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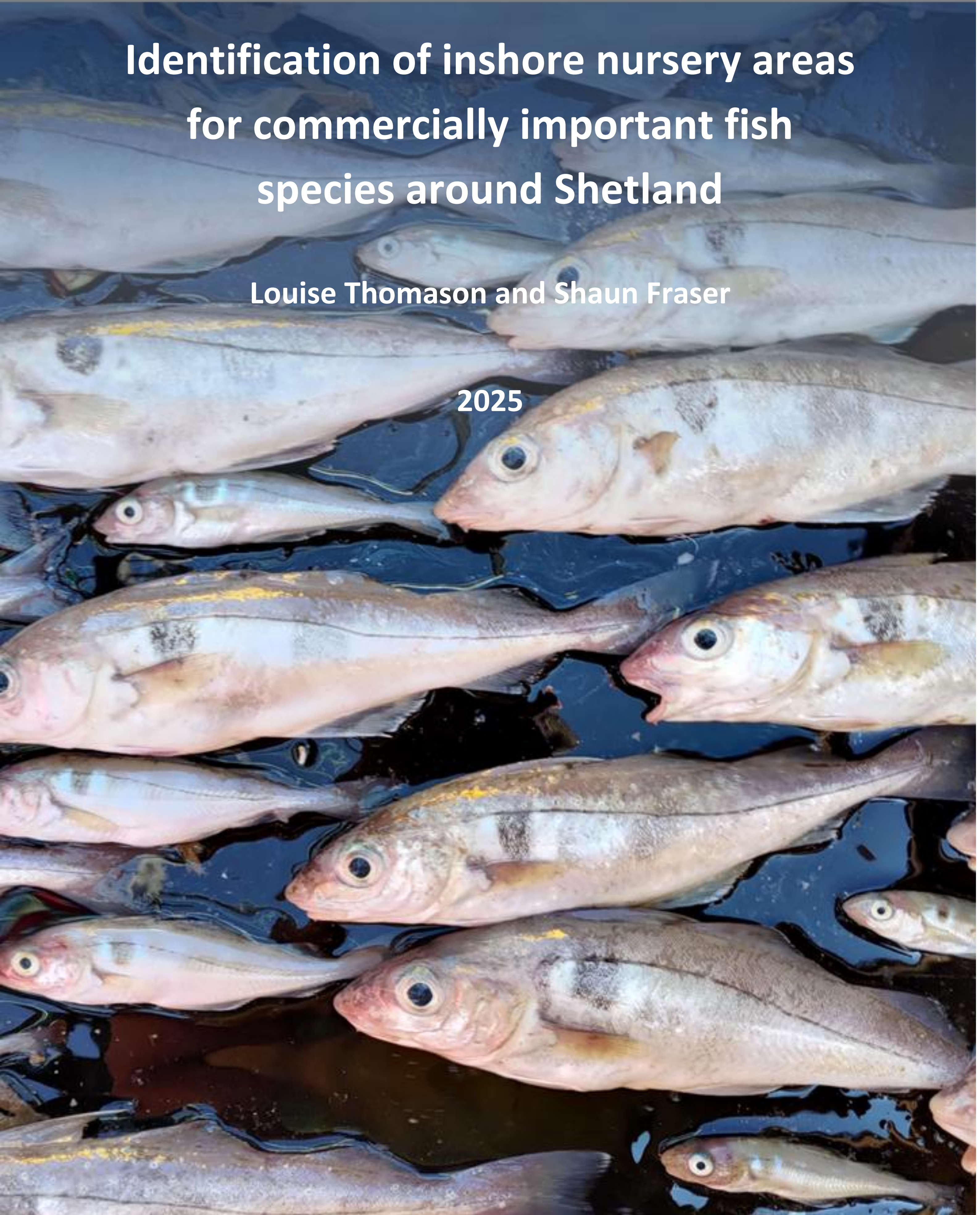

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Identification of inshore nursery areas for commercially important fish species around Shetland

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Contents

Executive summary

Coastal environments provide many ecologically significant services, delivered through high productivity and diversity. As fish habitats, nearshore environments are considered most valuable to juvenile fish where shallow, sheltered areas function as nursery habitats. Fish nurseries which demonstrate considerable value to adult fish stocks through improved growth and survival are considered a component of essential fish habitats (EFH). Given that the abundance of adult fish populations can be largely determined by the strength of early juvenile age-classes, identifying and assessing the significance of EFHs is vital to the management of commercial fisheries and to understanding the wider marine ecosystem.

The population age structure of fish and potential nursery habitats in nearshore waters has not previously been comprehensively studied in Shetland. The annual Shetland Inshore Fish Survey (SIFS) is a unique source of inshore data which provides an opportunity to estimate the age structure of nearshore fish populations, investigate their population dynamics, and to identify potential nursery grounds based on consistent use of specific areas by juveniles through time.

Species for analyses were selected based on commercial relevance and those sufficiently resolved in the available data. Specifically, these were Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*) and plaice (*Pleuronectes platessa*). Age-length keys (ALKs) for these species were produced from data available from the North Sea component of the International Bottom Trawl Survey (NS-IBTS). ALKs from NS-IBTS were selected for the area corresponding to Shetland (Area 1) in the third quarter (Q3) of 2017-2024 and applied to the observed length data from SIFS. From this, the age-structure of cod, haddock, whiting, and plaice inshore populations around Shetland were modelled, and the relative abundance and spatial distribution of discreet age-classes were determined.

Juvenile subpopulations for all four species were identified in coastal areas. High concentrations of age-0 fish were shown to consistently inhabit shallow and sheltered voe environments which were often clustered in specific areas. Three clusters were identified as being particularly important nursery habitats for multiple species, these were: the Weisdale Voe and Sandsound Voe to the south of the west mainland; Lunna and Dales Lees off the east mainland; and Cole Deep and Skeetlie (Aith Voe) to the north of the west mainland. Some other nearshore areas were also identified as having high persistence rates of age-0 fish for one or more species (e.g. age-0 cod were present at Ollaberry in 100% of survey years), and juvenile plaice were more widespread but with lower catch rates than the other species considered here.

For gadoid species (i.e. haddock, cod, and whiting), high age-0 catches were recorded in coastal areas where adults from the same species were absent. This evidence of spatial separation of juvenile and adult populations further supports the classification of the

identified areas as nursery habitats. The environmental characteristics of the identified nursery habitats include shallow depths (<50m), shelter from wave action and tides, and various (often sandy) sediments with some evidence of macroalgal (i.e. seaweed) cover. The available data indicates offshore movement of growing fish from these nursery habitats towards deeper fishing grounds which highlights the potential significance of these areas to nearby fish stocks and to local fisheries.

This study concludes that it is more important than ever to maintain and continue valuable time series such the Shetland Inshore Fish Survey, especially given the unprecedented scale of ongoing and proposed industrial developments in the Shetland region. Empirical data such as those presented in this report are vital for understanding complex nearshore environments and identifying essential fish habitats. It is recommended that annual monitoring is continued and that further research is carried out to fully investigate the extent and significance of the nursery areas identified here and to detect any changes in fish populations and habitat use in the future.

1 Introduction

1.1 Essential fish habitat

Coastal environments are under increasing pressure from anthropogenic developments; however, much uncertainty exists in the spatial distribution of essential habitats for commercial fish species. Shallow, coastal areas are widely recognised for significant ecological and economic services, delivered through high productivity and diversity (Beck et al., 2003; de Groot et al., 2012; Dahlgreen et al., 2006). Nearshore habitats are of critical importance to juvenile fish populations, as they provide a range of fundamentally important ecosystem services (Sheaves et al., 2015). Essential Fish Habitats (EFHs) are defined as "those waters and substrata necessary to fish for spawning, breeding, feeding, or growth to maturity", and thus include fish nursery areas (Franco et al., 2022). Nursery habitats are recognised to support juvenile survival, growth and recruitment to adult stocks, to a greater extent than other comparable habitats (Beck et al., 2001). The value of coastal habitats for juveniles is linked to the structural and hydrodynamic complexity of nearshore systems which may provide predator refuge and food availability (Boesch & Turner, 1984; Lefcheck et al., 2019).

Finfish and shellfish species associated with coastal habitats make up 77% of commercial landings in the Northeast Atlantic and nursery function is the most prevalent method of coastal habitat use for these species (Seitz et al., 2014). The importance of identifying juvenile habitats for demersal fisheries is underpinned by the knowledge that cohort size is known to be established in their abundance as first year, settled juveniles (Able et al., 1999; Campana et al., 1989). Given this, the sustainability of fish populations and their respective fisheries can be supported by identifying juvenile habitats and considering anthropogenic pressures within them (Valavanis et al., 2008).

In Scotland, the spatial distribution and importance of EFHs, specifically nurseries, for several commercial finfish species is recognised as a key knowledge gap which could be resolved by inshore monitoring studies (Franco et al., 2022). The appropriate methodologies for assessment of early life stages in fish vary across species groups. In contrast to pelagic species, like mackerel (*Scomber* scombrus) egg surveys and assessment of specific herring (*Clupea harengus*) spawning habitats, alternative methods are not as established for the study of demersal whitefish. Assessment of juvenile demersal species requires dedicated fisheries-independent data collection, typically through broad-scale surveys such as the International Bottom Trawl Survey (IBTS). International survey efforts provide valuable biological data for the study of fish stock structure including the production of age-length keys (ALK) which can be determined from a subset of specimens and applied across a wider dataset to mediate the costs associated with direct ageing all individual fish (Coggins et al., 2013). While there are benefits of the IBTS in the study of juvenile demersal fish populations, there is also limited spatial coverage of nearshore environments within such large-scale surveys; where data gaps in identifying nursery habitat use are known to occur (Franco et al., 2022).

1.2 Shetland context

The population age structure of fish in nearshore waters has not previously been studied comprehensively in Shetland. Yet, there is high availability of relevant data. The Shetland Inshore Fish Survey (SIFS) is a fisheries-independent source of fish distribution and relative abundance data and has been conducted annually since 2011 (Fraser et al., 2024). The survey has a concentrated effort within Shetland's coastal waters, maintaining a fine spatial resolution within areas not sampled by other survey efforts (e.g. IBTS). This effort was further enhanced by an expanded coverage into shallow water areas in 2017, intended to collect data on juvenile fish in potential nursery areas. SIFS is a unique source of data which is otherwise unavailable from commercial landings and which provides higher spatial resolution and improved sensitivity to local trends when compared to IBTS. Thus, data from SIFS can be complementary to those from large-scale trawl surveys and can be used to address concerns highlighted in literature on the lack of long-term nearshore survey data and resulting knowledge gaps relating to juvenile habitats (Able, 1999).

A recent publication, produced from the SIFS dataset, presents findings on high juvenile elasmobranch densities in shallow zones around Shetland (McAllister et al., 2023) and identifies areas of persistent use by juvenile thornback ray (*Raja clavata*), indicative of nursery areas. Given that this study considers a single species observed within SIFS area, it warrants investigation of other species' juvenile subpopulations present in the Shetland nearshore environment which may make important contributions to nearby adult fish stocks. Particularly, commercially important demersal whitefish species such as Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*) and plaice (*Pleuronectes platessa*). Collectively, these species accounted for 49% of weight (>8,000 tonnes) and 45% of value (£16.6 million) for all whitefish landings to Shetland ports in 2021 (Napier, 2022). The high commercial value of these species highlights the economic importance of understanding the juvenile relative abundance and potential for nursery habitats throughout the Shetland nearshore environment.

1.3 Study aims

This project will have the following main aims:

- Estimate the age structure of fish populations in nearshore waters using data from the Shetland Inshore Fish Survey and available ALKs.
- Use these results to investigate the population dynamics, through the relative abundance of age groups, for commercial fish species in the nearshore Shetland environment.
- Assess the spatial distribution, inter-annual variation, and persistence of habitat use to identify important nursery grounds that support local inshore fisheries.

2 Materials and methods

2.1 Study area

The Shetland Islands (Shetland) are Scotland's northernmost region, situated between the Orkney Islands, the Faroe Islands and Norway. As an archipelago, Shetland has an expansive coastline of over 2700km across over 100 islands. This study is focused within the inshore Shetland region within 12nm of shore. The study area covers a range of narrow, sheltered inlets, known locally as "voes" as well as commercial inshore fishing grounds.

2.2 Shetland inshore fish survey

The Shetland Inshore Fish Survey has been undertaken annually in its current expanded format since 2017, during August and September. The total 52 tow stations (Figure 1) cover a depth range of approximately 20 – 150m and have a variable tow duration of 0.2 - 1.0 hours depending on the size of available grounds. The survey is carried out aboard the 12m MFV *Atlantia II* (LK502), using a standard four-panel box trawl with small mesh (20mm) inner net. The survey gear is towed at approximately 2.5 knots and is fitted with a Notus net sensor system to monitor headline height and trawl door spread for consistency. Further details on the survey gear and methodology are available in Fraser et al. (2024).

The catch from each haul is sorted first, then weighed by species groups. For all commercially important species, total fish length measurements are recorded in cm. For species caught in particularly high abundance, subsampling of length measurements is carried out with a random subsample and the remainder of the catch is weighed.

In some instances, the survey design and location of sampling stations has been adjusted during the period considered within this report. Specifically, these are the "Sandsound" and "Hillswick Shallow" stations. The Sandsound survey location was in place from 2017-2020 before being discontinued due to proximity with a nearby, shallow station (Weisdale Voe, SHA05). In 2023, the Sandsound station was reinstated as a substitute when subsea cable laying operations obstructed surveying at the Weisdale Voe station. The Hillswick Shallow station was in place from 2017-2019 and was discontinued due to proximity to the tow path of an inshore station (Hillswick, BA03) and replaced with a station at Housa Voe.

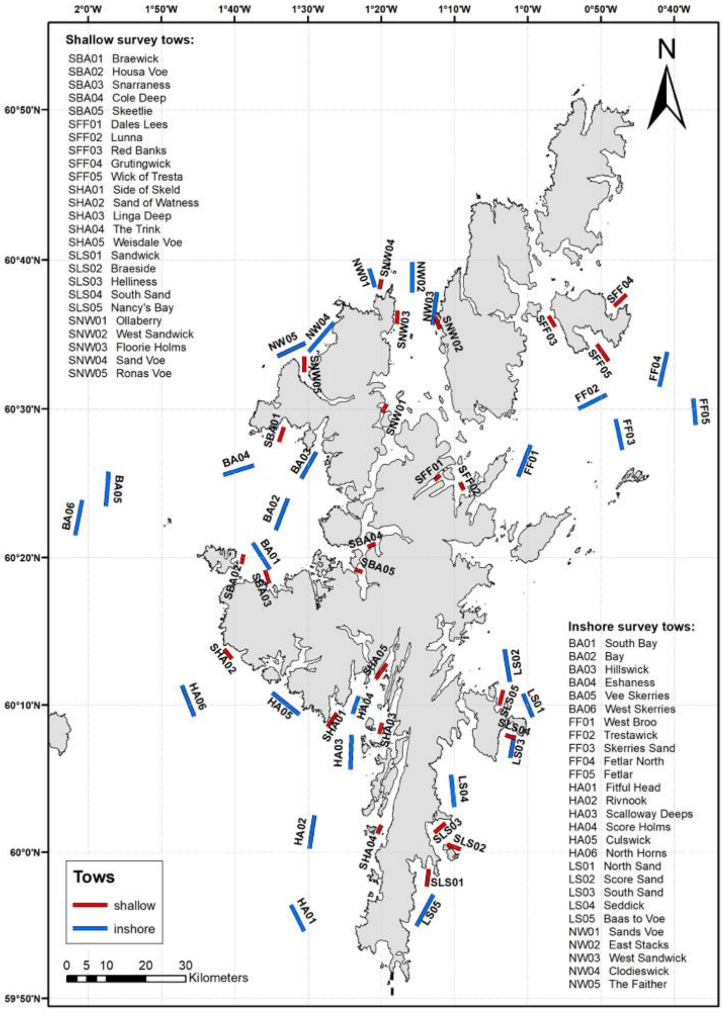

Figure 1. Shetland Inshore Fish Survey coverage, which comprises 27 inshore (blue) and 25 shallow (red) pre-determined sampling stations.

2.3 Data analysis

The study considers data collected from the Shetland Inshore Fish Survey 2017 to 2024. Species for analyses were selected based on commercial relevance and those sufficiently resolved in the available data, specifically:

- Atlantic cod (*Gadus morhua*)
- Haddock (*Melanogrammus aeglefinus*)
- Whiting (*Merlangius merlangus*)
- Plaice (*Pleuronectes platessa*)

ALKs for commercially important fish species are produced from IBTS as commissioned by the International Council for the Exploration of the Seas (ICES) and made publicly available through the Database of Trawl Surveys (DATRAS). The North Sea component of the IBTS (NS-IBTS) is spatially divided by roundfish areas, where ALKs for species in Area 1 are relevant to Shetland. Given that SIFS takes place in August-September, Area 1 ALKs from the NS-IBTS which took place in the third quarter (Q3) of 2017-2024 were selected for the study to account for seasonal growth differences. Individual ALKs for each study year were first inspected to confirm that inter-annual variation was minimal. From here, a merged ALK was composed for each species to combine age-at-length data for all study years.

Length data from SIFS were converted from cm to mm to facilitate comparison with NS-IBTS ALK data. Where required, catch data from SIFS was raised to account for subsampling. To correct for effort, catch per unit effort (CPUE; with units number of fish per hour) was calculated for each length interval.

To apply the NS-IBTS ALK of each species to the observed lengths of SIFS, analysis was conducted in RStudio (Version 2024.09.1), following the rationale in Ogle (2016). Based on the merged ALK, a smooth modelled ALK was produced for a given species using a multinomial logistic regression model with an iterative algorithm at 500 iterations which accounts for any missing length intervals. This produced a matrix of probabilities for age at any given length interval, accounting for variability in the length-at-age relationship for the species or dataset, i.e. a fish at 150mm may be 95% likely to be assigned age-0 and 5% likely to be assigned age-1. To estimate the abundance of each age class, CPUE of each observed length interval was multiplied by the corresponding age-at-length probability. As the focus here is on the smaller juvenile age classes, those fish interpreted to be over four years old were considered together and combined to form an age-5+ group.

In the case of plaice, age data were particularly limited for the youngest age classes in NS-IBTS Area 1. To ensure a comprehensive review of plaice age from the sampled population of SIFS, adjustments to the ALK were made. Length ranges for age-0 and age-1 plaice were manually input to reflect the lengths of the juvenile plaice, informed by literature review as well as the full NS-IBTS dataset for the species.

A series of length-frequency histograms for each species were produced and colourised by age class to visualise age structure. The histograms present the abundance and length range of age classes for SIFS 2017-2024. For each species, a time series line graph was produced to visualise temporal trends in relative abundance by considering the total age class CPUE, which is equivalent to the CPUE sum across relevant length classes for a given year and age. Species distribution maps were produced for survey years 2017-2024, to visualise the spatial and temporal distribution of age class CPUE. The output was used to identify habitat preference by age groups throughout the study period as well as inter-annual variation in distribution.

Lastly, persistent use of habitats by each species' juvenile subpopulations was interpreted through two methods. Here the focus was applied to the age-0 class, or first settled juveniles, as latter cohort size is known to be established within this initial stage. Firstly, the spatial distribution maps were used to identify species-specific areas of abundant age-0 concentrations which appeared repeatedly during the study period. Then persistence was assessed in a tabular form, where age-0 CPUE for each station from 2017-2024 was arranged by survey stations to investigate how consistently age-0 fish were present in each area through the years. A CPUE threshold (> 10 n / hr for all gadoids, > 1 n / hr for plaice) was applied prior to calculating annual persistence to reduce the influence of any spurious catches. This produced a persistence rate for each survey station as a percentage, which was used to highlight potential nursery areas.

3 Results

The results are arranged by species in the following subsections where length-frequency histograms are presented to show age structure results, time series line plots are used to interpret the relative abundance of different age classes, and spatial distribution maps are considered for evidence of habitat preferences and inter-annual variability. For all plots, the modelled age structure is presented in colour, where each age-at-length group can be visually differentiated in accordance with the figure legend. Colour classification of age groups is consistent throughout all results.

3.1 Haddock

3.1.1 Age structure

The length-frequency histograms presented in Figure 2, illustrate the observed lengths for haddocks from the sampled population of the 2017-2024 SIFS. For haddock, total length observed during the time series ranged from 60-700mm. Individuals from age-0 to age-5+ classes were observed in all survey years, with varying abundances between years. This variation in abundance was greatest in the youngest age classes (age-0, age-1); compared to the oldest classes, where CPUE appeared more stable throughout.

Length distributions of the age-0 class were largely well-defined and distinct, generally presenting a normal, bell-shaped curve. The modal length of the age-0 population was centred at approximately 120mm, with a consistent length range of 60-160mm. However, the sampled population of 2017 deviates from this normal pattern with a markedly low CPUE. Also, the length-frequency distributions of the age-0 class in 2020 and 2024 were positively skewed (to the right), where the most frequently observed lengths were at the larger end of the length distribution. In 2020 and 2024, the modal age-0 length was centred at approximately 140 and 130mm, respectively. Notably, the length range of the age-0 class demonstrates minimal overlap with age-1 in all years.

Haddock age-1 length-frequency distribution also presented a bell-shaped curve, yet over a broader distribution. This highlights a greater range of lengths, presented at approximately 150-320mm, with a peak abundance concentrated within the 240-270mm range. Overlap of the upper length limits for the age-1 class and the lower limits of age-2 was consistent throughout the study period.

Similarly, age-2 exhibited a wide distribution of lengths and substantial overlap with the successive age classes. The age-2 group lacked a stable mode, generally varying over the length range 240-360mm.

Length range overlap of the three oldest age groups is notable, with both age-3 and age-4 individuals observed from approximately 280-500mm. The length-frequency distribution of the age-5+ group lacks a structure in most years due to the limited number of observations. However, in 2017 and 2023 the age-5+ class is seen from approximately 340mm, overlapping the peak frequency of age-3 and age-4 groups.

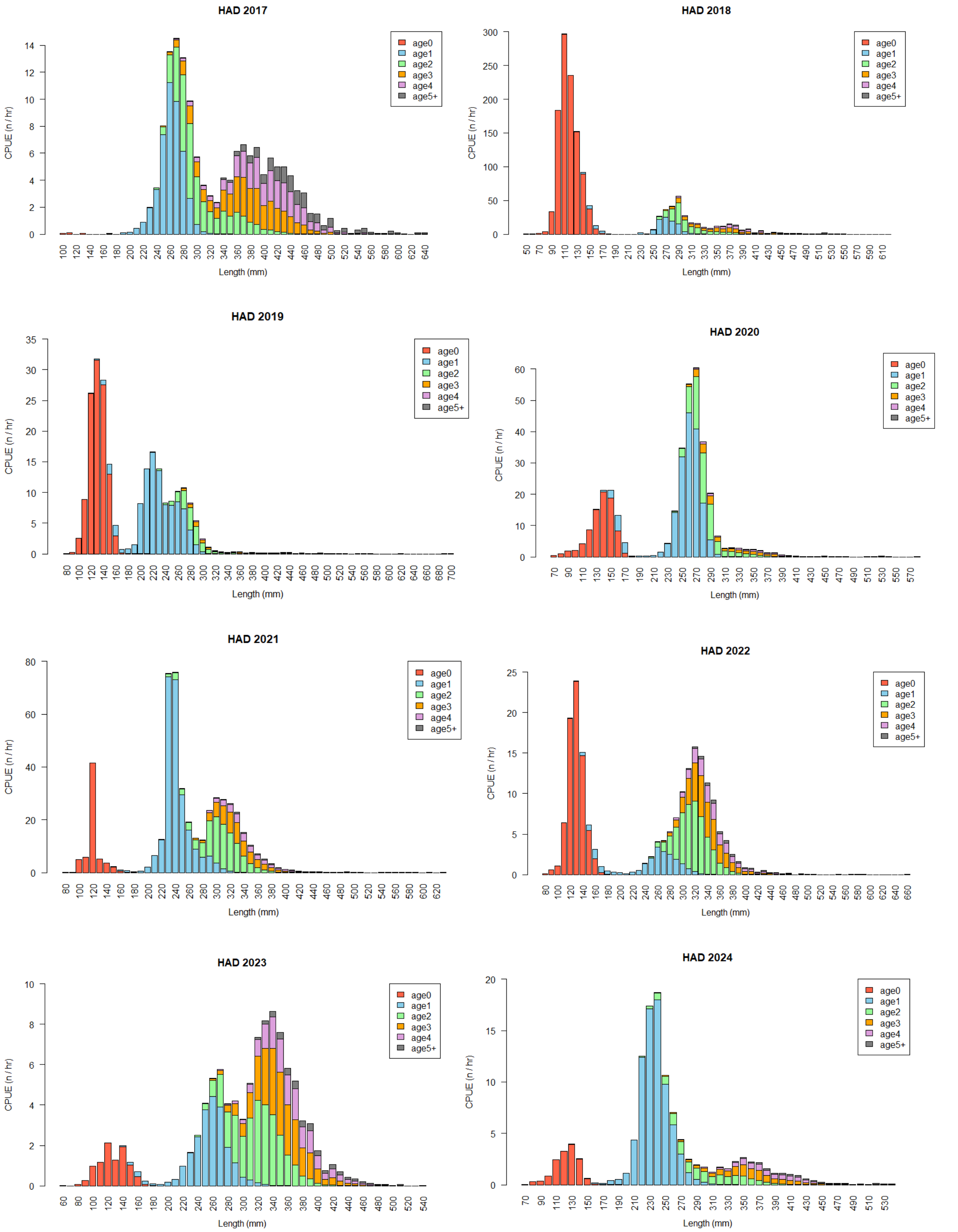

Figure 2. Haddock age structure from SIFS 2017-2024, categorised by colour as shown in the legend. Here, frequency of individuals within a length interval is given as CPUE (number of fish caught, per hour) and length is recorded in millimetres (mm).

3.1.2 Relative abundance

The population dynamics of haddock age classes from the sampled populations of SIFS 2017-2024 are presented in Figure 3.

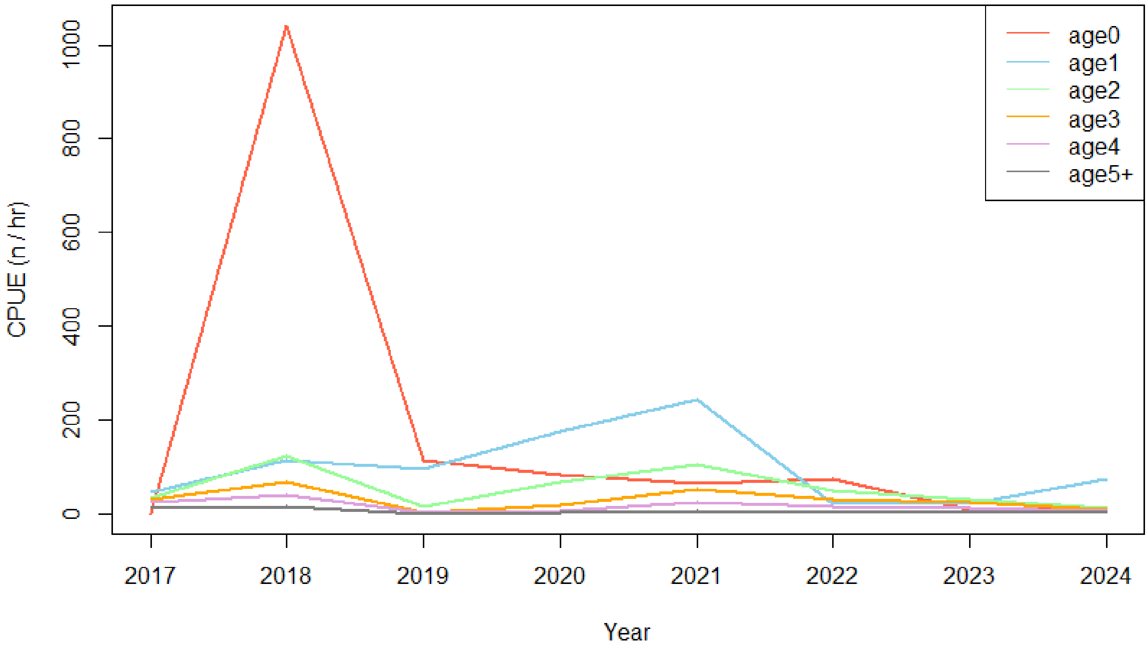

Figure 3. Relative abundance in CPUE of haddock age classes from SIFS 2017-2024. Colouration of age groups follows the same order as previous plots.

Throughout the time series, the youngest age classes (age-0, age-1) were generally most abundant within the sampled population. Older age groups (age-4, age-5+) consistently held the lowest abundance of all cohorts comparatively. The inter-annual variability in CPUE was greatest for younger age groups and decreased progressively in successive classes. A peak abundance for age-0 was observed in 2018, but the trend did not translate directly into an exceptional year-class strength for the 2019 age-1 cohort. Similarly, the relatively high abundance of age-1 in 2021 was not linked to an overall stronger age-2 cohort for 2022. Collectively, the age-at-length groups of age-2 to age-5+ follow a consistent pattern throughout the time series. A decline in CPUE for all groups was observed from 2022 until evidence of an increasing abundance for age-1 in 2024.

3.1.3 Spatial distribution and persistence

The spatial abundance of haddock age classes 0-5+ from the sampled population of SIFS 2020 and 2023 are presented in Figure 4 and Figure 5, respectively. These selected results exemplify two differing spatial trends exhibited by haddock juvenile subpopulations throughout the study period. Haddock results for other years are presented in Appendix A.

Spatial distribution of all haddock age classes in 2020 (Figure 4) presented two fundamental trends which aid the identification of nursery habitats. Firstly, a high, concentrated abundance of age-0 primarily localised to four shallow area stations. These stations are clustered into specific voe systems in the central West (Sandsound and Weisdale Voe) and Northeast (Lunna and Dales Lees) of mainland Shetland. The age-1 class of 2020 exhibits the first stage of a progressive offshore movement trend of the successive age groups. This is evidenced by the wide distribution of age-1 haddock observed in the deeper water, inshore stations which encompasses the majority of the survey area. Age-1 haddock were also observed across the shallow stations noted for age-0, with lesser abundance. Age-2 haddock presented a similar widespread distribution as age-1, maintaining a presence in Weisdale Voe but were no longer utilising the Lunna and Dales Lees sites. In age-3 to age-4 classes, distribution remains broad but with declining relative abundance which is seen proportionally across all stations. Distribution of the age-5+ class is sparse, with the lowest abundance of all age-at-length groups.

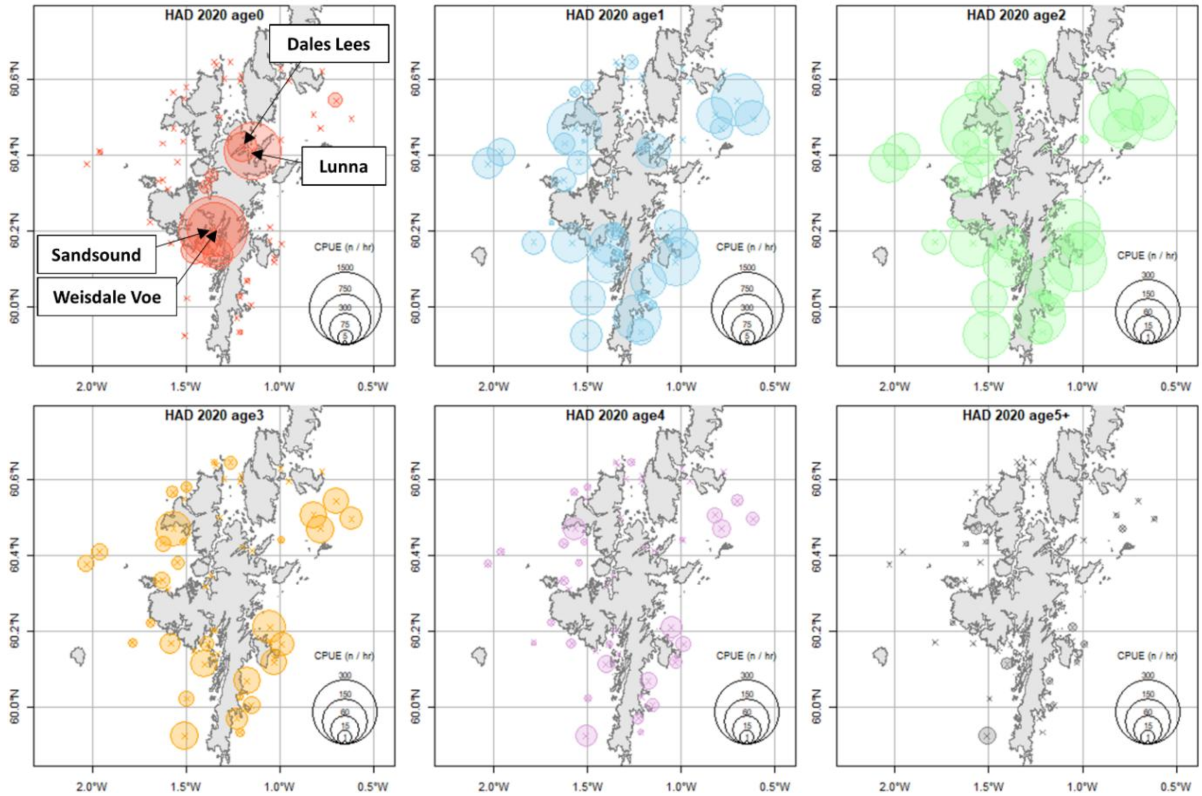

Figure 4. Spatial abundance of haddock age classes from the sampled population of SIFS 2020. The plots are arranged into windows by age groups which follow the same colouration as previous plots. SIFS 2020 station midpoints are denoted by 'x' symbols. CPUE of haddock age class from each station is presented by a bubble scale. The size of the bubble is scaled relative to the CPUE scale in the bottom-right corner of each window.

Conversely, the haddock spatial distribution of 2023 (Figure 5) shows a broad use of shallow and inshore sites by the age-0 group. The greatest abundances of age-0 remain concentrated within two shallow areas on the West mainland (Sandsound and Skeetlie). Age-0 haddocks observed in inshore, deeper water areas were seen in lesser concentrations than in shallow areas. The inshore sites with a presence of age-0 spanned the full survey area. An offshore movement trend was observed in the following age classes. This is evidenced by the increased abundance of age-1 haddocks across inshore stations and a decrease in utilisation of shallow sites which overlap with age-0. The age-2 group presents a similar distribution to age-1, with a presence and strong abundance across the majority of the inshore survey area. Spatial range of the age-3 to age-5+ cohorts remains consistent, spanning the full range of inshore survey locations, with progressively declining CPUE through the age groups.

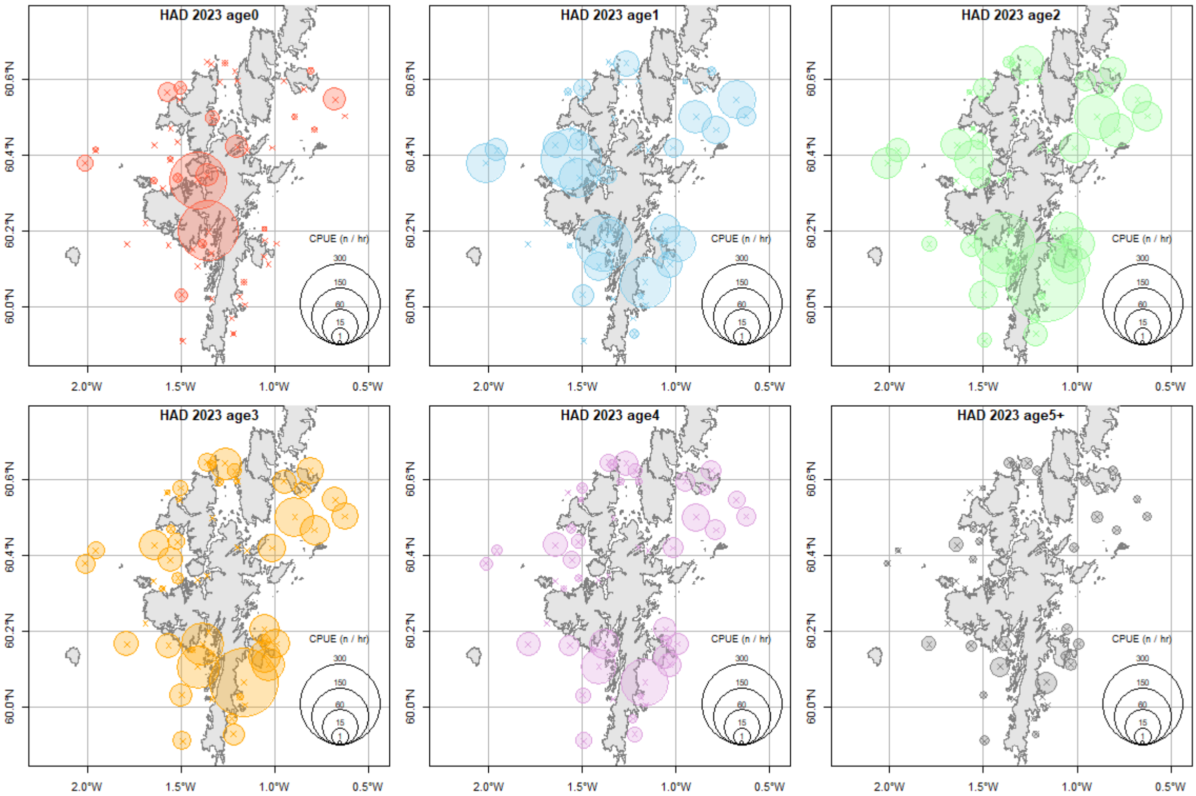

Figure 5. Spatial abundance of haddock age classes from the sampled population of SIFS 2023. The plots are arranged into windows by age groups which follow the same colouration as previous plots. SIFS 2023 station midpoints are denoted by 'x' symbols. CPUE of haddock age class from each station is presented by a bubble scale. The size of the bubble is scaled relative to the CPUE scale in the bottom-right corner of each window.

Throughout the study period, persistent abundances of juvenile haddock were observed over a broad range of shallow and inshore stations. Consequently, a large range of age-0 persistence rates were produced (Table 1). Of these, sites with ≥ 75% persistence of juveniles were limited to specific shallow areas. This included the Cole Deep (88%), Weisdale Voe (86%), Skeetlie (86%), Sandsound (80%), Linga Deep (75%) and Dales Lees (75%) stations. The Cole Deep and Weisdale Voe stations presented high juvenile haddock abundance in all sampled survey years, except for in 2017 which saw markedly low age-0 CPUE values ubiquitously. The Weisdale Voe station also saw a peak CPUE in 2018. Cole Deep was the primary hotspot of age-0 haddock in 38% of survey years presented, these were 2019, 2021 and 2022. The Skeetlie station was established in 2018 at the north end of the Aith Voe and observed variable age-0 catch rates throughout. The survey location at Sandsound was in place intermittently and was the primary hotspot of age-0 haddock in 2020 and 2023. Across all years, the greatest abundance of juvenile haddock was seen at Linga Deep in 2018. A decline in CPUE at Linga Deep was observed in successive years to a low in 2023 but increased again in 2024. Similarly, the Dales Lees station observed variable juvenile abundances but was the primary age-0 hotspot of haddock in 2024.

Table 1. CPUE (n/hr) for each survey year and average CPUE of age-0 haddock is presented for stations which demonstrate a persistence rate ≥ 50%. Persistence is calculated as the percentage of years which observed >10 n/hr within the station, across all survey years.

Grounds	Station	2017	2018	2019	2020	2021	2022	2023	2024	Average CPUE	Persistence (%) >10 n/hr
Cole Deep	SBA04	0.00	1054.51	2585.28	50.60	2004.26	2534.63	23.66	10.65	1032.95	88
Weisdale Voe	SHA05	0.00	2798.39	409.22	861.58	232.51	77.87	-	142.73	646.04	86
Skeetlie	SBA05	-	1730.73	1494.88	54.54	340.81	714.89	154.04	0.00	641.41	86
Sandsound	-	0.00	2606.18	772.31	1378.32	-	-	171.03	-	985.57	80
Linga Deep	SHA03	0.01	14743.83	567.07	264.72	151.47	12.22	0.00	56.39	1974.46	75
Dales Lees	SFF01	0.00	680.20	0.00	272.89	11.98	319.13	23.97	401.50	213.71	75
Score Holms	HA04	0.44	10347.77	16.60	134.77	14.27	31.20	3.84	6.20	1319.39	63
Lunna	SFF02	0.00	2312.19	1.39	942.81	296.82	15.57	0.00	23.89	449.08	63
Fetlar North	FF04	0.00	15.74	0.00	60.62	2.55	20.37	25.47	11.29	17.01	63
West Skerries	BA06	1.25	15.48	0.00	1.46	39.77	1.94	13.05	18.72	11.46	50

The remaining stations with persistence rates ≥ 50% were the Score Holms (63%), Lunna (63%), Fetlar North (63%) and West Skerries (50%) stations. Notably, as an inshore, deeper water station, Score Holms was the second greatest hotspot of age-0 haddock in 2018 but presents overall decline in CPUE in successive years. Age-0 abundances were highly variable at the Lunna station but exhibited a peak abundance in 2018 as seen in other locations. The Fetlar North station is an inshore, deeper water site which presented moderate CPUE values which peaked in 2020. West Skerries, another deeper water station, saw moderate age-0 catch rates in 50% of the survey years presented. In 2017, the West Skerries station was one of three inshore sites which saw juvenile haddock CPUE values >1.

3.2 Cod

3.2.1 Age structure

The length-frequency histograms presented in Figure 6, illustrate the observed lengths for cod from the sampled population of the 2017-2024 SIFS. For cod, total length observed during the time series ranged from 50-1020mm. Individuals from age-0 to age-5+ classes were observed in all survey years, with varying abundances between years. This variation in abundance was greatest in the youngest age classes (age-0, age-1); compared to the oldest classes, where CPUE appeared more regular throughout.

Length distribution of age-0 cod was well-defined, ranging from 50-180mm, with a variable structure. Certain years presented a curve with a well-defined peak (2017, 2018, 2020, 2022 and 2024); whereas other years (2019, 2021 and 2023) featured a relatively flat distribution where the frequency of lengths within the age-0 class were more evenly distributed. Age-0 cod in 2017 and 2020 had a positively skewed distribution (to the right), where the most frequently observed lengths were at the larger end of the length distribution. Conversely, age-0 of 2018 and 2024 presented a negatively skewed distribution (to the left), where the mostly frequently observed lengths were at the smaller end of the length distribution. Thus, overall, the modal age-0 length for cod varied between 80-130mm through the study period. The upper length limits of the age-0 group demonstrated some overlap with the lower lengths of age-1.

The cod age-1 group typically presented a normal, bell-shaped length-frequency distribution. The range of lengths was consistently broad throughout the study period, ranging from 180-390mm. Peak frequency for the age class was centred at approximately 270-300mm. Consistent overlap between the upper limits of the age-1 length range and lower limits of age-2 was also observed.

Similarly, age-2 cod exhibited a broad distribution of lengths and substantial overlap with the successive age classes. The age-2 class was distributed over a length range of 240-600mm and lacked a strong mode. However, the sampled population of 2018 and 2024 are an exception to this, with a peak frequency centred around 450mm.

An overlap of length range in the three oldest age groups is also noted. Due to lower CPUE values, the length-frequency distributions of the age-3 to age-5+ classes were generally poorly defined. Length observations for the age-3 group were seen over a wide range, from 390-770mm, overlapping with the age-4 class from approximately 560mm. Lengths of the age-5+ class range from approximately 690mm to the largest individual at 1020mm in 2017.

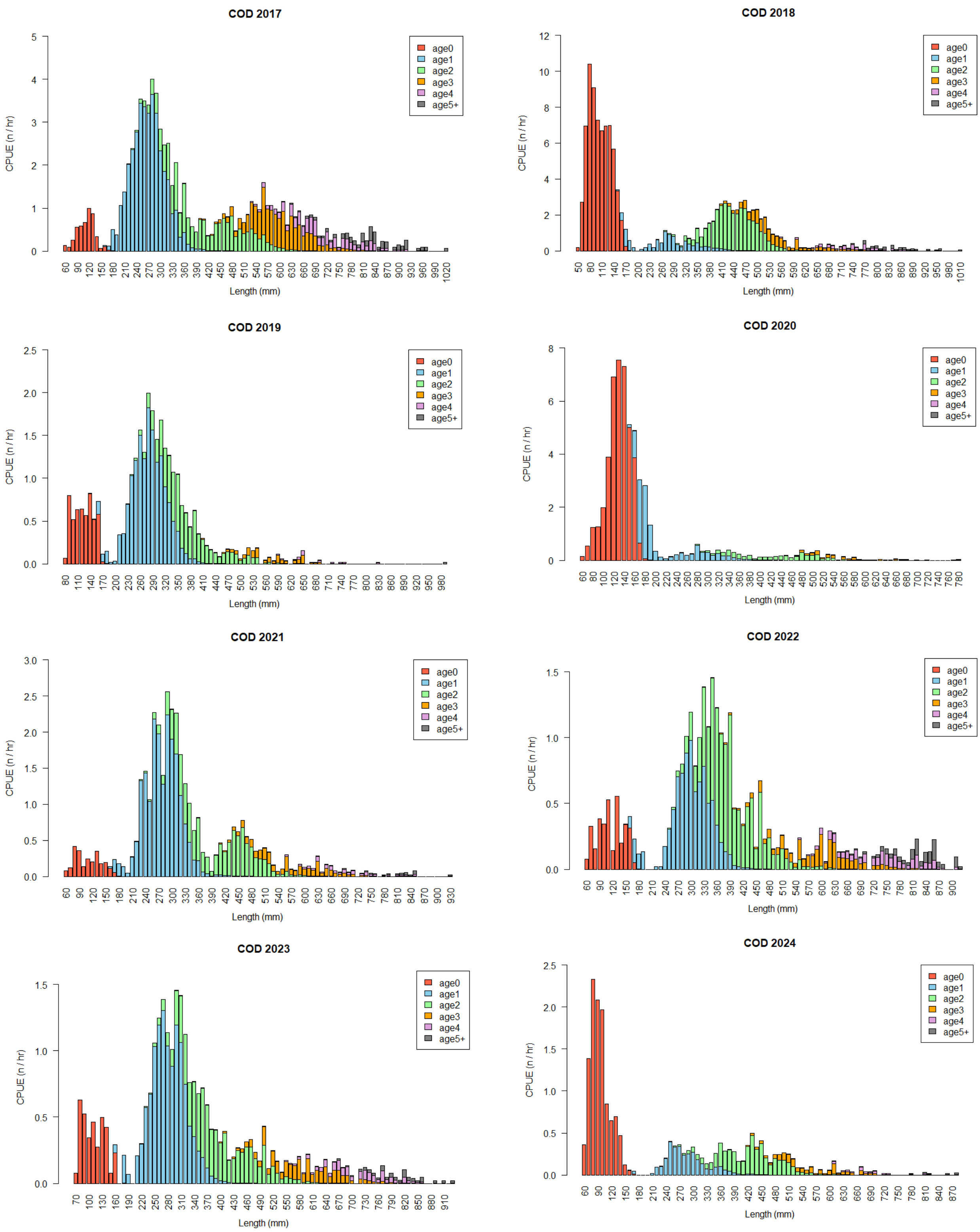

Figure 6. Cod age structure from SIFS 2017-2024, categorised by colour as shown in the legend. Here, frequency of individuals within a length interval is given as CPUE (number of fish caught, per hour) and length is recorded in millimetres (mm).

3.2.2 Relative abundance

The population dynamics of cod age classes from the sampled populations of SIFS 2017-2024 are presented in Figure 7.

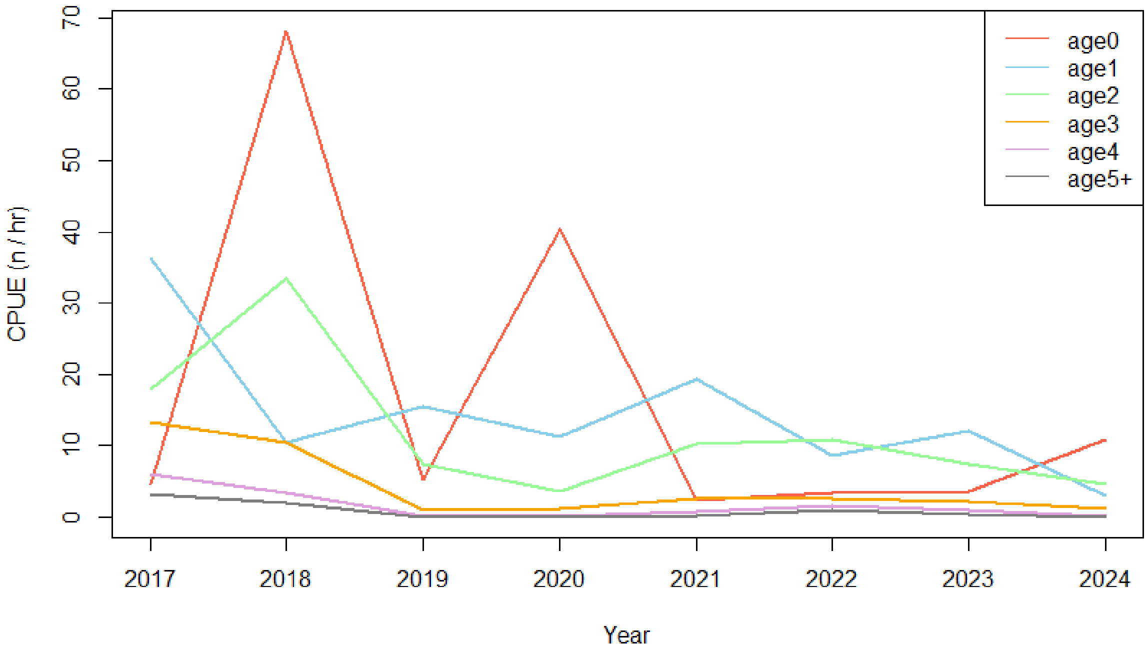

Figure 7. Relative abundance in CPUE of cod age classes from SIFS 2017-2024. Colouration of age groups follows the same order as previous plots.

Throughout the time series, the youngest age groups (age-0 to age-2) were most abundant within the sampled population. Older age groups (age-3 to age-5+) were characterised by relatively lower abundances which followed a consistent pattern throughout the study period. Inter-annual variation in cod CPUE was also greatest in the younger age groups. However, this became more consistent from 2021 onward. Peak abundance for age-0 was observed in 2018 and 2020, which was followed by increased abundance for age-1 in the successive years in both cases. The age-0 peak abundance for 2020 was also associated with an increase of age-2 in 2022. The cod age-1 group exhibited a peak abundance in 2017, which was followed by the greatest abundance of age-2 in 2018.

3.2.3 Spatial distribution and persistence

The spatial abundance of cod age classes 0-5+ is presented in Figure 8 with data from SIFS 2020 selected as a representative example. Cod results for other years are presented in Appendix B.

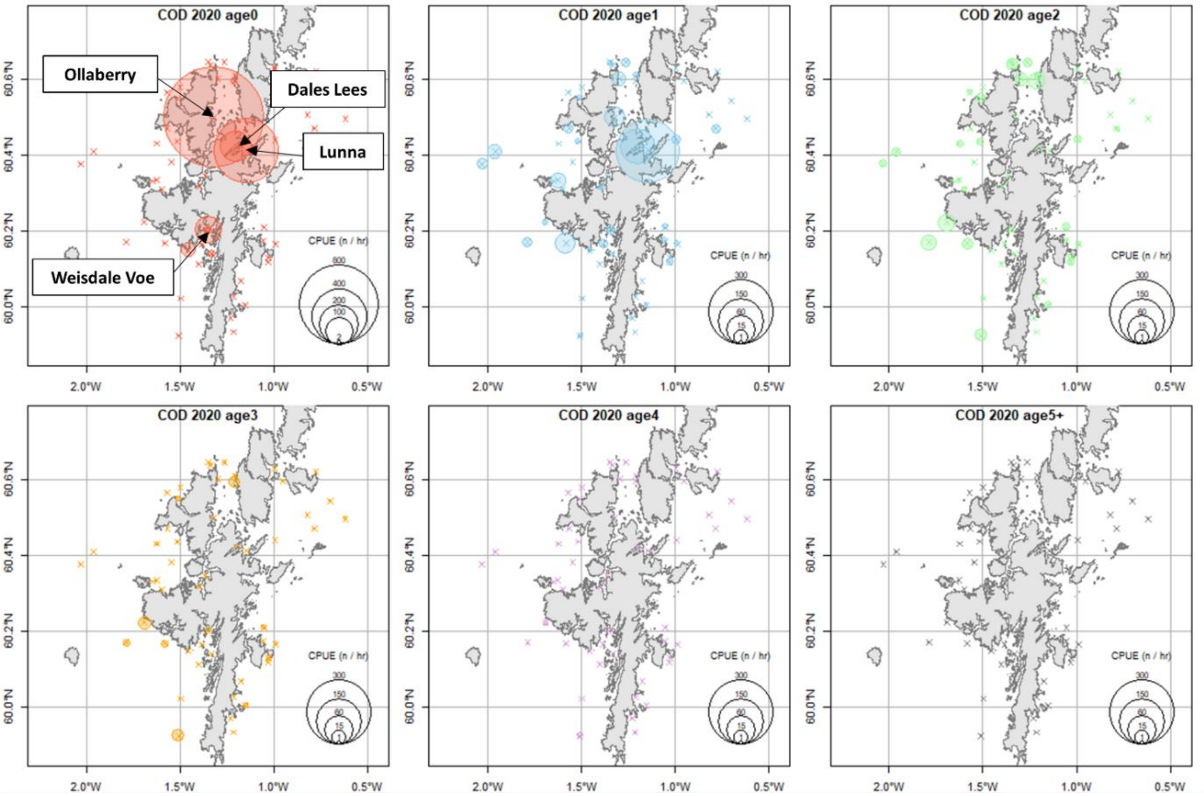

Figure 8. Spatial abundance of cod age classes from the sampled population of SIFS 2020. The plots are arranged into windows by age groups which follow the same colouration as previous plots. SIFS 2020 station midpoints are denoted by 'x' symbols. CPUE of cod age class from each station is presented by a bubble scale. The size of the bubble is scaled relative to the CPUE scale in the bottom-right corner of each window.

Spatial distribution of all cod age groups in 2020 present two trends which are the characteristic of nursery habitat use. Firstly, highly concentrated abundances of age-0 cod localised to three specific shallow area stations. These sites are localised to sheltered, shallow inlets in the North mainland of Shetland (Ollaberry, Lunna and Dales Lees). Secondly, the age-1 class exhibits the first stage of a progressive offshore movement trend of the successive age classes. Age-1 cod were seen with a wider spatial distribution into deeper water, inshore sites. The age-1 group also maintained a presence within the shallow sites utilised by age-0, in particular the sites in the northeast of the study area but with a lesser abundance. However, age-2 cod were no longer present in these shallow sites. The age-2 group presented a similar distribution across inshore sites to age-1, with greater abundance in some areas. As previously described, CPUE of older age classes for cod begins a gradual decline from age-2 onwards. In the age-3 class, distribution remains spread across inshore sites with an overall decrease in abundance. Distribution of the age-4 to age-5+ classes is sparse, with the lowest abundances of all age-at-length groups.

Throughout the study period, persistent abundance of juvenile cod was only seen in specific shallow sites (Table 2). The Ollaberry station was recognised as a persistent hotspot of age-0, with juveniles seen in 100% of the survey years presented. Peak abundance of age-0 cod was seen in Ollaberry in 2020 and a decline in CPUE was observed in successive years. Following this, the only station with a persistence rate ≥ 75% was the Dales Lees (88%) site. Dales Lees was the primary hotspot of age-0 cod for 50% of survey years, including the three most recent survey years (2022-2024).

Table 2. CPUE (n/hr) for each survey year and average CPUE of age-0 cod is presented for stations which demonstrate a persistence rate ≥ 50%. Persistence is calculated as the percentage of years which observed >10 n/hr within the station, across all survey years.

Grounds	Station	2017	2018	2019	2020	2021	2022	2023	2024	Average CPUE	Persistence (%) >10 n/hr
Ollaberry	SNW01	26.98	385.77	129.08	1296.65	42.00	13.33	23.33	31.30	243.56	100
Dales Lees	SFF01	136.65	283.22	20.78	125.03	8.00	114.09	70.31	323.93	135.25	88
Weisdale Voe	SHA05	0.00	95.01	11.91	94.66	0.00	30.59	-	151.05	54.74	71
Lunna	SFF02	0.00	6.14	17.77	532.08	38.29	6.71	60.00	59.99	90.12	63
Sandsound	-	0.68	56.91	17.57	10.00	-	-	30.40	-	23.11	60

The remaining sites with persistence rates ≥ 50% were the Weisdale Voe (71%), Lunna (63%) and Sandsound (60%) stations. The Weisdale Voe station held lower age-0 CPUE values, including two years with no cod age-0 observations. However, Weisdale Voe was the second greatest hotspot of age-0 cod in 2024. The Lunna site showed a variable presence of age-0 cod, with a peak abundance in 2020. In 2020, 2021 and 2023, Lunna was the second greatest hotspot for juvenile cod across the full survey area. As previously mentioned, the station at Sandsound was sampled intermittently and catches of age-0 cod were present in all sampled years. Beyond the stations presented in Table 2, the next greatest persistence rates were 25% at two sites, Linga Deep and Side of Skeld. Notably, these stations are in close proximity to the Weisdale Voe and Sandsound sites.

3.3 Whiting

3.3.1 Age structure

The length-frequency histograms presented in Figure 9, illustrate the observed lengths for whiting from the sampled population of the 2017-2024 SIFS. For whiting, total length observed during the time series ranged from 50-560mm. Individuals from age-0 to age-5+ were observed in all survey years, with varying abundances between years. The variation in abundance was greatest in age-0, compared to the older age groups where CPUE was more consistent. Length distribution of the age-0 class was well-defined, typically presenting a normal, bell-shaped curve. The modal length of the age-0 population was centred at approximately 110-120mm, with a consistent length range of 50-180mm. Overlap of the upper limits of the age-0 length range and the lower limits of age-1 was frequent throughout the study period, starting at approximately 150mm.

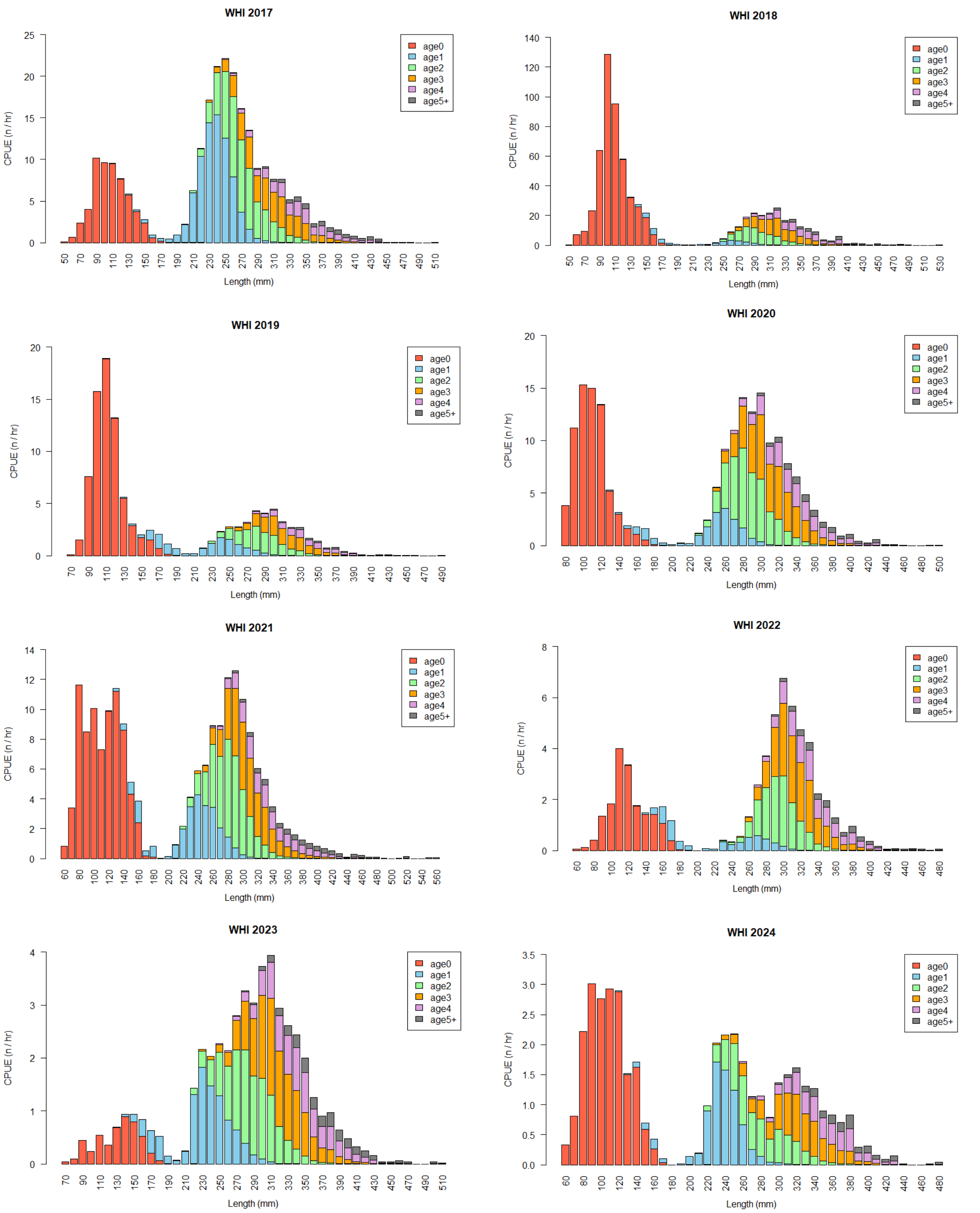

Figure 9. Whiting age structure from SIFS 2017-2024, categorised by colour as shown in the legend. Here, frequency of individuals within a length interval is given as CPUE (number of fish caught, per hour) and length is recorded in millimetres (mm).

Whiting age-1 to age-5+ groups exhibit substantial overlap in length range. Nonetheless, age-1 and age-2 groups present a normal distribution structure. The length range of age-1 is consistent throughout the study period, ranging from 150-300mm with a variable modal length of 230-270mm. Similarly, the age-2 length range has a broad distribution over 210-

370mm and the peak frequency of length observations varies from 240-300mm. The length distribution structure of the age-3 to age-5+ classes is less distinct, given the progressively decreasing abundance. Length range overlap of the older classes is also substantial, with age-3 and age-4 observed from approximately 250-410mm. The peak length frequency of age-4 is centred at approximately 300mm, where the overlap of the age-5+ class begins.

3.3.2 Relative abundance

The population dynamics of whiting age classes from the sampled populations of SIFS 2017-2024 are presented in Figure 10. Over the time series, the age-0 class were typically most abundant within the sampled population. However, the sampled populations of 2022 and 2023 deviate from this trend and exhibited the lowest abundances for both age-0 and age-1 classes. Of all age-at-length groups, age-1, age-4 and age-5+ were consistently least abundant in the sampled populations. Variability in CPUE was greatest for age-0 and more consistent for the successive age groups. A peak abundance for age-0 was observed in 2018, but the trend did not translate directly into a higher year-class strength for the 2019 age-1 cohort. The greatest abundance of age-1 was seen in 2017, which was followed by a relatively high abundance for the age-2 cohort in 2018. Collectively, the age-at-length groups of age-2 to age-5+ follow a more consistent pattern throughout the time series. With the exception of age-0 increasing abundance in 2024, an overall decline in CPUE was exhibited by all groups from 2021 onwards.

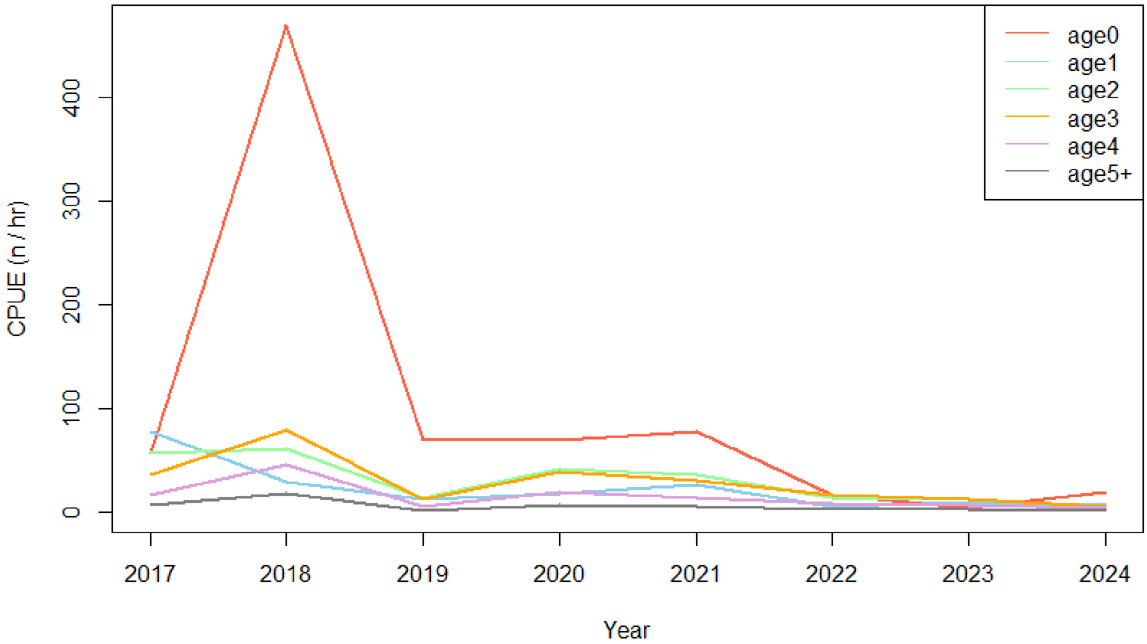

Figure 10. Relative abundance in CPUE of whiting age classes from SIFS 2017-2024. Colouration of age groups follows the same order as previous plots.

3.3.3 Spatial distribution and persistence

The spatial abundance of whiting age classes 0-5+ is presented in Figure 11 with data from SIFS 2022 selected as a representative example. Whiting results for other years are presented in Appendix C.

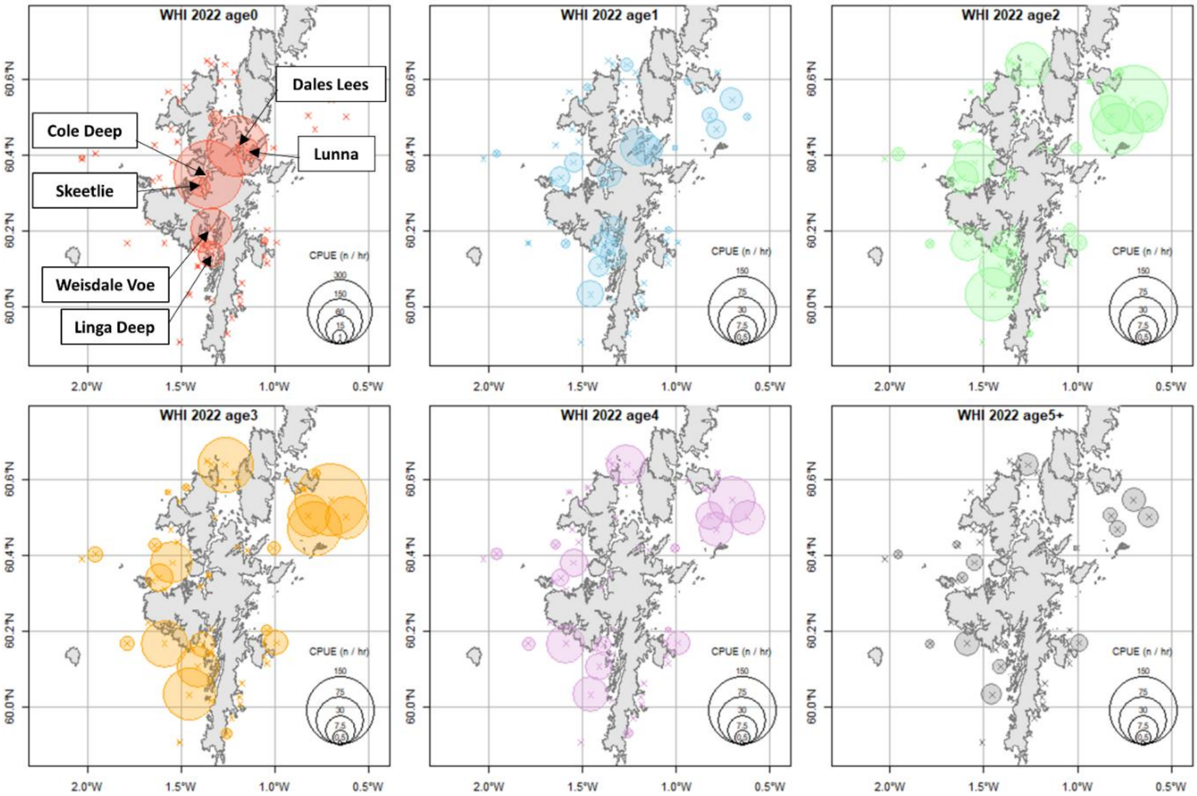

Figure 11. Spatial abundance of whiting age classes from the sampled population of SIFS 2022. The plots are arranged into windows by age groups which follow the same colouration as previous plots. SIFS 2022 station midpoints are denoted by 'x' symbols. CPUE of whiting age class from each station is presented by a bubble scale. The size of the bubble is scaled relative to the CPUE scale in the bottom-right corner of each window.

The spatial distribution of all whiting age classes in 2022 (Figure 11) showed two fundamental trends which indicate nursery habitat use by juveniles. Firstly, a highly concentrated abundance of the age-0 class, localised to six shallow survey areas. These stations are clustered into three separate shallow and sheltered areas: Cole Deep and Skeetlie to the north of the Westside; Weisdale Voe and Linga Deep to the south of the Westside; and Dales Lees and Lunna to the east of mainland Shetland. The age-1 class in 2022 shows the first stage of a progressive offshore movement trend of the successive age groups. This is demonstrated by the wide distribution of age-1 whiting in deeper water, inshore stations. Age-1 whiting continued to maintain a presence in the shallow areas utilised by age-0, but with less abundance. As previously described, observed whiting abundance generally increased from age-1 to the age-2 class. Age-2 presented a similar inshore spatial distribution to age-1 but were no longer present in the Weisdale Voe, Skeetlie, Dales Lees and Lunna sites. In age-3 to age-4 classes, distribution remains spread throughout the inshore stations, with minimal presence in the shallow areas. Spatial distribution of age-5+ whiting was confined to the deeper water areas, with the lowest abundances of all age-at-length groups.

Throughout the study period, highly persistent abundances of juvenile whiting were primarily seen at specific shallow stations (Table 3). The Weisdale Voe, Sandsound and Dales Lees survey locations were recognised as persistent hotspots of age-0, with juveniles seen in 100% of the survey years presented. For each of these stations, a peak abundance of age-0 whiting was observed in 2018. Aside from these areas, other sites with ≥ 75% persistence of juveniles were limited to: Lunna (88%), Skeetlie (86%) and Ollaberry (75%). Across all years, the greatest abundance of age-0 whiting was seen at Skeetlie in 2018 and a decline in CPUE here was observed in successive years to <0.01 n/hr in 2024. The greatest age-0 densities for 2019 and 2020 were observed in Ollaberry.

Table 3. CPUE (n/hr) for each survey year and average CPUE of age-0 whiting is presented for stations which demonstrate a persistence rate ≥ 50%. Persistence is calculated as the percentage of years which observed >10 n/hr within the station, across all survey years.

Grounds	Station	2017	2018	2019	2020	2021	2022	2023	2024	Average CPUE	Persistence (%) >10 n/hr
Weisdale Voe	SHA05	1143.25	1280.74	153.45	640.62	53.34	123.12	-	546.22	562.96	100
Sandsound	-	105.20	1353.93	413.15	694.41	-	-	36.84	-	520.71	100
Dales Lees	SFF01	535.22	2094.92	158.94	297.24	161.45	263.72	130.91	78.27	465.08	100
Lunna	SFF02	10.45	514.40	85.33	669.31	682.56	38.88	3.33	278.64	285.36	88
Skeetlie	SBA05	-	10092.97	532.25	210.73	110.37	29.57	46.82	0.00	1574.67	86
Ollaberry	SNW01	44.75	28.61	1818.17	1046.78	1236.54	13.28	3.33	0.04	523.94	75
Cole Deep	SBA04	15.25	1000.41	135.67	5.16	1550.86	339.83	0.00	8.65	381.98	63
Score Holms	HA04	0.04	392.45	0.02	1.71	2.13	21.40	11.92	35.75	58.18	50
Linga Deep	SHA03	4.21	176.87	169.66	11.99	5.53	50.72	3.33	2.60	53.11	50

The remaining stations with persistence rates ≥ 50% were the Cole Deep (63%) and Linga Deep (50%) and Score Holms (50%) sites. Cole Deep presented as the primary hotspot of juvenile whiting in 2021 but was seen with variable catch rates across all years. Similarly, the Linga Deep station observed variable presence of age-0, with a decline in CPUE in recent years. Score Holms is an inshore, deeper water survey location which presented variable whiting juvenile abundances characterised by a peak in 2018 followed by a low in 2019 and an increase trend in recent years.

3.4 Plaice

3.4.1 Age structure

The length-frequency histograms presented in Figure 12 illustrate the observed lengths for plaice from the sampled population of the 2017-2024 SIFS. In contrast to the gadoid species, the sampled population of plaice from SIFS comprised a majority of age-5+ individuals. Observations of juvenile plaice were relatively low throughout the study period compared to the other species considered.

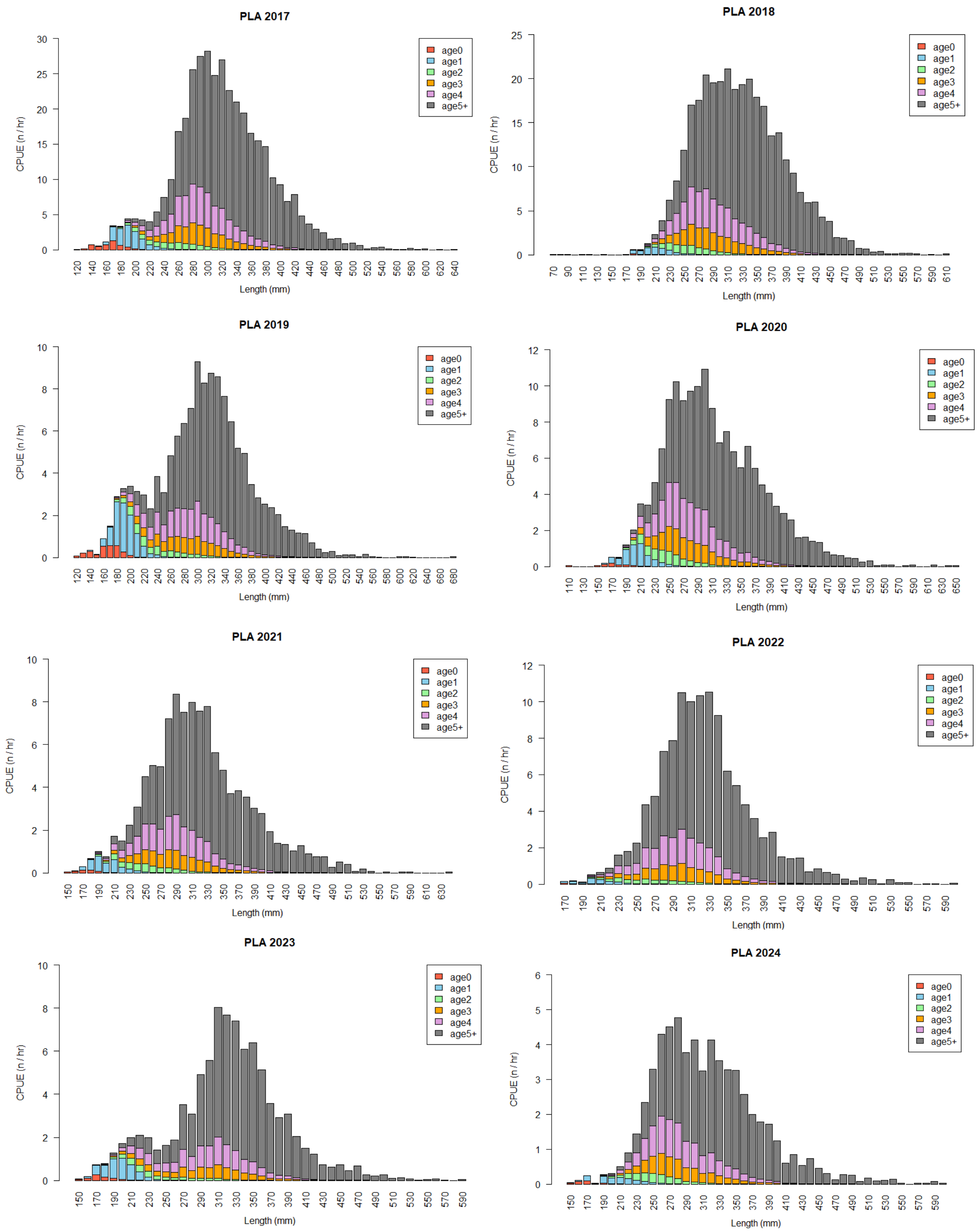

Figure 12. Plaice age structure from SIFS 2017-2024, categorised by colour as shown in the legend. Here, frequency of individuals within a length interval is given as CPUE (number of fish caught, per hour) and length is recorded in millimetres (mm).

For plaice, total length observed during the time series ranged from 70-680mm. Individuals from age-0 to age5+ were observed in all survey years, with varying abundances between years. The length distribution structure of the age-0 group is poorly defined in some years, given the low abundances observed. Consequently, the age-0 group lacked a stable modal length. The observed length range was variable, starting at 70-170mm but held a consistent upper limit of approximately 200mm across the study period.

The plaice age-1 group exhibited overlap with age-0 but held a consistent peak length frequency at 190mm over a length range of 160-250mm. Similarly, the lower length range limits of the age-2 group showed overlap with the upper limits of age-1. The age-2 group lacked a strong modal length over a consistently broad length distribution of 180-330mm. Significant overlap of length intervals of all age groups was observed from approximately 190mm. The age-3 to age-5+ groups consistently followed a more similar length distribution structure and the overall modal length for the sampled population was centred at approximately 300mm.

3.4.2 Relative abundance

The population dynamics of plaice age classes from the sampled population of SIFS 2017-2024 are presented in Figure 13. Throughout the time series, the oldest age classes were most abundant within the sampled population. The age-0 class consistently held the lowest observed abundance of all cohorts comparatively. Variability in CPUE was greatest for the age-5+ class and decreased progressively in the successive age groups. A slight increase in abundance for age-1 plaice was observed in 2019, but the trend was not reflected in any earlier or later cohorts. The peak abundance for all age-at-length groups was observed in 2017, which was followed by a general decline in CPUE for all groups thereafter.

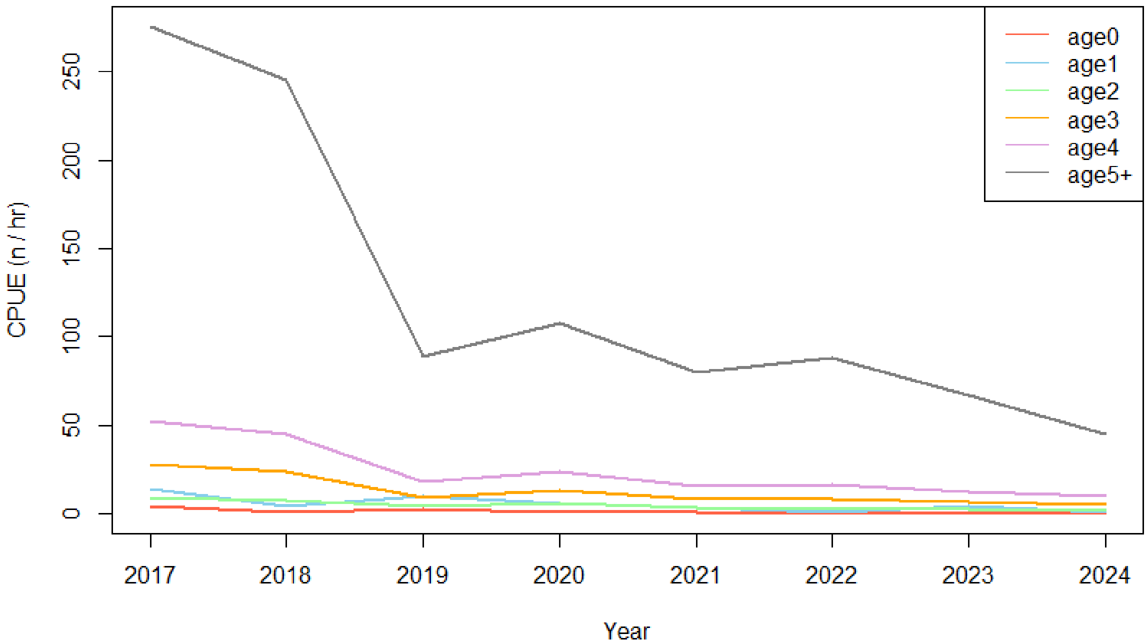

Figure 13. Relative abundance in CPUE of plaice age classes from SIFS 2017-2024. Colouration of age groups follows the same order as previous plots.

3.4.3 Spatial distribution and persistence

The spatial abundance of plaice age classes 0-5+ is presented in Figure 14 with data from SIFS 2022 selected as a representative example. Plaice results for other years are presented in Appendix D.

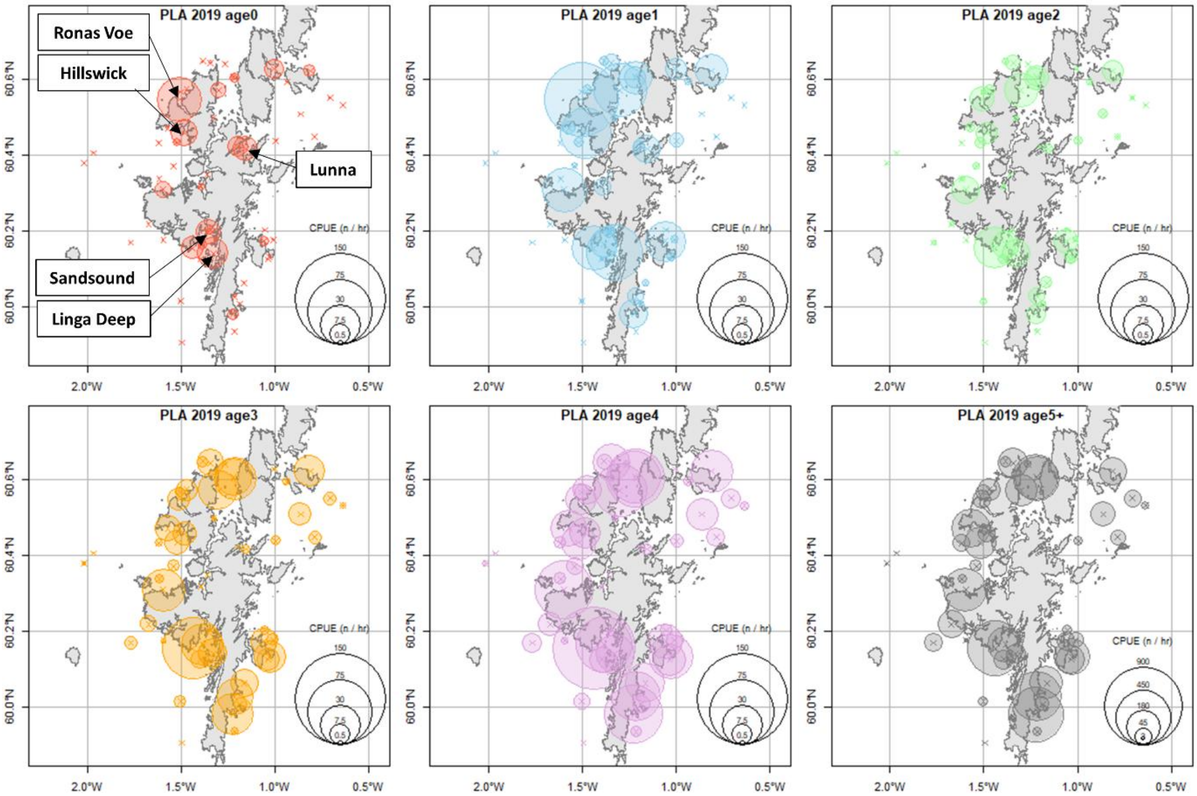

Figure 14. Spatial abundance of plaice age classes from the sampled population of SIFS 2019. The plots are arranged into windows by age groups which follow the same colouration as previous plots. SIFS 2019 station midpoints are denoted by 'x' symbols. CPUE of plaice age class from each station is presented by a bubble scale. The size of the bubble is scaled relative to the CPUE scale in the bottom-right corner of each window.

The spatial range of age-0 plaice was broad and concentrated to shallow area stations but with relatively low abundance. Notably, the greatest presence of age-0 plaice was localised to three shallow areas, in the central west (Sandsound and Linga Deep), in the northwest (Ronas Voe and Hillswick) and the northeast (Lunna). The distribution of the subsequent age classes (age-1 to age-5+) shows a broad use of shallow and inshore sites across the full survey area. In consideration of site usage overlap, the youngest age classes (age-0 and age-1) have a greater abundance in the Lunna site than older cohorts. Beyond this, all shallow station areas utilised by age-0 also have a presence of the age-1 to age-5+ groups.

Throughout the study period, abundance of age-0 plaice declined across the full survey area (Table 4). Overall, low levels of age-0 abundance were observed, with persistent use of areas primarily seen in shallow stations. The Hillswick Shallow station was identified as an area of persistence, with age-0 plaice observed in 100% of survey years presented. However, Hillswick Shallow was never the primary hotspot during these three years. Following this, sites with ≥ 75% persistence of juveniles were limited to two shallow stations at Linga Deep (88%)

and Sandsound (80%). Of the sites presented, Linga Deep was identified as the primary hotspot of age-0 plaice in three years (2018, 2021 and 2022) and observed a peak abundance in 2019. The Sandsound station observed the greatest average CPUE overall and was the primary hotspot, of the sites presented, for age-0 plaice in 2023.

Table 4. CPUE (n/hr) for each survey year and average CPUE of age-0 plaice is presented for stations which demonstrate a persistence rate ≥ 50%. Persistence is calculated as the percentage of years which observed >1 n/hr within the station, across all survey years.

Grounds	Station	2017	2018	2019	2020	2021	2022	2023	2024	Average CPUE	Persistence (%) >1 n/hr
Hillswick Shallow	-	3.34	1.16	13.17	-	-	-	-	-	5.89	100
Linga Deep	SHA03	3.58	8.24	18.01	0.68	3.55	1.29	1.28	1.00	4.70	88
Sandsound	-	11.55	0.02	11.12	1.99	-	-	9.30	-	6.80	80
Ronas Voe	SNW05	2.66	0.42	36.24	2.22	2.11	0.02	2.06	0.56	5.79	63
Nancy's Bay	SLS05	13.08	0.36	2.11	2.33	1.36	0.05	1.41	0.18	2.61	63
Weisdale Voe	SHA05	7.38	0.16	2.15	0.00	0.00	1.13	-	2.57	1.91	57
Skeetlie	SBA05	-	0.00	1.01	1.33	0.03	0.00	1.61	2.71	0.95	57
Lunna	SFF02	22.26	0.23	11.67	15.01	0.30	0.00	4.52	0.00	6.75	50
Side of Skeld	SHA01	9.17	0.96	9.36	2.30	0.60	0.90	0.05	1.12	3.06	50
Floorie Holms	SNW03	4.51	0.89	4.60	1.37	2.03	0.00	0.11	0.02	1.69	50
Score Holms	HA04	3.71	0.45	1.46	2.64	2.16	0.00	0.00	0.06	1.31	50

The remaining sites with persistence rates ≥ 50% were the Ronas Voe (63%), Nancy's Bay (63%), Weisdale Voe (57%), Skeetlie (57%), Lunna (50%), Side of Skeld (50%), Floorie Holms (50%) shallow stations and Score Holms (50%) inshore station. Notably, these stations occur in nearshore areas across the whole survey area. The Ronas Voe station presented as the primary hotspot in 2019, this was also the greatest abundance for age-0 plaice observed across all years. The Nancy's Bay and Weisdale Voe stations saw a peak abundance in 2017 with variable abundances thereafter. The Skeetlie station observed comparatively low CPUE values of age-0 throughout all survey years, with the greatest abundances observed in the most recent survey years. Of the sites presented, the Lunna station was identified as the primary hotspot of age-0 plaice in two years (2017 and 2020). The Side of Skeld and Floorie Holms stations each saw a peak age-0 abundance in 2019. Score Holms is an inshore, deeper water station, which presented variable juvenile abundances and has seen an overall decrease in age-0 CPUE in recent years.

4 Discussion

This report provides the first detailed assessment of inshore habitat use by juvenile haddock, cod, whiting and plaice in Shetland. Using SIFS data, distinct juvenile (age-0, age-1) and adult subpopulations were shown to consistently present throughout the study period in specific nearshore environments for all species considered. While there were similarities in population dynamics and habitat use for some species, especially among the gadoids; in other cases there were clear differences, for example in the relatively older composition of inshore plaice. These results and associated limitations are discussed below in the context of related studies.

4.1 Haddock

The spatial distribution of the haddock age-0 class identified two differing distribution patterns. Of the years presented, the 2023 age-0 group were observed across a range of shallow and inshore sites around Shetland (Figure 5). This trend was also seen for the haddock age-0 groups of 2017, 2018 and 2024 (Appendix A). The use of deeper water habitats by juvenile haddock is as expected from literature on post-settlement movement of haddock in the North Sea (Fogarty et al., 2001; Health & Gallego, 2000). It is generally accepted that once haddock settle following the pelagic stage, they favour deeper water offshore, occupy the same habitat as adults and are not believed to aggregate as juveniles (Bastrikin et al., 2014). Yet, the age-0 group from the SIFS sampled population of 2020 was seen in high abundance, almost exclusively at specific shallow stations (Figure 4). This juvenile distribution pattern was also observed for the age-0 class of 2019, 2021 and 2022 (Appendix A). The settlement of haddock is known to take place over the 30-80mm length range (Bastrikin et al., 2014; Health & Gallego, 2000), while the greatest proportion of the age-0 class of 2020 were seen with lengths >130mm consistent with post-settlement.

Throughout the study period and area, the age-0 haddock population were seen in varying abundances across 10 key stations with a range of high persistence values (Table 1). This suggests that the age-0 class demonstrated a relatively broad selection preference for juvenile habitat. It should be noted that natural inter-annual differences in abundance for the subpopulation are expected to arise due to temporal variability in spawning periods, often relating to environmental cues (González-Irusta & Wright, 2016). However, age-0 haddock habitat persistence rates ≥ 75% were limited to shallow stations only. Across these persistently used shallow areas, the absence of adult haddock was also highlighted through the identification of a progressive offshore movement trend from age-1 onwards. Consequently, a substantial proportion of the age-0 subpopulation were seen repeatedly within specific shallow stations which were not occupied by the adult subpopulation. Collectively, these results are indicative of nursery habitat use by haddocks in the nearshore Shetland environment. This finding diverges from long-standing literature on the early life stages of gadoids in the North Sea (Hislop, 1996) as well as a recent report commissioned by the Marine Directorate (Franco et al., 2022) which employed data-based modelling and habitat proxy assessment to map EFH within the Scottish marine environment. The assessment of early life stages for haddock was omitted in Franco et al. (2022), as the authors state that juvenile haddock do not occupy "*distinct areas of habitat […], therefore suggesting no particular use of nursery areas.*" while the authors also identify several important data gaps in the assessment of the inshore environment. This considered, the findings presented here indicate the value of dedicated inshore fish surveys such as SIFS that provide data from shallow and nearshore environments, without which the early life history of commercially important demersal fish communities would remain only partially understood. SIFS provides an annual snapshot of fish distribution during August-September, and so it is unclear from the data available at what point in the year the age-0 class migrate into deeper areas, additional research could be carried out to investigate this.

4.2 Cod

Cod spatial distribution results indicated highly consistent use of specific shallow survey stations by the age-0 group throughout the study period. Evidenced by the spatial distribution plot for 2020 (Figure 8), high abundances of juvenile cod were seen concentrated within two shallow areas in the north (Ollaberry and Dales Lees) and, to a lesser extent, the west (Weisdale Voe) of the Shetland mainland. This spatial distribution pattern was seen consistently in all other survey years, with the exception of 2018 (Appendix B) when age-0 cod were observed ubiquitously across the survey area. Particularly high age-0 group persistence rates were observed for 5 stations, several of which were noted to be in close proximity to one another. Here, site specificity of age-0 cod was shown to be high as juveniles were heavily localised to specific shallow habitats. This result is consistent with literature for the species, where cod of lengths >70mm are known to settle in depths of <20m (Elliot et al., 2016; Ellis et al., 2012) and high juvenile abundance are recorded in discrete concentrations in sheltered areas (Gibb et al., 2007). Atlantic cod are also recognised to have a narrow selection preference for complex benthic habitats following settlement. Complex, structured habitats provide refuge from predation and are recognised for mediating post-settlement mortality of juvenile cod (Juanes, 2006; Lough, 2010). The term “structured” refers to habitat features which protrude above the seabed, as biotic or abiotic structures. These include kelps, seagrasses or other submersed macroalgae as well as reefs, boulders or loose accumulated shells (Lefcheck et al., 2019). Observational data from the SIFS indicates substantial quantities of detached macroalgae in trawl catches at the sites identified for persistent age-0 cod use which further indicates an association with structured nearshore environments.

4.3 Whiting

Similarly to haddock, assessment of inter-annual variation in spatial distribution of the whiting age-0 group identified use of a range of shallow sites and one deeper water, inshore site. High abundances of age-0 were observed in specific shallow sites spanning the north, northeast and west portions of the survey area. Of the 9 stations found to be persistently used by the age-0 group, many are seen to be in close proximity to one another within sheltered inlets. In comparison to haddock and cod, a greater proportion of adult whiting (age-2+) were seen to remain nearshore and were sampled in stations across the full survey area. This result is consistent with literature as mature adults are known to spawn both inshore and offshore (Burns et al., 2020). Much of the current understanding of nursery habitats for juvenile whiting is based on research conducted from the 1960s-1980s, with a focus on Western Scotland and England (Ellis et al., 2012; Franco et al., 2022). Resultantly, the understanding of habitat requirements and specificity for juvenile whiting in the North Sea is limited, particularly in inshore areas, which further highlights the value of SIFS data.

4.4 Plaice

Assessment of the spatial distribution of juvenile plaice across the nearshore Shetland environment was complicated by comparative lack of length data for the age-0 group in available data. The NS-IBTS ALK for the area around Shetland had few records of all plaice age groups and no records for age-0 and age-1 groups. Further work to improve ALKs for juvenile plaice would be beneficial. Within the SIFS dataset, the sample size of age-0 plaice was low for all years and consequently the sampled length range was less consistent than the other species considered. In early summer, following metamorphosis, age-0 plaice shift to become benthic at a settlement length of 10-20mm (van der Veer et al., 1990; Pihil & Wennhage, 2000). A study considering age-0 plaice across the North Sea reported a range of mean lengths from 30-78mm for fish sampled during August (van der Veer et al., 1990). Given that plaice within this length range, identified here as the age-0 group, are not entirely absent from the survey area, low catch rates may relate to capture efficiency of small flatfish. Catchability limitations are a recognised issue in the survey of juvenile flatfish populations (Rogers & Lockwood, 1989). These limitations are associated with the unique morphology and anti-predation behaviour of flatfishes which enables them to evade capture by lying flat to the sediment (Ryer, 2008). Juvenile flatfishes are also known to bury in sediments to avoid predation, which could further limit their capture by standard trawl gear, in the absence of tickler chains (Støttrup et al., 2019; Rogers & Lockwood, 1989). Low age-0 plaice catch rates could also be related to operational limitations of the sampling gear in shallower (<12m) juvenile habitats that may be preferred by plaice (Franco et al., 2022). In light of this, the spatial distribution of juvenile plaice may be better exemplified by the age-1 group which were predominantly observed in shallow stations across the full survey area and in most cases overlapping with the distribution of juvenile gadoids. Older plaice age-classes (age-2+) were observed more evenly across the shallow and inshore survey areas, typically overlapping with the distribution of juveniles, which indicates less spatial separation of age classes than observed in the other species considerer here.

4.5 Key sites and associated conditions

This study identified several key areas which support consistent concentrations of juvenile haddock, cod, whiting and plaice. Several of the stations which demonstrate nursery area use for all four species were clustered in the west of the survey area, particularly the Weisdale Voe and nearby sampling stations (Sandsound, Linga Deep, Side of Skeld, Score Holms), as well as the Cole Deep and Skeetlie. Further key areas used persistently by juveniles for multiple species were found in the northeast (Dales Lees, Lunna) and north (Ollaberry) of the survey area. Further, for plaice specifically there were additional areas in the north (Hillswick Shallow, Ronas Voe, Floorie Holms) and east (Nancy’s Bay) which indicated persistent use by juveniles.

From the spatial distribution of all gadoid age classes considered here, it was noted that high juvenile abundance in shallow areas was generally seen in the absence of adult conspecifics. This result aligns with a definition of a nursery habitat proposed by Beck et al. (2001) which specifies that a degree of disjunction should be seen between juvenile and adult habitats for a given area to be recognised as a nursery. Without this physical separation in range, the area would simply be considered as the species habitat. However, the separation of juvenile and adult habitat necessitates interconnectivity between the respective habitats. When a nursery area is considered an effective juvenile habitat, it will ultimately contribute to recruitment in adult populations through improved survival and ontogenetic movements (Beck et al., 2001; Dalghren et al., 2006). Given this, offshore movements from the aforementioned shallow stations into deeper water stations by age-1 and age-2 gadoids further supports the identification of these areas as nursery habitats for haddock, cod and whiting. For plaice, some hotspots of high juvenile concentrations are less clearly identifiable as nursery habitats due to considerable spatial overlap with older age classes and the methodological limitations discussed previously.

Most of the potential fish nursery areas were seen across shallow survey stations of approximately 20-50m depth. Within these stations, the dominant habitat biotopes are reported as a combination of muddy sand, fine sand, mixed sediment, macroalgal communities and mussel beds (Riley and Shucksmith, 2025). All potential nursery areas identified here are associated with sheltered inlets and voe systems. These areas are semi-enclosed by nearby islands and headlands, which reduces exposure to winds, wave action and tidal currents. The topography and oceanographic conditions provide an overall more stable habitat, particularly in respect to macroalgal growth and diversity (England et al., 2008; Menge et al., 2005). Algal cover, as well as sediment structure, is known to influence vulnerability to predation for juvenile fish (Lefcheck et al., 2019; Wennhage, 2002). Alongside providing refuge from predation and improving survival, algal cover can maintain communities of prey for juvenile fish. Soft sediments are also known to contribute to growth for juveniles, as mud or silt often harbour greater organic content which can ultimately support higher prey abundance (Byers & Grabowski, 2014). Further research to characterise the environmental conditions which deliver nursery functions in the areas identified would be beneficial in understanding the extent of essential fish habitats around Shetland.

Further investigation of known nursery habitats or unsampled regions in nearshore areas would be highly beneficial but may be complicated by several factors. For example, there are practical limitations of any sampling gear, and scientific trawl surveys require areas of unobstructed seabed within some depth range. Many nearshore areas and voe environments around Shetland are already heavily constrained by other marine users (e.g. static fishing gear, marine farms). In these cases, alternative methodologies may be useful. For example, insights into a shallow nursery habitat were made available through the opportunistic deployment of a baited remote underwater video (BRUV) camera lander near Lunna (coordinates: 60.42833, -1.10565) during SIFS in 2024. As pictured in Figure 15, the footage featured clusters of macroalgae among fine sand sediment. The faunal community was characterised by an assemblage of shellfish, small flatfish and round fishes including juvenile cod and whiting, providing further evidence of nursery use of the area by commercially important fish species.

Figure 15. Baited remote underwater video camera footage from Lunna in August 2024. Centred above the red bait canister are a juvenile whiting (left) and cod (right) amongst an assemblage of other small fish.

4.6 Commercial implications and anthropogenic pressures

The spatio-temporal persistence of high concentrations of juveniles suggests high importance to adjacent recruited fish stocks (Colloca et al., 2009). Thus, the identification and conservation of nursery areas in the nearshore Shetland environment has clear commercial implications for the sustainability of local fish populations and the wider marine ecosystem. Fishing activity is in these specific nursery areas is mainly limited to some small-scale use of static gear targeting shellfish. However, many of the identified areas are under unprecedented potential pressure from other anthropogenic stressors relating to large-scale energy projects and aquaculture proposals.

For example, in the vicinity of the Sandsound Voe and Weisdale Voe nursery areas, planning consent has been given for the Billy Baa project which would involve the consolidation of four existing salmon farms into a larger single development. Similarly, there is a proposal in development to consolidate several other salmon farms into a larger site at Fish Holm, which is close to the Lunna and Dales Lees nursery areas. Further, a new salmon farm has been proposed in the waters between Muckle Roe and Vementry, which is at the entrance to the voe system where the Cole Deep and Skeetlie nursery areas were identified.

Onshore infrastructure developments also have implications for many of the nursery areas identified in this project. For example, a high-voltage direct current (HVDC) subsea cable was laid through the middle of the Weisdale Voe during 2023 to export power from the Viking Energy windfarm, and the associated cable laying operations prevented fish surveying in the Weisdale Voe area during that year. These onshore industrial developments have also been linked to disruption to water catchments with sediment run-off and changes of hydrochemistry recorded in the Weisdale Burn and Burn of Lunklet, with potential implications for the water quality in the Weisdale Voe and Skeetlie nursery areas. Further large-scale onshore wind developments and energy projects have recently been proposed in the Sullom Voe and Yell Sound areas with potential consequences for other nursery areas identified in this region.

A second subsea HVDC link between Shetland and the Scottish mainland has also been proposed, motivated by massive planned offshore wind developments to the east of Shetland which further potential associated impacts on identified nursery areas. The offshore windfarms proposed to the east of Shetland would be located beyond inshore fishing grounds and while direct impact of the turbines themselves may be unlikely, the associated cabling and infrastructure running ashore could be much more consequential to nearshore essential fish habitats. Impacts on fish nursery areas are possible not only though physical disturbance, but also through anthropogenic noise and electromagnetic fields which are ongoing research areas, with potential implications for juvenile growth and survival poorly understood. Magnetic fields as intense as those generated by HVDC cables have been shown in recent research to reduce swimming activity in haddock and cod larvae with unknown consequences at the population scale (Cresci et al., 2023).

5 Conclusions

This report describes the first detailed assessment of population age structure and essential fish habitats for haddock, cod, whiting and plaice in the nearshore Shetland environment. Age structure results for the gadoid species were generally characterised by distinct and well-defined juvenile age classes, with high inter-annual variability observed in the overall relative abundance of the age-0 class which in some cases is linked to future recruitment. In contrast, plaice results were characterised by less intermittency in recruitment and a population structure dominated by older age classes.

The findings identify discreet juvenile subpopulations of key commercial fish species with strong evidence of persistent inshore nursery habitat use. High concentrations of juvenile fish were shown to inhabit specific shallow and sheltered environments which were often clustered in specific areas important to multiple species, notably:

- Weisdale Voe and Sandsound Voe (haddock, cod, whiting, plaice)
- Lunna and Dales Lees (haddock, cod, whiting, plaice)
- Cole Deep and Skeetlie (haddock, whiting, plaice)

Some other nearshore areas, such as Score Holms, Ollaberry, and Linga Deep, were also identified as having high persistence rates of age-0 fish for one or more species. Some deeper areas were also identified as having persistent populations of juvenile haddock (Fetlar North, West Skerries) but with catch rates much lower than the above nearshore areas. Juvenile plaice were more widespread than the other species considered here and were consistently observed with relatively low catch rates in some other specific areas (Hillswick, Ronas Voe, Nancy's Bay, Side of Skeld, and Floorie Holms).

The spatial separation of juvenile and adult gadoids further supports the classification of many of the above areas as nursery habitats. The available data indicates the offshore movement of growing gadoids from these nursery habitats towards deeper fishing ground which highlights the importance of these areas to nearby fish stocks and to local fisheries.

Given the unprecedented scale of ongoing and proposed industrial developments in the Shetland region, it is more important than ever to maintain and continue valuable time series such the Shetland Inshore Fish Survey. Empirical data from small scale surveys are vital for ensuring that nearshore environments are adequately resolved and understood. Continued annual survey effort is essential to detect changes in fish populations and habitat use, and it's recommended that further research is undertaken to fully investigate the extent and significance of the nursery areas identified here.

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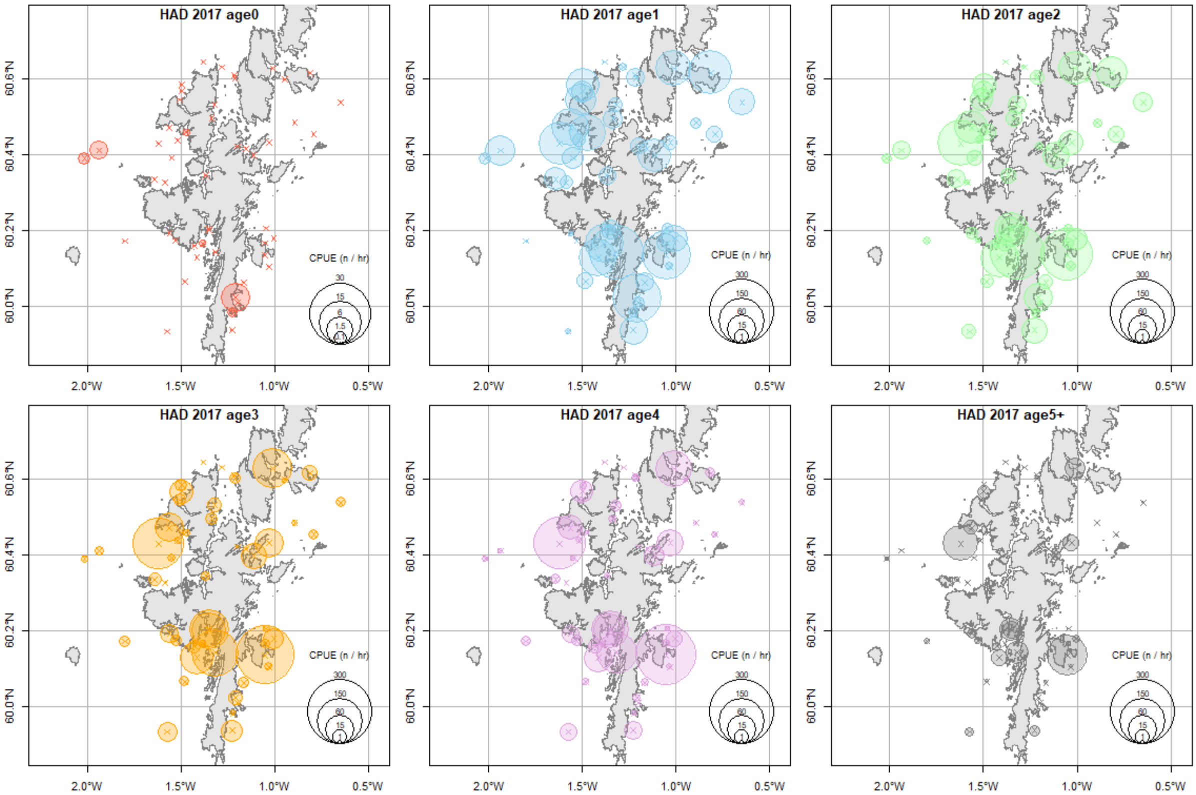
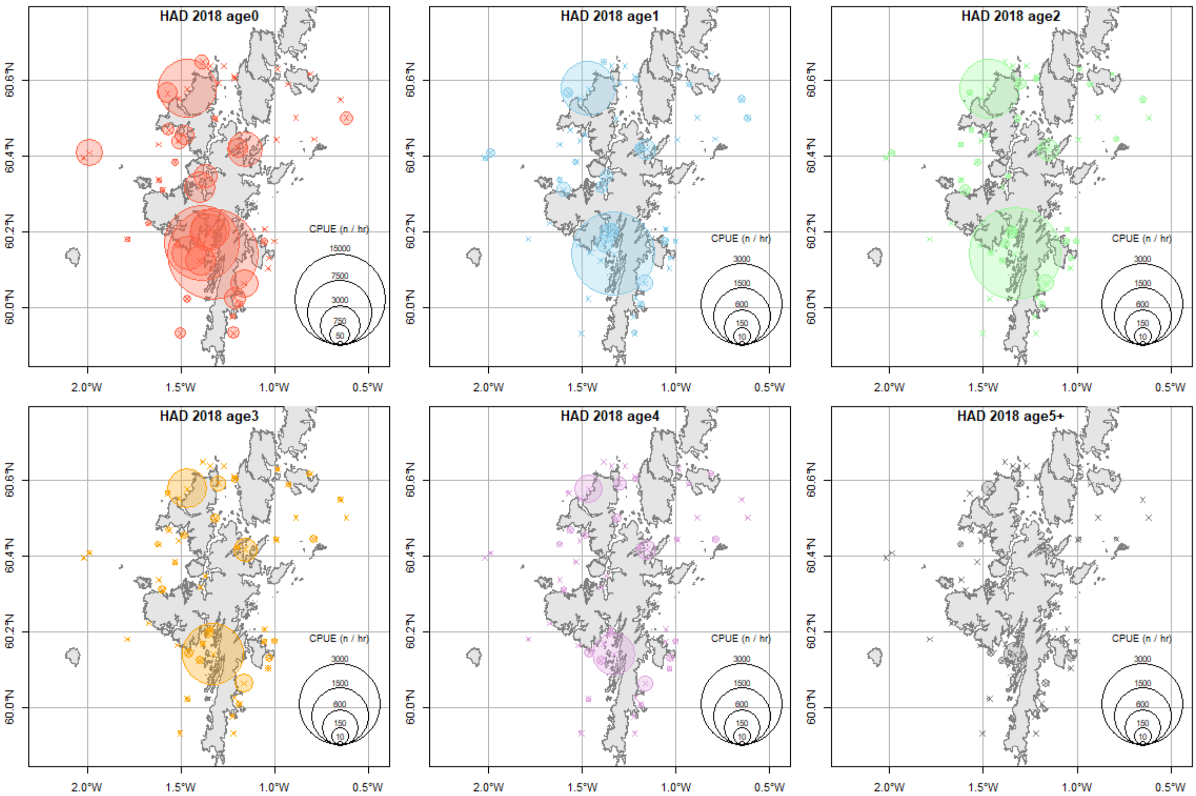
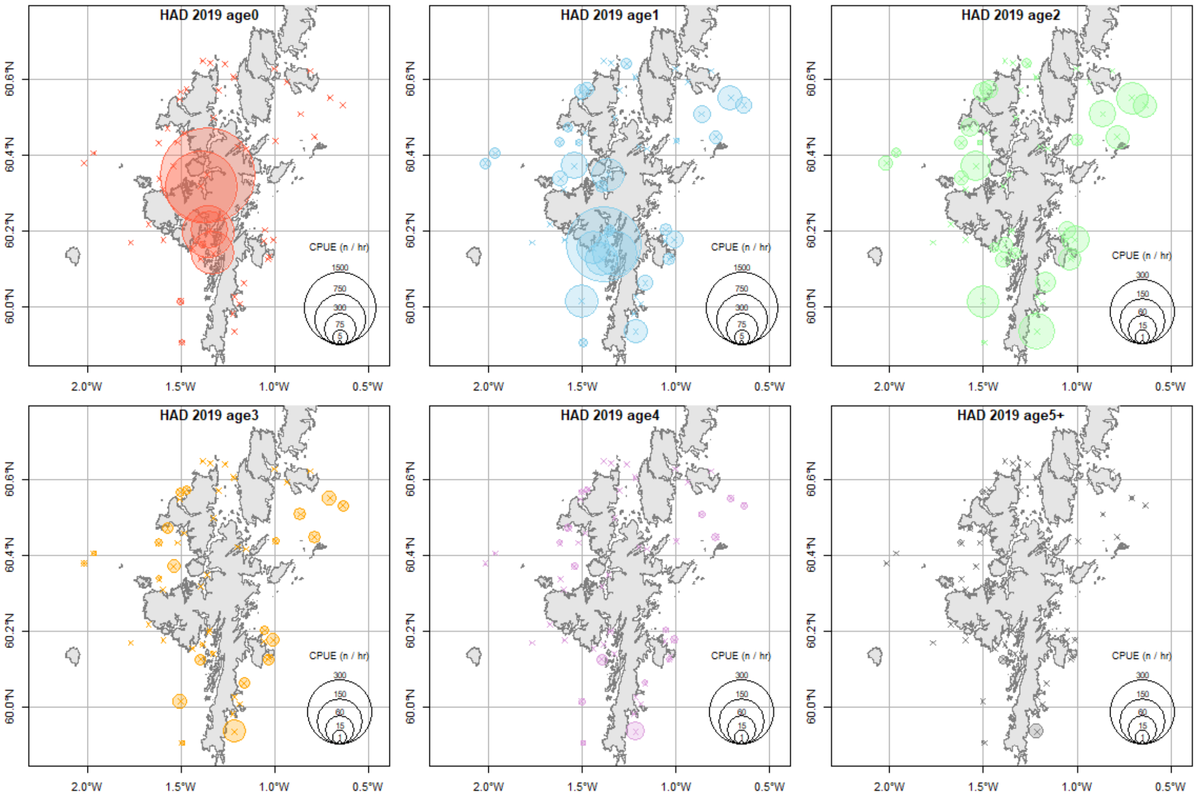
Appendix A – Haddock spatial distribution



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HAD 2019 age1
HAD 2019 age2
HAD 2019 age3
HAD 2019 age4
HAD 2019 age5+
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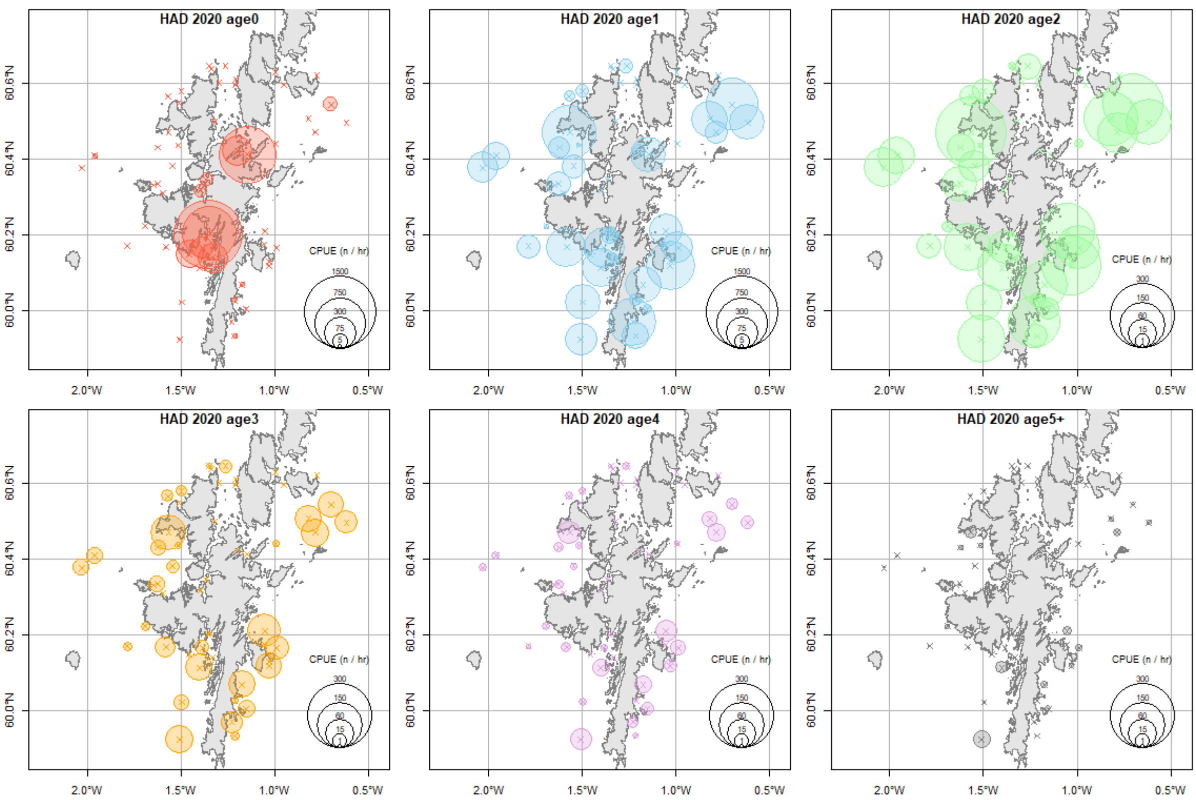
60.4°N
60.2°N
60.0°N
2.0°W
1.5°W
1.0°W
0.5°W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HAD 2020 age1
HAD 2020 age2
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HAD 2020 age5+
CPUE (n / hr)
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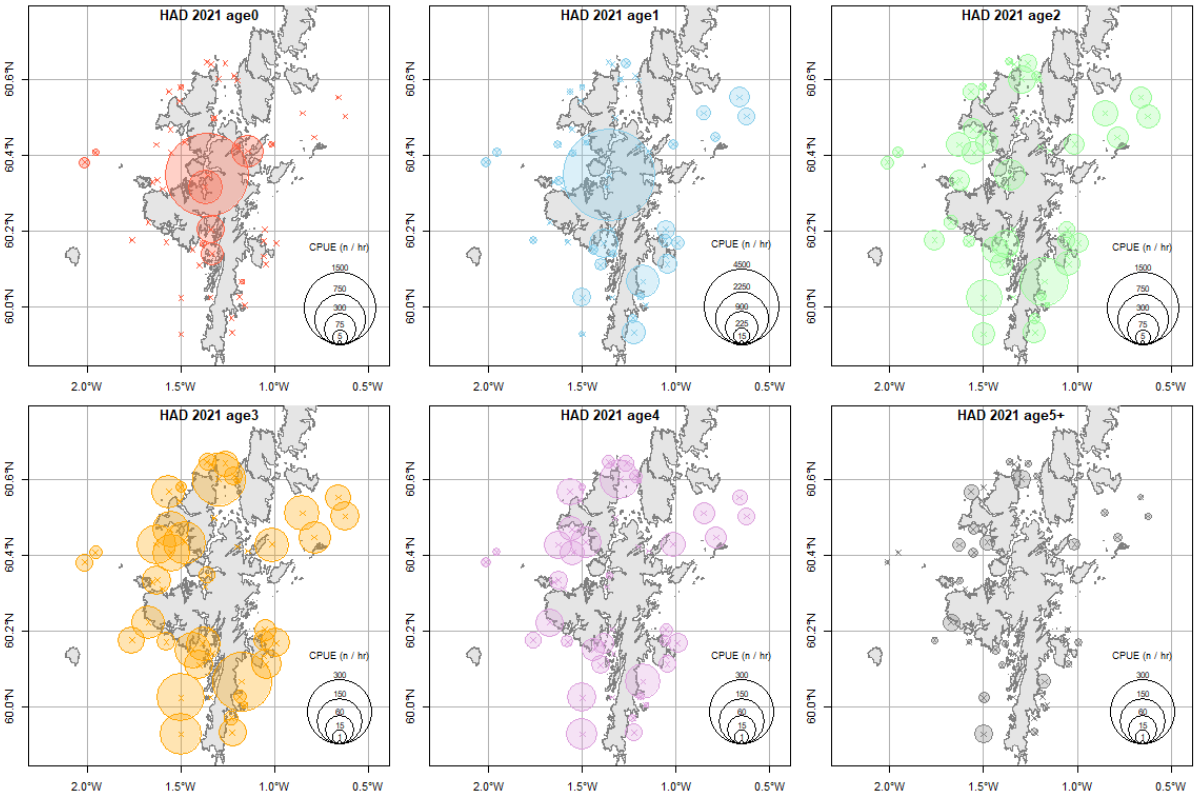
60.0°N
2.0°W
1.5°W
1.0°W
0.5°W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HAD 2021 age1
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HAD 2021 age5+
CPUE (n / hr)
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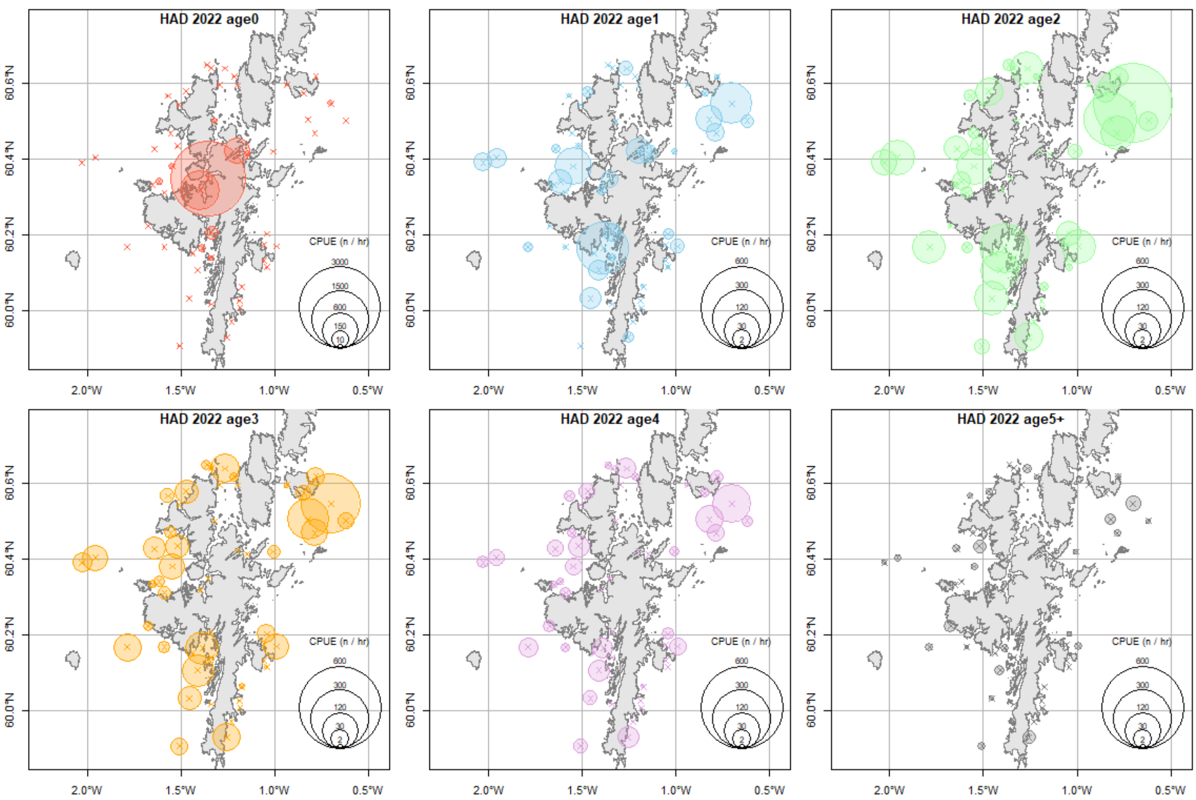
60.2°N
60.4°N
60.6°N
2.0°W
1.5°W
1.0°W
0.5°W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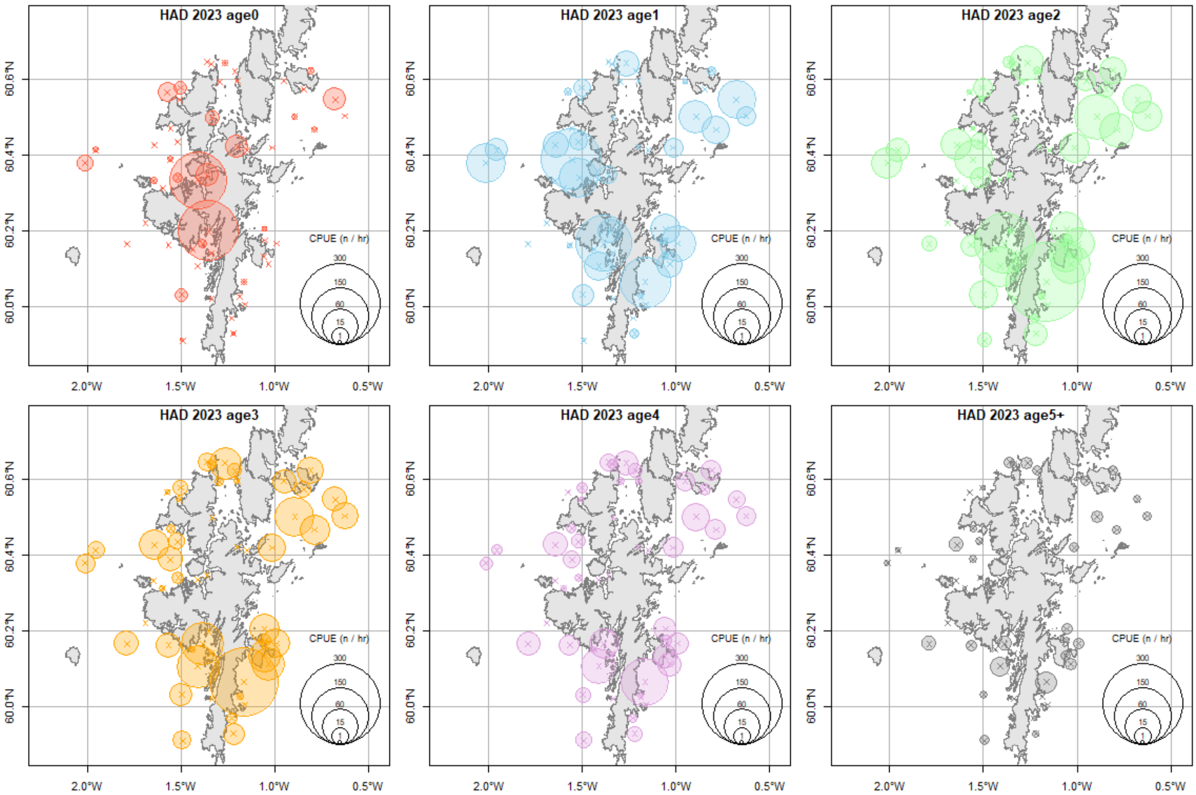
1.5°W
1.0°W
0.5°W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150
60
15
1
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1.0°W
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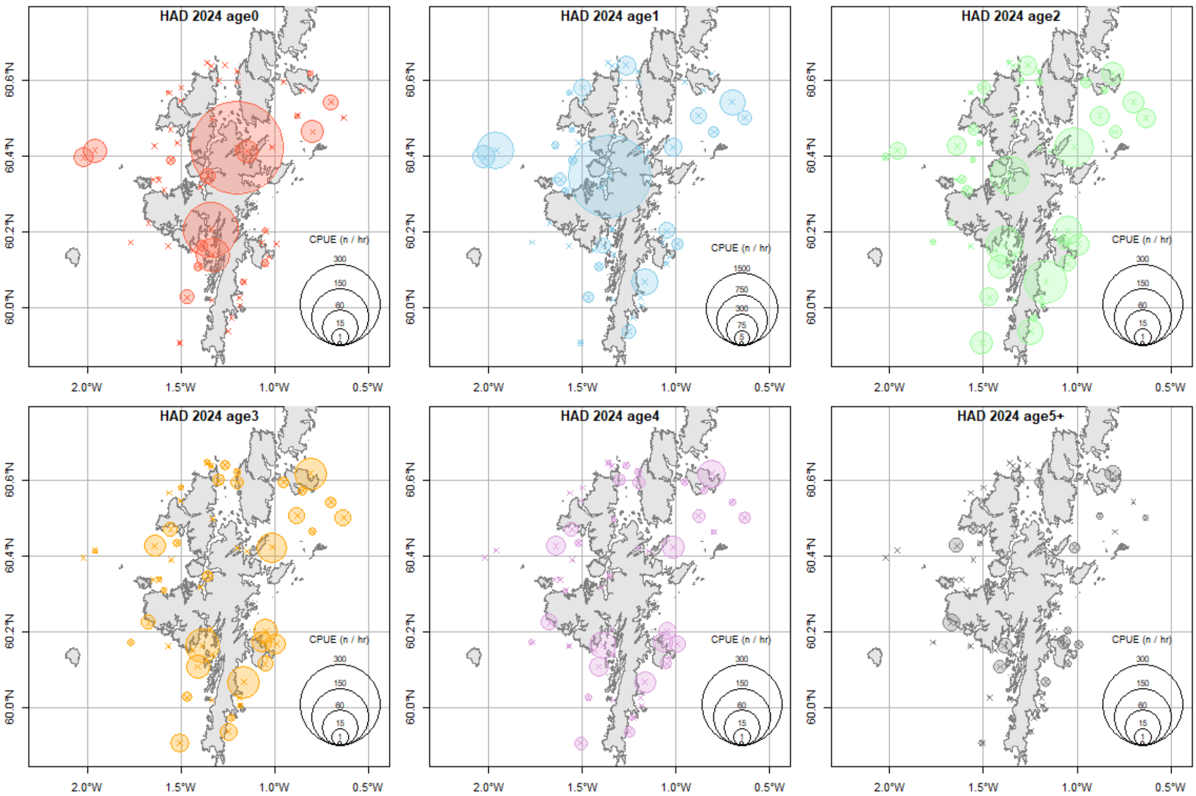
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300
150
75
60
15
1
60.0°N
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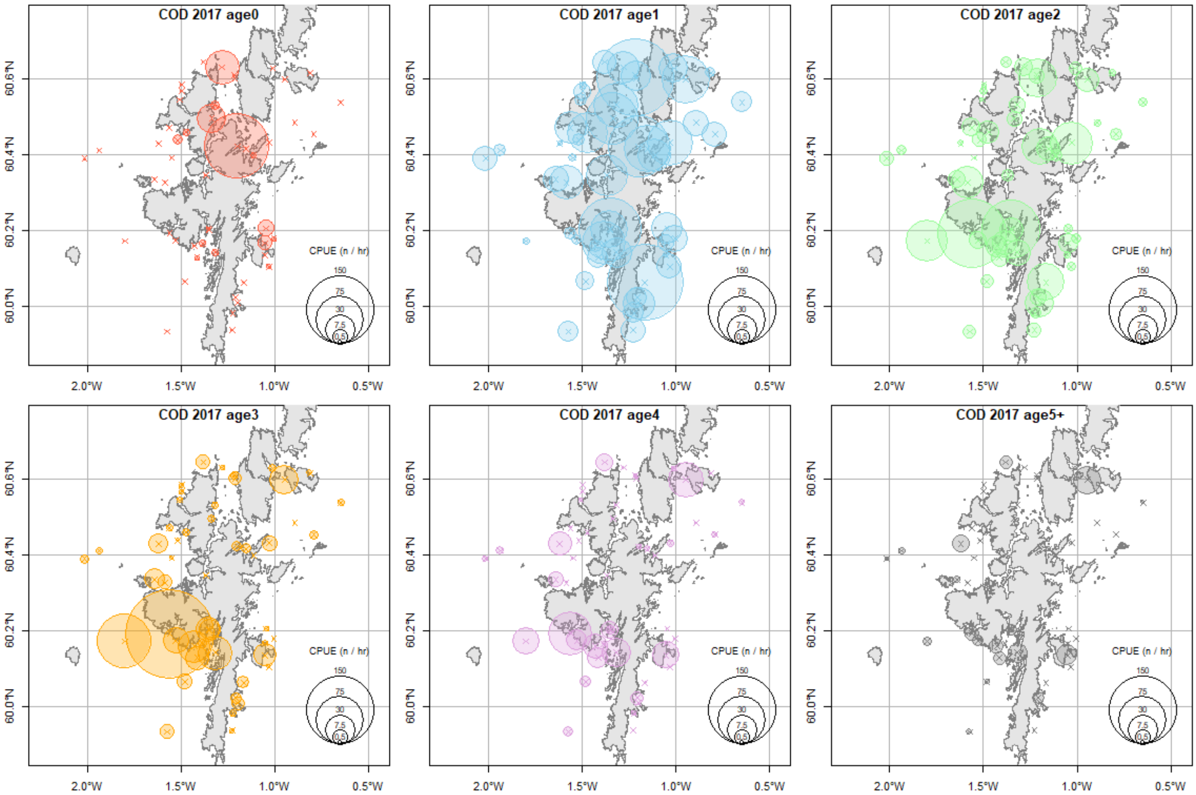
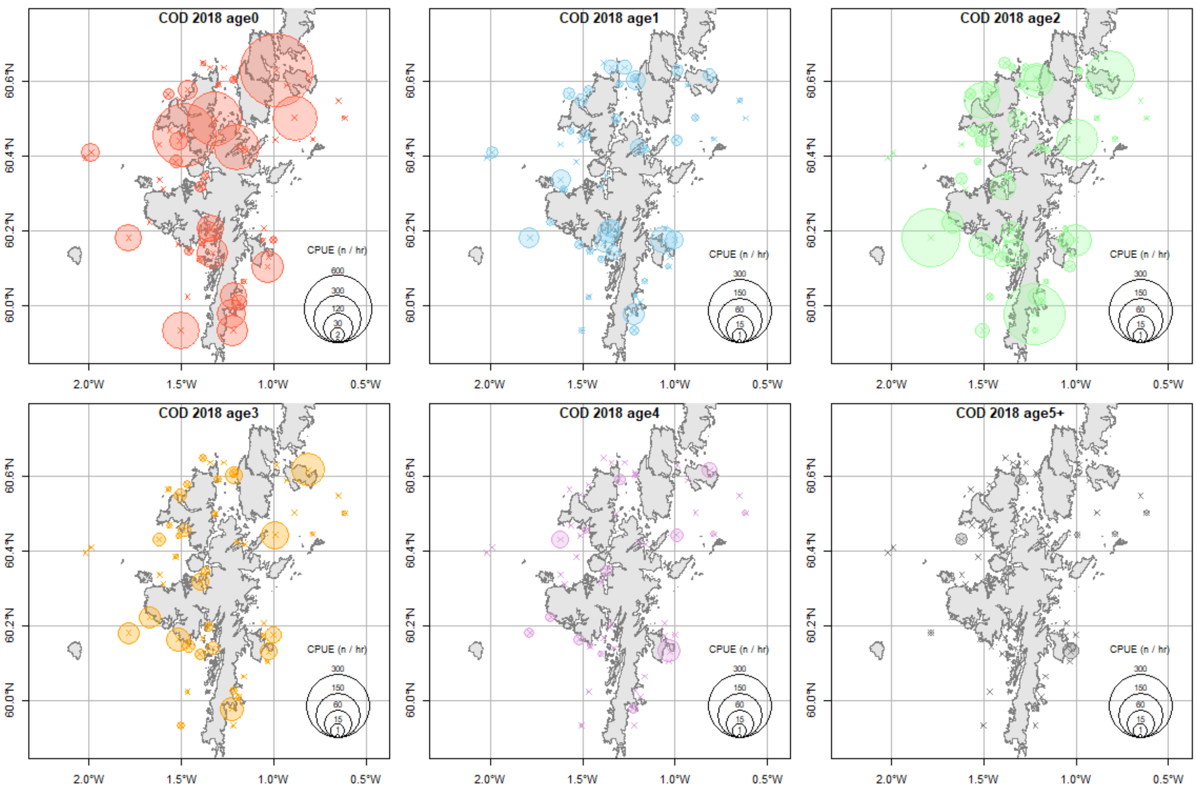
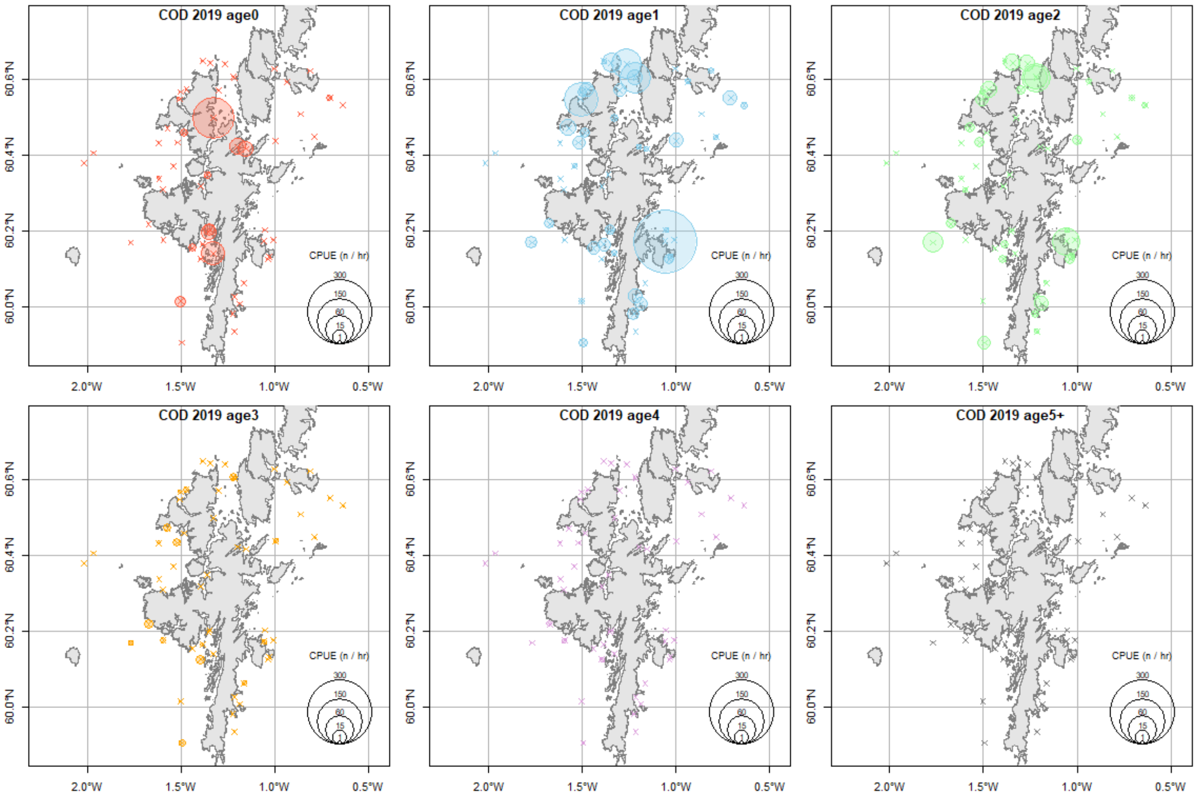
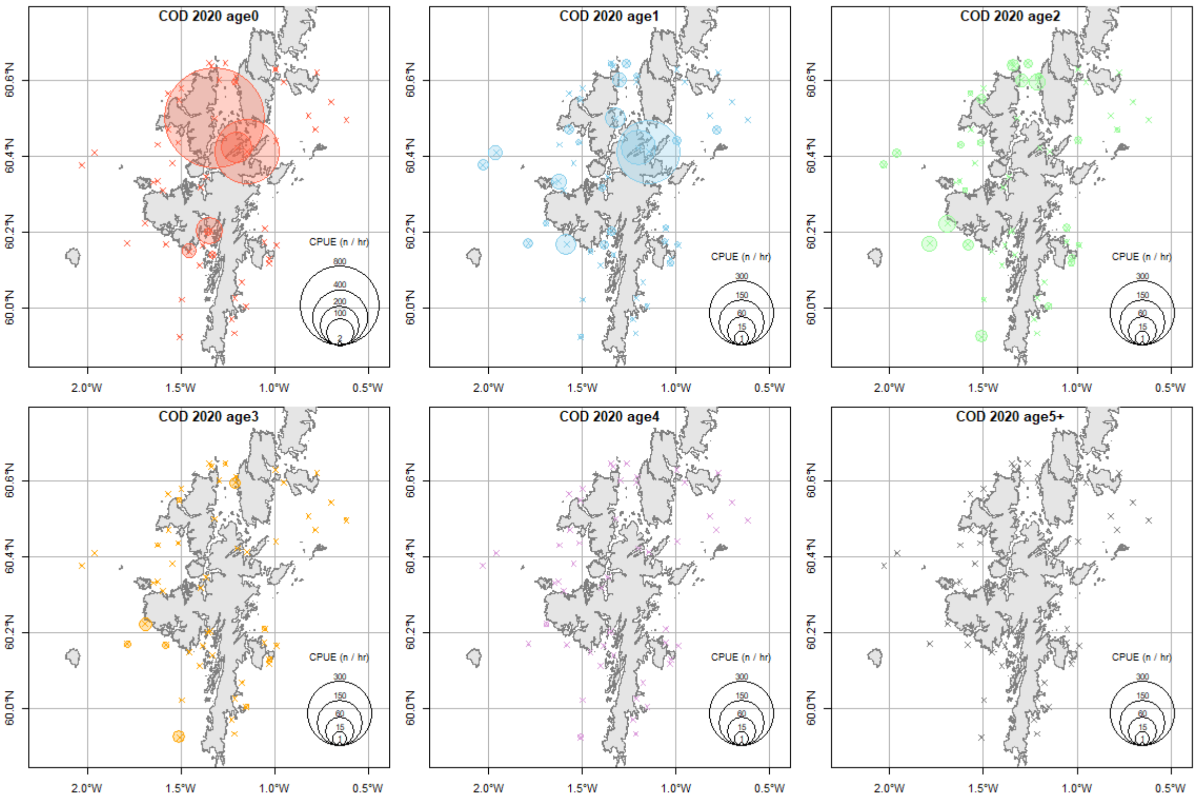
0.5°W

Appendix B – Cod spatial distribution






COD 2019 age0
COD 2019 age1
COD 2019 age2
COD 2019 age3
COD 2019 age4
COD 2019 age5+
CPUE (n / hr)
300
150
60
15
1
60.6°N
60.4°N
60.2°N
60.0°N
2.0°W
1.5°W
1.0°W
0.5°W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COD 2020 age1
COD 2020 age2
COD 2020 age3
COD 2020 age4
COD 2020 age5+
CPUE (n / hr)
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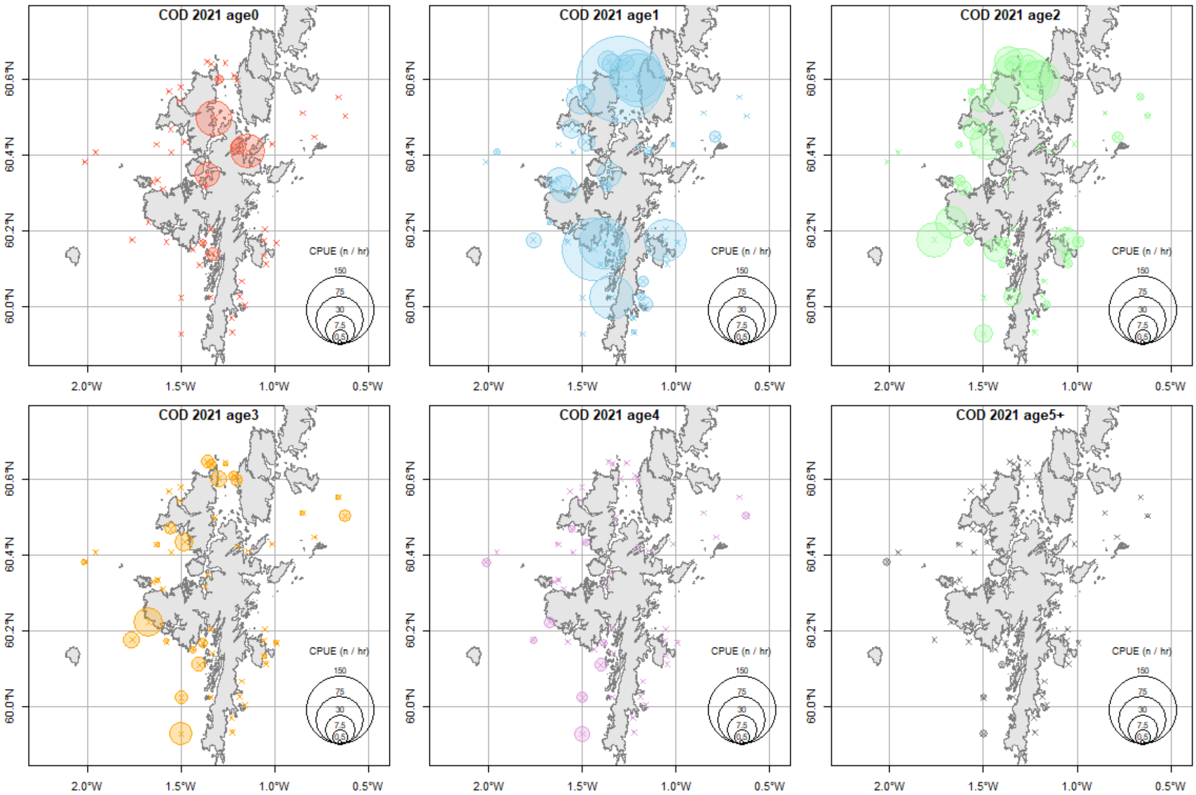
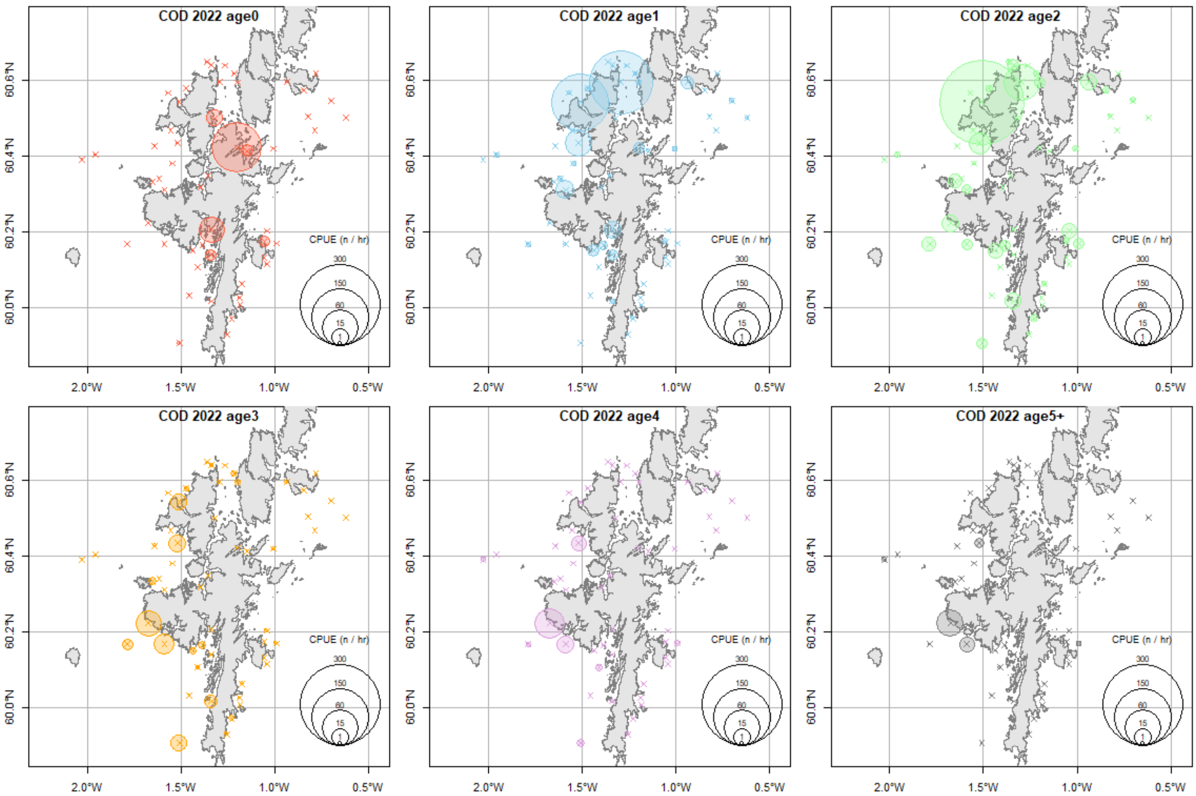
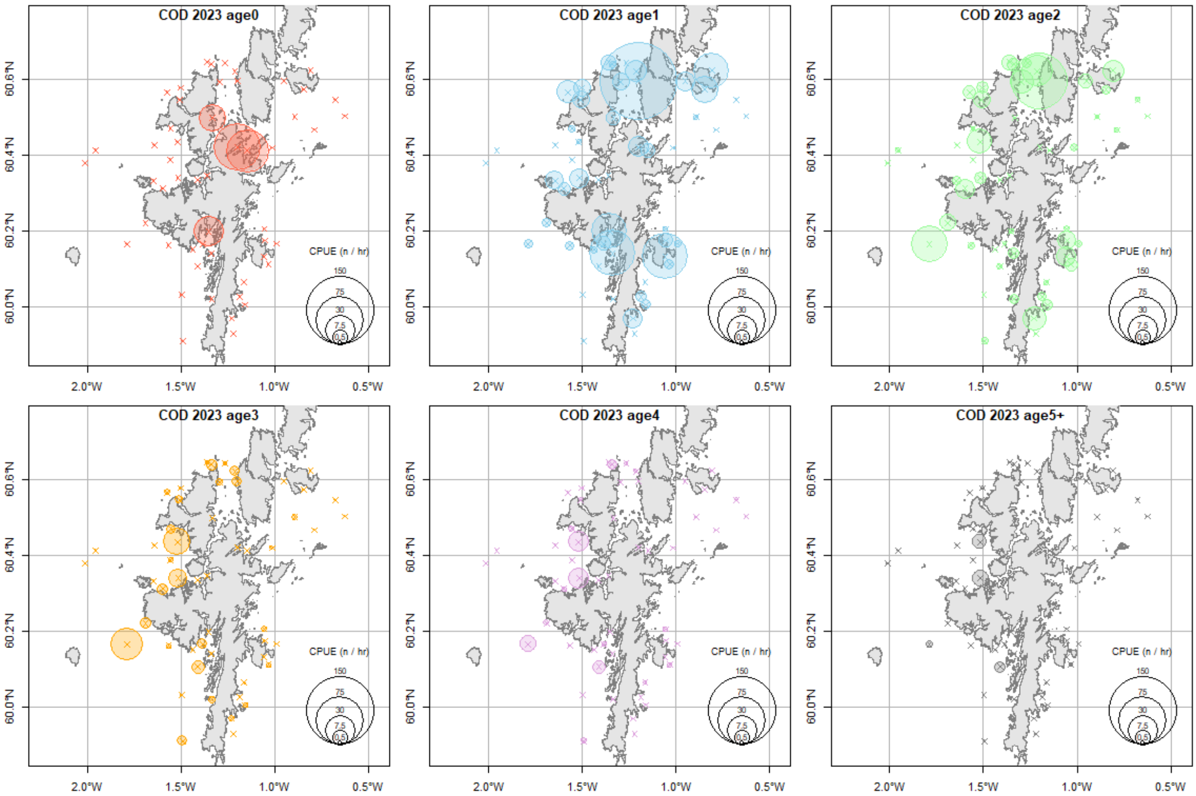
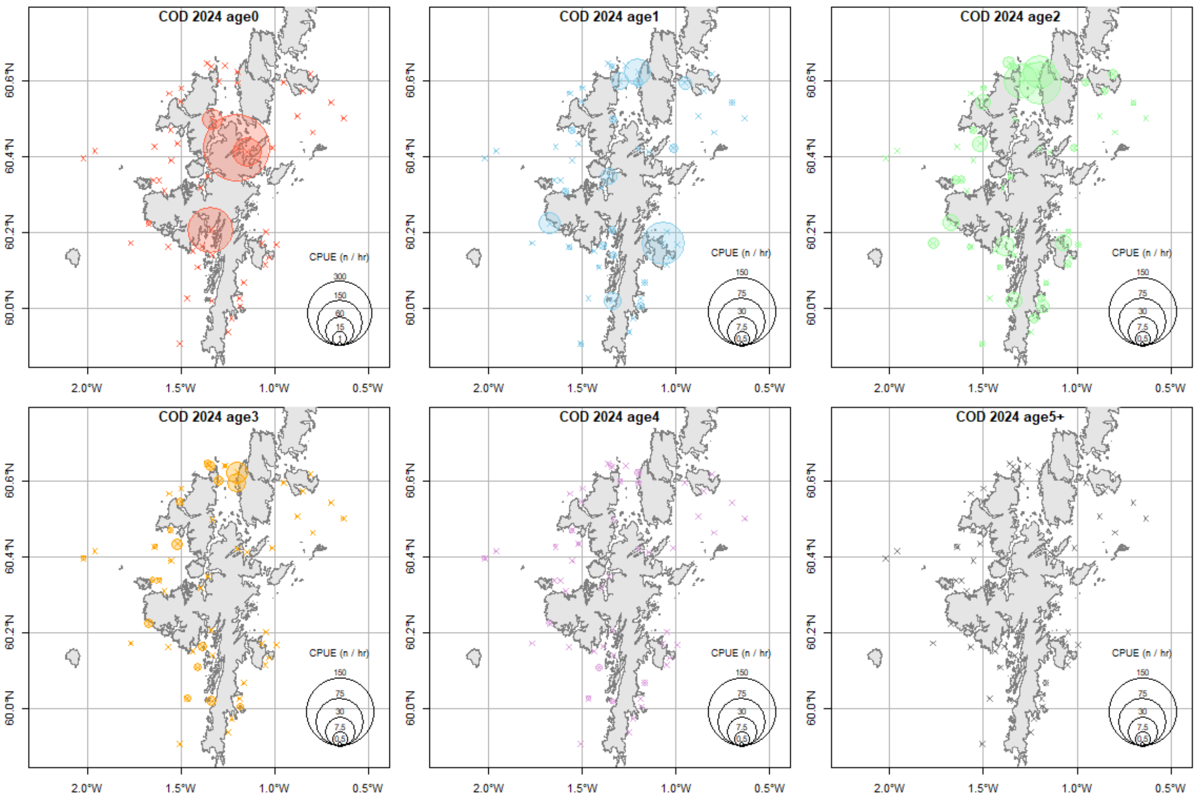
400
200
100
2
300
150
60
15
1
60.6°N
60.4°N
60.2°N
60.0°N
2.0°W
1.5°W
1.0°W
0.5°W

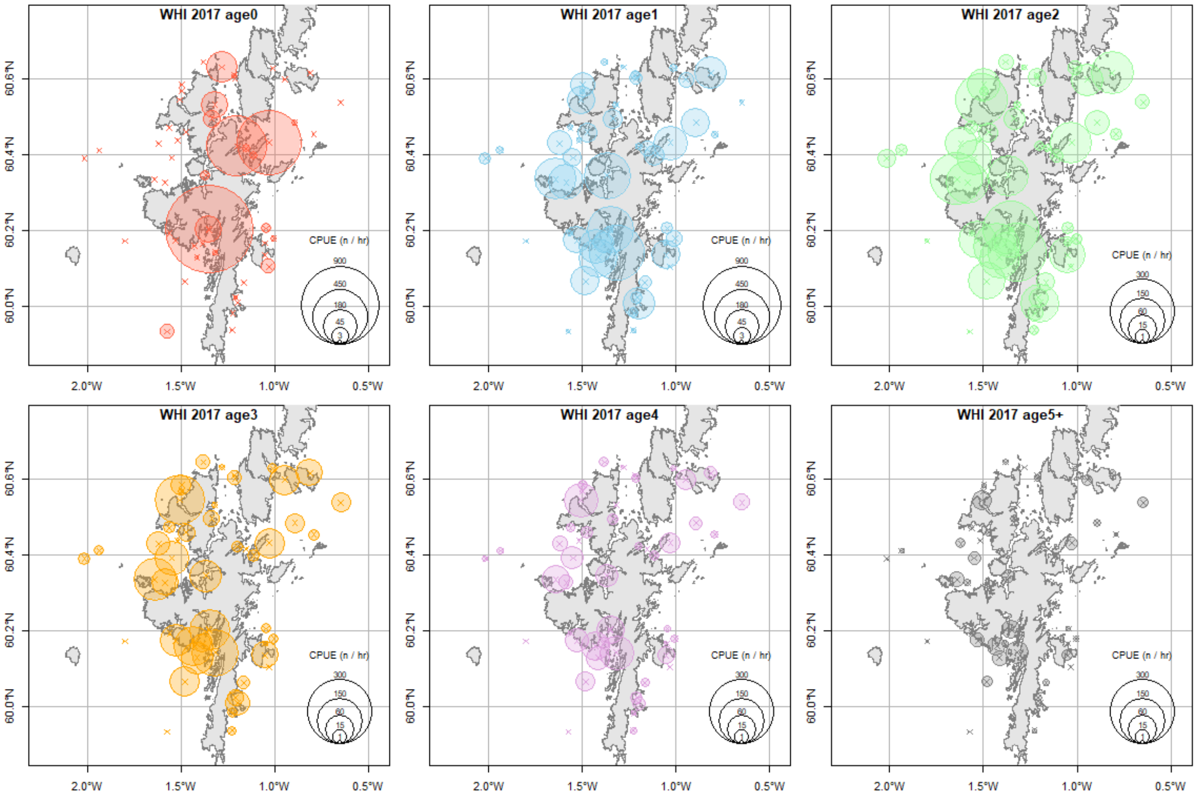

COD 2021 age0
COD 2021 age1
COD 2021 age2
COD 2021 age3
COD 2021 age4
COD 2021 age5+
60.6°N
60.4°N
60.2°N
60.0°N
2.0°W
1.5°W
1.0°W
0.5°W
CPUE (n / hr)
150
75
30
7.5
0.5

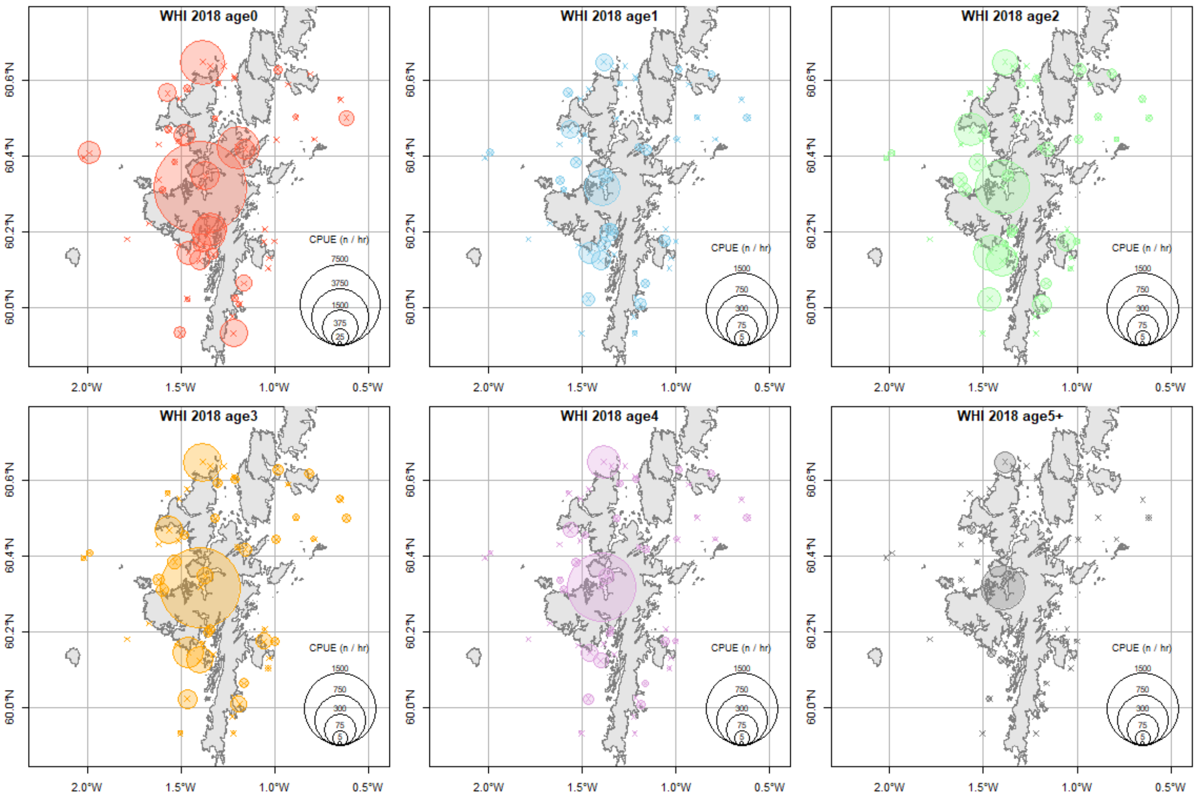

COD 2022 age0
COD 2022 age1
COD 2022 age2
COD 2022 age3
COD 2022 age4
COD 2022 age5+
60.6°N
60.4°N
60.2°N
60.0°N
2.0°W
1.5°W
1.0°W
0.5°W
CPUE (n / hr)
300
150
60
15
1

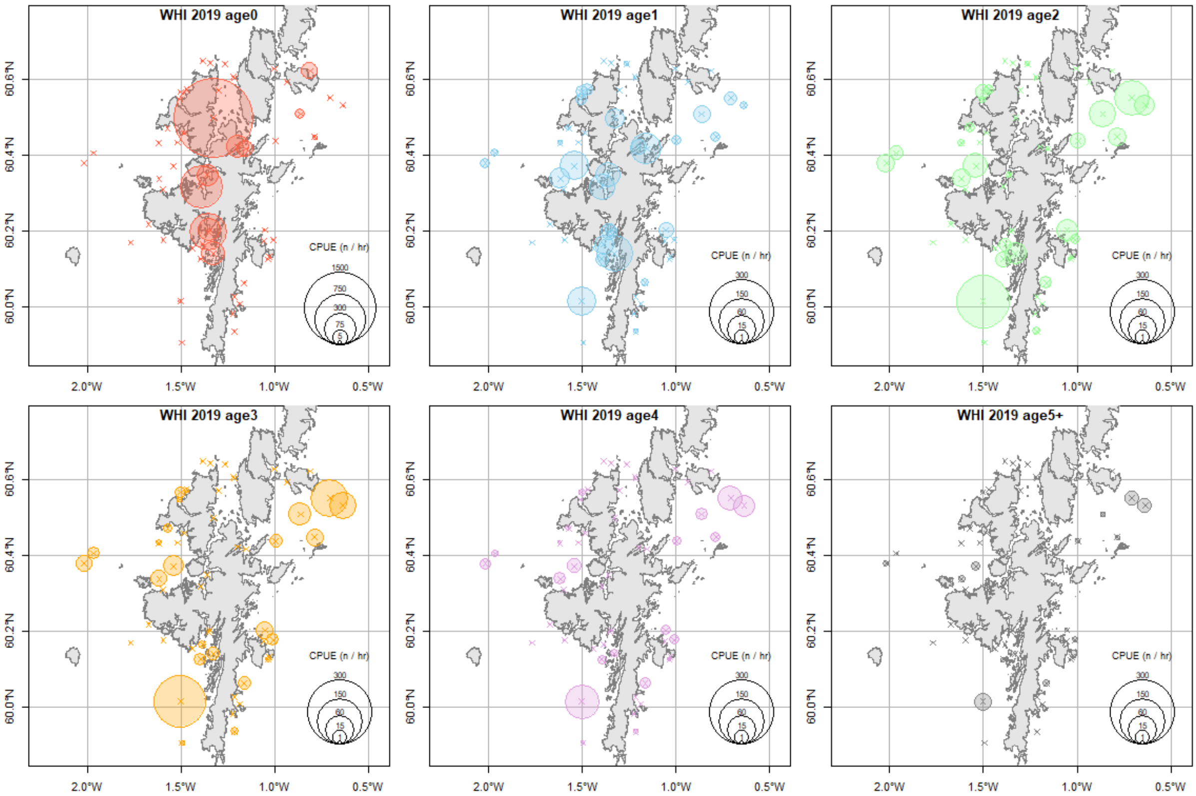

COD 2023 age0
COD 2023 age1
COD 2023 age2
COD 2023 age3
COD 2023 age4
COD 2023 age5+
60.0°N
60.2°N
60.4°N
60.6°N
2.0°W
1.5°W
1.0°W
0.5°W
CPUE (n / hr)
150
75
30
7.5
0.5

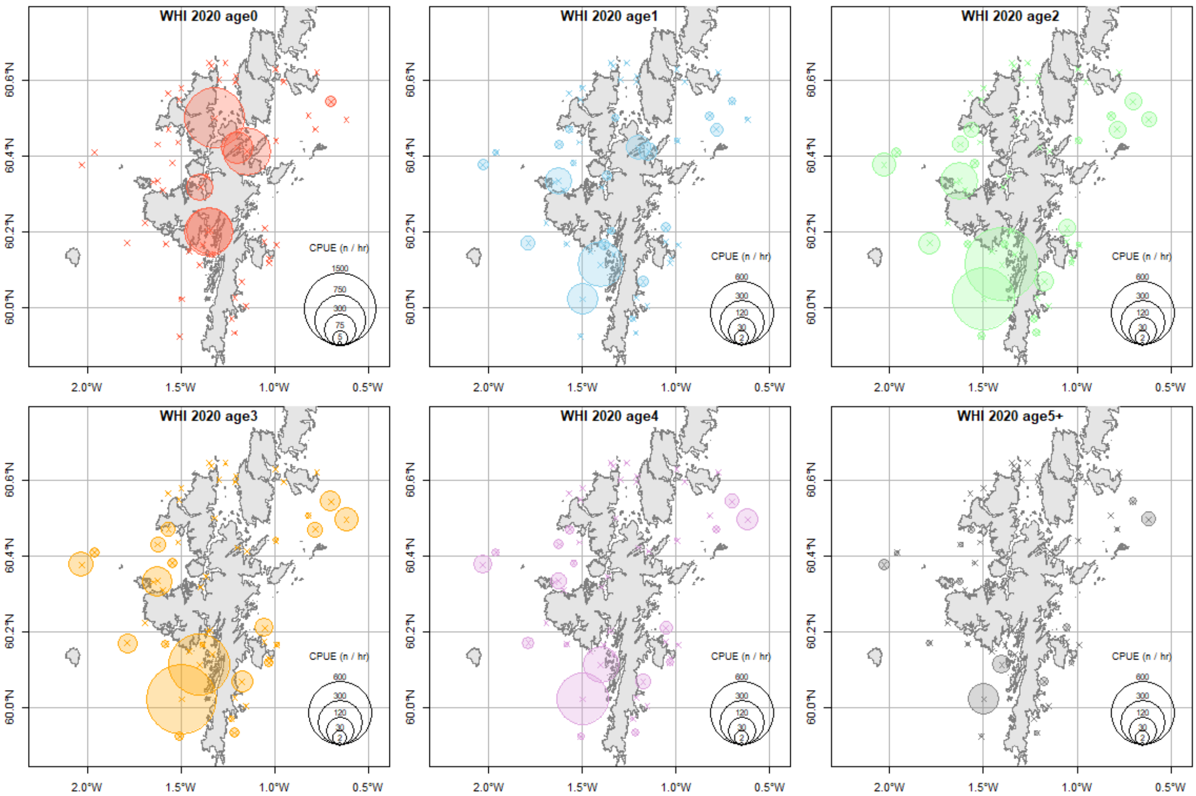

COD 2024 age0
COD 2024 age1
COD 2024 age2
COD 2024 age3
COD 2024 age4
COD 2024 age5+
60.0°N
60.2°N
60.4°N
60.6°N
2.0°W
1.5°W
1.0°W
0.5°W
CPUE (n / hr)
300
150
75
60
30
15
7.5
1
0.5

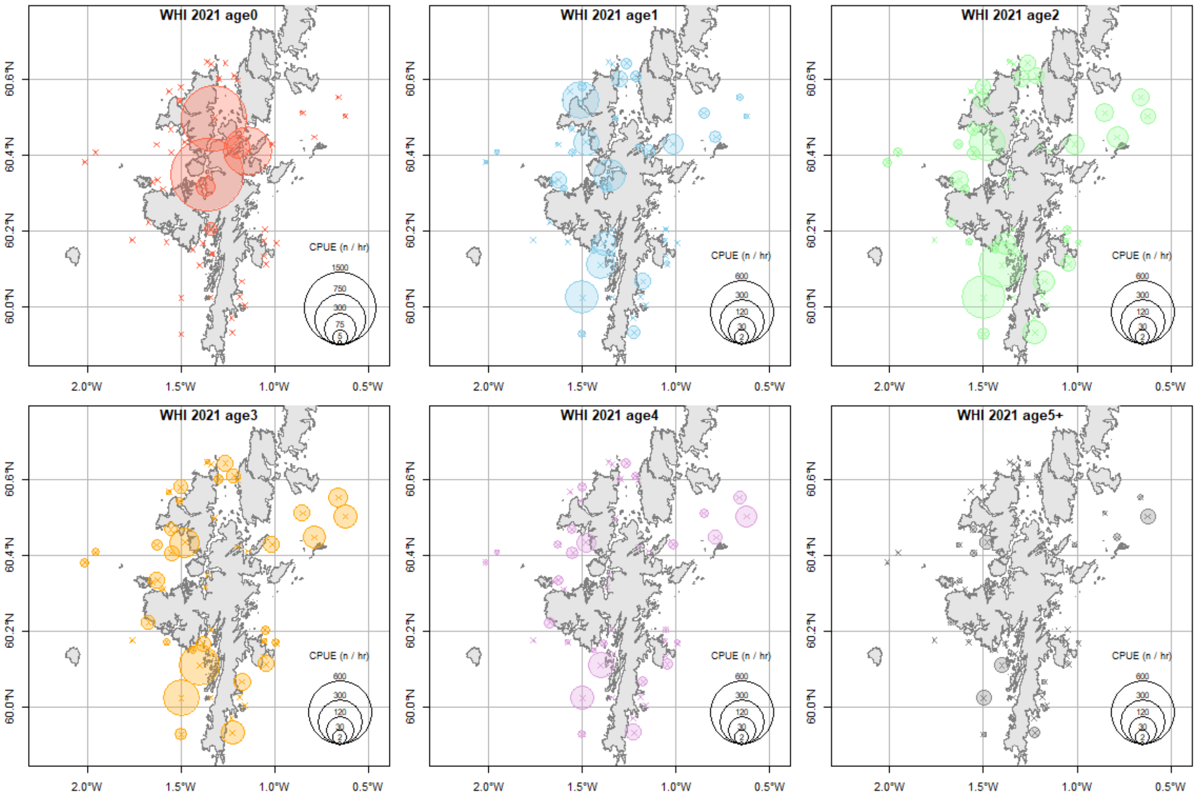
Appendix C – Whiting spatial distribution

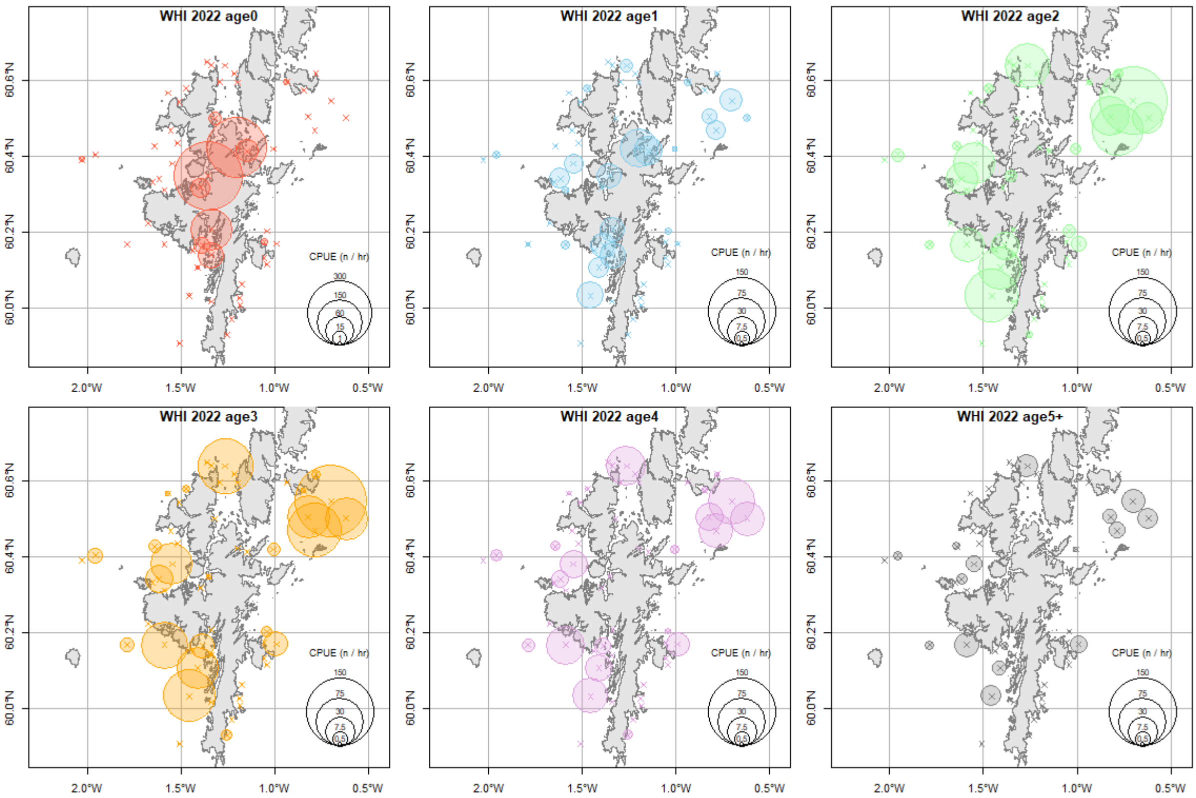


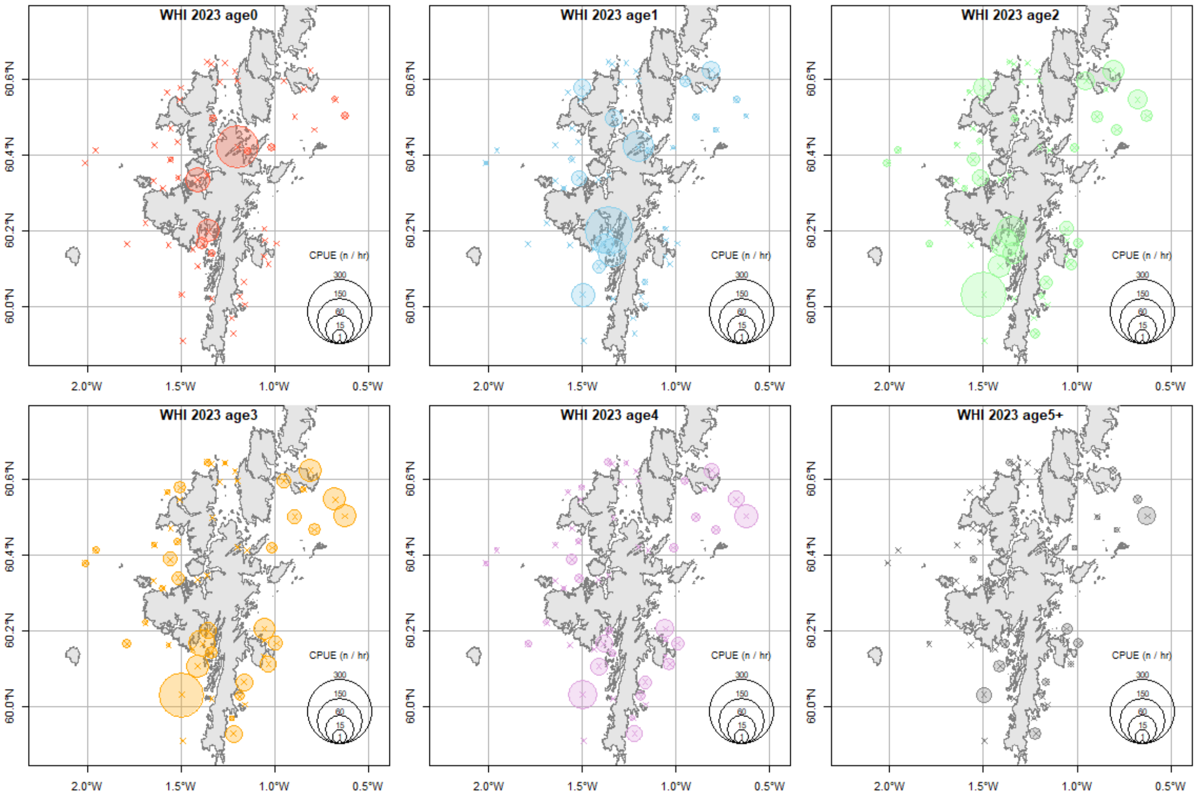


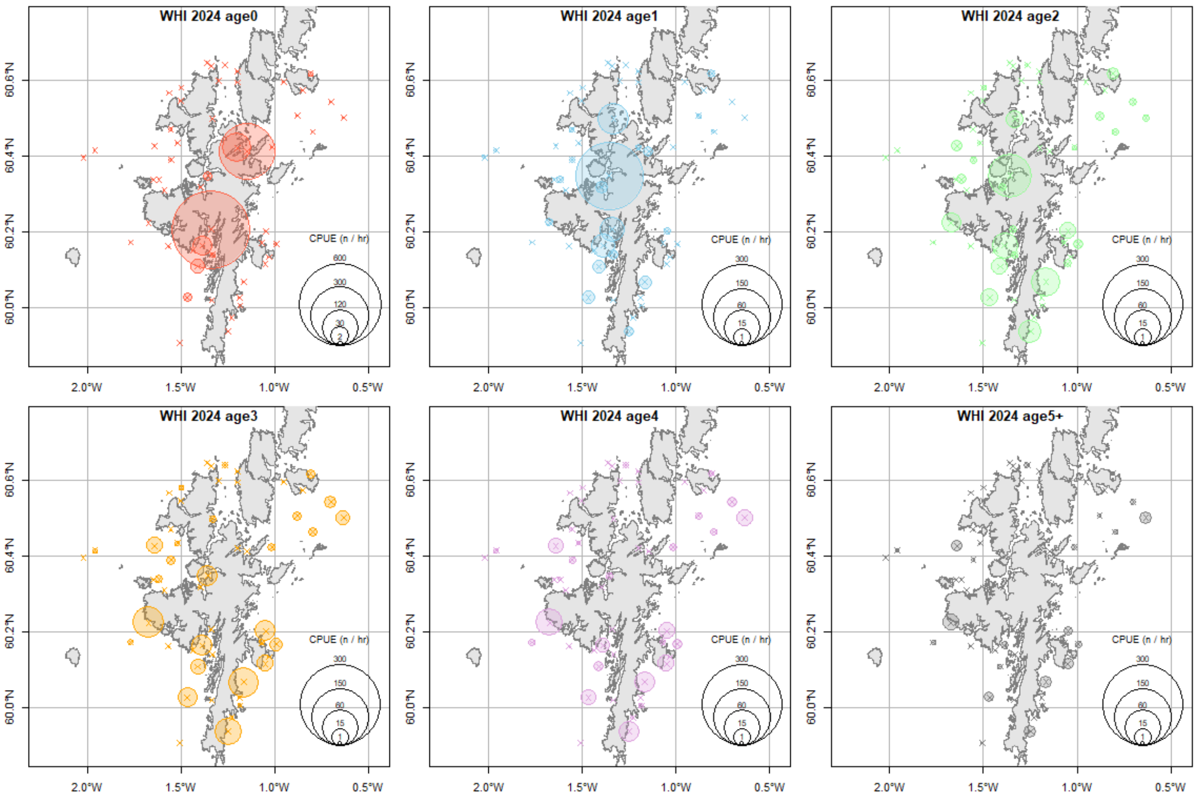

WHI 2019 age0
WHI 2019 age1
WHI 2019 age2
WHI 2019 age3
WHI 2019 age4
WHI 2019 age5+
CPUE (n / hr)
1500
750
300
75
5
300
150
60
15
1
60.6°N
60.4°N
60.2°N
60.0°N
2.0°W
1.5°W
1.0°W
0.5°W


WHI 2020 age0
WHI 2020 age1
WHI 2020 age2
WHI 2020 age3
WHI 2020 age4
WHI 2020 age5+
CPUE (n / hr)
1500
750
300
75
5
600
300
120
30
2
60.6°N
60.4°N
60.2°N
60.0°N
2.0°W
1.5°W
1.0°W
0.5°W

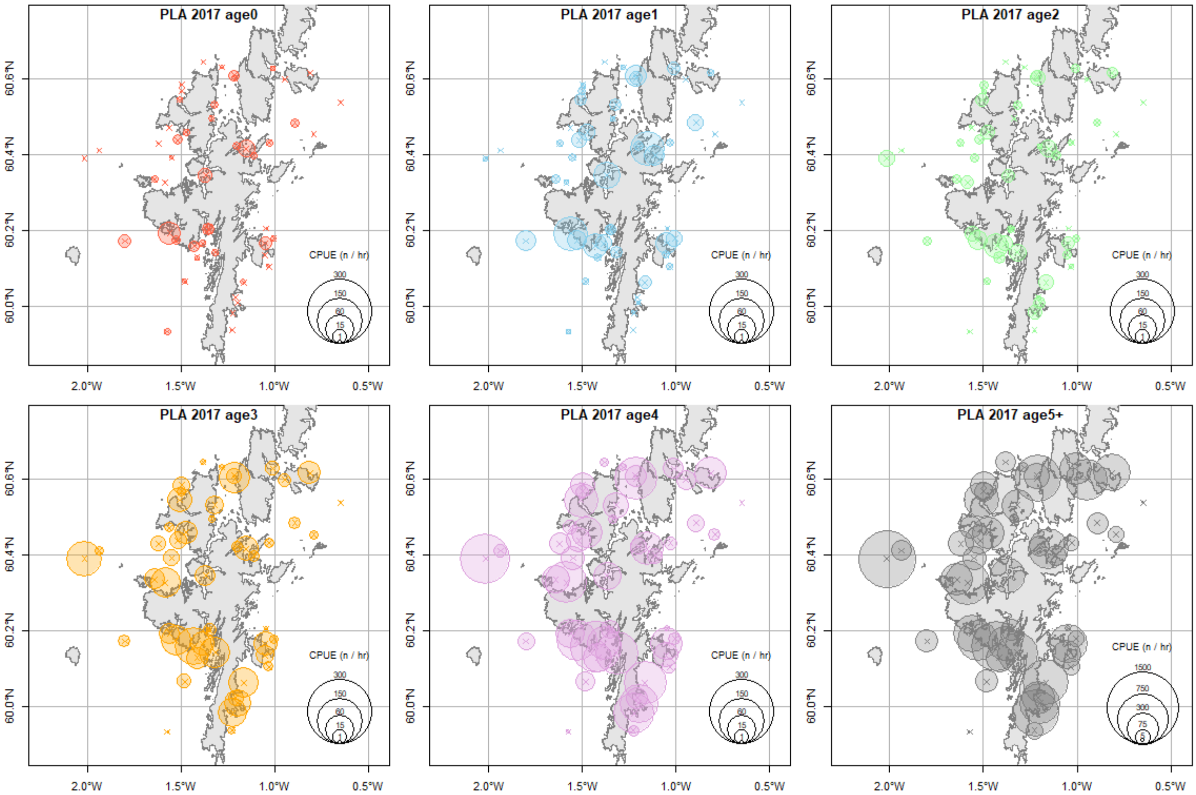

WHI 2021 age0
WHI 2021 age1
WHI 2021 age2
WHI 2021 age3
WHI 2021 age4
WHI 2021 age5+
CPUE (n / hr)
1500
750
300
75
600
300
120
30
60.6°N
60.4°N
60.2°N
60.0°N
2.0°W
1.5°W
1.0°W
0.5°W

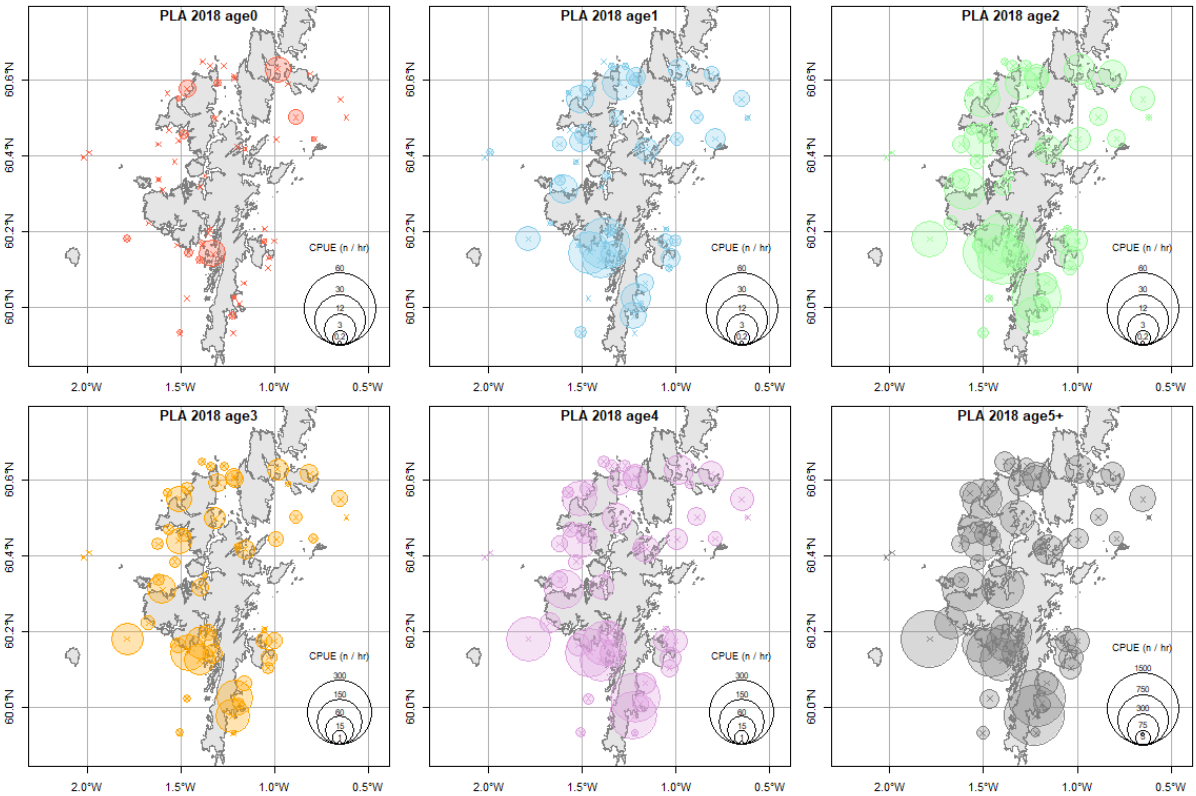

WHI 2022 age0
WHI 2022 age1
WHI 2022 age2
WHI 2022 age3
WHI 2022 age4
WHI 2022 age5+
CPUE (n / hr)
300
150
60
15
150
75
30
7.5
60.6°N
60.4°N
60.2°N
60.0°N
2.0°W
1.5°W
1.0°W
0.5°W

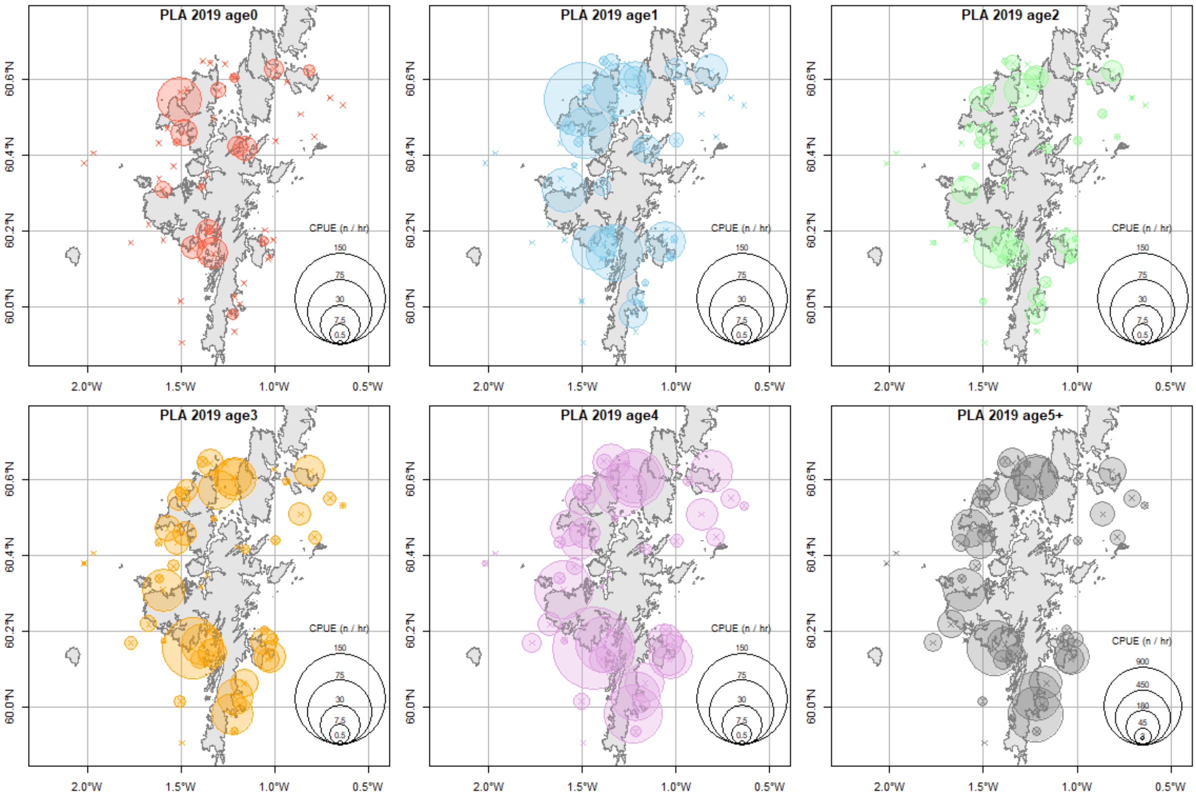

WHI 2023 age0
WHI 2023 age1
WHI 2023 age2
WHI 2023 age3
WHI 2023 age4
WHI 2023 age5+
CPUE (n / hr)
60.0°N
60.2°N
60.4°N
60.6°N
2.0°W
1.5°W
1.0°W
0.5°W

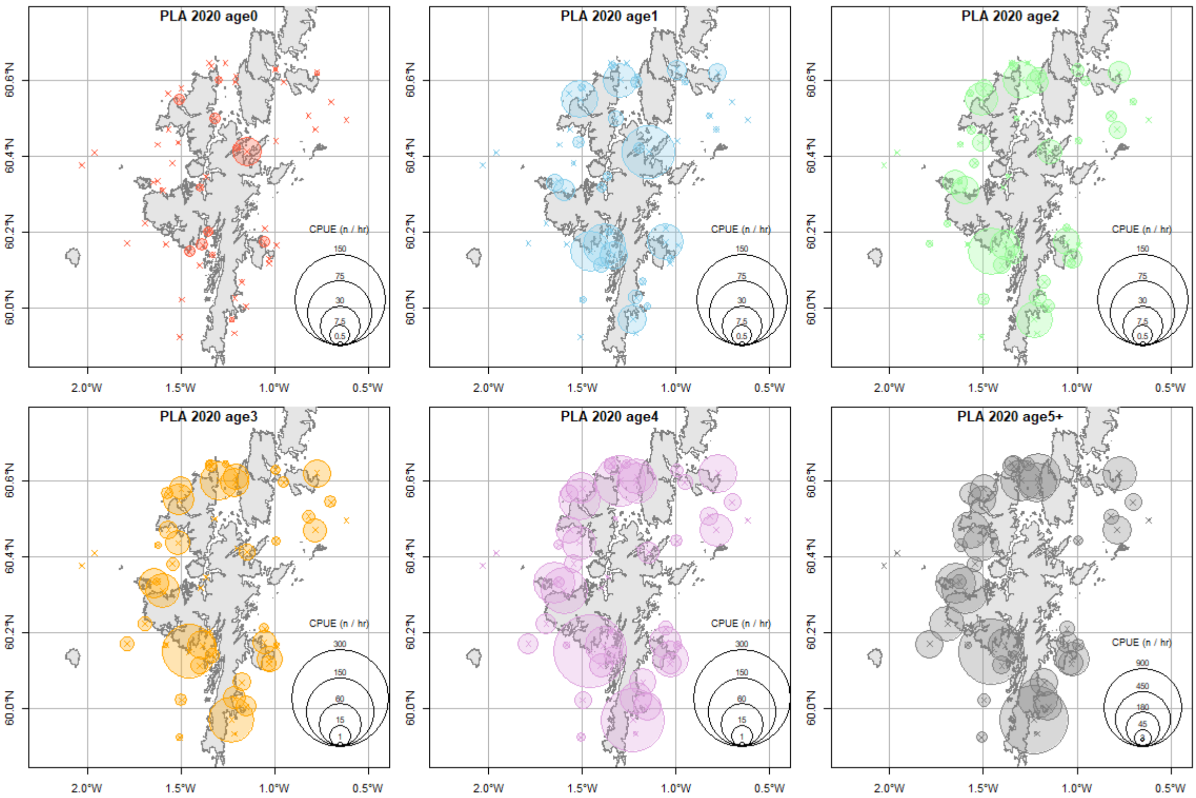

WHI 2024 age0
WHI 2024 age1
WHI 2024 age2
WHI 2024 age3
WHI 2024 age4
WHI 2024 age5+
CPUE (n / hr)
60.0°N
60.2°N
60.4°N
60.6°N
2.0°W
1.5°W
1.0°W
0.5°W

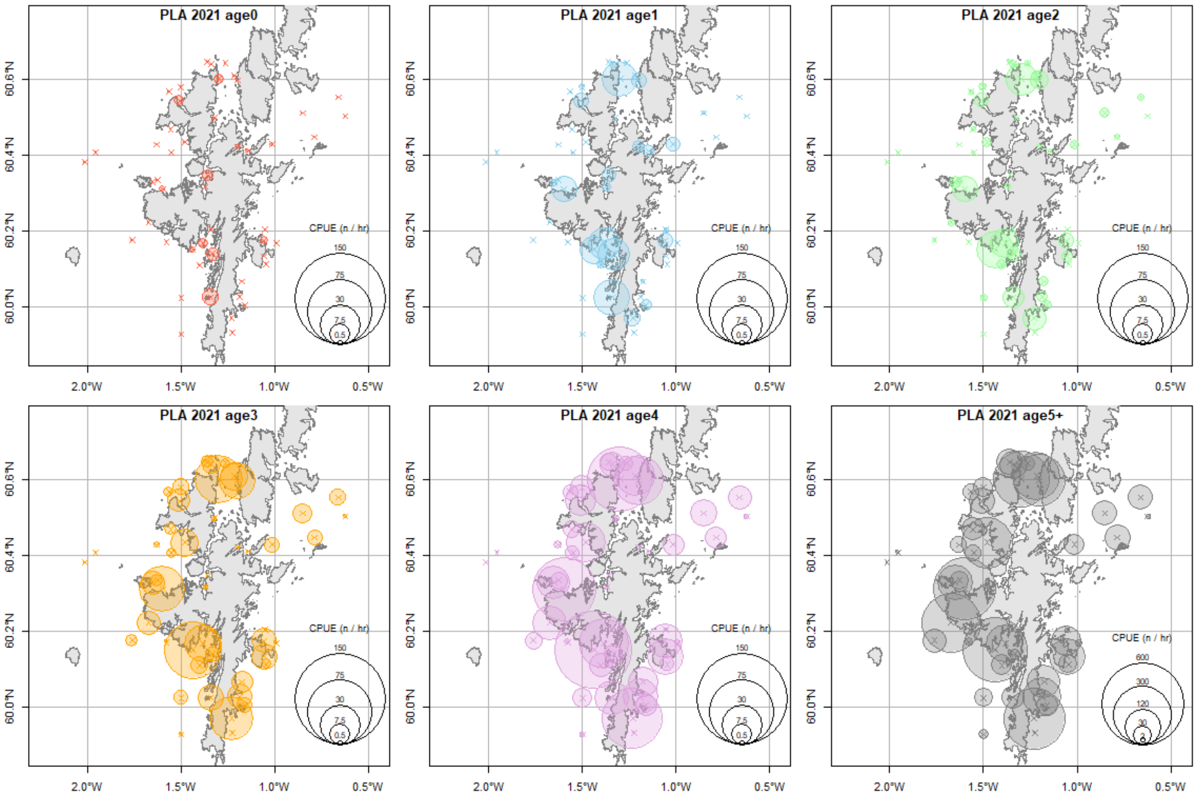
Appendix D – Plaice spatial distribution

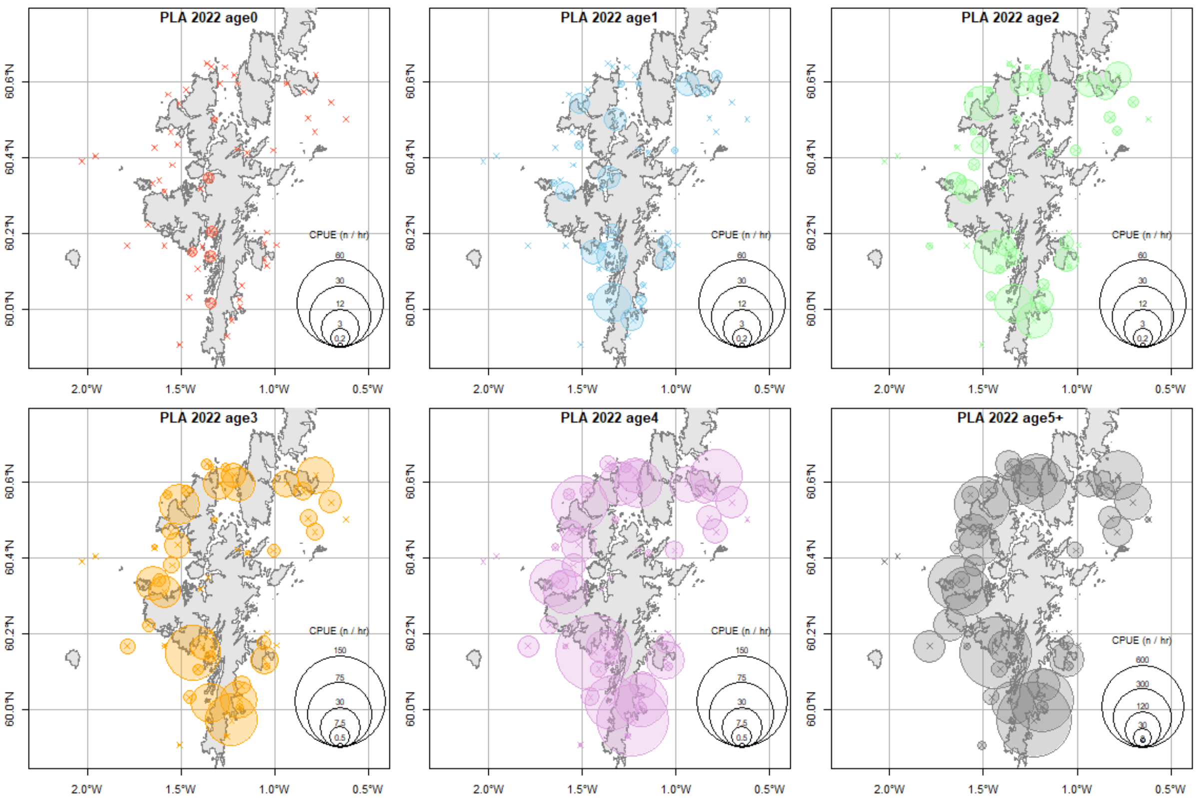


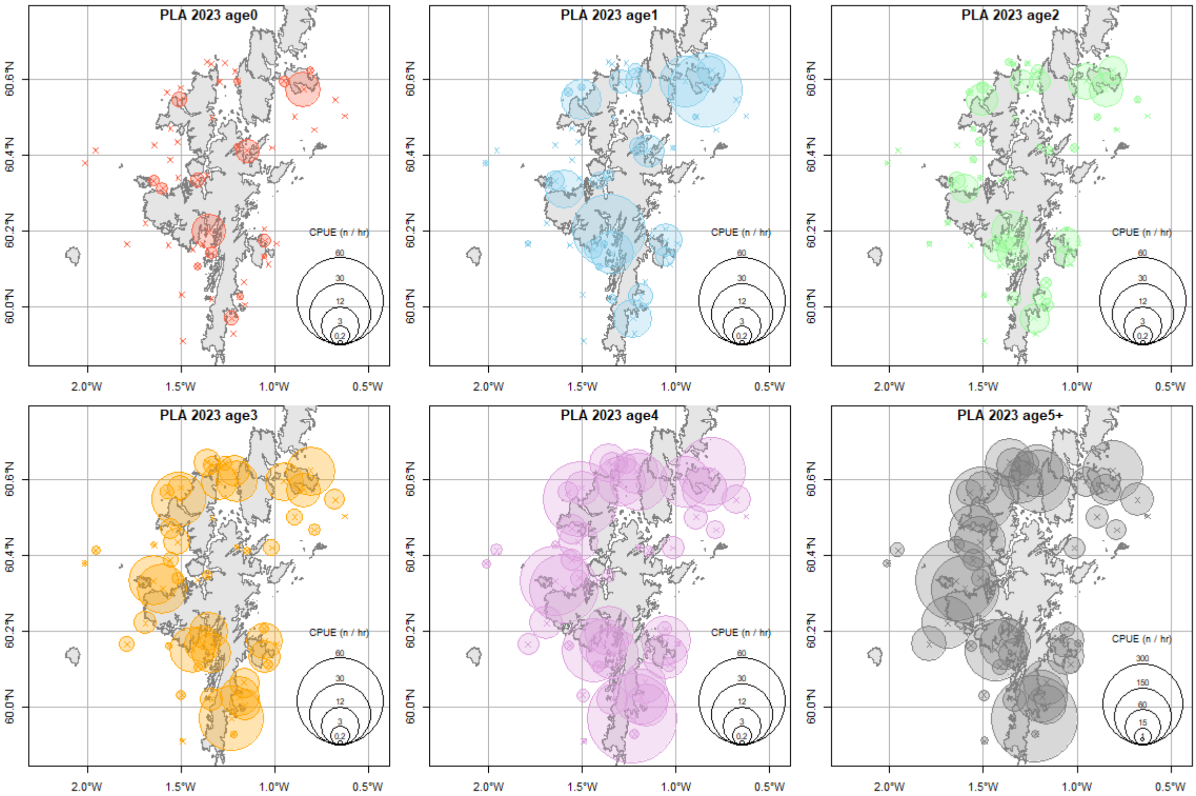


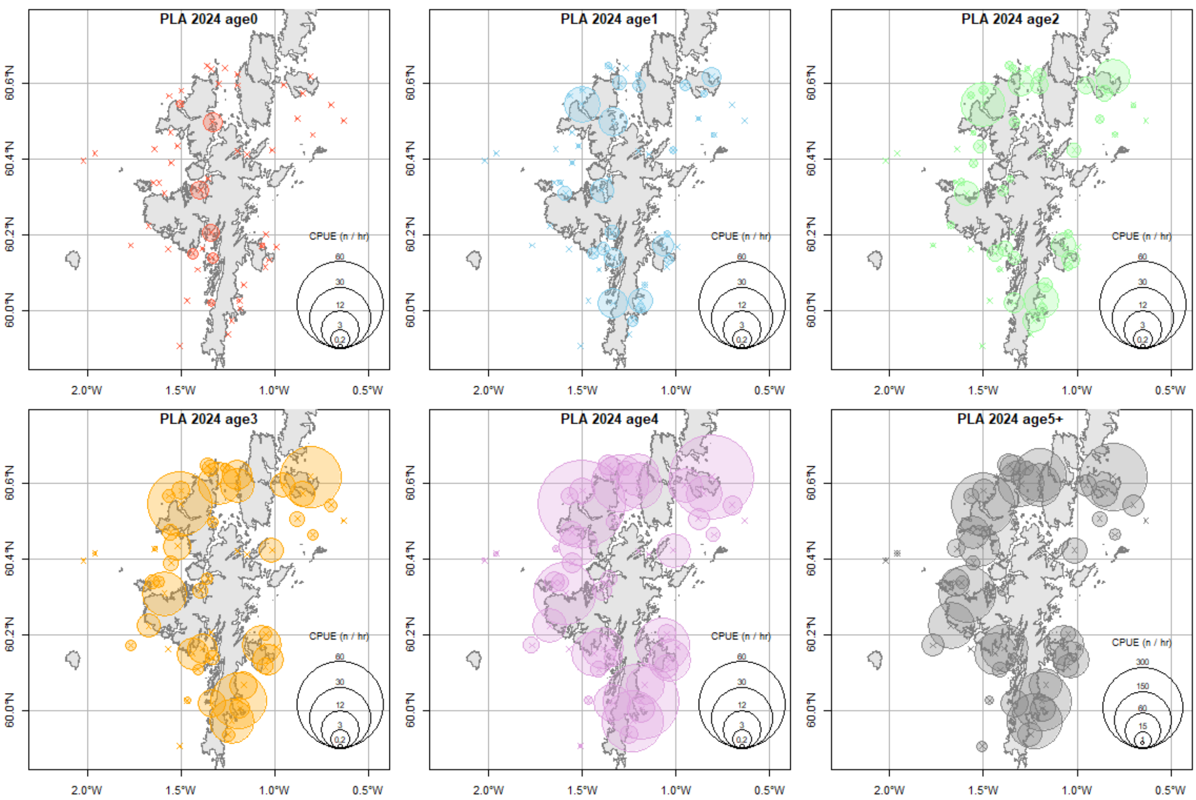

PLA 2019 age0
PLA 2019 age1
PLA 2019 age2
PLA 2019 age3
PLA 2019 age4
PLA 2019 age5+
CPUE (n / hr)
60.6°N
60.4°N
60.2°N
60.0°N
2.0°W
1.5°W
1.0°W
0.5°W


PLA 2020 age0
PLA 2020 age1
PLA 2020 age2
PLA 2020 age3
PLA 2020 age4
PLA 2020 age5+
CPUE (n / hr)
60.6°N
60.4°N
60.2°N
60.0°N
2.0°W
1.5°W
1.0°W
0.5°W


PLA 2021 age0
PLA 2021 age1
PLA 2021 age2
PLA 2021 age3
PLA 2021 age4
PLA 2021 age5+
60.6°N
60.4°N
60.2°N
60.0°N
2.0°W
1.5°W
1.0°W
0.5°W
CPUE (n / hr)
150
75
30
7.5
0.5
600
300
120


PLA 2022 age0
PLA 2022 age1
PLA 2022 age2
PLA 2022 age3
PLA 2022 age4
PLA 2022 age5+
60.6°N
60.4°N
60.2°N
60.0°N
2.0°W
1.5°W
1.0°W
0.5°W
CPUE (n / hr)
60
30
12
3
0.2
150
75
7.5
0.5
600
300
120


PLA 2023 age0
PLA 2023 age1
PLA 2023 age2
PLA 2023 age3
PLA 2023 age4
PLA 2023 age5+
CPUE (n / hr)
60
30
12
3
0.2
300
150
60
15
60.6°N
60.4°N
60.2°N
60.0°N
2.0°W
1.5°W
1.0°W
0.5°W


PLA 2024 age0
PLA 2024 age1
PLA 2024 age2
PLA 2024 age3
PLA 2024 age4
PLA 2024 age5+
CPUE (n / hr)
60
30
12
3
0.2
300
150
60
15
60.6°N
60.4°N
60.2°N
60.0°N
2.0°W
1.5°W
1.0°W
0.5°W