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Crab and Lobster Fisheries in Scotland: Results of Stock Assessments 2013-2015

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This report presents the results of marine and freshwater scientific work carried out by Marine Scotland Science.

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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 2013-15.

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 crab and lobster fishery into Scotland were 13,600 tonnes in 2015 with a first-sale value of over £29M.

- **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 fluctuated around 11,000 tonnes. The principal fishing areas for brown crab in Scotland are the Hebrides, Orkney, Sule, East Coast, Papa and South Minch; landings from these areas accounted for around 80% of the total in recent years.

- **Velvet crab:**

Velvet crabs are caught in the inshore creel fishery with lobster and brown crab with few fishermen fishing solely for velvet crab. In recent years, landings have decreased and were around 1,500 tonnes in 2015. 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 15 years to about 1,000 tonnes in 2015. The majority of landings of lobster in Scotland have been from the Hebrides, Orkney, South Minch, with the South East and East Coast areas becoming increasingly important in more recent years.

Assessments and Stock Status

LCA is the method used for assessing Scottish crab and lobster stocks. It uses commercial catch size composition data and estimates of growth parameters and natural mortality to estimate fishing mortality at length. Assessments are conducted on a regional basis and males and females are assessed separately.

For the period between 2013 and 2015, LCAs were conducted for each species with sufficient data, by assessment area. A summary of stock status in terms of fishing mortality in relation to F_{MSY} (F_{MAX} was used as a proxy for F_{MSY}) 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 Clyde, East Coast, North Coast, Orkney, South East, South Minch and Sule areas. In the Hebrides, fishing mortality for males was at F_{MSY} while females were fished above F_{MSY}. In Papa, recent fishing mortality was around F_{MSY} or lower. In Shetland, fishing mortality for males was estimated to be above F_{MSY} while assessment results for Shetland females were inconclusive. No assessments were performed for the Mallaig and Ullapool areas.

- **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, recent fishing mortality for males was below F_{MSY} while females were fished above F_{MSY}. In the South East, males were fished at F_{MSY} while females were fished above F_{MSY}. Shetland assessments were inconclusive and 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, East Coast, South East, Shetland and South Minch areas. In the 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.

- 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 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.

Management Considerations

- The results of assessments for the period 2013-15 indicated that in the majority of the assessment areas, brown crab, velvet crab and lobster were fished close to or above F_{MSY}. In many of the assessment areas, a higher yield and biomass per recruit in the long term could potentially be obtained by reducing the level of fishing mortality (effort).

Data and Recommendations

- With the exception of Shetland, limited effort data (pots fished) has been collected from creel fisheries although recent changes in the FISH1 form may improve data availability for vessels under 10 m. For larger offshore vessels, VMS data integrated with logbook landings could potentially be used to obtain indicators of landings-per-unit-effort and provide information on stock dynamics.

- 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 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 such as bait type, creel density and soak time could be collected by engaging with fishers and industry. Work being conducted within the SIFIDS projects may provide an improved understanding of the drivers of fishing behaviour.

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 quantity landed is small relative to finfish landings, crab and lobster attain high prices. In 2015, the combined crab and lobster species landings of 16,000 tonnes had a value at first-sale of over £29M (Scottish Government, 2016). 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, has resulted in a substantial increase in the Scottish landings over the last thirty years.

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 now take part in an offshore fishery to the north and west of Scotland. These vessels, which are up to 18 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 and Ullapool 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 lorries containing cooled ponds for the transport of live shellfish), within a day of landing. Today it is common for Scottish crabs and lobsters to be transported live to the continent, particularly Spain, where there is a good market. More recently, brown crab have also been exported to emergent Asian markets including China, where "dry transport" of live animals is the preferred method.

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).

The lobster most commonly landed in Scotland is the European lobster (*Homarus gammarus*), 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 7 tonnes over the last 10 years. *Nephrops* stocks are assessed by ICES (International Council for the Exploration of the Sea) working groups and managed under the EU Total Allowable Catch (TAC) system and are 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 10 m and under 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. Fishermen are 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 of length over 10 m, data on fishing activity by trip must be recorded in a EU logbook and submitted to the Fishery Office within 48 hours of landing. Licensed fishing vessels which do not hold a shellfish entitlement are allowed to land a maximum of 5 lobsters and 25 crabs per day. New 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 species), 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 and entitlements are being granted. There are, however, non-active (latent) licence entitlements which mean that there is the potential for the number of vessels 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 EU TAC regulations or national quotas, although there are EU measures to restrict fishing effort. Under EU Regulations, the annual fishing effort of UK vessels over 15 m participating in the brown crab fishery is restricted to 702,292 KW days in ICES Areas 5 and 6 and 543,366 KW days in ICES Area 7 (EC, 2004).

Minimum landing size (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 will introduce a number of 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 lobster (from 155 mm to 145 mm CL, except Orkney and Shetland). Other extant regulations in the crab and lobster fishery are described in detail in previous assessment reports (Mill et al., 2009; Mesquita et al., 2011).

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 2013 and 2015. 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 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 border, while on the west coast, the Clyde assessment area stops short of the Irish 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 (ICES rectangle), the species and the weight landed into ports in Scotland. These data are collated by Marine Scotland Compliance from sales notes and EU logbook and FISH1 forms, and are held in the Marine Scotland Fisheries Information Network (FIN) database and in the Marine Scotland Science (MSS) Fisheries Management Database (FMD). 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.

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. Historical Shetland sampling data were provided by 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 the NAFC Marine Centre under the Memorandum of Understanding (MoU) between NAFC Marine Centre 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, factors which explain 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. The stock assessments reported here use sampling data collected between 2013 and 2015. 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 FIN) by assessment area are shown, respectively, 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. It is thought that survival rates are likely to be high 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 a number of years (2013-15) 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 three years – 2013-15); sampling seasonality; 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). 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

In theory, size-based indicators 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 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 data 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 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. 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 catch 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). However, the parameter values for *M* and *K* as used in the LCA (Table 6) were not recent, originating from Chapman (1994). As 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 $L_{F=M} = 0.75L_c + 0.25L_\infty$ (ICES, 2014b). L_∞ refers to the asymptotic size parameter from the von Bertalanffy growth equation (ICES, 2014b).

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 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. 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 the NAFC Marine Centre 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, 2014a; CEFAS, 2014b).

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 recruitment and exploitation rates have been stable. 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 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 (Fbar) for each stock. Using a fixed length range in the calculation of Fbar enables comparisons of the recent F value (2013-15) with those calculated in previous assessments (2002-05, 2006-08 and 2009-12) and offers the potential to detect trends in F.

2.7. Reference Points

The results of LCA were used to calculate yield-per-recruit (YPR) 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 (in addition to 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 stock 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 were taken from a per-recruit analysis from an LCA of 2006–2008 landings-at-length data. Where 2006-08 sampling data were not available, data from the following round of assessments (2009-12) were used instead. 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 have fluctuated in recent years at around 11,000 tonnes. 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 ‘buyers and sellers’ legislation. The value of landings has increased in line with the tonnage landed. However, the price per kilogram has changed little over this time (Figure 2b and Figure 2c). One kilogram of brown crab was sold for an average of £1.28 at first sale during the period 2013 to 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, Sule, East Coast, Papa and South Minch; landings from these areas accounted for around 80% 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 stabilized in Papa and decreased in Sule in the last three years. Landings from Orkney, East Coast and Hebrides show an increasing trend in recent years. The spatial distribution of brown crab landings by ICES statistical rectangle (including Irish landings) from 2013 to 2015 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 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 2013-15. A decline in the number of sampling trips was noted in Sule from 2014 with no samples collected in 2015. 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 the Clyde (which was not included in the previous round of assessments) for 2013-15 was sufficient to conduct an assessment. Sampling data were considered to be insufficient (low numbers and infrequent sampling) to run assessments in the Mallaig and Ullapool areas (Annex A). Amongst the assessed areas, the South Minch had the lowest sampling levels with less than 1% of fishing trips sampled in the period 2013-15. 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. The mean sizes of brown crabs caught on the west coast are generally larger than in other areas. In recent years (2013-15), the mean size of males was above the respective reference point in the Hebrides and Papa (Table 14). For females, the mean size was above the reference point only in Orkney. In several areas, the mean size in the landings appears to have increased (both sexes), which is driven mainly by an increase in length at first capture following the implementation of a MLS in 1998.

In recent years (2013-15), the mean sizes of the largest 5% of males and females were above the reference point in Papa (Table 14). 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 2015. In contrast, a negative trend was observed in the mean size of the largest individuals since early 2000s for both sexes in the East Coast, South East and Sule.

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 (88%), Papa (87%), Sule (85%) and North Coast (82%). The only inshore area with a clear predominance of females in landings is the South Minch (68%). 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 50% in recent years, whereas the sex ratio in Shetland and East Coast displayed the opposite trend.

3.1.4. Stock Assessment

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 18 (males) and Figure 19 (females). Brown crab biomass and yield-per-recruit plots for each assessment area are shown in Figure 24 (males) and Figure 25 (females).

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

Assessment period		F (Fishing Mortality) 2006-2008	2009-2012	2013-15	
Clyde	Males	✗	?	✗	Above F_{MSY}
	Females	✗	?	✗	Above F_{MSY}
Hebrides	Males	✗	✓	O	At F_{MSY}
	Females	✗	✗	✗	Above F_{MSY}
North Coast	Males	✗	✓	✗	Above F_{MSY}
	Females	✗	✓	✗	Above F_{MSY}
Papa	Males	?	✓	✓	Below F_{MSY}
	Females	?	✓	O	At F_{MSY}
Shetland	Males	?	?	✗	Above F_{MSY}
	Females	?	?	?	Unknown
Sule	Males	✗	O	✗	Above F_{MSY}
	Females	O	✗	✗	Above F_{MSY}

Assessment period		F (Fishing Mortality) 2006-2008	2009-2012	2013-15	
East Coast	Males	✗	✗	✗	Above F_{MSY}
	Females	✗	✗	✗	Above F_{MSY}
Mallaig	Males	?	?	?	Unknown
	Females	?	?	?	Unknown
Orkney	Males	✗	✗	✗	Above F_{MSY}
	Females	✗	✗	✗	Above F_{MSY}
South East	Males	✗	✗	✗	Above F_{MSY}
	Females	✗	✗	✗	Above F_{MSY}
South Minch	Males	✗	✗	✗	Above F_{MSY}
	Females	✗	✗	✗	Above F_{MSY}
Ullapool	Males	?	?	?	Unknown
	Females	?	?	?	Unknown

In the most recent assessments, nine of the ten assessed areas were fished above F_{MSY} to some extent (Table 11). Fishing mortality for both males and females was estimated to be above F_{MSY} in the Clyde, East Coast, North Coast, Orkney, South East, South Minch and Sule areas. In the Hebrides, fishing mortality for males was at F_{MSY} while females were fished above F_{MSY}. In Papa, recent fishing mortality was around F_{MSY} or lower. In Shetland, fishing mortality for males was estimated to be above F_{MSY} while assessment results for Shetland females were deemed inconclusive due to contradictory results obtained when using the two alternate sets of biological parameters (see section below and discussion). No assessments were performed for Mallaig and Ullapool areas as the sampling data collected were considered insufficient to run LCAs.

3.1.5. 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 (Mill et al., 2009; Mesquita et al., 2011; Mesquita et al., 2016). Estimated F has increased in relation to the last assessment in the East Coast, Hebrides, North Coast, Orkney, South Minch and Sule (males and females), South East, Shetland (males) and Papa (females). F has shown a slight decreasing trend in the South East (females) and remained approximately the same in Papa (males) and the Clyde (Figure 18 and Figure 19). The main change in status in relation to F_{MSY} are evident in the North Coast (both sexes) and Sule (males) which were previously at or below F_{MSY} and are now fished above F_{MSY}.

Estimates of F for Shetland (using Shetland parameters) are higher than those estimated elsewhere (Table 11, Figure 18 and Figure 19). 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 and F_{MAX} (the F_{MSY} proxy) compared with other areas, particularly for female brown crab (Figure 19 and Table 11). This is further discussed in section 4.3.

3.1.6. Management Considerations

The results of assessments for the period 2013-15 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 yield and biomass per recruit in the long term could potentially be obtained by reducing the level of fishing mortality (effort).

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 'buyers and sellers' legislation or an expansion of the fishery at this time. In recent years, landings have decreased and were around 1,500 tonnes in 2015. The value per unit weight of velvet crab remains higher than that of brown crab and is currently approximately £2.50 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). These three areas accounted for about 65% of velvet crab landings in Scotland in the period 2013-15 (Table 9). Figure 7 shows the spatial distribution of velvet crab landings 2013-15. Most landings were taken from inshore areas; only very small amounts were reported from offshore grounds in Papa and Sule. There were no significant landings of velvet crab from around Scotland reported from outside the assessment areas.

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, Orkney and Shetland, temporal coverage was good with samples generally being obtained throughout the year in the period 2013-15. The East Coast and South East have smaller velvet crab fisheries and generally lower sampling rates than the main areas. The South Minch is one of the important areas for the velvet crab fishery where the number of samples has been relatively low although this improved in 2013-15 compared to 2009-12, when data were not collected in all years (Mesquita et al., 2016). It has proved difficult to access and measure velvet crabs caught and landed in the Inner Hebrides which explains the low rate of trips sampled in the South Minch. Assessments were conducted for the Clyde, Hebrides, Orkney and Shetland and also for South Minch, East Coast and South East (the latter was not assessed in 2009-12). Sampling data were considered to be insufficient (low numbers and infrequent sampling) to run assessments in the Mallaig North Coast, Papa, Sule and Ullapool areas (Annex A).

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 2013-15, the mean sizes of the largest 5% of both males and females were on average below the reference points in all assessment areas (Table 15). However, there is a weak positive trend in the mean size of the largest 5% since 2000 in the Hebrides and in Orkney and since 2010 in the Clyde. A decrease in the mean size and the size of the largest 5% of individuals was noted in the East Coast since 2008. The size at first capture was generally above maturation size (Figure 11, Figure 12).

The sex ratio for velvet crab showed little evidence of a trend with males dominating in the landings, representing 65% to 72% (by number) in the well sampled areas (Figure 16).

3.2.4. Stock Assessment

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 20 (males) and Figure 21 (females). Velvet crab biomass and yield-per-recruit plots for each assessment area are shown in Figure 26 (males) and Figure 27 (females).

Velvet crab in the Clyde, East Coast, Orkney and South Minch, were fished at levels above F_{MSY} (both males and females) in the most recent assessments. In the Hebrides, recent fishing mortality for males was estimated to be below F_{MSY} while females were fished above F_{MSY}. In the South East, males were fished at F_{MSY} while females were fished above F_{MSY} (Table 12). 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 and 2013-15.

Assessment period		F (Fishing Mortality)			
		2006-2008	2009-2012	2013-15	
Clyde	Males	✗	✗	✗	Above F_{MSY}
	Females	✗	✗	✗	Above F_{MSY}
Hebrides	Males	✓	✓	✓	Below F_{MSY}
	Females	✗	✗	✗	Above F_{MSY}
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	2013-15	
East Coast	Males	O	✗	✗	Above F_{MSY}
	Females	O	✗	✗	Above F_{MSY}
Mallaig	Males	?	?	?	Unknown
	Females	?	?	?	Unknown
Orkney	Males	✗	✗	✗	Above F_{MSY}
	Females	✗	✗	✗	Above F_{MSY}
South East	Males	O	?	O	At F_{MSY}
	Females	✗	?	✗	Above F_{MSY}
South Minch	Males	✗	✗	✗	Above F_{MSY}
	Females	✗	✓	✗	Above F_{MSY}
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 (Mill et al., 2009; Mesquita et al., 2011; Mesquita et al., 2016). In the South Minch, female fishing mortality increased above 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 20 and Figure 21). Velvet crab F estimates for Shetland (using Shetland parameters) are much higher than those estimated elsewhere (Table 12, Figure 20 and Figure 21). 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}=3.0; F_{female}=3.4) and F_{MAX} (the F_{MSY} proxy) for both sexes compared with other areas (Figure 20, Figure 21 and Table 12). This is further discussed in section 4.3.

3.2.6. Management Considerations

The results of assessments for the period 2013-15 showed that velvet crab in the majority of the areas with sufficient sampling data to conduct assessments were fished close to or above F_{MSY}. In some assessment areas (Clyde, East Coast, Orkney and South Minch), a higher yield and biomass per recruit in the long term could potentially be obtained by reducing the level of fishing mortality (effort).

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 15 years, from 415 tonnes in 2001 to about 1,000 tonnes in 2015 (Figure 2a). The average price per kilogram of lobster has been stable at over £10 per kilogram over the last 15 years (Figure 2c), and is nine times higher than that of brown crab. Between 2013 and 2015 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, with the South East and East Coast areas becoming increasingly important in more recent years. 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. 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 '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 2011 and accounted for almost 60% of landings into Scotland over the last three years (Table 10). Figure 8 shows the spatial distribution of lobster landings around Scotland in the period 2013-15. ICES rectangle 41E7 in the South East consistently has the largest amount of landings. Small quantities of lobster were landed from grounds outside the assessment areas, including ICES rectangles to the west of the 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 3% in most assessment areas, where daily inshore trips are common. The best sampled areas were the East Coast, South East, Hebrides, Orkney and Shetland. Despite an increase in sampling in the South Minch and Papa in recent years, which allowed assessments to be run in 2009-12, the number of sampling trips carried out in these areas remains lower than elsewhere. 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).

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 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 5 years for both sexes. For males only, there is a slight decreasing trend in the East Coast over the past five years and in the Hebrides over the last ten years. In recent years, the mean size and the mean size of the largest 5% of males were generally below the reference points (Table 16). Only in individual years for females in Papa (2013) and Hebrides (2013, 2015) were both the recent mean size and the mean size of the largest 5% above the reference points. In the

East Coast and South East, the size at first capture was above the size at first maturity for both sexes. In the other assessment areas, maturation size is assumed to be larger and size at first capture was below size at maturity.
The sex ratio in landings for lobsters was close to 50% in all areas and showed no trends (Figure 17).

3.3.4. Stock Assessment

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 22 (males) and Figure 23 (females). Lobster biomass and yield-per-recruit plots for each assessment area are shown in Figure 28 (males) and Figure 29 (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, East Coast, South East, Shetland and South Minch. In the Hebrides, Orkney and Papa, fishing mortality for females was at or below F_{MSY} while males were fished above F_{MSY} (Table 13). 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 and 2013-15.

		F (Fishing Mortality)			
Assessment period		2006-2008	2009-2012	2013-15	
Clyde	Males	✗	✗	✗	Above F_{MSY}
	Females	✗	✗	✗	Above F_{MSY}
Hebrides	Males	✗	✗	✗	Above F_{MSY}
	Females	✓	✓	✓	Below F_{MSY}
North Coast	Males	?	?	?	Unknown
	Females	?	?	?	Unknown
Papa	Males	?	✗	✗	Above F_{MSY}
	Females	?	✓	✓	Below F_{MSY}
Shetland	Males	?	✓	✗	Above F_{MSY}
	Females	?	✗	✗	Above F_{MSY}
Sule	Males	?	?	?	Unknown
	Females	?	?	?	Unknown

		F (Fishing Mortality)			
Assessment period		2006-2008	2009-2012	2013-15	
East Coast	Males	✗	✗	✗	Above F_{MSY}
	Females	✗	✗	✗	Above F_{MSY}
Mallaig	Males	?	?	?	Unknown
	Females	?	?	?	Unknown
Orkney	Males	✗	✗	✗	Above F_{MSY}
	Females	✓	o	o	At F_{MSY}
South East	Males	✓	✗	✗	Above F_{MSY}
	Females	✗	✗	✗	Above F_{MSY}
South Minch	Males	?	✗	✗	Above F_{MSY}
	Females	?	✗	✗	Above F_{MSY}
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 (Mill et al., 2009; Mesquita et al., 2011; Mesquita et al., 2016). Shetland's lobster results are only presented from 2009 onwards. The MoU between MSS and NAFC 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 Shetland, estimated F for males increased and was above F_{MSY} in the latest assessment. An increase in F was also found for males in the East Coast and for females in Shetland and the Clyde. The South East estimated F decreased in 2013-15 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. Estimates of F in Papa remained approximately the same in relation to previous assessments. The estimated F for lobster has been found to be relatively stable over the time series in the Hebrides area (Table 13, Figure 22 and Figure 23).

3.3.6. Management Considerations

The results of assessments for the period 2013-15 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 yield and biomass per recruit in the long term could potentially be obtained by reducing the level of fishing mortality (effort).

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. Landings from Orkney, East Coast and Hebrides increased, whereas those from the offshore areas of Papa and Sule appear to have stabilized or decreased in the last three years. The latter may be related to market prices, which have not increased substantially in recent years, and reduced effort rather than any change in the abundance of the stock offshore. Total landings of velvet crab show a decreasing trend in recent years. 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 ‘buyers and sellers’ legislation. Some major increases in landings evident in the mid 2000s are more likely to be explained by improved reporting than by changes in the abundance of stocks. 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 has not been accompanied by an increase in crab prices, particularly for brown crab for which the price per kilo is lower than it was 10 years ago. 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. ACRUNET comprised several work packages with the collective aim of securing the economic and social viability and sustainability of the European brown crab industry. 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. In recent years, both the UK and Ireland fishermen have emphasized the issue of latent effort, pointing out that this was one of the biggest obstacles to shellfish 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

Brown crab sampling levels were relatively high in most areas where landings are important. 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 and, in general, this is supported by the LCA results. 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, both mean size and mean size of the largest 5% were above the reference points for females in Papa and for males in Hebrides and Papa. This suggests that despite high exploitation in Papa both sexes appear to have extended size structure. The mean size of the largest individuals in Shetland increased throughout the time series, in particular for females. In contrast, the mean size of the largest individuals decreased in the East Coast, South East and Sule 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, especially for Sule. 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.

Assessments based on the 2013-15 data (using LCA) were carried out for brown crab in ten of the twelve assessment areas. Fishing mortality for stocks in most of the areas remains above F_{MSY}. For those stocks, a long term reduction in effort would probably increase yield and biomass-per-recruit. The results from the LCA were in general agreement with the indicator evaluation in relation to reference points. In the Papa (males and females) and Hebrides (males) areas both approaches suggested that these stocks were being fished below the reference points. The mean sizes of brown crabs in the South East and East Coast assessment areas were smaller than in other areas, as found in previous assessments (e.g., Kinnear, 1988; Mill et al., 2009). 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. Assessment results using 2013-15 data for the North Coast, Hebrides, Sule, Orkney and East Coast all show a clear increase in fishing mortality estimates compared to those reported previously (Mesquita et al., 2016), with most crab stocks fished well above F_{MSY}.

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 2013-15, all stocks of velvet crabs appeared to have truncated size distributions and are exploited above the F_{MSY} proxy. Only 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 year. 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 the Hebrides would indicate that the fishing mortality may have declined over the time series in this area. Decreasing 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 2013-15 data (using LCA) were carried out for velvet crab in six of the twelve assessment areas. Fishing mortality for stocks in most of these areas remains above F_{MSY}. For those stocks, a long term reduction in effort would probably increase yield and biomass-per-recruit. For both Orkney and male Hebrides stocks, fishing mortality showed a decreasing trend from the 2002-05 assessment estimate (Mill et al., 2009), although in 2013-15 Orkney remained above F_{MSY} while Hebrides male velvet crabs were fished below F_{MSY} and females above F_{MSY}. Fishing mortality in the South Minch female stock has increased compared to previous assessments and is now above $F_{MSY.}$ Results based on indicators for velvet crabs were less optimistic than the LCA analysis. However, the mean size of the largest males in Hebrides increased in recent years, such that, if this continued, the reference point may be reached in the coming years.

4.2.3. Lobster

Lobster market sampling data from 2013-15 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 and East Coast, 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 2013-15, with exception of mean size in Hebrides. In some individual years, the mean size of the largest females in Papa (2013) and the Hebrides (2013, 2015) were above the size reference point. According to the indicators, female lobster in Orkney were still slightly below their size reference point. In the South East and Orkney, the mean sizes, mean sizes of the largest individuals and length frequency data appear relatively stable suggesting a stable stock and fishery. The size at 50% maturity can vary substantially between assessment areas. Currently, the evaluation of exploitation level on immature individuals should be viewed as preliminary as length at maturity is not known for all areas.

The evaluation of mean size and mean size of largest 5% in the landings relative to the reference points was generally in agreement with the LCA. It is assumed 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. Length at first catch was above length at first maturity only in the East Coast and South East.

Assessments based on the 2013-15 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. For those stocks, a long term reduction in effort would probably increase yield and biomass-per-recruit. The results from the LCA were in general agreement with the indicator evaluation. Females in Papa, Hebrides and Orkney were fished below or at 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 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.

4.3. Quality of the Assessment and Data

4.3.1. 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-poor 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 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. Landings from most of the Scottish assessment areas tend to fluctuate, which may reflect year to year variation in recruitment and/or fishing effort. An average of the length frequency data (2013-15) was used in order to limit the effects of these variations. However, any systematic changes in exploitation rate or recruitment over this three year period could still 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 and lobster), the Clyde (brown crab) and Papa (lobster), 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.

4.3.2. 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 (and vice-versa).

In these assessments, the same biological parameters have been applied across all areas except Shetland (Chapman, 1994; Mill et al., 2009; Mesquita et al., 2011; Mesquita et al., 2016). 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 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. Velvets in the Clyde, East Coast, Orkney and South Minch 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 reflects the shape of the YPR curves generated in the LCAs using Shetland parameters, which are more flat topped resulting in a higher F_{MAX} to be taken as a 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 the crab and lobster stocks, especially for velvet crab. To progress this discussion it would be worthwhile holding a joint NAFC Shetland/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.

4.3.3. Size-based Indicators

ICES has previously suggested a multiple-indicator-based approach (including LPUE, size-based indicators and recruitment indices) as a potential way forward in the provision of advice on stock status for crab stocks (ICES, 2009). An approach using commercial length frequency data and biological parameters in the evaluation of stock status for data limited stocks has recently been implemented by ICES and is followed here (e.g. ICES, 2015a; Miethe et al., 2016). 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 can help to develop robust size-based indicators for assessment purposes.

Assumptions for biological parameters (M/K, L_∞, 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, relating to an expectation of more large individuals in the size distribution of an unexploited stock (Hordyk et al., 2015; Jardim et al., 2015).

4.3.4. 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 size and in the mean size of largest 5% of individuals were explored (ICES, 2014b; ICES, 2015a).

The conclusions in this report are all 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 result in MSY. 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), it provides 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. In addition to a yield-per-recruit curve, calculating F_{MSY} requires good estimates of recruitment and spawning stock biomass, which are not available for Scottish crab and lobster stocks. 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., 2016). 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.

4.4. 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.

4.4.1. Fishing Effort

Prior to 2016, no useful measures of creel fishing effort are 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 will provide new effort data for vessels under 10 m fishing around Scotland and should allow for calculation of LPUE indices in the future.

VMS (vessel monitoring system) 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). A number of work packages within the Scottish Inshore Fisheries Integrated Data System project (SIFIDS) (recently funded by the European Maritime Fisheries Fund, EMFF), are concerned with improving data collection from inshore creel vessels through the use of new technology. It is envisaged that one of the project outcomes will be a system that can be used on small vessels to collect and transmit spatial fishery data including effort. Data collection would, however, need to be coordinated and maintained, to build up useful time series.

4.4.2. Discard Data

Discards in crab and lobster fisheries are not sampled on a regular basis. More regular sampling to obtain information on catches of undersized animals could provide an indication of inter-annual variation in recruitment. 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. 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.

The results of a series of pilot projects to support sustainable Scottish inshore fisheries, funded by the European Fisheries Fund suggest that many of these data deficiencies could be addressed through self-sampling and EM technology (Course et al., 2015). Further advances in data collection technology are expected as part of the SIFIDS project (see Section 4.4.1).

4.4.3. 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 crab 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. Work being undertaken in both Shetland and Orkney, 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 will be reviewed by ICES WGCRAB in the future.

4.4.4. Growth Studies

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.

4.4.5. 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 (Anon, 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. Many fishers acknowledged that low brown crab market prices in the late 2000s resulted in the species being targeted to a lesser extent than usual, which could explain the reduction in landings in some areas. 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. Through liaison with fishers and the use of spatial data on fishing location, work being conducted within the SIFIDS project 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 2015. Landings information from the Fisheries Management Database.

	Landings (tonnes)						
	2009	2010	2011	2012	2013	2014	2015
Brown crab	9465	10546	11832	10892	10891	12306	11089
Velvet crab	2728	2474	2147	2032	1576	1641	1494
Deep-water crab	11	6	8	0	2	16	2
Northern stone crab	6	3	1	2	0	0	1
Green crab	226	214	237	301	272	225	194
European lobster	1092	1100	1219	1132	1026	1208	1042
Spiny lobster	4	6	5	13	9	5	4
Squat lobsters	2	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[1]	150 (CW)	Hebrides	2016
	140 (CW)	All areas except Hebrides and East coast South of 56°	1998
	130 (CW)	East coast South of 56° excluding Firth of Forth	1998
Lobster[2]	87 (CL)	All areas except Shetland and Hebrides	1999
	90 (CL)	Shetland and Hebrides	2001/2016
Velvet Crab[3]	65 (CW)	All areas except Shetland and Hebrides	1989
	70 (CW)	Shetland and Hebrides	2001/2016

[1] An increase in MLS to 150 mm is planned for most areas in 2017.

[2] A phased increase to 90 mm in MLS is planned for some areas in 2017.

[3] An increase in MLS to 70 mm is planned for all areas where MLS is currently 65 mm in 2017.

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, 2013-15.

	Year	Clyde	East Coast	Hebrides	Mallaig	North Coast	Orkney	Papa Bank	Shetland	South East	South Minch	Sule	Ullapool
Animals measured	2013	343	4913	6052	0	1423	29648	4533	2096	5025	676	9365	194
	2014	267	6292	8838	0	1030	24016	4705	2405	5238	379	1316	0
	2015	418	6079	5892	0	1422	53372	3651	1185	4474	428	0	0
Trips sampled	2013	7	25	30	0	3	137	4	17	45	9	9	2
	2014	5	36	22	0	1	186	3	13	41	4	2	0
	2015	6	32	24	0	2	385	2	8	43	4	0	0
Percentage of trips sampled (%)	2013	3.3	0.9	2.1	0	1.0	5.8	4.0	2	2.4	0.7	5.2	0.3
	2014	2.1	1.1	2.1	0	0.4	7.5	2.0	1.4	2.0	0.2	1.0	0
	2015	2.6	0.9	2.4	0	0.6	15.0	2.0	1.1	2.1	0.3	0	0

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, 2013-15.

	Year	Clyde	East Coast	Hebrides	Mallaig	North Coast	Orkney	Papa Bank	Shetland	South East	South Minch	Sule	Ullapool
Animals measured	2013	2914	1514	2848	0	0	4100	0	4427	509	1798	0	228
	2014	3502	1177	2313	73	0	9852	0	4272	2113	649	0	0
	2015	1870	745	2403	0	0	22116	0	3233	1657	1160	0	0
Trips sampled	2013	15	10	17	0	0	17	0	9	5	11	0	2
	2014	18	8	16	1	0	46	0	10	13	4	0	0
	2015	10	4	14	0	0	94	0	9	15	6	0	0
Percentage of trips sampled (%)	2013	10.1	0.5	1.5	0	0	0.8	0	1.0	0.3	1.0	0	0.7
	2014	9.0	0.4	1.5	2.3	0	2.1	0	1.3	0.8	0.3	0	0
	2015	6.2	0.2	1.7	0	0	4.3	0	1.3	0.9	0.4	0	0

Table 5 – MSS market sampling statistics, number of animals measured, number of trips sampled and percentage of trips sampled for lobster by assessment area, 2013-15.

	Year	Clyde	East Coast	Hebrides	Mallaig	North Coast	Orkney	Papa Bank	Shetland	South East	South Minch	Sule	Ullapool
Animals measured	2013	633	879	1018	0	51	634	209	2123	1629	116	0	85
	2014	244	1608	2477	0	22	1860	265	1967	3475	103	0	0
	2015	231	574	1832	0	362	6185	77	2338	3046	300	0	0
Trips sampled	2013	13	17	25	0	1	17	2	14	26	6	0	1
	2014	8	20	24	0	1	56	3	18	66	3	0	0
	2015	8	11	23	0	2	173	2	10	43	6	0	0
Percentage of trips sampled (%)	2013	4.0	0.5	1.9	0	0.4	0.7	2.7	2.2	0.8	0.5	0	0.3
	2014	1.9	0.5	2.0	0	0.4	2.2	2.4	3.0	1.9	0.2	0	0
	2015	1.9	0.3	2.2	0	0.7	6.7	2.7	1.8	1.2	0.4	0	0

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, 2002
	Males	125	(Shetland data)
	Females	133.5	
Velvet crab			Tallack, 2002
	Males	45	(Shetland data)
	Females	56	
Lobster			Lizárraga-Cubedo et al., 2003
East Coast & South East	Males	80	(data from Firth of Forth)
	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 2013–2015, by assessment area. Data are from the Fisheries Management Database.

Species	Year	Clyde	East Coast	Hebrides	Mallaig	North Coast	Orkney	Papa Bank	Shetland	South East	South Minch	Sule	Ullapool
Brown crab (%)	2013	1.5	11.7	19.6	0.1	5.3	17.6	8.6	5.6	4.3	8.0	13.7	4.0
	2014	1.5	10.6	21.7	0.1	4.4	16.0	10.1	5.4	3.2	9.7	13.9	3.4
	2015	1.6	10.9	20.1	0.1	9.2	18.5	8.4	4.1	4.1	6.3	14.8	1.9

Table 9 – Percentage of total landings into Scotland of velvet crab 2013–2015, by assessment area. Data are from the Fisheries Management Database.

Species	Year	Clyde	East Coast	Hebrides	Mallaig	North Coast	Orkney	Papa Bank	Shetland	South East	South Minch	Sule	Ullapool
Velvet crab (%)	2013	4.3	10.8	16.5	0.4	0.5	31.9	0.1	11.7	7.4	14.7	0	1.7
	2014	6.1	10.1	17.1	0.9	0.4	31.5	0	9.9	6.0	16.2	0	1.8
	2015	5.8	10.0	17.8	1.4	0.5	30.8	0	9.2	5.4	18.1	0	1.0

Table 10 – Percentage of total landings into Scotland of lobster 2013–2015, by assessment area. Data are from the Fisheries Management Database.

Species	Year	Clyde	East Coast	Hebrides	Mallaig	North Coast	Orkney	Papa Bank	Shetland	South East	South Minch	Sule	Ullapool
Lobster (%)	2013	2.4	21.8	9.9	0.1	1.0	11.9	0.6	3.6	39.4	7.6	0.1	1.6
	2014	3.9	19.3	12.7	0.1	0.9	14.0	0.7	3.4	34.9	8.6	0.1	1.4
	2015	3.6	23.0	11.6	0.1	1.3	11.5	0.3	4.1	35.2	7.9	0.1	1.3

Table 11 – Brown crab fishing mortality (F_{bar}) from Length Cohort Analysis (2013-15) 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	0.50	0.43	0.39	0.20	LCA 2006-08
East Coast	0.70	0.46	0.37	0.30	LCA 2006-08
Hebrides	0.42	0.51	0.41	0.35	LCA 2006-08
Mallaig	-	-	-	-	-
North Coast	0.61	0.52	0.39	0.43	LCA 2006-08
Orkney	0.77	0.45	0.33	0.36	LCA 2006-08
Papa Bank	0.30	0.38	0.36	0.39	LCA 2009-12
Shetland	0.68	0.41	0.38	0.31	LCA 2013-15
Shetland par*	0.99	0.56	0.84	1.72	LCA 2013-15
South East	0.82	0.53	0.39	0.28	LCA 2006-08
South Minch	0.75	0.5	0.34	0.25	LCA 2006-08
Sule	0.64	0.52	0.36	0.36	LCA 2006-08
Ullapool	-	-	-	-	-

*Fs calculated using Shetland biological parameters

Table 12 – Velvet crab fishing mortality (F_{bar}) from Length Cohort Analysis (2013-15) 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	0.38	0.55	0.15	0.39	LCA 2006-08
East Coast	0.35	0.54	0.15	0.21	LCA 2006-08
Hebrides	0.17	0.34	0.20	0.23	LCA 2006-08
Mallaig	-	-	-	-	-
North Coast	-	-	-	-	-
Orkney	0.21	0.38	0.08	0.17	LCA 2006-08
Papa Bank	-	-	-	-	-
Shetland	0.60	1.03	0.48	0.58	LCA 2013-15
Shetland par*	3.04	3.43	3.89	4.70	LCA 2013-15
South East	0.22	0.47	0.22	0.26	LCA 2006-08
South Minch	0.31	0.53	0.26	0.43	LCA 2006-08
Sule	-	-	-	-	-
Ullapool	-	-	-	-	-

*Fs calculated using Shetland biological parameters

Table 13 – Lobster fishing mortality (F_{bar}) from Length Cohort Analysis (2013-15) 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	0.85	0.64	0.26	0.28	LCA 2006-08
East Coast	0.40	0.43	0.26	0.32	LCA 2006-08
Hebrides	0.33	0.27	0.18	0.34	LCA 2006-08
Mallaig	-	-	-	-	-
North Coast	-	-	-	-	-
Orkney	0.43	0.32	0.23	0.32	LCA 2006-08
Papa Bank	0.36	0.19	0.21	0.31	LCA 2009-12
Shetland	0.36	0.46	0.24	0.16	LCA 2009-12
South East	0.51	0.48	0.35	0.36	LCA 2006-08
South Minch	0.50	0.59	0.36	0.41	LCA 2009-12
Sule	-	-	-	-	-
Ullapool	-	-	-	-	-

Table 14 – 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 2013-15). 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	1.00	1.00	1.00	0.96
East Coast	0.97	1.00	0.96	0.99
Hebrides	1.01	0.99	1.00	0.97
Mallaig	-	-	-	-
North Coast	0.99	0.99	0.97	0.97
Orkney	0.98	1.01	0.94	0.99
Papa Bank	1.02	1.00	1.06	1.01
Shetland	0.94	1.00	0.86	0.97
South East	0.97	0.99	0.94	0.97
South Minch	0.97	0.99	0.95	0.98
Sule*	-	-	-	-
Ullapool	-	-	-	-

*Average 2013-15 not calculated as 2015 data were missing.

Table 15 – Velvet crab. Size-based indicators as a ratio between mean length, $\overline{L}$, and mean length of the largest 5%, $L_{max5\%}$ and the respective reference points (average for 2013-15).

Assessment area	$\overline{L}/L_{F=M}$		$L_{max5\%}/0.9L_{\infty}$	
	Males	Females	Males	Females
Clyde	0.96	0.94	0.89	0.88
East Coast	0.96	0.95	0.90	0.85
Hebrides	0.99	0.97	0.95	0.92
Mallaig	-	-	-	-
North Coast	-	-	-	-
Orkney	0.98	0.97	0.93	0.92
Papa Bank	-	-	-	-
Shetland	0.95	0.95	0.89	0.91
South East	0.97	0.96	0.93	0.90
South Minch	0.96	0.94	0.90	0.89
Sule	-	-	-	-
Ullapool	-	-	-	-

Table 16 – Lobster. Size-based indicators as a ratio between mean length, $\overline{L}$, and mean length of the largest 5%, $L_{max5\%}$ and the respective reference points (average for 2013-15). Values larger than 1 (green) and equal to 1 (yellow) indicate exploitation consistent with F_{MSY}.

Assessment area	$\overline{L}/L_{F=M}$		$L_{max5\%}/0.9L_{\infty}$	
	Males	Females	Males	Females
Clyde	0.89	0.92	0.76	0.84
East Coast	0.90	0.92	0.85	0.88
Hebrides	0.99	1.00	0.91	0.99
Mallaig	-	-	-	-
North Coast	-	-	-	-
Orkney	0.93	0.96	0.87	0.94
Papa Bank	-	-	-	-
Shetland	0.95	0.92	0.86	0.86
South East	0.89	0.91	0.81	0.84
South Minch	0.92	-	0.81	-
Sule	-	-	-	-
Ullapool	-	-	-	-

7. Figures

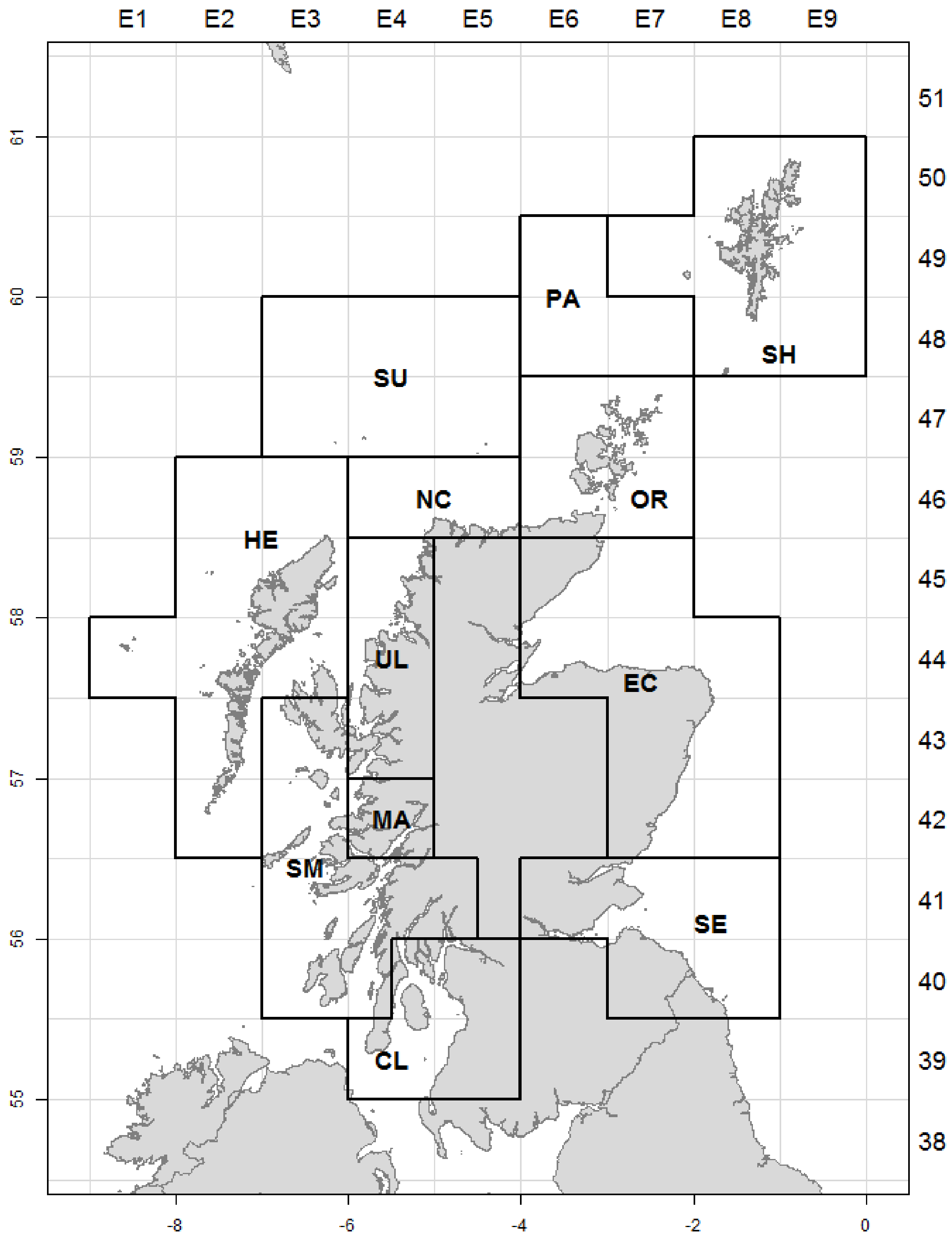

Figure 1. Crab and lobster fishery assessment areas in Scotland. See Annex D for abbreviations.

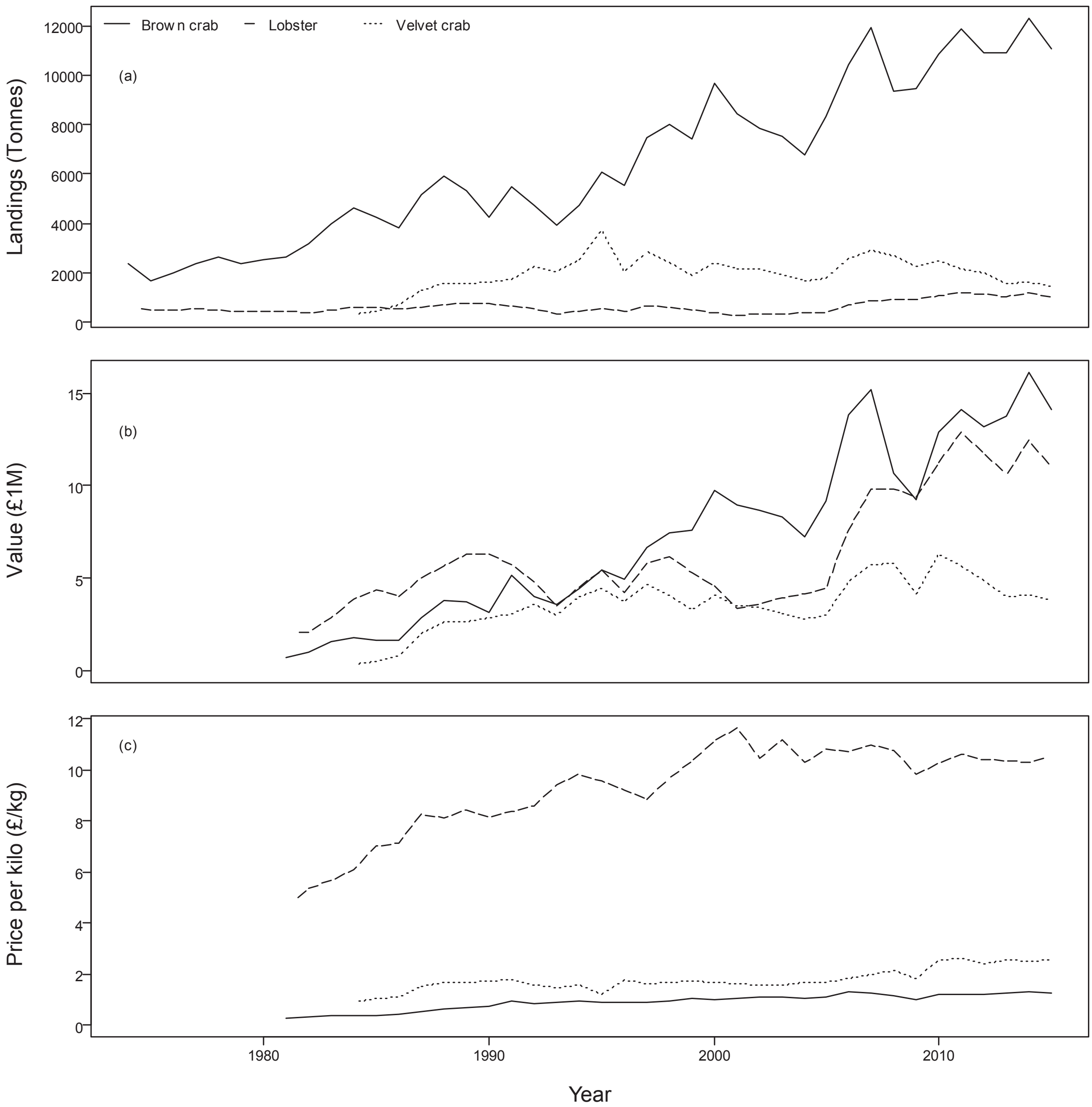

Figure 2. Scottish crab and lobster fishery statistics. a) Landings (tonnes) into Scotland, b) landings value (£IM), and, c) price per kilo (£/kg) for brown crab, velvet crab and lobster, 1974 -2015. Data sourced from Fisheries Management Database.

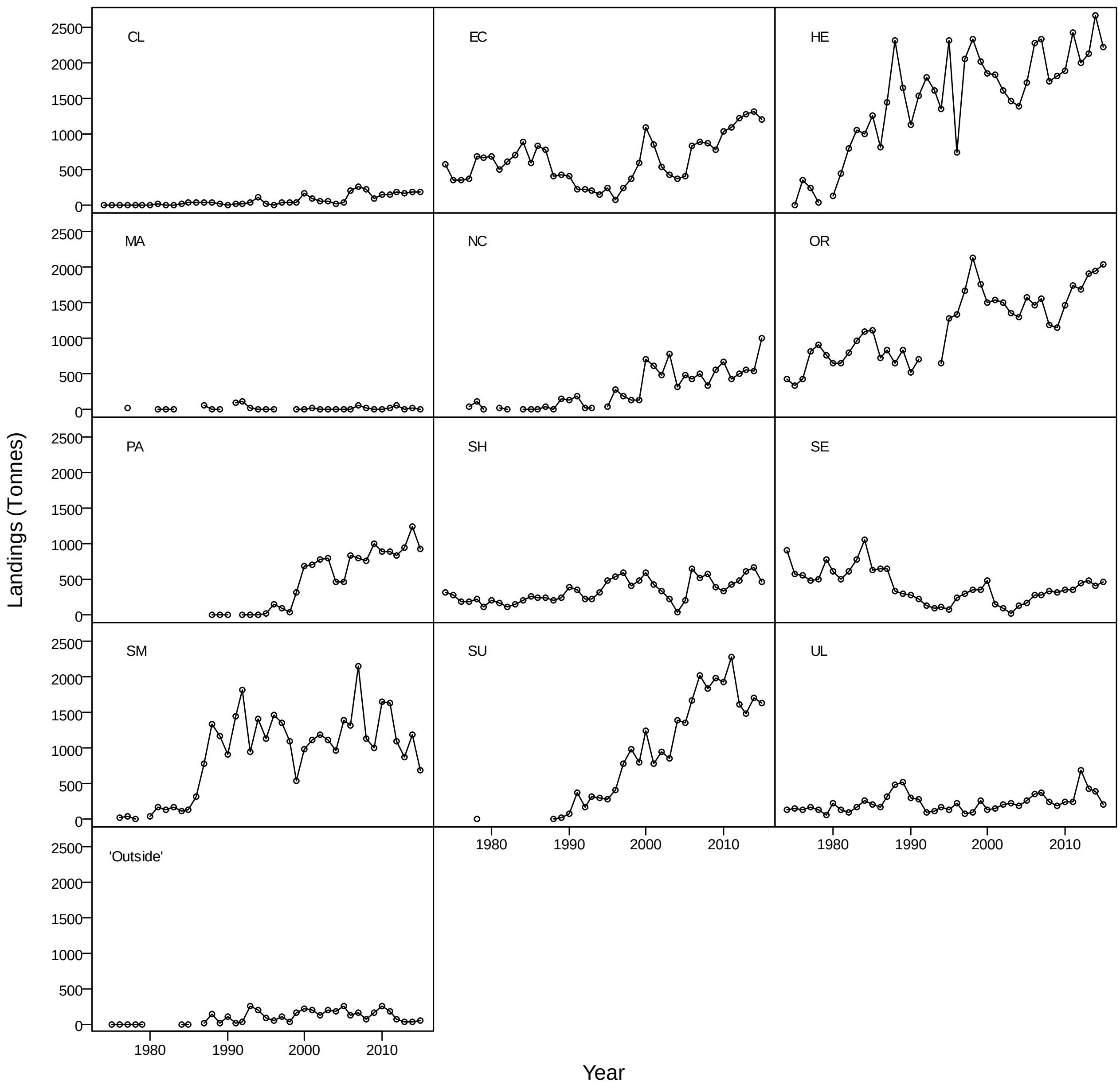

Figure 3. Brown crab landings (tonnes) into Scotland by assessment area, 1974-2015. Data from the Fisheries Management Database; ‘Outside’ relates to brown crab landed outside MSS crab and lobster assessment areas; see Figure 1 for area locations and Annex D for abbreviations.

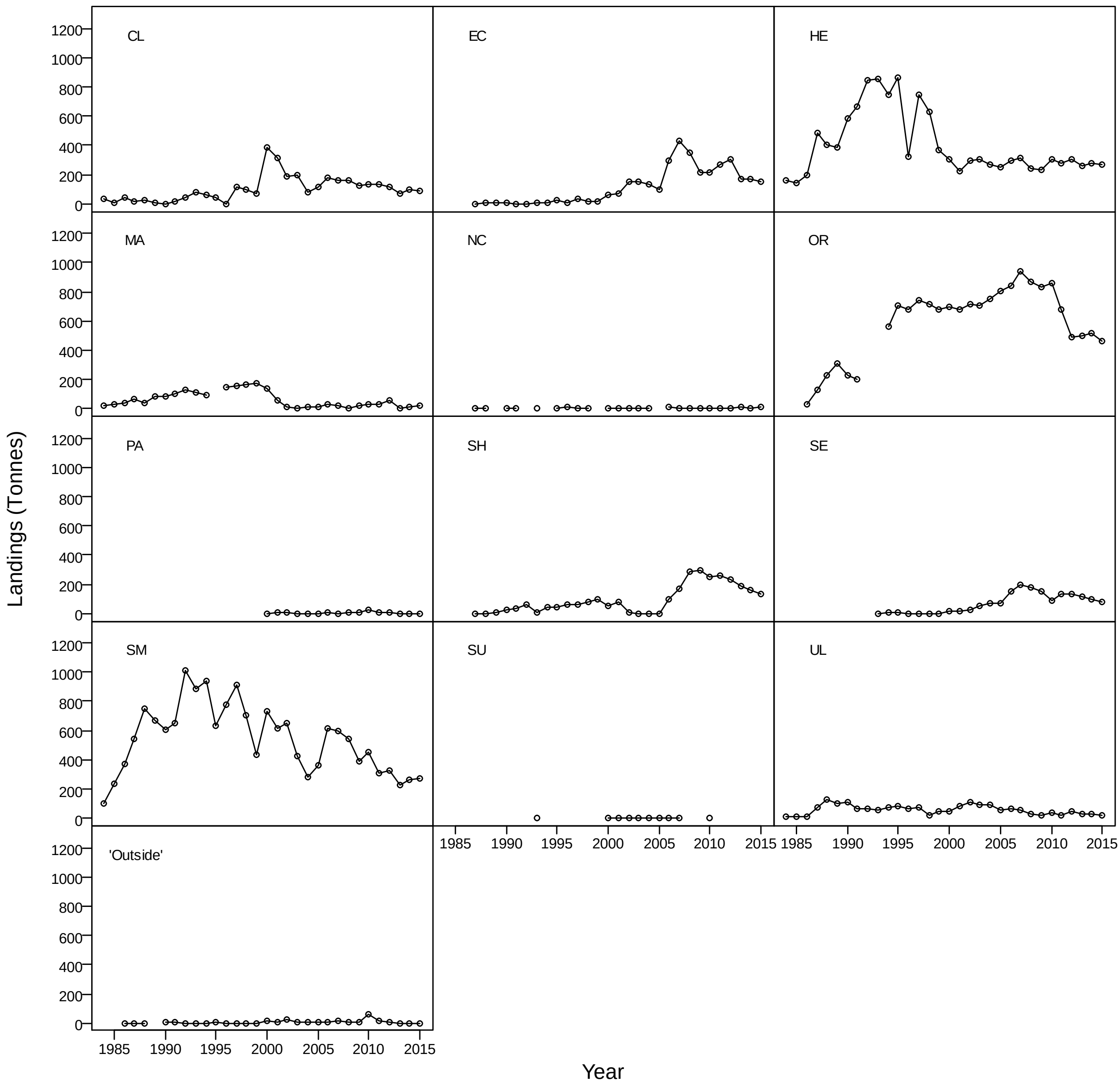

Figure 4. Velvet crab landings (tonnes) into Scotland by assessment area, 1984-2015. Data from the Fisheries Management Database; ‘Outside’ relates to velvet crab landed outside MSS crab and lobster assessment areas; see Figure 1 for area locations and Annex D for abbreviations.

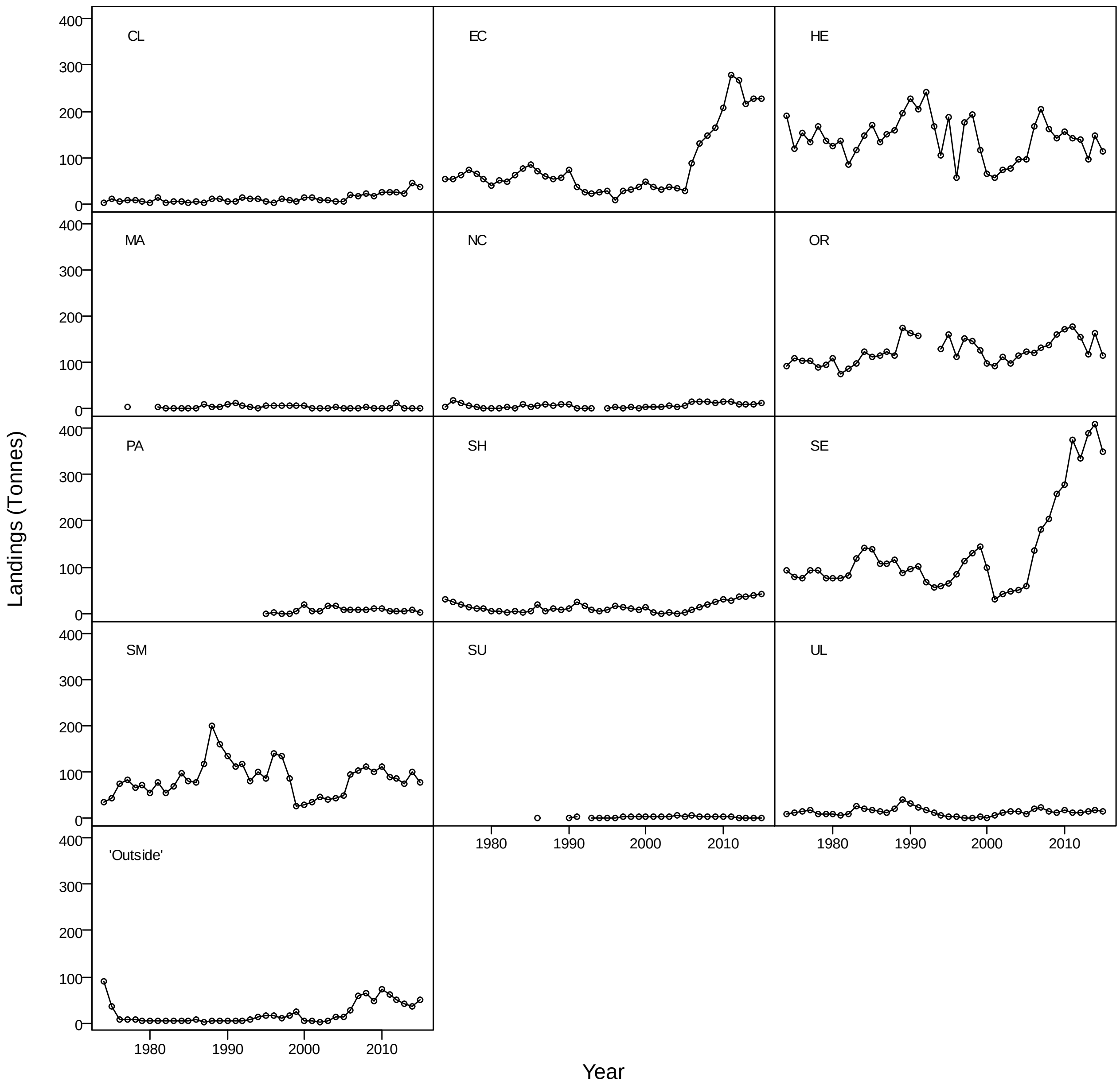

Figure 5. Lobster landings (tonnes) into Scotland by assessment area, 1974-2015. Data from the Fisheries Management Database. 'Outside' relates to lobster landed outside MSS crab and lobster assessment areas; see Figure 1 for area locations and Annex D for abbreviations.

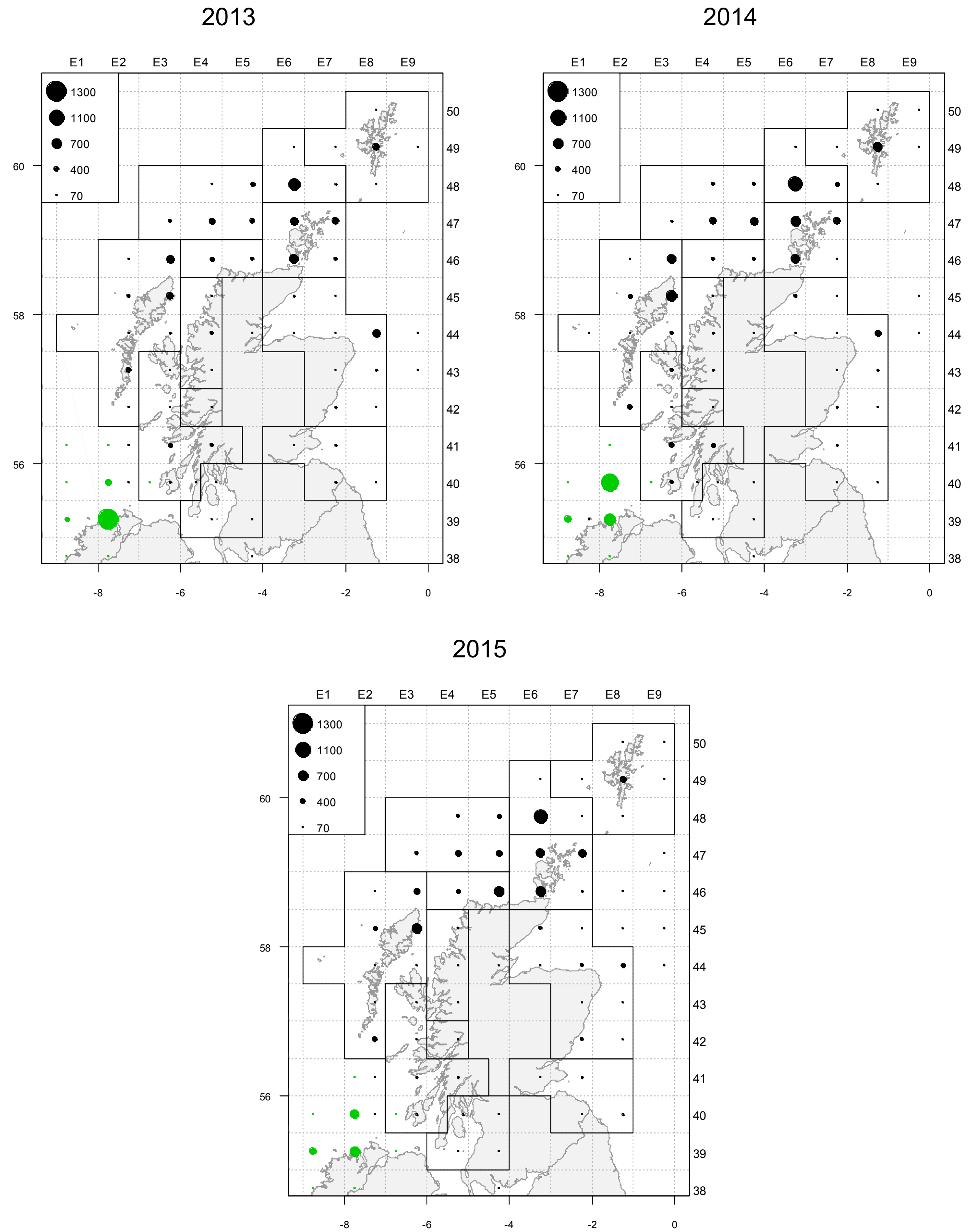

Figure 6. Brown crab landings (tonnes) by statistical rectangle between 2013 and 2015. Black circles represent landings into Scotland. Data are from Fisheries Management Database. Green circles represent landings into Republic of Ireland – data provided by the Irish Marine Institute.

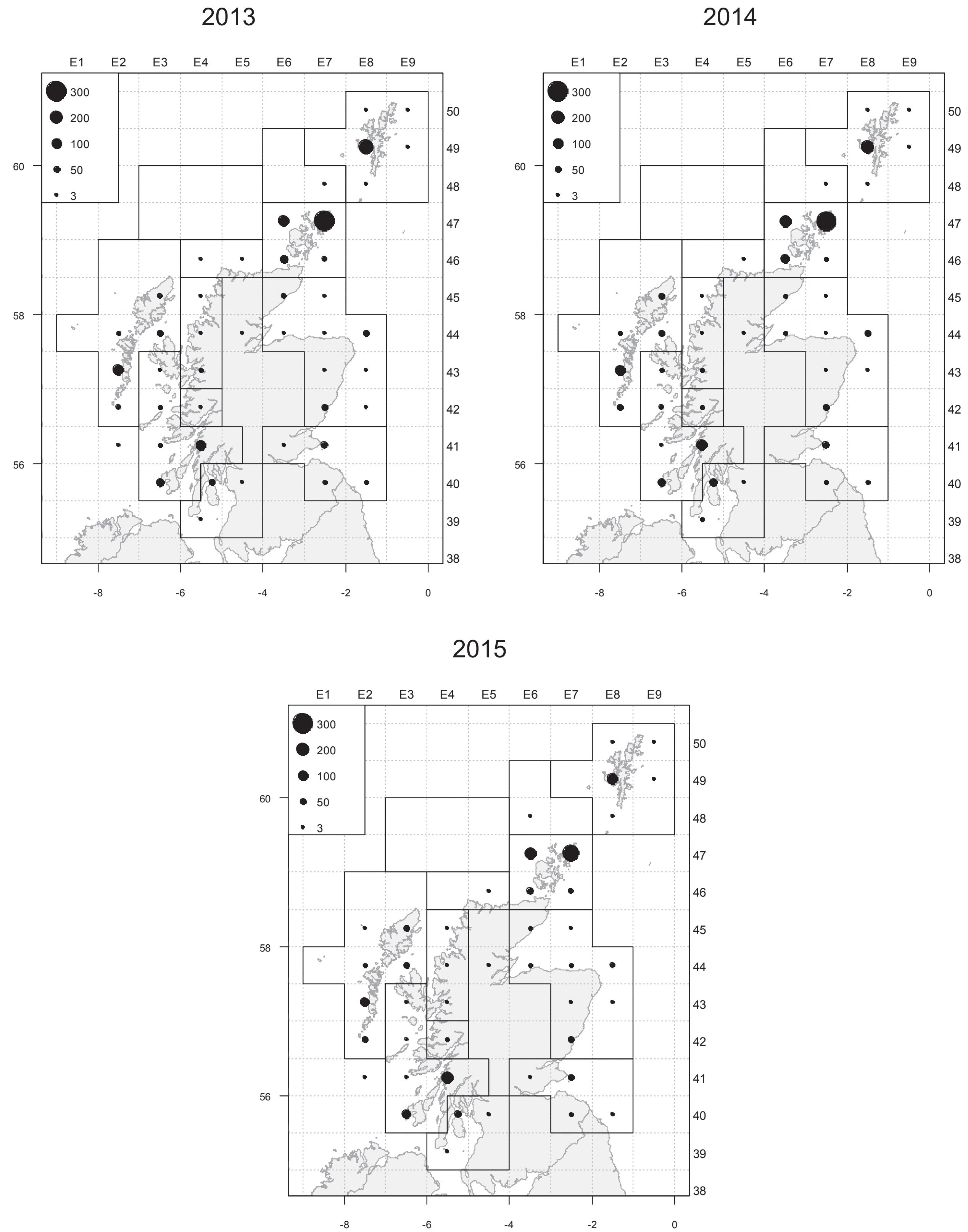

Figure 7. Velvet crab landings (tonnes) by statistical rectangle between 2013 and 2015. Black circles represent landings into Scotland. Data are from Fisheries Management Database.

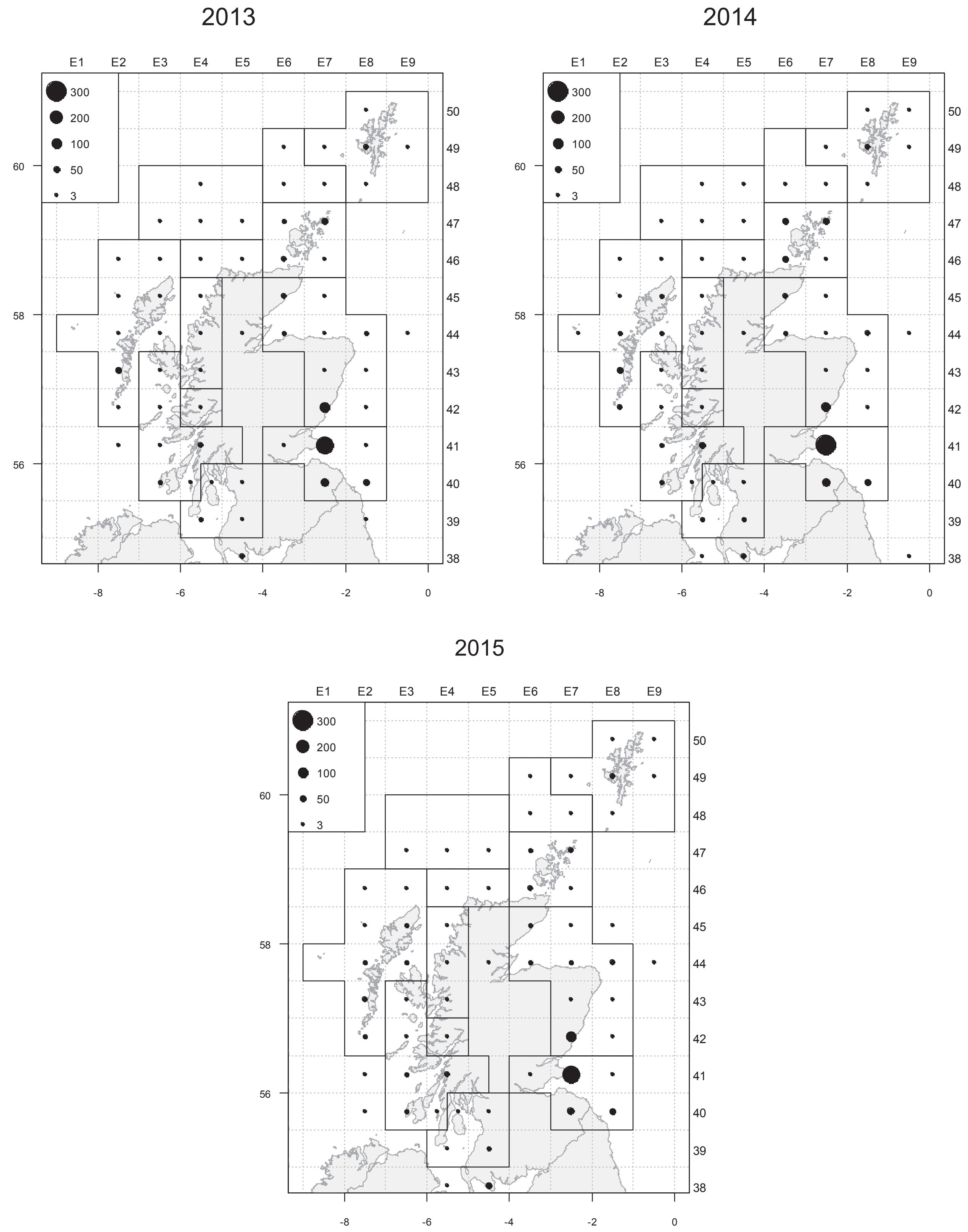

Figure 8. Lobster landings (tonnes) by statistical rectangle between 2013 and 2015. Black circles represent landings into Scotland. Data are from Fisheries Management Database.

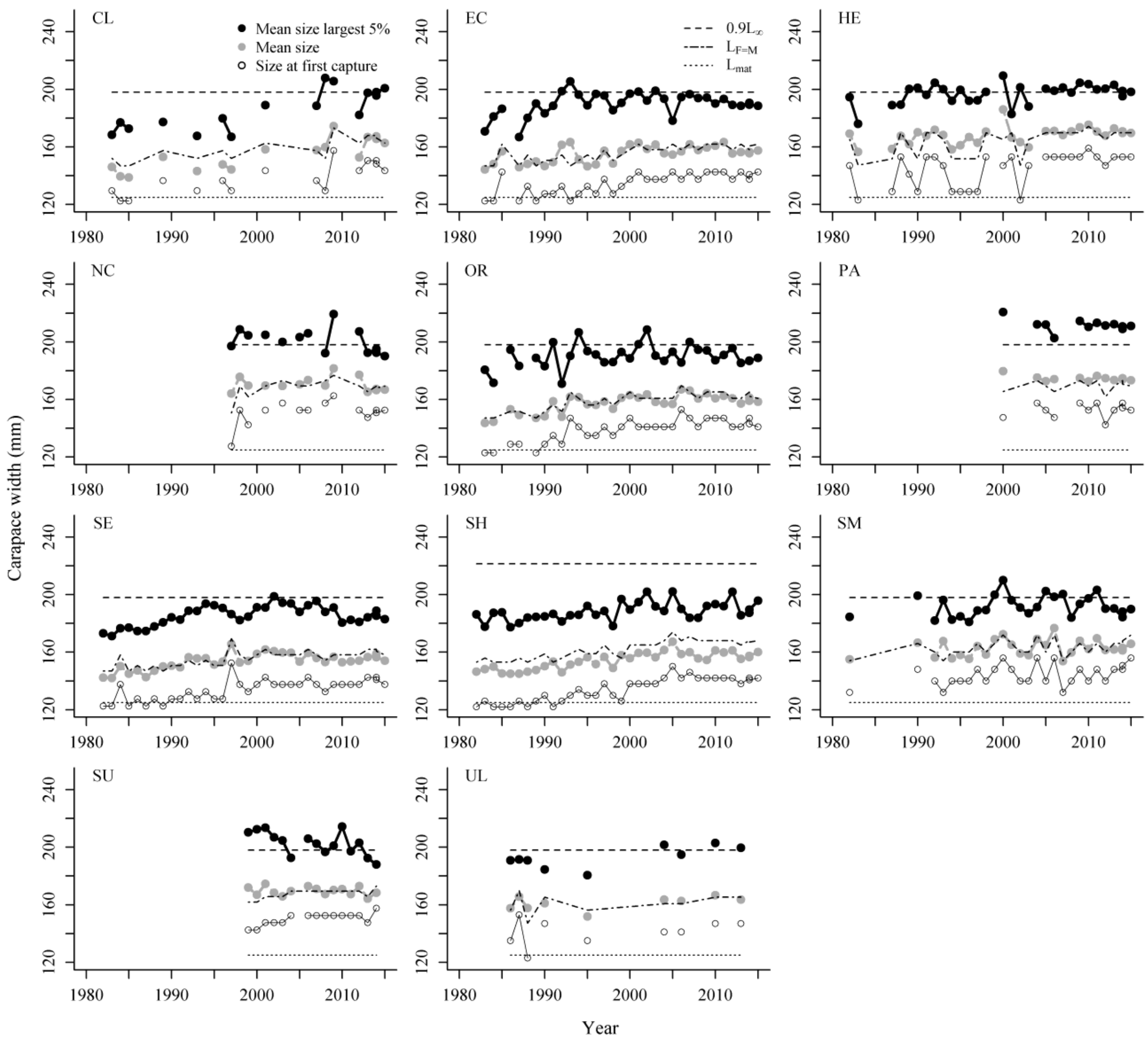

Figure 9. Brown crab males mean size in landings (grey circles), mean size of the largest 5% of individuals (black circles) and length at first capture (open circles) by assessment area, 1981-2015. Reference points $0.9L_{\infty}$ (dashed line), $L_{F=M}$ (dot-dashed line) and L_{mat} (dotted line), respectively. A minimum of 50 individuals was used each year to calculate mean sizes.

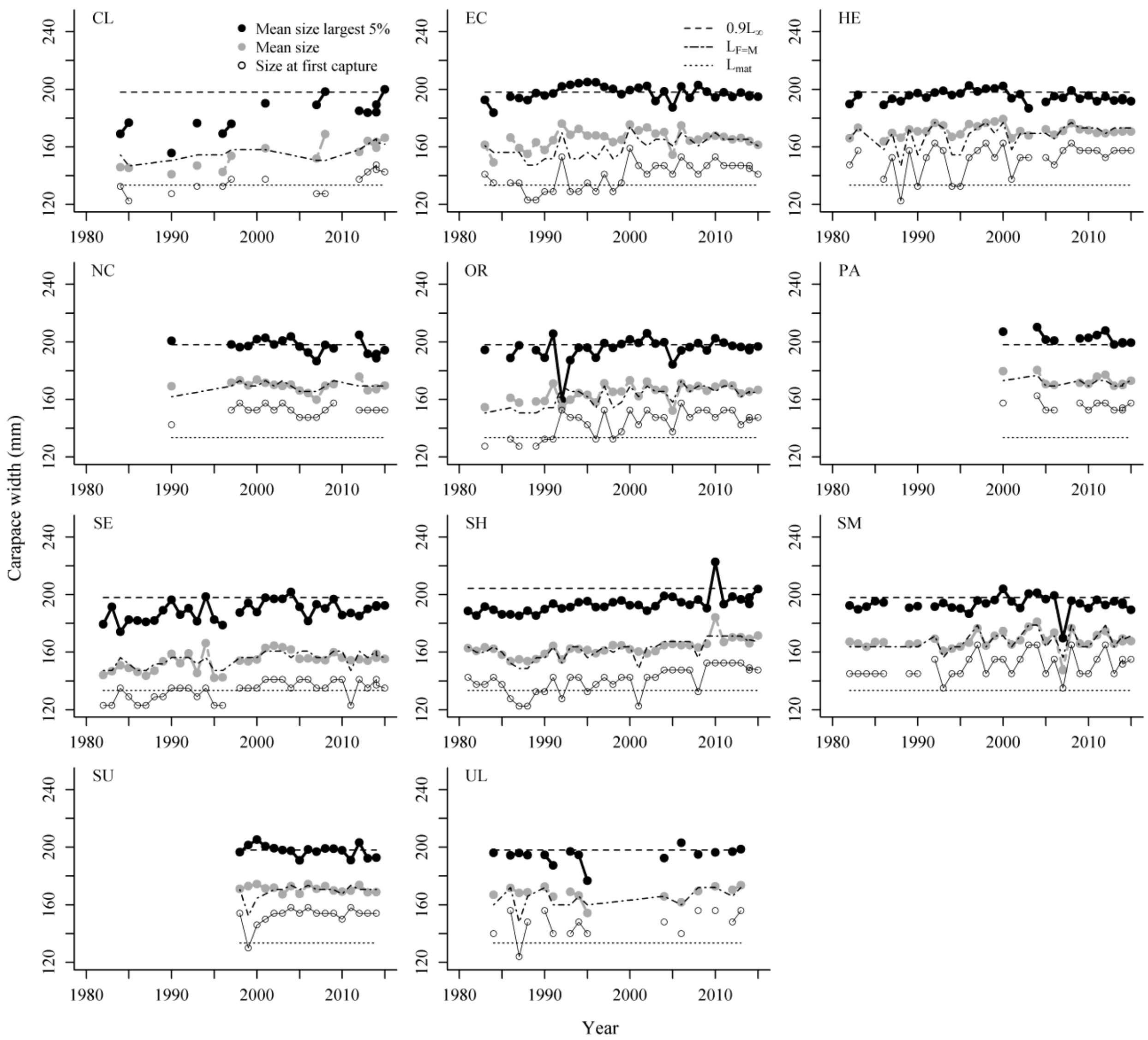

Figure 10. Brown crab females mean size in landings (grey circles), mean size of the largest 5% of individuals (black circles) and length at first capture (open circles) by assessment area, 1981-2015. Reference points $0.9L_{\infty}$ (dashed line), $L_{F=M}$ (dot-dashed line) and L_{mat} (dotted line), respectively. A minimum of 50 individuals was used each year to calculate mean sizes.

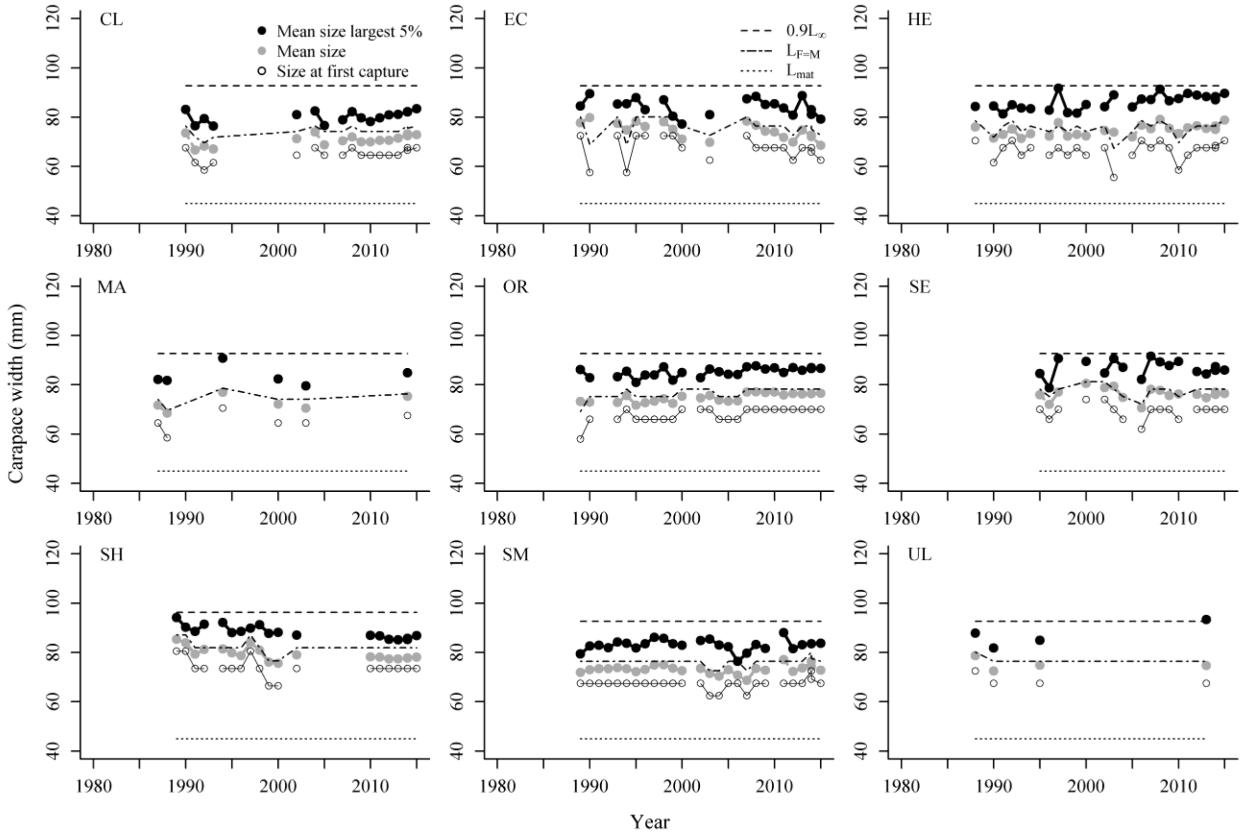

Figure 11. Velvet crab males mean size in landings (grey circles), mean size of the largest 5% of individuals (black circles) and length at first capture (open circles) by assessment area, 1987-2015. Reference points $0.9L_{\infty}$ (dashed line), $L_{F=M}$ (dot-dashed line) and L_{mat} (dotted line), respectively. A minimum of 50 individuals was used each year to calculate mean sizes.

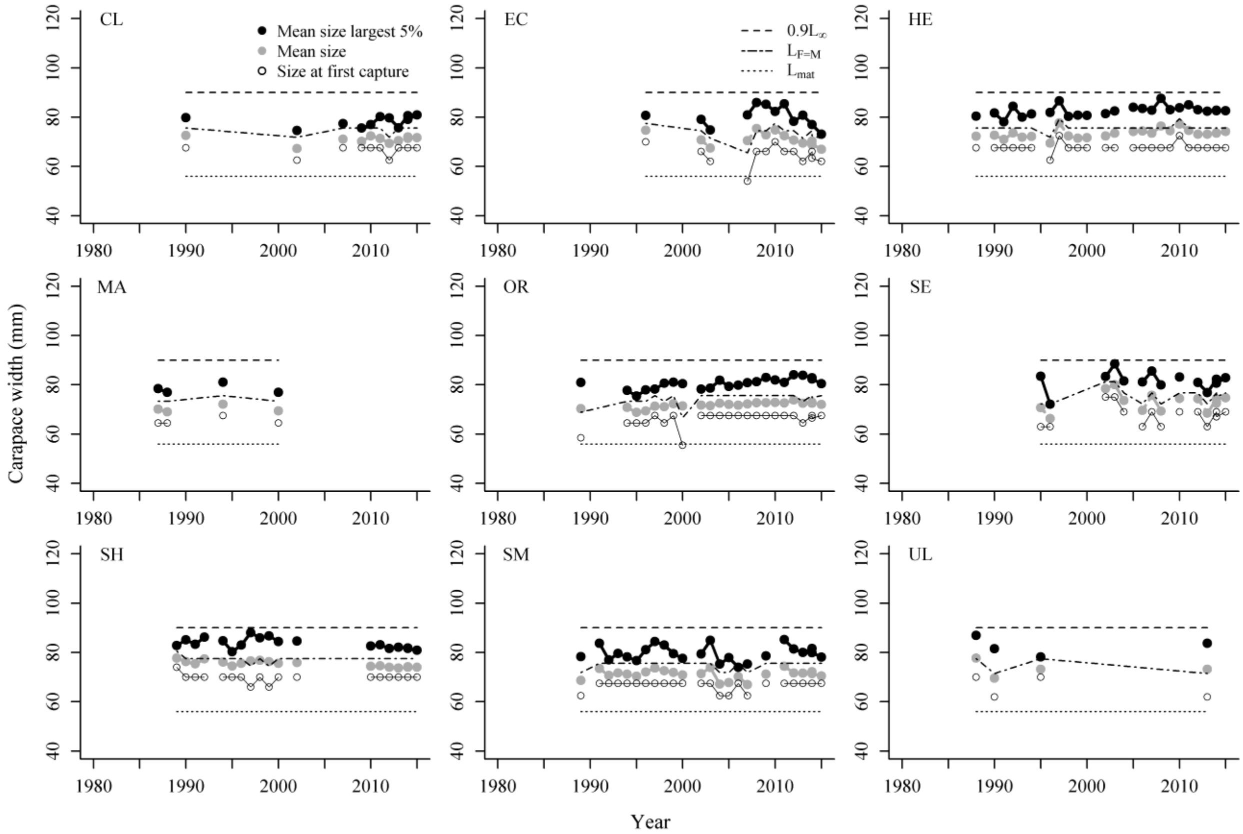

Figure 12. Velvet crab females mean size in landings (grey circles), mean size of the largest 5% of individuals (black circles) and length at first capture (open circles) by assessment area, 1987-2015. Reference points $0.9L_\infty$ (dashed line), $L_{F=M}$ (dot-dashed line) and L_{mat} (dotted line), respectively. A minimum of 50 individuals was used each year to calculate mean sizes.

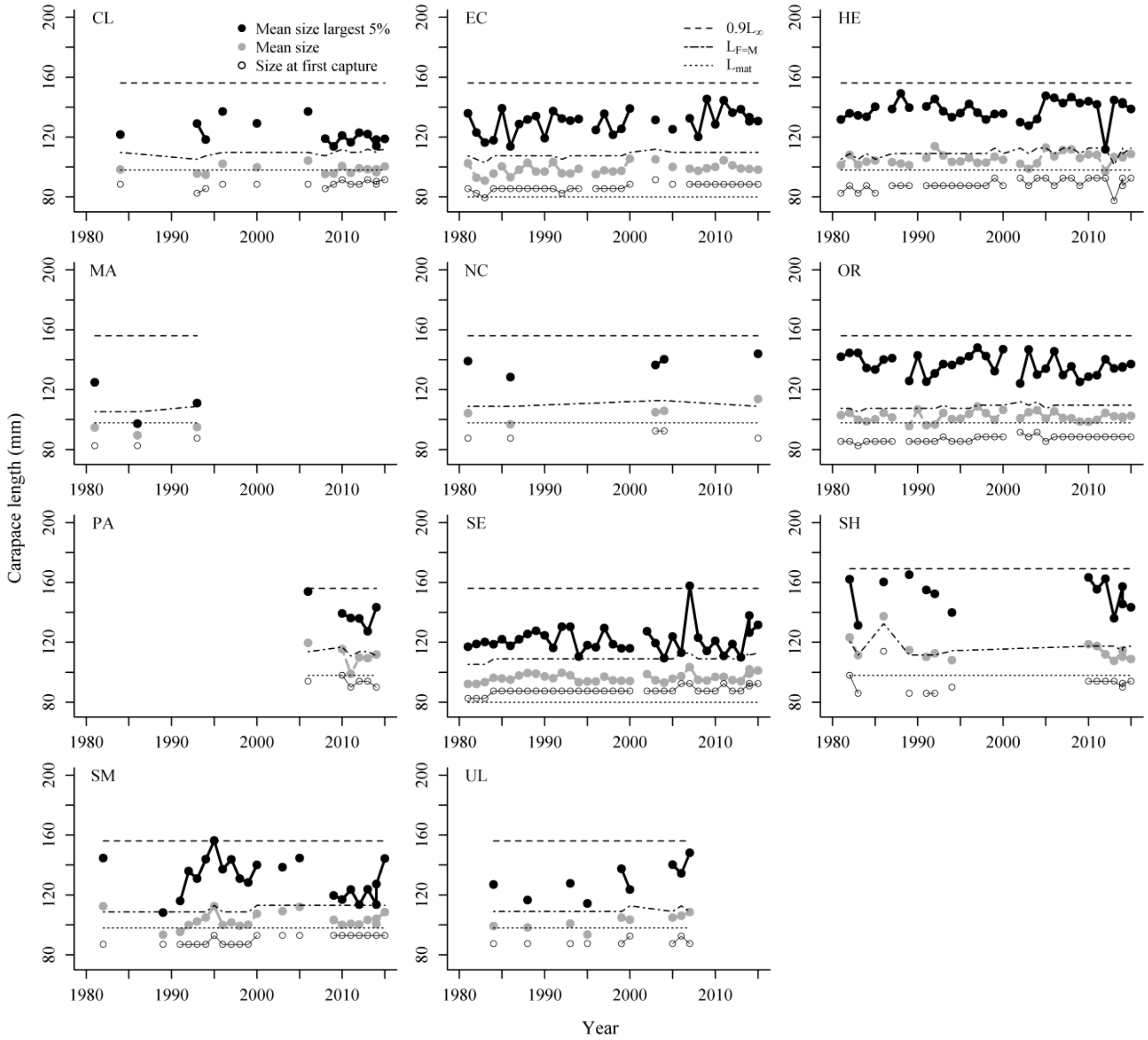

Figure 13. Lobster males mean size in landings (grey circles), mean size of the largest 5% of individuals (black circles) and length at first capture (open circles) by assessment area, 1981-2015. Reference points $0.9L_{\infty}$ (dashed line), $L_{F=M}$ (dot-dashed line) and L_{mat} (dotted line), respectively. A minimum of 50 individuals was used each year to calculate mean sizes.

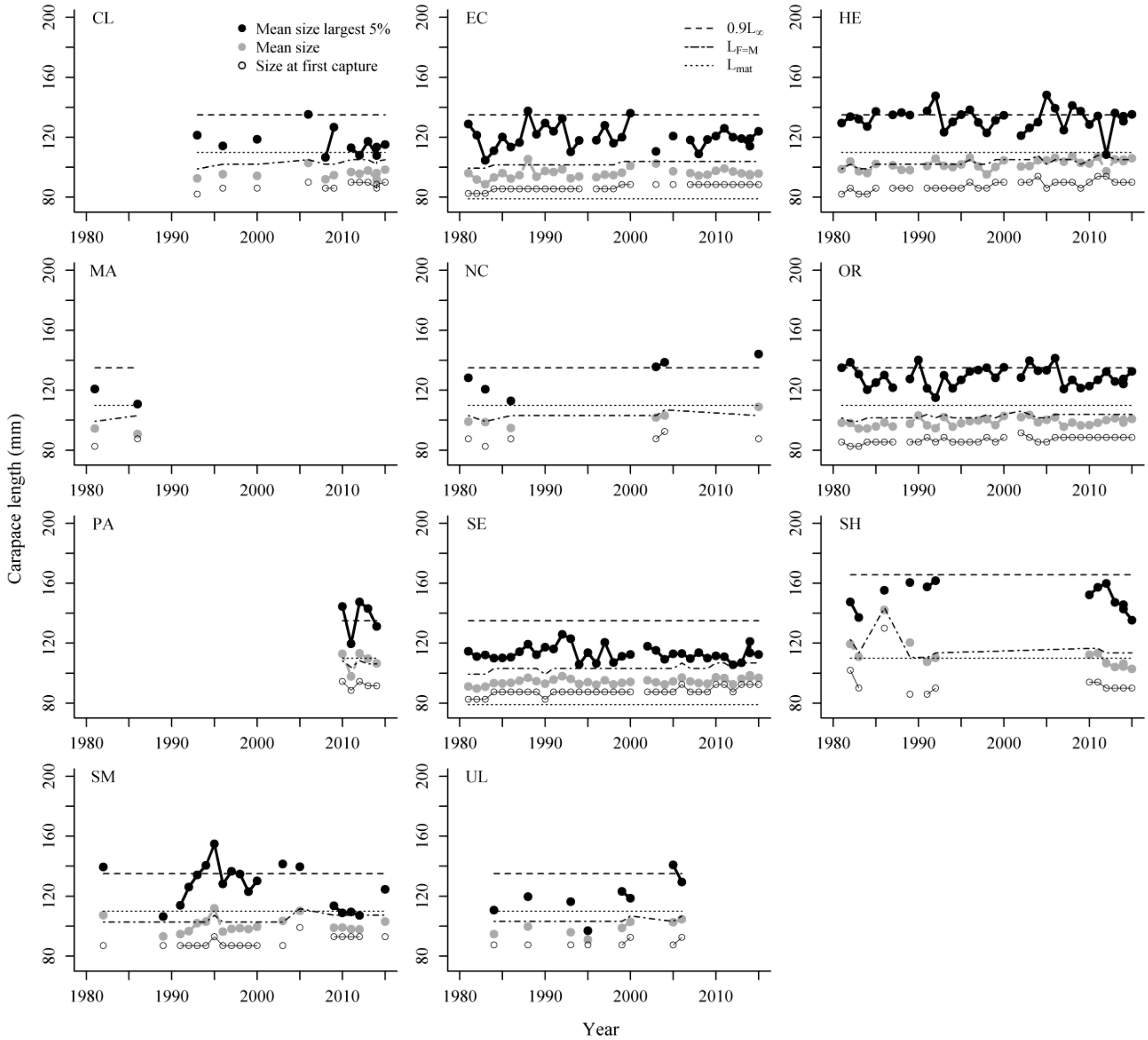

Figure 14. Lobster females mean size in landings (grey circles), mean size of the largest 5% of individuals (black circles) and length at first capture (open circles) by assessment area, 1981-2015. Reference points $0.9L_{\infty}$ (dashed line), $L_{F=M}$ (dot-dashed line) and L_{mat} (dotted line), respectively. A minimum of 50 individuals was used each year to calculate mean sizes.

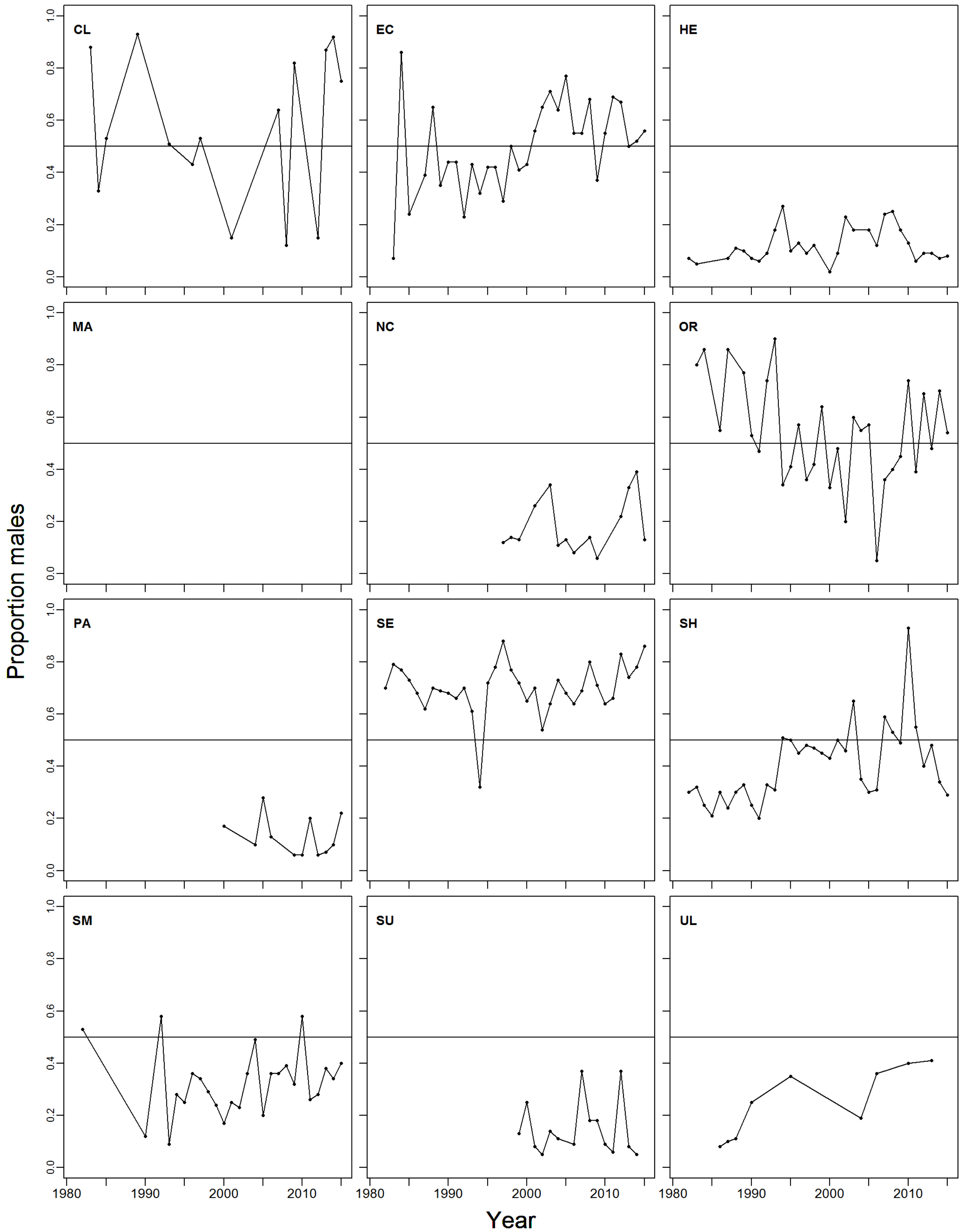

Figure 15. Brown crab sex ratio (percentage of males) in landings by assessment area, 1981-2015.

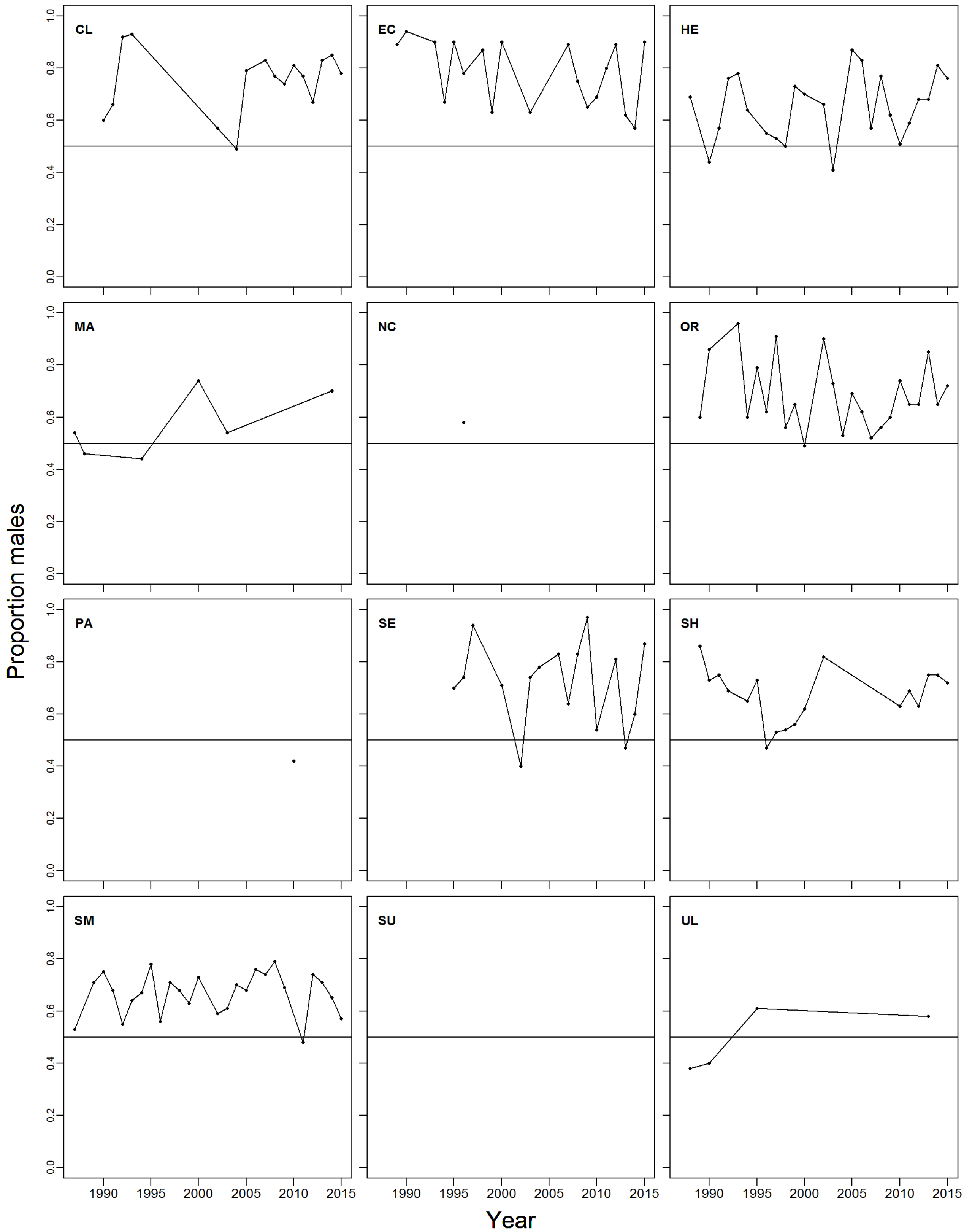

Figure 16. Velvet crab sex ratio (percentage of males) in landings by assessment area, 1987-2015.

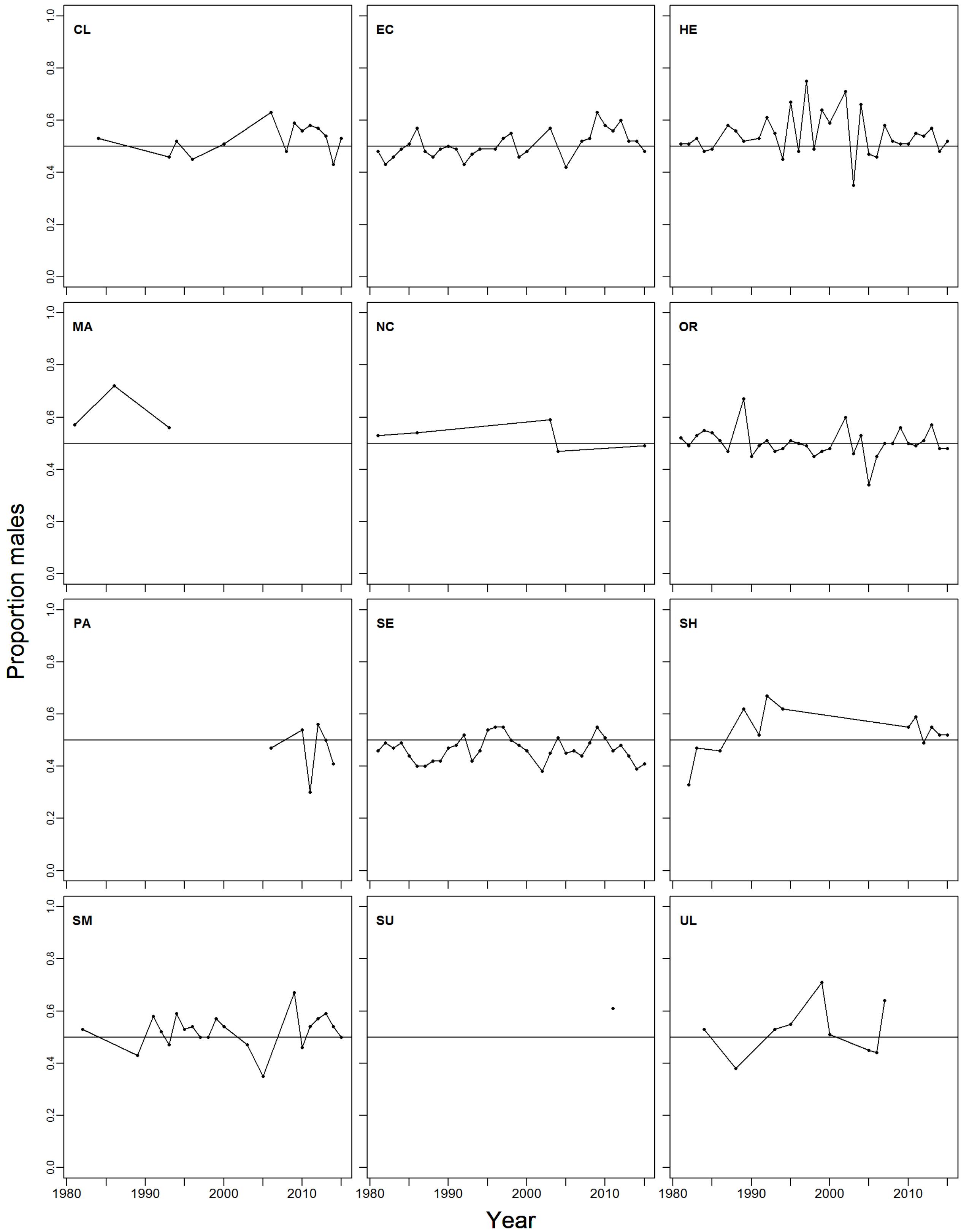

Figure 17. Lobster sex ratio (percentage of males) in landings, 1981-2015.

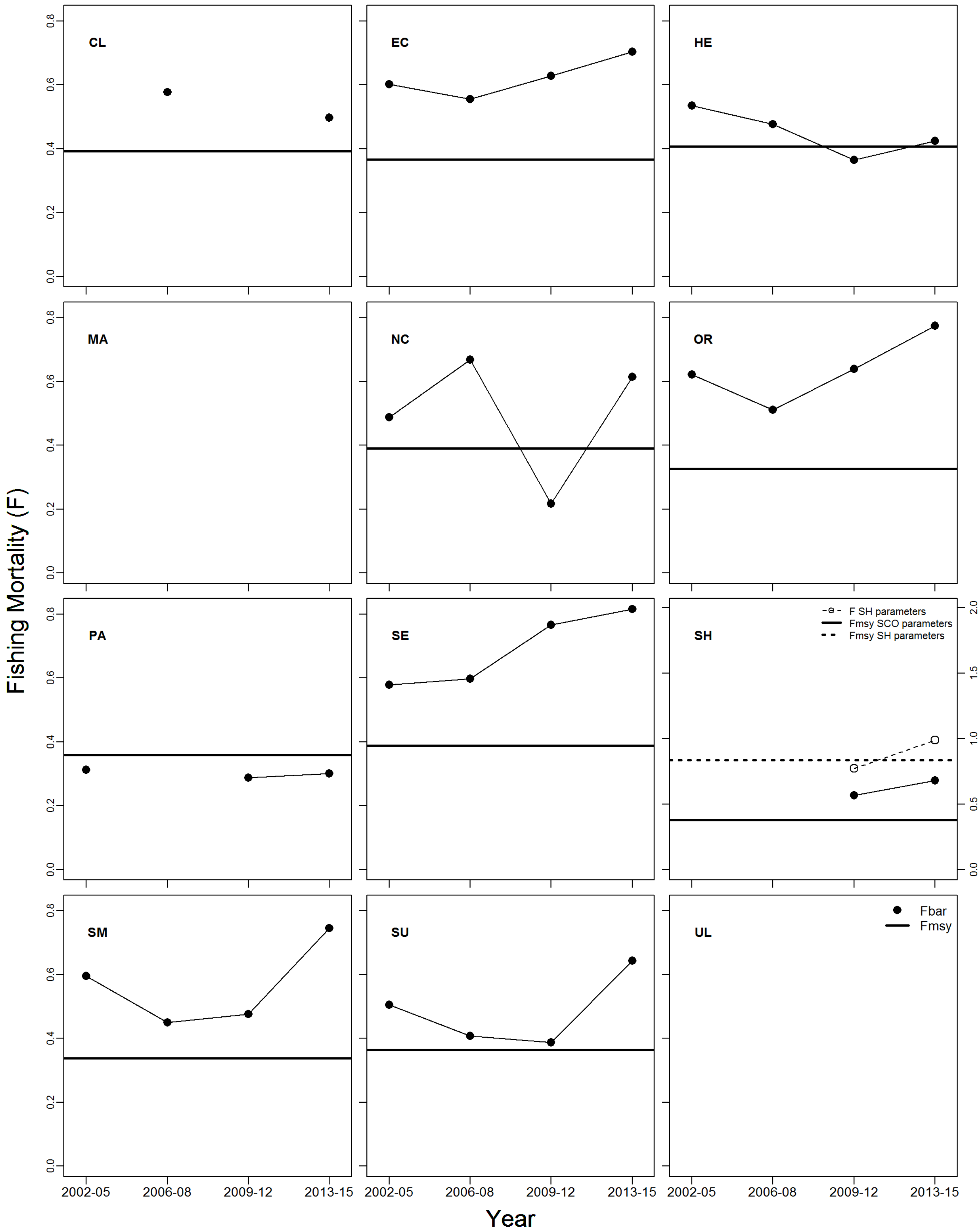

Figure 18. Male brown crab fishing mortality (Fbar) time series for the last four assessments in relation to F_{MSY}. For the Shetland area, F values (on a different scale in the right vertical axis) are shown as estimated using two sets of biological parameters (Shetland and rest of Scotland).

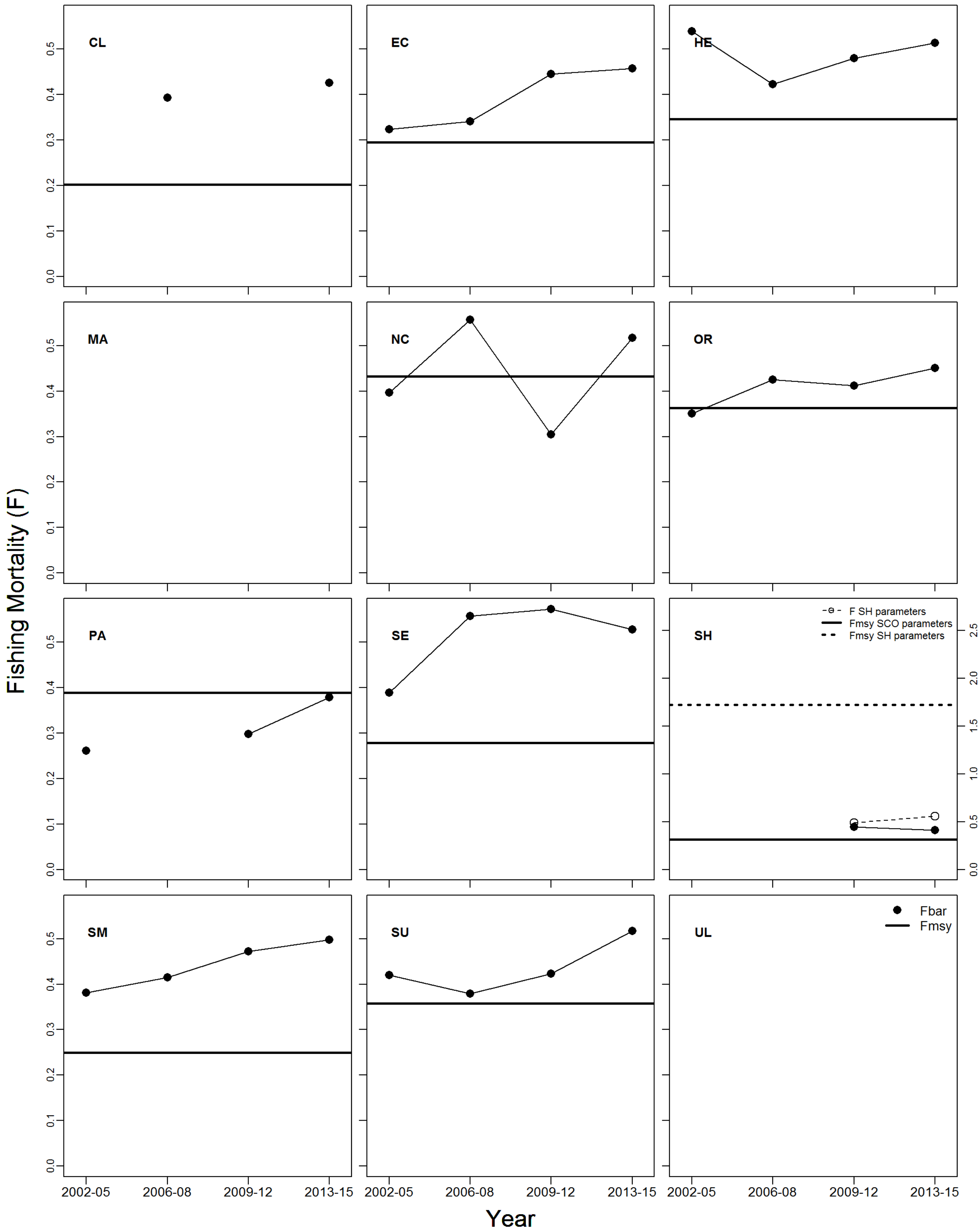

Figure 19. Female brown crab fishing mortality (Fbar) time series for the last four assessments in relation to F_{MSY}. For the Shetland area, F values (on a different scale in the right vertical axis) are shown as estimated using two sets of biological parameters (Shetland and rest of Scotland).

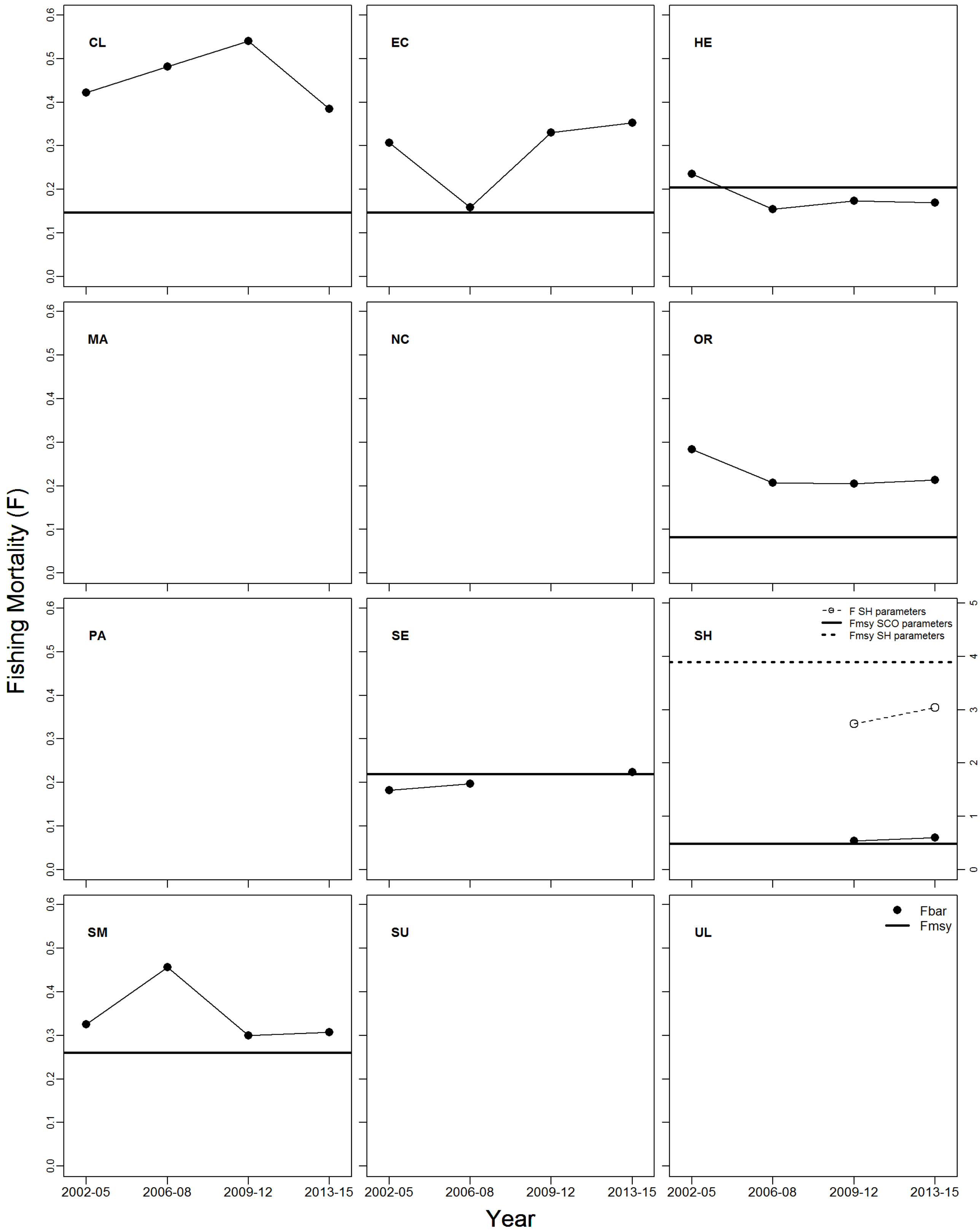

Figure 20. Male velvet crab fishing mortality (Fbar) time series for the last four assessments in relation to F_{MSY}. For the Shetland area, F values (on a different scale in the right vertical axis) are shown as estimated using two sets of biological parameters (Shetland and rest of Scotland).

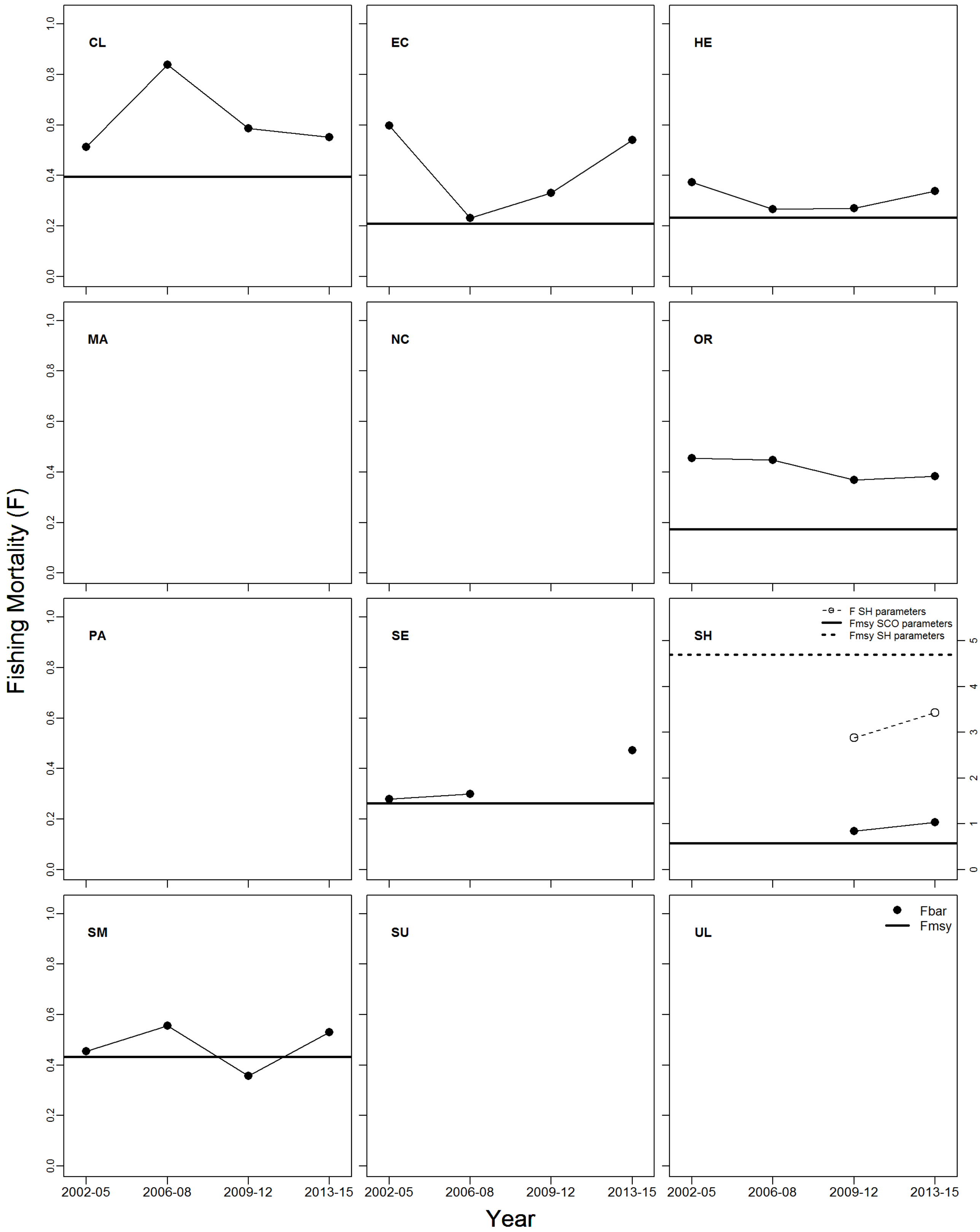

Figure 21. Female velvet crab fishing mortality (Fbar) time series for the last four assessments in relation to F_{MSY}. For the Shetland area, F values (on a different scale in the right vertical axis) are shown as estimated using two sets of biological parameters (Shetland and rest of Scotland).

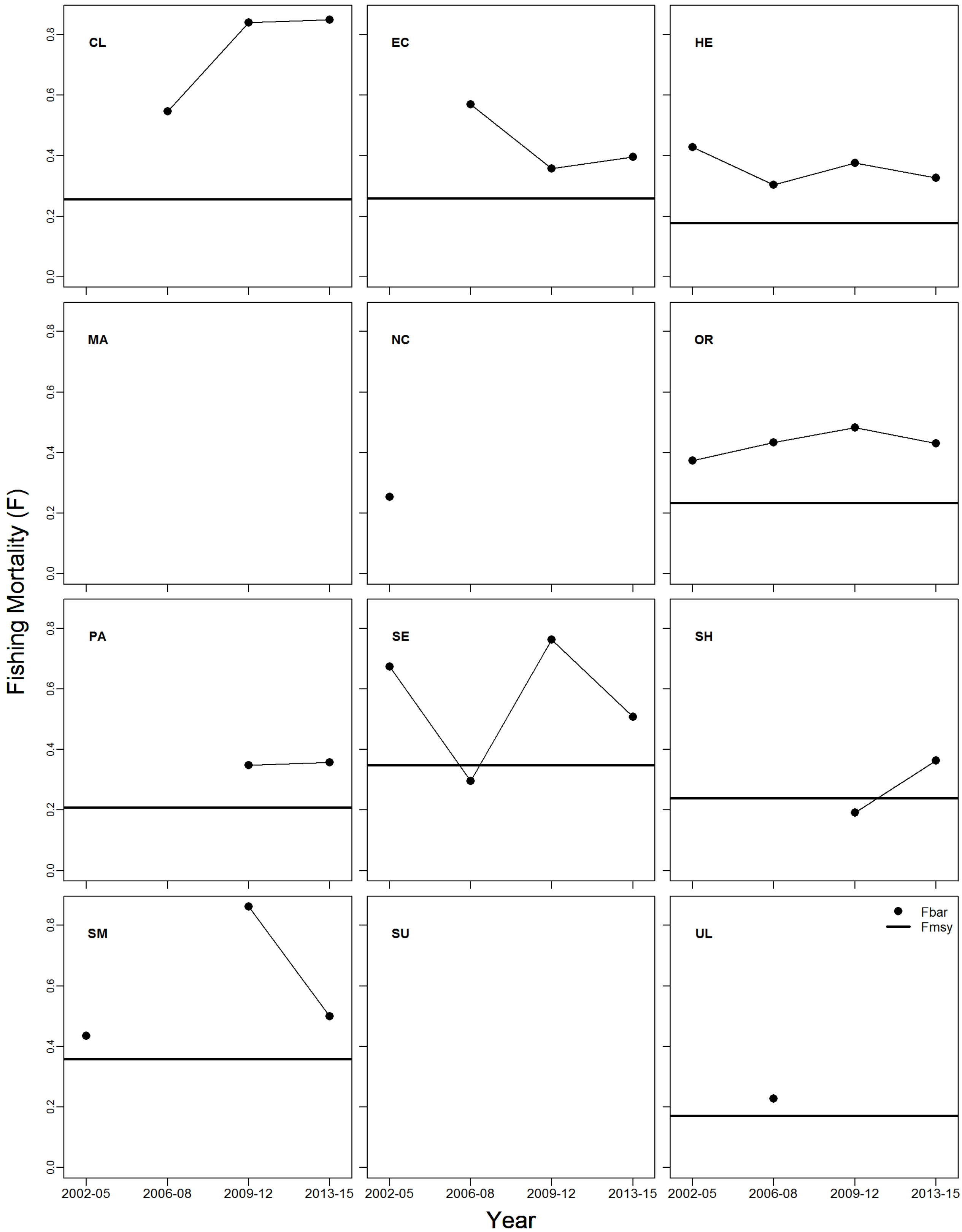

Figure 22. Male lobster fishing mortality (Fbar) time series for the last four assessments in relation to F_{MSY}.

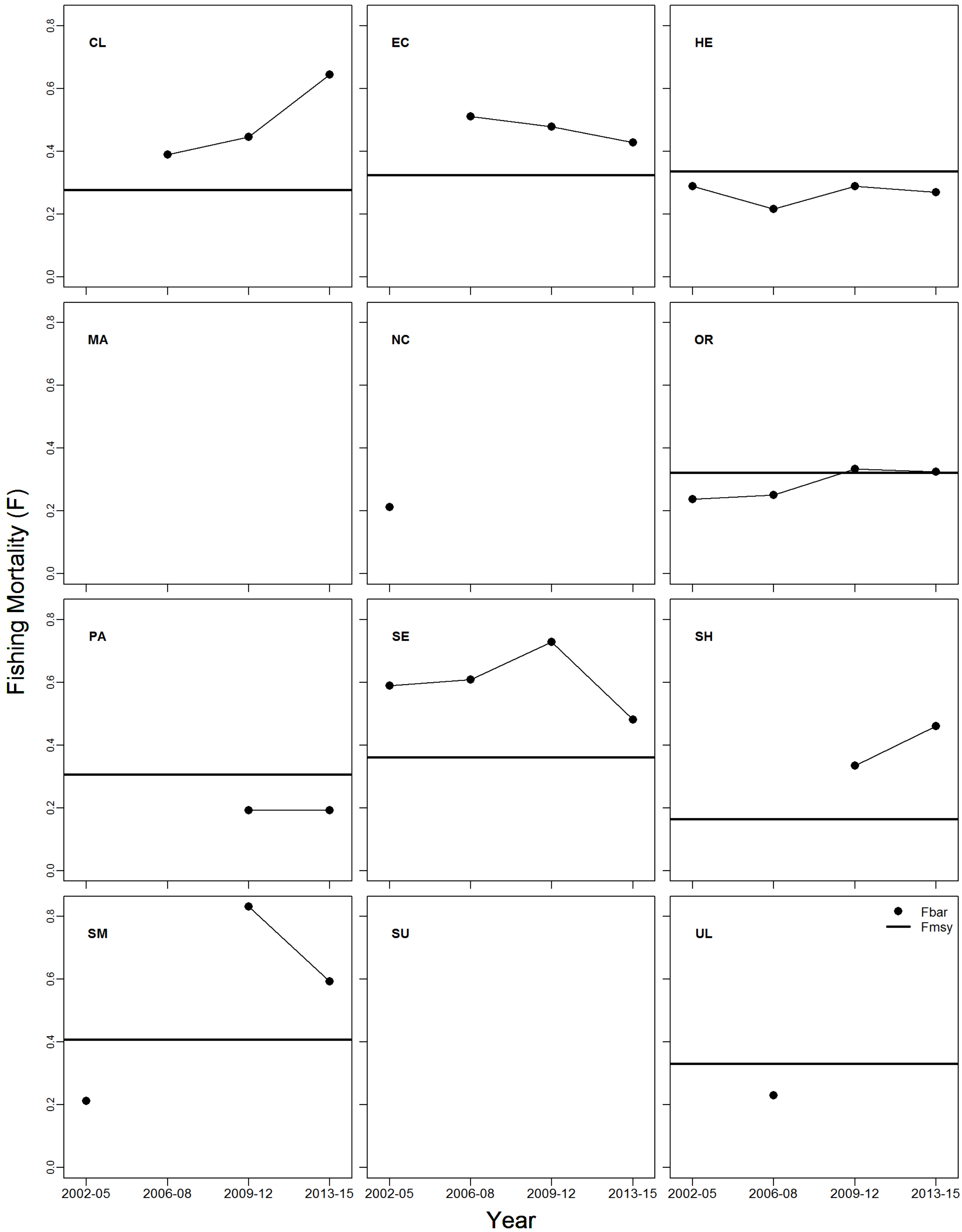

Figure 23. Female lobster fishing mortality (Fbar) time series for the last four assessments in relation to F_{MSY}.

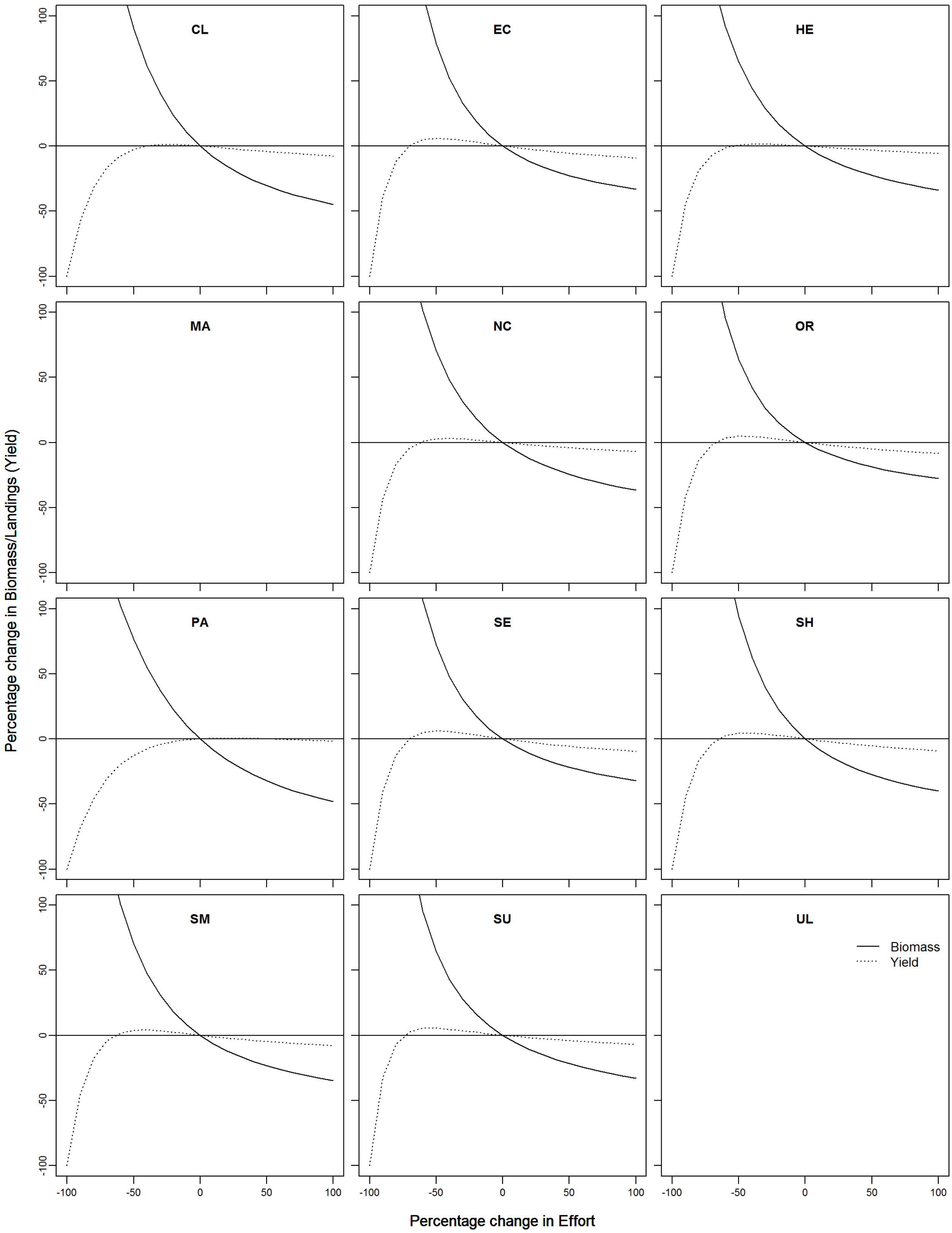

Figure 24. Male brown crab biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2013-15.

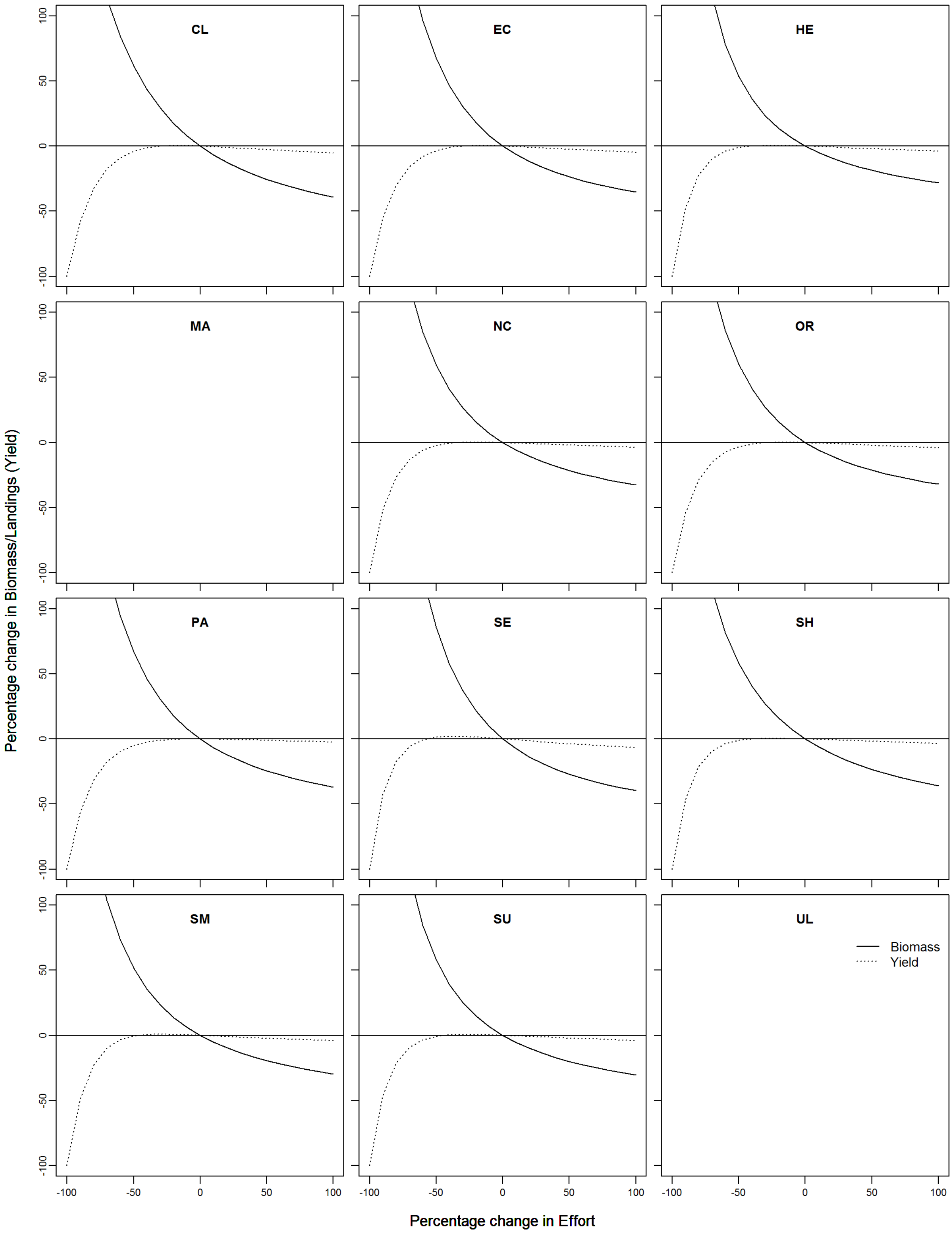

Figure 25. Female brown crab biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2013-15.

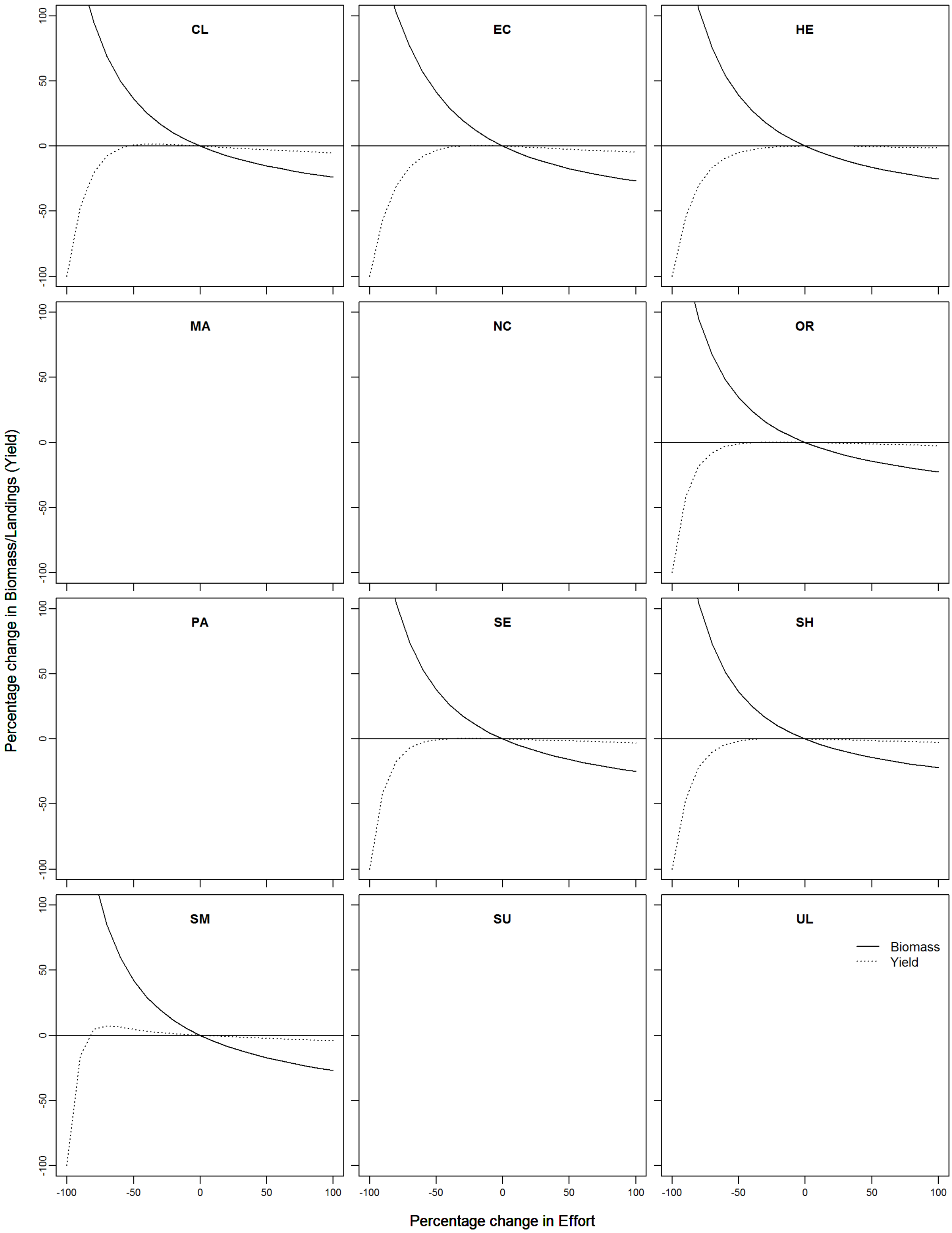

Figure 26. Male velvet crab biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2013-15.

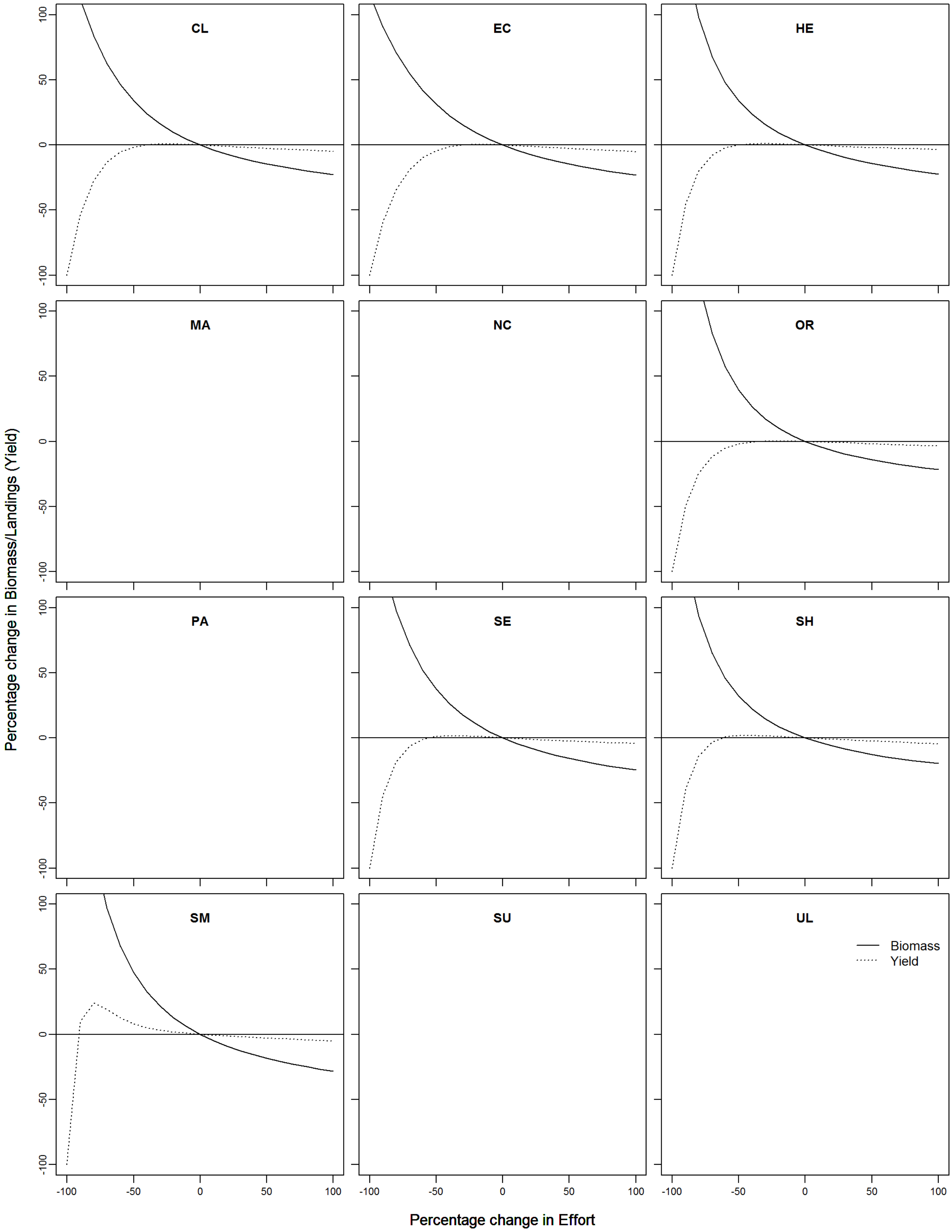

Figure 27. Female velvet crab biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2013-15.

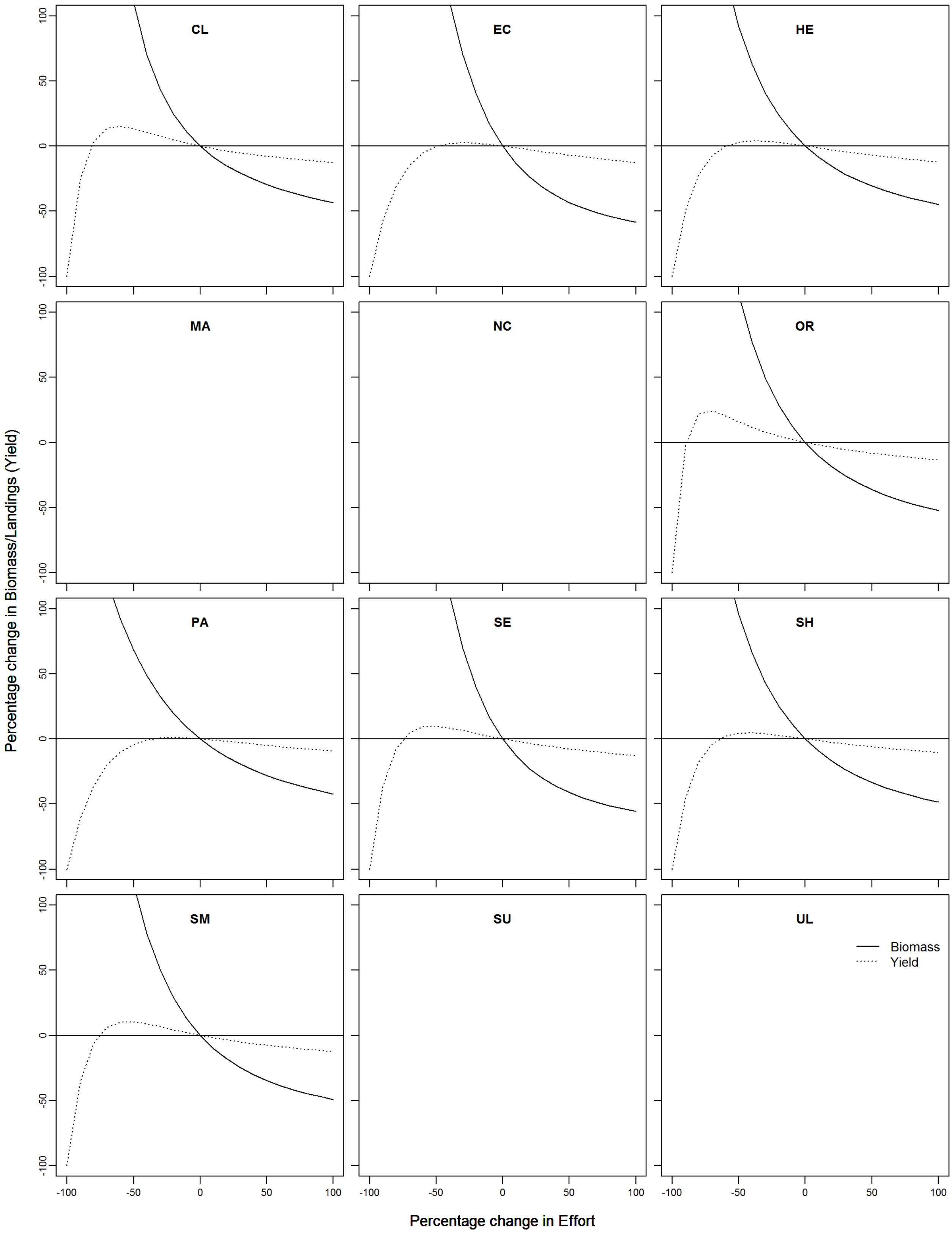

Figure 28. Male lobster biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2013-15.

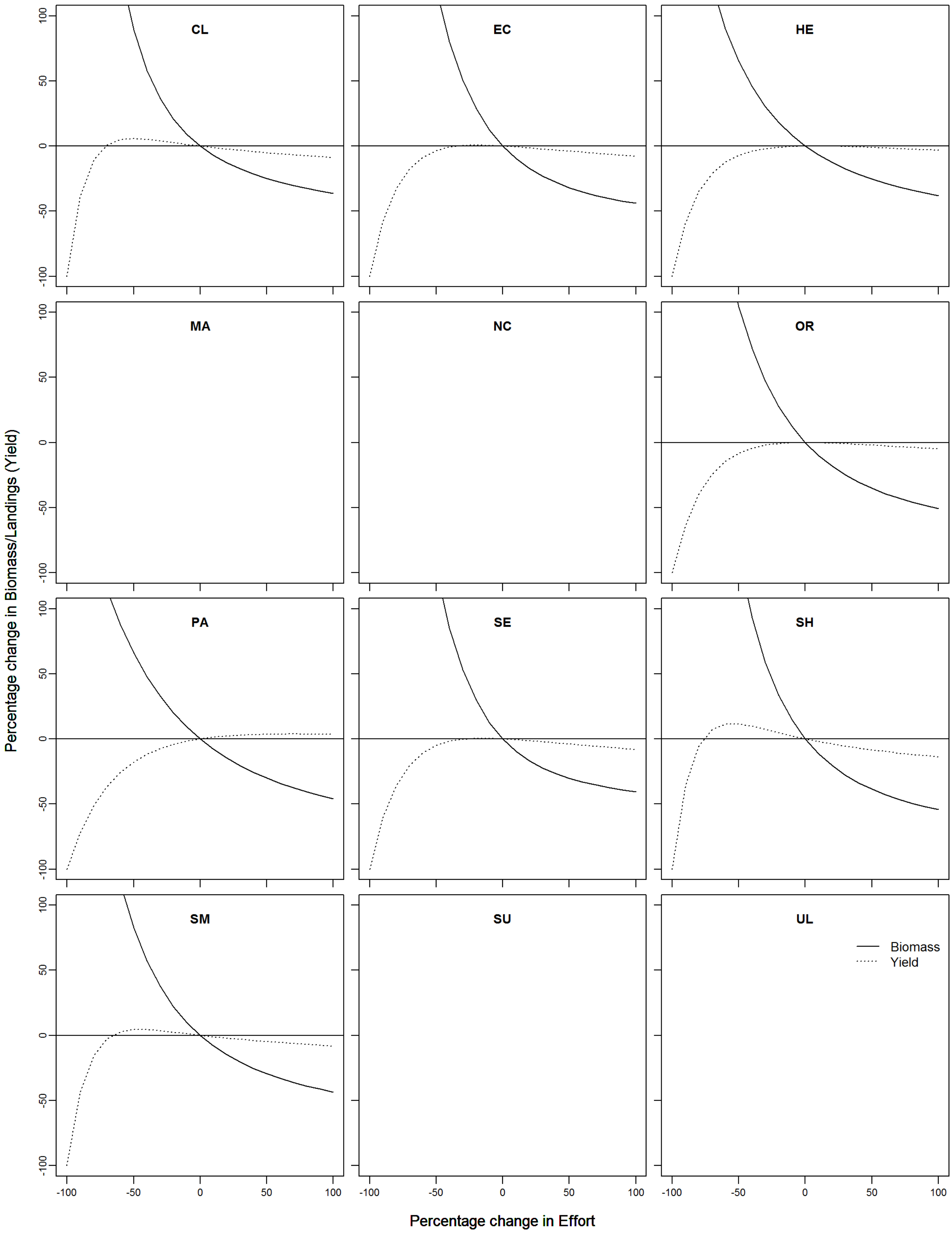

Figure 29. Female lobster biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2013-15.

8. Annexes

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

Table A 1 – 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 2009-12?		✓	✓		✓	✓	✓	✓	✓	✓	✓	
N individuals/landings sampled												
N years available for average LF											2	
Sampling seasonality (quarters)						2/3/4					2/3	2/4
LFD shape												
Assessment 2013-15	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	

Table A 2 – 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 2009-12?	✓	✓	✓			✓		✓		✓		
N individuals/landings sampled												
N years available for average LF												
Sampling seasonality (quarters)		2/3/4	2/3/4			2/3/4						3/4
LFD shape												
Assessment 2013-15	✓	✓	✓			✓		✓	✓	✓		

Table A 3 – Decision Table for Lobster

Lobster	Clyde	East Coast	Hebrides	Mallaig	North Coast	Orkney	Papa Bank	Shetland	South East	South Minch	Sule	Ullapool
Assessed in 2009-12?	✓	✓	✓			✓	✓	✓	✓	✓		
N individuals/landings sampled												
N years available for average LF												
Sampling seasonality (quarters)			2/3/4		1/2	2/3/4						
LFD shape												
Assessment 2013-15	✓	✓	✓			✓	✓	✓	✓	✓		

Table A 4 – Legend for Decision Tables

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

8.2. Annex B: Length Frequency Distributions

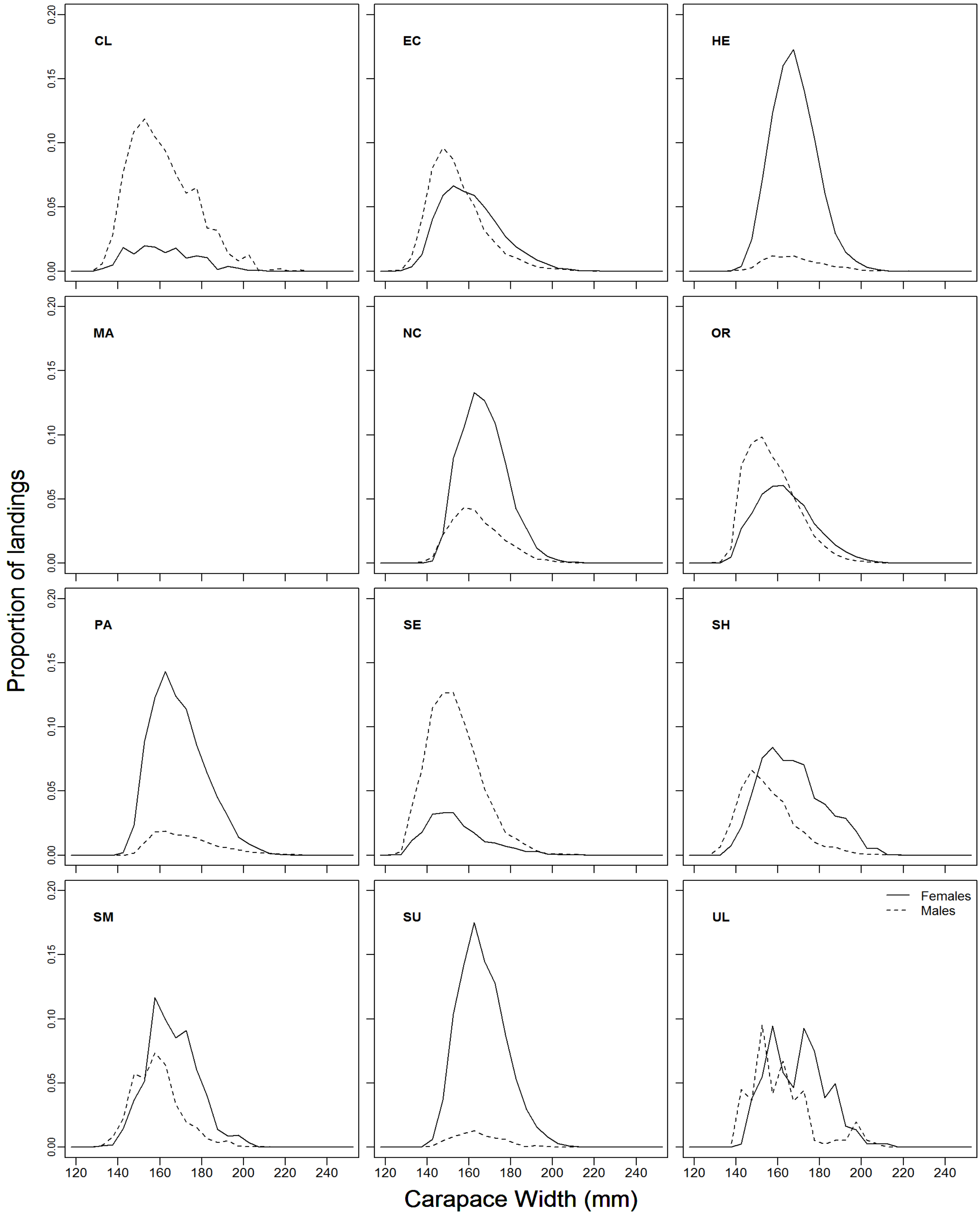

Figure B 1. Brown crab carapace width (mm) frequency histogram by assessment area averaged over the period 2013-15. The data presented are aggregated by 5 mm increments and shown as a proportion of the total landings.

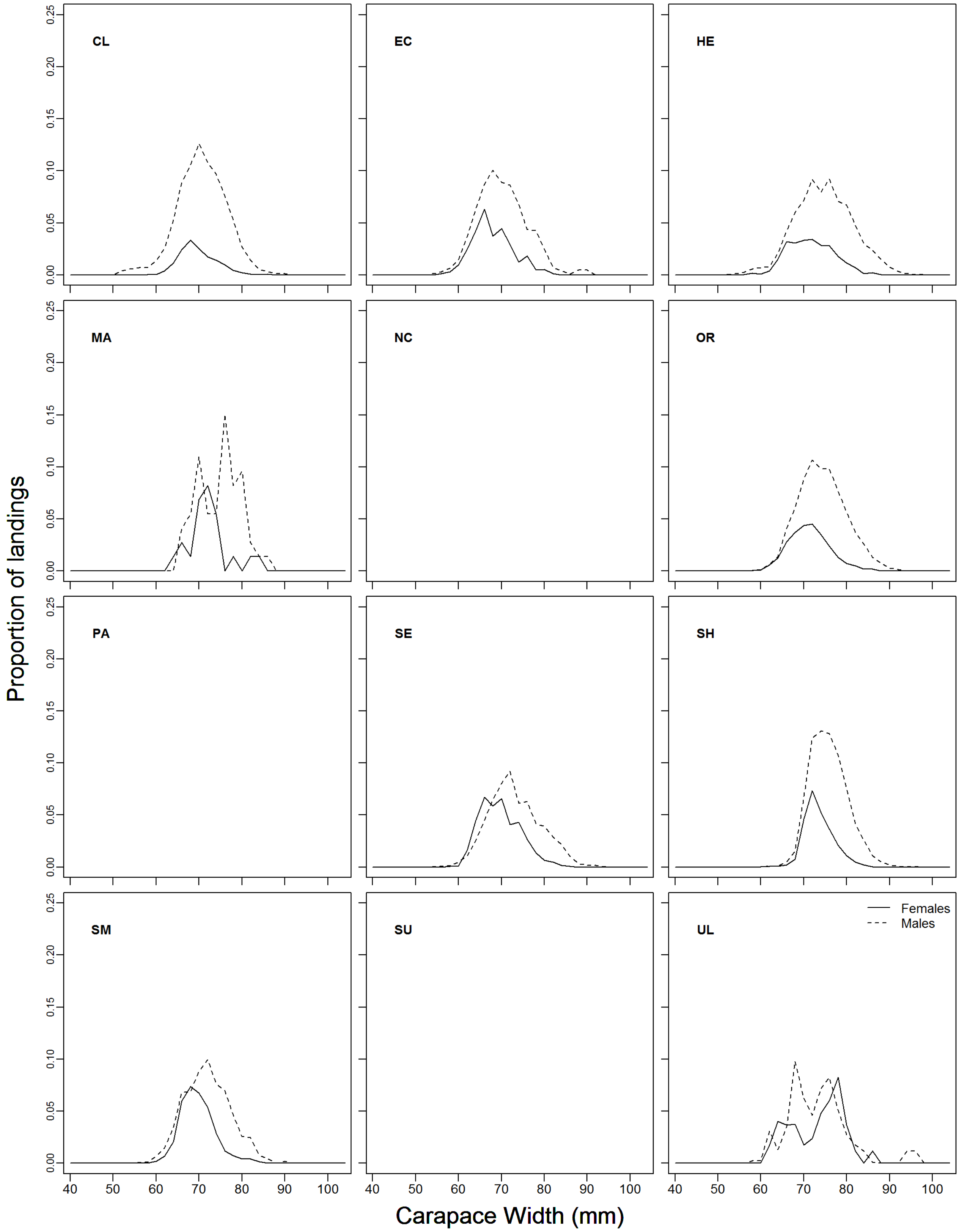

Figure B 2. Velvet crab carapace width (mm) frequency histogram by assessment area averaged over the period 2013-15 for males and females. The data presented are aggregated by 3 mm increments and shown as a proportion of the total landings.

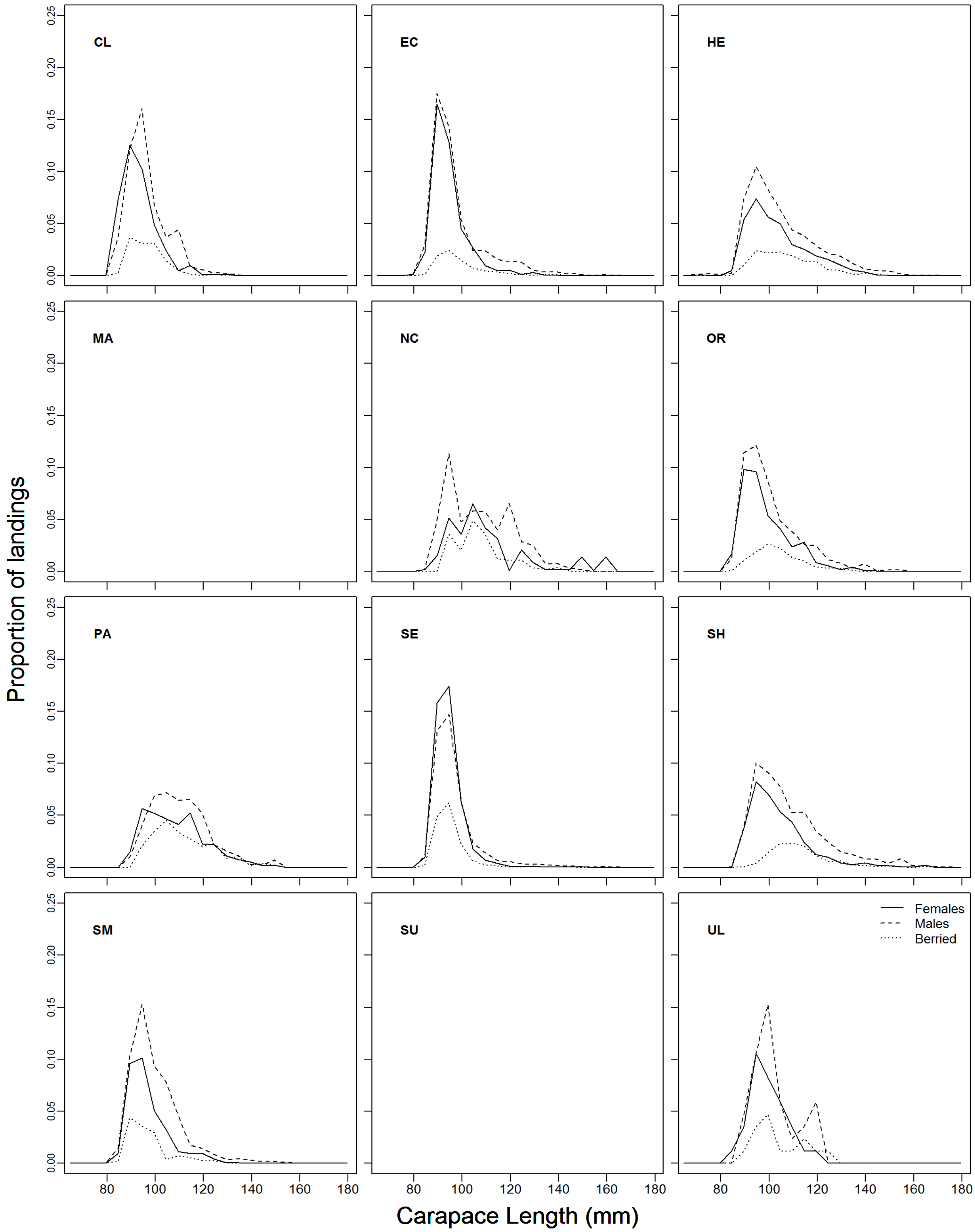

Figure B 3. Lobster carapace length (mm) frequency histogram by assessment area averaged over the period 2013-15 for males, females (berried also shown). The data presented are aggregated by 5 mm increments and shown as a proportion of the total landings.

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

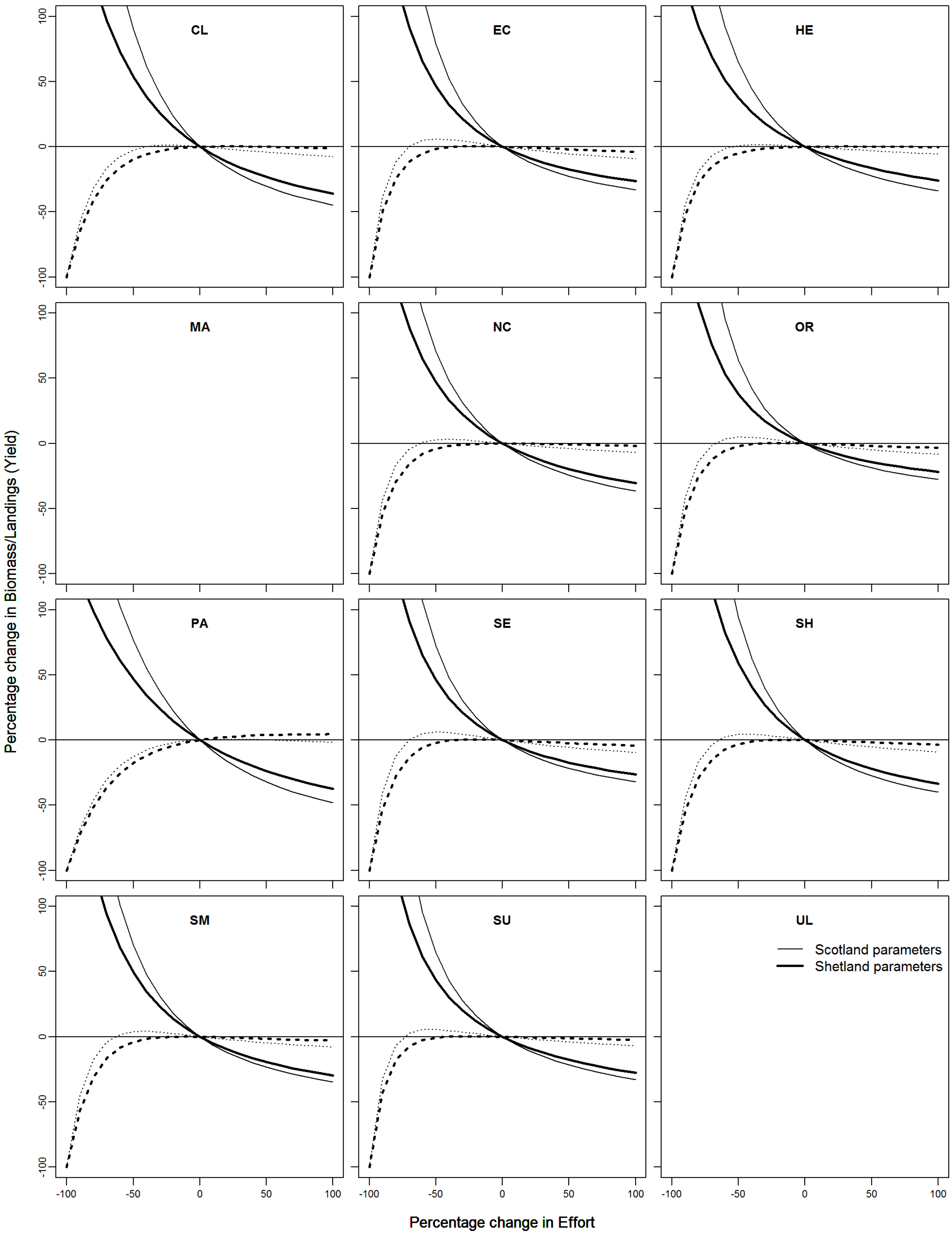

Figure C 1. Male brown crab biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2013-15. The YPR analysis was run using two different sets of biological parameters (Shetland and rest of Scotland).

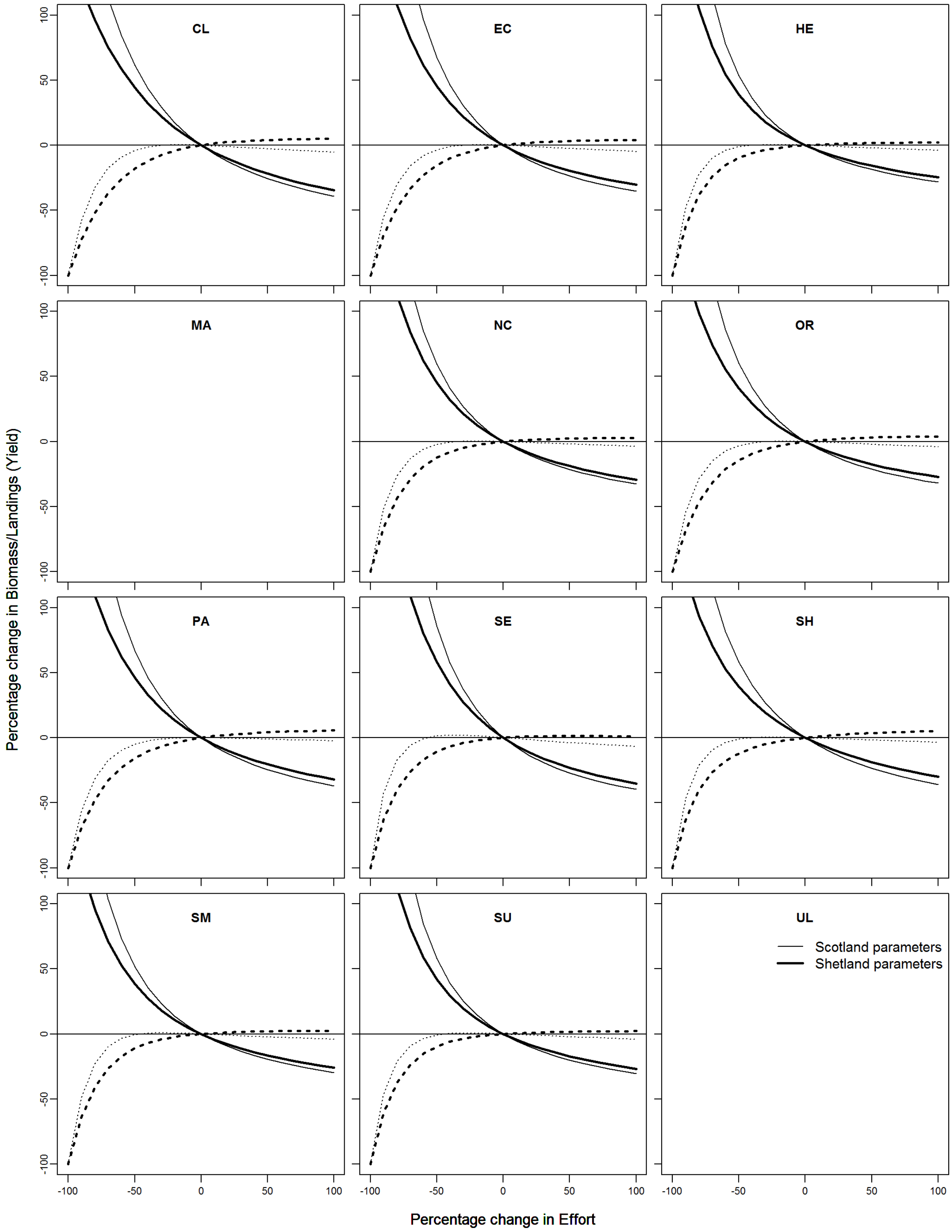

Figure C 2. Female brown crab biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2013-15. The YPR analysis was run using two different sets of biological parameters (Shetland and rest of Scotland).

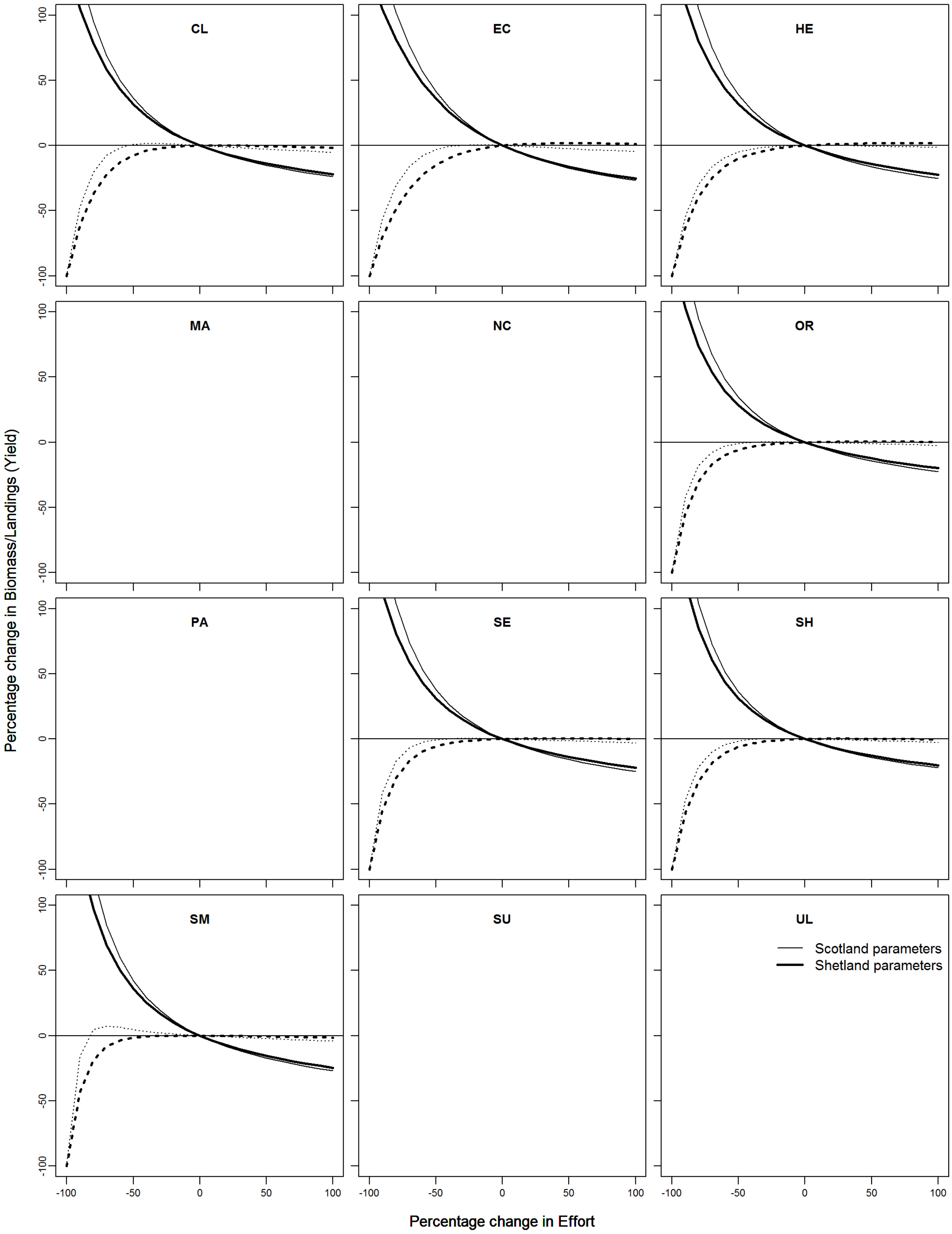

Figure C 3. Male velvet crab biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2013-15. The YPR analysis was run using two different sets of biological parameters (Shetland and rest of Scotland).

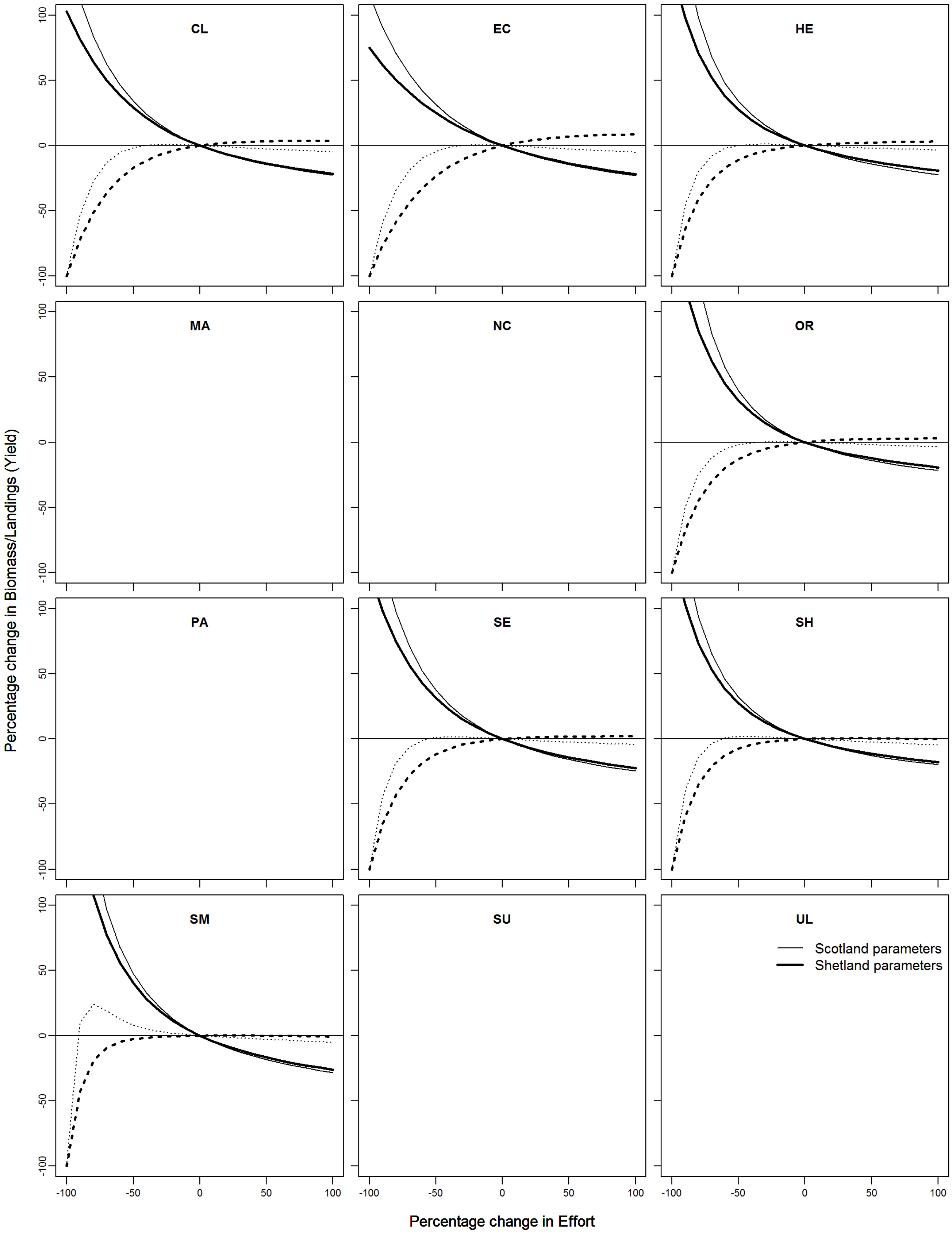

Figure C 4. Female velvet crab biomass and yield-per-recruit (YPR) predictions given changes from current effort by assessment area, data from 2013-15. The YPR analysis was run using two different sets of biological parameters (Shetland and rest of Scotland).

8.4. Annex D: Assessment Areas Names and Abbreviations

Table D 1 – 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	PA
South East	SE
Shetland	SH
South Minch	SM
Sule	SU
Ullapool	UL