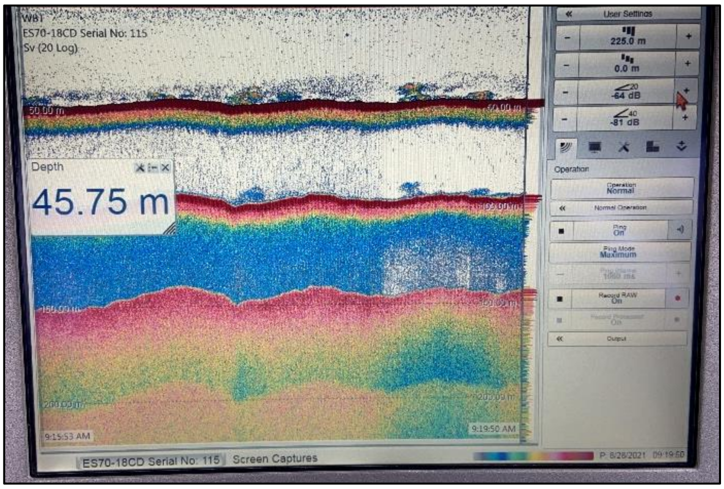

Strategic Environmental Assessment of Wave Energy Technologies

SEA Wave

Fisheries biomass response to ocean energy technology

December 2021

UNIVERSITY OF PLYMOUTH
UNIVERSITY OF EXETER
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Task 4.3 Fisheries biomass

Deliverable 4.3. Report on Fisheries Biomass Response to Ocean Energy Technology

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1. INTRODUCTION

Demersal and pelagic fish are known to be attracted to physical structure either on the seabed or in the water column, thought to be due to the enhancement of favourable habitat and/or protection from predators [1, 2]. This aggregating effect around artificial structures near, or at, the sea surface has led them to be referred to as 'fish aggregation devices' or FADs [3]. Where these structures are found on the sea-floor they are termed 'artificial reefs' [4]. Whereas introduced artificial reefs are mostly used to restore habitat to enhance fish diversity or abundance, FADs have often been used in fisheries activity to attract and capture fish for consumption [5]. Both these attraction and aggregating effects of fish can also be created unintentionally by the introduction of structures used for other activities, such as, aquaculture [6] and marine renewable energy generation [7].

Wave energy convertor (WEC) designs are diverse but many under development are either on the surface or just below, with connection to the seabed with anchor systems [7]. These devices and their associated floats, chains and seabed mooring structures have the potential to act as FADs and artificial reefs, by attracting fish throughout the water column from the surrounding area. Whether this behaviour could then lead to an increase in overall abundance or biomass through increased production of fish is often debated [1], but with larger arrays and structures, the cumulative effect could alter the local fish assemblage and, potentially, alter overall biomass.

Fish (and other marine organisms) can be detected in the water column using an acoustic technique that records the echo of an acoustic pulse (or 'ping') emitted into the water column from a transducer and reflected back (backscatter) from the organism [8]. These data can be collected and processed to provide an estimate of biomass within a body of water, either as a relative or absolute value, depending on whether fish samples are caught during the survey to provide species, size and weight information for context and subsequent integration [8]. The technique is often applied to assess fish populations in relation to fisheries stock assessments [8], but can also be useful in providing evidence for change in biomass in relation to area protection (e.g. MPAs, no-take zones), habitat variation and introduced structures (e.g. windfarms, oil and gas platforms).

To help toward understanding how WECs and the associated infrastructure may influence the distribution of fish biomass within the water column the aforementioned acoustic technique was used by the SEA Wave project in Task 3.3. The objective of Task 3.3 was to conduct surveys to provide a baseline understanding of the distribution, variability and magnitude of fish biomass in an area where a WEC had been deployed (i.e. Penguin) and further deployments planned (i.e. Penguin and other device types), and at a reference site in the same region. The effect of a single WEC, or the cumulative effect of multiple WECs (an array), could then be assessed by Task 4.3 by analysing the change in biomass at each site over time and/or with distance to devices to determine whether there was evidence for FAD and/or artificial reef effects. Further acoustic surveys specifically designed around individual WECs were proposed to allow more detailed investigation into these effects, but were not conducted due to the condition and/or absence of WECs in the survey sites throughout the SEA Wave project. Of the five WECs that were scheduled to be present at the Billia Croo (EMEC) wave energy test site as part of the SEAWave project, only one was deployed (Wello's Penguin 1) and this sunk to the seabed in March 2019 before any acoustic surveys could be conducted. Although this eliminated the possibility to detect a change in fish biomass distribution due to the FAD effect, the sunken WEC had the potential to become an artificial reef and attract/aggregate fish. The three month extension to the SEAWave project (extended till Dec

2021) also enabled data from the surveys conducted in 2021 to be processed, analysed and included in this report.

2. METHODS

2.1 Study area, survey design

The fisheries biomass acoustic surveys were designed to encompass two areas; the Billia Croo wave energy test site and a reference site 2.5 km (min. distance) to the north, using 8 systematic saw-tooth transects 2.3 km long (total 18.4 km) at each site (Figure 1 (a)). The surveys were to be conducted in a consistent north to south direction at each site and completed for three consecutive days during August in 2019, 2020 and 2021. A Simrad EK80 echosounder set to transmit at 70 kHz (0.5s pulse duration) was used to conduct the surveys. The transducer was pole mounted to the side of the 11 m vessel "Challenger" and the transceiver with data collection equipment (i.e. laptop, software etc.) located in the wheelhouse (Figure 1(b), (c) & (d)). A GPS was connected to the EK80 operational software to enable spatially geo-located data acquisition. The system was calibrated with a tungsten sphere and relevant environmental variables before each annual survey period.

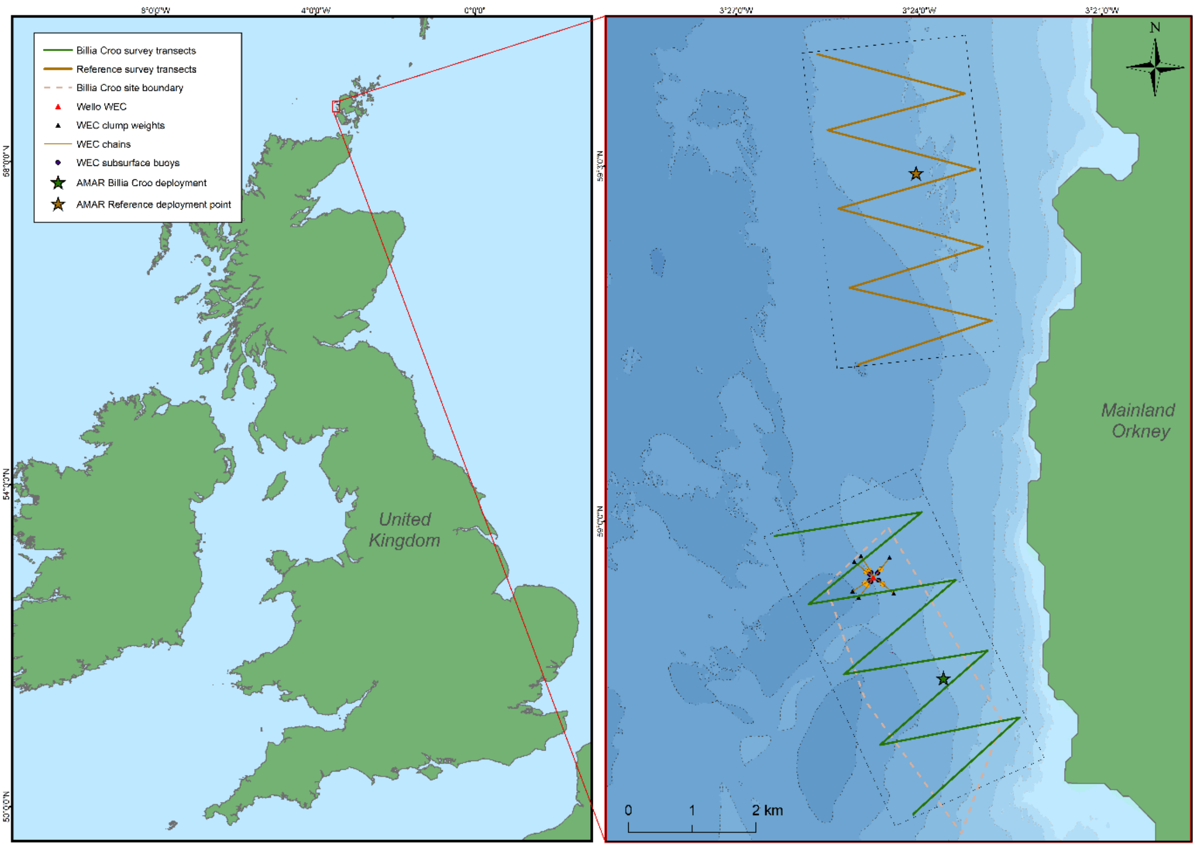

Figure 1. *Acoustic fish biomass survey design*. Study area with annual boat survey transects, WEC location and EMEC Billia Croo test site boundary.

2.2 Data processing

2.2.1 Raw data

Data resulting from each survey were processed for downstream analyses using a workflow constructed and run in the hydroacoustic software Echoview version 12 (Echoview Software Pty. Ltd). To limit the risk of non-biological backscatter data (e.g. created by water turbulence and boat movement) being incorporated into the biomass estimates the first 3 m of data were excluded. Acoustic backscatter noise removal and conservative erosion/dilation filters (7x7 cells) were applied to data with a minimum target strength (TS) threshold of -70 dB. At 70 kHz pulse frequency, this TS range would be expected to record most epi-benthic and pelagic fish (and elasmobranch) species with a known distribution in the region, while filtering out smaller and/or less dense organisms and material (i.e. zooplankton) detected at lower TS levels (processed raw data is available on MARENDATA https://marendata.eu). These data were than used to calculate relative biomass estimates (NASC = Nautical Area Scattering Coefficient - m^2nmi^{-2}) for the whole water column and for 5 m depth layers, at 25 m horizontal intervals along the survey route.

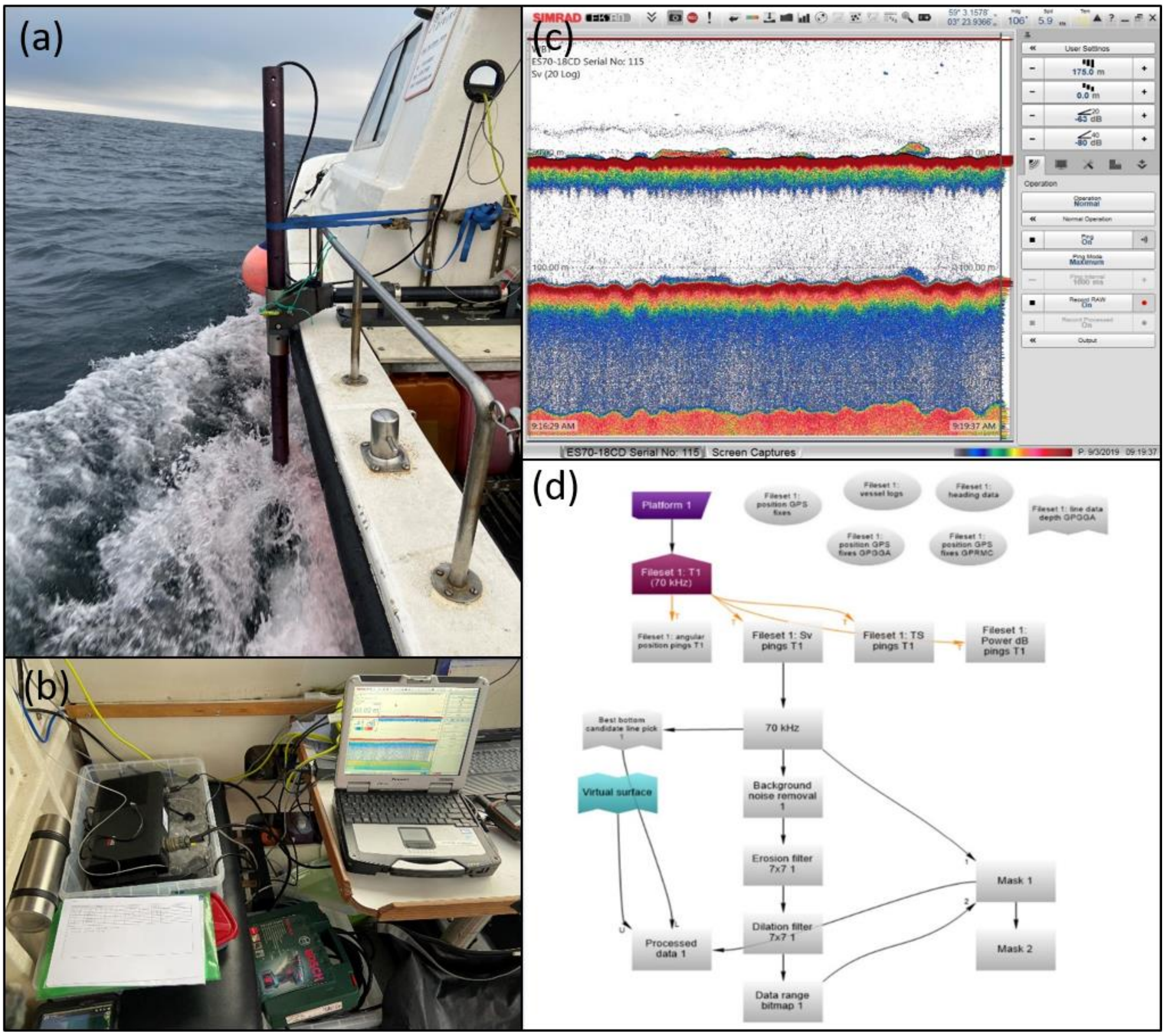

Figure 2. *Acoustic fish biomass survey data collection and processing*. (a) image of the transducer pole mounting from the side of the vessel, (b) image of a Simrad EK80 transceiver and data collection field computer, (c) screenshot of echogram during data collection, and (d) data processing workflow used in Echoview software during data analyses.

2.2.2 Depth layers

To enable separate assessment of fish biomass for species that inhabit different vertical components of the water column (i.e. epi-benthic and pelagic), and therefore potentially influenced by different attraction or aggregation effects, the five metre depth layers for each 25 m distance interval were aggregated into the top 25%, middle 50% and bottom 25% of the water column. Each five metre depth layer was converted into percentages of the whole water column, by dividing by the maximum number of layers (which varied with depth), and the relatively biomass estimates then combined (summed) to provide totals for each of the three layers.

2.2.3 Rasterization and extraction

To aid comparison of surveys within and between years and sites, the NASC values for the whole water column and the three depth layers were mapped to 125 x 125 m cells (15,625m^2) in a raster (map) of the survey area (rasterized). The median NASC value that occurred within each cell was extracted for each year (annual) and across years (site). The same rasterization and extraction process was used for seabed depth values associated with each 25 m horizontal interval on the survey routes to provide a co-variable for analyses.

2.2.4 Distance to WEC

For the purpose of investigating whether proximity to the WEC influenced relative fish biomass, the distance (metres) between the WEC and each raster cell containing NASC values was calculated and the median value for these cells extracted. These NASC values where then assigned to a 250 m distance ranges (bins) from the WEC (i.e. 0-250, 251-500, 501-750…up to 3751-4000) to use for plotting and analysis.

Data processing in 2.2.2, 2.2.3 and 2.2.4 were conducted in R version 4.1.1, using tidyverse, dplyr, sp and raster packages.

2.3 Data analyses and models

2.3.1 Site comparison

NASC values extracted from the rasterised data were used to compare fish biomass between Billia Croo and the Reference site for the whole water column and the three depth layers (top 25%, middle 50% & bottom 25%) using Generalised Linear Mixed Effect models. To remove the need to use zero-inflated models, a 1 was added to all NASC values. Models contained NASC+1 as the response, Site and Year as fixed effects, a Site:Year interaction and Depth as a random effect. All models used a Gamma distribution with either a log or identity link, depending on the skew of the data and model fit.

2.3.2 Billia Croo site and distance to WEC

To investigate whether biomass changed through time within the Billia Croo site, NASC values were compared between years for the whole water column and three depth layers. The models contained NASC+1 as the response, Year as a fixed effect and Depth as a random effect. All models used a Gamma distribution and identity link.

To assess whether biomass changed with distance to the WEC within the Billia Croo site, models where constructed with NASC as the response variable, the Distance (250 m distance ranges) and Year as fixed effects, a Distance:Year interaction and Depth as a random effect. The models where run for the whole water column and the three depth layers, with a Gamma distribution and identity link.

All models in 2.3.1 and 2.3.2 were run in R version 4.1.1, using the glmer function in the lme4 package.

3. RESULTS

3.1 Surveys and data

Fisheries biomass acoustic surveys were completed for at least three days during each annual survey period (**Table 1**). Due to bad weather during the 2019 survey period affecting the quality of the data collected, leading to inconsistent comparability between days, only data from two survey days were used in the analyses.

Table 1. Summary of fisheries acoustic (EK80) surveys.

Survey Site	Year	Number of successful survey days (rejected days)	Survey Dates
Billia Croo	2019	2 (2)	03/09/2019 - 08/09/2019
	2020	3	17/08/2020 – 19/08/2020
	2021	4	27/08/2021 – 02/09/2021
Reference	2019	2 (2)	03/09/2019 - 08/09/2019
	2020	3	17/08/2020 – 19/08/2020
	2021	4	27/08/2021 – 02/09/2021

3.2 Site comparison analyses

The results from the site comparison models revealed significant differences between Billia Croo and the References site for the whole water column biomass and the three depth layers (**Table 2; Figures 2 & 3**). Pairwise comparison between sites were significant for all models ($p<0.01$), except between biomass estimates in 2019 and 2021 for the top 25% of the water column ($p>0.05$; Supplementary Tables S1-S4).

Table 2. Coefficient estimates (standard errors) and significance indication for generalized linear mixed effects models for biomass comparisons between survey sites.

	Whole Water Column	**Top 25%**	**Middle 50%**	**Bottom 25%**
Reference Site	**553.93***** (26.43)	0.05 (0.12)	**21.46 ***** (2.57)	**500.24***** (95.59)
Year(2020)	**6.13 *** (2.91)	**1.07 ***** (0.17)	**2.42 ***** (0.54)	-2.94 (11.38)
Year(2021)	**39.82 ***** (5.93)	**0.45 ***** (0.13)	**3.92 ***** (0.69)	**75.52 ***** (22.64)
Reference:2020	**-497.68 ***** (27.67)	**-0.95 ***** (0.21)	-4.44 (3.55)	**-364.05 ***** (101.11)
Reference:2021	**-526.39 ***** (26.86)	-0.25 (0.18)	**42.35 ***** (8.03)	**-373.34 ***** (107.09)
N	1181	1181	1179	1181
N (Depth)	1181	1181	1179	1181
AIC	11709.39	3898.64	7064.77	13460.46
BIC	11749.99	3939.23	7105.35	13501.05

***** p < 0.001; ** p < 0.01; * p < 0.05.**

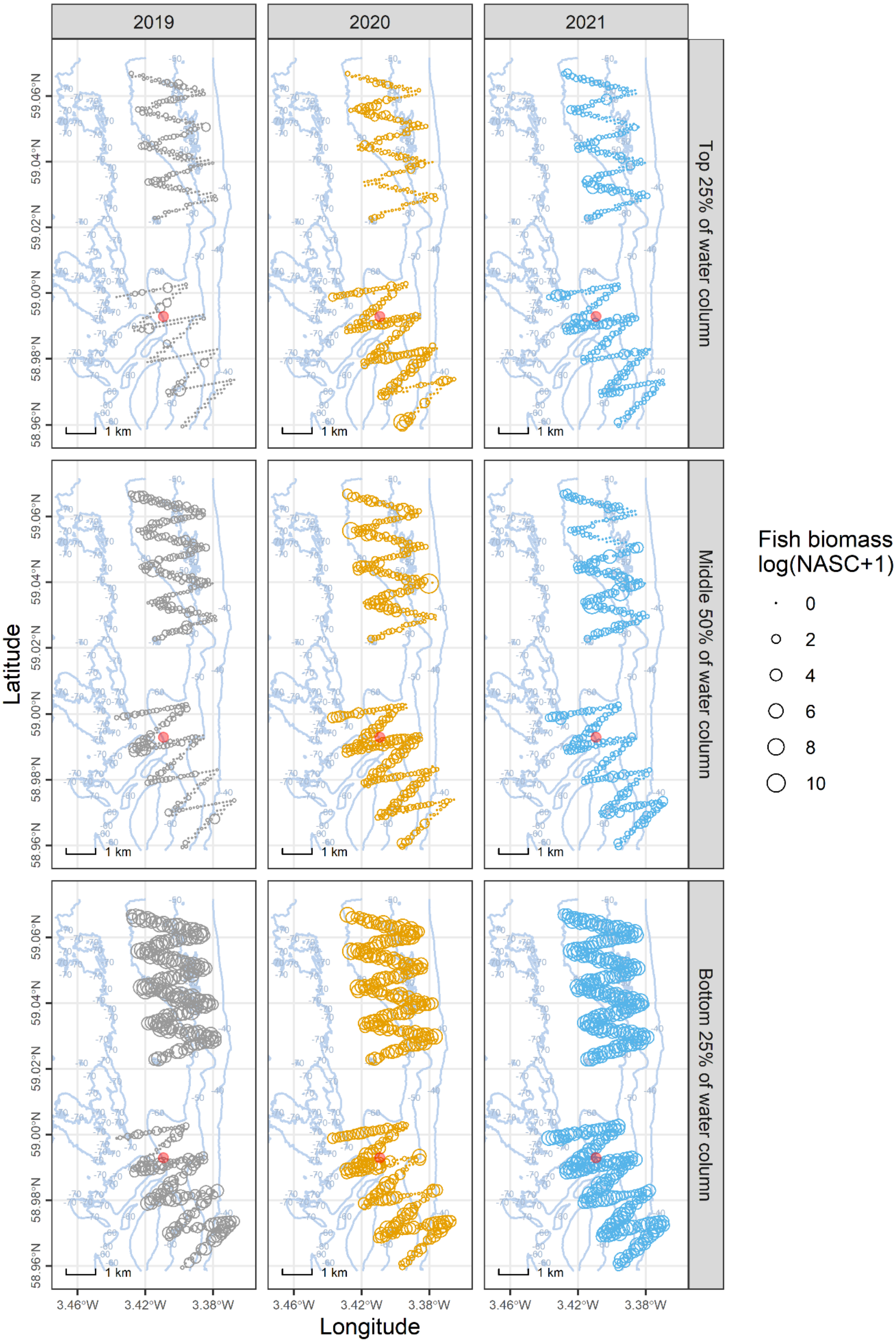

Figure 3. Bubble plot of relative fish biomass (log NASC+1) for each survey year and depth layer. Grey bubbles = 2019 (2 survey days), orange bubbles = 2020 (3 survey days) & blue bubbles = 2021 (4 survey days).

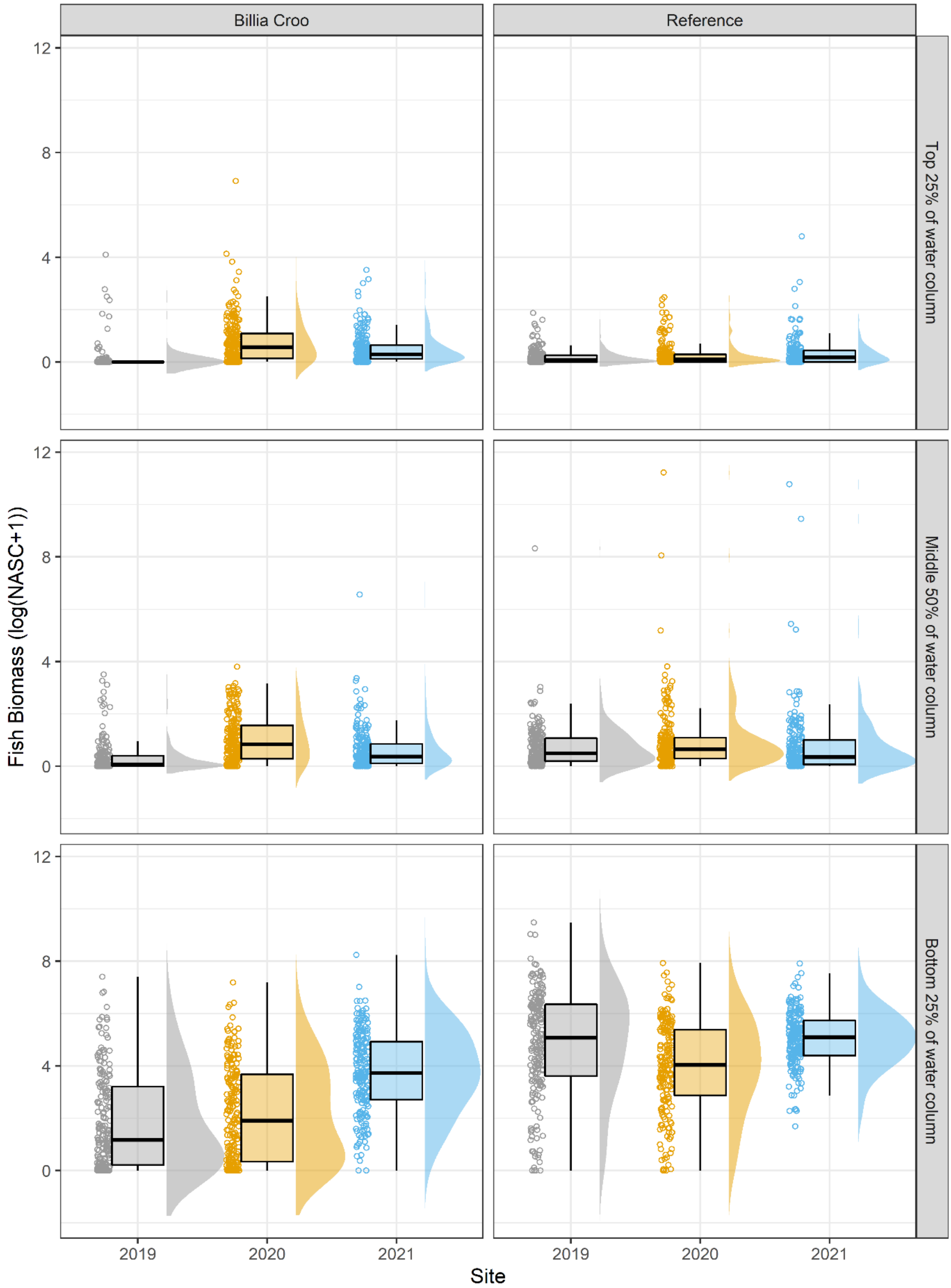

Figure 4. Relative fish biomass (log NASC+1) boxplots also displaying raw data points (with jitter applied) and frequency distributions for years and depth layers within Billia Croo and Reference survey sites. Grey colour = 2019 (2 survey days), orange colour = 2020 (3 survey days) & blue colour = 2021 (4 survey days).

3.3 Billia Croo site and distance to WEC analyses

Relative fish biomass was significantly different between years within the Billia Croo site for the whole water column and the three depth layers (**Table 3; Figure 4**), except between 2019 and 2020 for the whole water column and bottom 25% layer (**Table 3; Supplementary Tables S5-S8**).

Table 3. Coefficient estimates (standard errors) and significance indication for Billia Croo within site generalized linear mixed effects models

	Whole Water Column	Top 25%	Middle 50%	Bottom 25%
Year(2020)	**6.13 *** (3.107)	**1.06 ***** (0.001)	**1.38 ***** (0.00)	-2.94 (7.03)
Year(2021)	**39.82 ***** (6.28)	**0.43 ***** (0.001)	**0.42 ***** (0.00)	**75.52 ***** (13.29)
N	600	600	600	600
N (Depth)	600	600	600	600
AIC	4785.33	2381.26	2613.93	5788.18
BIC	4807.31	2403.24	2635.92	5810.17

***** p < 0.001; ** p < 0.01; * p < 0.05.**

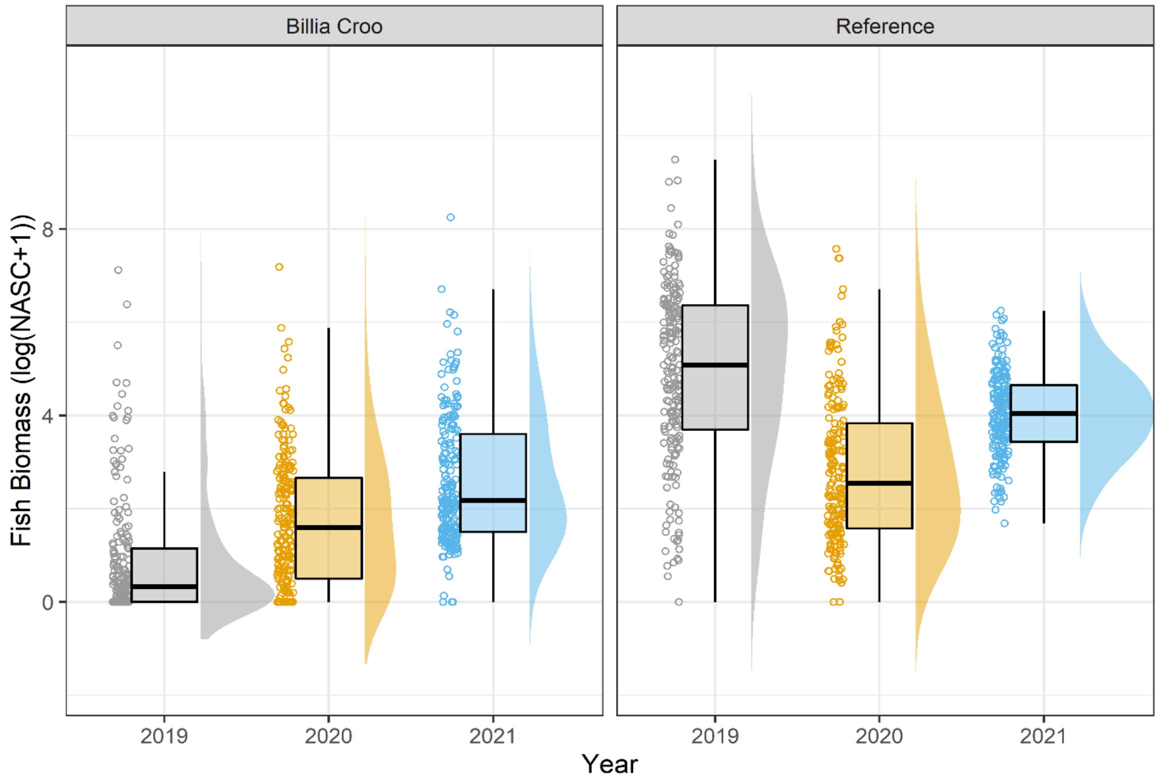

Figure 5. Relative fish biomass (log NASC+1) boxplots also showing raw data points (with jitter applied) and frequency distributions for years within Billia Croo and Reference survey sites. Grey colour = 2019 (2 survey days), orange colour = 2020 (3 survey days) & blue colour = 2021.

The effect of distance from the WEC on relative fish biomass in Billia Croo was significant in the majority of years for the whole water column and three depth layers (8 of 12; **Table 4; Figures 5 & 6**). The direction (slope) of change was inconsistent, with a decrease in biomass with distance found in 3 years and an increase in 3 years (**Table 4; Figure 6**).

Table 4. Coefficient estimates (standard errors) and significance indication for the Billia Croo site distance to WEC generalized linear mixed effects models

	Whole Water Column	**Top 25%**	**Middle 50%**	**Bottom 25%**
Distance from WEC	**-5.21 **** (1.83)	-0.03 (0.09)	-0.19 (0.12)	**25.69 ***** (6.06)
Year(2020)	5.72 (3.19)	**3.63 ***** (0.61)	**1.90 ***** (0.29)	-6.57 (7.58)
Year(2021)	**40.28 ***** (6.838)	**0.61 ***** (0.17)	**0.47 *** (0.19)	**71.99 ***** (13.62)
Distance:2020	5.12 (3.44)	**2.85 ***** (0.47)	**-1.04 ***** (0.23)	**-17.94 *** (7.63)
Distance:2021	**-13.24 *** (6.19)	-0.21 (0.15)	**0.42 *** (0.20)	**-32.45 *** (14.72)
N	600	600	600	600
N (Depth)	600	600	600	600
AIC	4778.04	2343.15	2573.84	5780.61
BIC	4813.21	2378.33	2609.02	5815.78

***** p < 0.001; ** p < 0.01; * p < 0.05.**

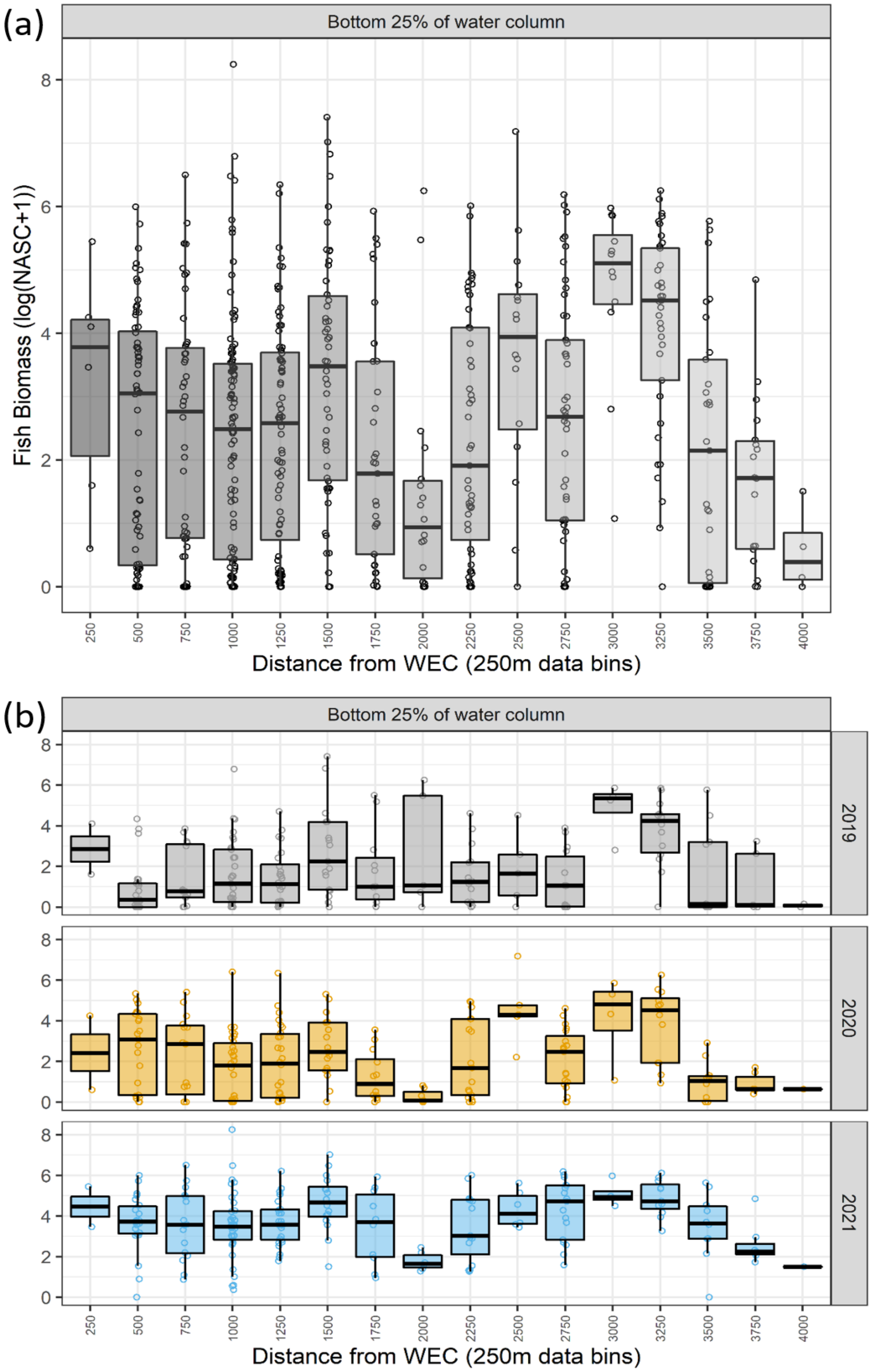

Figure 6. Relative fish biomass (log NASC+1) boxplots with raw data points for 250 m distance bins from the WEC at Billia Croo site. (a) Total relative biomass of all surveys. (b) Relative biomass for each year, where grey colour = 2019 (2 survey days), orange colour = 2020 (3 survey days) & blue colour = 2021.

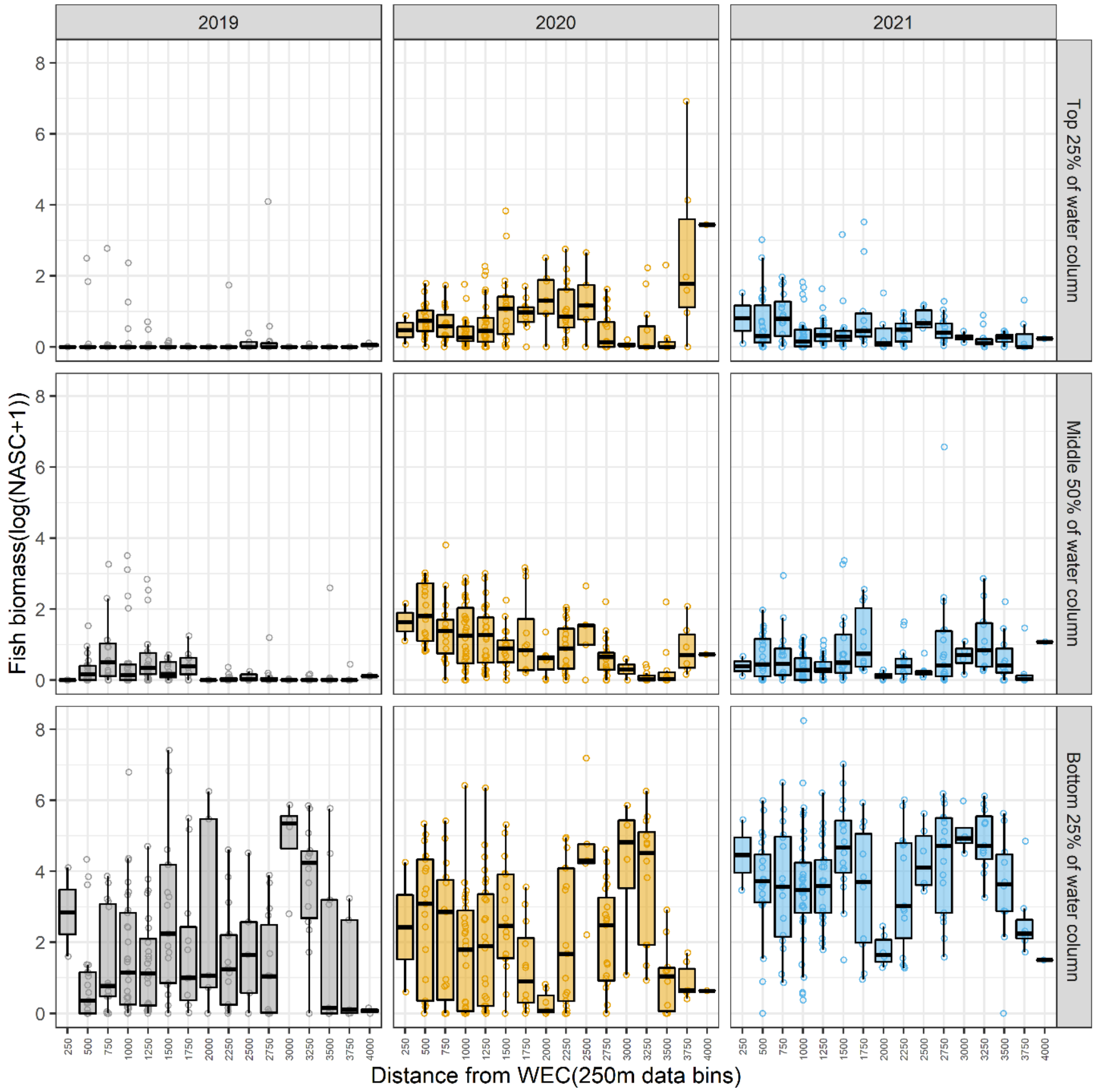

Figure 7. Relative fish biomass (log NASC+1) boxplots with raw data points for 250 m distance bins from the WEC at Billia Croo site. Horizontal panels present years and vertical panels depth layers. Grey colour = 2019 (2 survey days), orange colour = (3 survey days) & blue colour = 2021.

4. DISCUSSION

Wave energy devices and arrays have the potential to alter and/or redistribute fish abundance and biomass through attraction and aggregation. FAD and artificial reef effects have been found when other structures have been introduced to the marine environment [3, 4, 9, 10], so WECs and their associated infrastructure may have similar effects, but the scale and magnitude of these effects are still to be understood.

The surveys and analyses as part of Tasks 3.3 and 4.3 were able to provide a broad scale understanding and characterisation of the distribution and annual variability of fish biomass throughout the water column at the EMEC Billia Croo wave energy test site and a reference site in close proximity to the north (**Figure 2**). With only Wello's sunken Penguin 1 converter present during the three years of surveys, the opportunity to assess the effect of an operational WEC and/or an array (included multiple designs) was unfortunately lost as part of the SEAWave project. Furthermore, the sunken WEC represented a hazard for vessels in 2019 and 2020 (prior to urgent works to remove loose sub-sea anchors and moorings), which meant a 100m safety exclusion zone was imposed around the device and subsea buoys. This exclusion zone prevented additional (fine scale) surveys to be conducted in close proximity to a device.

The relative fish biomass data collected over the three surveys years revealed the variability among years and different parts of the water column. The majority of fish biomass found at both sites was in the bottom 25% of the water column and, for this depth layer, the reference site revealed a higher biomass and larger annual variability than the Billia Croo site. These results are consistent with the main habitat types found at the sites, which were confirmed through the seabed camera surveys conducted as part of the Task 3.1 and 3.2. The reference site consists mainly of rocky reef and mixed sediment habitat, whereas the Billia Croo site is mainly fine mixed sediment and sand (hence more suitable for the deployment of WECs). Rocky reefs are known to contain a higher species diversity and abundance compared to sandy substrate [11], so these findings would be expected. A cautionary note for the site comparison results would be the difficulty for acoustic surveys to distinguish between the seabed and benthic fish. Fish species composition varies with habitat type, with more flat fish species (Soleidae spp., Scophthalmidae spp., Bothidae spp.) that swim very close to the seabed inhabiting sandy bottom habitat found in Billia Croo (see reports associated to SEA Wave Tasks 4.1 & 4.2), and these will be harder to detect by acoustic methods. However, the variability and trend in biomass in the whole water column and in the bottom 25% suggests the variability at the reference site is higher. Furthermore, biomass may have increased in the Billia Croo site in 2021 (**Figures 3 & 4**). This pattern may be indicative of the presence of the sunken WEC providing a reef effect and attracting fish to the site, but the trend would need to be monitored for further years to be validated and not an effect of natural variation at the site.

A FAD or reefing effect caused by a WEC on fish biomass would, by its nature, be expected to be concentrated closer to the device, becoming less with increasing distance away from the device. However, distance to the Wello's Penguin device was not a consistent predictor of a negative trend in biomass, with there being a positive, negative or neutral trend equally across water column depths and surveys years. Similar to the total biomass assessment for the whole water column and bottom 25% in Billia Croo, there was a significant decrease in biomass with increasing distance away from the sunken WEC in 2021 that could be suggestive of a reef effect being detected after three years. However, the broad scale nature of the survey and lack of close proximity to the device (the nearest acoustic biomass observation being >125 m from the device) meant the distances assessed (250 – 4000 m) are likely to coarse to robustly detect a reef effect from a relatively small, single device. The results from the seabed camera surveys at Billia Croo and Scapa Flow test sites (see Task 4.1 & 4.2 deliverable report) indicate the need to be within 50 m of a device to detect change in fish and benthic communities, adding substance to this theory.

The acoustic fish biomass surveys have provided invaluable baseline data for future deployments at the EMEC Billia Croo wave energy test site to use for impact assessments, and some emerging results that could be indicative of the aggregating effects of a single device. With further annual monitoring these effects could be validated (or not) and help start to understand how wave energy infrastructures could have positive or negative effects on an important component of the marine ecosystem. There is also an ecological case for conducting such surveys seasonally (more than once a year), since there is likely variability in the presence of some fish species (e.g. pelagic) during the year due to migration and/or spawning events, which could influence aggregation effects. This was not possible with the resources available within SEAWave project, but represents an important future avenue of investigation. The validation and conversion to absolute biomass estimates that catching fish as part of the acoustic surveys can provide, would also be helpful in reducing uncertainty in biomass estimates and the species detected.

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Supplementary Tables

Table S1 Pairwise comparisons amoung site and year from whole water column model

Pairwise contrast	Year	Estimate	SE	z.ratio	p.value
Billia Croo - Reference	2019	-553.933	26.428	-20.960	***0.000***
Billia Croo - Reference	2020	-56.255	8.545	-6.583	***0.000***
Billia Croo - Reference	2021	-27.539	9.999	-2.754	***0.006***

Table S2 Pairwise comparisons between sites and year from top 25% layer model

Pairwise contrast	Year	Estimat	SE	z.ratio	p.value
Billia Croo - Reference	2019	-0.054	0.123	-0.441	0.659
Billia Croo - Reference	2020	0.900	0.171	5.274	***0.000***
Billia Croo - Reference	2021	0.198	0.134	1.481	0.139

Table S3 Pairwise comparisons between sites and year from middle 50% layer model

Pairwise contrast	Year	Estimate	SE	z.ratio	p.value
Billia Croo - Reference	2019	-21.456	2.574	-8.336	***0.000***
Billia Croo - Reference	2020	-17.021	2.482	-6.859	***0.000***
Billia Croo - Reference	2021	-63.807	7.678	-8.310	***0.000***

Table S4 Pairwise comparisons between sites and year from bottom 25% layer model

Pairwise contrast	Year	Estimate	SE	z.ratio	p.value
Billia Croo - Reference	2019	-500.235	95.585	-5.233	***0.000***
Billia Croo - Reference	2020	-136.183	32.953	-4.133	***0.000***
Billia Croo - Reference	2021	-126.900	48.301	-2.627	***0.009***

Table S5 Pairwise comparison of survey year within Billia Croo site from whole water column model

Pairwise contrast	Estimate	SE	z.ratio	p.value
2019 - 2020	-6.130	3.107	-1.973	0.049
2019 - 2021	-39.822	6.275	-6.347	***0.000***
2020 - 2021	-33.692	6.500	-5.183	***0.000***

Table S6 Pairwise comparison of survey year within Billia Croo site from top 25% layer model

Pairwise contrast	Estimate	SE	z.ratio	p.value
2019 - 2020	-1.061	0.001	-1463.087	***0.000***
2019 - 2021	-0.430	0.001	-592.781	***0.000***
2020 - 2021	0.631	0.001	615.440	***0.000***

Table S7 Pairwise comparison of survey year within Billia Croo site from middle 50% layer model

Pairwise contrast	Estimate	SE	z.ratio	p.value
2019 - 2020	-1.378	0.000	-3596.742	***0.000***
2019 - 2021	-0.418	0.000	-1090.830	***0.000***
2020 - 2021	0.961	0.001	1772.911	***0.000***

Table S8 Pairwise comparison of survey year within Billia Croo site from bottom 25% layer model

Pairwise contrast	Estimate	SE	z.ratio	p.value
2019 - 2020	2.943	7.032	0.418	0.676
2019 - 2021	-75.516	13.295	-5.680	***0.000***
2020 - 2021	-78.459	13.450	-5.833	***0.000***