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Multiparametric monitoring of fish activity rhythms in an Atlantic coastal cabled observatory

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Abstract

Cabled video-observatories offer new opportunities to monitor fish species at frequencies and durations never attained before, quantifying the behavioural activities of their individuals, and providing ancillary data to inform stock assessment (in a fishery-independent manner). In this context, our objective was to improve the ecological monitoring capability of SmartBay observatory (20 m depth, Galway Bay, Ireland), through a pilot study dedicated to tracking of fish counts (as a proxy of populations activity rhythms), in a context where species behaviour and consequent community turnover may occur at different temporal cycles (i.e. tidal versus day-night). In order to understand how animals can regulate their behavioural activity upon those cycles, we enforced a time-lapse (1 h interval) image collection and concomitant multiparametric oceanographic plus acoustic data acquisition continuously during 24 h, over 30 days in August 2018 (when turbidity is at a minimum). For each image, we classified and then counted all visible fish and derived count time series. Periodogram and waveform analyses were used to calculate their fluctuations' periodicity (i.e. the ruling cycle) and phase (i.e. peak timing in relation to the cycle). A total of 12 marine teleost species were pictured with *Trisopterus minutus*, *Trachurus trachurus* and *Chelidonichthys lucerna* characterized by day-night related rhythms, while others, such as *Trisopterus luscus* and *Gadus morhua*, were influenced by the tidal cycle. 24 h count patterns were compared together and investigated for time-based ecological niche-partitioning in a wave and current-affected soundscape. These findings were discussed in relation to the ecology of species and the feasibility of promising observatory-based monitoring applications in fishery assessment practices, when targeted species have commercial value.

Keywords: Activity rhythms, time-lapse imaging, SmartBay, EMSO, observatories, soundscapes, multiparametric monitoring, fishes, tides

1. Introduction

The exploration of the benthic oceanic realms is rapidly changing, thanks to advances in imaging and sensor (i.e. oceanographic and geochemical) technologies, installed on cabled observatories (e.g. Widder et al., 2005; Schoening et al., 2012; Vardaro et al., 2013; Osterloff et al., 2016; De Leo et al., 2018). The image and contemporary environmental data collection these platforms provide, provide ecologists with high-value ecological data which experimentally approximate species Hutchinson niche (Aguzzi et al., 2020). In fact, for each species in each frame, the number of individuals can be directly related with concomitant environmental characteristics, which define the “eco-field” of those individuals (Farina and Belgrano, 2004). When multivariate time series analysis approaches are used on those bio- and environmental data sets, new indications of species life traits can be derived.

A potential of this monitoring approach is the temporal fluctuations in counted individuals can be considered as a proxy of variations in local abundance. Individuals within a population responds to habitat cycles in photophase and tides, consequently modulating their behavioural activity. In the case of fishes which show high motility, changes in behavioural swimming rate directly influence video-counting levels (e.g. Condal et al., 2012; Aguzzi et al., 2010; 2012; 2015; Chauvet et al., 2018; Rountree et al., 2020). At the same time, recurring synchronous increments in counts for different species can be linked to their trophic status, deriving information on interspecific relationships and thus allowing the food-web architecture to be depicted (Aguzzi et al., 2020). Finally, when this highly integrated biological and environmental monitoring is executed over consecutive years, it can, in principle, also provide clues on the overall performance of benthic ecosystems’ productivity (e.g. Thomsen et al., 2017), being derived information of relevance for management policies (Danovaro et al., 2017).

Time-lapse image and coupled multiparametric video monitoring could also be used to explore communities’ response to stochastic environmental events e.g. seismic activity or meteorology (e.g. Aguzzi et al., 2012; Matabos et al., 2014). To date, the response of animal behaviour to those effects is still poorly characterized. The analyses of the soundscape (i.e. the sounds in an environment from geophysical, oceanographic or biological source, including maritime activities) (Pijanowski et al., 2011) could provide an additional layer of information since its quality might condition fish

behaviour (e.g. predators' presence; Rountree et al., 2006; Slabbekoorn et al., 2010; Wall et al., 2014). Moreover, the simple passive acoustic recognition of fish vocalizations could complement traditional survey methods (Staaterman et al., 2017), allowing species traceability beyond imaging methods (Rountree et al., 2020).

Time-lapse multiparametric synchronous video, oceanographic and sound monitoring by cabled observatories may provide a roadmap to deliver ancillary behavioural information, to explain the temporal variability in catches of commercial species. As per image spotting probability, activity rhythms influence species availability to fishing at all depths of the continental margin and in the deep sea (Aguzzi and Company, 2010; Aguzzi et al., 2015b). In the case of fish, important ancillary data could be produced by cabled observatory video-monitoring, by adding new behavioural observations for capture management models (e.g. Follana-Berná et al., 2019; Rountree et al., 2020). In fact, the comparison of video and trawl data has an established research record using movable lander assets (Priede and Merret, 1997; Bailey et al., 2007) and an important advancement has been recently conducted with Baited Remote Underwater Video Systems (e.g. BRUVS; Bicknell et al., 2016; Langlois et al., 2018).

To the best of our knowledge, there are no previous studies on the behaviour of coastal Atlantic fish communities by cabled observatories, combining time-lapse imagery with concomitant oceanographic monitoring including sound. Therefore, the modulatory effect on the behaviour of coastal fishes (and resulting species composition) of combined tidal and day-night cycles in a variable soundscape, is still poorly known. Here we used such a multiparametric video and environmental monitoring approach to track several fish species of commercial value in Galway Bay. Species activity rhythms response (in terms of video-capture availability) was evaluated into an area where behavioural modulation must occur upon tidal and light mixed regimes, and potentially, upon a non-previously quantified environmental noise.

2. Material and Methods

2.1. The study area and the platform

Galway Bay (Galway, Ireland) is a large semidiurnal tidal bay, protected from the open Atlantic Ocean by the Aran Islands (**Fig. 1**). The dynamics within the bay are

mainly influenced by the Atlantic flows toward the bay and by wind driven currents, but freshwater discharges, primarily from the River Corrib, are also significant. The general direction of water coincided with the tidal current direction, i.e. into Galway Bay, on the flooding tide (O'Donncha et al., 2015). In this area, the SmartBay cabled seafloor video-observatory is deployed as a European Multidisciplinary Seafloor and water column Observatories (EMSO) test-site. The platform is positioned at 21 m depth, on the northern side of the Bay, 1.5 km off the coast of Spiddal (located at 53° 13.638'N, 9° 15.980'W). The deployment area is characterized by depths less than 30 m, while the outer bay reaches up to 70 m deep (O'Conchu'hair et al., 2016).

The observatory hosts a High-Definition (HD) camera (Kongsberg OE14-522), carrying out imaging either in time-lapse or continuous filming mode at a 1080i resolution, by day and night (i.e. *via* two Kongsberg OE11-141 lamps). The platform is connected with a fibre optic and power cable (100 /DC), feeding instrument power requirements and allowing the real-time data transfer to a shore station at the Marine Institute (Berry et al., 2016). The platform is also provided with a number of permanent oceanographic and geochemical sensors: turbidity (by WetLabs ECO FLNTU), temperature, salinity, dissolved oxygen and pressure (by CTD: Idronaut Ocean Seven 304 Plus), sound (by hydrophone: icListen HF, Ocean Sonics), significant wave height (by Datawell Waverider Wk3), current velocity and direction (by ADCP: RDI-Teledyne Workhorse Sentinel 600kHz).

2.2. Protocol for image and environmental data acquisition

In order to study the temporal fluctuations in fish counts (as proxy for relative abundances) and resulting community changes, as a product of the behavioural response of individuals to overlapping tidal and day-night cycles, a time-lapse video-filming (i.e. 3 min each 1 h) was continuously enforced during 30 days in summer (i.e. from August 10th 2018 at 00:00 h to September 10th 2018 at 23:00 h). That monitoring time window was chosen to allow best conditions of visibility (for lower turbidity).

The camera always pointed to the same Field of View (FOV) with a 45° inclination, in order to capture fishes appearing against a constant water column background. All videos were saved on a server with the time stamp of acquisition

(<http://spiddal.marine.ie/data/video/aja-helo-1H000314/2018/08/09/>). Therefore, all data were presented according to local timing.

In addition to the video imaging, a suite of environmental data was also acquired concomitantly, in order to link behavioural activity to environmental conditions, at the following time-lapse intervals: turbidity each two seconds, temperature, salinity, dissolved oxygen and pressure each one second, sound each 0.5 second (see below), and finally, significant wave height, current velocity (horizontal and vertical components) and direction each 15 minutes.

2.3. Faunal data processing

Per each video, individuals that appeared in the FOV were counted one by one. We classified them all to the lowest taxonomical level as possible with the help of web data bases as, e.g. FishBase (<https://www.fishbase.de/>). Classification results were also cross-checked by Marine Institute experts. Since fish tracking was not possible, we may have been introducing recounting errors (i.e. considering as a new entry each fish re-entering the FOV). Notwithstanding, such an error is usually constant throughout the video filming processing and overall population activity rhythms are not affected by it (Aguzzi et al., 2010; 2012). In cases where fishes appeared in large schools, hence overlapping together, the process of counting was carefully undertaken pausing the video every 10 seconds and counting all the individuals that appeared in each frame. Non taxonomically determinable fishes (e.g. too distant in the FOV or crossing it too fast) were also reported in an “Unclassifiable” category. At the end of each video, all the counts for each species were summed up to give the total numbers (plus taxonomically undermined individuals) for that time interval.

2.4. Acoustic data processing and analysis

The acoustic data were processed to obtain hourly mean values of ambient sound pressure (spectral density, dB re 1 $\mu\text{Pa}^2/\text{Hz}$) from averaged power spectra (sampling rate 64 kHz; FFT 1024). The following frequency bins were chosen for successive analysis: 63, 125, 1000 and 2000 Hz. Those frequencies were chosen to look for impacting effects of maritime activities in the best ranges of fishes listening capability (i.e. below 2 kHz; see Kastelein et al., 2008), hence complying with the

Marine Strategy Framework Directive (MSFD) standards (2008/56/EC) (Tasker et al., 2010). In order to assess how sounds were related to weather conditions, a correlation analysis between the significant wave height and selected frequency bins was performed. Since the probability distribution of the raw data failed the Kolmogorov-Smirnov test for normality, a Spearman's rho correlation was chosen (Statistica v8.0).

2.5. Time series analysis

Time series of video-counts of each species were considered as a proxy for changes in its local abundance, i.e. the probability of animal video-spotting depends upon rhythmic displacements across depths or between sleeping and activation phases (e.g. Reebbs et al., 2002; Aguzzi et al., 2013; Myers et al., 2016). The occurrence of significant periodicities in all temporal data sets was analysed with the Lomb-Scargle periodogram by in the El Temps chronobiology software package (www.el-temps.com). All periodicities were screened in a window of frequencies between 600-1620 min (equivalent to 10-27 h, respectively), which includes the range of internal tides to the day-night cycles (Aguzzi et al., 2018). In the output periodogram plot the peak exceeding a significant threshold ($p < 0.05$) represented the maximum percentage of total data variance explained by the coherent dominant periodicity (Refinetti, 2004).

Waveform analysis in visual count fluctuations for the different species and the environmental data was performed following Chiesa et al. (2010). All time series were subdivided into 24 h segments (i.e. 24 values per each segment, at 1 h sampling frequency). All values were then averaged at corresponding 1 h time intervals throughout all segments. Resulting averages (plus standard deviations) were converted into 24 h plots (i.e. the waveform), along with a Midline Estimated Statistic of a Rhythm (MESOR). This is a daily average obtained by re-averaging all waveform values (Refinetti, 2004). In the waveform plot the phase of a rhythm (i.e. the averaged peak) is identified by all values above the MESOR. Waveforms for fishes only were represented with the day-night phase in overlay, considering averaged sunset and sunrise timings within the monitoring month (i.e. 6:00 dawn and 21:00 dusk). This was done to identify the linkage between the behaviour and the overall environmental illumination.

An integrated chart depicting the temporal relationships of fish activity phases was created (Aguzzi et al., 2012; 2015). The hourly average values of each waveform of each species were compared with the respective MESORs through an inequality function in Excel. All waveforms values identified as greater than the MESOR represented the peak duration (i.e. the phase of activity of each species) and were then plotted as horizontal continuous lines. Peaks continuous bars for the different species were then plotted according to their temporal similarity in relation to the day-night cycle.

2.6. Multivariate analysis

In order to establish a linkage between the behavioural response of fishes and the environmental conditions, the different oceanographic variables (i.e. turbidity, salinity, oxygen concentration, sound ranges, significant wave height, water column pressure, absolute current speed plus its spatial components as velocity east, north and upward) were contrasted with species video-counts by Canonical Correspondence Analysis (CANOCO; Legendre and Legendre, 1998). Being an ordination technique, CANOCO was applied to observe in a same multidimensional space, the contributions of both environmental and species count matrices. The ordination axes are linear combinations of the environmental variables. Both matrices (environmental and species counts) were standardized using correlation matrices. CANOCO was performed using the free software PAST 2.17c (<http://folk.uio.no/ohammer/past/>).

3. Results

3.1. Faunal general remarks

A total of 747 videos were viable for faunal inspection, with the remaining 21 unusable due to high turbidity or lighting malfunction. In that imaging material, we detected several fish species, a majority of which are of commercial relevance (**Table 1** and **Fig. 2**): *Clupea harengus*, *Trachurus trachurus*, *Trisopterus minutus*, *T. luscus*, *Gadus morhua*, *Pollachius pollachius*, *Melanogrammus aeglefinus*, *Merlangius merlangus*, *Ctenolabrus rupestris*, *Labrus bergylta*, *Chelidonichthys lucerna* and *Zeus faber*. Among all these classified fishes, counts for *T. minutus* followed by *T. trachurus*

together build up the $\approx 56\%$ of all observations. A large percentage of fishes was unclassified ($\approx 34\%$), since appearing too far in the FOV, especially at night time.

The visual count time series for all species indicate different patterns of occurrence during the monitoring period (see **Appendix 1A**), with a progressive change in community composition and in species relative numbers during the seasonal transition from summer to autumn. The fishes *P. pollachius* and *C. lucerna* were replaced by *T. trachurus* around the 20th of August, while some species occurred during the entire period of observations (e.g. *T. minutus*). Others are always present but are more frequent in the second period (e.g. *G. morhua*). Sea temperature time-series showed the seasonal transition from summer to autumn, around the middle of the monitoring period, when values decreased from 16.7-17 to 16 °C (see **Appendix 2**).

3.2. Activity rhythms of fishes

The combined periodogram and waveform analysis in counts time series demonstrated the presence of defined activity rhythms for some species, while temporally inconsistent results were obtained for others (see **Table 1**). Waveform analysis is presented for comparison in **Figure 3A**. Some arrhythmic species were shown as *C. arengus*, *M. merlangus* and *Z. faber* (all not further described in this section). Rhythms strength and temporally coherent peaks in waveform plots are linked to differential count levels of species, with those of higher counts often showing clearer fluctuations.

T. trachurus and *T. minutus* showed a day-night periodicity equal to 24.2 h and 24.0 h, respectively (i.e. 1450 and 1440 min, respectively). Both species presented opposite phases, being the former nocturnal and the latter fully diurnal. Waveform analysis also indicated a day-night periodicity for *C. lucerna*, characterised by a nocturnal peak. This daily periodicity was slightly less defined in the periodogram, being equal to 24.8 h, (i.e. 1490 min).

T. luscus and *G. morhua* also presented day-night rhythmic patterning with a less defined periodicity at 23.7 and 24.5 h, respectively (i.e. 1420 and 1470 min, respectively). For both species, the waveform analysis highlighted the presence of two daytime peaks of different intensity, occurring at 9:00-10:00 and 16:00, showing a time interval of about 6 hours. For both species, the diurnal cycle is dominant (as

demonstrated by the periodogram analysis), but a peak splitting may also occur in association to the semidiurnal tide, as fish activity is stimulated just after the maximum current displacement due to high and low levels (see water level waveform analysis).

The same dynamic of behavioural modulation upon currents would apply for *P. pollachius*, but this time with a night pattern; i.e. this species also showed a day-night related periodicity (a significant period at 23.3 h equal to 1400 min in periodogram analysis), but the waveform plot showed a subdivided nocturnal peak similar to *T. luscus*, occurring at 10:00 and 15:00-16:00. Differently, *M. aeglefinus* and *L. bergylta* showed a periodicity in counts at 24.1 and 24.3 h, respectively (i.e. 1448 and 1460 min, respectively) but with the two peaks during a diurnal phase in waveform analysis. In the case of *M. aeglefinus* the distance between the two peaks is of the order of 4 hours, while it is about 9 hours for *L. bergylta*.

Finally, time series for total of individuals and those within the unclassified category, both demonstrated an emerging global day-night periodicity with significant periods of 24.2 and 23.2 h respectively (i.e. 1450 and 1394 min respectively). The waveform for total counts showed a major daylight peak, being that analysis influenced by the most abundant diurnal species (i.e. *T. minutus*). For the unclassified group, the waveform analysis showed a nocturnal peak, probably caused by individuals of *P. pollachius* and *T. trachurus*.

3.3. Environmental changes

All time series for the measured environmental variables are presented in **Appendix 1B** and **C**. Periodogram analysis for all these variables are presented in **Table 1**, while waveform results are shown in **Figure 3B** for comparison. The combination of both analyses demonstrated that some variables are better proxies for the description of the local tidal regime than others, and are hence associated with fish behaviour.

For the turbidity, the periodogram showed a periodicity with a unimodal significant period of 25.3 h (i.e. 1520 min). Differently, the waveform analysis did not show any clear pattern.

Temperature confirmed its high variability during the monitoring period (as shown by the high standard deviation values in **Figure 3B**), due to a seasonal fluctuation. It presented a clearer semidiurnal periodicity of 12.2 h (i.e. 730 min) and

the waveform showed a weak temperature increase during night time, in relation to the local tidal pattern of circulation. Moreover, around the 20th of August a marked transition from higher to lower temperatures was identified (see **Appendix 1B**). Superposition of waveforms showed the temporal relationship of the temperature vs. water column pressure (as a proxy for internal tides; see below), which was not synchronous (plot not shown).

The salinity periodogram indicated arrhythmia. Notwithstanding, the waveform showed a weak salinity increase during daylight hours. Dissolved oxygen periodogram was also arrhythmic in periodogram analysis, although the waveform presented a weak nocturnal tendency toward an increase.

Water column pressure was the best proxy for local tidal regime description. A bimodal semidiurnal fluctuation was demonstrated by periodogram analysis with a significant period at 12.5 h (i.e. 750 min). This pattern is well described in the waveform which showed a clear bimodal pattern of variation. At the same time, current speed presented a similar bimodal semidiurnal periodicity for the East-West and North-South components, with significant periods at a high frequency of 12.3 h (i.e. 740 min) in both cases. For vertical current velocity a non-significant periodicity was detected, being arrhythmic with the waveform showing a weak nocturnal increment (**Fig. 3B**). The wave height periodogram did not show a significant peak and waveform analysis failed to demonstrate any clear cyclic oscillation (see **Figure 3B**).

Finally, the periodogram analysis on sound could not be carried out because of a gap in data acquisition during three-consecutive days (i.e. from August 29th to 31st; see **Table 1**). In any case, also the waveform analysis failed to show a clear pattern of cyclic fluctuation for any of the measured frequency bands (**Figure 3C**). The considered bands were significantly and positively correlated with the wave height (see **Appendix 3**). Mechanic drag and associated movement of the infrastructure components during bad weather conditions introduced noise, which was confirmed through aural and visual scrutiny of the files.

3.4. The waveform comparison among the different species

The waveform integrated chart, where all waveform peaks are compared together (**Figure 4**), clearly evidences that most of species showed a day-night related

(and tidal-independent) pattern in count variation. A general temporal subdivision between diurnal and nocturnal species is evident within the monitored fish community, with two major activity blocks timed at photo- and scotophases. Punctual and sparse increases are seldom reported.

3.5. Multivariate statistic outputs

Multivariate statistic outputs are presented in **Figure 5** with two graphs, an enlarged version of the centre depicting precisely the distribution of hours (based on similarity in fish species commotion) for better visualization (**Fig. 5A**) and a more general one, showing species distributions according to the environmental variables (i.e. as vectors) (**Fig. 5B**). Temperature, salinity and dissolved oxygen were excluded because did not present a variability at the second decimal number.

The visualization of the full sequence of 24 hours (**Fig. 5A**) is expressed between the axes with a positioning that depends on the similarity in video sampled composition of species: there were two main fish groups. One is located on the left, which corresponds to “night” and the other is located on the right, as corresponding to “day”. In agreement with waveform analysis (see **Figure 3A**), some species appeared as associated with darkness (from 21:00 to 7:00) and others with light (from 7:00 to 21:00 local time). The hours appearing at the middle of the graph are hours of transition between these two groups, corresponding to dusk and dawn. While, species samples at day-night transition are not clearly associated to certain hours, those at the quadrants’ extremes clearly represented nocturnal and diurnal ones.

The species more associated with night hours were *C. lucerna*, *P. pollachius* and *T. trachurus*. There were also entries associated with the unclassified categories that showed an association with those darkness hours. Contrarily, the species associated with light hours were *G. morhua*, *T. minutus* and *Z. faber*. Other species that appear at the right extreme of the graph were even more associated to daylight hours such as *L. bergylta*, *C. rupestris*, *M. aeglefinus* and *T. luscus*. However, periodogram and waveform analyses failed to demonstrate clear rhythmic patterns for *Z. faber*, *L. bergylta*, *C. rupestris* and *T. luscus*. This is an indication that poor counts for those species influenced the multivariate analysis, whose results are a product of randomness, rather than a true indication for activity patterning (see **Table 1**).

In the second graph (**Fig. 5B**) the association of species into different light and dark hours can be visualized against the oceanographic factors' vectors (whose length is proportional according to the relationship with variability in species). That plot hence presented a global overview on how species composition was affected by the environment, confirming that light and not tides, was the primary video-counts modulator. *T. trachurus* and *P. pollachius* presence was affected by the mean turbidity and the spatial components of the current speed, especially the vertical one. *C. lucerna* and the unclassified category were affected by the north-south current, while *L. bergylta* was predominantly affected by sound and *M. aeglefinus* and *C. rupestris* were affected by the significant wave height.

4. Discussion

In this study, we characterized behavioural rhythms of species in a coastal fish community, by high-frequency video and environmental multiparametric monitoring in Galway Bay. Despite the marked semi-diurnal tidal regime of the coastal area, most of the fishes showed marked day-night and not hydrodynamic driven visual count patterns. Those behavioural results are framed in a strongly tidal context. Tidal current direction is from the Atlantic Ocean towards Galway Bay, on the flooding tide (O'Donncha et al., 2015). Hence, during daytime, seawater temperatures slightly increase in correspondence of the lowest water level (i.e. during the ebb tide) due to the inflow of heated water from the shallow coastal zone, but decrease during the daytime highest level (i.e. flood tide), due to the inflow of colder water of Atlantic origin. Interestingly, the night ebb tide was also characterized by an increase in temperature, despite the loss of heat to the atmosphere. The inflow of warm water heated by the tidal flat during the preceding flood tide may be responsible for that.

4.1. Fish behavioural rhythms

In this environmental scenario, most of our video-monitored species showed a day-night related (and tidal-independent) pattern in count variation as a proxy for the effects of light intensity regulation of swimming behaviour (see **Figure 4**). In Western Mediterranean areas where internal tides are negligible and coastal cabled observatories have been similarly used for time-lapse image surveying of fishes (e.g.

OBSEA; www.obsea.es; Aguzzi et al., 2011; Del Rio et al., 2020), species showed clear day-night activity patterns (Aguzzi et al., 2013; 2015b). In Galway Bay, where both light and internal tides cycles are present, the results were similar to those at OBSEA, with a majority of species either diurnal or nocturnal. Taken together, our results showed how a light-based temporal niche partitioning framework (Kronfeld-Schor and Dayan, 2003) rules on species 24 h turnover even in those coastal areas where tidal current effects are consistent.

Our results on diel species succession should be interpreted considering literature data on their behavioural life traits. Gadoids species as *Trisopterus minutus* are benthopelagic (Carpentieri et al., 2005). Benthopelagic displacements are those occurring vertically (back and forth) in the water column with animals entering in contact with the seabed (Aguzzi and Company, 2010). In the area of the SmartBay Observatory, animals may not have sufficient depth to properly perform this rhythmic displacement. Accordingly, individuals may enter the area *via* nektobenthic diel migrations (i.e. along the seabed, within the benthic boundary layer; Aguzzi and Company, 2010): inshore migration to shallow water coastal realms during the day, offshore migration at night toward deeper realms. A similar behaviour could be accounted for *Gadus morhua* and *Melanogrammus aeglefinus*, where diurnal visual counts increases indicate an offshore retreat into deeper realms after sunset (Gibson et al., 1996). In particular, *G. morhua* has a diurnal rhythm of swimming activity with a slightly lower swimming speed during the night (Løkkeborg, 1998), which indicates that animal presence at SmartBay site may be related to enhanced diurnal (visual) predatory activity (Løkkeborg and Fernö, 1999).

Similarly, species with higher detections at night may follow the same pattern of displacement. *Trachurus trachurus* has been classified as benthopelagic (Ragonese et al., 2004) and it also may perform offshore migrations at daytime out of Galway Bay to the open ocean's deeper and darker realms in order to feed on euphausiids (i.e. krill; Simard and Harvey, 2010), avoiding visual predators such as birds (Certain et al., 2011). During the night, when *T. trachurus* was highly present, a species that it predated, *T. minutus*, synchronously disappeared (i.e. its waveform indicated a nocturnal trough, see **Figure 3A**) (Jardas, 2004). Data on the behaviour of *Pollachius*

pollachius and *Chelidonichthys lucerna* are scant to the best of our knowledge, but present observations indicated a rhythmic behaviour similar to that of *T. trachurus*.

Nocturnal offshore migration in our monitored fish species may also result from the necessity to avoid apical predators such as marine mammals that are very active at night in the area. *Phoca vitulina* feeds mostly at night (Boulva and McLaren, 1979; Harkonen and Heide, 1991), targeting on our video-monitored fish species. Such a predator-prey relationship may explain nocturnal offshore fish migrations considering that their displacements and the associated food intake must be balanced by a concomitant reduction of mortality risk (Savino and Stein 1989; Burrows et al., 1994; Trzcinski et al., 2006).

For *T. luscus* and *G. morhua* waveform peak was split in two halves separated by 6 hours, considered as marker for tidal rhythm (see **Figure 3A**). The periodogram results also supported the presence of significant diurnal periodicity. Both species showed increased activity during daylight and about 2 hours after the maximum tidal current, that is, at mid-way between the high and low tides (see **Fig. 3B**). Because water is in motion when a tide is changing, those fish species seem to take advantage of hydrodynamism to feed or displace and so a higher number of individuals was recorded. Commonly, deep-sea megafauna including benthic fishes do respond to changes in the status of tidal flow (e.g. Wagner et al., 2007; Aguzzi et al., 2010; 2018; Doya et al., 2014; Cuvelier et al., 2014, 2017), within a framework of low energetic budget requirements at displacement (Aguzzi et al., 2010; Chatzievangelou et al., 2016).

In the case of *M. aeglefinus* and *L. bergylta* the same pattern is present, but this time the two peaks were separated by 4-9 hours respectively, being not concomitant with maximum falling or rising tides. Possibly, both peaks correspond to different demographic components (e.g. females and males or juveniles and adults) with a temporal shift in activity timing, as an adaptive strategy often used to reduce intraspecific competition (Webster, 2000; Kroneld-Schor and Dayan, 2003; Aguzzi and Company, 2010). An example of how interspecific competitive interactions influence the demographic structure of populations is the relationship between juveniles and adults for the food resources (Persson, 1988). Unfortunately, this issue remains unsolved in the present study, since no stereo-imaging systems for size scanning are

presently installed at the SmartBay platform, nor dimorphic shape/colour features to be evidenced with its current imaging equipment. Stereo imaging has been used to accurately size fishes within trawls (e.g. Rosen, 2013; Sorthis et al., 2013), as well as in mariculture tanks (Harvey et al., 2003; Costa et al., 2009; Torisawa et al., 2011) and its application for cabled observatories is also foreseen (Aguzzi et al., 2019; Rountree et al., 2020).

Other species as *Z. faber*, *C. arengus* and *M. merlangus*, have been rarely detected and did not show any rhythmicity. *Zeus faber* undergo changes in diet with increasing size, shifting its preference from demersal fishes to pelagic fishes (Preciado et al., 2008). The diet is however highly determined by the availability of these prey species (Silva, 1999).

A seasonal succession of species at our monitoring site has been detected, despite the short duration of the study. This phenomenon is visible in the most abundant species and mirrored in the faunal assemblage shift from *P. pollachius* to *T. trachurus* (see **Appendix 1**). The same transition also occurs for less represented species such as *T. luscus*, *C. rupestris* and *Z. faber*, which only appeared in the second half of the monitoring period, whereas *C. lucerna* was present only during the beginning of the study. Around the 20th of August a marked transition from higher to lower temperatures was clearly identified (see **Appendix 2**). Seasonal variability is expected to play a crucial role on the succession of coastal communities, as background community composition and relative abundances change substantially moving from summer to autumn (Condal et al., 2012).

4.2. The characterized soundscape

Numerous sounds of biological origin were recorded at SmartBay. Echolocation and whistles from dolphins and several sounds referable to fish species were detected during aural and visual scrutiny of a small random subset of the audio files. Indeed, six out of the twelve species here identified through visual count are known in literature to produce sounds, namely *C. harengus*, *T. trachurus*, *G. morhua*, *P. pollachius*, *M. aeglefinus*, and *Z. faber* (Protasov, 1965; Hawkins and Chapman, 1966; Fish and Mowbay, 1970; Wilson et al., 2014; Radford et al., 2018). In addition, *Labrus bergylta* and *C. lucerna* are defined as potential producers of sounds (Quigley 2005;

Carrigo et al., 2019). *T. minutus* and *M. merlangus* have been acoustically studied but resulted to not produce sounds, whereas *T. luscus* was defined as an unlikely producer of sounds (Hawkins and Picciulin, 2019). Despite the sustained presence of soniferous species, the acoustic data did not show significant association with the reported behavioural rhythms of fishes. No clear diel pattern of sound increase was reported as an indirect indication of overall production by animal activity. Sounds were mainly driven by weather conditions (see **Appendix 3**). Accordingly, the strongest predictor of the low frequency bands (i.e. <2 kHz) at the SmartBay site was the wave height, as also demonstrated by the multivariate analysis. During our monitoring, significant wave height was always higher than 40 cm and frequently reached over 150 cm. Such harsh weather conditions caused the introduction of sounds produced by waves and, more importantly, of noise generated by moving parts or some component of the observatory. This noise affected the entire bandwidth of the recordings (0-32.000 Hz), thus hampering an effective measurement of sounds produced by marine species (fishes or cetaceans).

In such a context, sound pressure levels could be informative only in optimal weather conditions (absent wind and calm sea state) or, alternatively, only a manual acoustic census could help in disentangling biological/anthropogenic inputs from the ones generated by the SmartBay infrastructure. Anthropogenic noise is known to impact behaviour and communication in many marine species (Tyack, 2008; Clark et al., 2009; Slabbekoorn et al., 2010), and its monitoring is considered critical. On the other hand, animal acoustic cues can be used to track diel activity rhythms of fishes, crustaceans and marine mammals (Buscaino et al., 2016; Pieretti et al., 2017). In this sense, the synchronous use of audio and video recordings offered by cabled observatories could substantially help in obtaining a more accurate understanding of fishes' activity rhythms, particularly when associated with other physical oceanographic parameters as in the present study (Lindseth and Lobel, 2018). At SmartBay and likely at other similar sites, a reduction of noise is recommended as a fundamental step to permit a more informative use of acoustics as a proxy for the assessment of biological sounds (i.e. observatory components should be fixed and not oscillate at currents, being connected with non-metallic ropes).

4.3. Future monitoring perspectives

Cabled observatories and their networks are acquiring a clear roadmap toward an enhancement of their monitoring capability in terms of sensor development and package combinations, allowing the tracking capability of species beyond optoacoustic technologies (Aguzzi et al., 2019). This is the case of omics approaches (Fanelli et al., 2020). Thanks to recent analytical and technological advances, new methodologies are becoming available for the study of marine life including indirect and non-invasive approaches such as environmental DNA (eDNA), which works by detecting DNA traces shed by any organism in their surrounding environment where such signal can persist for days or even longer (Ruppert et al., 2019). Here, we obtained a temporally comprehensive video-richness that can be used in the future for comparison with eDNA markers. Such comparison would result in the augmented capability to trace species in future (see **Figure 2**). The use of eDNA has shown great potential for its integration in biodiversity monitoring of a wide range of species, including teleost fish (e.g. Collins et al., 2018). Like any other approach, there are a number of limitations that still affect eDNA's full potential and these can be overcome by further refining the method itself (Zaiko et al., 2018) but also by corroborating it with other types of data (e.g. Ratcliffe et al., 2020). Thus, cabled observatories such as SmartBay offer a unique opportunity to conduct multi-disciplinary studies combining video, oceanographic, physical (audio-visual) approaches for cross validation with eDNA, hence obtaining an augmented status of such sites, leading to a result that is greater than the sum of parts.

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Table 1. Detected fish species are reported for SmartBay video-monitoring along with the taxonomical ranking (Family) and codes (for multivariate statistic) as well as total counts (Num.) and relative percentages (%), in taxonomic order (according to their Family; see also **Fig. 2** for referencing images). Time series analysis outputs are also reported in terms of significant ($p>0.05$) periods (in minutes and converted in hours) as well as waveforms' MESOR. Arrhythmic time series were indicated as "Arr.". Periodogram analysis on time series for sound data was not carried out since data acquisition was interrupted from the 28th to the 31st of August (hydrophone maintenance).

Family	Species	Code	Num.	%	MESOR	Period	
						min	hours
Clupeidae	<i>Clupea harengus</i>	Cluerr	1	0.001	0.001	Not Done	-
Carangidae	<i>Trachurus trachurus</i>	Tratra	11572	14.458	15.198	1450	24.167
Gadidae	<i>Trisopterus minutus</i>	Trimin	33341	41.298	43.413	1440	24.000
Gadidae	<i>Trisopterus luscus</i>	Trilus	117	0.145	0.152	1420	23.667
Gadidae	<i>Gadus morhua</i>	Gad mo	1923	2.382	2.504	1470	24.500
Gadidae	<i>Pollachius pollachius</i>	Poipol	4694	5.814	6.112	1400	23.333
Gadidae	<i>Melanogrammus aeglefinus</i>	Melaeg	1186	1.469	1.551	1448	24.133
Gadidae	<i>Merlangius merlangus</i>	Mermer	3	0.004	0.004	Not Done	-
Labridae	<i>Ctenolabrus rupestris</i>	Ct erup	47	0.058	0.06	1290	21.500
Labridae	<i>Labrus bergylta</i>	Labber	10	0.012	0.012	Arr.	-
Triglidae	<i>Chelidonichthys lucerna</i>	Cheluc	540	0.668	0.702	1490	24.833
Zeidae	<i>Zeus faber</i>	Zeufab	4	0.005	0.005	Not Done	-
-	Unclassified	Uncl	27197	33.687	35.412	1450	24.167
-	Total of individuals	Tot	80733	100	82.687	1394	23.233
-	Turbidity	Turb			1.481	1520	25.333
-	Sound (2000 hz)	2000hz			25.279	Not Done	-
-	Sound (1000 hz)	1000hz			28.710	Not Done	-
-	Sound (125 hz)	125hz			16.401	Not Done	-
-	Sound (63hz)	63hz			7.737	Not Done	-
-	Total sound	Tot hz			97.590	Not Done	-
-	Temperature	Not included			16.608	730	12.167
-	Salinity	Not included			34.812	Arr.	-
-	Dissolved O ₂	Not included			6.377	700	11.667
-	Column pressure	Col Pres			25.242	750	12.500
-	Absolute Current Speed	Abs Cur			93.369	890	14.833
-	East-West current speed	EW Cur			-1.963	740	12.333
-	North-South current speed	NS Cur			-0.503	740	12.333
-	Vertical current speed	UP Cur			2.676	Arr.	-
-	Wave height	Wave			77.700	Arr.	-

Figure Captions

Figure 1. Location of SmartBay and platform details. (A) Ireland with the Galway Bay area enlarged, (B) a close view of the bay, and (C) a nocturnal image of the camera installed on the benthic platform, surrounded by school of *Trisopterus minutus*.

Figure 2. List of fishes imaged at the SmartBay cabled observatory, as (A) *Clupea harengus*, (B) *Trachurus trachurus*, (C) *Trisopterus minutus*, (D) *Trisopterus luscus*, (E) *Gadus morhua*, (F) *Pollachius pollachius* (G) *Melanogrammus aeglefinus*, (H) *Ctenolabrus rupestris*, (I) *Merlangius merlangus*, (J) *Labrus rupestris*, (K) *Chelidonichthys lucerna*, and finally (L) *Zeus faber*.

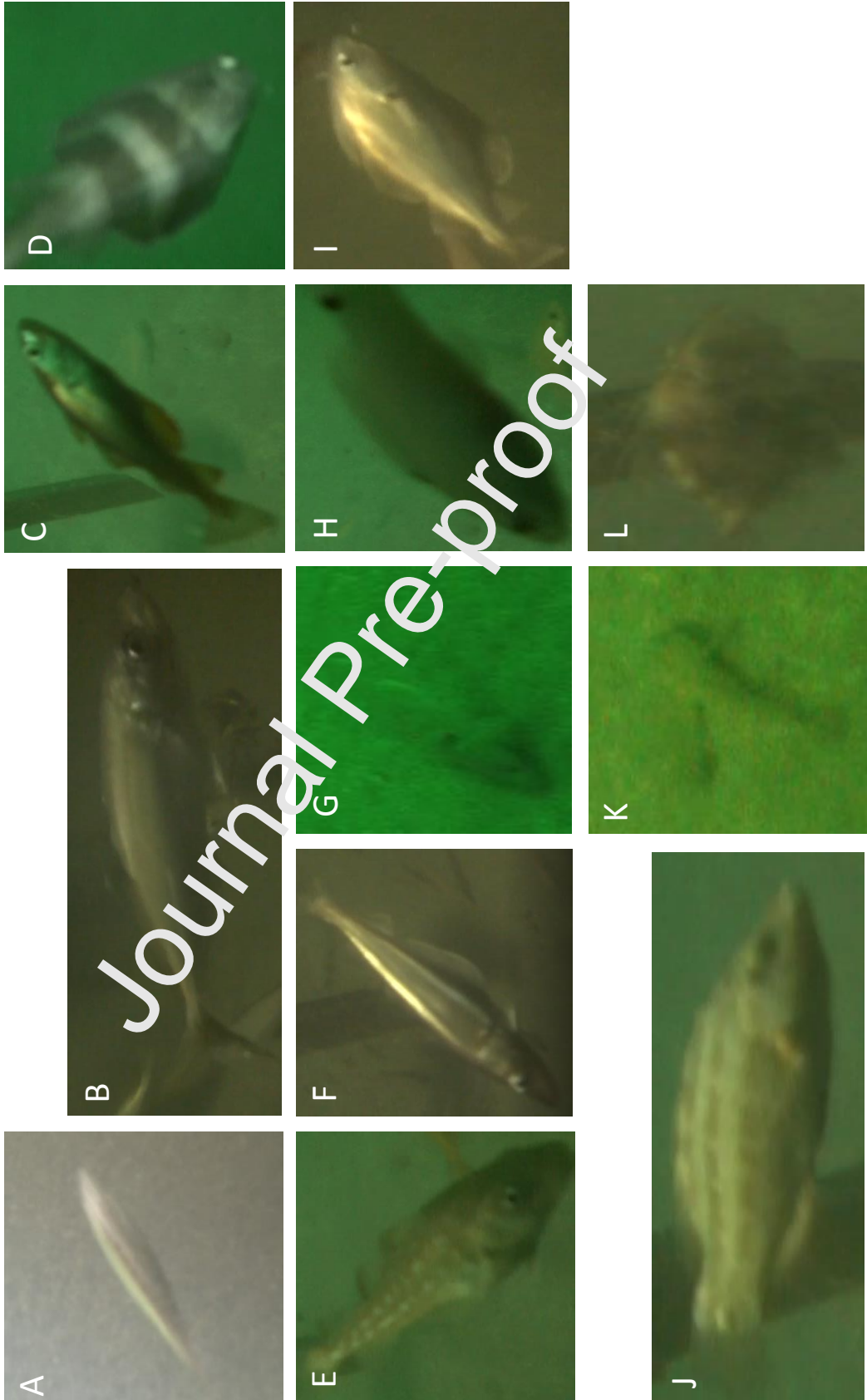
Figure 3. Waveforms for (A) fishes, (B) environmental variables, and finally (C) sounds. The MESOR is represented by the dashed horizontal line. Grey rectangle depicts approximated night duration during the monitoring month.

Figure 4. The integrated waveform chart depicting the temporal relationships of fish count phases (from waveform analysis in **Figure 3A**). From this global overview it is evident how species subdivide into two major temporal halves according to the day-night cycle.

Figure 5. Canonical Correspondence Analysis. (A) Full sequence of 24 hours expressed depending on the similarity in video sampled composition of species, and (B) species distributions according to the environmental variables and hours of the day.



Fig. 1



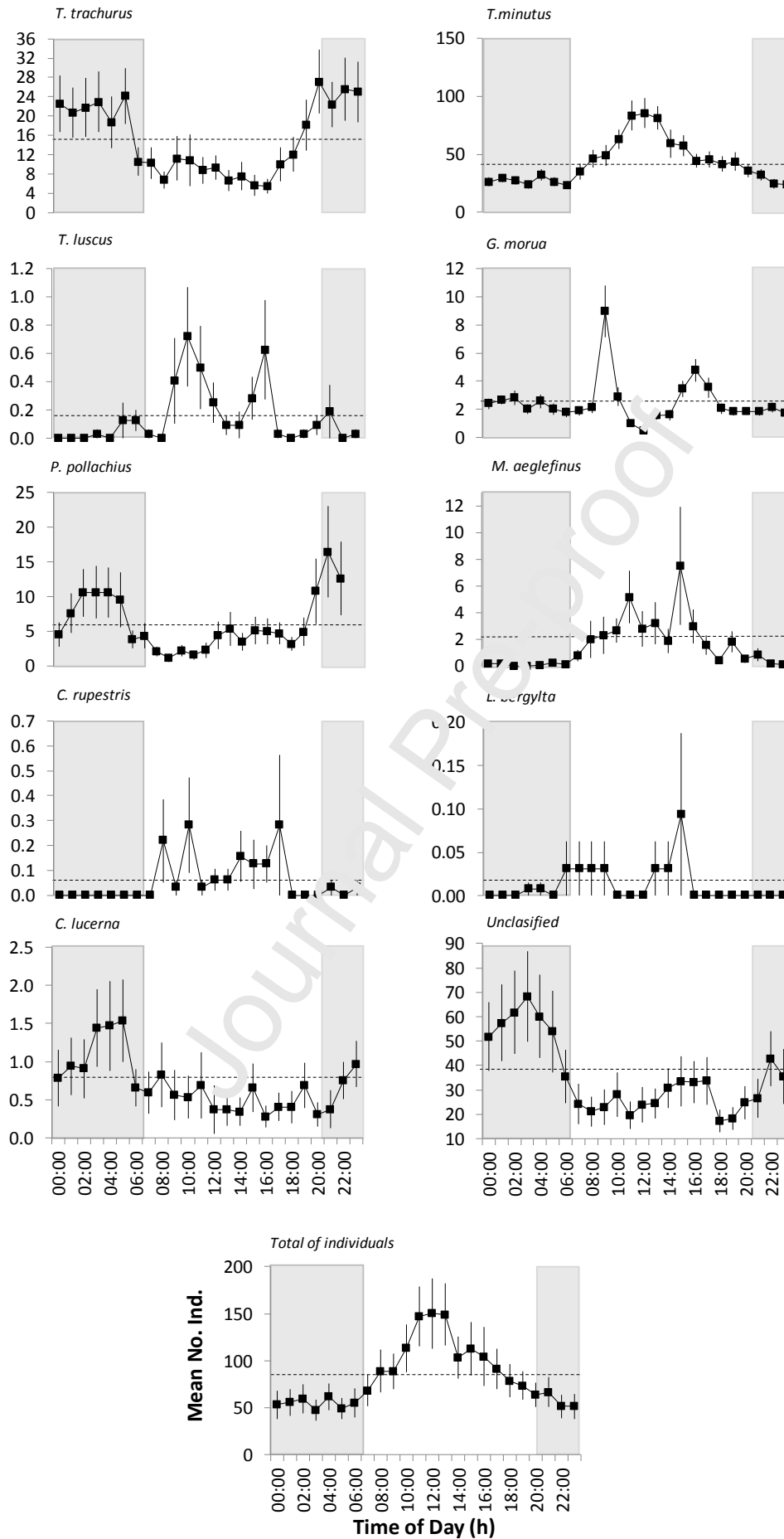


Fig. 3A

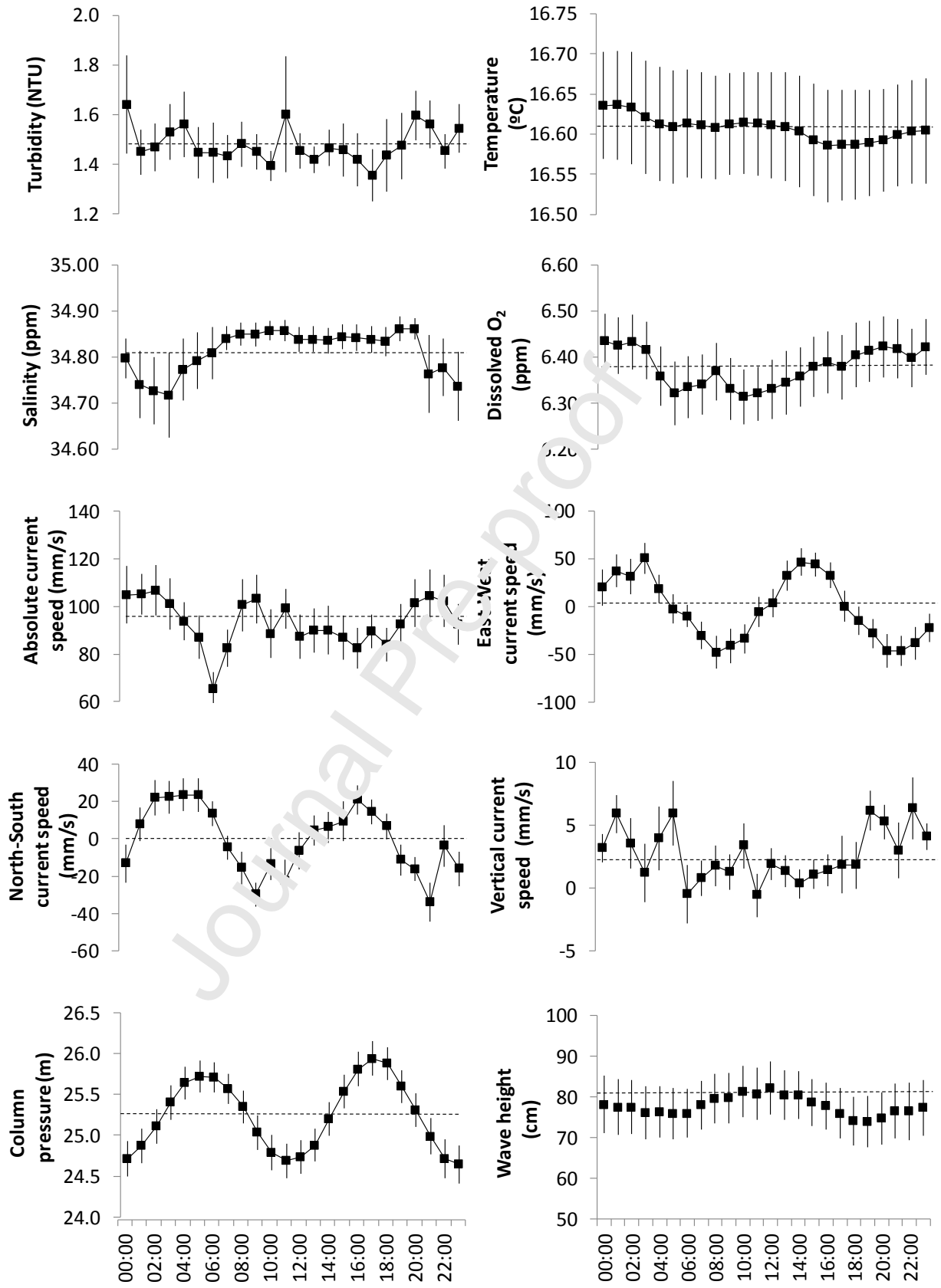


Fig. 3B

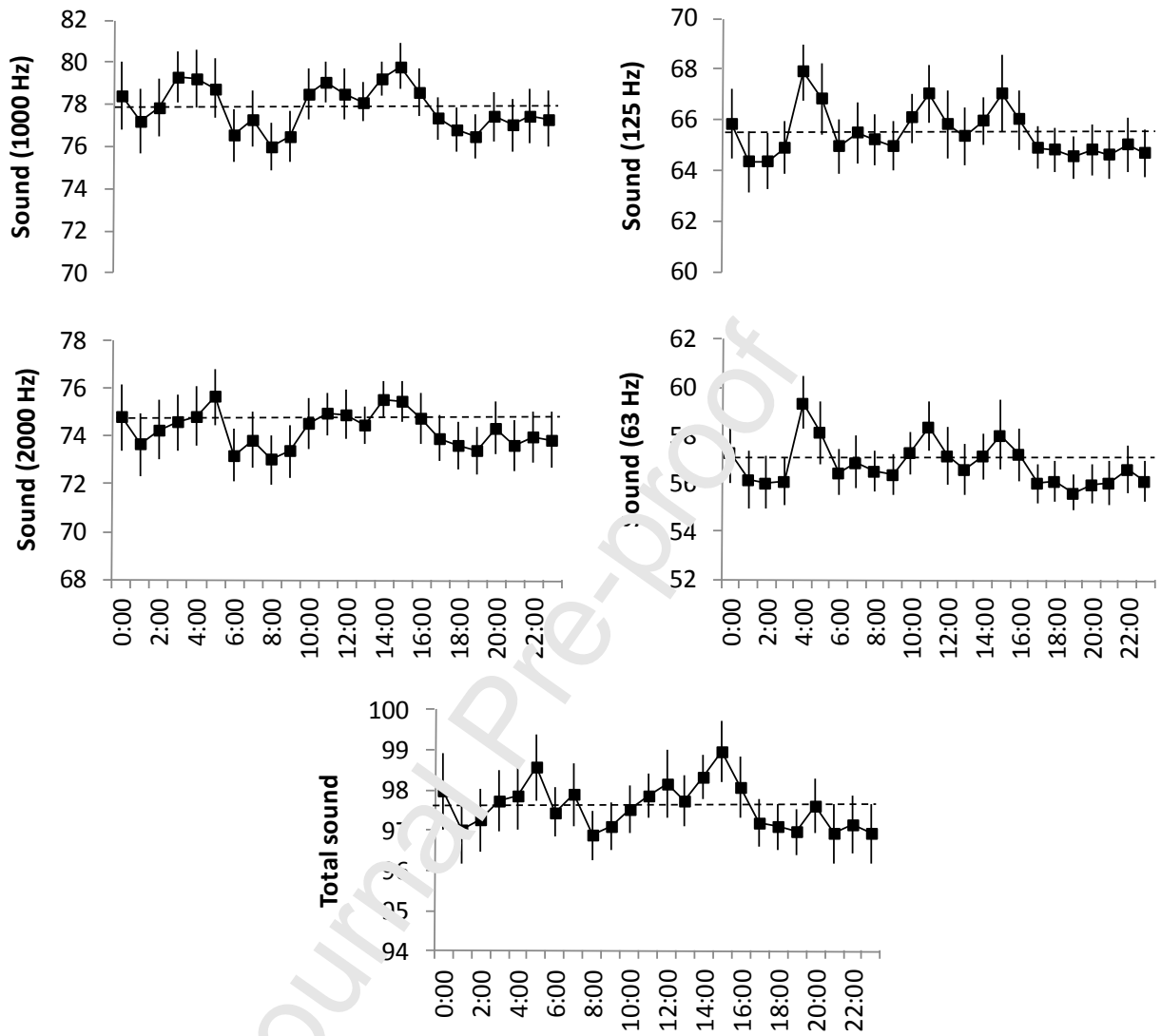


Fig. 3C

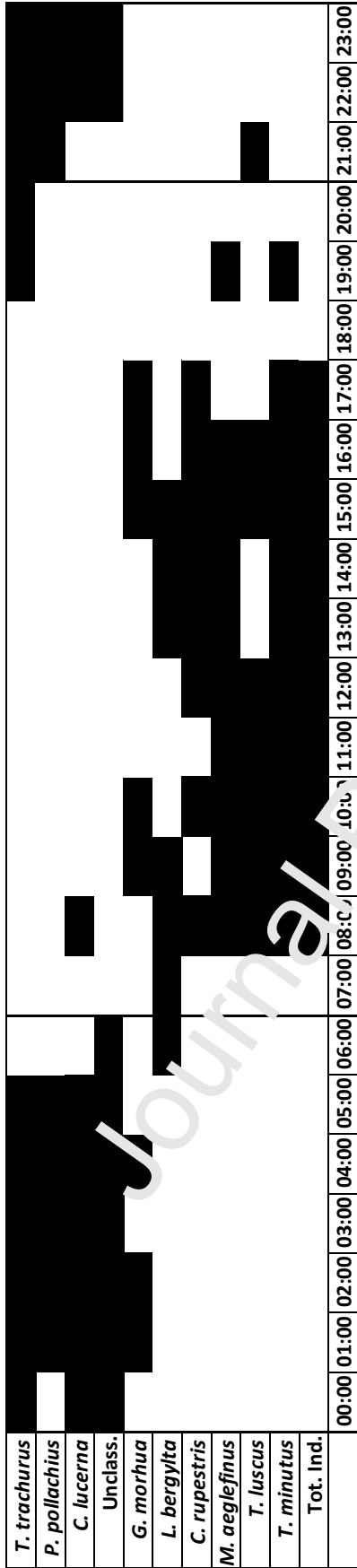


Fig. 4

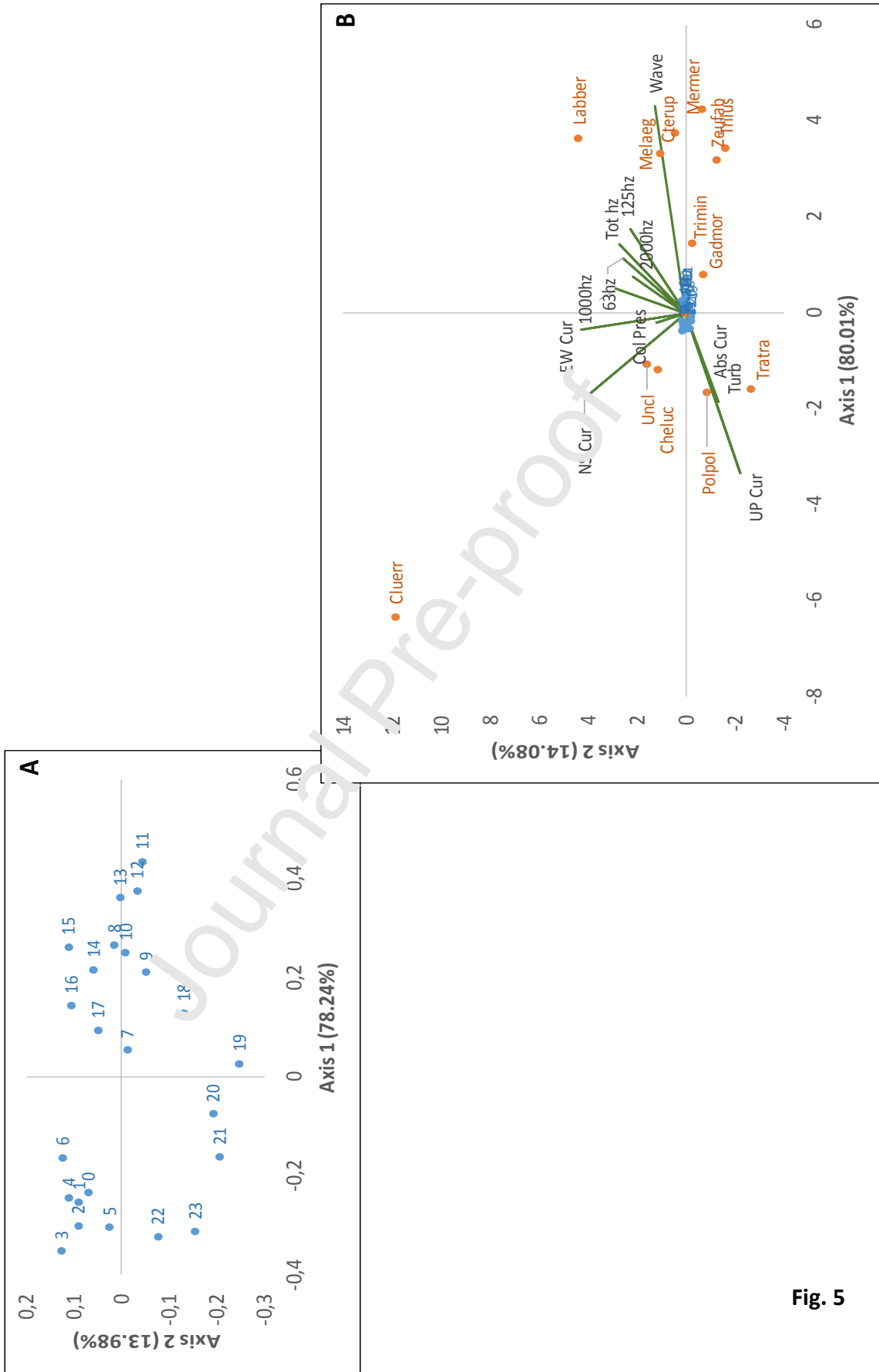
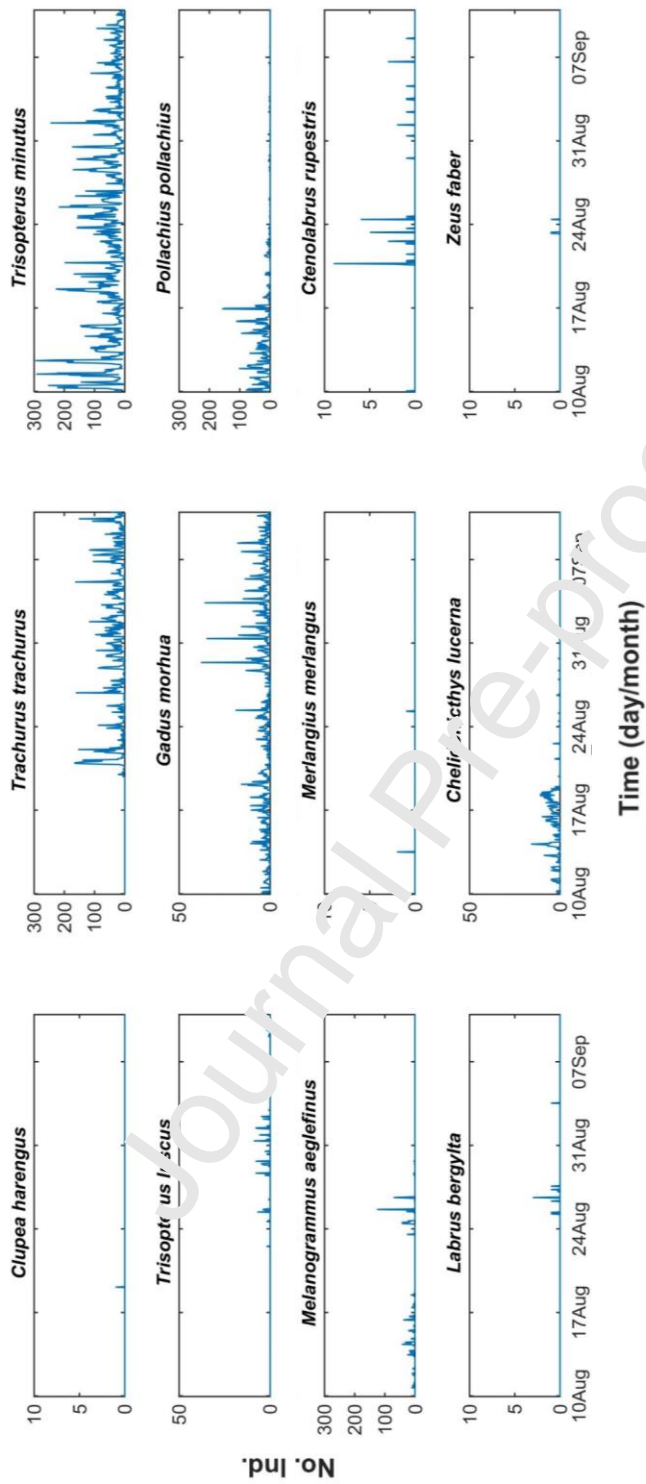
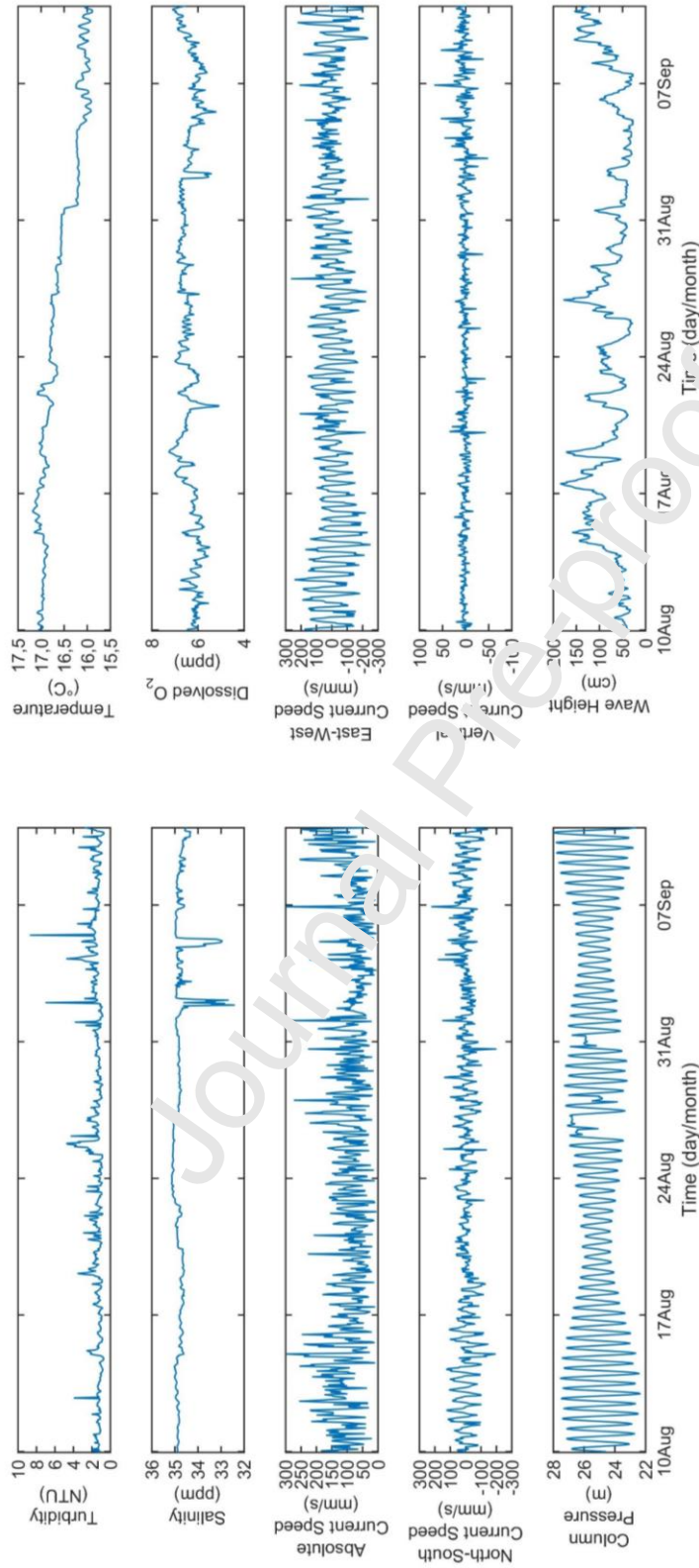


Fig. 5

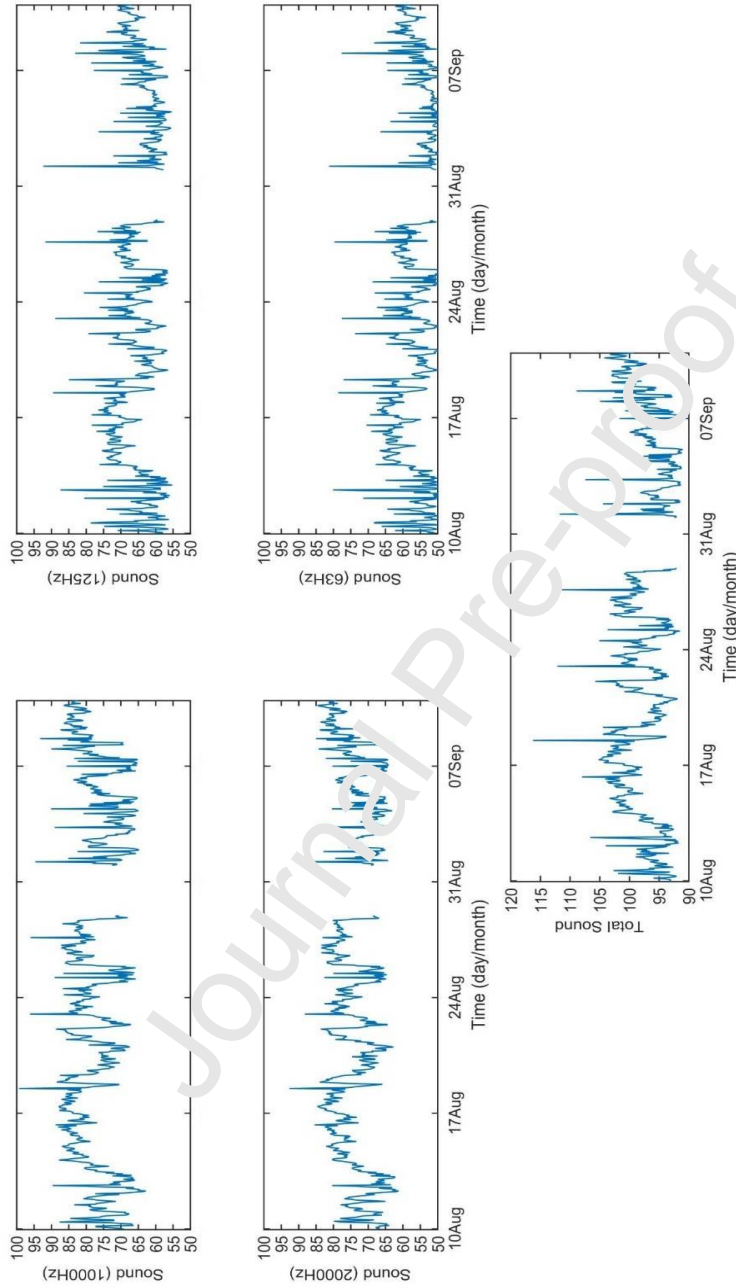
Appendix 1.A 30 days' time-series of visual counts for the different fish species identified during the monitoring period (following the same taxonomical order as in **Figure 2**).



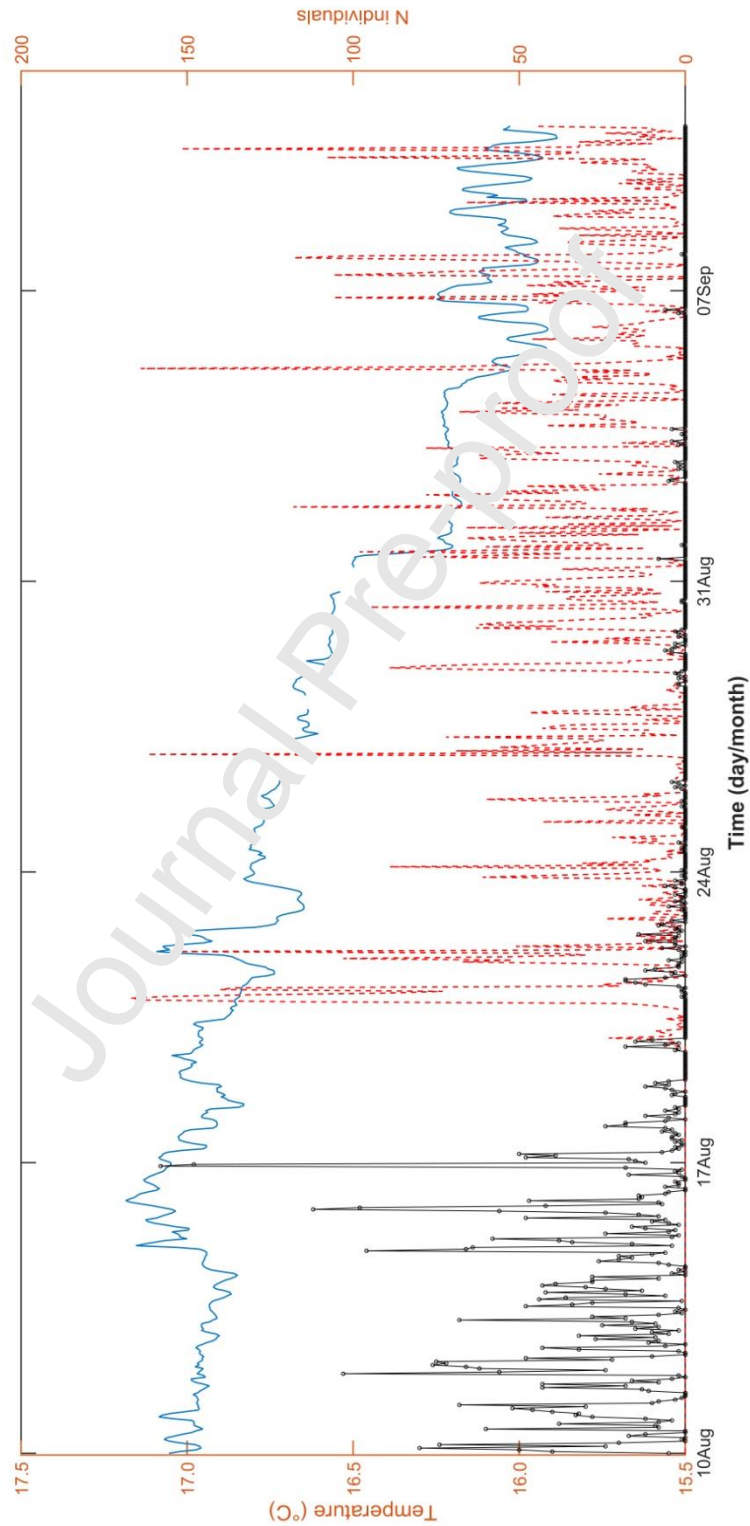
Appendix 1.B: 30-days' time series of environmental data, as collected during the monitoring period (from August 10th to September 10th, 2018).



Appendix 1.C: 30 days' time series of acoustic data, as collected during the monitoring period (from August 10th to September 10th, 2018)



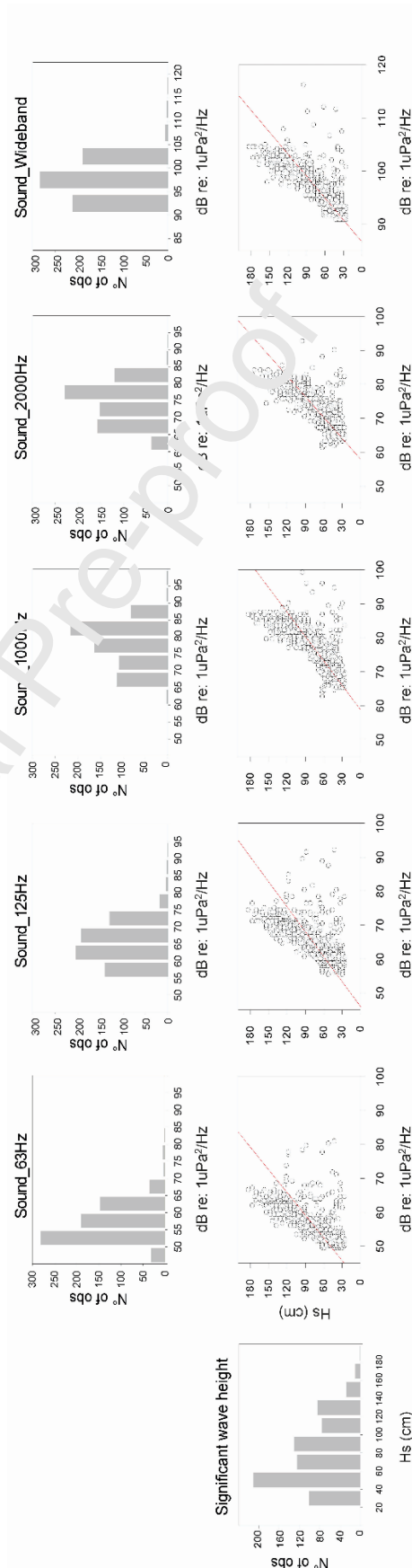
Appendix 2. Time-series of visual counts for *P. pollachius* and *T. trachurus* (one should notice different counts levels) in relation to the trend of decrease in temperature (blue line) as an indication of seasonal species succession in the area. *P. pollachius* is represented by the black line with circle markers, while the red dashed line stands for *T. trachurus* time-series.



Appendix 3A. Spearman's Rank Order Correlations correlation matrix (n = 679; $p < .001$)
(Statistica v8.0).

	Hs (cm)
Sound_63Hz (dB re: 1uPa ² /Hz)	0.762
Sound_125Hz (dB re: 1uPa ² /Hz)	0.745
Sound_1000Hz (dB re: 1uPa ² /Hz)	0.797
Sound_2000Hz (dB re: 1uPa ² /Hz)	0.809
Sound Total band (dB re: 1uPa ² /Hz)	0.816

Appendix 3B. Scatterplots showing the dependency of sound variables from weather conditions (i.e. significant wave height, H_s). For each variable, a frequency distribution histogram is plotted alongside the scatterplots (bins: 5 dB for the sound variables and 20 cm for the H_s , significant wave height).



Highlights

Cabled video-observatories allow new opportunities for fish communities monitoring

SmartBay coastal platform (Galway, Ireland) was used to survey fish activity rhythms

1-h time-lapse image and oceanographic data acquisition occurred over 30 days

Most of fishes showed day-night but not tidal activity patterns

A time-based ecological niche-partitioning was found in nocturnal and diurnal species

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