Vessel Monitoring Systems as a tool for mapping fishing effort for a small inshore fishery operating within a Marine Protected Area

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Abstract

Robust, quantified evidence of spatial and temporal patterns of inshore fishing activity is required to assist management in the face of a growing number of Marine Protected Area (MPA) designations. Vessel Monitoring System (VMS) technology has provided such data for the offshore fleet but has yet to be studied in relation to the inshore fleet. This study tested the effectiveness of VMS on quantifying fishing activity for a near inshore fishery, comprised solely of <12m vessels, operating within the Poole Harbour MPA (Dorset, UK). VMS data were collected from up to three vessels between 2012-2013 and 2014-2015. Analysis using GIS allowed spatial and temporal comparisons of fishing effort down to 250m^2 and enabled activity to be overlaid with MPA features. A 10-minute reporting interval was determined suitable for quantifying fishing effort at the operational scale of this <12m fleet. Results showed a decline in overall fishing effort in 2014 and mixed seasonal usage of four defined areas of the Harbour. Fishing effort intensity was lowest during November to February, coinciding with the period of greatest sensitivity for designated features of the MPA and no active fishing was detected within defined sensitive areas for these features. It is concluded that VMS data can be used successfully on the <12m inshore sector, over small spatial scales, to quantify patterns of activity and detect overlap with MPA features. VMS should be used to create high confidence datasets for the inshore sector that assist in the development of evidence-based, rather than precautionary, management.

Keywords

Vessel monitoring system, fishing effort, inshore fisheries, marine protected areas, fisheries management, UK fisheries

1. Introduction

The evolution of fisheries management within the UK has resulted in a move away from sustaining species' stocks purely as a food resource towards management based on an understanding of the interaction between fisheries and the wider marine environment [1]. One of the largest drivers of this change has been the development of the Marine Protected Area (MPA) network; fisheries regulators face increasing pressure to ensure that fishing activity is compatible with the conservation designations of a protected site [2].

For fisheries management to promote sustainable fishing and reconcile interactions between gear types and conservation features, a better understanding is needed of the spatial and temporal distribution of fishing activity [3,4], particularly in relation to MPA boundaries [5,6,7]. This is especially true for inshore fisheries (within the 12 nautical mile boundary), where commercial fishers are subject to additional regulations in the face of an increasing number of MPA designations [8]. As of June 2019, 37% of UK inshore waters were covered by 309 MPAs equating to 60,111km^2 [9]. One hundred and twenty-two of these are within the near inshore area (out to 6nm) covering an area of 16,062km^2 in England [10]. The near inshore sector is particularly at risk of being subject to regulation based on precautionary management [11]. The EU Habitats Directive [12] establishes the legal framework for the protection of natural habitats and wild fauna and flora, and sets out duties for Member States and their corresponding competent authorities to ascertain that activities (referred to as plans or projects) must not adversely affect the MPA concerned [13]. In 2012, the Department for Environment, Food & Rural Affairs in Britain introduced the Revised Approach to fisheries management within MPAs classed as European Marine Sites (EMSs). This clarified that fishing should be subject to the same assessment as other activities and put the onus on fisheries managers to determine 'no adverse effect' on MPA site integrity by fishing activity [11]. The Precautionary Principle derives from scientific uncertainty about environmental degradation arising from human activities such as fishing [14] and is used within management of MPAs where there is an absence of data to support the legal requirement of 'no adverse effect' by a particular activity. For inshore fisheries management, the absence of data is most often centred around detailed and appropriate evidence of the overlap and therefore potential interaction between fishing activities and designated features. If such evidence can be made available, near inshore fisheries, where the footprint of a fishing activity such as dragging or dredging can occur over an area smaller than 250m^2, could be better integrated into the management of MPAs [15].

The collection of spatial data from the near inshore sector, focusing on the <12m fleet, has historically relied on opportunistic observational data collected by regulatory organisations as part of patrols. Such data can determine only generalised locations of fishing activity, resulting in a lack of standardisation and an inability to define the activity in space and time [16]. Further data sources such as logbooks and regulation specific requirements to produce catch data are also limited for the inshore sector. The <10m fleet are not required to keep a logbook [17] and catch reporting is subject to human error or deliberate false reporting [16].

Vessel Monitoring Systems (VMS) enable the position of fishing vessels to be monitored in near real time to accurately define spatial and temporal patterns of activity [18]. The European Commission first legislated for the use of VMS in 1998 for the purposes of enforcement and to contribute to a control system to ensure compliance with the Common Fisheries Policy (Council Regulation (EC) 1224/2009) [17]. By 2012 the legislation encompassed all vessels >12m in length, requiring them to have a VMS device installed that transmits data at regular intervals e.g. 2 hourly reporting

Since the introduction of VMS, many studies have looked at VMS data as a tool to estimate fishing effort and distribution [3,18,19,20,21,22,23], potential impacts from fishing activity on habitats and species [24,25,26,27] and the impacts of regulatory and MPA boundaries [28,29,30]. The ability of this technology to define fishing activity in space and time has been well demonstrated for the offshore fleet. However, the legislative underpinning for VMS that mandates the technology only for vessels >12m has resulted in little to no data being generated by the near inshore fleet which is comprised mainly of <12m vessels.

With the increasing likelihood of VMS being mandatory on all fishing vessels in the future (consultation conducted by UK government on implementation, Nov 2018), there is need to determine if and how this technology can be used in fisheries operating within confined areas such as harbours, estuaries and associated MPA boundaries. The rate at which positional data is currently collected for the >12m fleet is commonly every 2 hours. Activity is mapped at the scale of a square mile ($2.6km^2$ or $0.8NM^2$) or even at the level of ICES rectangles (approximately $900NM^2$). At the most local level, near inshore fisheries can operate over an area less than $250m^2$ ($0.00007NM^2$) with fishing trips lasting only a few hours. Methods of data collection therefore need to reflect the behaviour of the particular fleet in question [31] and be at an appropriate scale to capture changes in vessel 'behaviour' so that periods of active fishing can be determined [26,32]. In addition, with the extent of overlap between near inshore fisheries and MPAs, there is a need to determine if VMS data can be used to indicate potential interactions between designated features and fishing gear.

Figure 1: Poole Harbour, Dorset on the south coast of Great Britain.

This study tested the effectiveness of VMS technology in quantifying spatial and temporal patterns of fishing effort within a small-scale, near inshore fishery operating inside an MPA. Poole Harbour in Dorset on the south coast of Great Britain (Figure 1) is designated as a Special Protection Area (SPA), Ramsar site and Site of Special Scientific Interest (SSSI). The SPA designation (under the Wild Birds Directive 2009/147/EC) [33] includes features of internationally and nationally important overwintering bird species and waterbird assemblages. For this site, Natural England, as one of the UK Government's nature conservation advisors, advised that there is a higher risk of impacts to the designated species in defined areas used by birds for feeding, roosting and breeding during the period November to March. The Harbour supports several fisheries, which involve vessels <12m that operate solely within the 3,600ha Harbour. One example is the bait dragging fishery that harvests ragworm (predominantly *Alitta virens* (M. Sars, 1835)). The maximum duration for a single fishing trip is within an approximate four-hour tidal window (resulting from the double high-water tidal regime in the Harbour). Fishers use specially constructed drags, a maximum of two per vessel, which are deployed and recovered every one to two minutes to target ragworm species which are sold as angling bait. For any fishery operating in an MPA managers must demonstrate 'no adverse effect' on designated features. In the absence of evidence to support the conclusion of 'no adverse effect', management will need to be more precautionary in order for management authorities to comply with their legal obligations for protection of the marine environment. When considering evidence for fisheries operating within an MPA, it is often quantified spatial and temporal data on fishing effort and the proximity of that activity to MPA features which is lacking The scale of the bait dragging fishery makes it ideal for trialling VMS for the near inshore sector to determine i) if and how this type of technology works on small vessels with rudimentary electronics, ii) to test the effectiveness of VMS for mapping fishing effort over a small spatial area within a short time period and iii) to test whether VMS can be used at this scale for quantifying interactions between a fishery and MPA features. This study focuses on the interaction between the fishery and the bird features of the Poole Harbour SPA. These features are the primary driver for the majority of fisheries management in this site. However, the principle being tested could be applied to quantifying interactions between fishing activity and any feature or supporting habitat for which an MPA is designated, for example the intertidal sediment habitats designated for Poole Harbour under both the SPA and SSSI designation as supporting habitat for the bird features.

2. Materials and Methods

VMS data for this study were collected using the Succorfish SC2 Vessel Monitoring System. The SC2 unit is a VMS unit, incorporating dual iridium satellite and GPS/GPRS/GSM mobile technology that allows the location of a mobile asset, such as a fishing vessel, to within two meters.

Data were collected between September 2012 and May 2013 and then again between July 2014 and October 2015 from between one and three vessels engaged solely in the bait dragging fishery. The data collected by the SC2 unit were remotely uploaded, at the time the vessel was active, to the Succorfish graphical user interface (GUI). These data were then stored in the GUI and periodically extracted for analysis.

2.1 Determining the rate of recording for positional data

The rate at which a position is recorded by the SC2 unit can be altered depending on the requirements of the end user. The standard rate for recording a position was set at 10-minute intervals for the periods September 2012 to April 2013 and July 2014 to October 2015. A 10-minute reporting rate had been used previously in the Isle of Man scallop fishery [26]. Although not used continuously within the fishery (the common reporting rate was 2 hours), the availability of a higher frequency of positional data improved the ability to define fishing activity location and potential impact on seabed habitats [26]. The study concluded that long term targets for the use of VMS data should be to use a polling frequency at a rate appropriate for the behaviour and fishing grounds of a specific fleet [26]. The 10-minute reporting interval used in this study was based on knowledge of the duration of a single fishing trip in the bait dragging fishery (four hours), the spatial extent of the fishing grounds (down to $250m^2$) and on-board observations of the duration of a single drag (1-2 minutes). During May 2013 the rate for recording a position was increased from 10-minute to 1-minute intervals to determine if finer scale spatial data would be more useful in determining fishing locations for the bait dragging fishery and so proximity to features of the protected site.

2.2 Cleaning the dataset

The SC2 units used in this study reported positional data whenever the unit was powered. It was necessary to 'clean' the dataset to remove points not associated with active fishing. The full dataset for each vessel was downloaded from the Succorfish GUI. For the period of 2014 to 2015 where data was obtained from multiple vessels, the data from all vessels was combined. All the vessels fitted with VMS are known to solely engage in the bait dragging fishery and operate exclusively within Poole Harbour.

The dataset was initially 'cleaned' based on speed criteria, removing any position where the speed of the vessel exceeded 2.5 knots. Onboard observations of vessel speed for bait dragging vessels in Poole Harbour revealed a mean speed of 1.9 knots when the vessel was actively engaged in fishing and at no time did the speed exceed 2.4 knots. Speed is a common filter applied to VMS data to remove positions corresponding to steaming or inactivity rather than active fishing [3,26,27,29,34,35,36]. Using this method there is the potential for false-positive results where a position is incorrectly assigned to active fishing when the vessel is steaming within the set speed range. The risk of false-positive results was mitigated in this study by visualising the data (MapInfo 7.8) during the process of cleaning and identifying areas such as main channels where fishing activity is known not to take place. These points were removed as part of the cleaning process even if speeds were consistent with the range assigned to active fishing. There was no minimum speed set for active fishing so, to ensure that low speeds associated with the vessel manoeuvring within a marina or in proximity to its berth were excluded, the same visual cleaning technique was used. Confidence in this procedure was underlined by observation and personal communication with the fishers. There is the potential for a false-negative result, where active fishing positions are missed. However, false-negative results are rare [37] and it is more likely that the 'cleaned' dataset represented an overestimate of fishing activity rather than an underestimate. In the context of informing management (which requires a certain element of precaution) this does not present an issue provided that the level of overestimation does not result in fishers being unduly restricted. Communication with local fishers and observations of activity, as was carried out during this study, will provide an initial indication of whether the data is indicative of common fishing patterns

2.3 Identifying patterns of activity

The cleaned dataset was plotted using QGIS 3.4. The positional data were overlaid onto a 250m^2 grid, reflecting the spatial scale at which the footprint of fishing activity by the inshore fishing sector operates, and each grid cell was assigned a numeric count value based on the number of data points contained within it. Each position point was defined to 6 decimal places and represented an area of 78mm longitude by 111mm latitude. The count value for each cell was then changed to a time period value with each data point representing a 10-minute period, corresponding to the 'ping' rate for the SC2 unit. The grid data was then visualised and graduated, using equal interval breaks of 15 minutes, to show time spent fishing per grid cell in minutes. For May 2013 the same process was used with each data point given a value of 1-minute corresponding to the increased reporting rate. There were a large number of grid cells where no activity took place and therefore the value of these cells was 0. Due to the prevalence of 0 count data, an arcsinh transformation was applied. Statistical analysis was carried out using the Kruskal-Wallis test with subsequent Dunn's test to compare the mean intensity of fishing effort between four defined fishing areas (see Results section 3.1) for each month of the study period and between months for each of the four areas. For this analysis intensity of fishing effort refers to minutes of active fishing.

2.4 Identifying overlap between fishing activity and MPA features

The visualisation of the data was overlaid with areas defined as 'sensitive' for the features of the Poole Harbour SPA designation. These included three areas of seagrass in the eastern end of the Harbour and nine areas defined as bird sensitive areas where fisheries managers are required to ensure that fishing activity does not cause a disturbance between November and March when bird species designated under the SPA are most at risk.

2.5 Identification of potential issues with data collection

The fitting of SC2 units to <12m vessels during this study highlighted some potential issues. Initially units were connected to the vessel's on-board battery supply but the unit drained the battery, preventing use of a vessel on three occasions in December 2012, January 2013 and April 2013. During the data collection in 2014-2015 the method of powering the SC2 units was changed to a self-contained battery pack. This method avoided any issues with the use of the vessel, however the self-contained battery packs required charging after each fishing trip which put the onus on the skipper to remember to charge the unit. In the main this was not an issue but data for a limited number of fishing trips could not be obtained where the skipper forgot to charge the unit. It is not possible to estimate the percentage of data lost due to this issue as an absence of data on a given day may also have been due to the fisher not fishing and therefore not returning the unit to the vessel. To remove the need for human intervention, at the end of June 2015, the units were connected to a small solar panel (approximately 20x10cm). This method proved the most effective at obtaining consistent data, although there were a limited number of days where bad weather meant that the solar panel was not able to charge the battery between fishing trips. It is possible to estimate the percentage of data lost using this set up as by removing the need for human intervention, an absence of data can be directly related to the unit not having charged. Considering the average number of days fished per month and the duration of time for which the units were operating with the solar panels, it is estimated that 4% of trips, equating to three fishing days, was lost due to lack of charge on the unit. This ability to estimate the percentage of data loss is an additional improvement resulting from the removal of human intervention in the operation of the unit. The issues encountered during this study would need to be resolved before this type of VMS unit can be reliably used for enforcement purposes and monitoring compliance within the <12m fishing fleet. However, building a dataset over an extended period of time (months to years) would help to reduce uncertainty in these data where they are being used to indicate discrete fishing areas and patterns of activity as well as proximity to or potential interaction with features of an MPA for the purposes of informing fisheries management.

3. Results

A visual output of the positional data from the VMS unit for the bait dragging fishery (Figure 2) allowed the identification of distinct activities including the vessel being on its berth, the vessel steaming and the vessel being engaged in active fishing. On average 37.9% of the data points were removed during the cleaning process. This was as a result of both cleaning via a speed filter and a visual assessment to remove data points consistent with the filtered speed range which occurred within main channels where fishing is known not to take place and within the confines of a marina. The percentage of data removed by the cleaning process varied depending on the power source for the VMS unit. When the solar panels were added, data recording occurred near continuously and therefore there was a larger percentage of data points removed due to presence of the vessel within the confines of a marina for example. The initial data output indicated that a frequency of 10-minute position reporting is appropriate for determining vessel behaviour at this scale of fishing activity.

Data collected during May 2013 on a 1-minute reporting interval was compared to data collected on a 10-minute reporting interval by comparing the linear distance covered by the fishing vessel between recorded positions. The distance was calculated between thirty consecutive positional data points for each reporting interval and compared using a Mann-Whitney U Test. The distance covered by the fishing vessel for a 10-minute reporting interval (average distance 54.0m ± SD 59.0m) was statistically greater than for a 1-minute reporting interval (average distance 13.2m ± SD 20.6m) ($P<0.001$). Reporting on a 1-minute interval therefore improved the spatial resolution of fishing activity. However, for the purposes of this study, to identify spatial and temporal patterns of fishing effort over a small scale (250m^2) and to provide quantified effort data in relation to the features of a protected site, a 10-minute interval provided data at an appropriate spatial resolution.

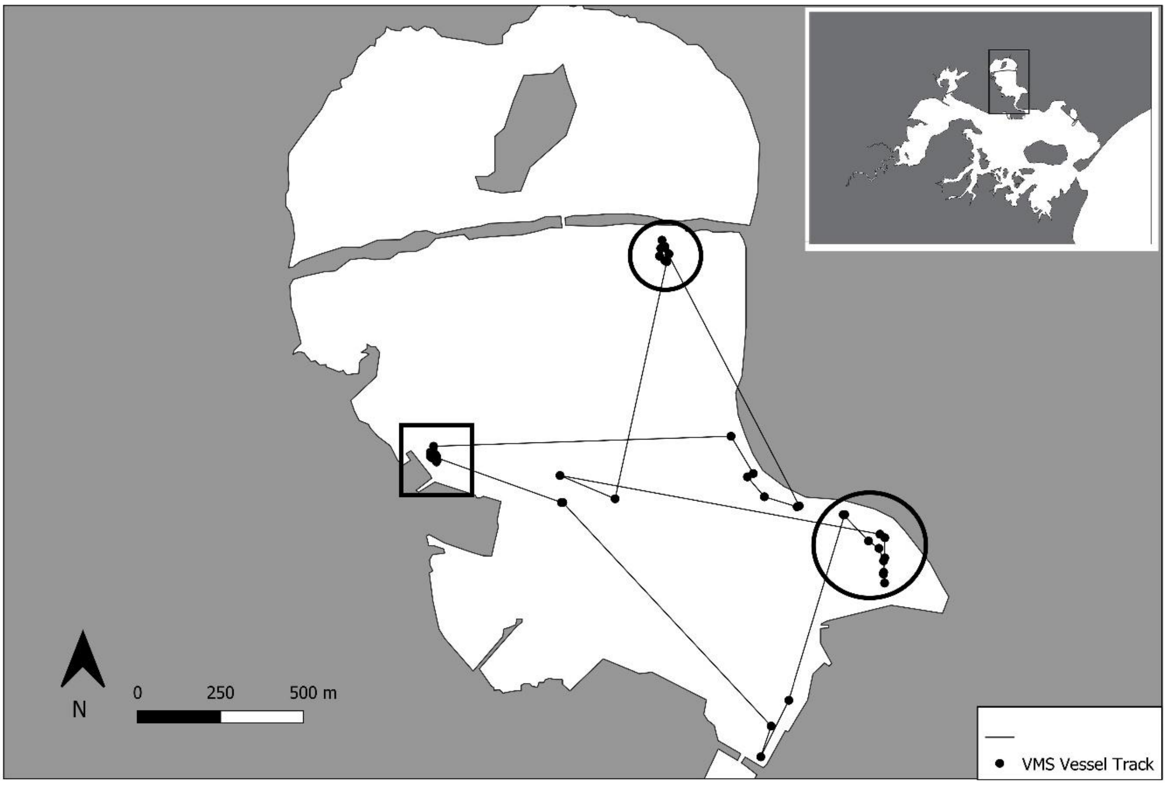

Figure 2: Visual output of uncleaned positional data from one of the VMS units in Holes Bay, Poole Harbour. Individual positions showing the vessel track are recorded as data points at 10-minute intervals. The black square represents the vessel on its berth and the black circles represent periods of active fishing. Extended distance between data points indicates increased speed associated with the vessel steaming.

3.1 Comparing spatial and temporal usage of Poole Harbour

VMS tracks for the 2012-13 (September 2012 to May 2013) and 2014-15 (July 2014 to October 2015) sampling periods showed distinct areas where fishing activity occurred (Figure 3). Based on a visual assessment of the data points, combined with local knowledge of defined fishing areas, the area over which active fishing was recorded was divided into four defined areas; Area 1 – Holes Bay, Area 2 – Brands Bay, Area 3 – Furzey Island and Area 4 – Round Island/Long Island/Arne Bay (Figure 3).

The data showed that the greatest differences in the time spent fishing (minutes) within a single area were between Area 1 (Holes Bay) and Area 4 (Round Island, Long Island and Arne Bay). During the 2012 to 2013 sampling period Area 1 was used significantly more for active fishing by the bait dragging fishery in October 2012 than any other area of the Harbour ($P<0.001$) (Figure 4) and Area 4 showed a significantly greater amount of time spent fishing (minutes) in March 2013 (Figure 5) compared to September 2012 ($P<0.001$). Levels of activity within other areas were not significantly different from one another.

A similar pattern was seen for the 2014-15 sampling period with Area 1 showing a significantly greater amount of time spent fishing (minutes) in the period July 2015 to October 2015 (Figure 6a) than the period of November 2014 to December 2014 (Figure 6b) ($P<0.05$) with activity predominantly seen to occur during October 2015. Area 4 also showed a higher usage by the fishery in the period July 2015 to October 2015 ($P<0.05$) with increased effort seen in the months of July 2015 and August 2015.

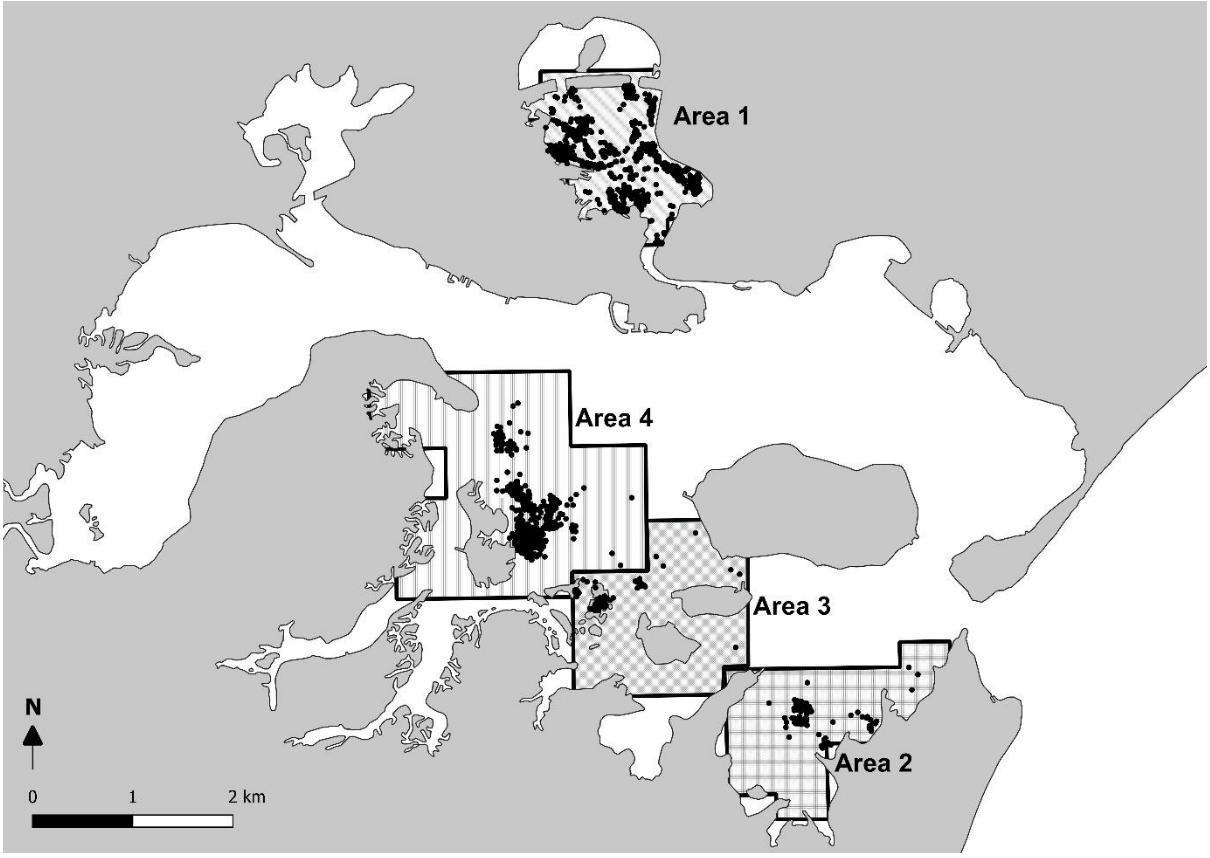

Figure 3: Fishing areas 1 to 4, defined based on a visual assessment of active fishing data points from the VMS units (black points) for the period 2012-13 and 2014-15 combined with local knowledge of distinct fishing areas.

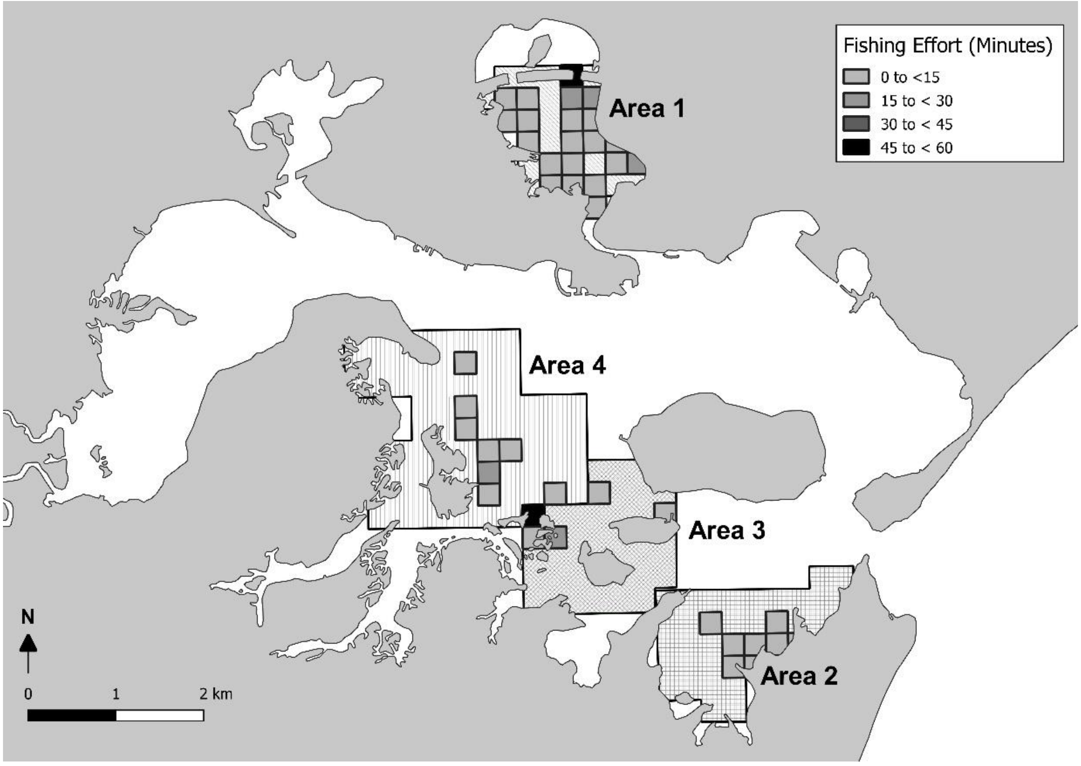

Figure 4: VMS data for October 2012 with data points assigned to a 250m^2 grid and overlaid with fishing areas 1 to 4. Time spent fishing per grid cell is graduated using equal interval breaks of 15 minutes.

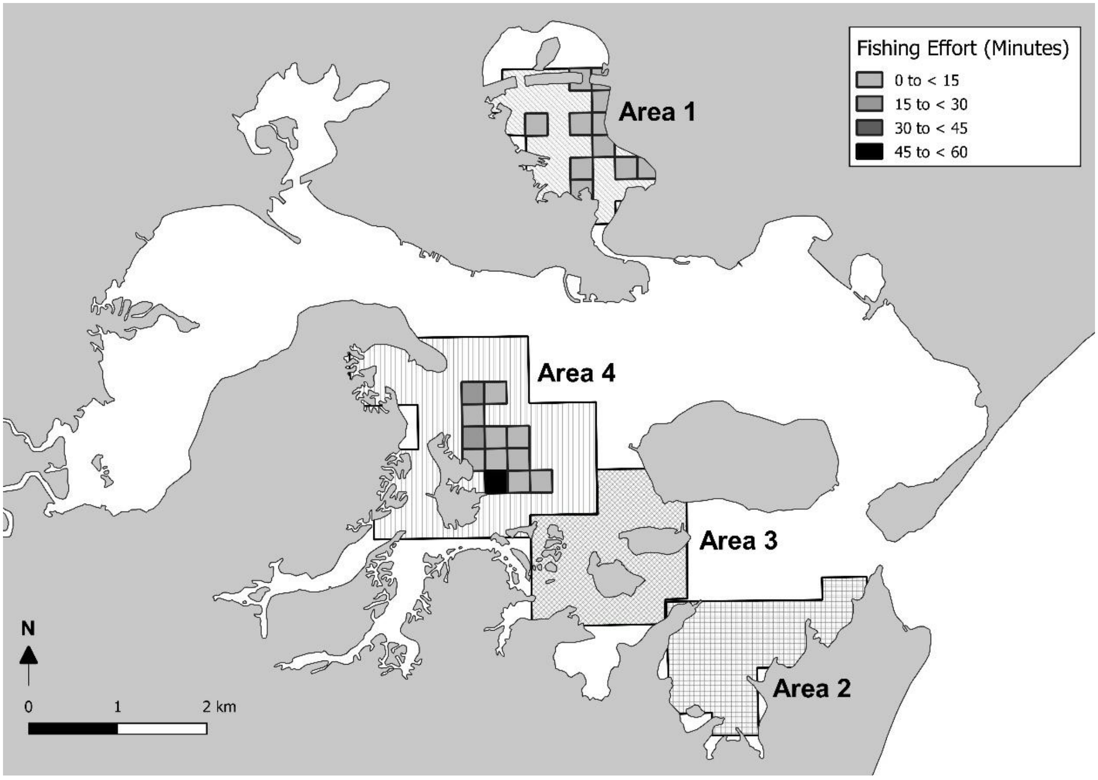

Figure 5: VMS data for March 2013 with data points assigned to a 250m^2 grid and overlaid with fishing areas 1 to 4. Time spent fishing per grid cell is graduated using equal interval breaks of 15 minutes.

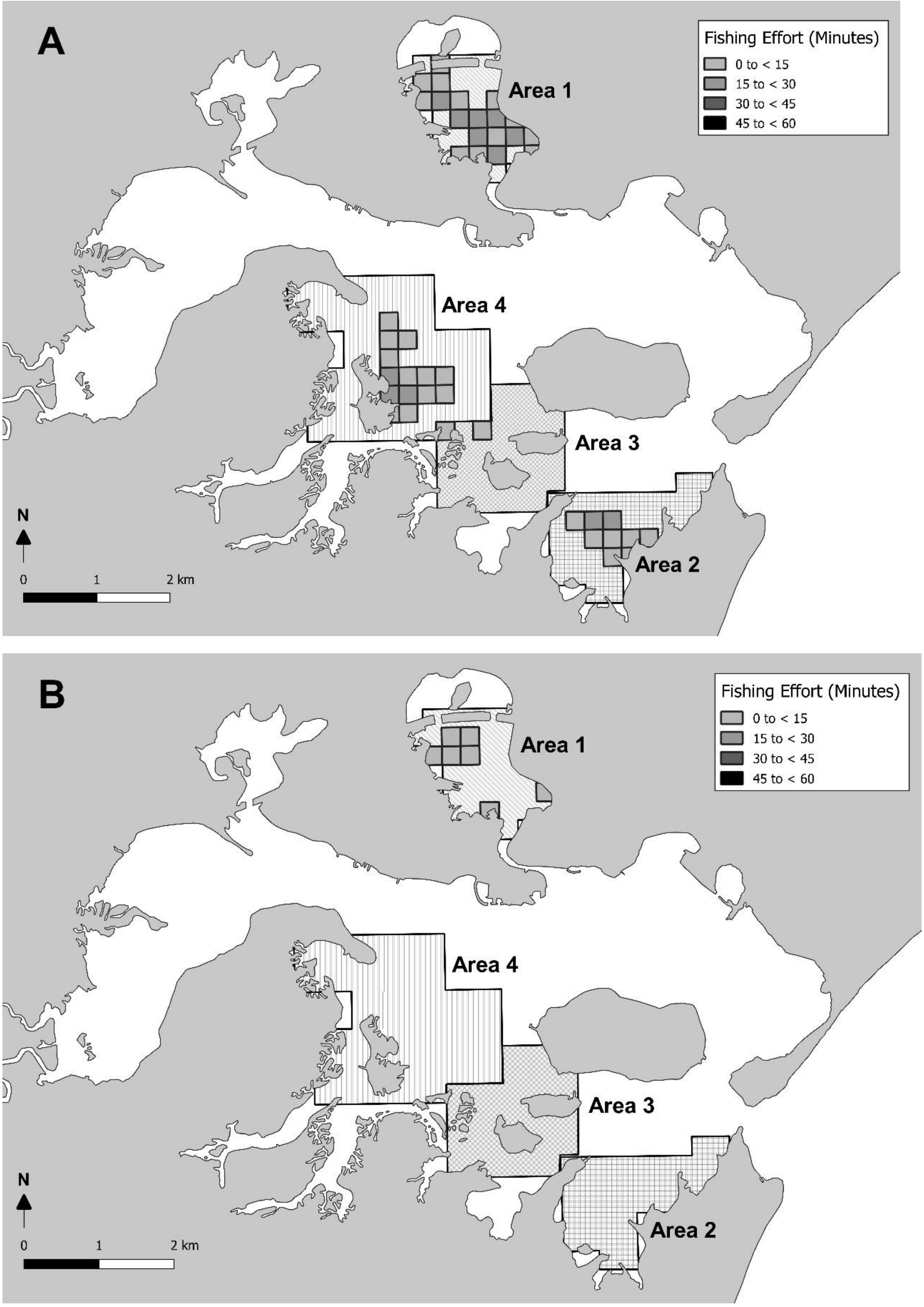

Figure 6: VMS data for A) July 2015 to October 2015 and B) November 2014 to December 2014 with data points assigned to a 250m^2 grid and overlaid with fishing areas 1 to 4. Time spent fishing per grid cell is graduated using equal interval breaks of 15 minutes.

3.2 Defining overall patterns of fishing effort

There was a significantly higher effort in 2015 than 2014 in Area 1 (July to October) ($P<0.05$), Area 2 ($P<0.05$) and Area 4 ($P<0.05$). During 2014 only Area 1 was fished.

3.3 Interaction of fishery activity with the conservation features of the Poole Harbour MPA

The intensity of fishing effort (time in minutes spent fishing per area) was lower within the period of November to February (corresponding to the period of greatest sensitivity to overwintering bird features of the SPA). The greatest number of minutes spent fishing within a single area for 2012, 2014 and 2015 occurred within the period July to October (Figure 7). For 2015, three out of the four fishing areas, areas 1, 2 and 4, all showed significantly higher levels of activity between July and October than all other periods ($P<0.05$ for all).

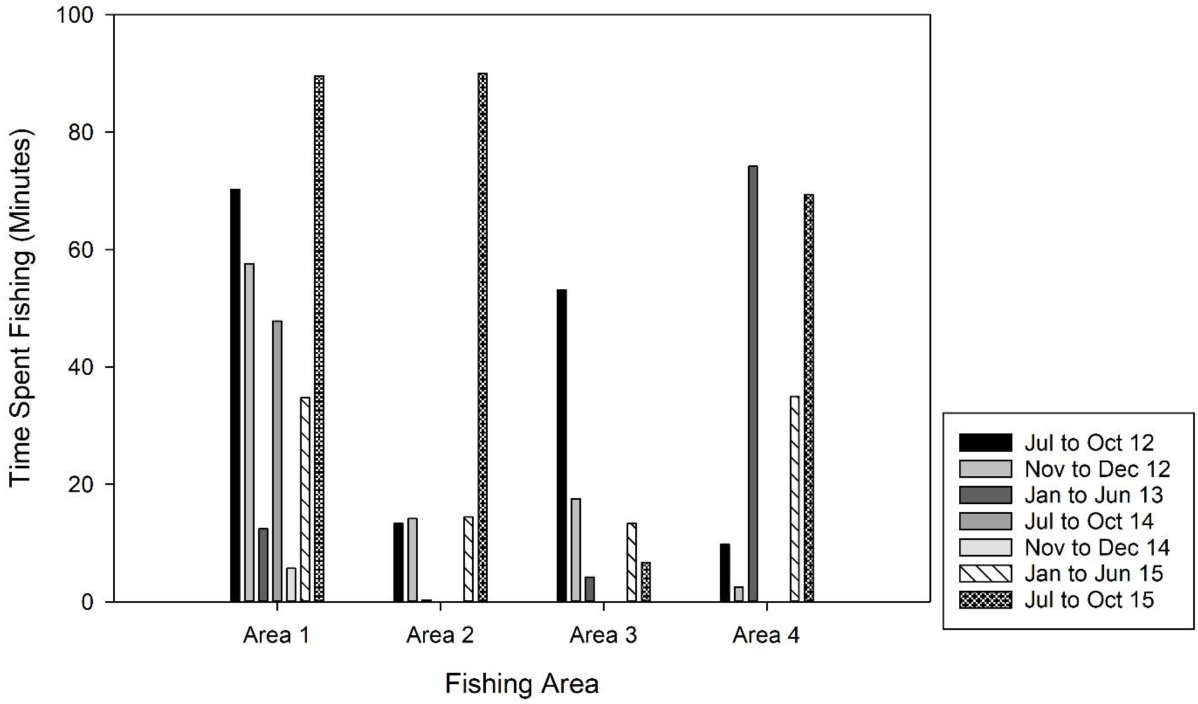

Figure 7: Average time spent fishing (minutes) in fishing areas 1 to 4 for defined seasonal time periods between 2012 and 2015.

Overlaying the visualised VMS data onto a chart detailing the higher risk areas for the SPA showed that active fishing did not occur within the areas defined as sensitive for feeding, roosting and breeding by birds at any point during the study period (Figure 8). There was also no overlap between the vessel's fishing activity and the protected supporting habitat of intertidal seagrass beds.

Figure 8: VMS positional data for active fishing (black points) overlaid with sensitive areas for the Poole Harbour SPA (hashed) and the supporting habitat of intertidal seagrass (dark grey).

4. Discussion

VMS was primarily introduced to aid monitoring and regulatory compliance in fisheries [38]. It has become evident, and is now recognised, that VMS is also an important tool for the collection of scientific data to inform fisheries management [18]. VMS data allows the identification and quantification of interactions between fishing activity and environmental features [24,25,26], and has been used globally in this way for the purposes of improving systematic conservation planning [39], increasing confidence in other methods of fishing activity reporting i.e. logbooks [40] and assessing impacts on the fishing industry from increases in spatial closures for the purposes of conservation [41]. However, these previous studies have utilised data from those vessels required by law to have VMS on-board, which is commonly vessels >15m, and have analysed fishing fleets which operate over large spatial scales, for example reporting at the scale of 1 ha with 1-hour reporting [39]. Interactions between the trawl fishery and spatial closures within the Great Barrier Reef World Heritage Area have made progress towards mapping activity at smaller spatial scales, with a resolution of 3.16km^2, however the corresponding assessment of temporal patterns of activity was carried out over a relatively large scale, limited to a definition of <5 hours [41]. There has been progress towards mapping activity at higher frequency resolutions, as demonstrated by a study of the Isle of Man scallop fishery [26]. In this study, higher frequency VMS data, reporting at 10-20 min intervals on certain occasions within a standard 2-hour reporting interval, was used to compare accuracy of interpolated positions, based on the standard 2-hour reporting, with known positions [26]. The study indicated that increasing the frequency of recording position can provide improved information for calculating fishing pressure indicators and it was concluded that a reduction in standardised reporting time from 2-hour to 30-min intervals would provide notable benefits [26]. Even with improvements in the analysis of fishing effort at temporal scales similar to those used in this study, the smallest spatial scale used was 1km^2 [26], albeit recognising that finer spatial scales would be required to fully document impacts on seabed habitats [26]. Although there are demonstrable examples of increasing levels of detail and refinement of spatial and temporal scales in analysis of VMS data in these studies, there is still no indication of how this technology may be used for a fishery operating exclusively at the scale of the UK inshore fleet (<12m) and within a defined area such as an estuary or harbour. This study is the first time that VMS dual iridium satellite and GPS/GPRS/GSM mobile technology has been applied solely to a fishery comprised of vessels from the small-scale (<12m) inshore fishing sector, over both small spatial (250m^2) and temporal (10 minute) scales, for the purposes of (1) identifying spatial and temporal patterns of fishing effort and (2) for providing quantified effort data in relation to the features of a protected site.

Spatial and temporal patterns of fishing effort have successfully been quantified for the bait dragging fishery in Poole Harbour and compared to the conservation features of Poole Harbour MPA. This study indicates that there are differences in the intensity and spatial distribution of fishing effort between years. Differences in the seasonal distribution of fishing effort were identified, however patterns of activity were not consistent between years.

Between 2012 and 2015, the number of vessels engaged in the bait dragging fishery declined from 17 during 2012 and 2013 to 14 in 2014 and then to 8 by October 2015 (per comm. Southern IFCA). In addition, fishing activity was restricted to Area 1 during 2014. Anecdotally, fishers suggest that two factors influenced activity in this fishery, weather conditions and demand for the catch. The influence of weather conditions was explored by analysing daily wind speed data from Poole Harbour over the study period but there was no correlation between wind speed and the usage of certain areas for bait dragging activity. A reduction in demand for catch was the dominant factor attributed to the overall decline in the number of vessels engaged in the fishery. The angling sector, the main consumer of live bait, were increasingly using frozen bait available from online retailers. This reduced the customer base for local tackle shops that employed the majority of bait draggers. The sole use of Area 1 in 2014 can also be attributed to a reduction in demand for catch. In order to reduce fuel costs and increase the profit margin associated with the catch fishers preferred to fish in close proximity to their vessel's berth located within Area 1. The variation in areas of the Harbour used in 2015 may further reflect changes in demand for the catch. The data shows that VMS can be used to indicate general changes in fishing effort and levels of participation across a fishery as a whole. This can then be further explored in terms of influencing factors indicating which are of greatest importance to different fishing fleets. In addition, changes in stock levels can be related back to trends in fishing effort for particular fishing fleets, giving greater confidence to managers when considering the influence of fishing on stock trends.

The interaction between the fishery and the features of the Poole Harbour MPA were also successfully quantified. The data shows that fishing effort was concentrated during a period of the year when the designated bird species of the MPA are not at risk, either due to species not being present in the Harbour or species not actively breeding, roosting and overwinter feeding. There is also no overlap between locations of fishing activity and sensitive bird-supporting habitats. Communication from fishers during the survey period indicated that they were aware of the sensitivity of particular areas of the Harbour during the period between November and March and therefore actively avoided fishing in these areas. The lack of activity in these areas observed during periods when the sensitivity of the MPA features was low (summer) is likely a result of a combination of these areas being shallow (<1m), and therefore only accessible for short time periods (less than 2 hours) during high tide, and a tendency for these areas to support large amounts of filamentous algae during the summer, making the deployment and recovery of bait drags more difficult (personal communication from fishers).

This study has shown that a rate of 10-minute reporting would be appropriate for fishing activities operating down to a spatial scale of 250m^2. These findings reinforce the importance of assessing a fishery at a scale appropriate to the activity being carried out, particularly when considering the potential impacts of that fishery on the marine environment [6, 26]. The current commonly used reporting rate of 2 hours for vessels using VMS in the >12m vessel sector would result in a notable loss of spatial and temporal detail for fisheries operating at a similar scale to that used in this study, greatly reducing the efficacy of the data obtained. This supports findings from the Isle of Man scallop fishery where the true distribution of fishing activities was underestimated by ca. 10% when comparing raw VMS data at a 2-hour polling interval with interpolated tracks against higher frequency (10-20 min) VMS data [26]. This study also demonstrated that VMS data could be obtained over even finer scales, down to a reporting interval of 1-minute. This shows that VMS technology has the ability to provide fine scale data to the extent that scarring in the seabed and associated impacts to the benthic community within an MPA could be related to a particular fishing activity or even an individual fishing vessel. The cost associated with the reporting interval is an important factor when considering the use of this technology in fisheries management. Increasing the reporting interval to 1-minute would incur additional charges compared to the 10-minute interval and the cost to the fishing industry of using this technology must be balanced against the spatial and temporal resolution required to create a quantified evidence base which can assist in supporting management, as well as enforcement, decisions. The technology does offer the ability to vary the reporting rate for a particular vessel, a function which could be triggered by proximity to the boundary of an MPA feature thereby providing additional resolution in the areas where it would be of most use. The decision on how to balance the frequency of the reporting interval with the cost to the industry would be best considered at the level of the relevant management body and with a consideration of the specific needs of a site, based on an understanding of how the data is to be used and what questions need to be addressed.

The successful use of VMS technology on vessels in the <12m fishing fleet in this study encourages an exploration of the ways in which the data could be used to inform fisheries management in the inshore (<12nm) area. If VMS were to become mandatory for the <12m sector, it would allow for the creation of a long-term time series of data which would indicate daily, seasonal and annual trends in activity for different fisheries. This would give higher levels of confidence when describing the patterns of inshore fishing activity. Furthermore, data would also be consistent; removing unintentional bias derived from officer-based sightings, which are limited to activity seen whilst on patrol.

It is recognised that there are issues associated with the use of VMS on vessels within the <12m sector which would need to be overcome in order for this technology to be successfully used. This is of primary importance if VMS it to be used for enforcement purposes as there is a greater need for the technology to function continually without reporting gaps. This study identified the biggest issue in reporting resulted from a requirement for human intervention, i.e. the onus being on the fisher to charge the unit and install it on the vessel for each fishing trip. The requirement for human intervention arose from the rudimentary electronics on vessels in the bait dragging fishery not being sufficient to charge the unit without impacting the vessel itself. The set-up of a bait dragging vessel is not dissimilar to that of other inshore fisheries, particularly those which operate within the confines of a single estuary or harbour. Consideration of the power source for VMS units in the inshore sector is therefore required. This study demonstrated that the most continuous and reliable data was obtained once the need for human intervention had been removed. This suggests that, for the <12m fishery, an independent power source, not connected to the vessel's own electronics, is required to ensure that data gaps are minimised. Whilst the use, in this study, of a solar panel to charge an independent battery provided a solution there are still potential problems which have not been addressed. Fouling of the solar panel and the requirement for cleaning, for example, would need to be investigated. There is a risk that a requirement to clean the solar panel reintroduces the need for human intervention which has already been shown to impact data collection. A longer-term study, looking at data days lost when using a solar panel, would clarify the effectiveness of this solution within the <12m sector.

In addition to the functionality of the unit itself, there are limitations to the use of VMS technology which need to be considered by managers when using VMS data to inform management. VMS does not indicate the particular activity being undertaken by a fishing vessel at a given time. The importance of 'cleaning' processes for the data go some way to addressing this, however there is likely to still be an overestimation of active fishing [37]. The use of 'ground truthing' observations of activity to support interpolation of data between positional records has been explored [26] and provides a method of quality assurance in matching VMS data to different types of fishing activity by a specific vessel. The need for additional data sources to quality assure data produced by VMS should be factored in to any VMS programme and the associated resources and costs required should be a consideration for management authorities. The confidentiality and security of data collected and the link between this and compliance on the part of the fishers also needs to be taken into account [42]. Management authorities will need to ensure that they can guarantee data confidentiality to fishery stakeholders and that this can be successfully communicated to the fishing community. It is noted that confidentiality is of primary importance to fishers and is a common cause of lack of co-operation with policies to introduce monitoring systems within fishing fleets [42]. One of the other main considerations is that VMS data does not provide any information on catch. The ability to combine logbook data with VMS has been explored [37,43,44] but this is dependent on the vessels in question being required to submit logbook records. Currently, the <10m fleet are not required to complete a logbook therefore it is only where specific, local regulations for a particular fishery require the submission of catch data that comparisons can be drawn between fishing effort patterns and the species and quantities landed. Fisheries managers should consider the need for regulation to require catch reporting in the <10m sector alongside that requiring the use of VMS in order to address this potential data gap.

The nature of the inshore fishing fleet does however provide increased benefits and pathways for addressing the limitations on the use of VMS which are not as easily achieved for the larger offshore fleets. The inability of VMS data to indicate a particular gear type or type of fishing activity often leads to misclassification of data when considering large, multi-species fisheries [24]. For the inshore sector, the majority of vessels either operate a single gear type or are highly seasonal in target species and gear use. There is the potential therefore for VMS data to be analysed in the context of local knowledge, both from fishers and management bodies, to allocate a gear type and possible species to the spatial and temporal patterns of fishing activity, addressing this gap in the data. Inshore fisheries are also often engrained in their local communities and coastal areas will often have fishermen's groups or associations representing a large section of the local industry. There is the opportunity therefore to engage more easily with the industry and collate local knowledge which can be used to quality assure VMS data and communicate more easily on the way in which data will be used and processed providing a level of confidence for fishers which is not as easily achieved for more dispersed offshore fisheries.

The importance of local knowledge to support and strengthen spatial data has been shown for other fisheries [36,45,46] and should be applied to VMS data. The benefits of involving the industry are apparent, and this approach is driving management bodies toward addressing the need for inclusive and participatory systems in the development of fisheries management [47] and wider marine spatial planning [48]. For the inshore fishing fleet, combining quantified VMS data with local stakeholder knowledge, could help to facilitate a co-management approach to fisheries management. The ability to define fishing effort spatially and temporally, by gear type and/or species, combined with an understanding of the drivers for that activity and the wider cultural and socio-economic context of the fishery would provide a detailed analysis of the interaction between inshore fisheries and the marine environment, which is currently absent.

Quantified data on fishing effort, which can give support and in turn be supported by local stakeholder knowledge creates a valuable tool which can be utilised by management authorities aiming to move away from a precautionary approach towards full evidence-based management. The legal requirement for authorities to conclude 'no adverse effect' for a particular activity on the features and supporting habitats of an MPA creates a heavy burden of evidence required to support such a conclusion. Unsubstantiated qualitative information from fishers or discrete, small datasets collected in an ad hoc manner by observation are often not robust enough to support the necessary requirements of a fisheries assessment. The ability to use VMS to create a quantified, independent dataset on fishing activity for the near inshore sector addresses the evidence gaps in a manner where there can be confidence in the data obtained. It is recognised that for a shift in management of MPAs away from precaution, there is a need for information from a variety of sources, not just fishing effort data. The use of quantified data on fishing activity patterns should be used alongside other data including robust stock monitoring assessments, catch recording systems and regular monitoring protocols in order to increase confidence in an evidence-led approach. As these different types of data become available, management can move from being precautionary to corrective and ultimately preventative where an understanding between activities, such as fishing, and the ecological components of an MPA are used to create a suite of management measures i.e. spatial restrictions, effort limitation and gear restrictions which provide for wider ecological protection [49]. Each of these measures can be individually developed but cumulatively create the ability for full-evidence based MPA management, providing data which is robust enough to support MPA assessments and therefore reduce the need for precaution. In addition, the creation of a continually evolving evidence base allows management to be flexible. Fisheries managers can be reactive to changes in the fishing industry and the marine environment with new designations and protections for the coastal area applied to fishing effort data in near real-time. Planning can also be improved through the ability to map all fishing activities within a defined area, such as an MPA, to determine usage by different fisheries that could be incorporated into fisheries management plans and provide quantified data to inform wider marine spatial plans [37,50,51,52].

4.1 Conclusion

This study has demonstrated that VMS technology can be used effectively on small vessels (<12m) in the inshore fishing sector to quantify fishing effort over small spatial (metres) and temporal (minutes) scales and in relation to features of an MPA. At the point that VMS is applied to the <12m sector, there will be the opportunity to create high confidence time-series datasets for inshore fisheries that can be used as part of an evidence base to support management decisions and reduce the risk to the industry of management based on precaution.

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7. Ethics Statement

The fishers engaged in this study did so on a voluntary basis and agreed to have the VMS units installed on their vessels for the duration of the project. Access to the raw data produced by the VMS unit for each vessel was only made available to the lead author and the fisher to whom the vessel belonged. Data was anonymised prior to any analysis being carried out to preserve commercial sensitivity of the fishing operations carried out by each individual fisher. Access to the data and the way in which the data would be processed was explained to each fisher prior to the start of the study.

Declaration of Interest Statement

Declarations of interest: none

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