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Do biomass indices from Icelandic groundfish surveys reflect changes in the population of female lumpfish (*Cyclopterus lumpus*)?

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ABSTRACT

The female portion of the population of lumpfish (*Cyclopterus lumpus*) in Iceland is currently monitored using a biomass index calculated using catch data from the Icelandic spring groundfish survey (referred to as the spring survey). This has been controversial among lumpfish fishers who insist that the behaviour and variations in the migration of lumpfish make the use of this survey inappropriate for assessment. To evaluate whether changes in the biomass index from the spring survey adequately reflect changes in the population, the spatial and depth distribution of catches of lumpfish from this survey are compared with the total coverage of the survey. The biomass index from the spring survey is also considered alongside data from two other surveys (gillnet survey and autumn groundfish survey) and catch per unit effort (CPUE) from the female lumpfish fishery. In the spring survey, female lumpfish were predominantly caught at depths shallower than 300 m and within 100 km of shore, while the survey extends to a depth of 500 m and 227 km from shore, indicating that survey coverage was fitting for this species. The changes in the biomass index from the spring survey were similar to that of the gillnet survey, and also to changes in CPUE of the fishery. A decrease in the biomass index of large lumpfish (≥ 45 cm) caught during the survey was correlated with the decreasing use of large mesh sizes in the fishery indicating that changes in size distribution in the population could be detected using the spring survey. These results indicate that the use of the spring survey to monitor changes in lumpfish population in Iceland is justified. The use of data from bottom trawl surveys to track lumpfish populations in other regions is discussed.

1. Introduction

As part of stock assessment, research survey data is used as a source of fishery independent data. For many high value species e.g. Atlantic cod (*Gadus morhus*) or orange roughy (*Hoplostethus atlunticus*), research surveys have been optimised specifically for biomass estimation of that species (Clark, 1996; Rose, 2003). Data on other species are commonly collected alongside that of the target species, this is then available for stock assessment purposes. However, for a variety of reasons, this catch data may not be appropriate for estimating the abundance of the 'bycatch' species e.g. the gear may not be suitable for the species in question, or changes in catch may not reflect real changes in population abundance due to shifts in distribution outside the survey coverage or changes in behaviour. The survey coverage may also not have sufficient overlap with the population distribution or depth range of the bycatch species (Helle and Pennington, 2004). It is therefore essential to carefully assess the data to ensure its use as the basis for management advice is justified.

Lumpfish (*Cyclopterus lumpus*) is a semi-pelagic species found in the north Atlantic (Cox and Anderson, 1922; Blacker, 1983; Kennedy et al., 2016). Outside the breeding season, it is found in open water far from land (Holst, 1993). Around February-March, lumpfish migrate from open water to coastal areas around Iceland to spawn. While they are at the coast they are targeted by fishers for their roe. The fish are targeted exclusively using small boats using large mesh gillnets, however they are caught as bycatch in increasing numbers by bottom trawlers and other fishing gear as the fishing season approaches (Directorate of Fisheries (Iceland), unpublished data). The female lumpfish fishery is an effort controlled fishery with restrictions on the number of nets and the number of consecutive days a boat can fish within a season.

The Marine Research Institute in Iceland had not given advice on a Total Allowable Catch (TAC) for lumpfish until 2012. Despite being an effort controlled fishery, TAC advice is given in biomass (MRI, 2016) which is taken into consideration by the Ministry of Industries and Innovation when deciding the number of fishing days per boat for the season. The advice is based on a biomass index of female fish derived from catches of lumpfish from the Icelandic spring groundfish survey (hereafter referred to as 'spring survey') (Pálsson et al., 1989). The

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biomass index from the current and previous year are taken into account, with a weighting of 70 and 30% respectively, when calculating the advised TAC for the upcoming fishing season. The biomass index from the spring survey is considered to be a relative measure of biomass and not absolute. The aim of the advice is to maintain the proxy for fishing mortality (landings/biomass index) below the average for 1985–2011. This has been met with resistance from lumpfish fishers who have rejected the methodology used to calculate the advised TAC (Bogason, 2014). Their primary grievance is with the use of bottom trawl to monitor changes in population size. Lumpfish fishers believe the fish spends the majority of its time in surface waters and thus bottom gear is inappropriate for assessing changes in the lumpfish population. They also contend that changes in the biomass index are changes in the timing of the migration and not changes in the population size.

When considering whether data from a particular survey is suitable for assessment purposes, there are a number of points which must be considered; is the survey gear appropriate for the species in question? Does the depth distribution of the survey suitably cover the depth distribution of the species? How does the spatial coverage of the survey compare with the spatial distribution of the species? Do annual variations in catch reflect real changes in the population? How is the size-selectivity of the gear i.e. is the survey capable of detecting changes in length composition of the population? Or will changes in the catch rate only reflect changes in abundance of a particular size range of the population? These questions will be addressed in the present study in order to evaluate whether using data from the spring survey for assessing the abundance of lumpfish over time is justified.

2. Materials and methods

In order to evaluate whether changes in the biomass index from the spring survey reflect changes in the population, data from two other research surveys carried out in Iceland was examined; the gillnet survey carried out in April and the autumn groundfish survey (hereafter referred to as the autumn survey) which takes place in October-November. The biomass index from the spring survey was also compared with catch per unit effort (CPUE) of the fishery. Data on the use of different mesh sizes in the fishery was compared with changes in size distribution of fish caught during the spring survey to establish whether these changes were reflecting changes occurring in the population.

It is common for CPUE to be negatively correlated with effort itself and a large change in effort has the potential to obscure any relationship between CPUE and abundance indices. However, due to concerns about incomplete logbook coverage, effort could not be estimated directly, therefore effort was estimated from CPUE and landings data. As landings of lumpfish roe and whole lumpfish were not officially recorded in Iceland before 2008, annual landings were estimated from the production of barrels of salted roe which was recorded by the National Association of Small Boat Owners (NASBO).

Unless otherwise specified, all mentions of lumpfish refer to female lumpfish only.

2.1. Standardisation of logbooks

Due to changes in the fishery and the way data was recorded in logbooks over time, conversion factors are needed in order to standardise logbook data between years and boats. The data recorded by the fishers could consist of weight of roe, which could either be fresh or have gone through one or more stages of the salting process, which affects the weight (the stage of the roe when it was weighed was given in the logbooks). They may also have, or only, recorded the number of lumpfish caught. The aim is to estimate the total weight of ungutted lumpfish for each entry in the logbooks. This first requires that the weight of roe is standardised to weight of fresh roe. A conversion factor

Table 1
Description of the four categories reported in lumpfish logbooks with the denominator used to convert to weight of fresh roe.

Description	Denominator
Roe with all fluid	1.00
Drained roe	0.94
Roe ready for salting	0.77
Salted roe	0.81

is then needed to estimate the ungutted weight from the weight of fresh roe. An estimate of average fish weight is also needed to convert number of fish to total weight.

In order to standardise weight of roe to fresh roe weight, a conversion factor was established for each stage in the salting process. Using all logbook entries which contained both number of fish and weight of roe, the total weight of roe was divided by the number of fish for each category of roe. Ratios between the quotients for the categories were divided into the weight of roe to estimate the equivalent weight of fresh roe (Table 1).

To convert weight of fresh roe to total weight of lumpfish, data from logbooks which contained both weight of roe and number of fish were utilised. The number of fish was converted to weight of fish by multiplying by 3.02 (see below). The weight of roe was then divided by weight of fish to give a value for the Gonadosomatic Index (GSI) ($n = 129,686$). Due to a continuous distribution into unrealistic values, the modal value was used after rounding to the nearest 0.5%, giving a value of 30.5%. This is similar to GSI values measured during sampling of the fishery (MRI, unpublished data). Thus, the weight of fresh roe was multiplied by 3.28 to give the weight of ungutted lumpfish.

To convert numbers of lumpfish to weight, logbook data of boats from 2013 to 2015 which reported total number of lumpfish caught ($n = 234$) was utilised. The total number of fish for each boat was calculated, the total landings for the same boats, as recorded by the Directorate of Fisheries, was then divided by number of fish. This gave an average fish weight of 3.02 kg.

2.2. Total landings

Landings of lumpfish roe and whole lumpfish were not officially recorded in Iceland before 2008. Before 2012, landing of whole lumpfish was uncommon, with fishermen disposing of the bodies at sea and landing only roe, but in 2012 it became mandatory to land the bodies. The only data available pre-2008 on catches is from NASBO who reported the number of barrels of salted roe produced after each season; this dataset dates back to 1945. In order to convert the number of barrels produced each year to kg of fresh roe, fishers logbooks which reported kg of roe landed and number of barrels produced were utilised (between 38 and 134 boats per year between 1990 and 2010). If the roe had entered the salting process, the original fresh weight was estimated (see Section 2.1). For each year, the total weight of roe reported in the logbooks was summed across all fishing trips and boats for the given year. The number of barrels reported in the same logbooks was summed across all boats. The relationship between barrels of roe and weight of fresh roe was then established using linear regression. The weight of fresh roe landed for each year was then estimated from the number of barrels reported by NASBO. The estimated weight of fresh roe was then multiplied by 3.28 (see section 2.1) to give the total weight of ungutted lumpfish.

2.3. CPUE and total effort

CPUE was estimated using the logbooks from fishermen targeting lumpfish with lumpfish gillnets. The calculations were standardised by estimating the total weight of ungutted lumpfish. For each logbook entry, CPUE was estimated by dividing the weight of ungutted lumpfish by the number of nets. Lumpfish gillnets have a mesh size of 267 or 292 mm (hereafter referred to as small and large mesh respectively) and can have a length of 110 (short) or 220 (long) m. For logbook entries which stated that long nets were used, the number of nets was multiplied by two to give short net equivalents. Soak time was not used in the estimation of CPUE as average soak time was relatively constant from 1980 until 2012, varying between 4 and 6 days (Supplementary Fig. S1). From 2012–2015, average soak time decreased to an average of 3–4 days due to the decrease in the maximum allowable soak time in 2013 from 6 to 4 days. After a soak time of 1 day, additional days led to only small increases in CPUE (Supplementary Fig. S1), therefore the decrease in soak time following 2012 is considered to only have minor impact on estimated CPUE. Two CPUE values were calculated for each year; one by taking the average of only data from boats using small mesh size, the other using data from all mesh sizes. CPUE was log transformed as there are indications that the relationship between gillnet CPUE and fish abundance is non-linear (Olin et al., 2016).

Due to incomplete logbook coverage, an index of effort was estimated by dividing total catch by CPUE (all mesh sizes combined) for each year. Soak time was not incorporated into the calculation of CPUE and effort as doing so had only a minor impact on the resultant effort and would have led to the exclusion of logbook entries which did not include soak time.

2.4. Groundfish trawl surveys

Two groundfish surveys are carried out each year; the Icelandic spring groundfish survey (spring survey) and the Icelandic autumn groundfish survey (autumn survey). The manuals for the surveys are fully described in MRI (2010) and a general description of the survey projects, their main objectives, planning, design and data sampling is given in Björnsson et al. (2007). The spring survey began in 1985 and takes place every year during late February and March. It covers the entire Icelandic continental shelf from depths of approximately 20–500 m (Supplementary Fig. S2). The number of stations has varied over time from 509 to 694. The Iceland-Faroe ridge is also surveyed but this was not covered between 1996 and 2003, with only partial coverage in 2004. The spring survey uses a Granton type trawl. The front section has a mesh size of 135 mm, the middle section (belly) 80 mm and the codend is covered inside with a 40 mm net. The towing speed over ground is 3.8 knots. The trawling distance is 4.0 NM with the start and end position taken using GPS when the trawl has set on the bottom and when hauling begins (i.e. excluding setting and hauling of the trawl). Trawling is carried out over 24 h. Lumpfish are known to exhibit diurnal migration with fewer lumpfish caught at night than during the day (Kennedy et al., 2016). For tracking relative abundance it is recommended not to make adjustments to the biomass index to compensate for the diurnal migration as it would introduce an extra source of variation (Hjellvik et al., 2002). Exclusion of night catches is also considered tantamount to throwing away valuable data, and it is also not clear when day and night should be defined as there is a gradual rise in catch from 0600 until approximately 1000. Catches then begin to decrease again around 1600 until 2000 (Hjellvik et al., 2002; Kennedy et al., 2016). A biomass index calculated using only stations trawled during the day (trawling started after 0600 and before 2000) and stations trawled during the night were significantly correlated (Linear regression, $p < 0.001$, $R^2 = 0.39$) and exclusion of the night stations only had a minor impact on the biomass index (Supplementary Fig. S3). Given the above reasons, it was decided to make no adjustments to night catches and to calculate the index using all stations.

The autumn survey began in 1996 and takes place in October-November each year with exception of 2011. The research area is the Icelandic continental shelf and slopes within the Icelandic Exclusive Economic Zone to depths down to 1500 m. The research area is divided into a shallow-water area (0–400 m) and a deep-water area

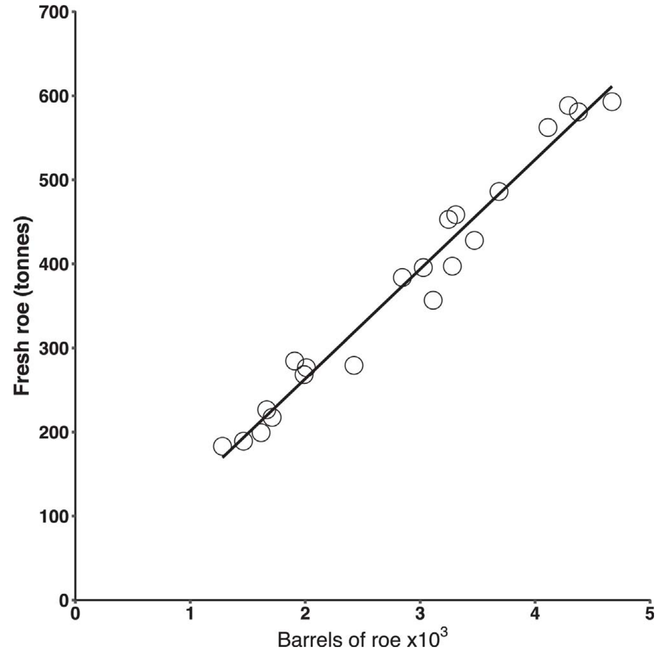

Fig. 1. Correlation between barrels of roe versus weight of fresh roe from logbooks of lumpfish fishers in Iceland. Each point represents one year. Linear regression line is shown.

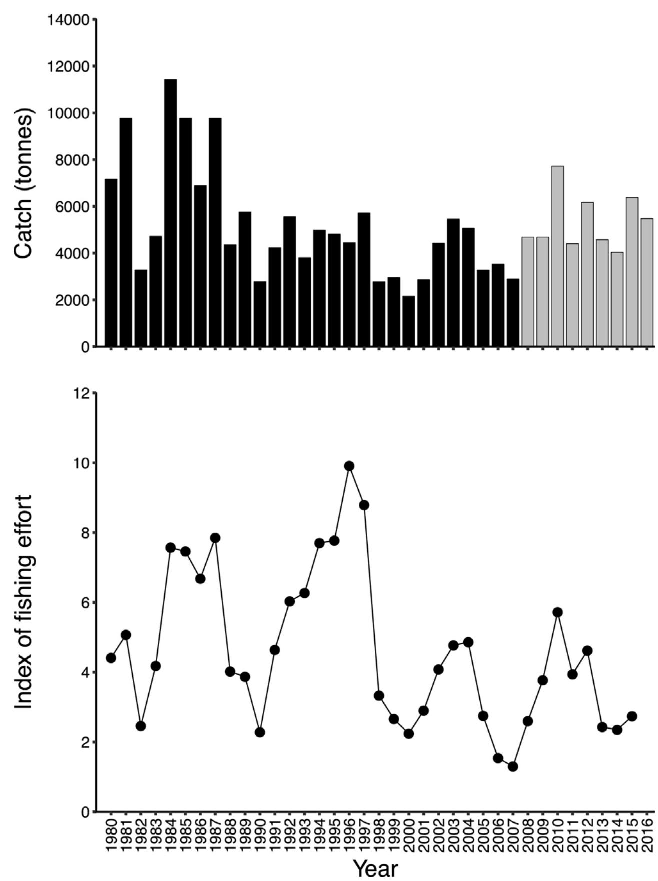

Fig. 2. Estimated landings of whole lumpfish in Iceland (top) and index of fishing effort (bottom) between 1980 and 2015. Black fill indicates landings estimated from barrels of roe reported by national association of small boat owners (NASBO), gray fill indicates landings estimated by Icelandic Directorate of Fisheries.

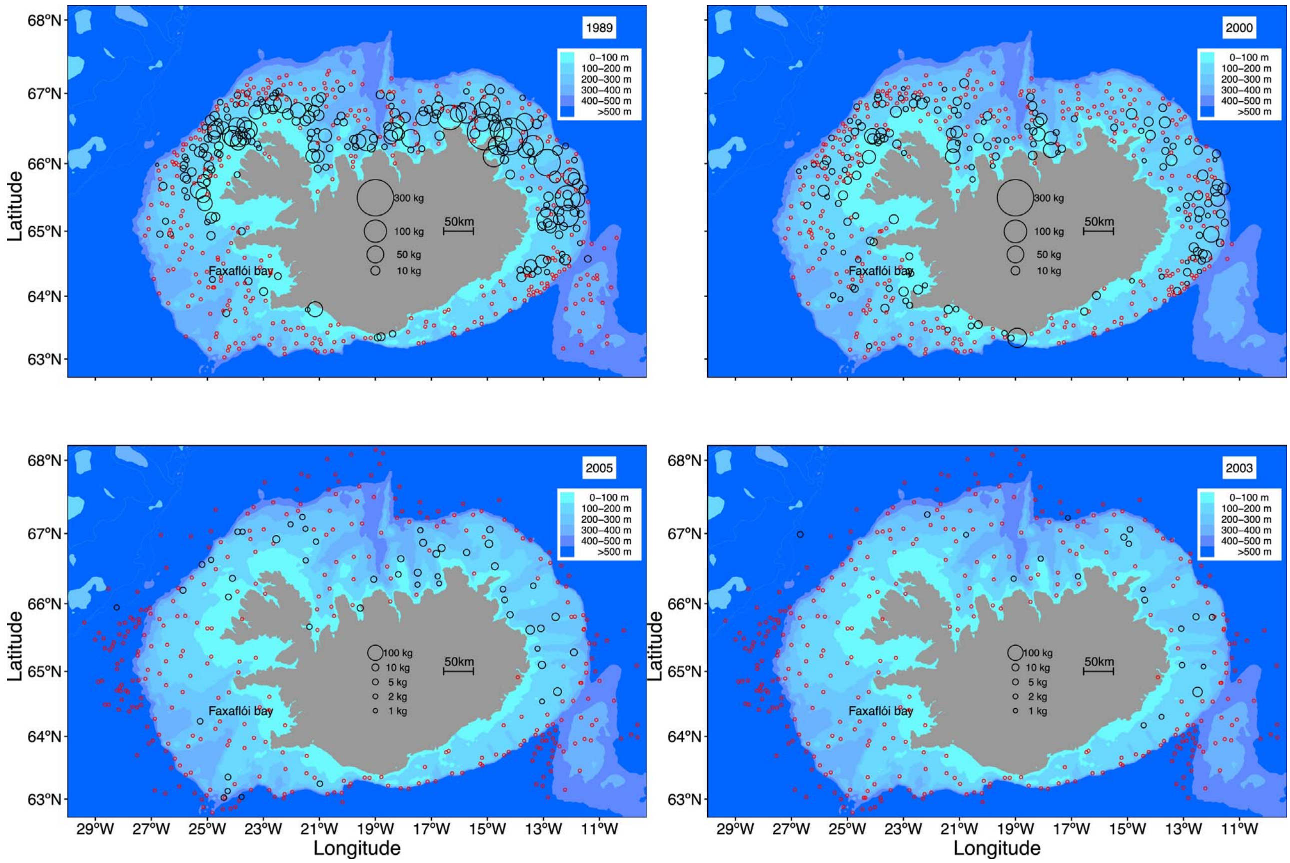

Fig. 3. Catch of lumpfish during the spring (top) and autumn surveys (bottom). Years of highest (1989 and 2005) and lowest (2000 and 2003) biomass index are shown. Red circles indicate zero catch of lumpfish. For other years see supplementary Figs. S2 and S4 . (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

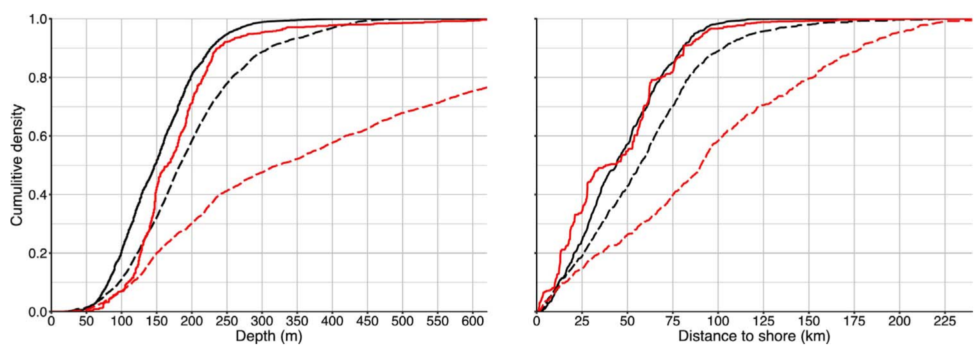

Fig. 4. Cumulative density of catches of female lumpfish (solid line) and number of stations (dashed line) vs. depth (left) and distance to shore (right) for the Icelandic spring groundfish survey (black) from 1985 to 2016 and Icelandic autumn groundfish survey (red) from 1996 to 2016. Note truncated x-axis scale for depth in autumn survey due to low catches at depths greater than 600 m. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(400–1500 m) (Supplementary Fig. S4). The number of stations has varied over time with 146-178 and 144-221 stations in the shallow and deep water area respectively. The autumn survey uses a "Golden Top" trawl. The front section has a mesh size of 135 mm, the middle section (belly) 80 mm and the codend is covered inside with a 40 mm net. The towing speed is 3.8 knots over the bottom. The trawling distance is 3.0 nautical miles calculated with GPS when the trawl has set on the bottom until the hauling begins (i.e. excluding setting and hauling of the trawl). Trawling is carried out over 24 h. Contrary to Casey and Myers (1998), there was no indication of decreased catchability of lumpfish at night during the autumn survey (data not shown), therefore trawling at night was not considered to have an impact on the biomass index.

For each station on both surveys, the length and sex of almost all lumpfish are determined. Any unmeasured fish are counted. At each station, for one female and one male (pre 2015, this was only for one lumpfish), the maturity is determined and the length, gonad weight, total weight and gutted weight is measured. For the spring and autumn survey, a stratified biomass index, similar to that used for cod, is calculated for male and female lumpfish separately. A large fish index was also calculated for the spring survey which was a biomass index for female lumpfish ≥45 cm. The aim was to examine whether changes in the size composition of the fish caught during the spring survey also occurred in the fishery. Ideally, this would be achieved by comparing this with length measurements taken from the fishery, however port sampling of the lumpfish fishery did not commence until recently. Therefore, changes in the proportion of boats using large mesh gillnets were considered to be an indicator of the abundance of large fish in the fishery and was compared with the large fish index from the survey.

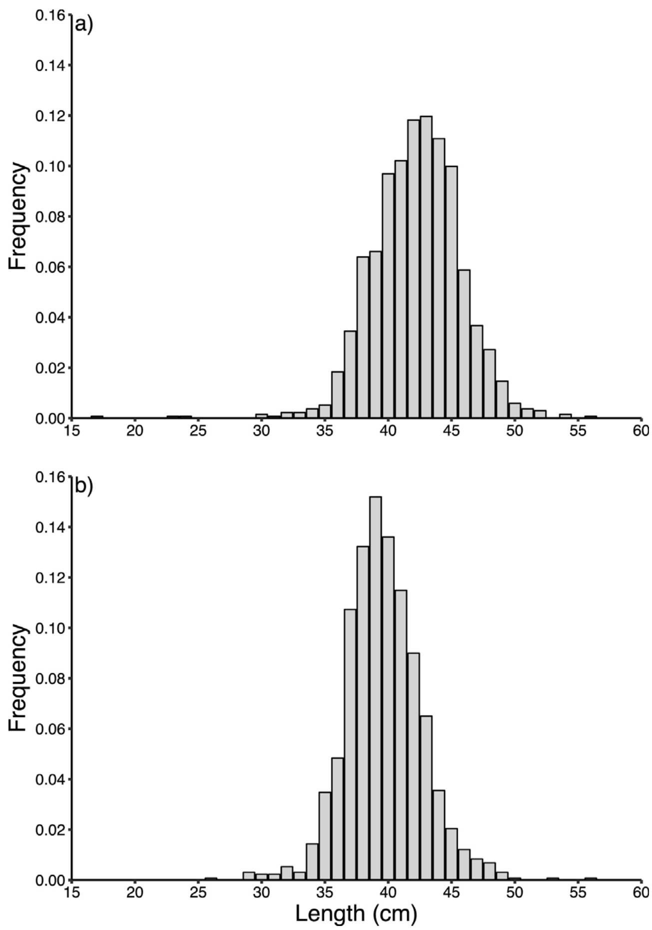

Fig. 5. Length frequency of female lumpfish caught in the spring survey in 1985 (a) and 2016 (b).

2.5. Gillnet survey

The Icelandic gillnet survey has been carried out in April each year since 1996 (Jónsdóttir et al., 2010). From 1996, this covered only the southern coast; this was expanded in 2002 to also include the northern coast. Between 2002 and 2016 there were between 295 and 332 stations. At each station, 12 nets (24 nets in parts of the survey area due to bathymetry), of 8 types (4 mesh size and two filament types) are linked together in one network. Each network consists of two 152 and 177 mm monofilament nets, two 202 and 228 mm multifilament, one 202 and 228 monofilament and one 177 and 152 multifilament, repeated for networks of 24. The 152 mm mesh net is 60 meshes deep whilst all others are 50 meshes deep. Stations range from a depth of 12–500 m. For each station, the length and sex of almost all lumpfish are determined. Any unmeasured fish are counted. An abundance index (total number caught/number of stations) is calculated for male and female fish separately. The abundance index was log transformed as there are indications that the relationship between gillnet CPUE and density is non-linear (Olin et al., 2016).

3. Results

3.1. Total catch

There was a significant linear relationship between the total reported/estimated weight of fresh roe as reported in the logbooks and the number of barrels produced as reported in the same logbooks (linear regression; $p < 0.001$, $R^2 = 0.97$) (Fig. 1). Using this relationship, the total weight of ungutted lumpfish could be estimated from the following equations:

$$R = 2754 + (130 * B)$$

$$L = R * 3.28$$

R = weight of fresh roe, B = Barrels of roe, L = total catch of whole lumpfish in tonnes.

Between 1980 and 2015, total catch fluctuated between approximately 2000 and 11 500 t of ungutted lumpfish per year with the highest catches during the 1980's (Fig. 2). The effort index (total landings/CPUE) fluctuated between 1.30 and 9.91 in the period 1980–2015 with effort generally being lower after 1997 when regulations limiting the number of vessels were imposed (Fig. 2).

3.2. Size, depth and spatial distribution

During the spring survey, lumpfish are predominantly caught north of 64°N in eastern Iceland and north of 65°N in western Iceland, but are also frequently caught within Faxaflói bay (Fig. 3, Supplementary Fig. S2). They are rarely caught on the southern coast or on the Iceland-Faroe ridge. Lumpfish were caught between depths of approximately 20 and 500 m, with 95 and 99% of the fish being caught shallower than 244 and 296 m respectively (Fig. 4). They were also generally caught less than 100 km from shore with 95 and 99% of the lumpfish being caught within 87 and 105 km from the shore, respectively, while the survey extends as far as 227 km from the shore (Fig. 4, Supplementary Fig. S2). The majority of the lumpfish caught during the spring survey

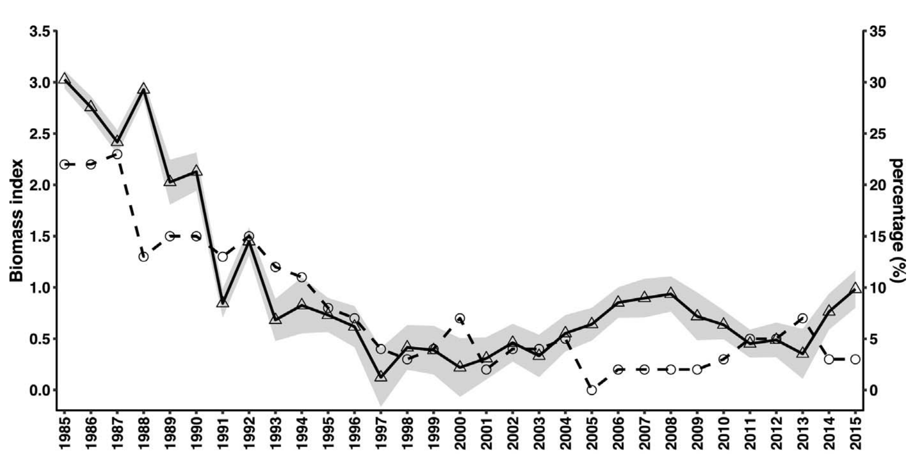

Fig. 6. Large fish (≥45 cm) biomass index (solid line, left axis) and proportion of boats using large mesh (292 mm) gillnets (dashed line, right axis) between 1985 and 2015. Coefficient of variation is shown in gray.

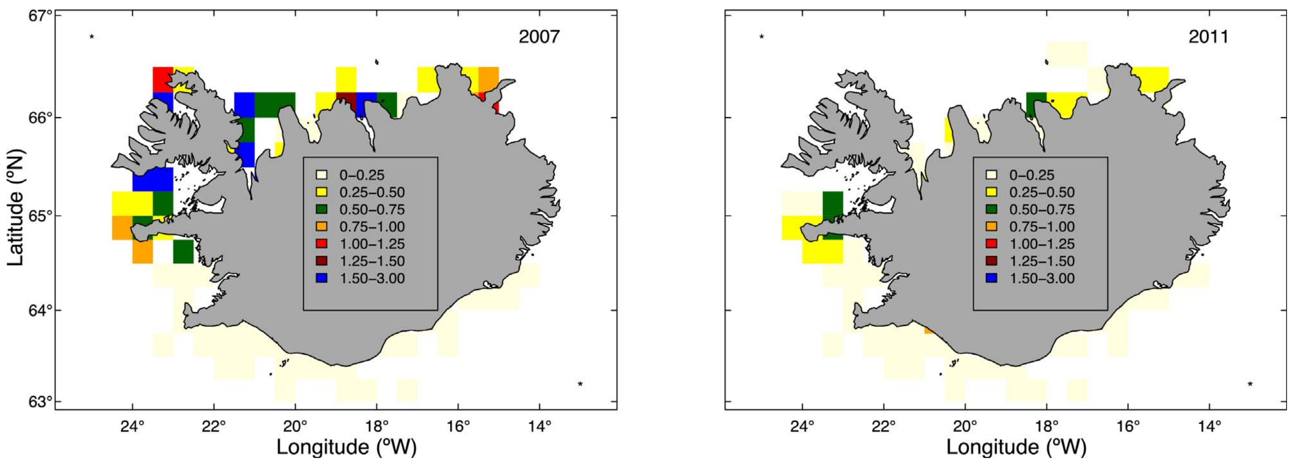

Fig. 7. Number of lumpfish caught per net per statistical square during the gillnet survey with the years of the highest (2007) and lowest (2011) catch shown.

are between 30 and 56 cm (Fig. 5) and are almost exclusively (> 99%) mature. The size distribution has changed between 1985 and 2016, with fewer fish ≥45 cm (Fig. 6) and a lower modal size in 2016 in comparison with 1985 (Fig. 5).

During the autumn survey, lumpfish were predominantly caught in eastern Iceland with a few caught in the north and west (Fig. 3, Supplementary Fig. S4). They were rarely caught south of 64°N. Lumpfish were caught between depths of 52 and 1252 m, with 95 and 99% of the fish being caught shallower than 284 and 553 m respectively and 95 and 99% of the lumpfish were caught less than 93 and 128 km from shore respectively (Fig. 4).

Lumpfish tended to be caught at shallower depths during the spring survey than during the autumn survey (Kolmogorov-Smirnov test; $p < 0.0001$). The distance to shore for catches of females was significantly different between the spring and autumn survey (Kolmogorov-Smirnov test; $p < 0.0001$), with a greater portion of the catch being caught within approximately 35 km of shore in the autumn survey in comparison with the spring survey (ca. 8%). Given the magnitude of this difference and that the cumulative catches of the two surveys converged at 40 km from shore, this difference was considered to have no practical significance (Fig. 4).

The spatial distribution of catches of lumpfish in the gillnet survey was similar to the spring survey with lumpfish predominantly being caught north of 64.5°N (Fig. 7).

3.3. Biomass index and CPUE

There was a significant correlation between the biomass index from the spring survey and log transformed abundance index from the gillnet survey (Pearson correlation analysis, $p = 0.02$). There was no significant correlation between the biomass index from the spring survey and the biomass index from the autumn survey (Pearson correlation analysis, $p > 0.05$).

There was no significant correlation between the log transformed abundance index from the gillnet survey and biomass index from the autumn survey (Pearson correlation analysis, $p > 0.05$). All three surveys did, however, follow roughly the same trajectories with an increasing trend from 2000 until 2005–2007, followed by a downward trend until 2013. The spring and gillnet survey show an increasing trend after 2013 but this was not evident in the autumn survey (Fig. 8).

Log transformed CPUE of the small mesh nets was positively correlated with spring biomass index and negatively correlated with the index of fishing effort (linear regression, $p < 0.0001$, $R^2 = 0.63$) (Fig. 9). The biomass index of large fish was significantly correlated with the proportion of boats using large mesh gillnets (linear regression; $R^2 = 0.66$, $p < 0.001$) (Fig. 6).

4. Discussion

The use of bottom trawl fishing gear to monitor changes in the population of lumpfish has been a contentious issue among lumpfish fishers in Iceland as many perceive lumpfish to be a pelagic species (Bogason, 2014). This is supported by the frequent capture of lumpfish in pelagic trawl hauls (Holst, 1993; ICES, 2016; Eriksen et al., 2014). However, as shown using data storage tags, during the time of the spring survey, lumpfish will spend a significant amount of time both in the pelagic zone and also associated with the seabed, with individual lumpfish frequently moving between the demersal and pelagic zones (Kennedy et al., 2016). Lumpfish also spend an increasing amount of time in the upper 20 m of the water column as the fishing season approaches, which explains the perception that lumpfish fishermen believe lumpfish spend most of their lives in surface waters. The capture of lumpfish in bottom trawl gear is not limited to Iceland; it has also been reported from bottom trawl surveys around Newfoundland and in the North Sea and the Barents Sea (Knijn et al., 1993; Casey and Myers, 1998; Wienerroither et al., 2013). Assuming the proportion of time spent associated with the sea bed remains constant between years, then, in regards to behaviour, the use of bottom trawl gear to monitor changes in the lumpfish population is supported.

Data from the spring survey show that lumpfish are predominantly distributed at depths from 50 to 300 m depth. This agrees with the data from data storage tags which show that lumpfish rarely dive to depths exceeding 300 m (Kennedy et al., 2016). As the survey covers depths from approximately 20–500 m, this covers the entire depth range of the species during the time of the survey. During the survey, 99% of the lumpfish are found < 105 km from shore, this distance is exceeded by the survey which extends as far as 227 km from shore and covers the entire Icelandic shelf. It has also been argued that changes in the biomass index from the spring survey are a result of changes in migration times between years (Bogason, 2014). Given that the survey extends beyond the distribution of the fish and covers the entire shelf, any change in timing of migration is likely to be detected by the survey with an increased proportion of lumpfish being captured in stations further from land. Given that the spring survey shows similar trends to the gillnet survey, and that it is positively correlated with CPUE of the fishery, we posit that changes in the spring biomass index are real changes occurring in the population.

With the use of large mesh gillnets in the fishery decreasing as the biomass of large fish decreased in the survey, it is clear that the fishermen also perceived a change in the size structure of the population. This is supported by reports from fishers who have stated that the size of fish has decreased in the past 30 years (Bogason 2014). This supports the assumption that the length composition of the spring survey reflects the length composition of the mature component of the

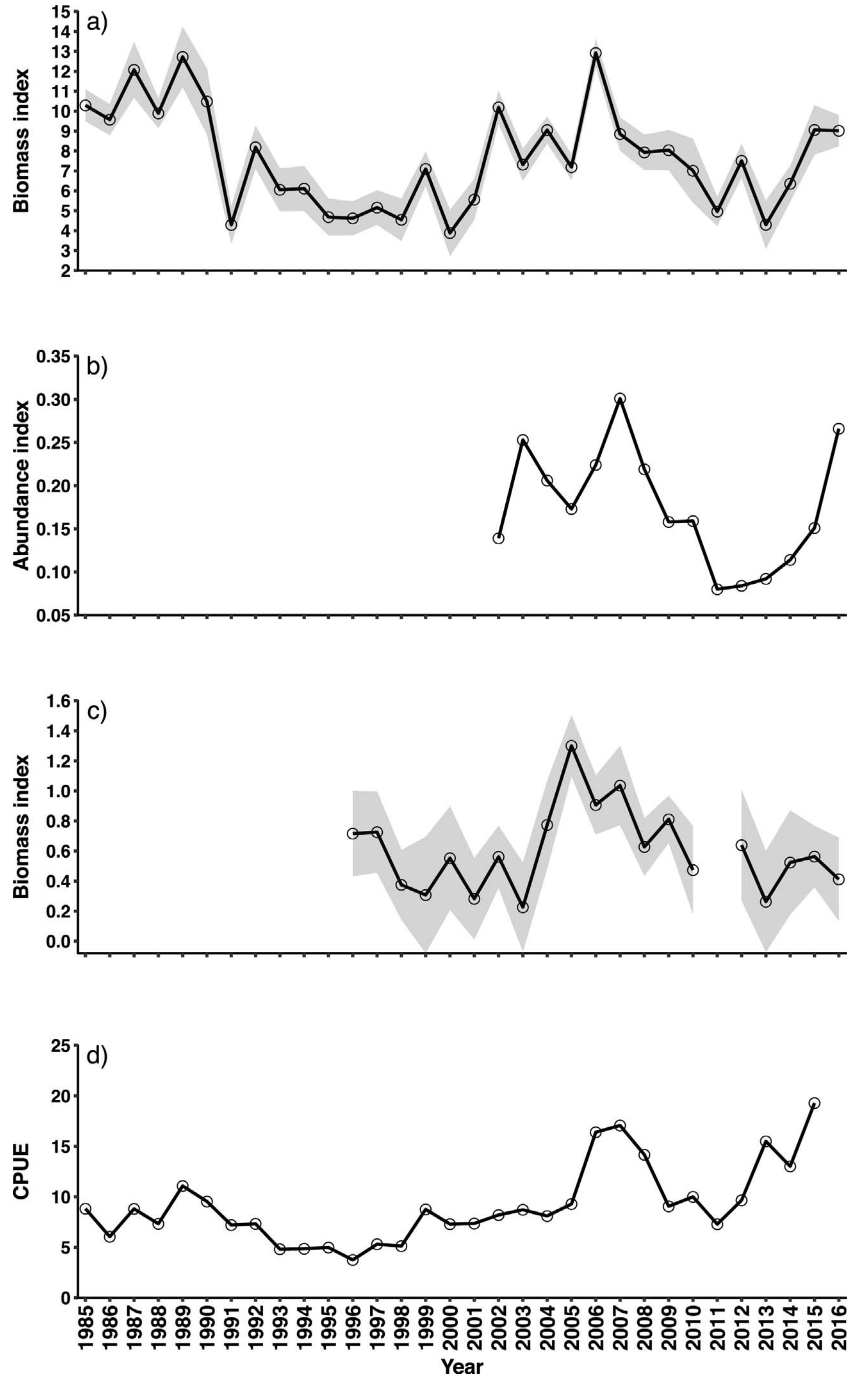

Fig. 8. Biomass index from the spring survey (a), abundance index from the gillnet survey (b), biomass index from the autumn survey (c) and CPUE from the fishery (d). Coefficient of variation is shown in gray.

lumpfish population. Based upon the small length range of the fish caught in the survey (in comparison with other species) and the use of a 40 mm mesh liner within the codend would suggest that the spring survey is unselective in regards to length of lumpfish. The reason for the decline in large fish, however, remains unclear. This may simply be a general decline in body growth rate or that the current rate of fishing mortality prevents significant numbers from attaining a size ≥45 cm.

The biomass index from the spring survey shows notable changes in biomass from year to year. This indicates that a significant proportion of the mature lumpfish population may be comprised of recruit spawners and that post-spawning mortality is likely to be high. This is partially supported by data from tagging studies where tag returns after one year were low and post spawning survival was estimated to be approximately 10%, however these studies are thought to have suffered from a high but unknown amount of tag loss (Fréchet et al., 2011; Kasper et al., 2014).

Fewer lumpfish were caught during the autumn survey than the spring survey and there was no significant correlation between the biomass indices from the two surveys. The reason why the catch of lumpfish is much lower during the autumn survey is unclear. This may be due to one, or a combination of several, of the following scenarios. High post-spawning mortality (Kasper et al., 2014) may have significantly reduced the population and the lower catches are reflective of lower abundance during autumn. It may also be that after spawning, lumpfish return to the open sea and rejoin the immature portion of the population which is spread across the Norwegian Sea (ICES, 2016). It

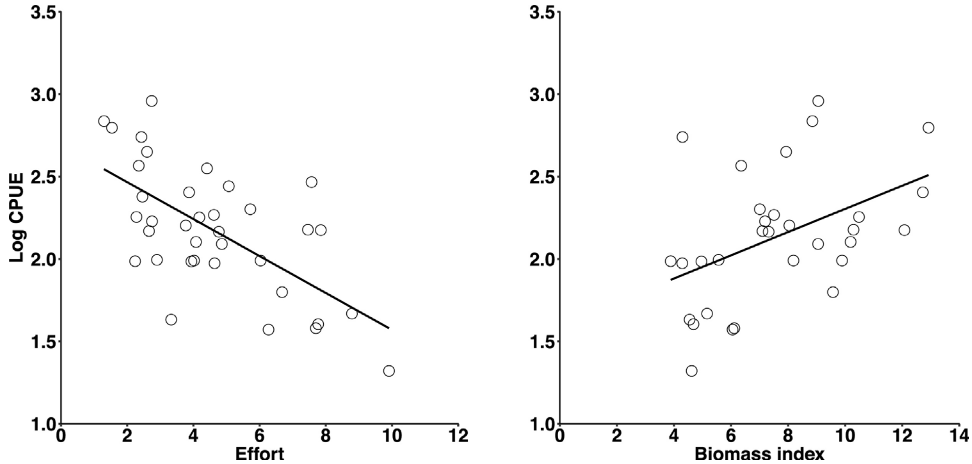

Fig. 9. Correlation between fishing effort and CPUE (a) and the biomass index from the spring survey and CPUE (b). Linear regression lines are shown.

may also be that during the autumn, lumpfish exhibit different behaviour to that seen during the spring. As the fish are presumably not actively migrating, they may spend more time feeding in the pelagic zone with correspondingly decreased catchability to a bottom trawl. It also brings about the question whether the distribution of catches during the autumn survey are reflective of the population distribution. Lumpfish are more frequently caught east of Iceland in comparison with areas to the west of Iceland. This may be a result of local environmental conditions which result in higher catchability by towed gear in this area as opposed to greater abundance; this warrants further investigation. In regards to whether the lumpfish biomass index from the autumn survey reflects changes in the population of lumpfish, this seems unlikely.

The difference in catches of lumpfish between the spring and autumn survey highlights the need for caution when considering bottom trawl survey data to monitor lumpfish populations in other areas. Being a migratory species, they must obviously be in the area during the survey and also, as they appear to alter the proportion of time spent associated with the sea bottom throughout the year, this needs to be considered in regards to the timing of the survey. Data from bottom trawl surveys in the North Sea and Barents Sea demonstrate this effect. Lumpfish are caught in almost every statistical rectangle in the North Sea during the winter survey (Febuary), but are more or less absent during the summer survey (August–September) (Knijin et al., 1993). In the Barents Sea, the catch of lumpfish is higher during the winter survey (February-March) in comparison with the ecosystem survey which takes place in August-September.

In data limited fisheries, a CPUE time series may be the only indicator available to track abundance over time. However, this data must be approached with caution as the relationship between abundance and the proportion of the stock captured by one unit of effort may not be constant over time due to changes in the efficiency of the fleet, the environment, and dynamics of the population or fishing fleet (Maunder et al., 2006) and CPUE is often negatively correlated with effort itself. This is evident when comparing two time periods of the lumpfish fishery, 1985–1990 and 2000–2015 where effort is generally high and low respectively, but the CPUE of both periods is similar despite the biomass index being approximately 25% lower in the latter period. This limitation in CPUE highlights the advantages of fishery independent scientific surveys which can give a more precise reflection of changes in abundance due to multiple factors being held relatively constant between years e.g timing, depth and spatial distribution, and fishing gear.

In conclusion, given that the biomass index from the gillnet survey and CPUE of the fishery show similar trends to the biomass index from the spring survey, upholds the use of data from this survey for assessment purposes. The use of this data is further supported by observations of the behaviour of lumpfish during the timing of spring survey that indicate bottom trawl gear is appropriate for capture of lumpfish (Kennedy et al., 2016), and that the spatial and depth coverage of the spring survey exceeds that of lumpfish during the survey period.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.fishres.2017.05.006.

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