in F was also found for males in the South Minch and East Coast. In the Clyde, estimated F decreased in 2016-19 for males and females but remains above F_{MSY}. Estimates of F for female stocks were generally lower than males, showing a slight decrease in relation to the previous assessments in the Hebrides and Orkney with F in the latter estimated to be below F_{MSY} for females (previously at F_{MSY}). In East Coast, the estimated F for females decreased and is now at F_{MSY} in the recent assessment.

Estimates of F in Papa remained approximately the same in relation to previous assessments with a slight decrease in F for both males and females. The estimated F for lobster has been found to be relatively stable over the time series in the Hebrides area, however an increase in the estimated F for males was noted in 2016-2019 (**Table 16**, **Figure 33** and **Figure 34**).

4. General Discussion

4.1. Landings

Brown crab remains the most important species, in terms of landed weight, in the crab and lobster fisheries around Scotland. However, brown crab landings have declined in most areas during the last five years with a particularly large decrease observed in 2020. It is unclear if the 2020 decline is related to market prices, which have not increased substantially in the last three years, reduced effort or changes in the abundance of the offshore stocks. The brown crab landings reduction coincides with a decrease in the abundance and recruitment indices calculated for the species (this is discussed in section 4.3.4) and anecdotal evidence from Scottish fishermen who have been reporting decreased catch rates in recent years. The Covid pandemic in 2020 may have affected the fishery but the extent of the reduction in brown crab landings was not observed in either velvet crab or lobster. Total landings of velvet crab have been stable in the last seven years but have declined since the high level recorded in the mid 2000's. There have been notable declines in reported landings from traditionally important areas including Orkney and South Minch. The spatial distribution of the velvet crab fishery is similar to previous years and the fishery continues to take place in inshore areas. Lobster landings, although still much lower than those of brown and velvet crabs, have more than doubled since 2001, with the East Coast and South East areas making the major contribution to this increase.

Landings of all three species are thought to have been under-reported prior to 2006, before the introduction of the UK 'buyers and sellers' legislation. Some major increases in landings evident in the mid-2000s are therefore more likely to be explained by improved reporting than by changes in the abundance of stocks or increased effort. There is little information on changes in fishing effort over the past 30 years, but it is likely that technological advancement and mechanisation of fishing and processing have allowed the crab and lobster fishery to expand and effort to increase. The emergence of European markets, and more recently, eastern markets in China, combined with the ability to transport live animals has increased the demand, particularly for brown crab. However, this was not accompanied by an increase in brown crab prices until 2016, when the price per kilo began to increase, reaching a peak value of £2.6 per kilo in 2018. Market and supply issues contributed to the setting up of a European project ACRUNET (A Transnational Approach to Competitiveness and Innovation in the Brown Crab Industry) in 2012. The project highlighted the disparity of fishery management measures in relation to the latent capacity in the fishery, between the main European crab producer countries, France on one hand and UK and Ireland on the other. Fishermen from both the UK and Ireland fishermen have emphasized the issue of latent effort, pointing out that this was one of the biggest obstacles to crab and lobster management. The latent effort was quantified as part of the ACRUNET project (Mesquita et al., 2015) and this information is likely to be useful in future discussions regarding the management of brown crab fisheries.

4.2. Stock Assessment

4.2.1. Brown Crab

Assessment areas with historically significant brown crab fisheries are relatively well sampled. However, the South Minch area is becoming more important for landings in recent years and is currently not as well sampled as the other key areas. In the northwest of Scotland, female crabs usually make the largest contribution to the landings. This suggests that females are exposed to higher exploitation than males on some of the offshore grounds such as the Hebrides or Papa. Tagging studies suggests that females migrate from deeper offshore grounds, where they live for most of the year, to inshore areas where they moult and mate with males (Edwards, 1979; Jones et al., 2010). Large females also predominate in the landings from offshore areas to the north of Ireland (Tully et al., 2006), and in the fisheries off the east coast of England and in the English Channel, aggregations of ovigerous females have been observed (e.g. Howard, 1982).

The evaluation of size-based indicators relative to reference points, allows for some inferences to be made on stock status in terms of exploitation level. In recent years, the mean size and mean size of the largest 5% of brown crabs were at or above the reference points for both males and females in Papa, Orkney and the Hebrides. This suggests that despite high exploitation in some offshore fisheries, brown crabs appear to have an extended size structure. The mean size of the largest individuals in Shetland increased throughout the time series, in particular for females. The mean size of the largest males has increased in recent years in Orkney and the South East. In contrast, the mean size of the largest individuals decreased in Sule and the North Coast in recent years; particularly for males. This could be indicative of a decrease in the proportion of large individuals in the stock, and possibly an increase in fishing mortality. It could, however, also be a reflection of changes in fishing or discard practices. Without further fishery information, it is difficult to conclude which is more likely.

Geospatial analysis of trawl and dredge survey data has allowed for a better understanding of the distribution of brown crab in Scottish waters. The recruitment (east and west coast) and abundance (all areas) indices show a general increase from 2008 until the 2013-2016 period and a decline in catch rates towards the end of the time series. This trend is similar across the three areas considered and is consistent with the recent reduction in brown crab landings and also with anecdotal reports from the fishing industry describing a general decrease in the fishery catch rates. There is a clear similarity in the crab abundance signal estimated from the dredge and scallop surveys in the east and west coast. The fact that distinct surveys using different gears show the same trend, indicates that active gear surveys can be used to estimate the distribution/abundance of brown crabs, even though dredging/trawling are not the main methods employed by the fishery to capture the species (Mesquita et al., 2021).

The length distributions obtained from the dredge surveys show that the mean size of brown crabs captured in the dredge surveys are smaller than those sampled in the landings. Brown crabs are more rarely caught on trawl surveys (compared with dredge surveys) and the mean size of trawl-caught crabs is generally above the mean size in landings for most years in the different assessment areas. The dredge surveys have a higher sampling effort than the trawl surveys with more stations per area. However, trawl surveys have a very large area coverage and include a variety of different sediment categories where not all ground types will be suitable for crabs. It is likely that the most coastal areas covered by dredge surveys targeting scallops coincide with areas of higher crab density. There are also differences in the catchability of trawl and dredge surveys and this subject is discussed further in section 4.3.

Assessments based on the 2016-19 data (using LCA) were carried out for brown crab in eleven of the twelve assessment areas. Assessment results using 2016-19 data for all assessed areas show a clear decline in fishing mortality estimates compared to those previously reported, however, most stocks are still fished well above F_{MSY}. The results from the LCA were in general agreement with the indicator evaluation in relation to reference points. In the Papa (males and females), Hebrides (males) and Orkney (females) areas both approaches suggested that these stocks were being fished below the reference points. The mean sizes of female brown crabs in the South East and East Coast assessment areas were smaller than in other areas, as found in previous assessments (Kinnear, 1988; Mesquita et al., 2017; Mill et al., 2009), but showing a slight recovery in the most recent 3 years. It should be noted that the growth parameters used in the assessments are the same for all areas and that this may not be appropriate if individuals in the East and South East are slower growing and reach smaller maximum sizes. Use of inappropriate growth parameters in the LCA could lead to overestimation of F and the conclusion that the stocks are more heavily fished than they actually are. This is discussed further in section 4.3 below.

4.2.2. Velvet Crab

Male velvet crabs were more common in the landings than females and were generally slightly larger. With respect to mean size and mean size of the largest 5% of individuals in 2016-19, all stocks of velvet crabs appeared to have truncated size distributions and are exploited above the F_{MSY} proxy. The mean size of males in the Hebrides indicated exploitation close to F_{MSY} (mean size just below $L_{F=M}$) in the most recent years. If the landings LFDs are representative of the population size structure and there have been no recent changes in the exploitation pattern, the increase in mean size and mean size of the largest individuals observed in these areas would indicate that the fishing mortality might have declined over the time series. A decrease in the mean size and the mean size of the largest individuals was observed in the South Minch, particularly for males. This may be due to changes in the fishery as fishing mortality estimated from both the LCA and LBI appears to show a downwards trend in recent years. Fluctuating trends in the mean size and the mean size of the largest individuals were observed in the East Coast, which may indicate (assuming no changes in the fishery) an increase in fishing mortality. These areas also show sporadic occurrences of large numbers of small individuals in the length frequency data, which could be due to increased recruitment in these years.

Assessments based on the 2016-19 data (using LCA) were carried out for velvet crab in seven of the twelve assessment areas. Fishing mortality for stocks in most of these areas remains above F_{MSY}. For all assessed areas, fishing mortality showed a decreasing trend from the 2013-15 assessment estimate (Mesquita et al., 2017) although the Clyde, East Coast and Orkney areas remained above F_{MSY} for both males and females. In the Hebrides, male velvet crabs were fished below F_{MSY} and females above F_{MSY}. Fishing mortality in the South Minch male stock has decreased compared to previous assessments and is now at $F_{MSY.}$ Results based on the LBI analysis for velvet crabs were less optimistic than the LCA analysis in terms of the relative status of fishing mortality in relation to the reference point. However, the trends in the two methods are generally agreeing on a decreasing trend in fishing mortality in the last four years.

4.2.3. Lobster

Lobster market sampling data from 2016-19 suggest that male and female lobsters were generally landed in equal proportions. For most areas, the mean size has remained stable in recent years. Following the evaluation of size-based indicators relative to the reference points, males appear to be exploited above the F_{MSY} proxy (mean size less than $L_{F=M}$) in all areas. In recent years, the mean size in landings of the largest males has decreased in the Hebrides, Orkney and Shetland, which may indicate an increase in the long term fishing mortality, although this could also be a reflection of changes in the fishing practices. For females, indicators were generally below the reference points in 2016-19, with exception of the mean size of the largest individuals in the Orkney assessment area. In the Hebrides, East Coast, Shetland and Orkney, the mean sizes, mean sizes of the largest females and length frequency data appear relatively stable suggesting a stable stock and fishery.
Size at first capture was above size at first maturity only in the East Coast and South East.
The L_{mat} is likely to vary between assessment areas but the current estimates were derived from two regions: the East of Scotland (East Coast and South East data) and west of Scotland (Hebrides data). For example, it is expected that lobsters to the west of Scotland as well as at Orkney and Shetland mature at a larger size than to the east of Scotland. Currently, the evaluation of exploitation level on immature individuals should be viewed as preliminary, as size at first maturity is not known for all areas.

Assessments based on the 2016-19 data (using LCA) were carried out for lobster in eight of the twelve assessment areas. Fishing mortality for stocks in most of the areas remains above F_{MSY}, especially among the males. The results from the LCA were in general agreement with the indicator evaluation. Females in Papa, Hebrides, Orkney and South Minch were fished below F_{MSY} while in other areas F is above F_{MSY}. There are differences in mean size in the sampled landings between areas, with lobsters from the North Coast, Orkney and Hebrides being significantly larger than those from the South East and East Coast areas. It should be noted that the growth parameters assumed are the same for all areas, except Shetland. This may not be appropriate if individual growth is generally slower in some areas such the East Coast and South East, and individuals typically attain smaller maximum sizes. The use of inappropriate growth parameters in the LCA could overestimate the degree of growth overfishing. This is discussed further in section 4.3. The LCA results were generally in agreement with the evaluation of mean size and mean size of largest 5% of lobsters carried out for the LBI analysis.

4.3. Management Considerations

4.3.1. Brown crab

The results of LCA assessments for the period 2016-19 showed that brown crab in the majority of the assessment areas in Scotland were fished close to or above F_{MSY}. In many of the assessment areas, a higher biomass and yield-per-recruit in the long term could potentially be obtained by reducing the level of fishing mortality (effort). LBI results were mostly in agreement with the LCA and indicated similar exploitation levels relative to F_{MSY} reference points. The evidence from the surveys showed that there was a widespread increase in recruitment until 2014-2015, which likely contributed to the increase in stock size. The increase in recruitment coincides with a period of relatively high fishing mortality and high landings, particularly for the North Sea stocks. This may be an indication that the stocks were not recruitment overfished at that time, although the recruitment indices presented in this report are relatively short and provide no information on historical levels. It is possible that even at a high level of fishing mortality (which has been estimated for a number of years), recruitment and stock biomass continued to increase. A change in stock trend was observed in the mid 2010's with both abundance and recruitment showing a general decrease in recent years. It is likely that if crab stocks had been subjected to a lower F over the years, this would have allowed the effects of the high recruitment/stock biomass to be sustained over a longer period, possibly generating higher total yields. Most brown crab stocks are being fished close to or above F_{MSY}, as indicated by the LCA/LBI analysis. It is recommended that effort/fishing mortality should be reduced for those Scottish brown crab stocks for which fishing mortality is estimated to be above F_{MSY}. Results from a recent study support that the current MLS in Scotland (140-150 mm) is appropriate since brown crab maturity is likely to occur at lower sizes than the MLS (Mesquita et al., 2020). Estimates of effort in creel fisheries are further discussed in section 4.5.1.

Brown crab stock status based on results from the LBI, LCA and survey data. The right down arrow indicates a decreasing trend in the surveys.

Area	**Length Based Indicators (LBI)**				**LCA 2016-2019**		**Surveys**	
	$\bar{L}/L_{F=M}$		$L_{max5\%}/0.9L_{\infty}$					
	Males	Females	Males	Females	Males	Females		
Papa	✔	✔	✔	✔	✔	✔		
Orkney	O	✔	O	O	✖	O		
East Coast	✖	✖	✖	✖	✖	✖	↘	East
South East	O	✖	✖	✖	✖	✖		
Sule	?	✔	?	O	✖	✖		
North Coast	?	?	?	?	✖	✖		
Hebrides	✔	✔	✔	O	✖	✖		
Ullapool	?	?	?	?	✖	O	↘	West
Mallaig	?	?	?	?	?	?		
South Minch	O	O	✖	✖	✖	✖		
Clyde	?	✖	?	✖	✖	O		
Shetland	✖	O	✖	✖	?	?	↘	

4.3.2. Velvet crab

Assessments have been conducted in seven out of the twelve assessment areas in Scotland, corresponding to those areas where fisheries for velvet crab have been in place. The status of F in relation to F_{MSY} does not appear to have changed considerably over time in most velvet crab stocks since the 2006-2008 assessments. The results of LCA assessments for the period 2016-19 showed that, in the majority of the areas with sufficient sampling data to conduct assessments, velvet crab remain fished close to or above F_{MSY}. In some assessment areas (Clyde, East Coast and Orkney), a higher biomass and yield-per-recruit in the long term could potentially be obtained by reducing the level of fishing mortality (effort). LBI results were mostly in agreement with the LCA with the exception of male stocks in the South East, Hebrides and South Minch, where the LCA showed a more optimistic outcome with fishing mortality estimates below or at F_{MSY}. There is no survey information available for velvet crabs as the species is mostly inshore and not commonly captured by any existing dredge or trawl surveys. Most velvet crab stocks are being fished close to or above F_{MSY}, as indicated by the LCA/LBI analysis. It is recommended that effort/fishing mortality should be reduced for those Scottish velvet crab stocks for which fishing mortality is estimated to be above F_{MSY}. Estimates of effort in creel fisheries are further discussed in section 4.5.1.

Velvet crab stock status based on results from the LBI and LCA.

Area	Length Based Indicators (LBI)				LCA 2016-2019	
	$\bar{L} / L_{F=M}$		$L_{max5\%}/0.9L_{\infty}$			
	Males	Females	Males	Females	Males	Females
Papa	?	?	?	?	?	?
Orkney	✖	✖	✖	✖	✖	✖
East Coast	✖	✖	✖	✖	✖	✖
South East	✖	✖	✖	✖	o	✖
Sule	?	?	?	?	?	?
North Coast	?	?	?	?	?	?
Hebrides	✖	✖	✖	✖	o	✖
Ullapool	?	?	?	?	?	?
Mallaig	?	?	?	?	?	?
South Minch	✖	✖	✖	✖	✖	✖
Clyde	✖	✖	✖	✖	✖	✖
Shetland	✖	✖	✖	✖	?	?

4.3.3. Lobster

Assessments have been conducted in eight out of the twelve assessment areas in Scotland, corresponding to the areas where higher volumes of lobster were reported and market sampling data has been collected. There are also small lobster fisheries in the North Coast, Ullapool and Mallaig and a by-catch of lobster in the Sule offshore brown crab fishery. However, sampling opportunities in these areas are very limited due to the small amounts of reported landings. The results of LCA assessments for the period 2016-19 indicated that lobster in the majority of the assessment areas in Scotland were fished close to or above F_{MSY}. In all assessment areas, a higher biomass and yield-per-recruit in the long term could potentially be obtained by reducing the level of fishing mortality (effort). There is no survey information available for European lobster as this species is found mostly inshore in rocky areas and not commonly captured by any existing dredge or trawl surveys. Most lobster stocks are being fished close to or above F_{MSY}, as indicated by the LCA/LBI analysis. It is recommended that effort/fishing mortality should be reduced for those Scottish lobster stocks for which fishing mortality is estimated to be above F_{MSY}. Estimates of effort in creel fisheries are further discussed in section 4.5.1.

Lobster stock status based on results from the LBI and LCA.

Area	**Length Based Indicators (LBI)**				**LCA 2016-2019**	
	$\bar{L}/L_{F=M}$		**$L_{max5\%}/0.9L_{\infty}$**			
	Males	Females	Males	Females	Males	Females
Papa	?	?	?	?	✗	✓
Orkney	✗	✗	✗	✓	✗	✓
East Coast	✗	✗	✗	✗	✗	o
South East	✗	✗	✗	✗	✗	✗
Sule	?	?	?	?	?	?
North Coast	?	?	?	?	?	?
Hebrides	✗	✗	✗	✗	✗	✓
Ullapool	?	?	?	?	?	?
Mallaig	?	?	?	?	?	?
South Minch	✗	✗	✗	✗	✗	✗
Clyde	?	?	?	?	✗	✗
Shetland	✗	✗	✗	✗	✗	✗

4.4. Quality of the Assessment and Data

4.4.1. Landings Data

From the range of stock assessment tools available, LCA is one of the least data intensive, and LCA and yield-per-recruit models are commonly used for assessing data-limited shellfish stocks. A major assumption of LCA is that the landings length frequency distribution is representative of the fishery removals from a single cohort of individuals throughout its life. However, since the length frequencies are derived from a single year of sampling, rather than from the lifetime of a single cohort, this assumption is only true if the population is in a steady state or at equilibrium, i.e. that recruitment and exploitation rate are constant. An average of the length frequency data (2016-19) was used in order to limit the effects of these variations. Landings from most of the Scottish assessment areas tend to fluctuate, which may reflect year to year variation in recruitment and/or fishing effort. Results of the dredge surveys seem to indicate reductions in the recruitment and stock biomass of brown crab over the time period covered by the latest LCA. Systematic changes in exploitation rate or recruitment over the four-year period could potentially result in biased estimates of fishing mortality.

Landings are generally well sampled, for length and sex composition in the most important fishing areas. However, in some areas such as South Minch (brown crab), the Clyde (brown crab), Ullapool (brown crab), Papa (lobster) and East Coast (velvet crab), size data are sparse, and sampling levels remain relatively low with few sampling trips taking place. Length frequencies derived for these areas are often similar to those in other adjacent areas and are therefore assumed to be representative, despite the low sampling levels. However, the effect of this assumption on LCAs has not been investigated and the results of these assessments should be interpreted with caution.

It was concluded based on data recorded in FISH1 forms that vessels fishing in the South Minch land in ports on the west of the Kintyre peninsula while fishing trips landing into ports on the east side are associated with fishing activity in the Clyde. Historically the split of landings in 40E4 between South Minch (west) and Clyde (east) was based on a zone code entered by fishery officers and recorded in the FIN database. This procedure was discontinued in the new iFISH database and it is expected that the port allocation method (described in section 2.2) will continue to be used in the future. Analysis of historical data (2000-2016) has shown that the previous allocation method based on the zone code was likely to overestimate 40E4 landings in the Clyde until 2016. Since 2017, the split of landings between South Minch and Clyde in rectangle 40E4 is based on the location of the port, which is considered a more reliable method compared to the previous use of zone codes.

4.4.2. Biological Parameters

LCA is frequently used for assessing crustacean species for which ageing techniques are not yet fully developed. Discontinuous growth within a cohort of animals (growth increments and frequency of moults) results in growth rates varying between individuals within a stock. This can make it difficult to track cohorts through length frequency data and hence assessment methods which translate between size-structured and age-structured data have not been widely applied to crustaceans (e.g. Sheehy et al., 1996; Sheehy and Prior, 2008; Kilada, 2012; Kilada and Acuña, 2015).

In addition to landings length frequency distribution data, LCA also requires estimates of other biological parameters, including von Bertalanffy growth parameters and natural mortality. LCA is very sensitive to these parameters and the choice of input parameters may critically influence the results obtained (Lai and Gallucci, 1988; Jones, 1990), such as the perception of the state of the stock (in terms of the position of the current exploitation rate in relation to F_{MSY}). Natural mortality (*M),* for example, has a marked effect on the shape of the relative yield-per-recruit curve. Using lower values for *M* results in a more pessimistic stock assessment, with current fishing mortality estimated to be higher in relation to F_{MSY}

(or *vice versa*). The values of the von Bertalanffy growth parameters (K and L_∞) also affect the shape of the yield-per-recruit curve and estimation of the value of F in relation to F_{MSY}. Using growth model parameters that result in growth rates that exceed the true growth rate (i.e. using values of K and L_∞ which are too large), results in the current exploitation rate (F) being over-estimated in LCA and could lead to the erroneous conclusion that a stock is growth-overfished (or *vice versa*).

For the LCA assessments, the same biological parameters have been applied across all areas except Shetland (Chapman, 1994; Mesquita et al., 2011; Mesquita et al., 2016; Mesquita et al., 2017; Mill et al., 2009). Studies of velvet crabs in Shetland (Tallack, 2002; Mouat et al., 2006) provided much higher estimates of M (0.58 compared to 0.1 elsewhere) and a higher value of K (0.46 compared to 0.1 elsewhere). For brown crab in Shetland, M is estimated to be higher than elsewhere (0.25 compared to 0.1) and the sex-specific von Bertalanffy K parameters are also different (lower at Shetland for males, but higher for females). The high value of K estimated for Shetland velvet crabs implies a very fast growth rate for young crabs (for example a 30 mm male crab would be expected to grow to nearly 60 mm carapace length in a single year). This seems unrealistic and merits closer scrutiny of the original data and methods used to estimate the growth parameters for this stock. For example, Electronic Length Frequency Analysis (ELEFAN) is a system of stock assessment methods which may be used to estimate L_∞ and K from length frequency data in the future (Mildenberger et al., 2017). For brown crab, the parameters derived from studies in Shetland are closer to those used by MSS for other assessment areas, but some notable differences persist, in particular for females. The difference in parameters is sufficient to explain the disparity in the results obtained for the velvet and brown crab assessments in Shetland when compared to other stocks with relatively similar length frequency distributions. Velvet crabs in the Clyde, East Coast and Orkney are estimated to be growth overfished, whereas in Shetland they are estimated to be fished below F_{MAX} (as estimated from a LCA using Shetland parameters), despite the estimated F in Shetland being much higher than in other areas. The F calculated from a LCA applied to Shetland data using the rest of Scotland parameters is much lower but estimated to be above F_{MAX}. For brown crab, as M and K parameters from Shetland and elsewhere are closer, F estimates are similar but the estimated $F_{MAX,}$ taken as a proxy for $F_{MSY,}$ from Shetland parameters is always higher. This is reflected in the shape of the YPR curves generated from the LCAs using Shetland parameters, which are more flat topped resulting in a higher F_{MAX} and hence a higher reference point. Because of the differences in the estimates of F obtained using the different sets of growth parameters and the associated issues of interpretation for the purposes of this report, we have described the stock status for Shetland velvet crab and brown crab as unknown. Owing to the uncertainty around appropriate input parameter values, care is required in drawing firm conclusions regarding the status of crab and lobster stocks, particularly for velvet crab. To progress this discussion it would be worthwhile holding a joint Shetland UHI/MSS crab working group in the near future.

Differences in size composition across areas, particularly the relatively small size of brown crab and lobster landed in the South East and East Coast compared to the north and west, suggest that area specific parameter values may be more appropriate and it is possible that the extent of growth overfishing of brown crab and lobster in the East Coast and South East is overestimated. Estimation of growth parameters for these areas would, however, require a large scale tagging project using tags that could be reliably retained on moult, with seasonal measurements of length and weight.

4.4.3. Size-based Indicators

ICES has previously suggested a multiple-indicator-based approach, including LPUE (landings per unit effort), size-based indicators and recruitment indices, as a potential way forward in the provision of advice on stock status for crab stocks (ICES, 2009). The exploratory analysis presented here makes use of commercial length frequency data and biological parameters in an approach for evaluating the status of data limited stocks proposed by the ICES WKLIFE V workshop (ICES, 2015a; Miethe et al., 2016). More recently, ICES have introduced some new approaches for the provision of advice for data limited stocks (ICES, 2020) which may be relevant for crabs and lobsters, although the latter are currently non-quota species. The new methods proposed by WKLIFE X are further discussed in section 4.5.5. In the assessments presented here, size-based indicators were calculated and compared to the respective reference points. In some cases it was possible to relate variations of the mean size and mean size of largest animals to trends in fishing mortality. The results are highly dependent on the quality of estimates of life history parameters by assessment area. In most cases, results were in agreement with the LCA results and indicated similar exploitation levels relative to F_{MSY} reference points.

Mean sizes of the largest individuals are quite variable from year to year, particularly in areas where data collection is more sporadic. This is likely to reflect sampling variability rather than changes in the population. The sampling levels achieved in some areas remain low. Improved sampling and better information on fishing activity and fishers' behaviour could help to develop robust size-based indicators for assessment purposes.

Assumptions for biological parameters (M/K, L_∞ and L_{mat}) are also important for the interpretation of size-based indicators. The estimated mean size indicator reference point $L_{F=M}$ depends on the ratio between natural mortality and the growth parameters. The collection of data on growth rate in different areas, in order to derive area-specific parameters, would help to improve the assessment using size-based indicators. With the exception of Shetland, the M/K ratios used for the LCA were below 1. A lower M/K ratio would result in a higher, more restrictive, size-based reference point, with an expectation of more large individuals in the size distribution of an unexploited stock (Hordyk et al., 2015; Jardim et al., 2015).

4.4.4. Survey Analysis

While the survey analysis provides an indicator of trends in abundance and of the distribution of brown crab in Scotland, currently these are only available for three large areas (east coast, west coast and Shetland) rather than for each of the brown crab assessment areas. The data collected from surveys around the Shetland Islands has been more limited than that from the east and west coast areas. This is due to the low number of trawl stations around Shetland combined with very low catch rates of crabs in the area. The Shetland dredge survey has also a number of missing points related to difficulties in conducting the surveys under adverse weather conditions. Additionally, very few crabs below 100 mm CL were caught in the Shetland dredge survey and hence the trawl abundance and dredge recruitment indices were not derived for Shetland brown crab. It is unlikely that trap surveys will be introduced in Scotland in the near future. Therefore, dredge and trawl surveys targeting scallops and whitefish, which already take place annually in the waters around Scotland, are likely to continue to be the main source of fishery independent data on brown crabs, providing useful information on distribution and trends in abundance and recruitment. Brown crabs are amongst the species more often caught as bycatch in these surveys, unlike velvet crabs and lobsters, which are rarely captured. The models applied in this study could be potentially improved by including other environmental and oceanographic variables normally associated with crustacean distribution, such as seabed temperature or currents strength.
An advantage of using dredge and trawl gears over passive gears such as traps for obtaining standardized catch rates is that the catchability of active gears is not affected by factors such as season, bait, current strength and direction (Mesquita et al., 2021). In addition, catch rates calculated from active gears eliminate issues of trap avoidance by berried females (Howard, 1982), and are not affected by

saturation effects resulting from the first animals which enter the traps. The main limitation associated with the use of active gear surveys applied to benthic crustaceans is that towed nets or dredges are limited to muddy/sandy seabed types, which may introduce biases given that crustaceans may also live in rocky habitats (Smith and Tremblay, 2003).

4.4.5. Reference Points

LCA provides long term equilibrium predictions and assumes constant recruitment and exploitation rates. It is therefore advisable to complement the outputs with additional data, which can provide information on trends in abundance, typically catch per unit effort data or exploitation rate. Effort data in terms of numbers of creels fished are not currently available for Scottish creel fisheries, precluding calculation of catch per unit effort. In an attempt to gain additional information on variation of fishing mortality from the available data , the mean overall size and the mean size of largest 5% of individuals were explored (ICES, 2014b; ICES, 2015a).

The landings at length data used as the input for the LCA were averaged over 2016-2019 which covers periods of time both pre- and post- increase in MLS. Data exploration focusing on comparing the left tails of the length frequency distributions (Annex B) with those from previous years (Mesquita et al., 2017) do not show major differences in the size of first capture for the three species, despite the MLS increase. Additionally, in some areas, particularly for the velvet crabs, it is clear that the first size of capture in the most recent data is below the old MLS. The changes to MLS therefore appear not to have resulted in a major selectivity change, at least in the first two years after being introduced. Despite these observations, some selectivity changes, even if minor, would be expected in the fisheries, and to account for that, the F_{MSY} reference points were re-estimated with a yield-per-recruit analysis for all stocks using the most recent LCA input data (2016-2019).

The conclusions in this report are based on estimates of fishing mortality in relation to a reference point for each stock, to infer whether or not a stock is fished above the level that would in theory result in MSY (in the long term). For the purposes of consistency in this report, all discussion relates to the F_{MSY} proxy (F_{MAX}). Although LCA and yield-per-recruit analysis give an indication of current F relative to the fishing mortality required to optimise yield (from a particular cohort), they provide no indication of whether or not a stock is recruitment overfished (i.e. whether fishing is compromising recruitment). F_{MSY}, the fishing mortality which gives the maximum sustainable yield (high long term yield with low risk of stock depletion), is difficult to estimate, requiring good estimates of spawning stock biomass and recruitment. In

the absence of such estimates, the survey based recruitment index, when considered in combination with estimates of current F, may in future provide an indication of periods of potential recruitment overfishing for brown crab.
In cases where F_{MSY} cannot be estimated directly, proxy values based on yield-per-recruit analysis are often used. ICES advises that in cases where the peak in the yield-per-recruit curve is well defined and there is no evidence of poor recruitment at this level of fishing mortality, then F_{MAX} may be an appropriate proxy for F_{MSY} (ICES, 2010). In cases where the peak is less well defined and the curve is more flat topped, then $F_{0.1}$ is likely to be a more appropriate proxy (Jennings et al., 2001). Another potential reference point is $F_{30\%SpR}$ which is defined as the fishing rate, which results in combined spawning biomass per recruit equal to 30% of the un-fished level. $F_{0.1}$ is usually the most conservative reference point while F_{MAX} is generally above $F_{30\%SpR}$, depending on the relative shape of the YPR and BPR curves. F_{MSY} proxies for *Nephrops* stocks assessed by ICES have been selected from these three candidate reference points ($F_{0.1}$, $F_{35\%SpR}$ or F_{MAX}) for each stock independently according to the perception of stock resilience, typical population density, biological knowledge and the nature of the fishery (e.g. ICES, 2015b). Most crab and lobster fisheries have been in existence for several decades with little evidence of between-stock differences in resilience. Therefore, despite some stocks showing very flat topped YPR curves (which might suggest $F_{0.1}$ as the most appropriate proxy for F_{MSY}), F_{MAX} was selected as a proxy for F_{MSY} for all stocks (Mesquita et al., 2017). However, these reference points remain preliminary and may be revised in the future as further data become available.

In most areas around Scotland, the crab and lobster stocks are being fished at levels which result in yield-per-recruit values not far below the maximum. However, in some cases, the estimated fishing mortality is substantially above F_{MSY}, making it more likely that these stocks are recruitment overfished as well as growth overfished. It should be noted, however, that so far lobster stocks have not showed signals of systematic changes in sex ratio, which has been associated with recruitment overfishing in other lobster species.

4.5. Data Gaps and Future Research Priorities

From the discussion above it is clear that there are a number of areas where research or additional data collection would improve Scotland’s crab and lobster stock assessments.

4.5.1. Fishing Effort

Prior to 2016, no useful measures of creel fishing effort were available from official log sheets with the exception of the Shetland area where the Shetland Regulating Order requires licensed fishers to return logbook information to the SSMO, detailing the catch location (at the 5 nmi scale) and the number of creels or pots fished. This has precluded the use of LPUE data as an indicator of abundance for the crab and lobster stocks around Scotland. Fishing effort for most finfish species can be estimated as fishing time (days fishing or KW days) using days absent from port and vessel power, but these are not particularly useful measures of effort in creel fisheries. The number of creels used or hauled when fishing for crabs and lobsters is considered to be a much more useful measure of effort in the fishery. The recent changes to reporting on the FISH1 form include the introduction of a mandatory field for the number of creels hauled. This provides new effort data for vessels under 10 m fishing around Scotland and allows for calculation of LPUE indices. These newly available effort data have recently been used by MSS to provide scientific support for the Outer Hebrides Inshore Fisheries Pilot (OHIFP). As part of this pilot project, work was carried out using FISH1 data to obtain effort information (total number of vessels and trip numbers) and preliminary estimates of LPUE for brown crab, velvet crab and lobster in the Outer Hebrides area which show a general decrease between 2017 and 2020. It has been highlighted that the reliability of this type of analysis depends heavily on the quality and accuracy of data reporting by fishers (Bell et al., 2022).

VMS data have become available for larger vessels (over 15 m from 2008 and over 12 m from 2012), and could potentially be integrated with logbook landings information to obtain indicators of LPUE for the offshore fleets. However, these monitoring tools do not cover the majority of the inshore fleet, which is mostly composed of smaller vessels (under 10 m).

The results of a series of inshore fisheries pilot projects to support sustainable Scottish fisheries, funded by the European Fisheries Fund suggest that many of these data deficiencies could be addressed through self-sampling and electronic monitoring technology (Course et al., 2015). A number of work packages within the Scottish Inshore Fisheries Integrated Data System project (SIFIDS) (funded by the European Maritime Fisheries Fund, EMFF), were concerned with improving data collection from inshore creel vessels through the use of new technology. One of the project outcomes was a system designed by the University of St Andrews (Ayers R. et al., 2019; James et al., 2018) which is currently being utilized as part of the OHIFP pilot project. These tracking devices collect and transmit spatial fishery data including effort. Remote Electronic Monitoring (REM) is a component of the Future

Fisheries Management Strategy (FFM) and the Bute House Agreement includes a commitment to cover all commercial fishing vessels by the end of the current parliamentary session. Proposals for REM for Inshore vessels will be subject to a Scottish Government consultation in 2022. Data collection would, however, need to be coordinated and maintained, to build up useful time series.

4.5.2. Discard data

Discards in crab and lobster fisheries are not sampled on a regular basis and fishing mortality associated with non-retained catch is not taken into account in assessments.

There are only a few studies estimating discards of brown crab in Scotland. A recent study showed that the percentage of discards in total catch may be close to 80% in the inshore crab fishery and just under 45% in the offshore fishery (Mesquita, 2020). Data for velvet crab and lobster are not currently available. Discarding practices are influenced by a combination of different factors, particularly fishing location, market requirements and the condition of the catch. More regular sampling to obtain information on catches of undersized animals could provide an indication of inter-annual variation in recruitment, which could support those data obtained from the dredge survey analysis. By-catch data collected on MSS scallop surveys may potentially provide information on variation in recruitment in areas where the scallop and the crab and lobster distributions overlap. Work on by-catch data from surveys targeting other species has been successfully carried out for brown crab but again, not for velvet crab or lobster. Discard studies of brown crab in Orkney estimate discard survival in creel trials at 92.7% (Rodrigues et al., 2021). However, further discard studies are also required to obtain estimates of discard survival and to help understand more fully the reasons for discarding in crab and lobster fisheries.

4.5.3. Population Structure

The population structure of crab and lobster stocks around Scotland, and the rest of the UK, is not well understood. The current assessment areas are empirical, based largely on past fishing patterns. Brown crabs are known to undertake extensive seasonal migrations in some areas while in contrast, velvet crabs and lobsters appear to make relatively limited movements. MSS previously conducted a tagging study of brown crab to the north of Scotland (Jones et al., 2010). The results suggest linkage between inshore and offshore crab stocks to the north and west of Scotland. Fishermen support the idea that crabs migrate between (and across) the ‘windsock’ and inshore grounds around Orkney, although there is only a limited fishery in the area in between. Large catches of female crab have also been reported on the shelf edge at depths greater than 200 m. Tagging studies of brown crab in Orkney indicated that female crabs make both localised movements and long distance migration across stock assessment boundaries (Coleman and Rodrigues, 2017). Further work being undertaken through the Scottish Regional Inshore Fisheries Group network (RIFGs) in collaboration with OSF should provide further evidence regarding the structure of brown crab stocks to the north of Scotland. Ideally, such studies should be followed up by population genetics/morphology studies and consideration of larval dispersal. It has been suggested, for example, that brown crab populations in the Irish Sea may be closely linked to the larger populations on the Malin shelf, which are contiguous with the Hebrides and South Minch in western Scotland (Tully et al., 2006; ICES, 2007). The current brown crab assessment areas may be reviewed by ICES WGCRAB in the future.

4.5.4. Growth studies and maturity

The currently used growth parameter estimates for crustaceans in Scotland were derived from tagging studies which took place in the 70’s in a few selected areas. More recent studies were carried out in Shetland and these show some relevant differences to those values previously estimated, in particular for the parameter *K* in crabs. Given the sensitivity of LCAs to the input growth parameters, further work in this area is required, especially for velvet crabs for which available data suggest very different growth rates between Shetland and elsewhere. Field studies based on tagging methods (using tags retained on moult) and subsequent evaluation of parameters would be desirable.

More recently, a number of studies concerning brown crab maturity have been carried in Scottish waters providing updated values for L_{mat} in the east coast, west coast and Orkney (Haig et al., 2016; Mesquita et al., 2020). The results have shown that brown crab maturity is likely to occur at lower sizes than the current MLS of 150 mm CW (140 mm in Shetland), implying that crabs may be able to reproduce at least once before being harvested (Mesquita et al., 2020). However, it is important to note that not all areas in Scotland have specific size-at-maturity estimates and that regional variations should be taken into account to inform the setting of appropriate MLS for all stocks.

4.5.5. Approaches to advice provision

The crab and lobster stock assessments presented in this report use length-based assessment methodologies with LCA and size indicators providing stock status for stocks with available data. For brown crab, additional stock size and recruitment indicators are available based on trawl and dredge surveys. The current survey indices for brown crab are based on GAMs and these models may be further developed in future to estimate abundance indices at the stock level. Developing such indices is complicated by the fact that dredge/trawls surveys are directed at other species (scallops and gadoids) and therefore, the survey design and spatial distribution of the survey stations do not cover all crab assessment areas. This mismatch is more evident in the west coast while the two main areas in the east of Scotland (East Coast and South East) appear to have an acceptable spatial coverage from the dredge surveys. Trawl surveys were also used to calculate abundance indices but the spatial discrepancy between crab stocks and sampling stations in these surveys is even more evident with only a small percentage of stations carried out in inshore waters. The development of abundance indices from the dredge surveys may provide an opportunity to develop stock specific harvest rates as those presented for *Nephrops* species, defined by the ratio between the catch and the biomass index (e.g. ICES, 2021).

Within the ICES assessment framework, a recent development implied that from 2022, advice provided for certain categories of data limited stocks should be based on the methods documented in the WKLIFE X report (ICES, 2020). These methods include production models such as the SPiCT model (Surplus Production model in Continuous Time (Pedersen and Berg, 2017) and a number of empirical harvest control rules (HCR) which have been tested through management strategy evaluation (MSE) simulations and were designed to follow the ICES precautionary approach, where the long-term risk of stocks falling below a limit reference point does not exceed 5% (Fischer et al., 2020). SPiCT models use catch and fisheries independent data to model stock dynamics, providing estimates of the exploitable biomass and fishing mortality as well as reference points. The new empirical catch rules make use of length data and the individual growth rate of the target species and therefore require an estimate of *K* (the von Bertalanffy growth parameter). The advice is then based on the product of a pre-existing catch advice (or recent catches) and a number of multipliers which may include biomass ratios (e.g. surveys, reflecting stock biomass trends), fishing mortality proxies relative to F_{MSY} (derived from length data) and biomass safeguards (ICES, 2020). These new advice approaches implemented by ICES may potentially be applied to the crab and lobster stocks considered in this report as both SPiCT and the HCR rules were designed to be used in data-limited species without full analytical assessments, reference points, or short-term forecasts, and requiring only some knowledge of life history and length data (which are available for Scottish stocks). At the latest ICES WGCRAB meeting (2022), preliminary SPiCT assessments were trialed for brown crab stocks off Ireland and Scotland using survey indices, commercial CPUE (catch per unit effort) and landings as input data. This WG is planning to consider how to adapt the currently available and commonly used ICES assessment frameworks to crustacean stocks given their biological and gear specificities.

4.5.6. Other Factors

The interpretation of trends in indicators derived from fishery dependent data would be helped by improved understanding of the economic and environmental factors that influence fishers' decision-making with respect to fishing location and target species. A component of the Lot 1 EU project (Armstrong, 2010) involved conducting questionnaires and interviews to establish the main factors in fishers' decision making. As well as providing information on historical changes in fishing practices, the interview responses suggested that the Scottish brown crab fishery has been influenced more by the market than by management measures. Additional information on factors affecting catchability such as bait type, creel density and soak time could also be collected by engaging with fishers and industry. Work being conducted within the RIFGs liaising with fishers through the inshore fisheries pilots, for example, collecting spatial data on fishing location, ought to provide an improved understanding of the drivers of fishing behaviour.

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6. Tables

Table 1

Crab and lobster species landed into Scotland by UK vessels between 2009 and 2020.

	Landings (tonnes)											
	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Brown crab	9465	10546	11832	10892	10891	12306	11089	12158	11882	10352	9996	6670
Velvet crab	2728	2474	2147	2032	1576	1641	1494	1607	1611	1190	1608	1566
Deep-water crab	11	6	8	0	2	16	2	1	1	0	0	0
Northern stone crab	6	3	1	2	0	0	1	0	0	0	0	0
Green crab	226	214	237	301	272	225	194	164	124	101	112	108
European lobster	1092	1100	1219	1132	1026	1208	1042	1143	1222	1219	1225	1089
Spiny lobster	4	6	5	13	9	5	4	1	2	2	2	1
Squat lobsters	2	1	1	1	1	1	1	1	1	1	1	1

Table 2

Minimum landing size (MLS) regulations in Scotland for commercially important crab and lobster species (CW – carapace width mm; CL carapace length mm).

Species	MLS (mm)	Area	Year measure introduced
Brown Crab	150 (CW)	All areas except Shetland	2018
Lobster	87 (CL)	East Coast	1999
	90 (CL)	West Coast (except Solway Firth)	2018
Velvet Crab	70 (CW)	All areas	2018

Table 3

MSS Market sampling statistics, number of animals measured, number of trips sampled and percentage of trips sampled for brown crab by assessment area, 2016-19.

	Year	Clyde	East Coast	Hebrides	Mallaig	North Coast	Orkney	Papa Bank	Shetland	South East	South Minch	Sule	Ullapool
Animals measured	2016	205	4314	7589	0	9417	79908	6187	1606	1782	413	13165	577
	2017	738	3896	7776	26	741	23108	2307	2523	3468	878	2559	0
	2018	1230	1974	4344	0	0	4579	2945	1381	1566	654	1420	251
	2019	140	1862	1822	0	182	11164	4229	1094	1010	482	243	318
Trips sampled	2016	2	22	26	0	11	467	4	12	19	6	10	3
	2017	11	22	32	1	3	203	3	17	31	12	6	0
	2018	8	23	25	0	0	32	3	12	23	11	4	3
	2019	3	15	21	0	1	114	4	6	26	11	1	1
Percentage of trips sampled (%)	2016	0.9	0.6	2.3	0	3.1	16.8	3.7	2.5	0.5	0.3	6.1	0.5
	2017	3.2	0.5	1.7	1.1	0.8	6.6	2.9	2.5	0.8	0.6	3.5	0
	2018	1.8	0.5	1.0	0	0	1.0	4.5	1.5	0.7	0.5	2.3	0.3
	2019	0.5	0.3	0.9	0	0.3	3.7	5.1	0.6	0.7	0.4	0.7	0.1

Table 4

MSS Market sampling statistics, number of animals measured, number of trips sampled and percentage of trips sampled for velvet crab by assessment area, 2016-19.

	Year	Clyde	East Coast	Hebrides	Mallaig	North Coast	Orkney	Papa Bank	Shetland	South East	South Minch	Sule	Ullapool
Animals measured	2016	1633	1518	2708	0	0	25109	0	2552	2844	1448	0	0
	2017	2665	1122	3358	0	0	14616	0	2809	1847	3708	0	0
	2018	1765	1232	3570	0	0	4661	0	2246	1392	3700	0	0
	2019	957	2150	3909	0	0	13134	0	1351	2034	3561	0	505
Trips sampled	2016	9	13	17	0	0	121	0	6	18	10	0	0
	2017	15	10	22	0	0	80	0	7	13	21	0	0
	2018	11	10	21	0	0	29	0	5	17	25	0	0
	2019	10	16	25	0	0	81	0	2	18	27	0	4
Percentage of trips sampled (%)	2016	6.2	0.4	1.6	0	0	5.6	0	1.0	0.9	0.5	0	0
	2017	8.6	0.3	1.3	0	0	3.5	0	1.1	0.6	1.0	0	0
	2018	7.2	0.3	1.1	0	0	1.3	0	0.8	1.0	1.3	0	0
	2019	7.5	0.4	1.2	0	0	3.8	0	0.3	0.7	1.4	0	1.1

Table 5

MSS Market sampling statistics, number of animals measured, number of trips sampled and percentage of trips sampled for lobster by assessment area, 2016-19.

	Year	Clyde	East Coast	Hebrides	Mallaig	North Coast	Orkney	Papa Bank	Shetland	South East	South Minch	Sule	Ullapool
Animals measured	2016	76	361	1881	0	49	5604	178	2163	1480	691	0	0
	2017	859	864	1598	3	7	3377	184	1940	2024	839	0	0
	2018	304	888	1705	0	0	2492	79	1885	1156	618	0	0
	2019	317	1182	1117	0	0	2844	148	2264	2153	1201	0	58
Trips sampled	2016	3	14	27	0	1	206	3	32	31	13	0	0
	2017	21	12	36	1	1	138	2	10	41	18	0	0
	2018	11	21	30	0	0	96	3	11	23	24	0	0
	2019	6	23	28	0	0	99	5	150	43	32	0	2
Percentage of trips sampled (%)	2016	0.6	0.3	2.3	0	0.4	7.8	3.1	5.3	0.6	0.7	0	0
	2017	4.4	0.2	1.8	1.2	0.3	4.9	2.2	1.3	0.8	0.8	0	0
	2018	2.3	0.3	1.2	0	0	3.3	6.1	1.5	0.5	1.0	0	0
	2019	1.0	0.4	1.1	0	0	3.5	7.7	17.5	0.8	1.2	0	0.3

Table 6

Biological parameters used in stock assessment for brown crab, velvet crab and lobster.

		Growth parameters		Length-Weight relationship		Terminal group Fishing Mortality	Natural Mortality	Source
		K	L_∞	a	b	F	M	
Brown crab								
	Males	0.197	220	0.000059	3.214	0.5	0.1	Chapman, 1994
	Females	0.172	220	0.000302	2.8534	0.5	0.1	Chapman, 1994
Shetland	Males	0.188	246	0.00008	3.166	0.406	0.242	Tallack, 2002
Shetland	Females	0.224	227	0.00024	2.895	0.174	0.256	Tallack, 2002
Velvet crab								
	Males	0.105	103	0.0003	3.0389	1.9	0.1	Chapman, 1994
	Females	0.118	100	0.0009	2.7405	1.1	0.1	Chapman, 1994
Shetland	Males	0.463	107	0.0011	2.75	0.31	0.576	Tallack, 2002
Shetland	Females	0.463	100.1	0.0038	2.42	0.202	0.576	Tallack, 2002
Lobster								
	Males	0.11	173.4	0.000126	3.36	0.5	0.1	Chapman, 1994
	Females	0.13	150	0.000919	2.922	0.5	0.1	Chapman, 1994
Shetland	Males	0.112	188	0.0017	2.797	0.316	0.1	Mouat et al., 2006
Shetland	Females	0.136	184	0.0004	3.123	0.452	0.1	Mouat et al., 2006

Table 7

Size at 50% maturity, L_{mat} (mm) for brown crab, velvet crab and lobster.

		L_{mat}	Source
Brown crab			Tallack, 2007
Shetland	Males	104.3	(data from Shetland)
	Females	133.5	
Orkney	Males	92	Haig et al., 2016
	Females	97	(data from Orkney)
East coast	Males	100.6	Mesquita et al., 2020
	Females	128.1	(data from East coast)
West coast	Males	106.5	Mesquita et al., 2020
	Females	127.2	(data from Hebrides)
Velvet crab			Tallack, 2002
	Males	45	(Shetland data)
	Females	56	
Lobster			Lizárraga-Cubedo et al., 2003
East Coast &	Males	80	(data from Firth of Forth)
South East	Females	79	
Other areas	Males	98	(data from Hebrides)*
	Females	110	

* Potentially higher variability between assessment areas along the west coast.

Table 8

Percentage of total landings into Scotland of brown crab 2016–2020, by assessment area.

Species	Year	Clyde	East Coast	Hebrides	Mallaig	North Coast	Orkney	Papa Bank	Shetland	South East	South Minch	Sule	Ullapool
Brown crab (%)	2016	0.6	13.3	19.8	0.2	8.6	20.3	7.3	2.3	5.1	9.0	10.7	2.8
	2017	1.5	15.3	15.7	0.1	7.5	21.2	6.8	4.1	5.5	10.3	8.2	3.8
	2018	1.9	17.2	13.9	0.2	5.8	20.3	6.0	5.4	5.8	12.6	6.7	4.2
	2019	2.7	17.8	11.5	0.5	4.5	19.5	5.4	6.1	5.9	17.2	5.3	3.6
	2020	1.1	20.0	12.2	0.5	4.3	22.2	6.2	7.1	5.5	14.5	3.8	2.6

Table 9

Percentage of total landings into Scotland of velvet crab 2016–2020, by assessment area.

Species	Year	Clyde	East Coast	Hebrides	Mallaig	North Coast	Orkney	Papa Bank	Shetland	South East	South Minch	Sule	Ullapool
Velvet crab (%)	2016	3.5	12.9	17.2	1.5	0.5	26	0	7.3	5.2	23.9	0	2.0
	2017	2.6	19.2	15.3	1.3	0.4	22.5	0	7.0	6.1	24.2	0	1.4
	2018	2.0	18.1	16.6	1.4	0.9	23	0	8.1	5.4	22.5	0	2.0
	2019	1.1	18.7	16.5	1.2	0.6	21.5	0	9.8	9.1	19.7	0	1.8
	2020	0.9	20.0	15.8	2.5	0.4	25.1	0	11.8	7.6	14.7	0	1.1

Table 10

Percentage of total landings into Scotland of lobster 2016–2020, by assessment area.

Species	Year	Clyde	East Coast	Hebrides	Mallaig	North Coast	Orkney	Papa Bank	Shetland	South East	South Minch	Sule	Ullapool
Lobster (%)	2016	3.2	23.4	11.7	0.1	1.3	10.8	0.3	4.8	33.7	9.4	0	1.3
	2017	3.2	29.8	11.4	0.1	1.4	9.8	0.3	4.8	28	9.6	0.1	1.5
	2018	2.5	30.4	14.7	0.2	1.0	8.4	0.1	3.3	28	9.6	0.1	1.7
	2019	2.3	25.1	14.2	0.2	1.0	9.7	0.2	3.8	30.1	11.0	0.1	2.3
	2020	2.0	24.0	17.0	0.4	1.0	11.0	0.2	3.7	26.8	12.2	0	1.7

Table 11

Brown crab. Size-based indicators as a ratio between mean length, $\bar{L}$, and mean length of the largest 5%, $L_{max5\%}$ and the respective reference points (average for 2016-19). Values larger than 1 (green) and equal to 1 (yellow) indicate exploitation consistent with F_{MSY}.

Assessment area	$\bar{L} / L_{F=M}$		$L_{max5\%}/0.9L_{\infty}$	
	Males	Females	Males	Females
Clyde**	-	0.99	-	0.99
East Coast	0.98	0.99	0.96	0.99
Hebrides	1.03	1.03	1.01	1.00
Mallaig	-	-	-	-
North Coast *	-	-	-	-
Orkney	1.00	1.01	1.00	1.00
Papa Bank	1.04	1.02	1.07	1.02
Shetland	0.98	1.00	0.88	0.97
South East	1.00	0.99	0.97	0.97
South Minch	1.00	1.00	0.99	0.99
Sule**	-	1.01	-	1.00
Ullapool	-	-	-	-

***Average 2016-19 not calculated as 2018 data were missing.

****Average 2016-19 for males not calculated as 2019 data were missing.

Table 12

Velvet crab. Size-based indicators as a ratio between mean length, $\bar{L}$, and mean length of the largest 5%, $L_{max5\%}$ and the respective reference points (average for 2016-19).

Assessment area	$\bar{L}/L_{F=M}$		$L_{max5\%}/0.9L_{\infty}$	
	Males	Females	Males	Females
Clyde	0.96	0.95	0.89	0.89
East Coast	0.96	0.95	0.91	0.88
Hebrides	0.99	0.97	0.95	0.93
Mallaig	-	-	-	-
North Coast	-	-	-	-
Orkney	0.97	0.96	0.93	0.92
Papa Bank	-	-	-	-
Shetland	0.97	0.97	0.90	0.91
South East	0.98	0.97	0.93	0.92
South Minch	0.96	0.94	0.90	0.89
Sule	-	-	-	-
Ullapool*	-	-	-	-

***Average 2016-19 not calculated as 2016-2018 data were missing.

Table 13

Lobster. Size-based indicators as a ratio between mean length, $\bar{L}$, and mean length of the largest 5%, Lmax5% and the respective reference points (average for 2016-19). Values larger than 1 (green) and equal to 1 (yellow) indicate exploitation consistent with FMSY.

Assessment area	$\bar{L}/L_{F=M}$		$L_{max5\%}/0.9L_{\infty}$	
	Males	Females	Males	Females
Clyde*	-	-	-	-
East Coast	0.91	0.93	0.85	0.90
Hebrides	0.95	0.99	0.88	0.98
Mallaig	-	-	-	-
North Coast	-	-	-	-
Orkney	0.94	0.99	0.90	1.01
Papa Bank**	-	-	-	-
Shetland	0.94	0.92	0.85	0.82
South East	0.88	0.91	0.78	0.82
South Minch	0.92	0.95	0.84	0.92
Sule	-	-	-	-
Ullapool	-	-	-	-

*****Average 2016-19 not calculated as 2016 data were missing.
******Average 2016-19 not calculated as 2018 data were missing.

Table 14

Brown crab fishing mortality (F_{bar}) from Length Cohort Analysis (2016-19) in relation to F_{MSY}. Fishing mortality calculated across a fixed range of 145-190 mm CW interval (150-200 mm for Shetland).

Assessment area	F_{bar}		F_{MSY}		F_{MSY} basis
	Males	Females	Males	Females	
Clyde	0.43	0.39	0.29	0.38	LCA 2016-19
East Coast	0.66	0.47	0.28	0.33	LCA 2016-19
Hebrides	0.41	0.40	0.35	0.33	LCA 2016-19
Mallaig	-	-	-	-	-
North Coast	0.43	0.44	0.24	0.29	LCA 2016-19
Orkney	0.51	0.36	0.36	0.34	LCA 2016-19
Papa Bank	0.25	0.29	0.32	0.34	LCA 2016-19
Shetland	0.56	0.44	0.36	0.36	LCA 2016-19
Shetland par*	0.83	0.59	0.80	1.68	LCA 2016-19
South East	0.64	0.48	0.40	0.36	LCA 2016-19
South Minch	0.54	0.44	0.35	0.33	LCA 2016-19
Sule	0.41	0.39	0.34	0.35	LCA 2016-19
Ullapool	0.48	0.30	0.43	0.30	LCA 2016-19

*Fs calculated using Shetland biological parameters

Table 15

Velvet crab fishing mortality (F_{bar}) from Length Cohort Analysis (2016-19) in relation to F_{MSY}. Fishing mortality calculated across a fixed range of 60-80 mm CW interval (75-85 mm for Shetland).

Assessment area	F_{bar}		F_{MSY}		F_{MSY} basis
	Males	Females	Males	Females	
Clyde	0.36	0.51	0.16	0.28	LCA 2016-19
East Coast	0.32	0.49	0.23	0.16	LCA 2016-19
Hebrides	0.15	0.32	0.16	0.20	LCA 2016-19
Mallaig	-	-	-	-	-
North Coast	-	-	-	-	-
Orkney	0.21	0.34	0.19	0.22	LCA 2016-19
Papa Bank	-	-	-	-	-
Shetland	0.47	0.82	0.41	0.57	LCA 2016-19
Shetland par*	2.31	2.62	3.83	6.42	LCA 2016-19
South East	0.22	0.33	0.20	0.23	LCA 2016-19
South Minch	0.27	0.52	0.21	0.38	LCA 2016-19
Sule	-	-	-	-	-
Ullapool	-	-	-	-	-

*Fs calculated using Shetland biological parameters

Table 16

Lobster fishing mortality (F_{bar}) from Length Cohort Analysis (2016-19) in relation to F_{MSY}. Fishing mortality calculated across a fixed range of 95-130 mm CL interval (110-155 mm for Shetland).

Assessment area	F_{bar}		F_{MSY}		F_{MSY} basis
	Males	Females	Males	Females	
Clyde	0.58	0.37	0.25	0.30	LCA 2016-19
East Coast	0.44	0.38	0.13	0.35	LCA 2016-19
Hebrides	0.41	0.26	0.18	0.32	LCA 2016-19
Mallaig	-	-	-	-	-
North Coast	-	-	0.11	0.34	LCA 2002-05
Orkney	0.36	0.23	0.17	0.31	LCA 2016-19
Papa Bank	0.27	0.16	0.19	0.31	LCA 2016-19
Shetland	0.42	0.56	0.23	0.21	LCA 2016-19
South East	0.70	0.58	0.27	0.38	LCA 2016-19
South Minch	0.52	0.36	0.26	0.32	LCA 2016-19
Sule	-	-	-	-	-
Ullapool	-	-	0.17	0.33	LCA 2006-08

7. Figures

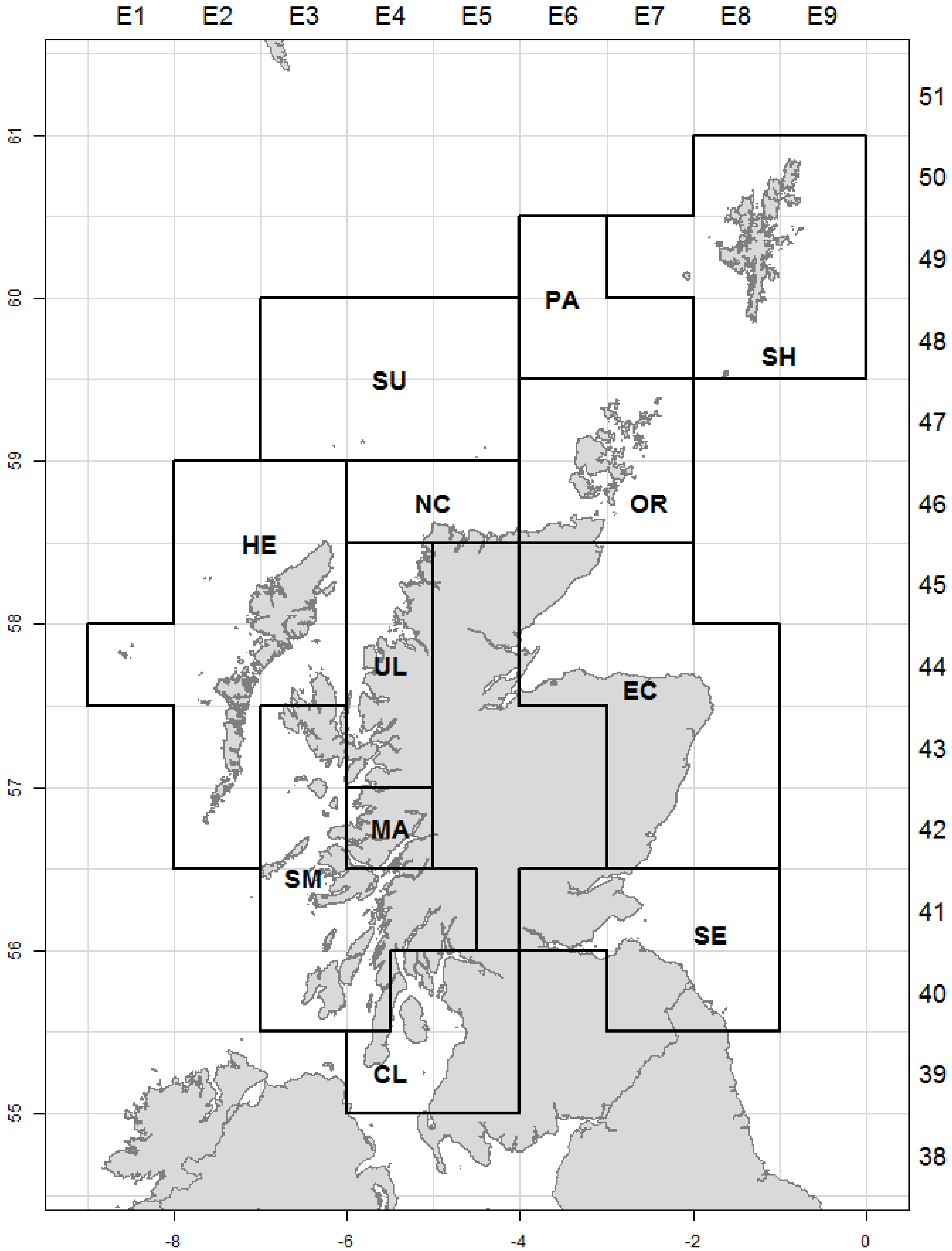


Figure 1: Crab and lobster fishery assessment areas in Scotland. See Annex D for abbreviations.

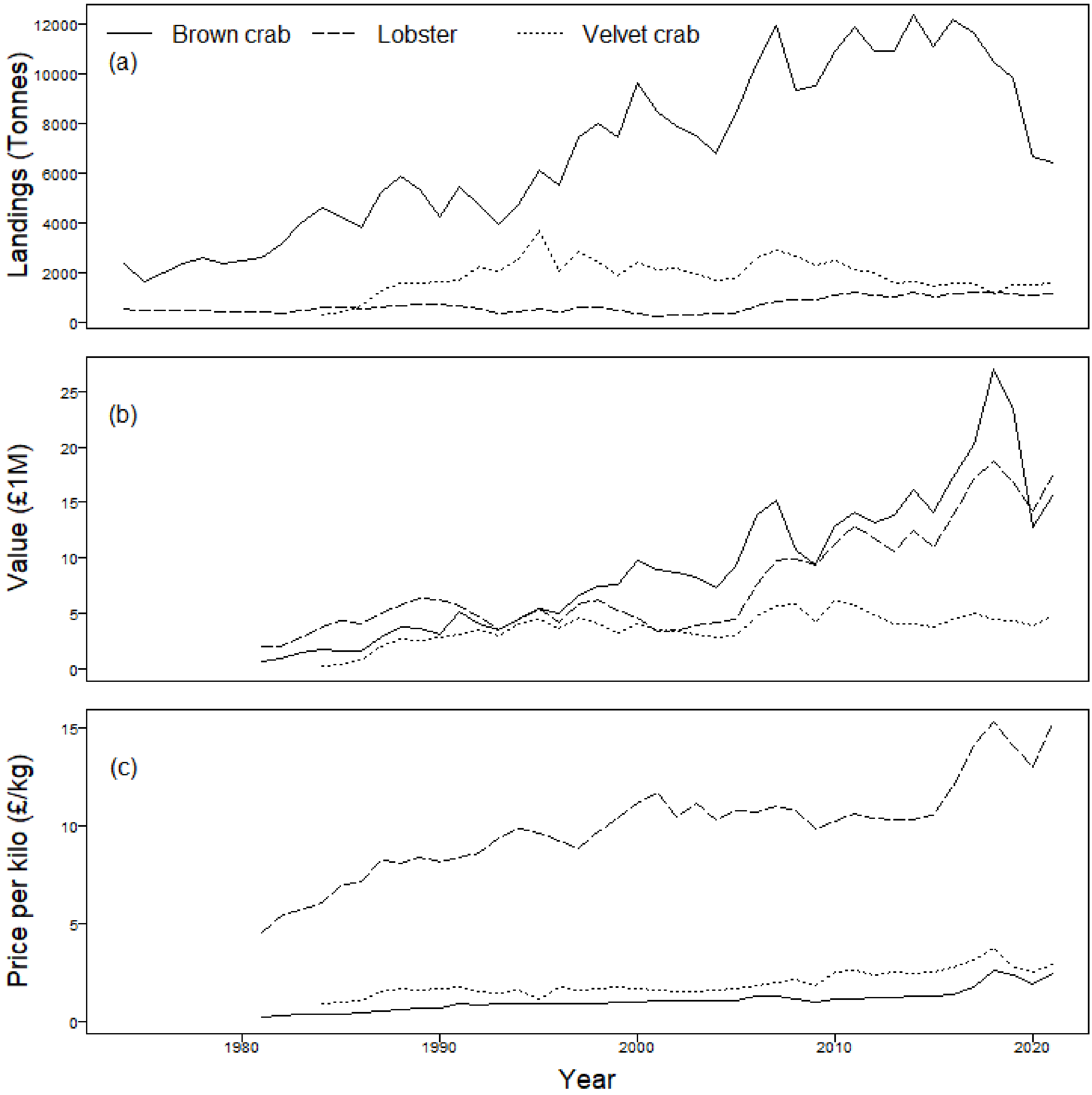


Figure 2: Scottish crab and lobster fishery statistics. a) Landings (tonnes) into Scotland, b) landings value (£M), and, c) price per kilo (£/kg) for brown crab, velvet crab and lobster, 1974 - 2020.

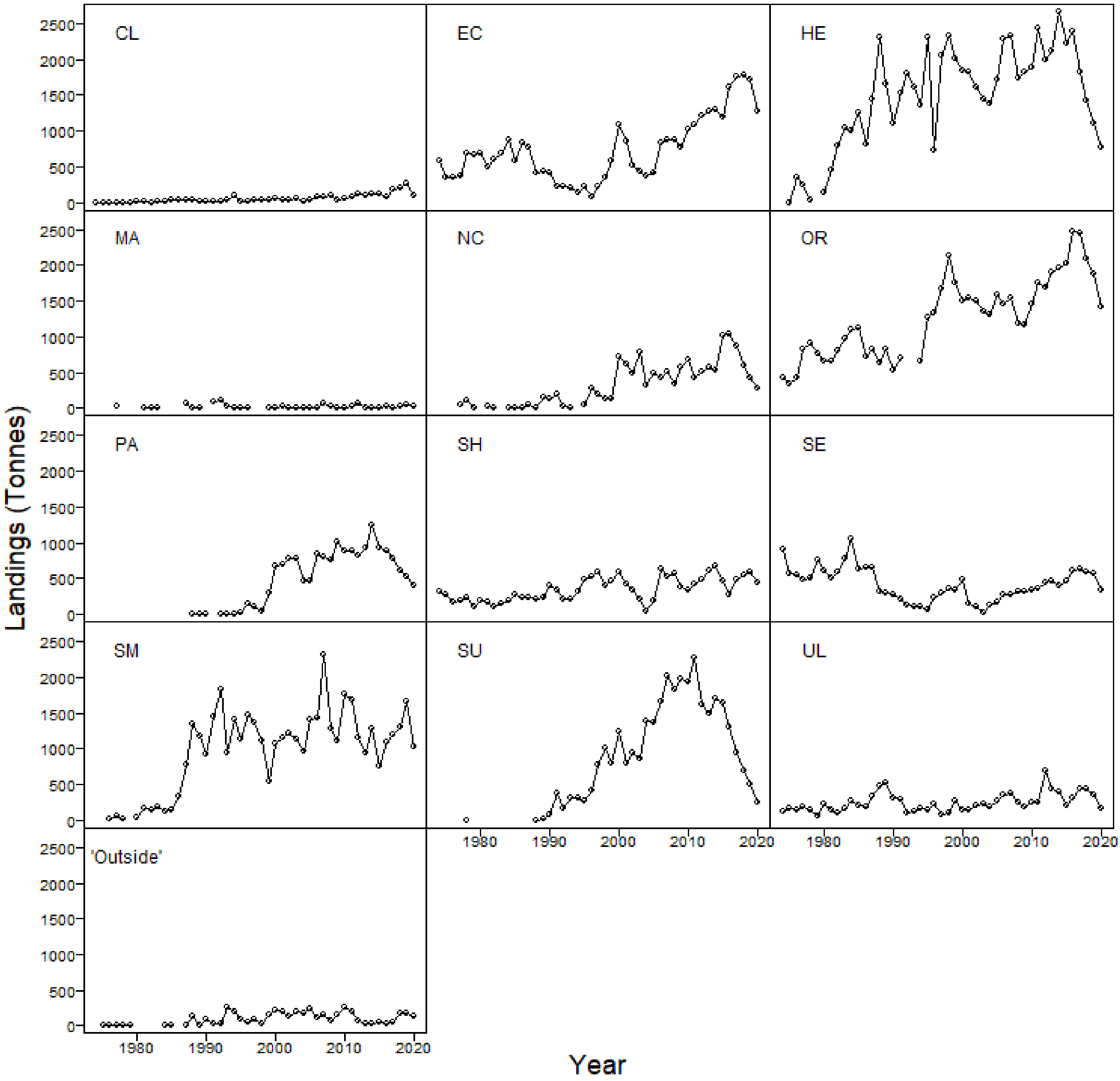


Figure 3: Brown crab landings (tonnes) into Scotland by assessment area, 1974-2020. 'Outside' relates to brown crab landed outside MSS crab and lobster assessment areas; see **Figure 1** for area locations and Annex D for abbreviations.

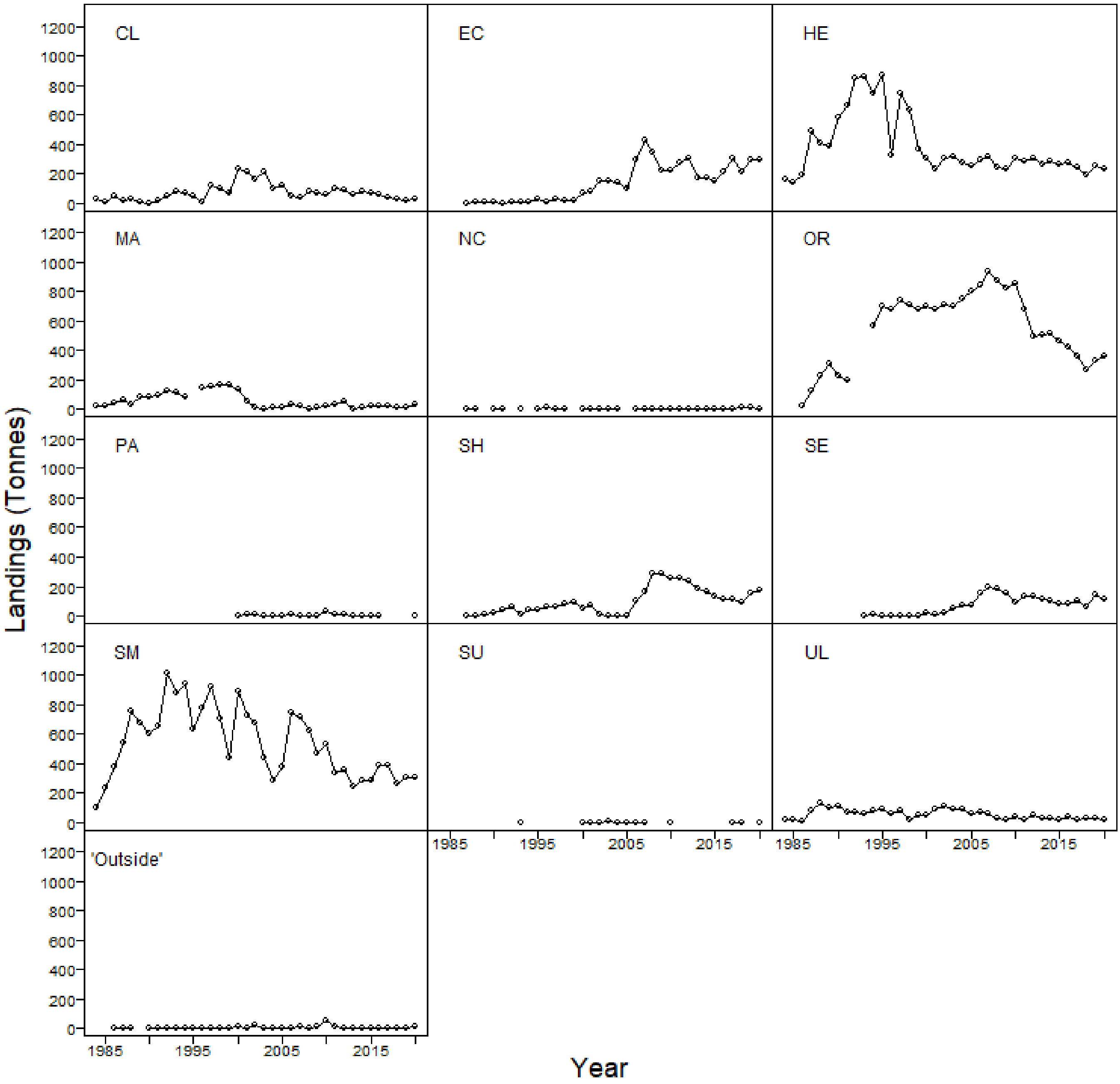


Figure 4: Velvet crab landings (tonnes) into Scotland by assessment area, 1984-2020. 'Outside' relates to velvet crab landed outside MSS crab and lobster assessment areas; see **Figure 1** for area locations and Annex D for abbreviations.

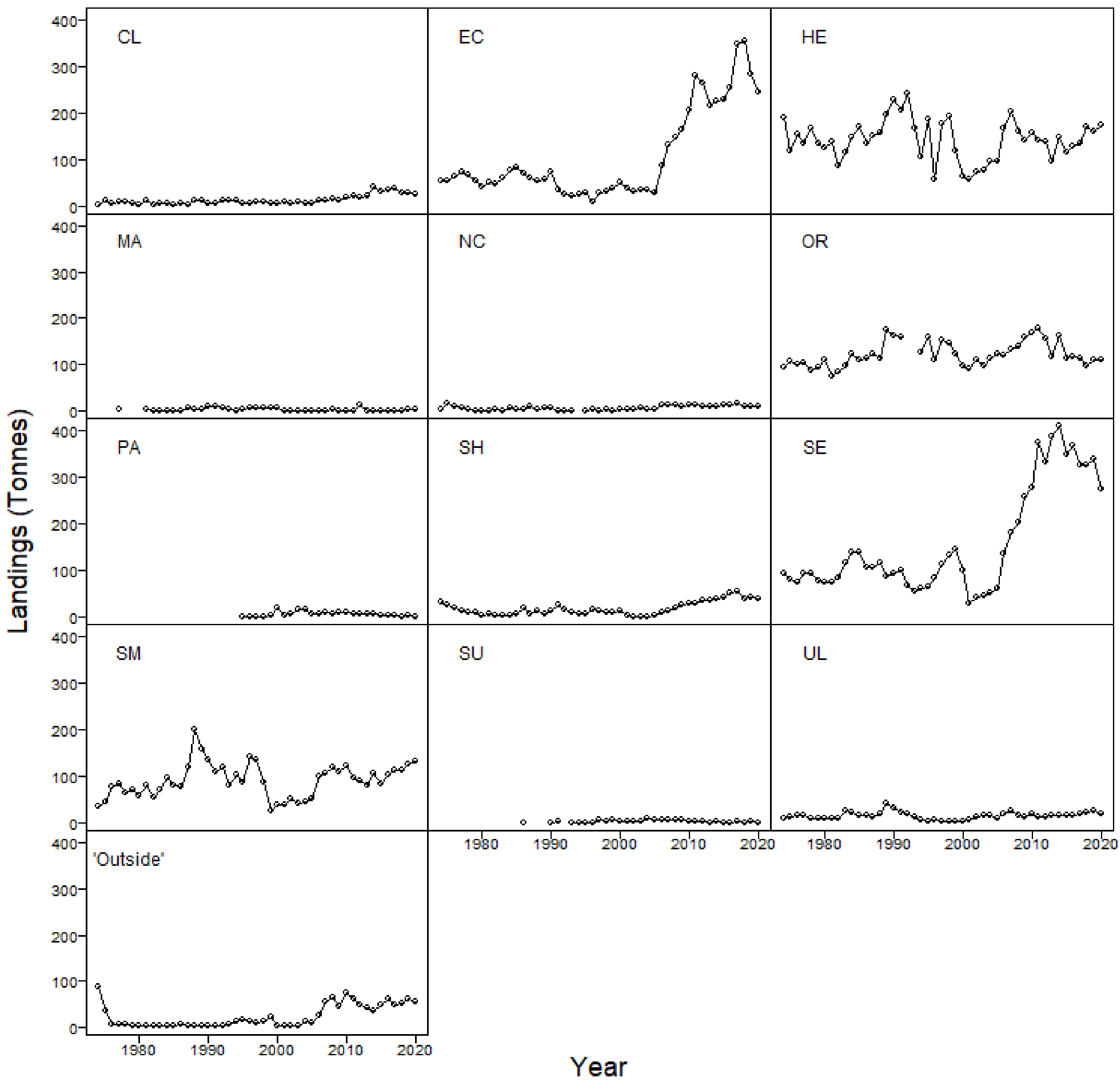


Figure 5: Lobster landings (tonnes) into Scotland by assessment area, 1974-2020. 'Outside' relates to lobster landed outside MSS crab and lobster assessment areas; see **Figure 1** for area locations and Annex D for abbreviations.

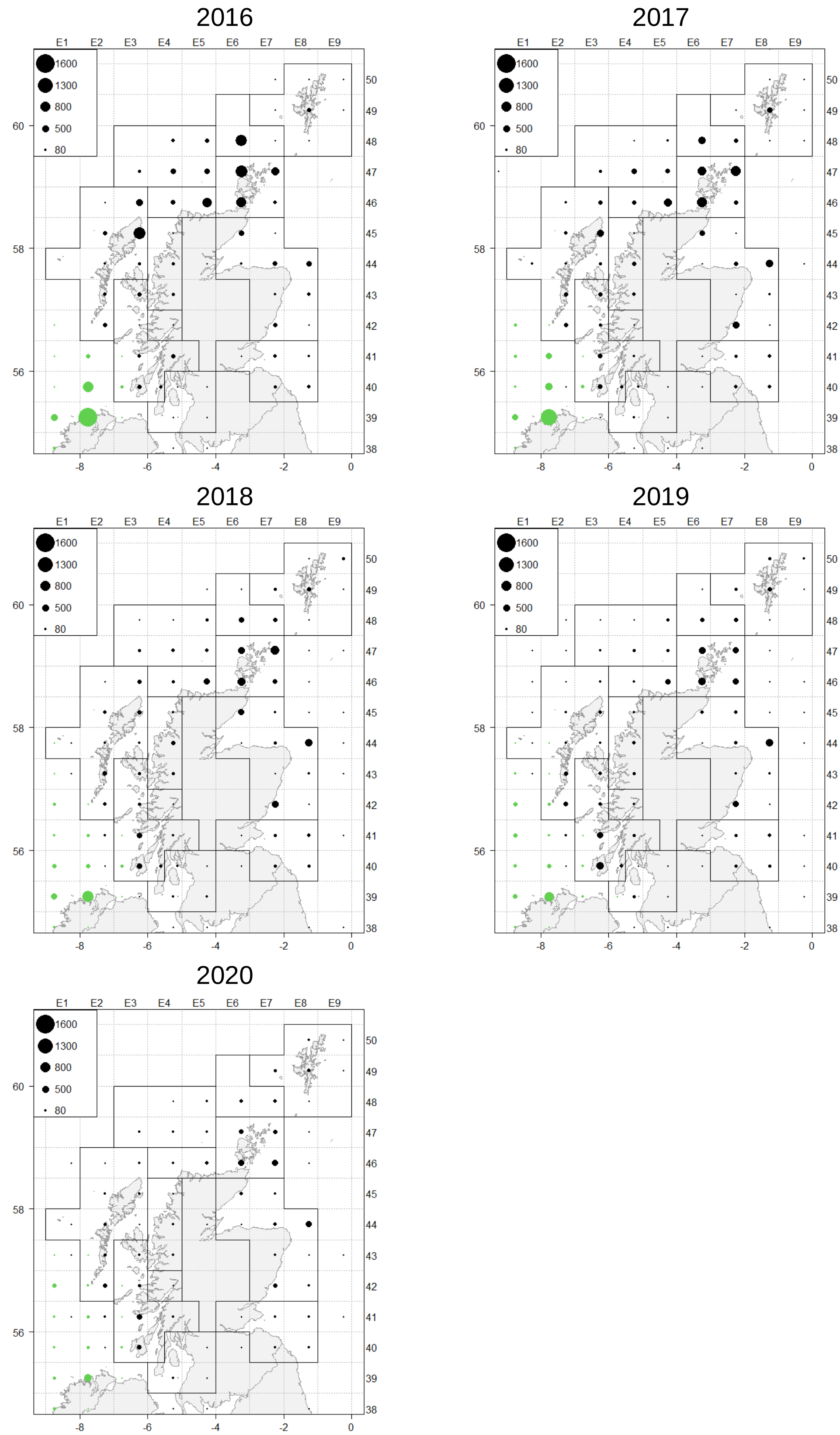


Figure 6: Brown crab landings (tonnes) by statistical rectangle between 2016 and 2020. Black circles represent landings into Scotland. Data are from iFISH database. Green circles represent landings into Ireland – data provided by the Irish Marine Institute.

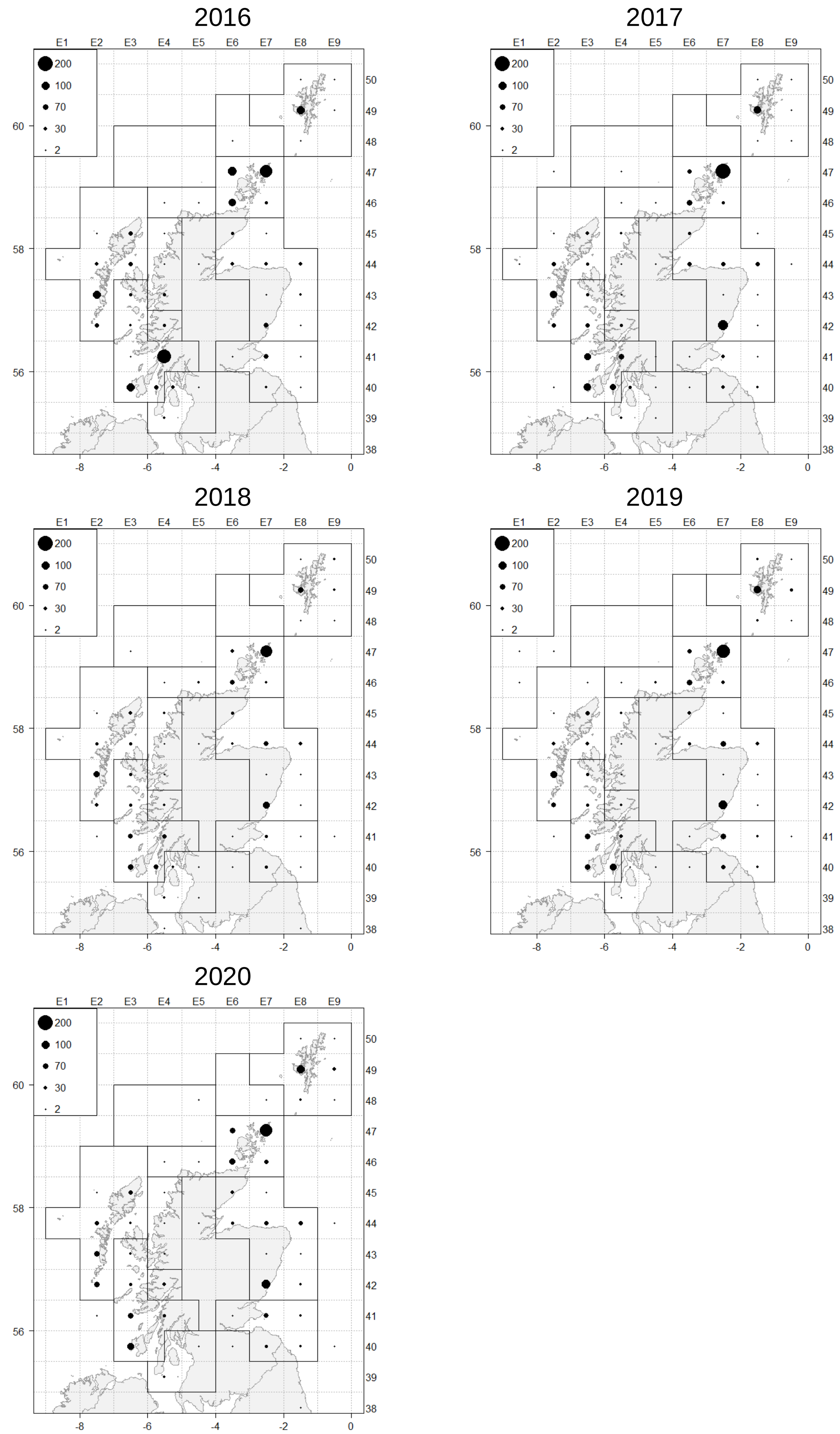


Figure 7: Velvet crab landings (tonnes) by statistical rectangle between 2016 and 2020. Black circles represent landings into Scotland. Data are from the iFISH database.

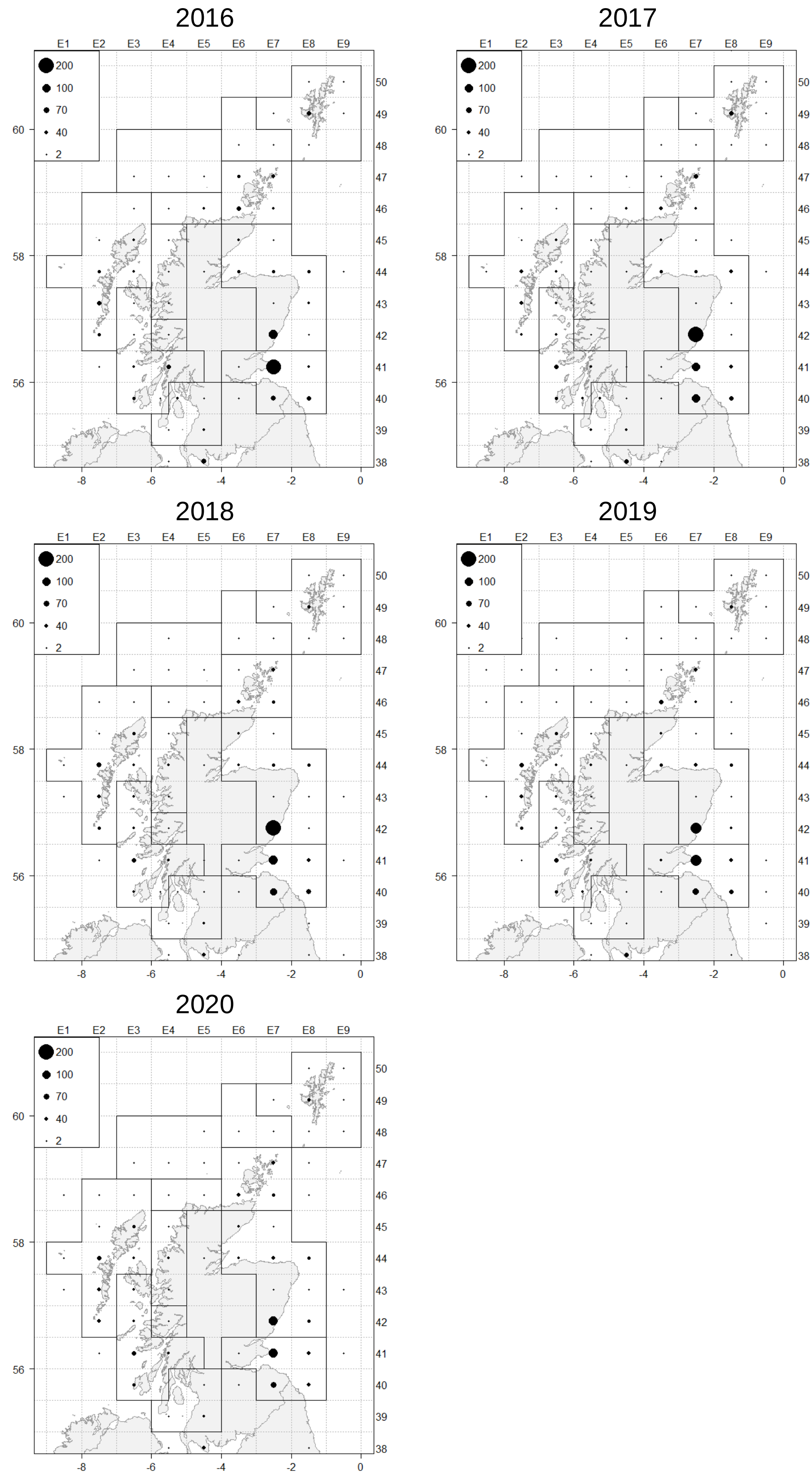


Figure 8: Lobster landings (tonnes) by statistical rectangle between 2016 and 2020. Black circles represent landings into Scotland. Data are from the iFISH database.

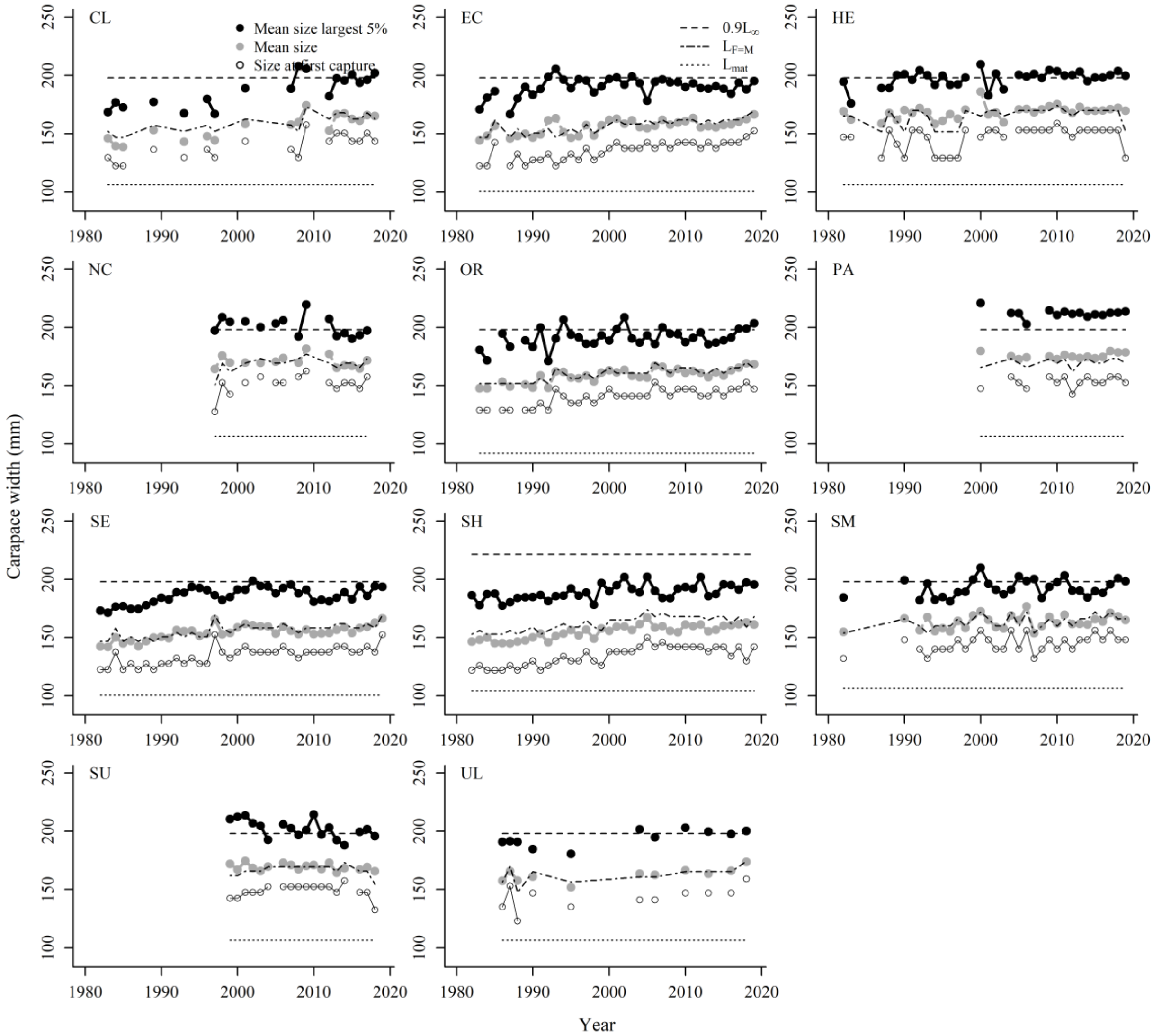


Figure 9: Brown crab males mean size in landings (grey circles), mean size of the largest 5% of individuals (black circles) and size at first capture (open circles) by assessment area, 1981-2019. Reference points 0.9*L*∞ (dashed line), LF=M (dot-dashed line) and L_{mat} (dotted line), respectively. A minimum of 50 individuals was used each year to calculate mean sizes.

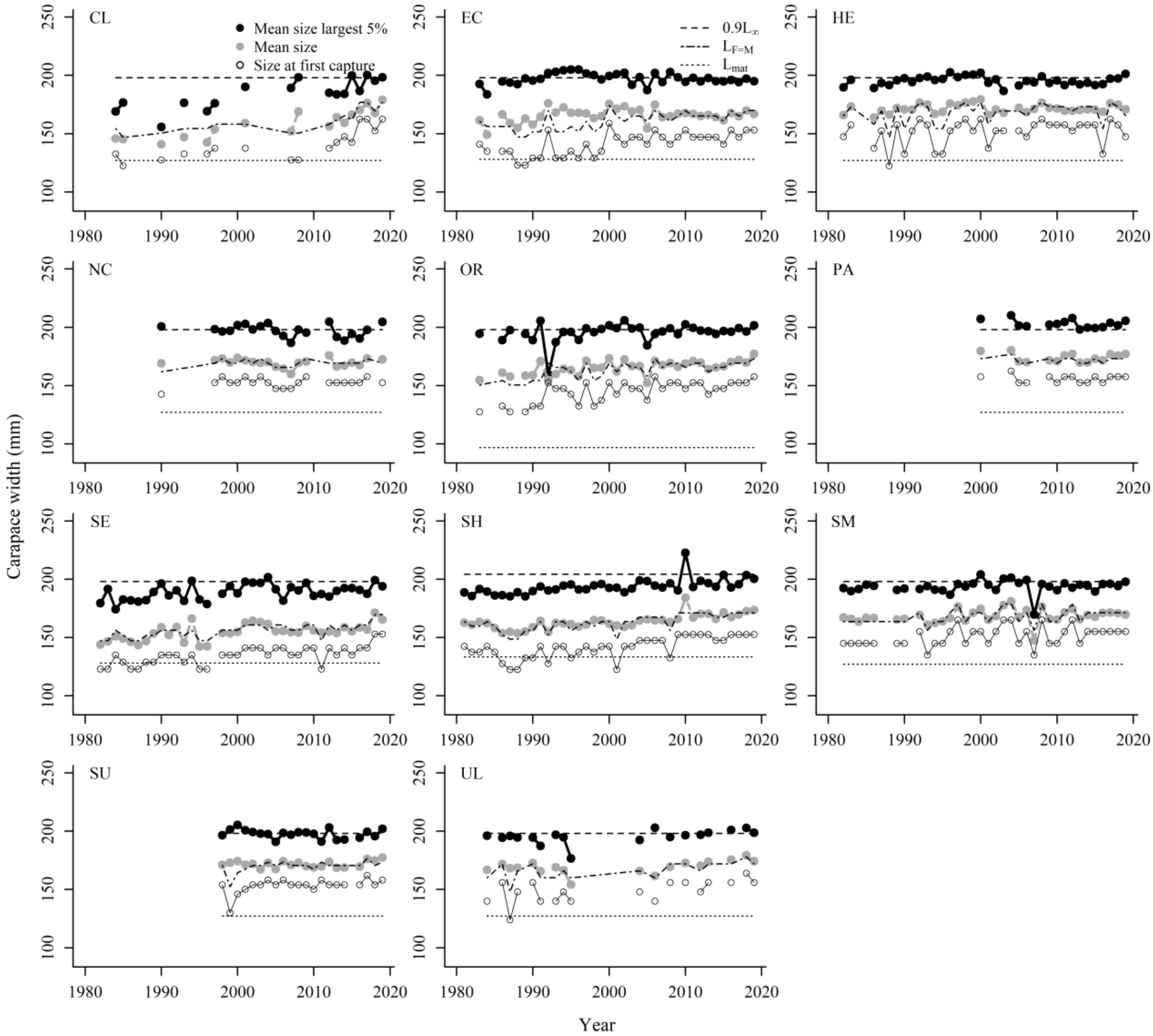


Figure 10: Brown crab females mean size in landings (grey circles), mean size of the largest 5% of individuals (black circles) and size at first capture (open circles) by assessment area, 1981-2019. Reference points 0.9L_∞ (dashed line), $L_{F=M}$ (dot-dashed line) and L_{mat} (dotted line), respectively. A minimum of 50 individuals was used each year to calculate mean sizes.

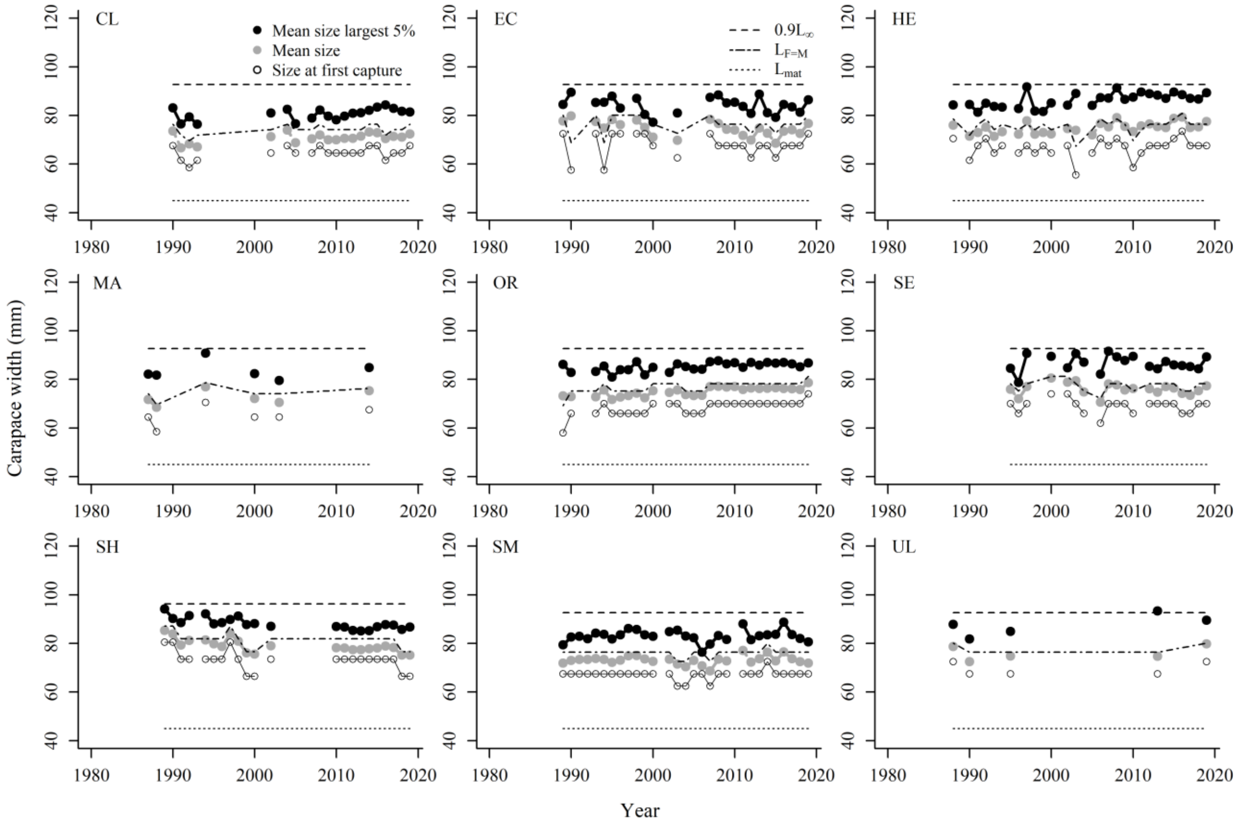


Figure 11: Velvet crab males mean size in landings (grey circles), mean size of the largest 5% of individuals (black circles) and size at first capture (open circles) by assessment area, 1987-2019. Reference points 0.9L_∞ (dashed line), $L_{F=M}$ (dot-dashed line) and L_{mat} (dotted line), respectively. A minimum of 50 individuals was used each year to calculate mean sizes.

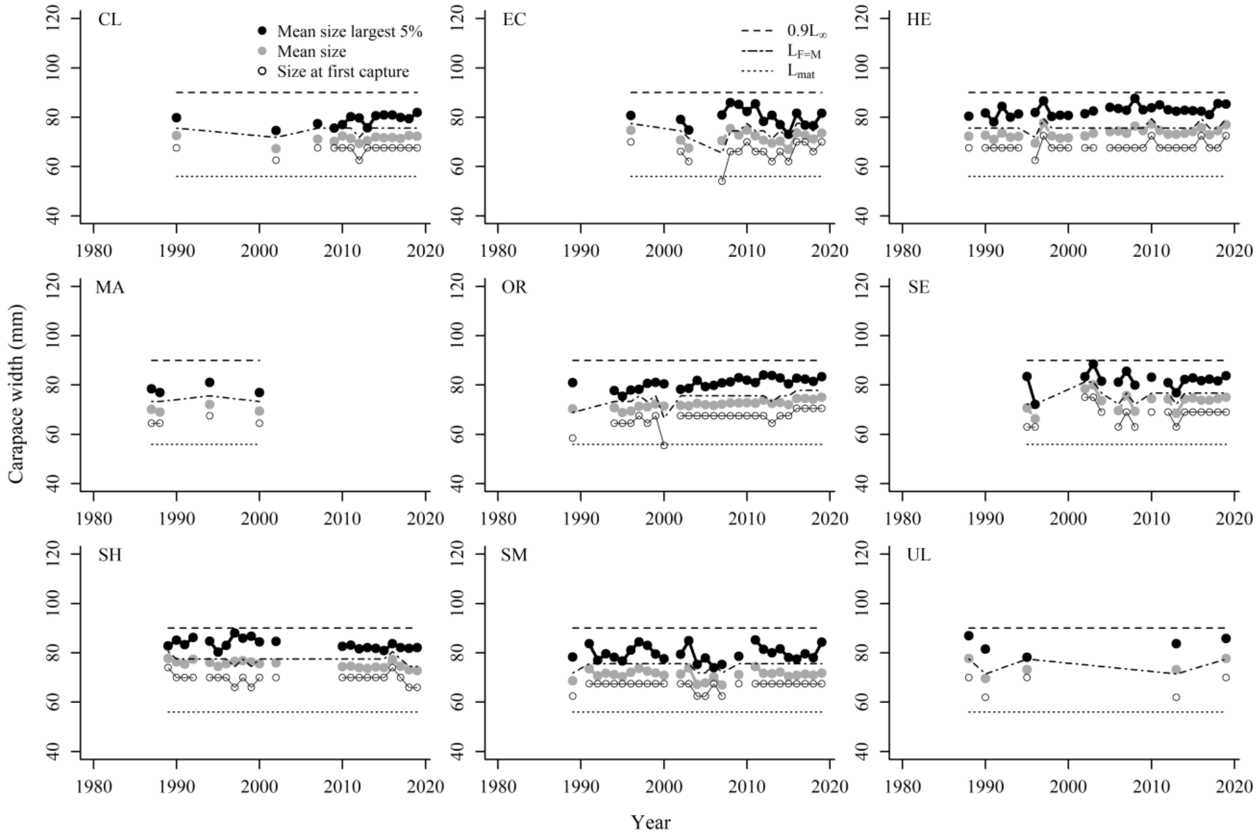


Figure 12: Velvet crab females mean size in landings (grey circles), mean size of the largest 5% of individuals (black circles) and size at first capture (open circles) by assessment area, 1987-2019. Reference points 0.9L_∞ (dashed line), $L_{F=M}$ (dot-dashed line) and L_{mat} (dotted line), respectively. A minimum of 50 individuals was used each year to calculate mean sizes.

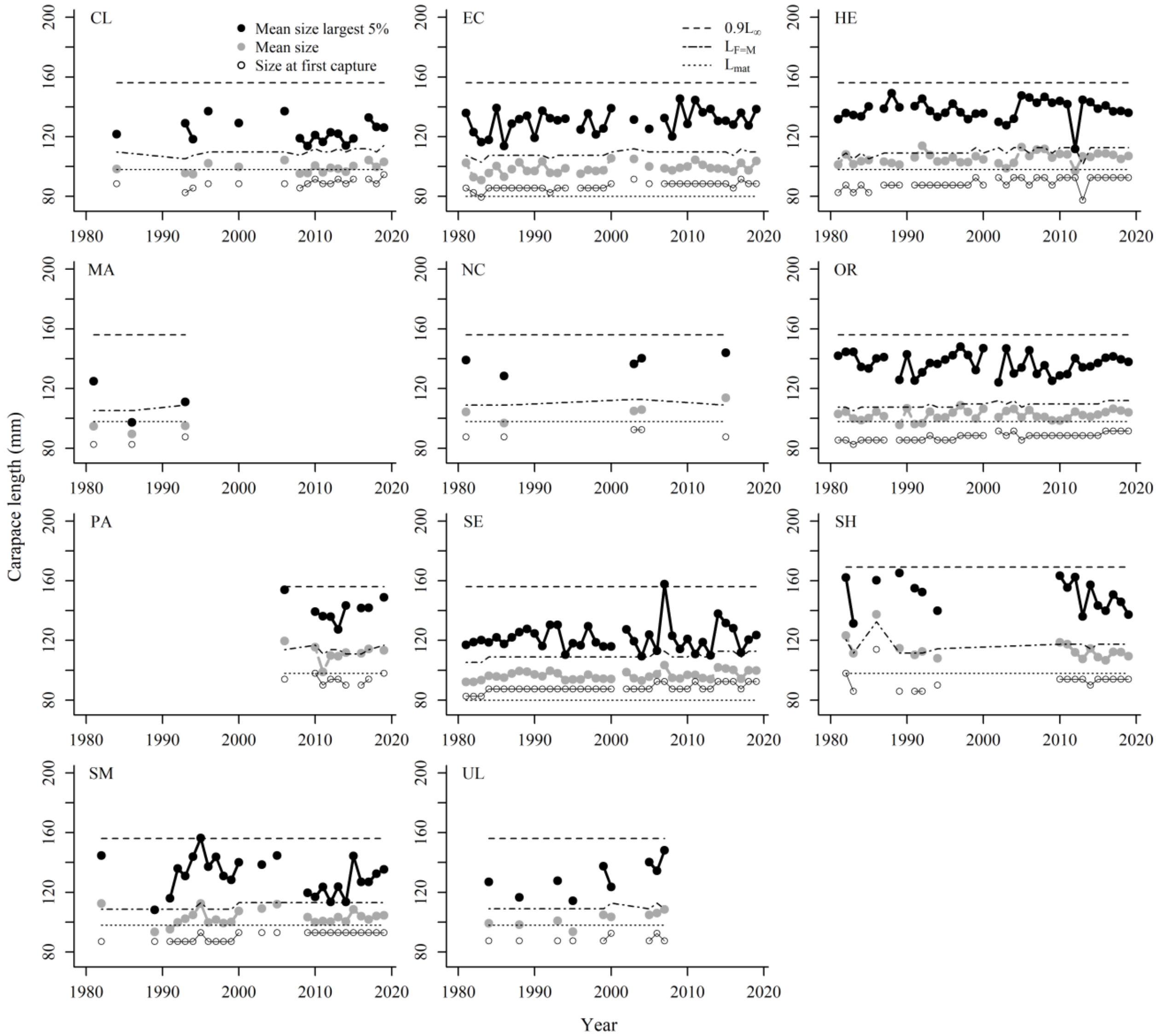


Figure 13: Lobster males mean size in landings (grey circles), mean size of the largest 5% of individuals (black circles) and size at first capture (open circles) by assessment area, 1981-2019. Reference points 0.9L_∞ (dashed line), $L_{F=M}$ (dot-dashed line) and L_{mat} (dotted line), respectively. A minimum of 50 individuals was used each year to calculate mean sizes.

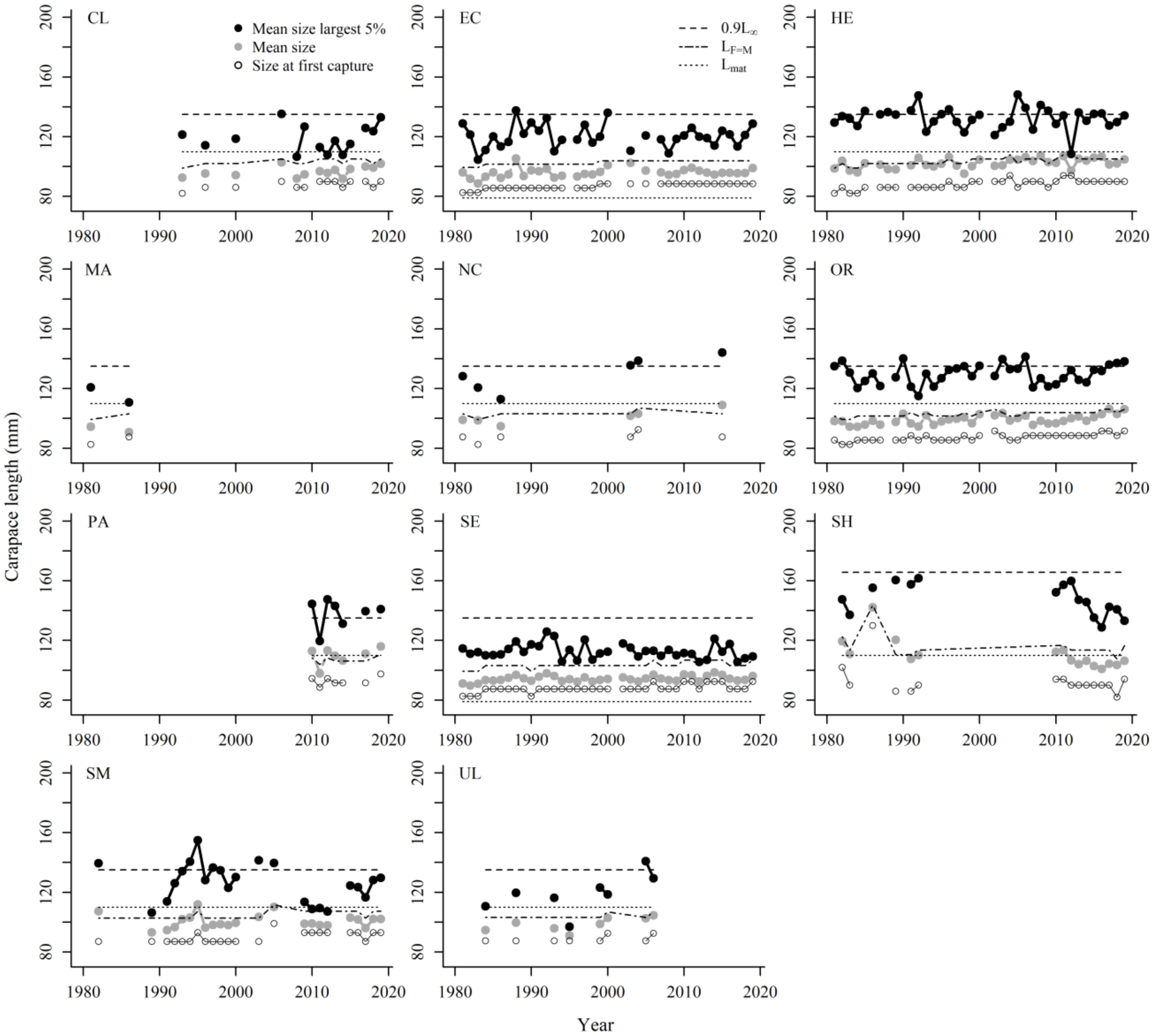


Figure 14: Lobster females mean size in landings (grey circles), mean size of the largest 5% of individuals (black circles) and size at first capture (open circles) by assessment area, 1981-2019. Reference points 0.9L_∞ (dashed line), $L_{F=M}$ (dot-dashed line) and L_{mat} (dotted line), respectively. A minimum of 50 individuals was used each year to calculate mean sizes.

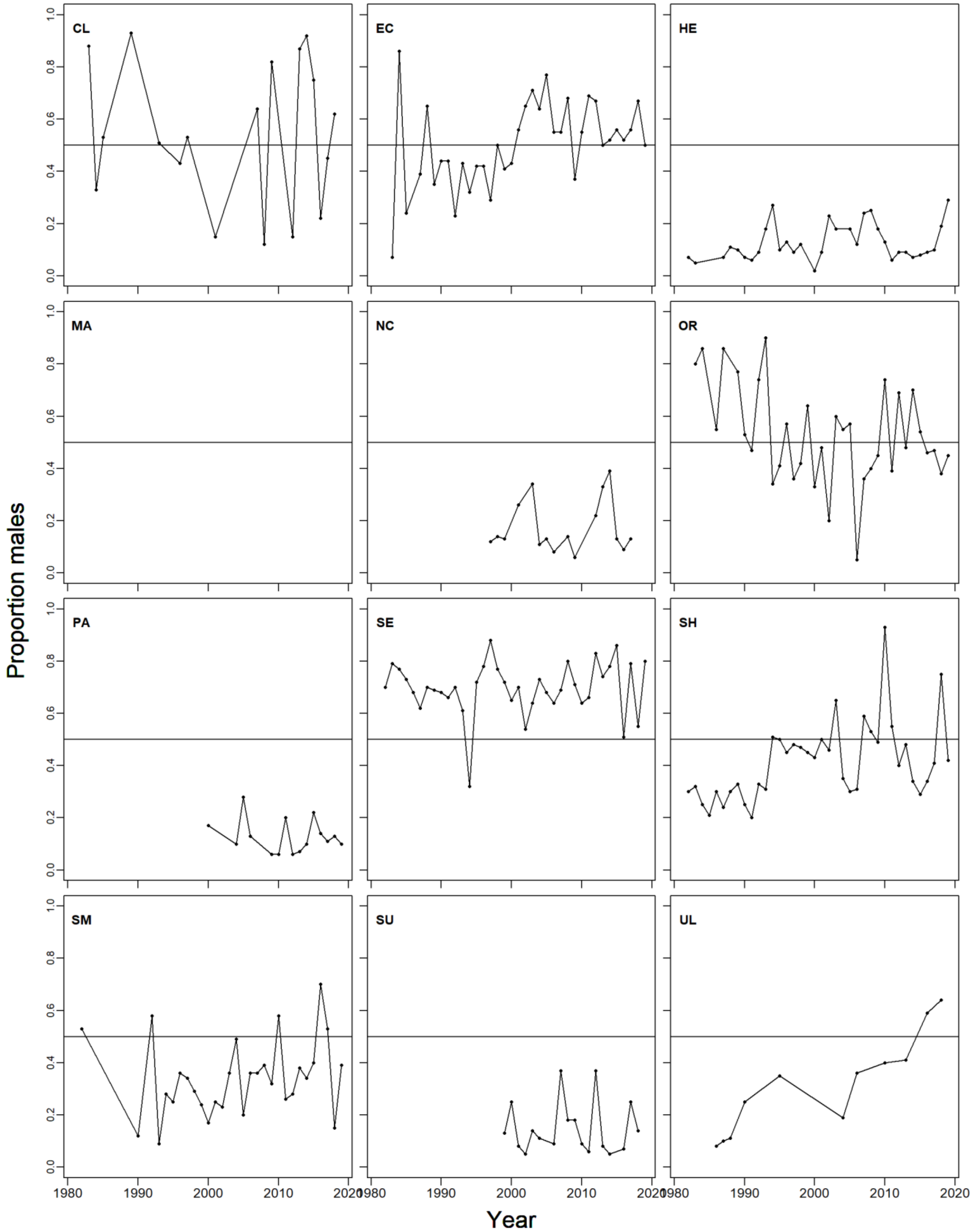


Figure 15: Brown crab sex ratio (percentage of males) in landings by assessment area, 1981-2019.

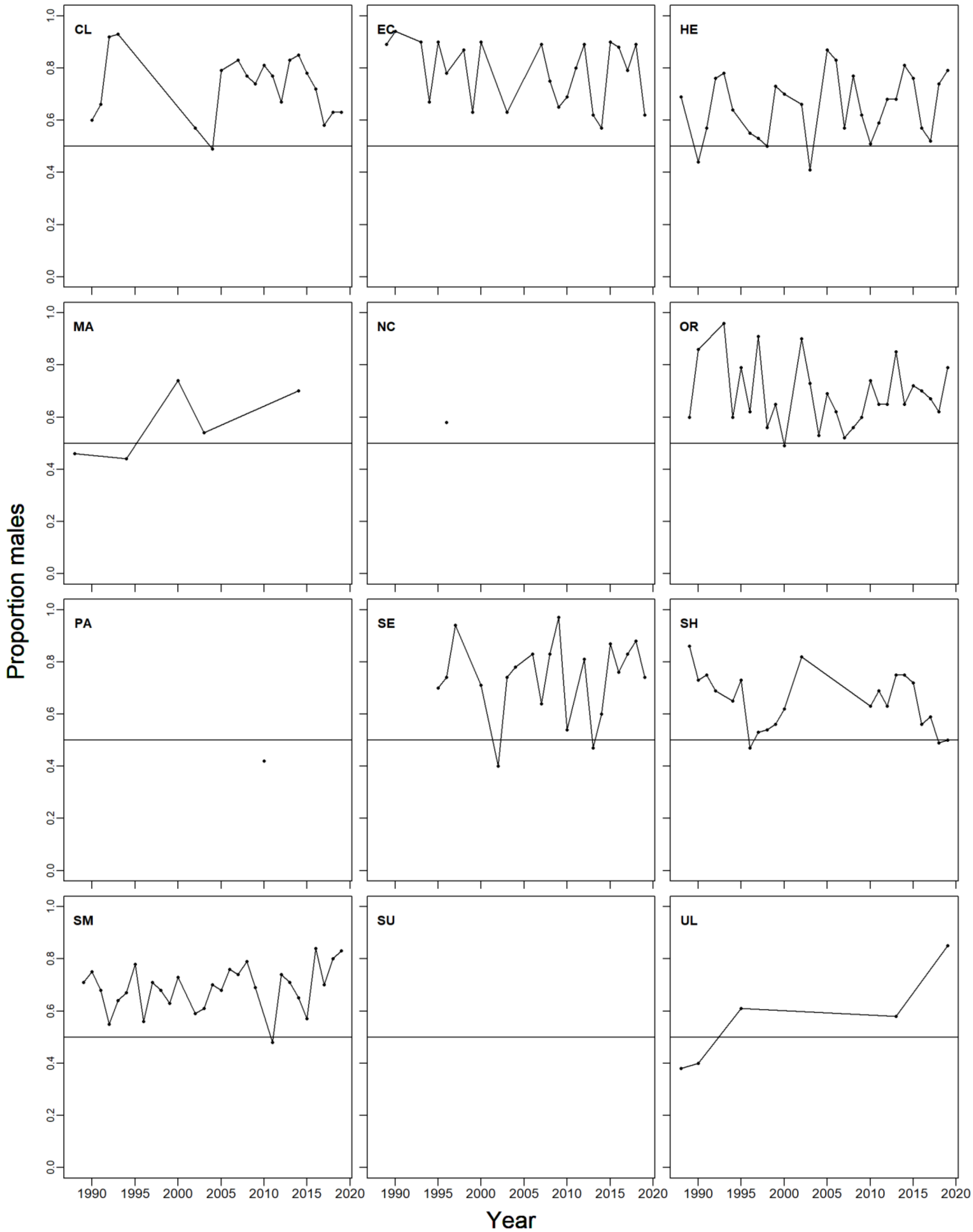


Figure 16: Velvet crab sex ratio (percentage of males) in landings by assessment area, 1987-2019.

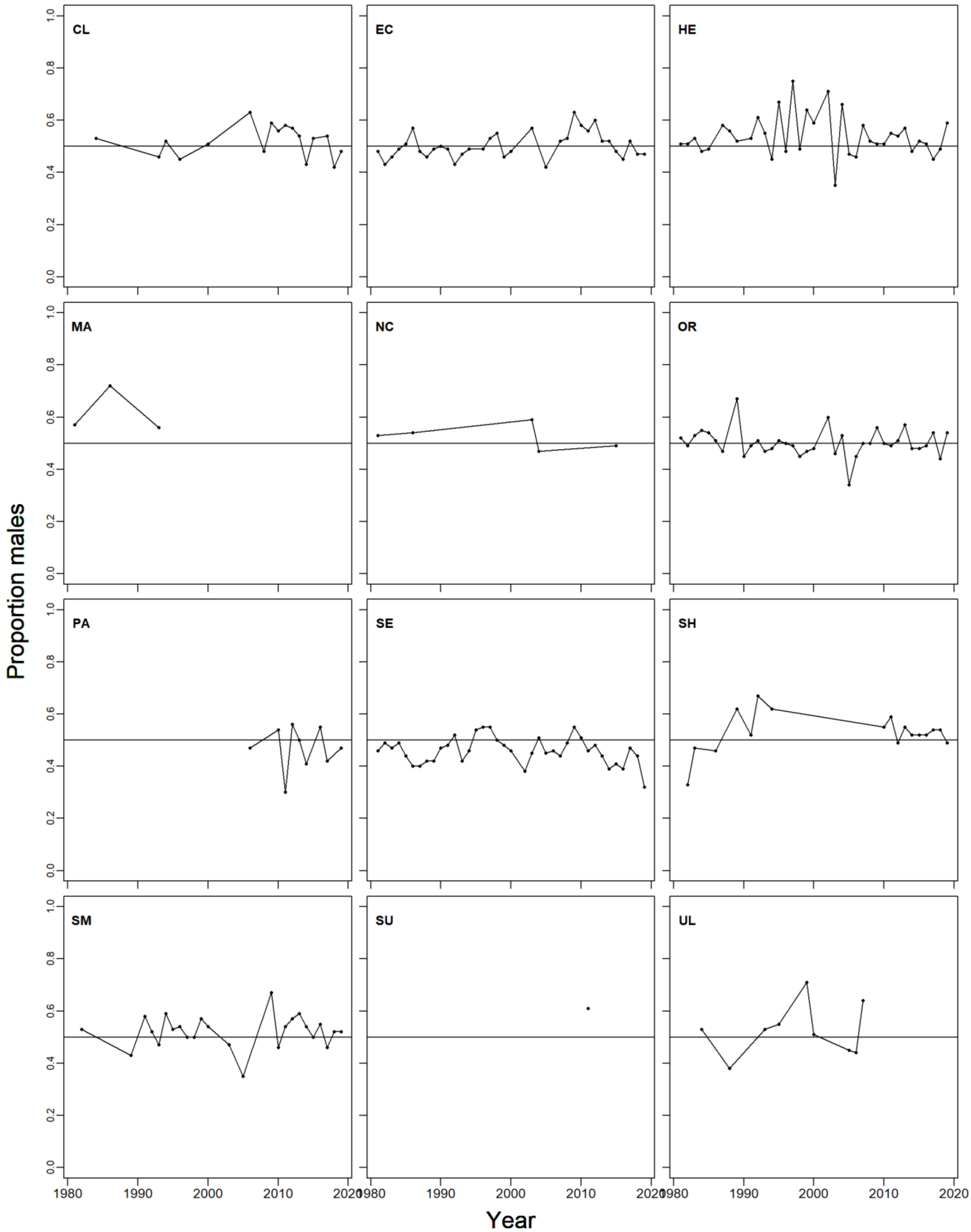


Figure 17: Lobster sex ratio (percentage of males) in landings, 1981-2019.

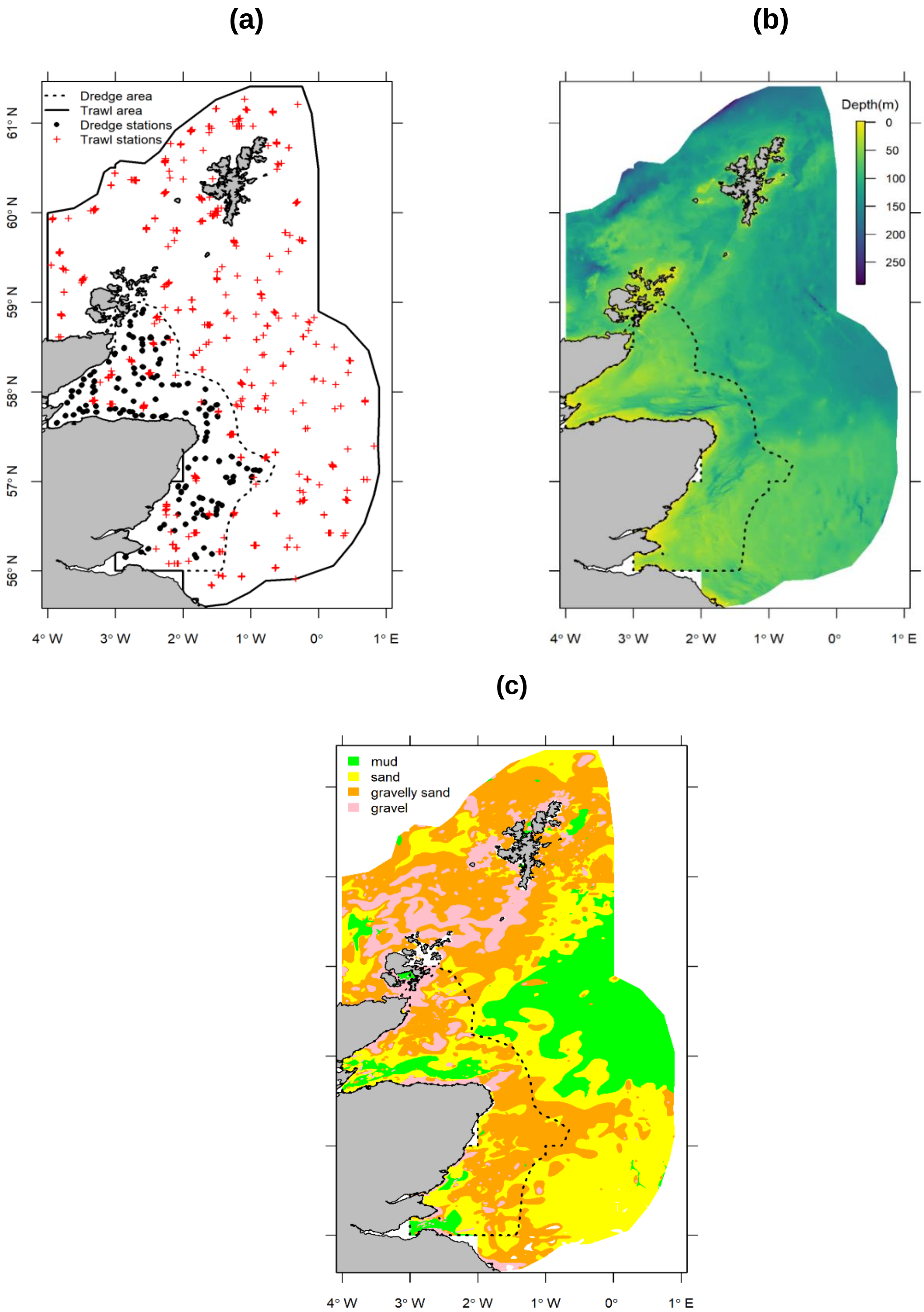


Figure 18: (a) Study region on the east coast of Scotland with the dredge and trawl survey areas and stations sampled (2008–2020. (b) Bathymetry map of the study area (depth in meters). (c) Distribution of marine sediments in the study area from the British Geological Survey (Cooper et al., 2013). Dredge stations around the Shetland Islands are shown in **Figure 20**.

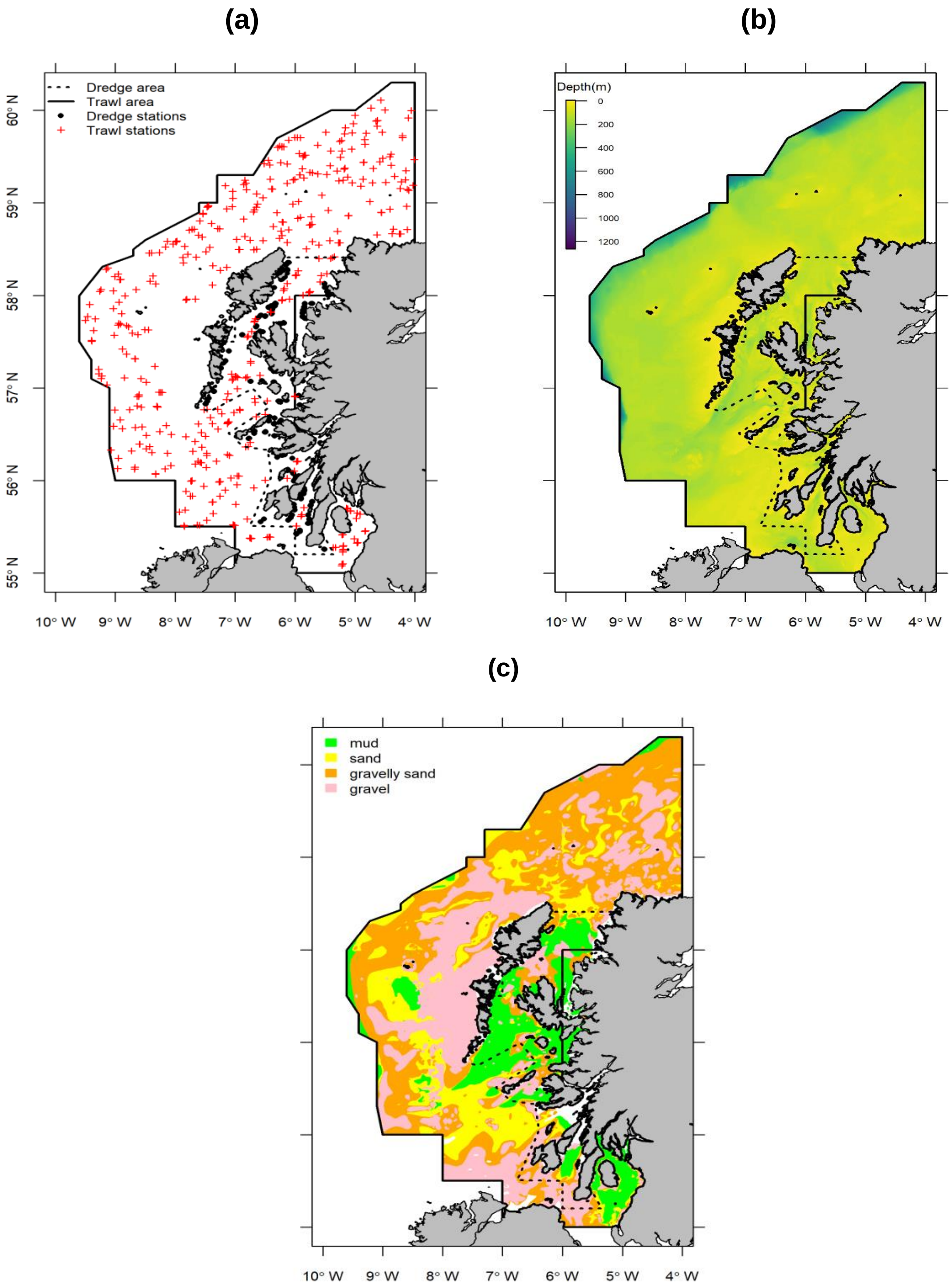


Figure 19: (a) Study region on the west coast of Scotland with the dredge and trawl survey areas and stations sampled (2008–2020). (b) Bathymetry map of the study area (depth in meters). (c) Distribution of marine sediments in the study area from the British Geological Survey (Cooper et al., 2013).

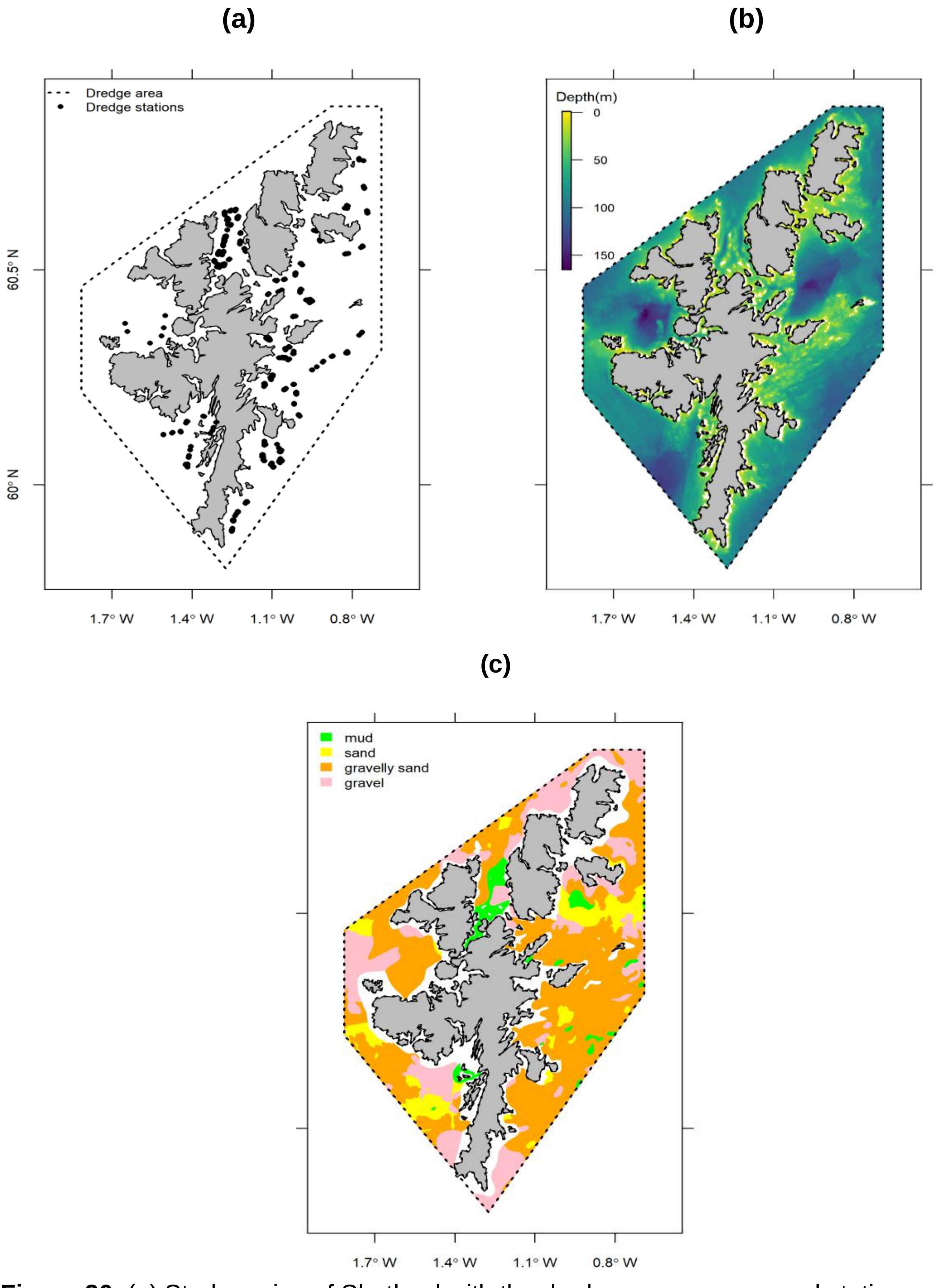


Figure 20: (a) Study region of Shetland with the dredge survey areas and stations sampled (2009–2020). (b) Bathymetry map of the study area (depth in metres). (c) Distribution of marine sediments in the study area from the British Geological Survey (Cooper et al., 2013).

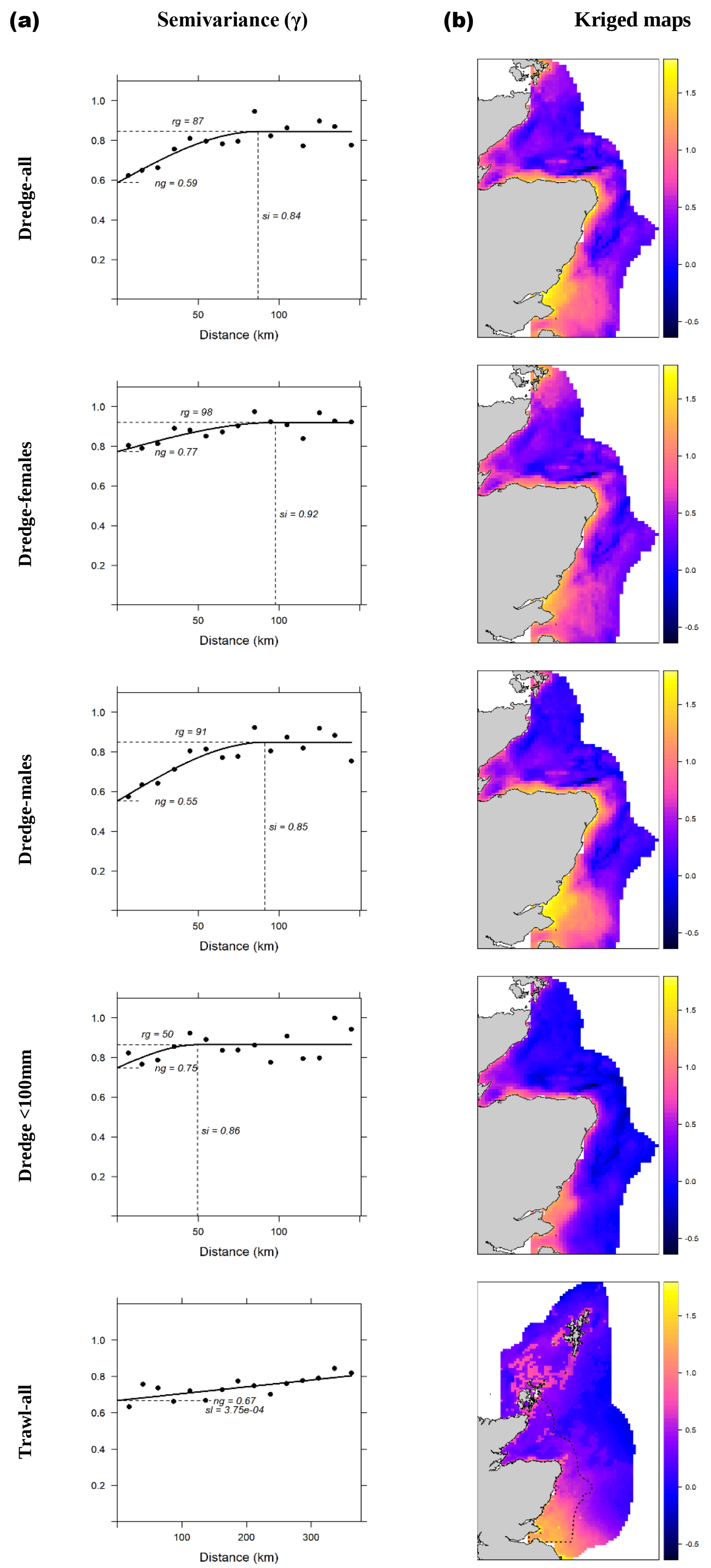


Figure 21: East Coast (a) Variograms estimating semi-variance (γ) with spherical (parameters: range-rg, sill-si, nugget-ng) and linear (parameters: intercept/nugget-ng, slope-sl) models. (b) Kriged maps showing predicted catch rates (in the transformed log scale). The five analysis scenarios considered are displayed from top to bottom: (1) all crabs (dredge), (2) females (dredge), (3) males (dredge), (4) juveniles (dredge), and (5) all crabs (trawl).

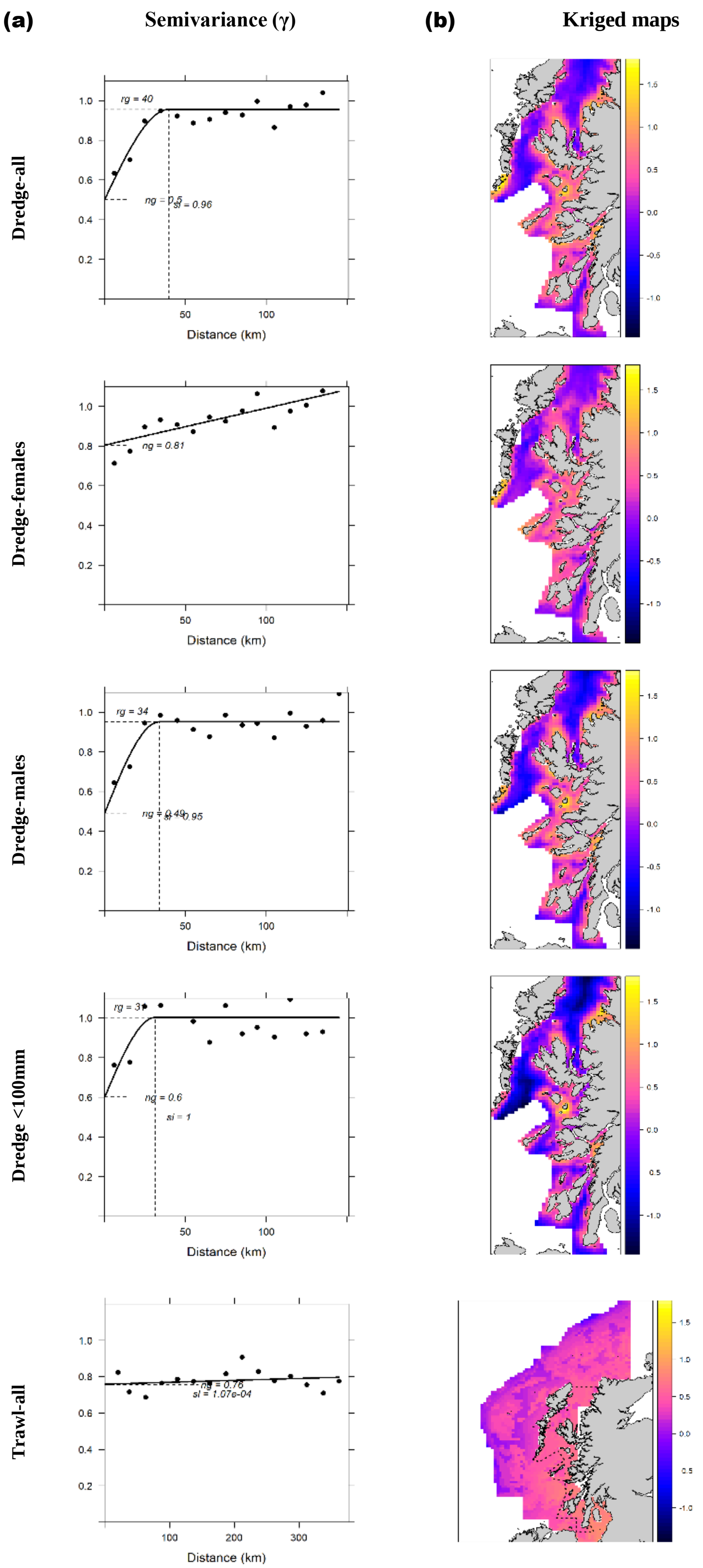
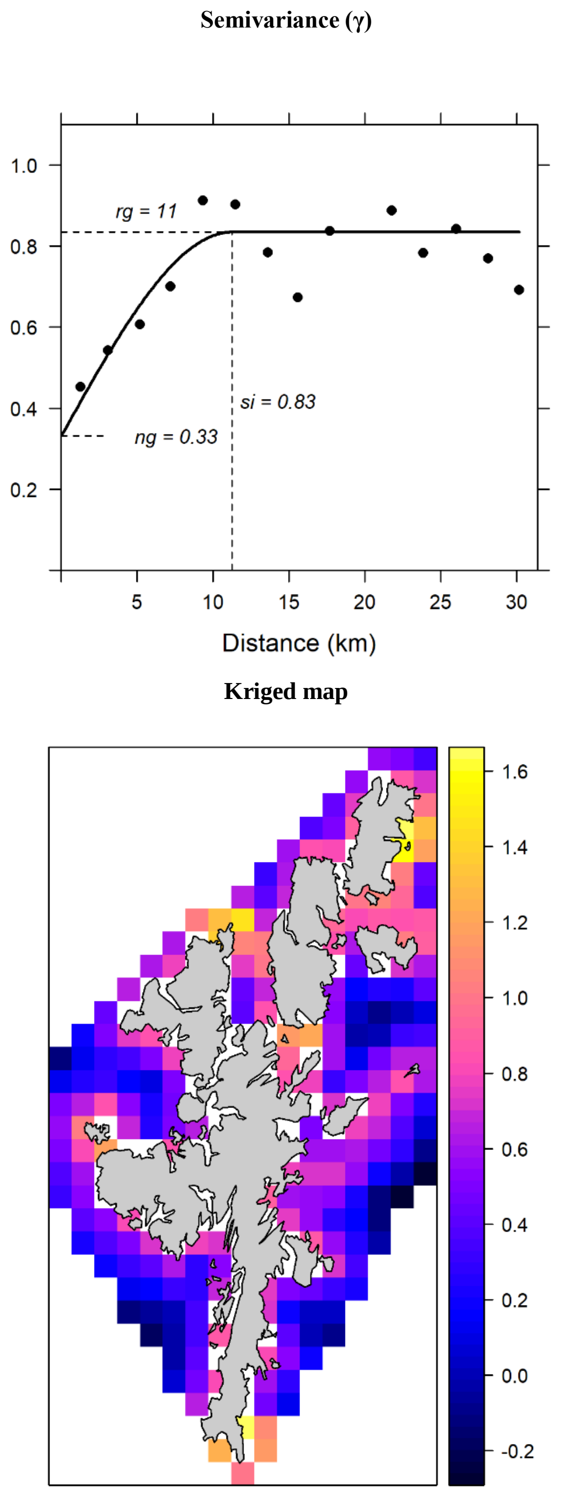


Figure 22: West Coast (a) Variograms estimating semi-variance (γ) with spherical (parameters: range-rg, sill-si, nugget-ng) and linear (parameters: intercept/nugget-ng, slope-sl) models. (b) Kriged maps showing predicted catch rates (in the transformed log scale). The five analysis scenarios considered are displayed from top to bottom: (1) all crabs (dredge), (2) females (dredge), (3) males (dredge), (4) juveniles (dredge), and (5) all crabs (trawl).

(a)



(b)

Figure 23: Shetland (a) Variogram estimating semi-variance (γ) with spherical (parameters: range-rg, sill-si, nugget-ng) and linear (parameters: intercept/nugget-ng, slope-sl) model. (b) Kriged map showing predicted catch rates (in the transformed log scale). The analysis scenario of all crabs (dredge) is displayed.

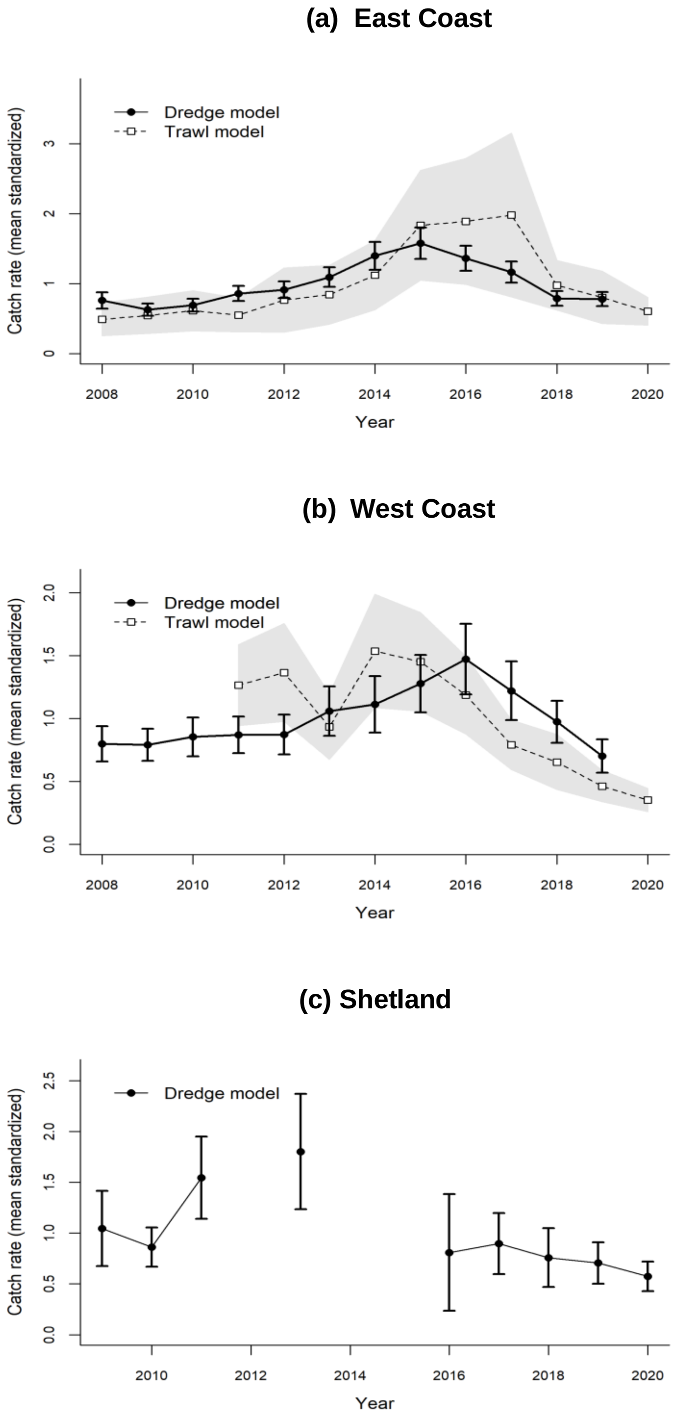


Figure 24: Brown crab abundance indices by year for (a) East Coast, (b) West Coast and (c) Shetland, estimated from GAMs applied to dredge (solid line) and trawl (dashed line) surveys (2008–2020) with 95% confidence intervals. The abundance indices for both the dredge and trawl models are mean standardized relative estimates. Predictions are averaged for grid cells within the dredge survey areas.

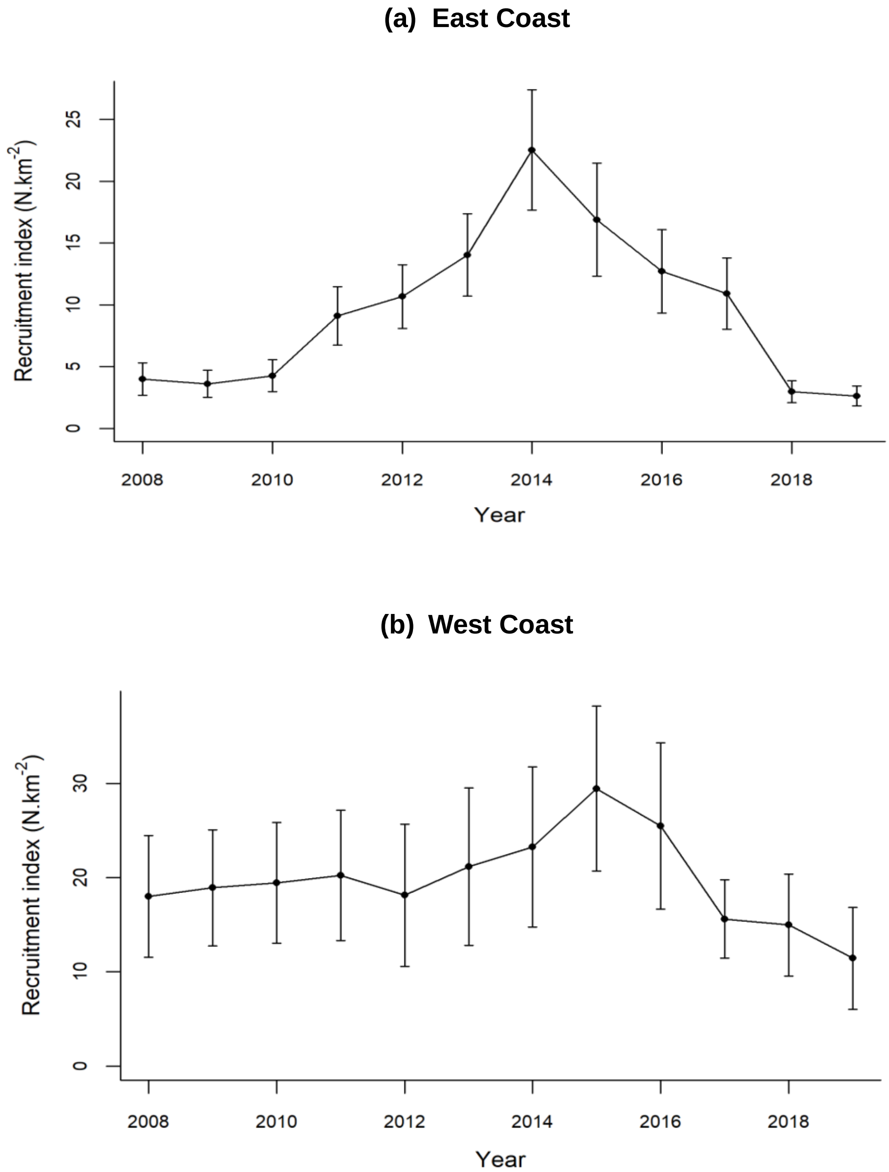


Figure 25: Brown crab recruitment index by year with 95% confidence intervals for (a) East Coast and (b) West Coast. The recruitment index is a relative estimate calculated as numbers per square kilometre (N.km^{-2}) of juvenile crabs <100 mm CW. Recruitment estimates were derived from a hurdle model applied to dredge surveys (2008–2019). Predictions are averaged for all grid cells within the dredge survey area.

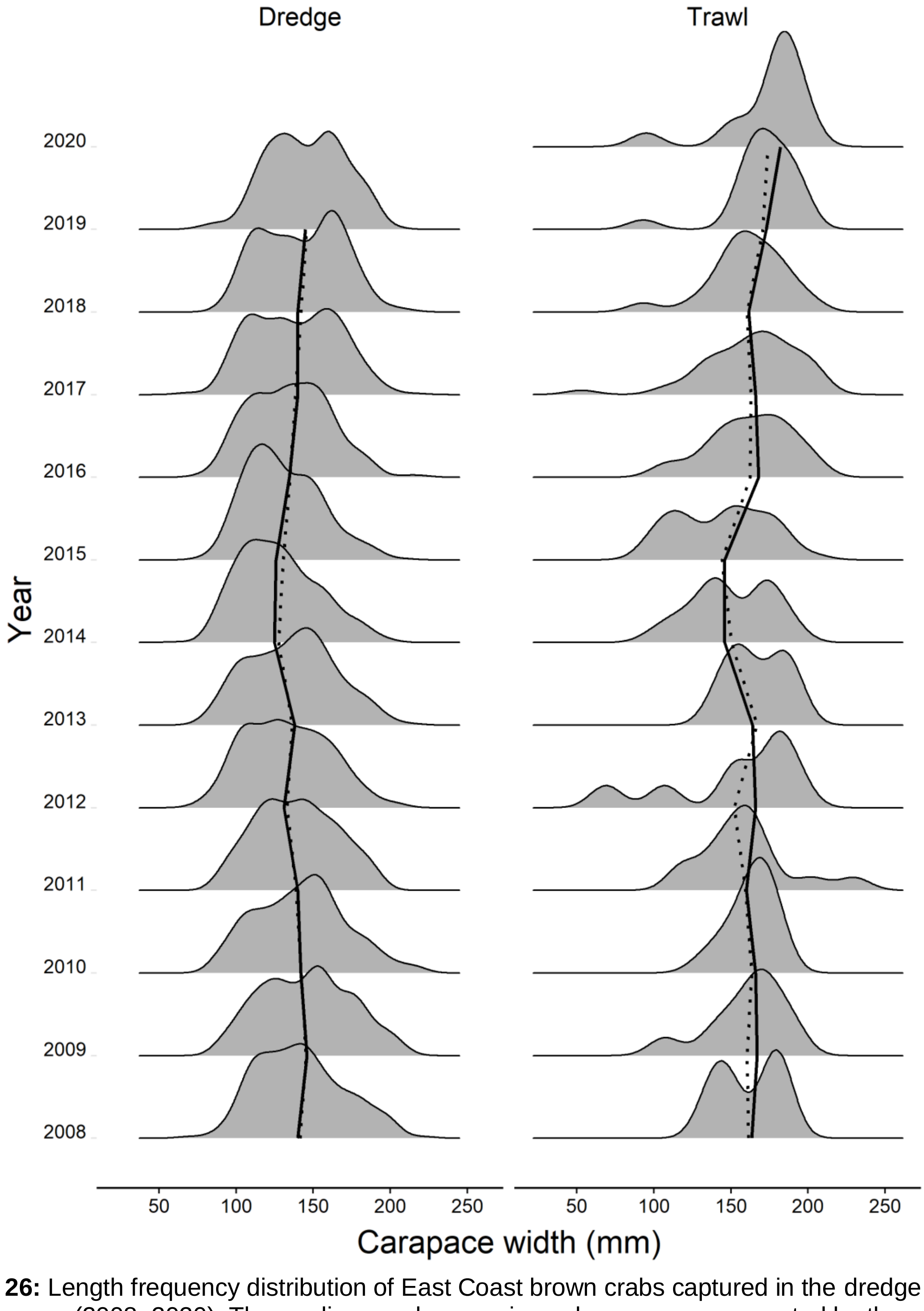


Figure 26: Length frequency distribution of East Coast brown crabs captured in the dredge and trawl surveys (2008–2020). The medians and means in each year are represented by the solid and dotted vertical lines, respectively.

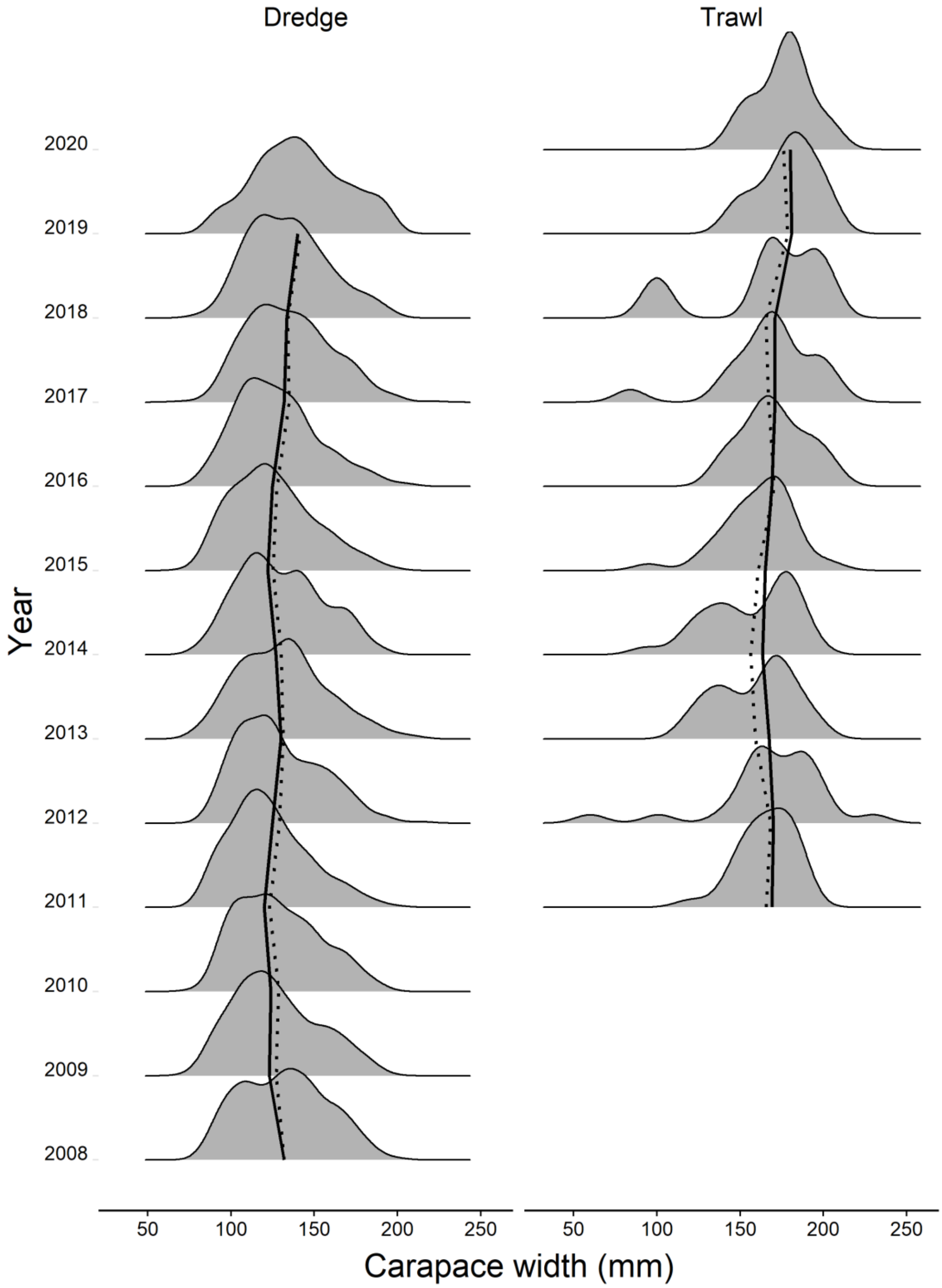


Figure 27: Length frequency distribution of West Coast brown crabs captured in the dredge and trawl surveys (2008–2020). The medians and means in each year are represented by the solid and dotted vertical lines, respectively.

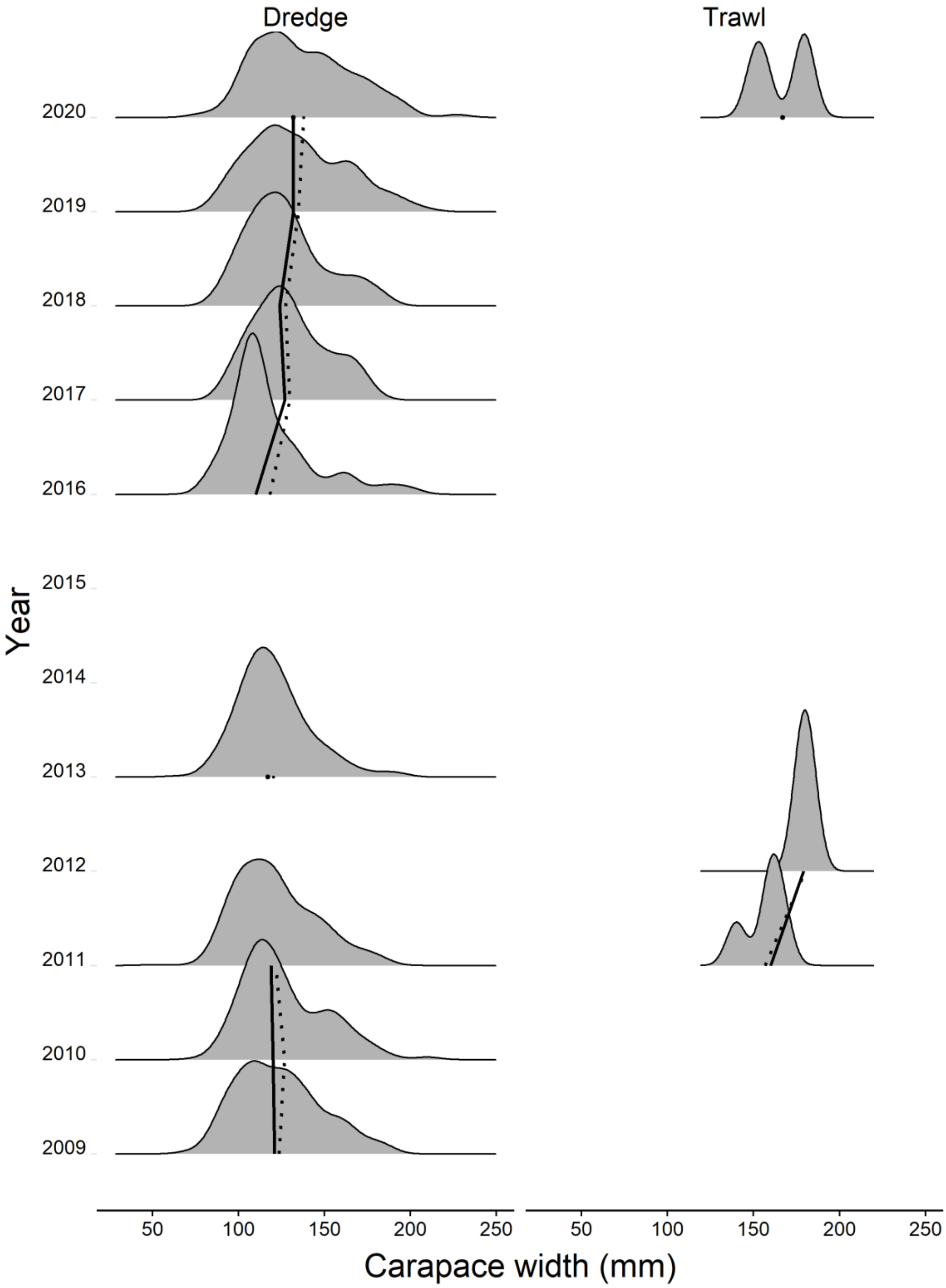


Figure 28: Length frequency distribution of Shetland brown crabs captured in the dredge and trawl surveys (2009–2020). The medians and means in each year are represented by the full and dotted vertical lines, respectively.

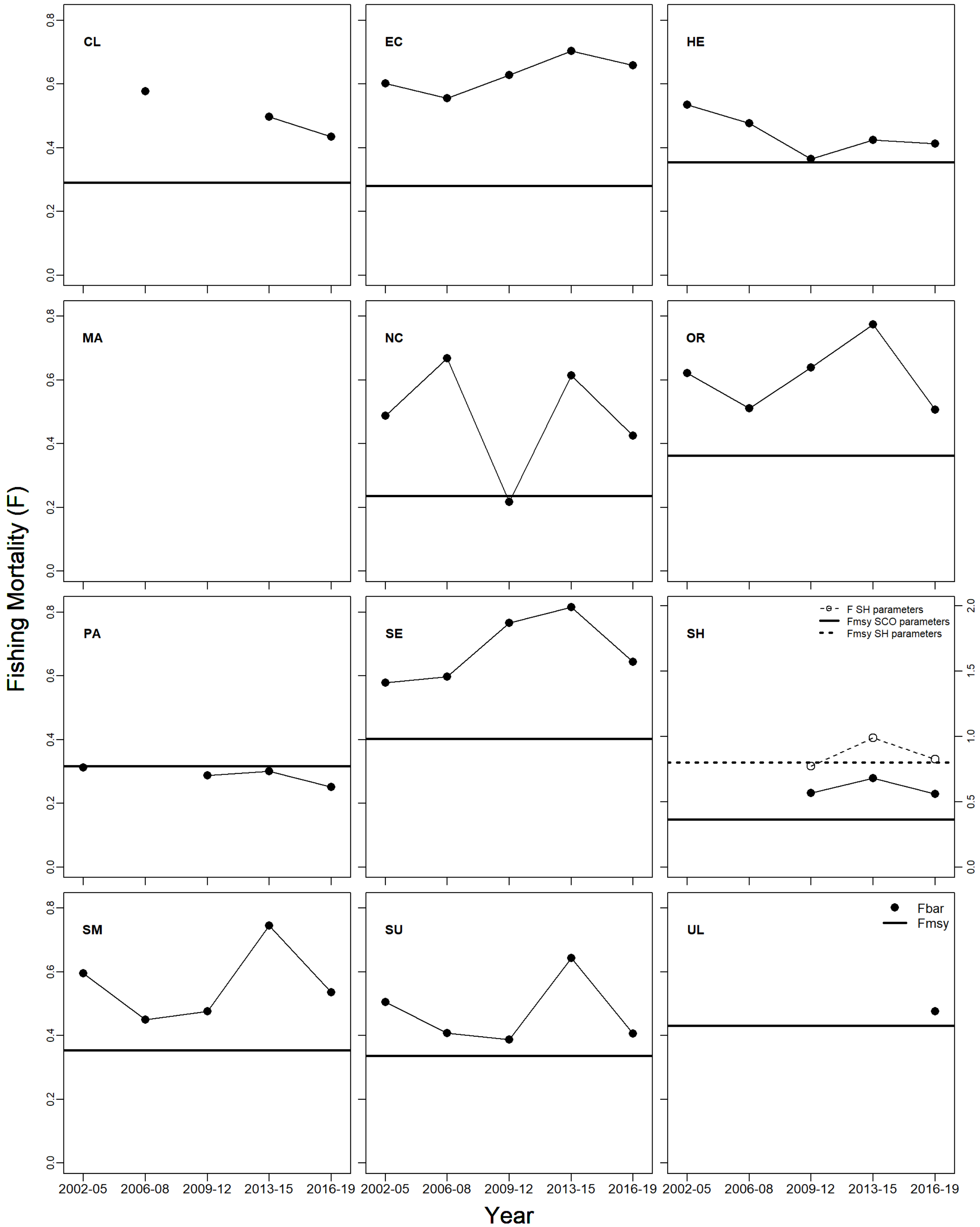


Figure 29: Male brown crab fishing mortality (Fbar) time series for the last five assessments in relation to FMSY. For the Shetland area, F values (on a different scale in the right vertical axis) are shown as estimated using two sets of biological parameters (Shetland and rest of Scotland).

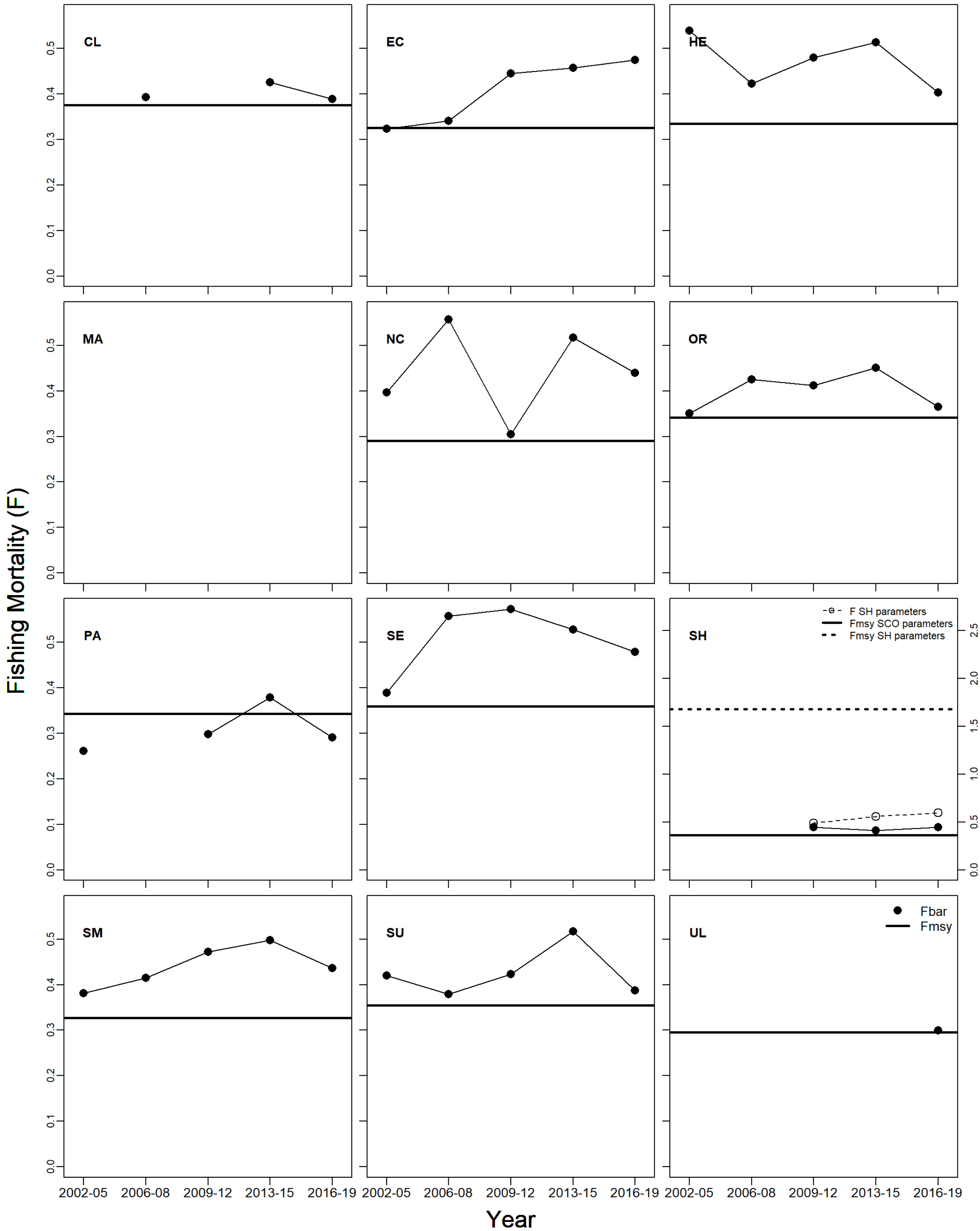


Figure 30: Female brown crab fishing mortality (Fbar) time series for the last five assessments in relation to FMSY. For the Shetland area, F values (on a different scale in the right vertical axis) are shown as estimated using two sets of biological parameters (Shetland and rest of Scotland).

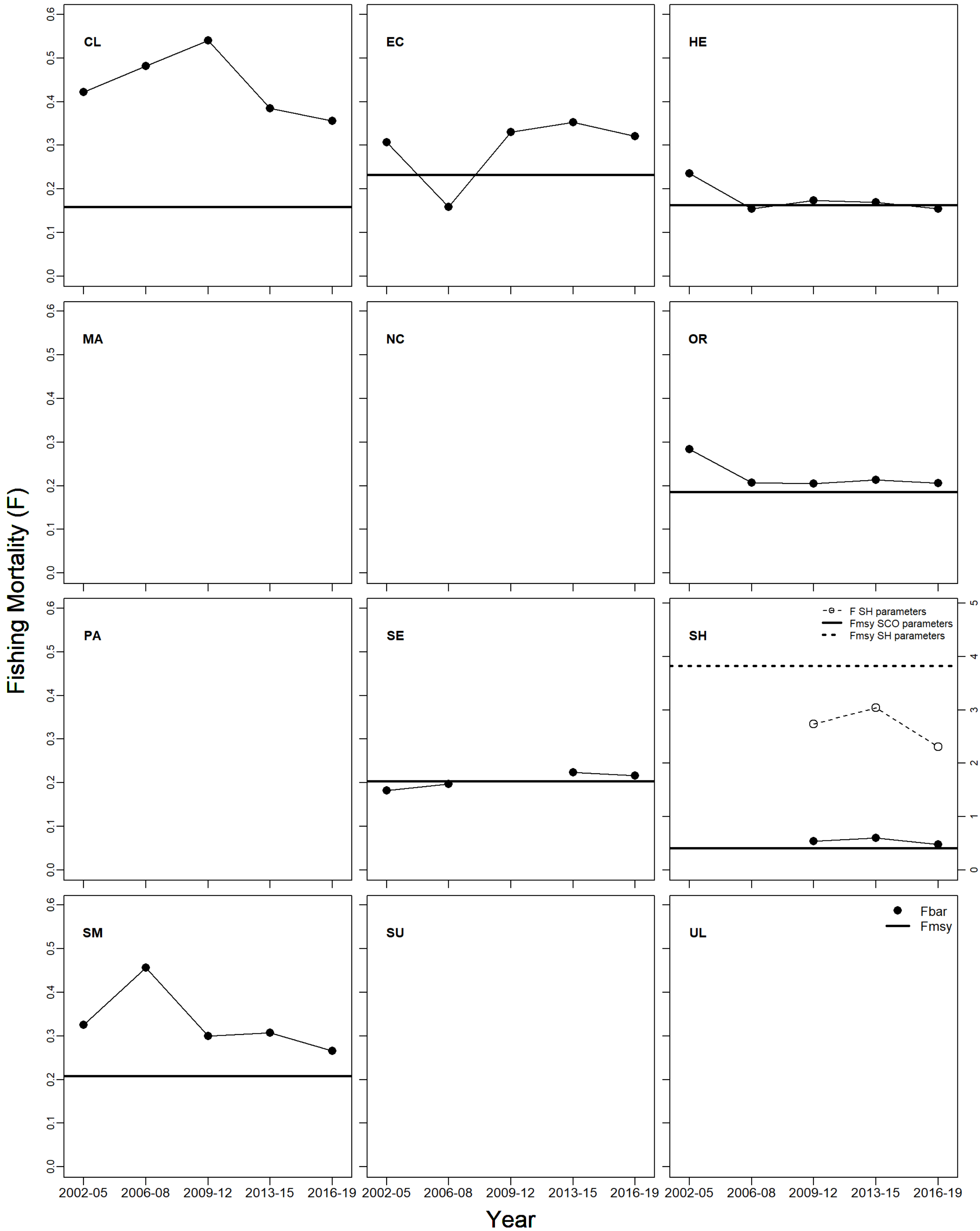


Figure 31: Male velvet crab fishing mortality (Fbar) time series for the last five assessments in relation to FMSY. For the Shetland area, F values (on a different scale in the right vertical axis) are shown as estimated using two sets of biological parameters (Shetland and rest of Scotland).

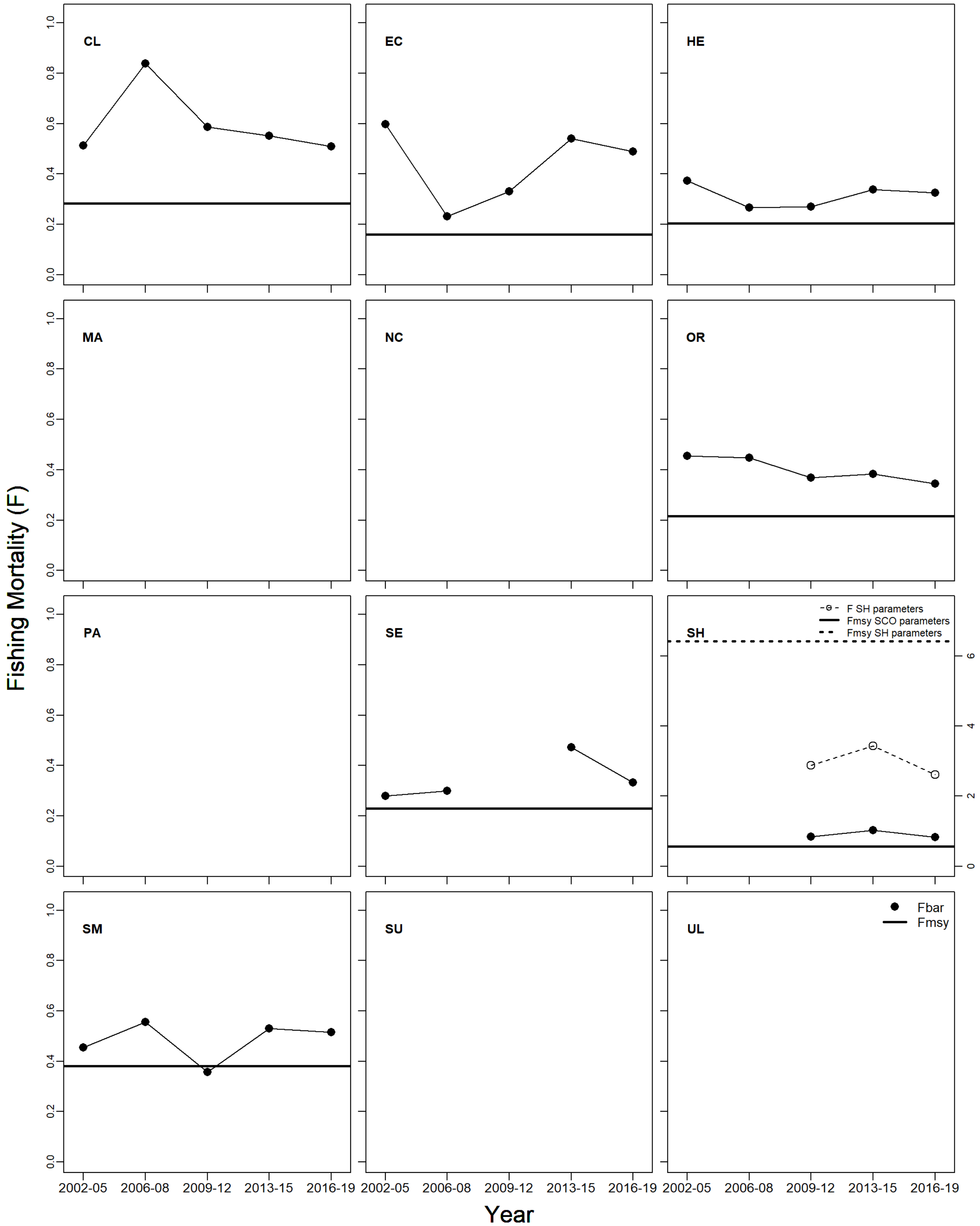


Figure 32: Female velvet crab fishing mortality (F_{bar}) time series for the last five assessments in relation to F_{MSY}. For the Shetland area, F values (on a different scale in the right vertical axis) are shown as estimated using two sets of biological parameters (Shetland and rest of Scotland).

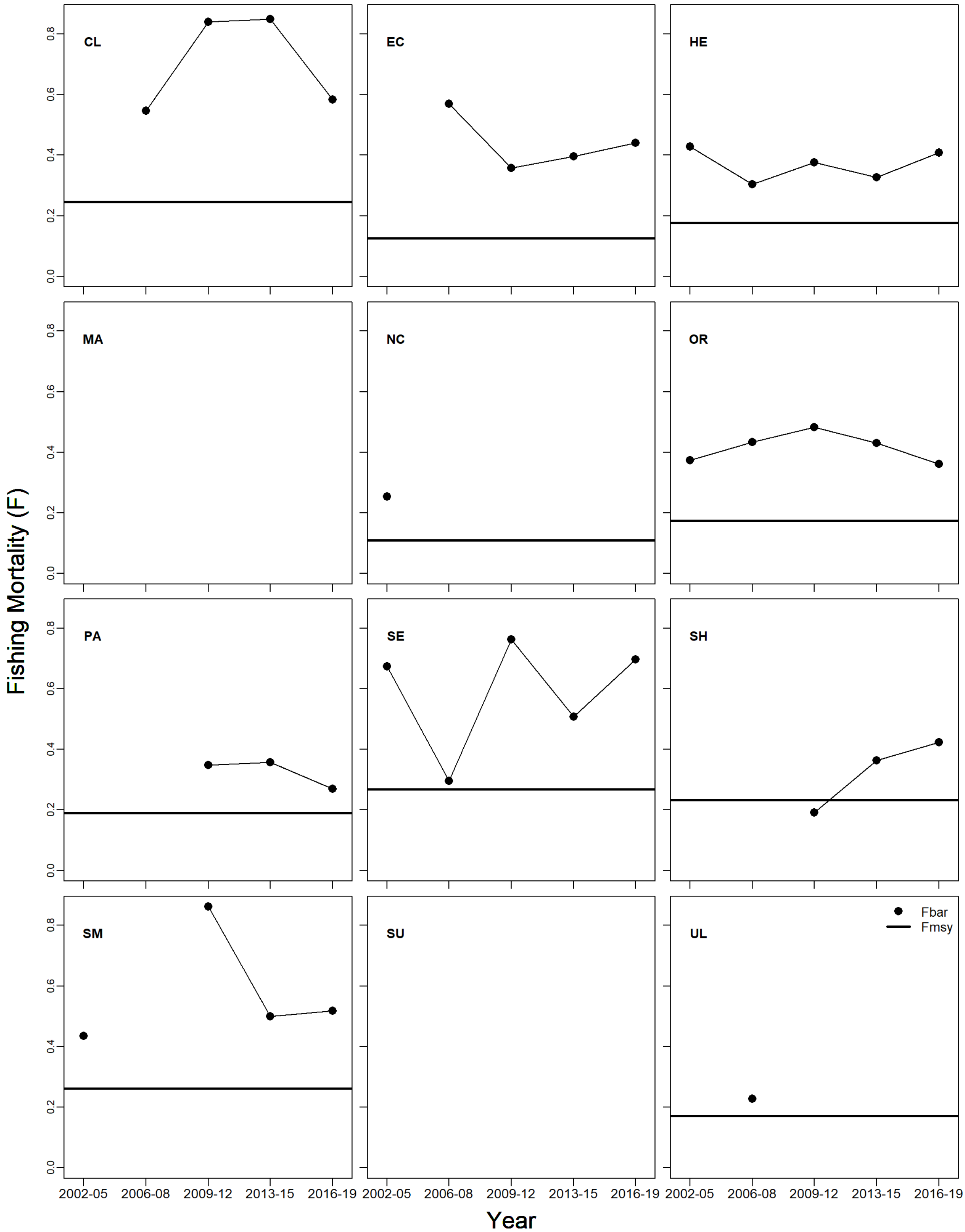


Figure 33: Male lobster fishing mortality (F_{bar}) time series for the last five assessments in relation to F_{MSY}.

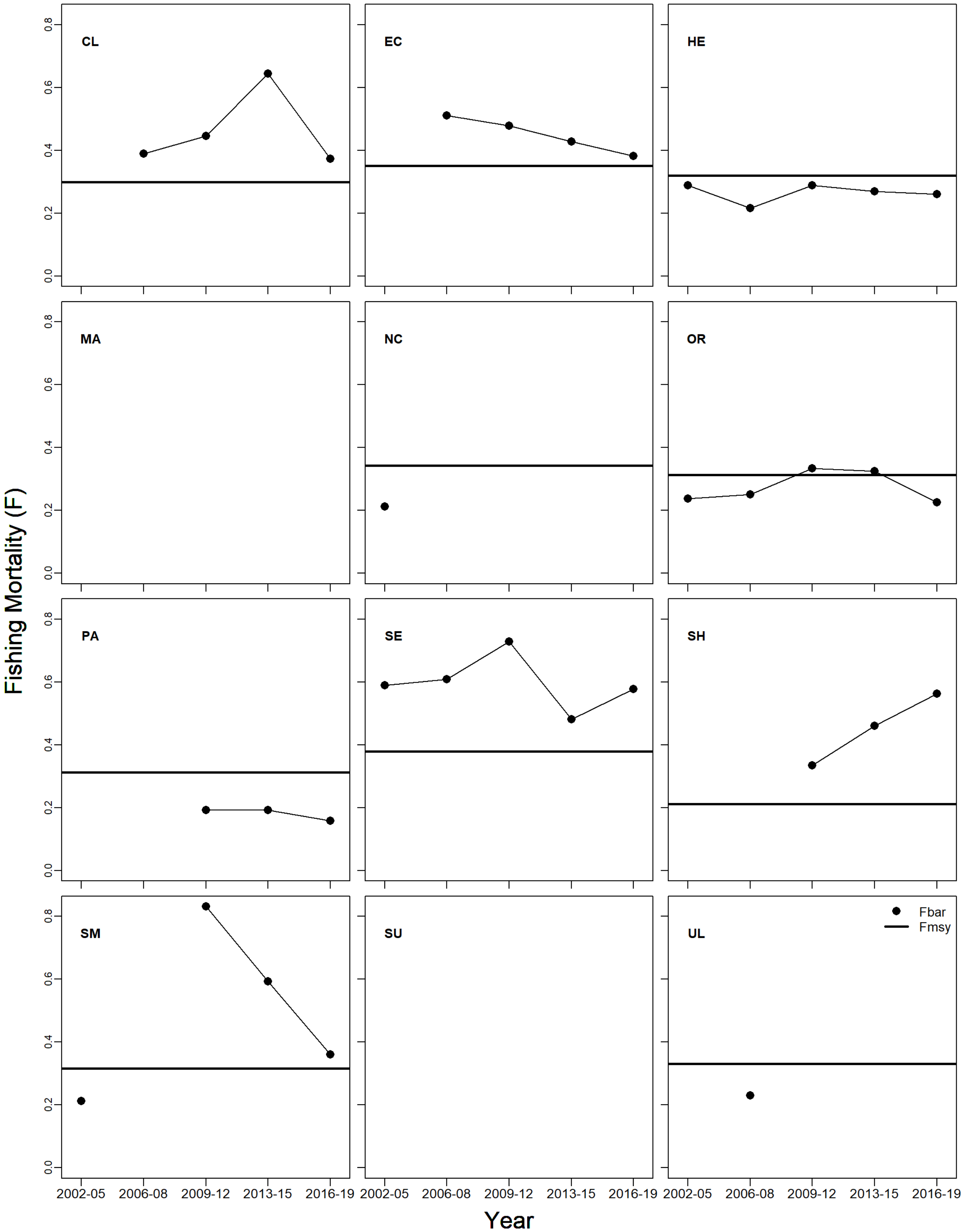


Figure 34: Female lobster fishing mortality (F_{bar}) time series for the last five assessments in relation to F_{MSY}.

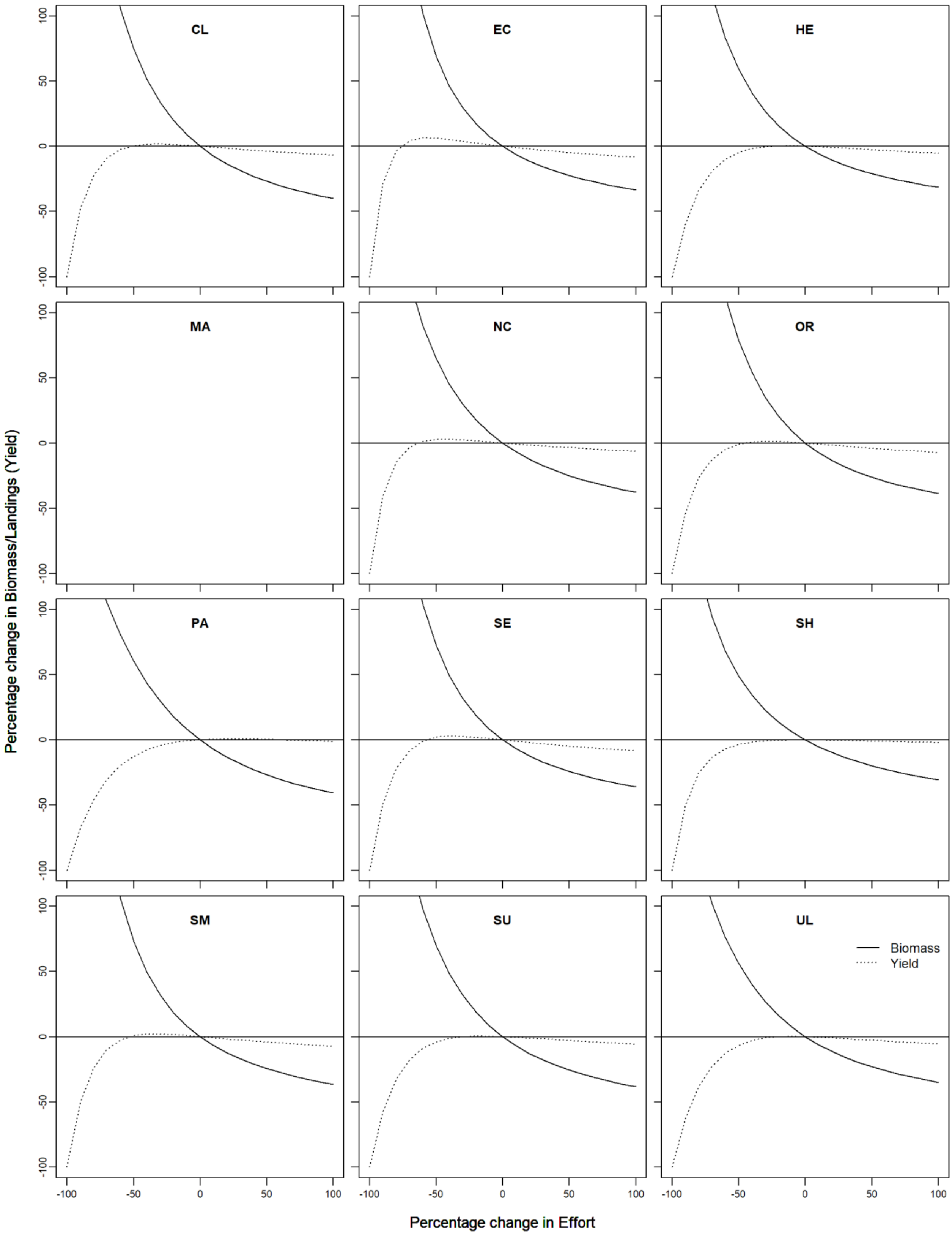


Figure 35: Male brown crab biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2016-19.

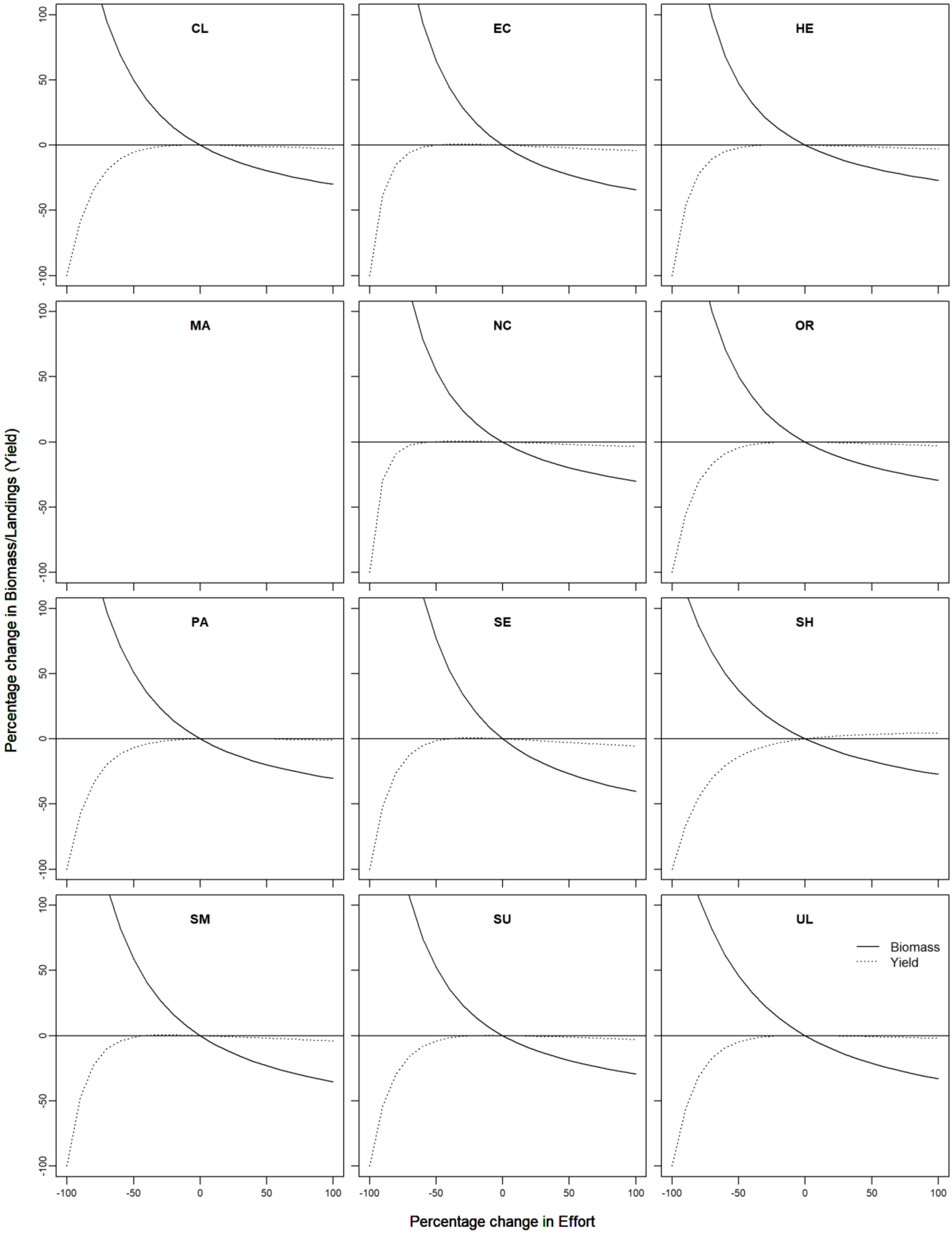


Figure 36: Female brown crab biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2016-19.

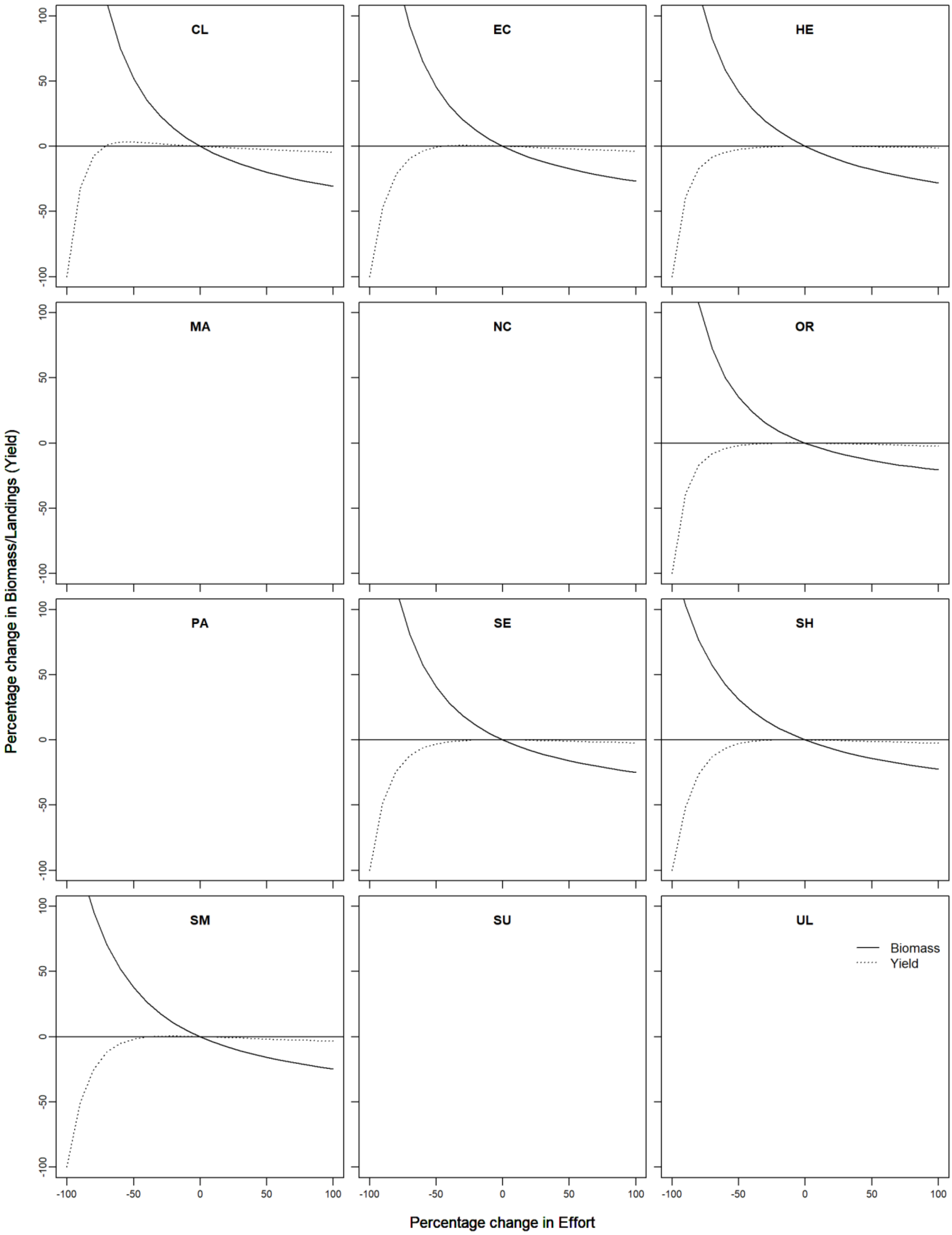


Figure 37: Male velvet crab biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2016-19.

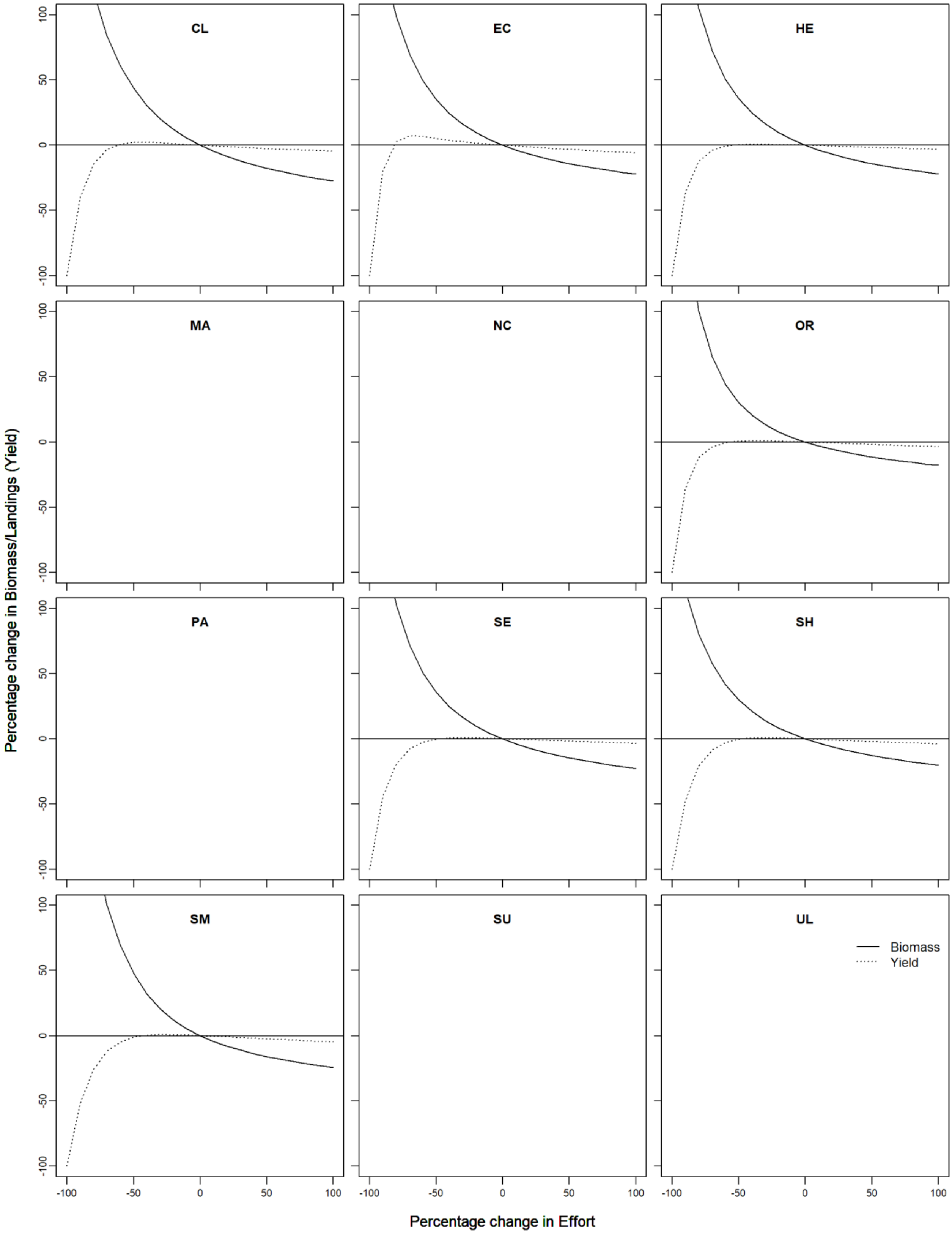


Figure 38: Female velvet crab biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2016-19.

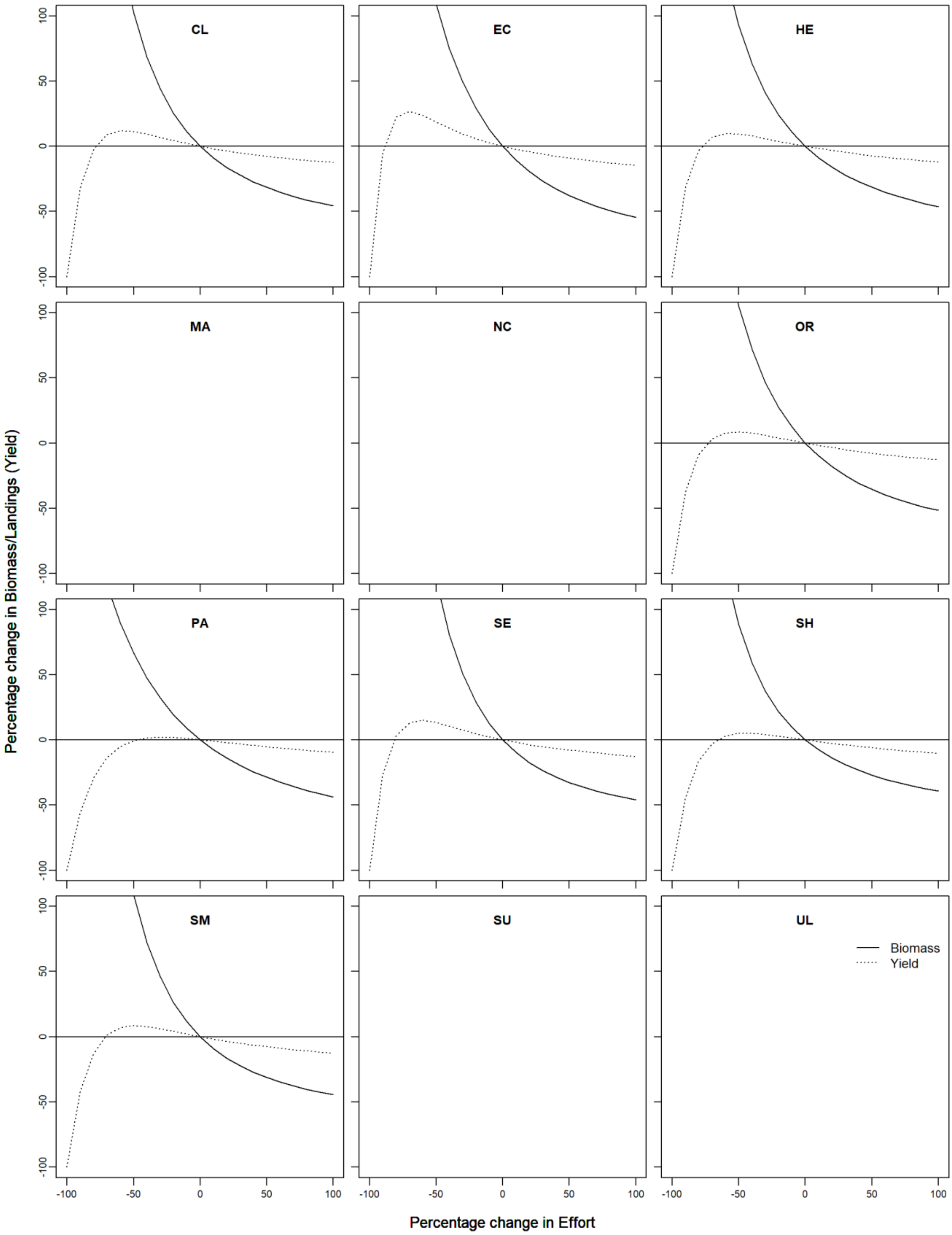


Figure 39: Male lobster biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2016-19.

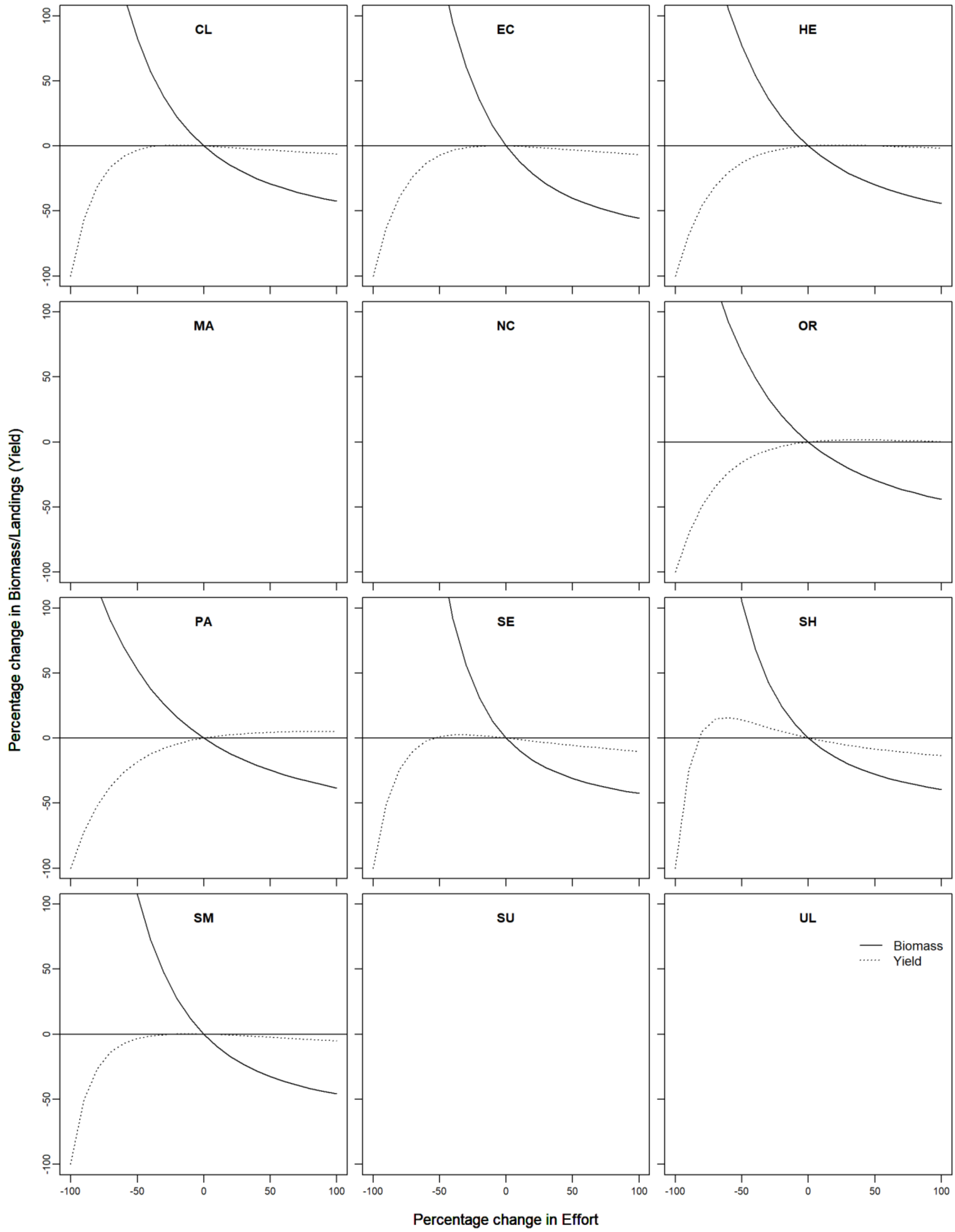


Figure 40: Female lobster biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2016-19.

8. Annexes

8.1. Annex A: Sampling Data – Decisions on which Species/Areas Stock Assessments Were Run

Table A1

Decision Table for Brown Crab

Brown crab	Clyde	East Coast	Hebrides	Mallaig	North Coast	Orkney	Papa Bank	Shetland	South East	South Minch	Sule	Ullapool
Assessed in (2013-2015)?	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	
N individuals/landings sampled												
N years available for average LF					3							3
Sampling seasonality (quarters)												
LFD shape												
Assessment 2016-2019	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓

Table A2

Decision Table for Velvet Crab

Velvet crab	Clyde	East Coast	Hebrides	Mallaig	North Coast	Orkney	Papa Bank	Shetland	South East	South Minch	Sule	Ullapool
Assessed in (2013-2015)?	✓	✓	✓			✓		✓	✓	✓		
N individuals/landings sampled												
N years available for average LF												
Sampling seasonality (quarters)												3/4
LFD shape												
Assessment 2016-2019	✓	✓	✓			✓		✓	✓	✓		

Table A3

Decision Table for Lobster

Lobster	Clyde	East Coast	Hebrides	Mallaig	North Coast	Orkney	Papa Bank	Shetland	South East	South Minch	Sule	Ullapool
Assessed in (2013-2015)?	✓	✓	✓			✓	✓	✓	✓	✓		
N individuals/landings sampled												
N years available for average LF					2							
Sampling seasonality (quarters)					1/2							3/4
LFD shape												
Assessment 2016-2019	✓	✓	✓			✓	✓	✓	✓	✓		

Table A4

Legend for Decision Tables

N individuals/landings sampled	(black)	POOR: No sampling or very few animals sampled (average < 100 per year)
	(grey)	OK: Few animals sampled (average < 500 per year)
	(white)	GOOD: Several animals sampled (average > 500 per year)
N years available for average LFD	(black)	POOR: < 2 years
	(grey)	OK: 2/3 years
	(white)	GOOD: 4 years
Sampling seasonality	(black)	POOR: Less than two quarters sampled over the 4 year period
	(grey)	OK: Two or three quarters sampled over the 4 year period
	(white)	GOOD: All quarters sampled over the 4 year period
LF shape	(black)	POOR: No data or very few animals sampled
	(grey)	OK: LF with some spikes
	(white)	GOOD: Approximately normal with no spikes

8.2. Annex B: Length Frequency Distributions

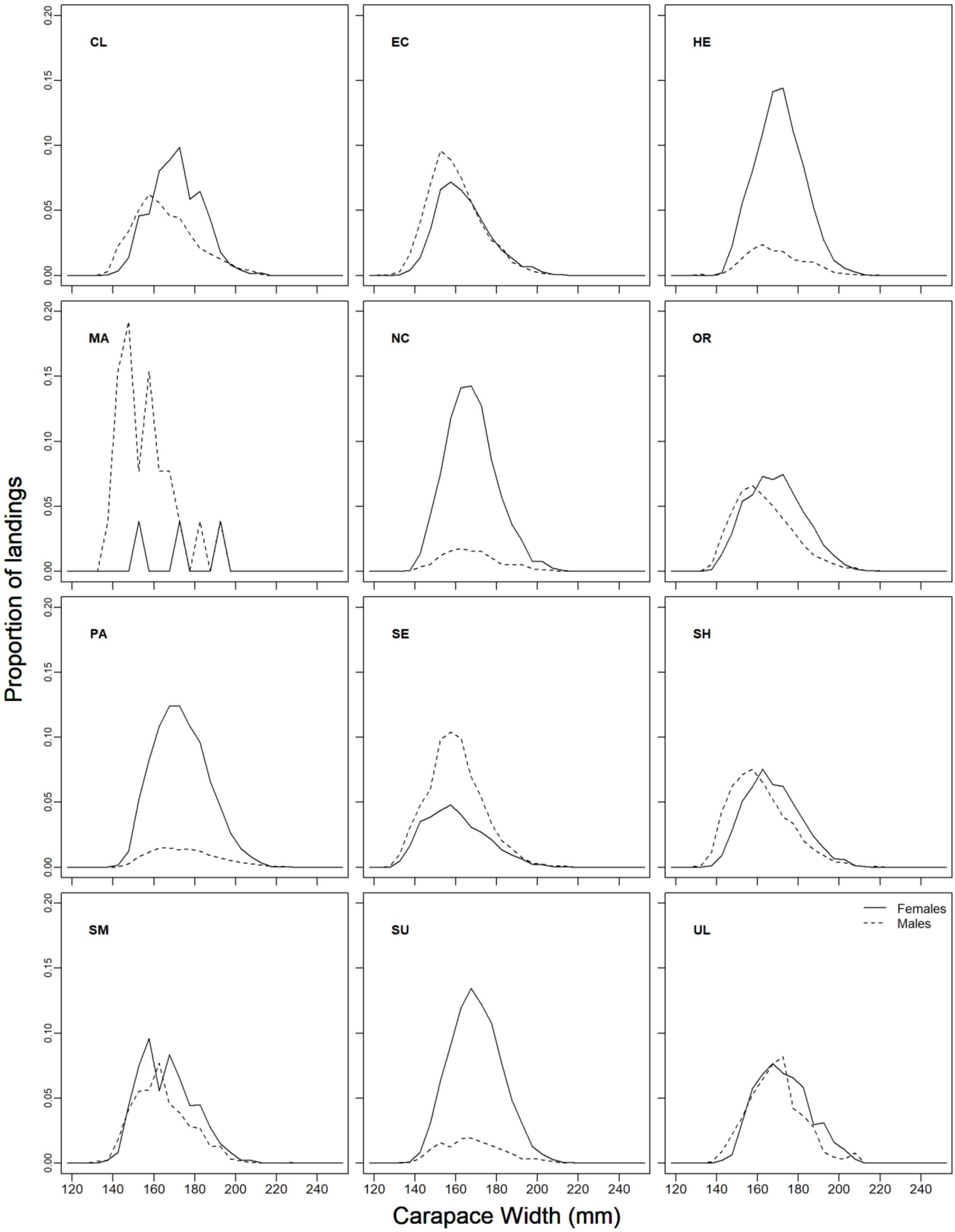


Figure B1: Brown crab carapace width (mm) frequency histogram by assessment area averaged over the period 2016-19. The data presented are aggregated by 5 mm increments and shown as a proportion of the total landings.

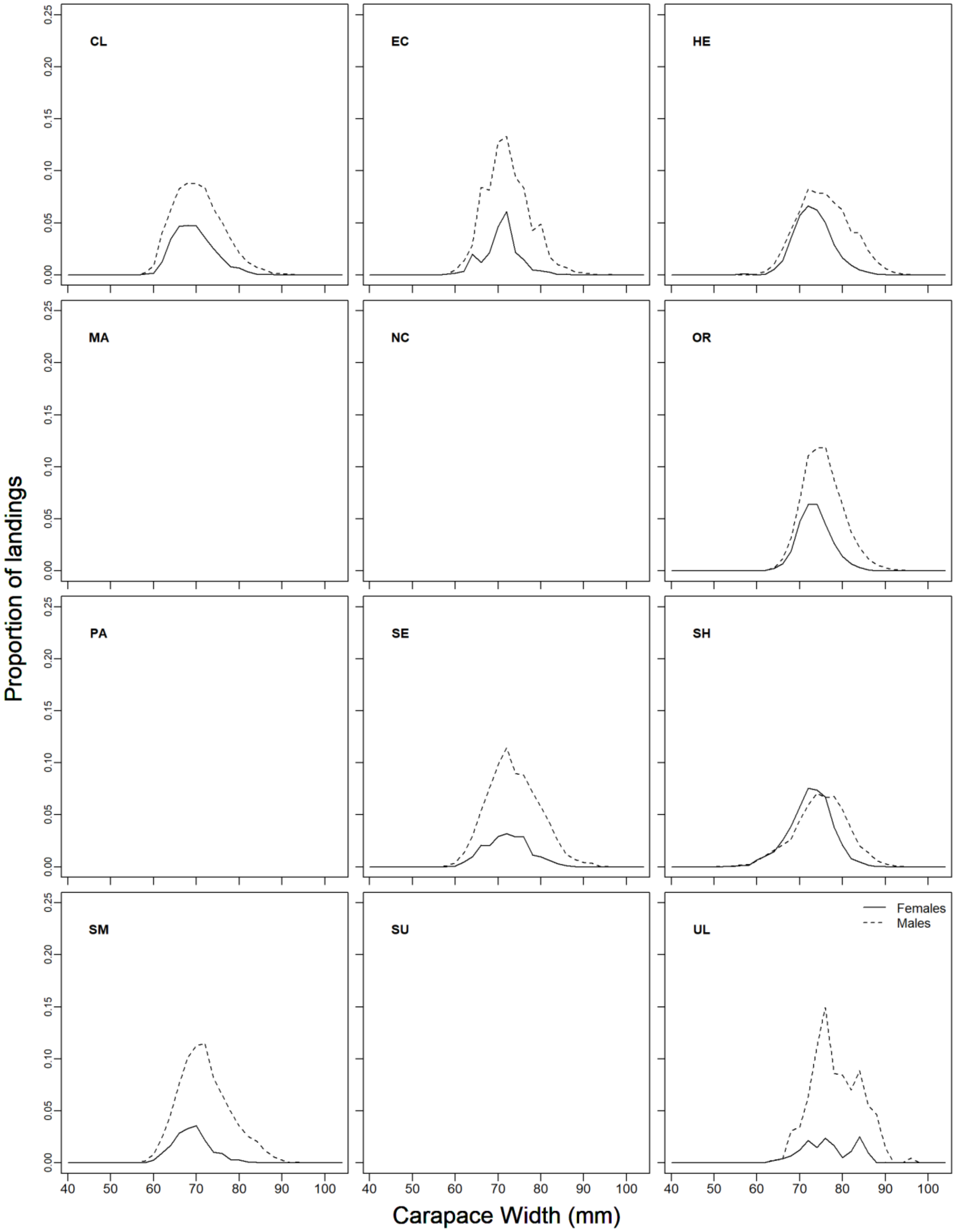


Figure B2: Velvet crab carapace width (mm) frequency histogram by assessment area averaged over the period 2016-19 for males and females. The data presented are aggregated by 3 mm increments and shown as a proportion of the total landings.

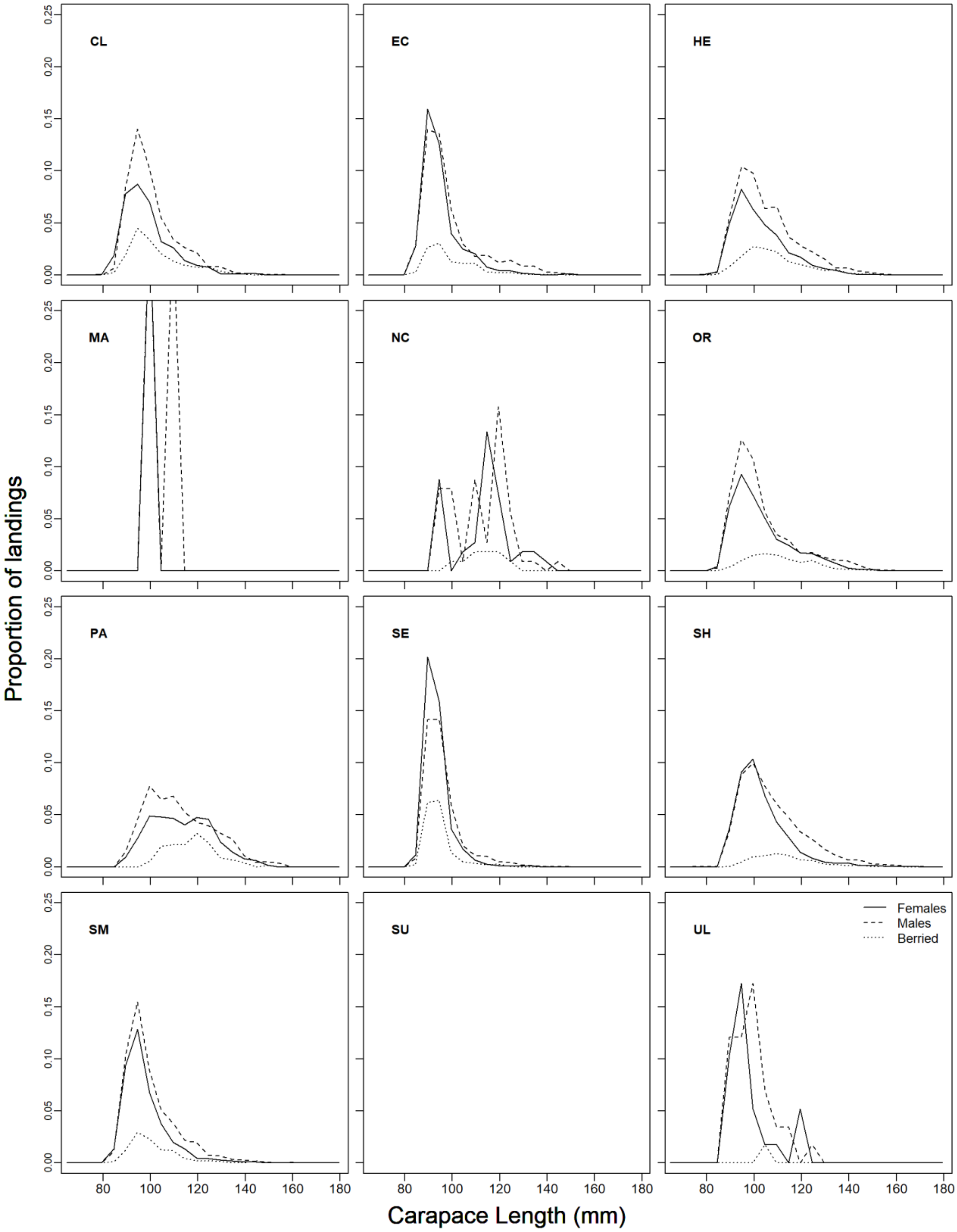


Figure B3: Lobster carapace length (mm) frequency histogram by assessment area averaged over the period 2016-19 for males, females (berried also shown). The data presented are aggregated by 5 mm increments and shown as a proportion of the total landings.

8.3. Annex C: Brown crab and Velvet Crab per Recruit Analysis using Different Biological Parameters

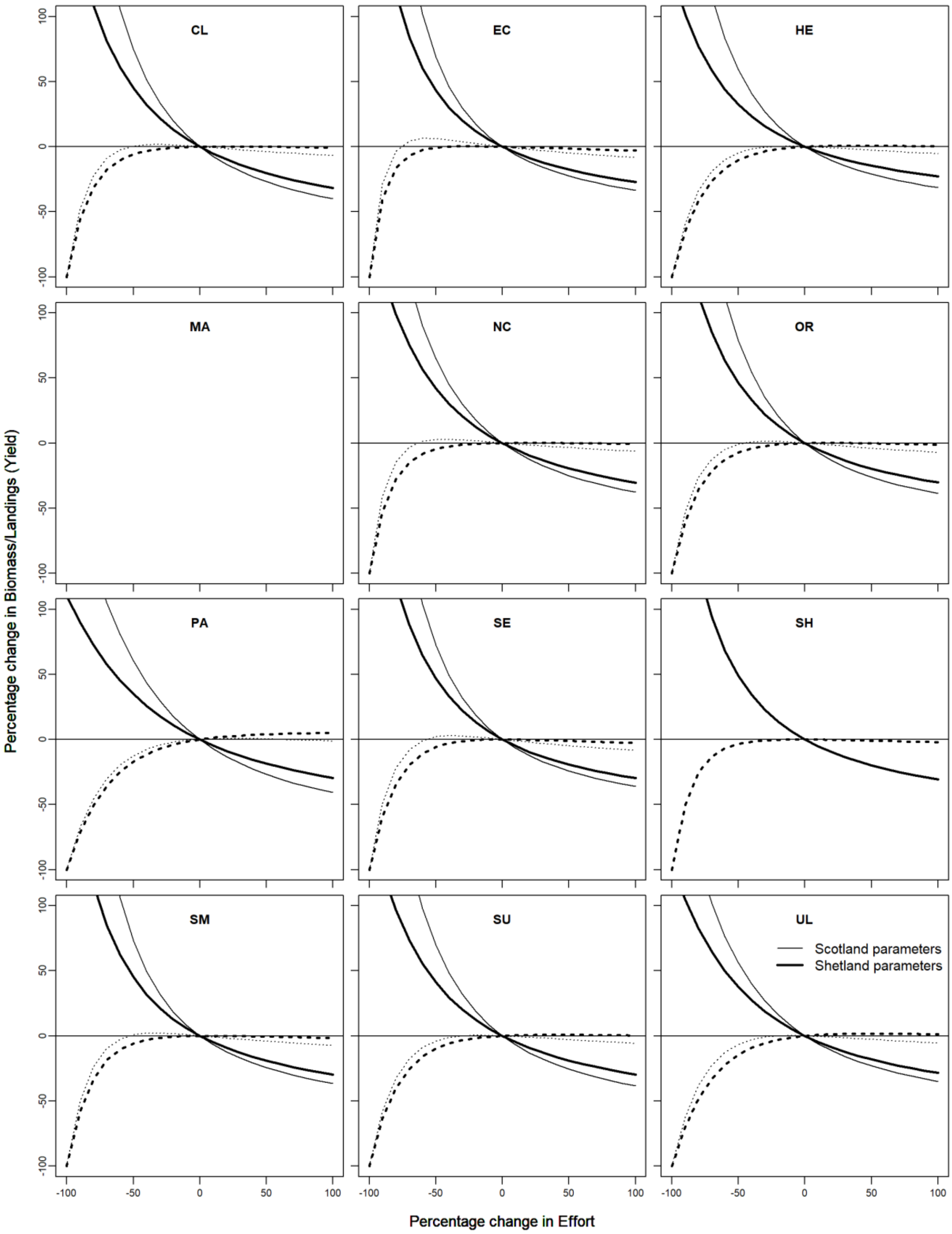


Figure C1: Male brown crab biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2016-19. The YPR analysis was run using two different sets of biological parameters (Shetland and rest of Scotland).

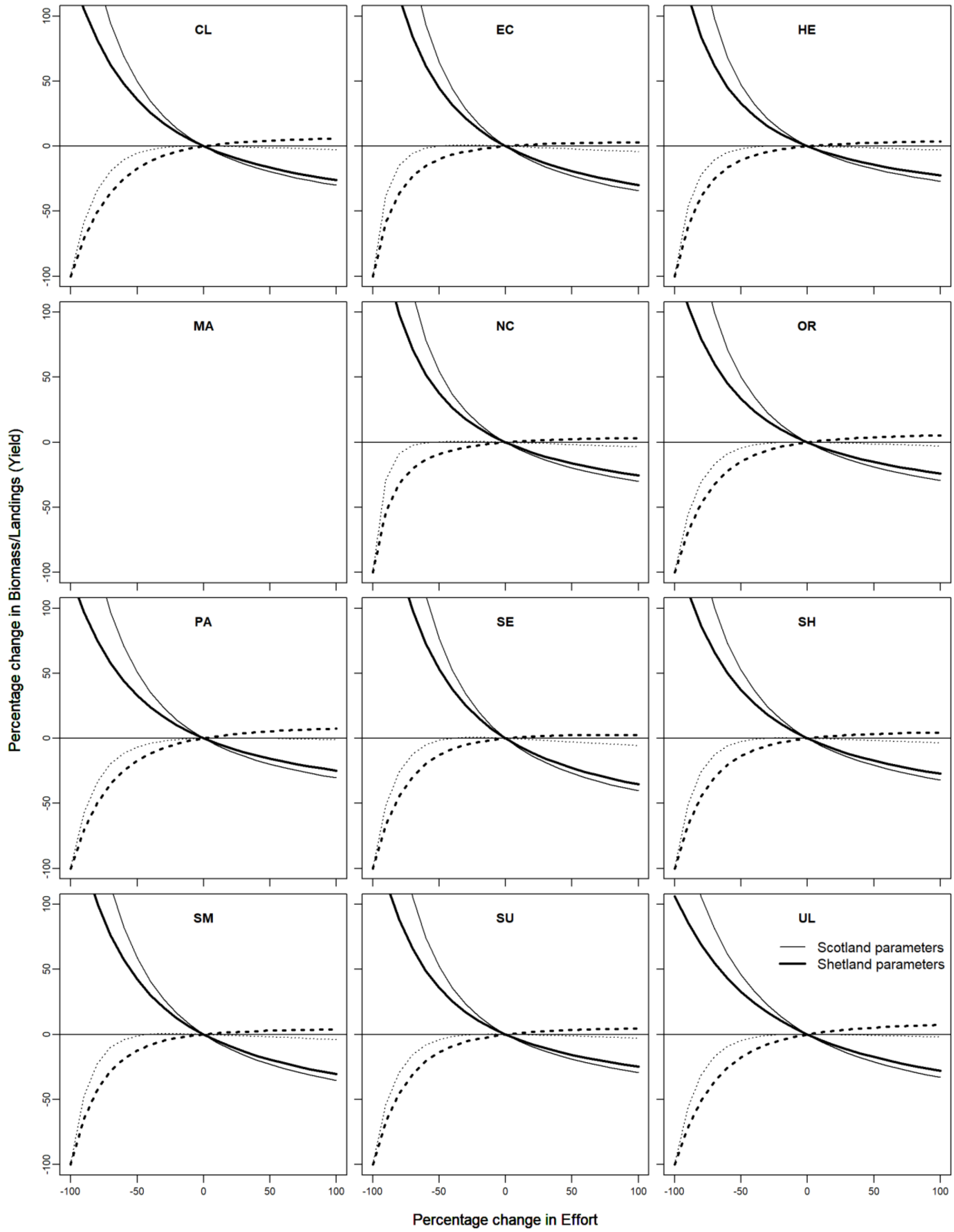


Figure C2: Female brown crab biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2016-19. The YPR analysis was run using two different sets of biological parameters (Shetland and rest of Scotland).

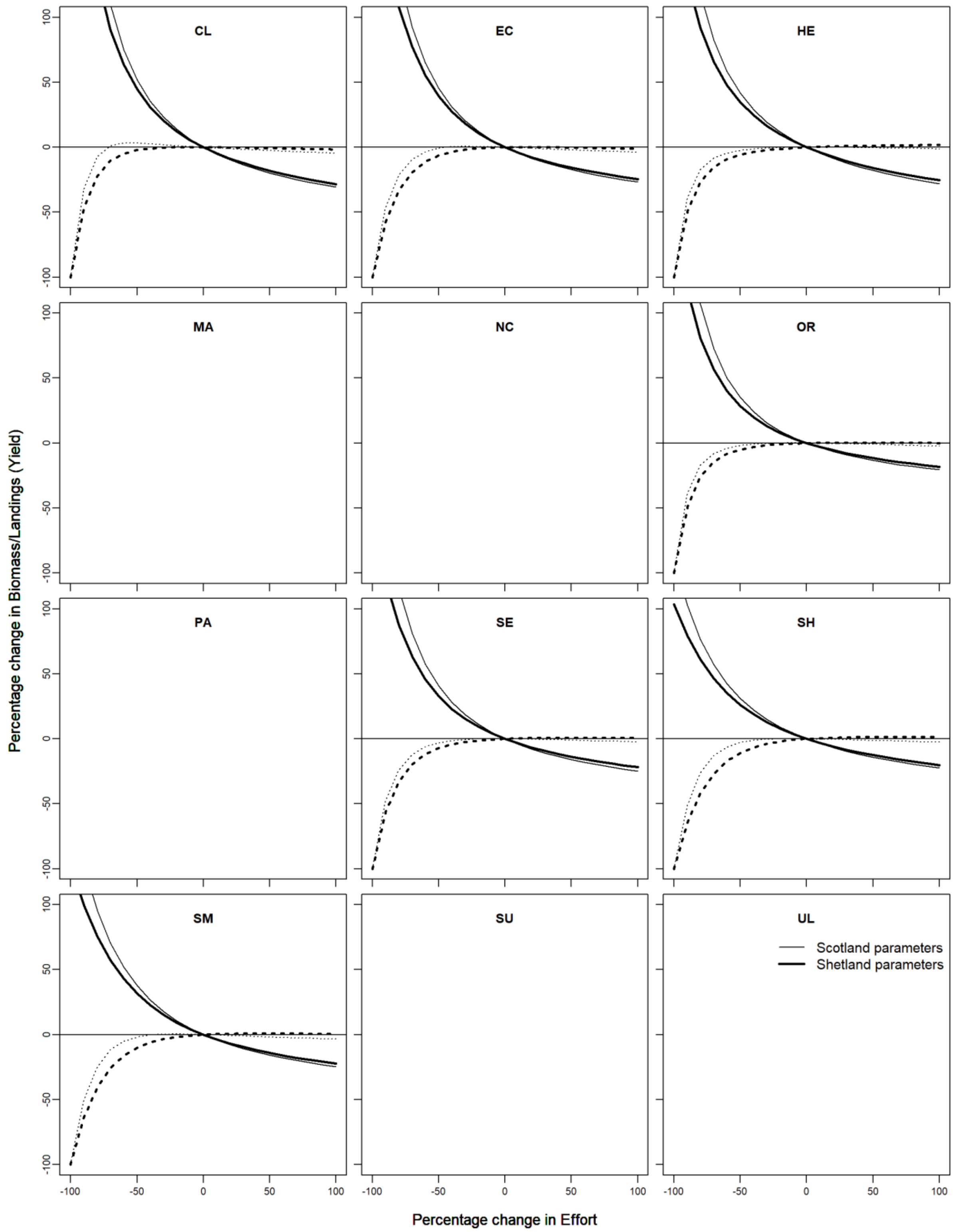


Figure C3: Male velvet crab biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2016-19. The YPR analysis was run using two different sets of biological parameters (Shetland and rest of Scotland).

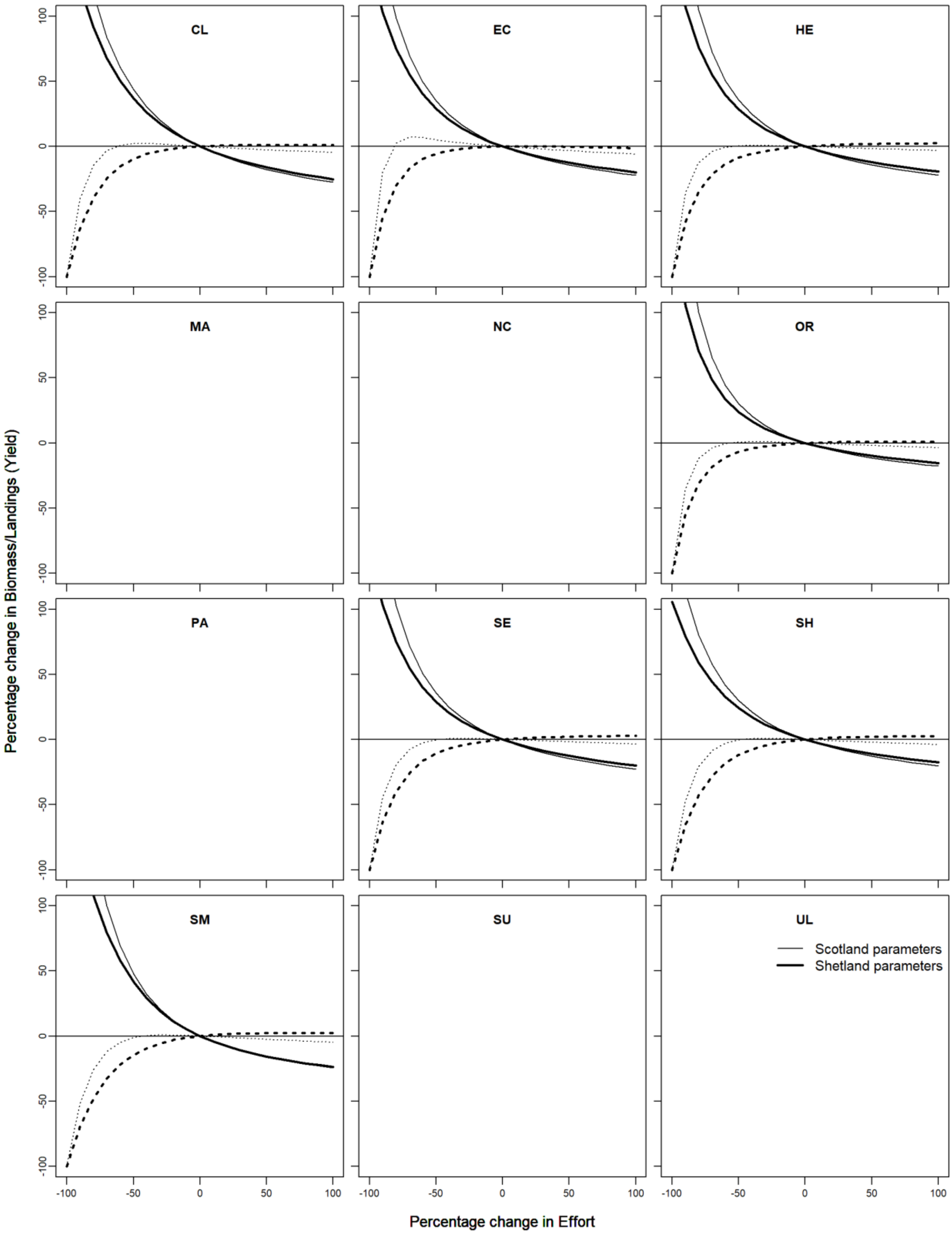


Figure C4: Female velvet crab biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2016-19. The YPR analysis was run using two different sets of biological parameters (Shetland and rest of Scotland).

8.4. Annex D: List of Abbreviations

ACRUNET	Transnational Approach to Competitiveness and Innovation in the Brown Crab Industry
BGS	British Geological Survey
BPR	Biomass-per-recruit
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CL	Carapace length
CPUE	Catch per unit effort
CW	Carapace width
ELEFAN	Electronic length frequency analysis
EU	European Union
F	Fishing mortality
$F_{0.1}$	Fishing mortality rate at which the marginal yield-per-recruit is 10% of the marginal yield-per-recruit on the unexploited stock
$F_{35\%SpR}$	Fishing rate which results in combined spawning biomass per recruit equal to 30% of the unexploited stock
$\mathbf{F_{bar}}$	Average fishing mortality
FFM	Future fisheries management strategy
$\mathbf{F_{MAX}}$	Fishing mortality rate that maximizes YPR
FMD	Fisheries Management Database
$\mathbf{F_{MSY}}$	Fishing mortality consistent with achieving MSY
GAM	Generalized additive model
HCR	Harvest Control Rule
ICES	International Council for the Exploration of the Sea
K	Grow rate parameter
KW	Kilowatt
$\bar{L}$	Mean length
L_{∞}	Asymptotic size parameter
LBI	Length-based indicator
L_c	Size at first capture
LCA	Length Cohort Analysis
$L_{F=M}$	Expected length in the landings when fishing mortality is equal to natural mortality
LFD	Length frequency distribution
L_{mat}	Maturation size
$L_{max5\%}$	Mean size of the largest 5% of individuals in the landings
LPUE	Landings per unit effort
m	Metre
M	Natural mortality
MLS	Minimum Landing Size
mm	Millimetre
MoU	Memorandum of Understanding
MSE	Management Strategy Evaluation
MSS	Marine Scotland Science
MSY	Maximum Sustainable Yield
NAFC	North Atlantic Fisheries College
OHIFP	Outer Hebrides Inshore Fisheries Pilot
OSF	Orkney Sustainable Fisheries

REM	Remote electronic monitoring
RIFG	Scottish Regional Inshore Fisheries Group
SPiCT	Surplus production model in continuous time
TAC	Total Allowable Catch
UHI	University of the Highlands and Islands
VMS	Vessel Monitoring System
WGCRAB	Working Group on the Biology and Life History of Crabs
WKLIFE	Workshop on the Development of Quantitative Assessment Methodologies based on LIFE-history traits, exploitation characteristics, and other relevant parameters for data-limited stocks
YPR	Yield-per-recruit

Table D1

Crab and lobster fishery assessment areas and abbreviations

Assessment area	Abbreviation
Clyde	CL
East Coast	EC
Hebrides	HE
Mallaig	MA
North Coast	NC
Orkney	OR
Papa Bank	PA
South East	SE
Shetland	SH
South Minch	SM
Sule	SU
Ullapool	UL

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