Short Term Temporal Behavioural Responses in Pollack, *Pollachius pollachius* to Marine Tidal Turbine Devices; a Combined Video and ADCP Doppler Approach.

Melanie Broadhurst[#1] and Sue Barr[*2]

[#]*Division of Biology, Imperial College London*
Silwood Campus, Berkshire
[1]melanie.broadhurst08@imperial.ac.uk
[*]*OpenHydro Ltd*
Muchgrange, Greenore, Co. Louth, Ireland
[2]sue.barr@openhydro.com

***Abstract*— Combining biological and environmental survey techniques can further knowledge relating to species behavioural responses with marine energy technologies. Underwater video footage was integrated with ADCP surveys to assess behavioural responses of Pollack, *Pollachius pollachius* to a deployed tidal turbine in the Orkney Isles.**

Surveys were conducted within 16 day trials during the summer months of 2009 and 2010. Five random photographic stills were taken at hourly intervals throughout each day to estimate mean fish abundance. Abundance was compared to hour and day temporal scales and ADCP tidal velocity rates between years.

Fish were observed to aggregate in shoals round the turbine, with larger counts observed in 2009 than 2010. Abundance was significantly associated to tidal velocity and not temporal scales. Increased abundance was related to a reduction in tidal velocity for both years (from GAM ^{2009}: $F = 38.31$, $p < 0.05$; GAM ^{2010}: $F = 4.45$, $p < 0.05$), with shoals potentially using the turbine for temporary protection or feeding strategies. Responses to tidal velocity differed between years, with 2009 abundances ranging from 0 – 1.2 m/s and 2010 abundances between 0.5 – 1.7 m/s. Overall the study outlined a different approach to investigate behavioural responses with new anthropogenic activities.

***Keywords*— ADCP doppler survey; Combined survey approach; Fish aggregation behaviour; OpenHydro Ltd tidal turbine energy device; *Pollachius pollachius*; Renewable energy ecological interactions; Underwater video camera system**

I. INTRODUCTION

The application of combining environmental and biological studies is extremely common, particularly in understanding species biological and behavioural trends [1], [2]. Advances in survey technology and sampling design provide a variety of potential approaches to monitor ecological interactions, such as acoustic sampling and video photography techniques [3], [4]. Integrated approaches can further ecological understanding of new anthropogenic activities in the marine environment, such as offshore tidal energy device deployment schemes. In-depth knowledge relating to ecological responses to tidal energy technologies is lacking, primarily due to gaps in baseline information and tidal devices still at early research and design test phases [5], [6], [7].

Tidal energy device development sites are located within extreme hydrodynamic environments, often associated with species and habitats that are adapted to the strong current flows and disturbance regimes [5], [8]. Tidal velocity is a key variable within these environments, and is important for device design in terms of energy generation and device site location [6]. Velocity rates are measured using equipment such as acoustic doppler current profilers (ADCP), which have also been applied to a number of biological, geophysical and oceanographical studies [9], [10], [11]. Current methods to assess marine ecology include the use of video or photography camera systems, for visual species observations and habitat classifications [12], [13], [14]. Video techniques can measure valuable biological responses at both the temporal and spatial scale, and are not limited in terms of sampling time or weather restrictions [15]. The use of video has been applied in extreme hydrodynamic environments, with recent studies evaluating ecological interactions from other renewable energy devices such as wind or wave device deployments [8], [16], [17], [18]. Such studies have examined direct biological population responses to renewable devices but few have investigated responses such as fish aggregation behaviour over temporal scales [19], [20], [16], [21].

Knowledge of the spatial structure or aggregation behaviour in fish populations has become inherently important, particularly in terms of commercial fisheries management strategies and environmental impact scenarios [13]. This is due to a number of commercial or by-catch species portraying aggregation behavioural traits round natural and anthropogenic structures including boulders, kelp forests, coastal defence structures and offshore oil rigs [22], [23]. The species *Pollachius pollachius* (common name: pollack) portrays natural aggregation tendencies and is known to form shoals round a variety of structures [24]. It is a gadoid predator, common throughout the British Isles and found within a number of inshore and offshore rocky and sand habitats, including tidal device deployment sites [25], [26].

By integrating tidal velocity with video photography techniques, species interactions in response to deployed tidal devices over temporal scales may be identified. Such pilot survey trials could aid renewable energy environmental impact assessments and further ecological knowledge on species behavioural patterns [18]. The overall aim for this study was to examine the abundance responses of *P.*

pollachius to a deployed tidal turbine device by (i) assessing *P. pollachius* abundance responses over temporal hour, day and year scales and (ii) comparing *P. pollachius* abundance responses with abiotic tidal velocity variables. This was undertaken through experimental trials combining underwater video observations with ADCP doppler tidal velocity measurements.

II. METHODOLOGY

A. Study Area

Trials were conducted in the European Marine Energy Centre (EMEC) offshore tidal test site, located off the coast of the Isle of Eday, Orkney Isles. The test site is situated within the Falls of Warness tidal stream which is approximately 2 km wide and 3.5 km long [27]. The stream portrays average depths of 30 – 35 meters, with tidal flow movements from both north-west and south-east directions within a daily tidal cycle [28].

The OpenHydro Ltd tidal device platform is installed at the most northern part of the test site (59°09.448`N, 02°49.561`W). The device is a sub-sea open turbine generator, consisting of a 6 meter diameter turbine mounted on a twin mono-piled platform which are placed into the seabed, producing a footprint approximately 10 m² [29].

The trial surveys were conducted between the summer months of June and July in 2009 and 2010. Months were chosen based on the ease of access to the device platform and potential for sampling problems in other periods of the year from reduced weather conditions. Surveys were conducted across 16 day trial periods, with the 2009 trial beginning at the end of June and the 2010 trial beginning at the start of June. The 2010 trial lost nine days of video footage after day seven. This survey was extended for a further nine days to account for the missing data.

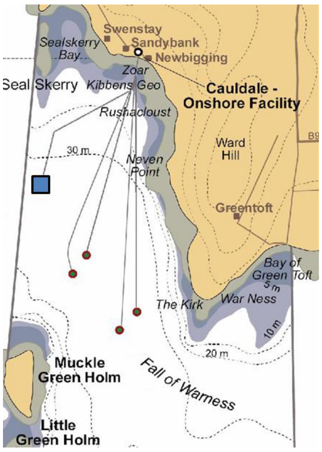


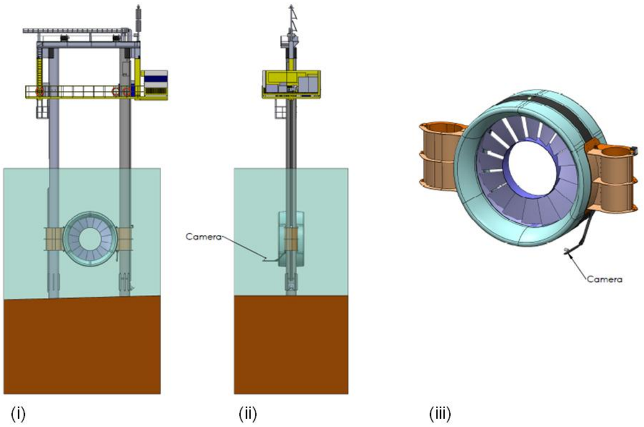
Fig. 1. Location of EMEC tidal test site and Open Hydro Ltd deployed tidal device, situated off the coast of the Isle of Eday, Orkney Isles. The square represents the deployed Open Hydro Ltd platform device, with circles representing other sub-sea cable locations (taken from [27]).

B. Video Fish Observation Sampling Method

The underwater footage was recorded using a video Triplex 8 Channel DVR, linked to a Submertec camera system mounted to the outside of the Open Hydro platform device. The camera was mounted approximately 2 meters from the face of the turbine allowing continuous recording of the entire 6 meter turbine area. Footage was collected manually after the full trial period each year and transferred to a compatible video computer software system.

The footage was split into 24 hour video intervals for each trial day and year separately. From these 24 hour video footage intervals, five still photographs were created for each individual hour using photographic software. The photographs were generated randomly from the video footage between the first two minutes of each individual hour. Random photograph selection within the two minute time period was determined by the second timeframe status, using a random number generation application accessed in the R statistical software package. Footage was excluded between the hours of 23:00:00 to 02:00:00 hours throughout all trial surveys as a result of poor natural light quality.

Fish observational response was measured by counting the maximum abundance of *P. pollachius* individuals identified within each individual hour interval photograph frame separately. Mean hour fish abundance (geometric mean) was then assessed across these five individual photographs separately for both trial day and year. Fish were identified to the lowest taxa visually from the photograph frames based on body shape, lateral line and mouth part descriptions where possible [30]. Where photograph clarity was poor or individual fish could not be recognised on the edges of the photograph frame or behind the turbine structure, they were excluded from the overall analysis. Each photograph frame was also examined if other species were present and recorded.



(i) (ii) (iii)

Fig. 2. Schematic diagrams of the front view (i), side view (ii) and location of the attached camera setup (iii) of the deployed Open Hydro Ltd tidal device platform in the EMEC test site, Eday.

C. ADCP Doppler Tidal Velocity Measurements

A Nortek Aquadopp two beam ADCP was deployed at the platform in order to measure horizontal tidal current flow around the turbine and through the Falls of Warness over a 24 hour cycle. A single ADCP was deployed on the North side of the platform, pointing North, which measures flow into the turbine during flood tides. A second single ADCP was mounted on the South side of the platform, pointing South, to measure ebb tides flowing into the turbine. Data was streamed live to a PLC which is used for control and monitoring of the turbine. Data was stored on an industrial PC, linked to the PLC in 10 second intervals during all testings to allow post-processing and analysis of results. The data was collected throughout each annual trial and then downloaded into a Microsoft Excel format for analysis, with velocity measured in meters per second (m/s). Mean (harmonic mean) hour tidal velocity rates were then assessed across each 10 second interval for both the North and South ADCP velocity measurements in the 2009 and 2010 annual trials separately. For analysis, the largest mean velocity value for each hour between the North and South ADCP measurements was then chosen and used for tidal velocity comparisons and model variables.

D. Data Analysis

Analyses were conducted using the R statistical programming software for all biotic, abiotic, model assumptions and interaction assessments [31]. A number of generalised linear models (GLM) and also a generalised additive model (GAM) were used to investigate fish abundance response with different temporal scales and the tidal velocity variable for both annual trials. Such models are useful for non-normal distributed errors and where variance is not constant, which is particularly valuable for count data where large numbers of zeros occur [32].

A GLM was used to compare mean hour fish abundance between the 2009 and 2010 trials, with year as the categorical explanatory variable and fish abundance as the response variable. Comparisons of fish abundance with the temporal scales, hour and day was investigated separately for each annual trial. A GLM was used to investigate mean hour fish abundance to the time of day. The categorical explanatory variable for this model was the time of day, with each interval hour assigned to the 24 hour daily time cycle and compared to the response variable, mean hour fish abundance. A GLM was also used to assess fish abundance response across each trial day, with the response variable as the mean fish hour fish abundance and the trial day number as the categorical variable.

Fish abundance response in relation to the tidal velocity variable was assessed using a GAM one variable regression, between fish abundance and tidal velocity separately for each year. The explanatory continuous variable was tidal velocity with the response variable as mean hour fish abundance. Analysis was implemented using the R library function ‘mgvc’ with all variables smoothed as a function with all interactions considered within the overall GAM model.

GLM and GAM models used the Poisson distribution of errors (family = quasipoisson, link function = log) and assessed in terms of homogeneity throughout [32]. The quasipoisson error structure was used to deal with over-dispersion, where the residual deviance is greater than the residual degrees of freedom in the fitted model. This error structure frees the model from specifying a specific distribution but maximum likelihood and likelihood ratio tests cannot be used [32]. The significance of the explanatory variables within each GLM or GAM was deduced by comparing models with and without the chosen variable term using analysis of deviance with the F test. Variables were deemed significant based on the increase in deviance from their resulting removal from the model following model deletion test methods (α = 0.05) [32].

III. RESULTS

E. Video Fish Abundance Response Observations

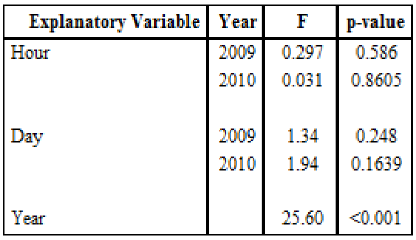
The presence of *P. pollachius* was observed in the 2009 and 2010 video survey trials, with both trials recording a total number of 261 hours of footage. In 2009, 13% of the total 261 hour footage was attributed to fish presence, with 8% in the 2010 trial. The total number of individual fish recorded was significantly larger in 2009 than 2010, with a total number of 664 individuals observed in 2009 and 121 individuals in 2010 respectively.

Within each hour the total number of fish observed ranged from 0 – 46 in 2009 (mean count per hour = 44) and from 0 – 11 (mean count per hour = 7) in the 2010 trials. There was no significant relationship identified between fish abundance and the overall time of day (24 hour clock) for both the 2009 and 2010 surveys.

Daily fish abundance fluctuated strongly during both survey trial years, with no significant relationship observed between fish abundance and the trial day for 2009 and 2010 trials. In the 2009 trial the lowest abundance was observed during days 1 and 12 (total day abundance counts = 0) and the largest counts during day 13 (total day abundance count = 106) and 14 (total day abundance count = 93). The 2010 trial portrayed the lowest abundance between days 1 - 2 and 6 - 10 (total day abundance count = 0) and the largest abundance during days 4 (total day abundance count = 26) and 16 (total day abundance count = 25).

TABLE I

Generalised linear model results for the temporal scales hour, day and year of fish abundance for the 2009 and 2010 video survey trials (quasi-Poisson distribution).



Explanatory Variable	Year	F	p-value
Hour	2009	0.297	0.586
	2010	0.031	0.8605
Day	2009	1.34	0.248
	2010	1.94	0.1639
Year		25.60	<0.001

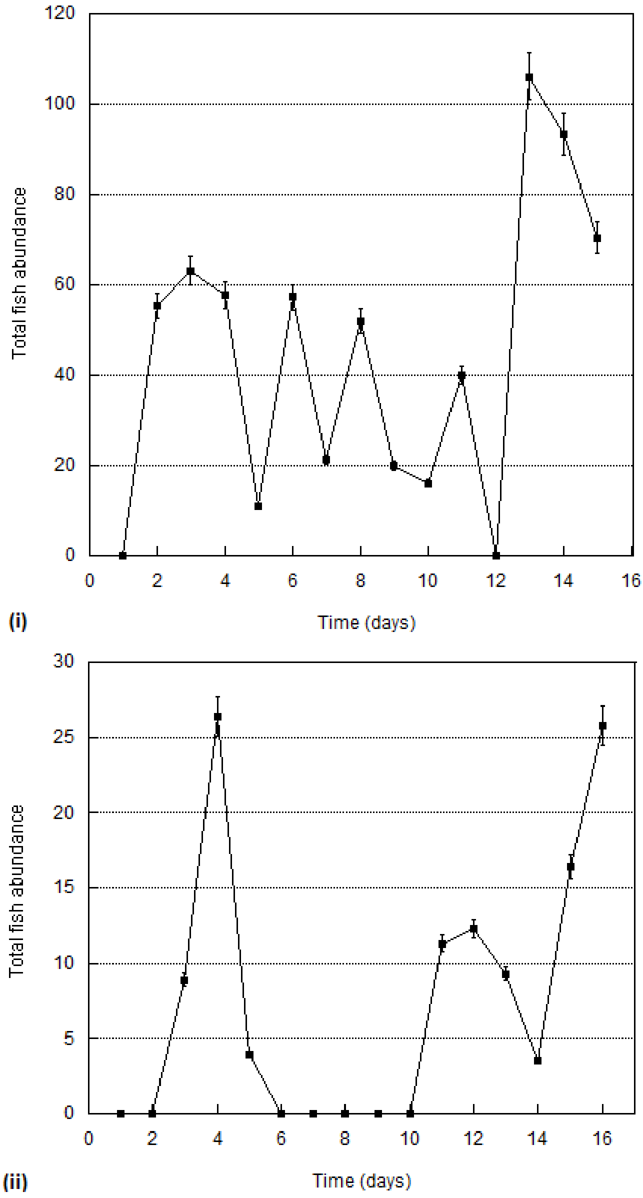


Fig. 3. Total abundance counts of *P. pollachius* per day within the 2009 (i) and 2010 (ii) video survey trials (± S.E.). Total abundance is the combined total of the mean hour fish abundance counts for every 24 hour survey trial day.

F. ADCP Doppler Surveys

The ADCP tidal velocity rate trial surveys identified a larger velocity range in 2010 than 2009 overall. Velocity rates fluctuated considerably in the 2009 survey, with the largest velocity ranges identified in days 8 (0.36 – 2.68 m/s) and 9 (0.27 – 2.68 m/s). The lowest velocity range was observed in days 2 (0.38 – 1.92 m/s) and 13 (0.40 – 2.03 m/s). Overall, day 9 portrayed the lowest velocity rates and day 10 portraying the largest. A slight curve in velocity range was identified across the total survey period; with velocity flow increasing gradually to day 9 and then decreasing slightly to day 15 overall. This is in-line with the typical profile of a tidal site.

The 2010 survey also portrayed substantial velocity ranges with days 11 (0.24 – 3.05 m/s) and 9 (0.34 – 3.00 m/s) portraying the largest. The lowest velocity range was observed in days 7 (0.21 – 1.96 m/s) and 2 (0.85 – 2.69 m/s) respectively. The survey observed day 7 to portray the lowest flow rate and day 9 as the largest flow rate overall. Two slight declining curves in the tidal velocity range were identified across the total survey period; with velocity range decreasing gradually from days 1 - 7 and then days 11- 16. This pattern generally mirrored the two separate time periods within the overall survey.

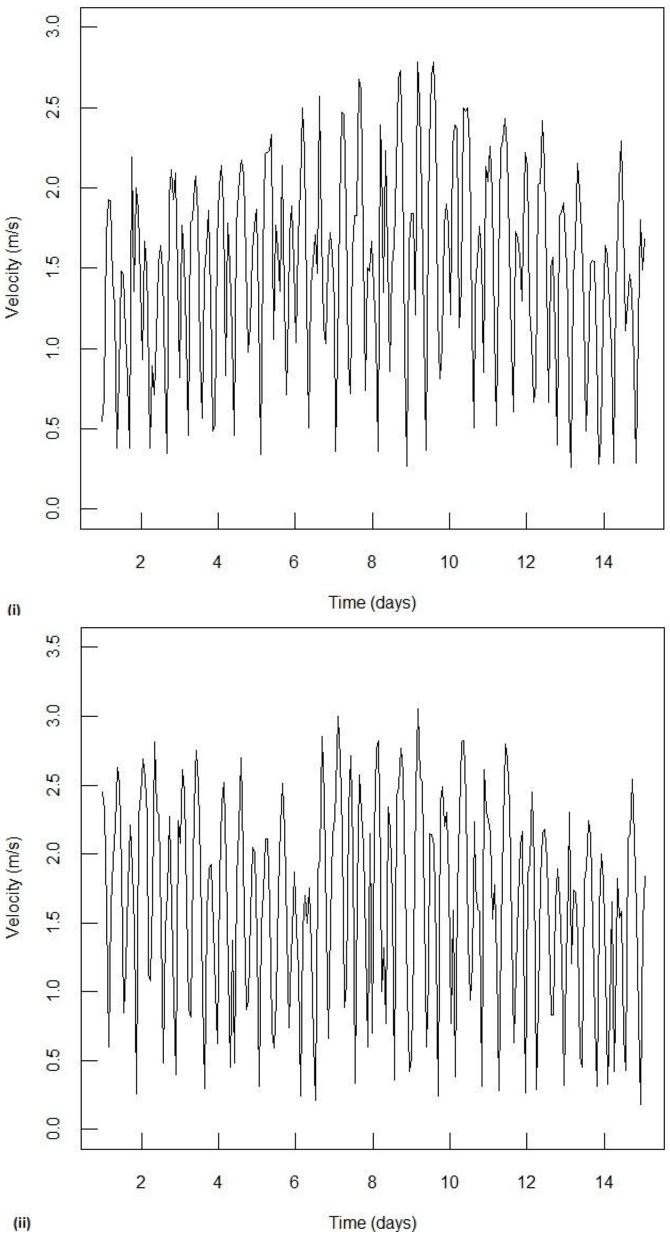


Fig. 4. ADCP tidal velocity flow rates across the total survey day trials for 2009 (i) and 2010 (ii) (velocity measured in m/s).

TABLE II

SUMMARY OF THE MINIMUM AND MAXIMUM TIDAL VELOCITY RATES AND RANGES (M/S) MEASURED IN THE 2009 AND 2010 SURVEY TRIALS. VELOCITY RANGE IS MEASURED BETWEEN THE MINIMUM AND MAXIMUM VELOCITY RATE WITHIN ONE 24 HOUR DAY PERIOD.

	Tidal Velocity Rate (m/s)		**Velocity Range (m/s)**	
Year	**Minimum**	**Maximum**	**Minimum**	**Maximum**
2009	0.26	2.78	1.54	2.32
2010	0.18	3.05	1.75	2.81

G. *Fish Abundance Response to Tidal Velocity*

The GAM models identified tidal velocity to be heavily related to fish abundance response for both survey trial years. Fish abundance was observed to decline significantly as tidal velocity flow rates increased for both year trials.

In the 2009 trial fish abundance was observed to occur largely between tidal velocity rates of 0 to 1.0 m/s, with few observations of fish presence after 1.3 m/s. During the 2010 trial fish presence was observed to predominately occur between the larger tidal flow rates of 0.5 - 1.7 m/s and decline after 1.8 m/s.

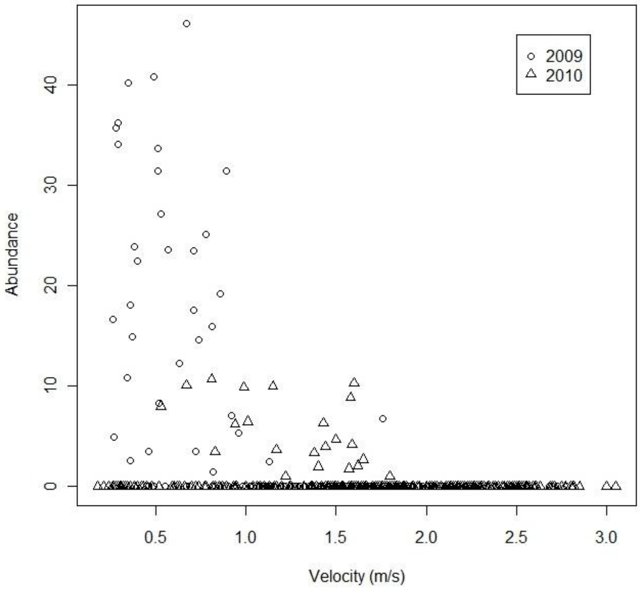


Fig. 5. Total abundance of *P. pollachius* individual counts with corresponding tidal velocities (continuous explanatory variable, measured in m/s) for the 2009 and 2010 survey periods (year as a categorical variable). Circles represent the 2009 survey period, with triangles representing the 2010 survey period.

TABLE III

GENERALISED ADDITIVE MODEL RESULTS FOR SURVEY TRIALS 2009 AND 2010 YEARS WITH THE TIDAL VELOCITY CONTINUOUS EXPLANATORY VARIABLE (QUASI-POISSON DISTRIBUTION).

Explanatory Variable	**Year**	**F**	**p-value**
Tidal Velocity	2009	38.31	**< 0.001**
	2010	4.45	**0.001**

IV. DISCUSSION

H. *Video Observations*

The video survey trials recorded the presence of *P. pollachius* in both years, with no other marine species observed. Fish were observed to predominately occur in groups, with few observations of solitary fish overall.

Grouping or shoaling activities are a common behavioural trait which is extremely advantageous; providing individuals with the potential for increased feeding, spawning and predator avoidance [33], [34], [35]. *P. pollachius* are also known to feed by remaining stationary in the water column and use natural and anthropogenic structures to strike out at passing prey [22], [25], [35], [36]. Therefore this study suggests that deployed tidal device structures can offer new aggregation sites for local species, particularly in terms of feeding or refuge behavioural activities.

The video observations portrayed considerable variation in fish abundance across all hour and day temporal scales, with no clear temporal relationships linked to overall fish presence. Fish populations fluctuate naturally, with daily movement patterns influenced by local biological and environmental cues such as competition, predation, food availability, water depth and water direction [25], [34], [37].

Annual trial comparisons also outlined significant differences in fish observations, with increased abundances seen in the 2009 trials overall. These movements are often linked to annual factors of temperature changes or spawning events [38]. Differences seen between the two years could also be due to the actual age/ size class structure of the aggregation itself, as group structure is often related to fish size i.e. juvenile nursery aggregations or grouped adult spawning events [39].

Fish abundance response may also occur at monthly or seasonal temporal scales, which were beyond the scope of these preliminary trials. *P. Pollachius* in general are known to remain within the vicinity of local waters and further temporal relationships with the deployed device may exist. Therefore extension of the trial time periods is recommended for future trial studies, to outline any further responses to the deployed device and the local area as a whole.

I. *Tidal Velocity Fish Response*

Tidal velocity rates within the local area significantly fluctuated across all temporal scales during annual trials. Such fast flow rates and differences are comparable to past independent ADCP doppler surveys, with the region known for substantially strong and varied tidal flow conditions [27].

This is due to the land masses of the Isle of Eday and Muckle Green Holm within the region creating a natural narrow channel constricting the tidal flow [27].

The GAM models portrayed comparative relationships between fish abundance response and tidal velocity rates surrounding the deployed tidal device for both annual trials. Significantly few abundance counts of *P. pollachius* were observed at high velocity flow rates, with increased abundance counts related to low tidal velocity rates. The large velocity rates observed may drive *P. pollachius* aggregations away from the deployed device to other local regions and structures, for protection, migration or better feeding conditions [38]. As tidal velocity declines, shoals may then be more inclined to move away from these areas and aggregate round the tidal stream device. The ADCP surveys for both years identified subtle tidal velocity curves, which could be the result of periodic neap and spring tidal pattern conditions. These tidal cycles could strongly influence fish abundance within the area, with resulting spring tidal conditions reducing the number of fish observations and neap conditions increasing them. Further comparisons to periodic tidal pattern currents such as spring and neap cycle scenarios or other tidal current patterns (such as ebb or flood cycles) could therefore advance the understanding of fish abundance responses to the tidal device overall and should be included in future studies.

During the 2010 trial, fish observations were also seen to occur at larger tidal velocity rates than the populations observed in the 2009 trial. Shoals are known to aggregate over different spatial scales, influenced by the complexity of physical structures, habitat patchiness and the natural behaviour of the species or population involved [39]. *P. pollachius* also portray opportunistic trait tendencies and are found in a variety of pelagic, benthopelagic and estuarine environments and often regarded as marine migrant opportunists [38], [40]. Overall fish abundance responses surrounding the tidal device could be described as temporary opportunistic aggregations, responding to local abiotic factors such as tidal velocity conditions.

A proportion of unexplained variation between abundance and tidal velocity rates was identified separately for both annual trials ($^{\delta}$ (from analysis of deviance) $^{2009} = 35$ %, $^{\delta\ 2010} = 86$ %), with the 2010 trial outlining considerable unexplained variation. This is the likely result of other direct or indirect biotic, abiotic and anthropogenic factors, or the sampling effort/ design. It should also be noted that the 2010 survey trial lost a number of video survey days which could therefore attribute to the high unexplained variation value. Area around the seabed and monopoles were also not covered in this observation. Fish aggregations could therefore have occurred surrounding or below the device legs and also behind the camera system itself. These factors should therefore be taken into consideration and assessed in more detail in terms of increasing the video/ camera system sampling efficiency or integrating other survey techniques into the experimental trials i.e. sea surface temperature analysis or fish tagging studies [38].

J. Combined Survey Trial Approach

Both the ADCP doppler and video/ still photography sampling procedures are ideal for such extreme environments and renewable energy device assessments due to the devices offshore location, cost effectiveness, reduced sampling bias and increased sampling effort [9], [10], [15], [41]. Video and still photography assessments are useful when assessing marine species across many scales but are ultimately a tool that requires further application with other techniques such as acoustic sampling for sound method design [42]. Therefore in the context of the survey aims, this new combined approach was useful outlining preliminary information of renewable energy device interactions with specific marine species. The survey method could be used for further preliminary species behavioural investigations, different renewable energy device interaction surveys and other marine management applications i.e. fisheries and conservation activities.

However more method testing between the sampling procedures, temporal scales and statistical analyses is required before application to other surveys and devices. This includes expanding the survey sampling effort in terms of increasing the number of generated photograph stills, length of survey trials and additional camera systems attached to the other side of the device or, placed at graduated distances away from the device. Additional environmental factors should also be included in future surveys such as sea temperature, wave climate and meteorological information [1], [28]. This also includes monitoring potential human influences within the overall tidal test site during the survey trials such as boat or other device deployment activities.

V. CONCLUSIONS

The experimental trials outlined *P. pollachius* to aggregate temporally surrounding the deployed renewable energy tidal stream device during 2009 and 2010. Fish aggregations fluctuated considerably across hour and day temporal scales, with no direct relationship to fish abundance observed in both annual trials. Tidal velocity was identified to influence the presence of fish aggregations, with increasing tidal velocities seen to clearly reduce the number of observations. Fish aggregations were not observed above 1.3 m/s in 2009 trials and 1.8 m/s in 2010 respectively.

Overall this combined experimental method identified preliminary responses of local species interactions with renewable energy devices in the marine environment. Additional method testing and assessment of the experimental trials is recommended to increase sampling efficiency for future applications to other devices or survey sites.

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