MMO FISHERIES CHALLENGE FUND

PROJECT FES 286:

"Impact of bait collecting in Poole Harbour and other estuaries within the Southern IFCA District"

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EXECUTIVE SUMMARY

Bait worm collection has occurred on British shores for hundreds of years both recreationally and commercially in two main forms, the manual digging for worms and the dragging of bait hooks from a vessel. In order to assess the need for management of bait dragging against conservation features for Poole Harbour European Marine Site (EMS) a robust assessment of effort is required along with evidence on the impact of this activity.

Data was collected on the position of fishing vessels both manually and by remote vessel monitoring. Grab and "Scoop" samples were taken for sediment and target species and were analysed to compare patterns between areas used for bait dragging and those that are not.

Effort was shown to vary spatially over the course of a year with an increase in activity in sheltered and enclosed bays in the autumn and winter when weather conditions reduce accessibility to the wider harbour. Overall, effort was related to the number of vessels and time spent in one area as activity of a single vessel over a fixed time period did not vary seasonally. Impacts to sediment parameters were shown to be related to the area of the harbour sampled. Differences between dragged and control sites were seen for areas subject to lower overall levels of disturbance with other areas indicating that background levels of disturbance and the effect of multiple activities in a single area make impacts of an individual activity harder to determine.

This project has provided effort and impact data that will be used to assess bait dragging activity against the conservation requirements for Poole Harbour European Marine Site and provide sustainable and proportional management.

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CONTENTS

1. INTRODUCTION

Bait worm collection has occurred on British shores for hundreds of years and is now supporting a well-developed angling sector with an estimated economic value of over $1 billion per annum (Folwer, 1999). Today, collection occurs both recreationally and commercially and although the level of demand, and therefore the number of people engaged in bait collection as an occupation, has fallen since a peak in the 1970s-80s (Fowler, 2001), some areas of the coast are still being utilised regularly by bait worm collectors.

With the introduction of the Marine and Coastal Access Act 2009 (MaCAA, 2009) the collection of bait can be regulated by Inshore Fisheries and Conservation Authorities (IFCAs). IFCAs were vested in April of 2011 under MaCAA (2009) and are responsible for ensuring the sustainable exploitation of sea fisheries resources whilst balancing the socio-economics of the fishing industry with the need to protect the marine environment. Prior to this, the collection of bait both for personal and commercial purposes has not been subject to fisheries legislation and as such has gone largely unmanaged. Previous attempts at local byelaws and voluntary codes for bait collection around the UK have been met with mixed reviews (Fowler, 1999; Fowler, 2001) and regulation has often been held to be un-enforceable or against common law rights. Future regulation will also need to take into account management specifically within European Marine Sites (EMS). From August 2012, the Department for Environment, Food and Rural Affairs (DEFRA) issued a change in approach to the way in which fishing activity within EMS are to be managed with activity being looked at on a risk prioritised basis against the conservation features for which a site is designated. For Poole Harbour, bait dragging has been given amber status with regard to a number of features including intertidal mud meaning that further information is required in order to determine whether the activity will have an adverse impact on this and other features. The process through which this is determined is dependent on the collection of robust scientific evidence and it is hoped that studies such as this will fill gaps in knowledge and allow for a uniform structure to management.

Bait collection occurs in two main forms; bait digging and bait dragging. Bait digging is the most common form of collection and involves manually turning the sediment with a fork with removal of target species by hand (Watson *et al.*, 2007; Sypitkowski *et al.,* 2010). Digging occurs at mid to low tide and has been documented both during the day and the night (Liley *et al.,* 2012) to harvest the common target species *Arenicola marina* (Lugworm), *Alitta virens* (King Ragworm) and *Nephtys hombergii* (Catworm) (Dyrynda and Lewis, 1994). Bait dragging involves collecting bait from hooked metal drags deployed from a boat (Dyrynda and Lewis, 1994) and is an activity apparently unique to the area of Poole Harbour in Dorset. Whilst a wealth of literature exists on bait digging, there is a lack of information on dragging activity both in terms of effort levels of the fishery and in terms of the impacts on the environment. This has left large gaps in knowledge which need to be filled to ensure that this activity is managed effectively and appropriately in accordance with the duties of the IFCAs. The aim of this project is to fill some of these gaps by investigating bait dragging in detail, determining effort levels and assessing the potential impacts on the conservation features of Poole Harbour.

1.1 Bait dragging

1.1.1 Method of collection

Bait dragging is a method of commercial fishing used to collect polychaetes of the family Nereididae, in particular *Alitta virens* (King Ragworm), for fishing bait. The activity appears to be unique to Poole Harbour, Dorset in the UK and has been carried out continually for over 20 years.

The collection of bait using this method, in combination with the more common practice of bait digging, increases the area of the Harbour that is available for collection as both high and low tide periods can be utilised, with bait dragging facilitating the exploitation of areas that are unavailable to bait diggers (Dyrynda and Lewis, 1994). Dragging vessels have been observed in a number of areas within Poole Harbour and, as with digging activity, both during the day and the night on suitable tides (Liley and Fearnley, 2011). The double high water in Poole Harbour coupled with an extensive network of intertidal mudflats allows for “large scale collection of bait” and supports a currently sustainable and stable fishery (Dyrynda, 1995).

The dragging method has been developed and refined over time, initially occurring in the Port Solent area of Portsmouth Harbour where the grapnels used to move canoe type vessels onto and off the shore were coming to the surface with *A. virens* (King Ragworm) attached (Gerry Gibbs, per comm.). Over time bait fishermen started to use these grapnels purely for bait fishing, manually pulling the drags through the sediment from stationary vessels. This activity evolved further with the use of powered vessels to pull the grapnel through the mud. The design of the grapnel also

Figure 1.1: A) Double-tined drags, showing the long stabilising bar which moves over the surface of the sediment and the penetrating hooks. B) Bait dragging vessel, yellow arrows indicating where the drag lines are going into the water. C) Bait drag being knocked on the sorting table, the worms are dislodged from the drag. D) Worms collected in sieves, over time the worms move through the sieve into the bucket where they are then stored.

developed to include longer tines and cross bars to facilitate its movement through the mud (Figure 1.1a) (Gerry Gibbs, per comm.). Currently, collection is carried out from small, powered fishing vessels with a shallow draft that are able to operate outside navigation channels and close into the shoreline (Dyrynda and Lewis, 1994). The method involves deploying one or two double-tined drags, a modern version of the old grapnels, from the stern of the vessel, attached via a rope (Figure 1.1b). The vessels are modified to enable steering from the stern, facilitating fishing by a single fisherman. As the boat turns, the drags penetrate approximately 25cm into the mud (Dyrynda and Lewis, 1994) and are towed forwards. After each turn, each drag is manually pulled onto the vessel, where the target species will have collected in a ball across the tines (Dyrynda, 1995) (Figure 1.1c). The drag is knocked on the side of the vessel to dislodge the worms, which are then collected, with any small or damaged individuals being returned to the water. The worms are then placed on a sieve over a large bucket containing seawater where they are retained and stored (Figure 1.1d). The use of multiple drags in rotation allows several hundred worms of marketable size to be retained in a single fishing trip (Dyrynda and Lewis, 1994).

Approximately 10-20 professional and amateur bait fishermen work in Poole Harbour, supplying tackle shops across the Southern IFCA District as well as larger internet based bait suppliers who in turn deliver the bait nationwide (Dyrynda, 1995; Fowler, 2001). The numbers engaged in bait dragging have fallen since a peak in activity in the 1970s-80s (Fowler, 2001). This is due in part to a reduction in demand for fresh bait from the recreational angling sector and an increase in production of bait by bait farms (Gerry Gibbs, per comm.). Bait dragging however, does remain an effective method of obtaining bait in commercial quantities and, when combined with digging activity ensures that an area of Poole Harbour is available for bait collection at any state of the tide.

1.1.2 Target species Alitta virens

The primary target species for bait dragging, *Alitta virens*, the king ragworm, is the most important species collected for fishing bait around the UK (Watson *et al.,* 2007). This is the species most commonly collected through bait dragging activity and thus is referred to as the target species for this study.

A. virens belongs to the family Nereididae, one of the most abundant and diverse families of the class Polychaeta (Snow and Marsden, 1974; Breton *et al.,* 2003).

Nereididae are errant polychaetes with a long slender body composed of many similar segments (Hayward and Ryland, 1995). They have a large eversible proboscis with two curved chitinous jaws and small horny teeth allowing them to feed as predators and scavengers (Nielsen *et al.,* 1995) as well as obtaining nourishment by swallowing the uppermost sediment layer which contains detritus and microbenthic algae. *A. virens* can grow to lengths of 200-300mm or more with approximately 100-175 segments and are vigorous swimmers employing a sinusoidal motion. Annelids are vulnerable to damage by predation and physical disturbance where loss of segments can involve loss of sensory and reproductive structures. Species have therefore developed the ability to regenerate lost body parts; in the family Nereididae this involves processes similar to growth through the proliferation of new segments (Golding, 1967). The rate of proliferation is more rapid after loss from the posterior of the body and can take up to 1 week after initial loss of segments. It is therefore important that individual damaged worms are able to rebury so that regeneration can occur within the burrow reducing risk of predation.

A. virens is found throughout the temperate zone of the Northern Hemisphere in shallow marine and brackish soft-bottoms habitats, commonly in sediments of medium to high organic content (Kristensen, 1983a; Nielson *et al.,* 1995; Miron and Kristensen, 1993; Breton *et al.,* 2003). King Ragworm have a weak tolerance to low salinities and are therefore often found toward the entrances of estuaries and never within areas of particularly low or fluctuating salinity (Kristensen, 1983b). Individual worms occupy mucus-lined, u-shaped burrows with a feeding area surrounding the burrow. The size of the feeding area is often defined by intra-specific competition and can vary as population size and food source availability change (Miron *et al.,* 1991; Lewis *et al.,* 2003). When buried in the sediment, individuals pump water through the burrows for oxygen and are able to switch between aerobic and anaerobic metabolism during periods of oxygen depletion (Kristensen, 1983a). Many factors are known to influence the distribution of different Polychaete species within a single habitat including sediment structure, organic content, depth, temperature and salinity (Hutchings, 1998) therefore changes to these parameters through disturbance has the potential to influence the distribution of populations.

A. virens has a strictly semelparous life cycle with a switch from somatic to reproductive growth before spawning (Breton *et al.,* 2003). Adults can reach sexual maturity at anywhere between 1 and 8 years and is thought to be partially dependent on initial growth rate where a fast growth rate leads to early onset of sexual maturity (Last and Olive, 1999). Differences in age of sexual maturity have also been found between adults of different populations, resulting from selection, restricted gene flow and phenotypic responses to environmental conditions (Breton *et al.,* 2003).

The onset of spawning is also through to be under environmental control (Last and Olive, 1999). Spawning occurs around April/May when external cues cause the coelomic fluid of the separate sexes to become filled with maturing oocytes and sperm (Olive *et al.* 1997). Previous studies have shown that for *A. virens* reproduction often occurs early, prior to the water reaching optimal temperature conditions (Lewis *et al.,* 2003). It is thought that intra-specific competition occurs at the post-settlement stage of larvae where the earlier arrival of *A. virens* larvae gives them a competitive advantage allowing the overall population to benefit from enhanced post-larval survival. Larval development consists of two benthopelagic followed by a brief pelagic phase which allows for dispersal (Breton *et al.,* 2003). The larvae will then settle again sublittorally until as adults they migrate into the littoral zone to spawn (Blake, 1979).

Not all of the population will undergo breeding in the spring, each year in the winter individuals will supress feeding activity to reduce the associated risk of predation and energy is put into reproduction. Once spawning has occurred, those individuals that did not breed will return to high levels of feeding activity increasing growth rates during the summer period (Last and Olive, 1999). This change in energy allocation and restriction in somatic growth will cause differences in the size frequency of the population across the seasonal cycle.

1.2 Impacts of bait dragging

There are a number of proposed effects of bait dragging activity on the environment, the most widely researched of these being disturbance effects on overwintering bird populations and reduction in bird prey availability. Other proposed adverse effects include a reduction in the target species population, impacts on non-target species populations through physical disturbance and habitat modification and changes to the sediment composition and water quality (Fowler, 1999; Fowler, 2001; Liley *et al.,* 2012). In Poole Harbour there is a considerable amount of fishing activity, primarily for clams and cockles as well as for bait, taking place over a relatively small area and this leads to overlap making it difficult to assign disturbance to a single cause. It is important therefore when assessing the effects of bait dragging disturbance on the environment to account for “in combination” effects that may be seen or exacerbated by numerous different activities.

1.2.1 Disturbance

In areas such as Poole Harbour the wide variety and scope of anthropogenic activity can lead to “in combination” disturbances which may have wide reaching effects on the benthic environment. Ecologists argue that disturbance is vital to achieving biodiversity as perturbations maintain species diversity when competitive process would otherwise have a predictable limiting effect (Odion and Sarr, 2007). There are a number of specific proposed effects of bait dragging disturbance however it is also important to consider more general effects of disturbance as areas dragged for bait are likely to be subject to a range of activities accounting for both high and low frequency disturbance events.

The intermediate disturbance hypothesis (Connell, 1978) indicates that high frequencies of disturbance will lead to dominance by rapidly colonising species where as low frequencies of disturbance will lead to dominance by highly competitive species. Intermediate levels of disturbance will therefore lead to a co-existence and greater species diversity within a given area. It is possible in areas like Poole Harbour, where disturbance can occur more or less frequently due to time of year and conditions that an intermediate level of disturbance is most commonly experienced with smaller scale events of high disturbance during peak activity periods. In combination with this, areas experiencing disturbance will also be subject to the dynamic equilibrium hypothesis (Huston, 1979) in which the process of population growth following disturbance and the initiation of competitive exclusion will often occur at rates dependent on the productivity of the environment. In Poole Harbour where combination disturbance events have different effects depending on the productivity and the environmental conditions within different areas of the

Harbour, it is likely that disturbance events may even have different effects within the Harbour itself.

Direct and indirect stresses can cause further population change with the increased likelihood that an ecosystem may suffer more from natural environmental change when already disturbed by anthropogenic activity (Odion and Sarr, 2007). These combinations of stress and disturbance can make management difficult as it is hard to assess the impacts of the disturbance against what are often termed “reference conditions”. Such baseline conditions are very difficult to establish especially in areas that have been disturbed over long periods of time such as Poole Harbour, it is often better to assess spatial and temporal patterns of existing disturbance against environmental parameters and to look to maintain conditions without making too many assumptions about what the “reference conditions” should be (Odion and Sarr, 2007). It is also important to consider the difference between a single disturbance event and continual disturbance over the same area as is caused by bait dragging and other fishing activities. The latter is likely to mean that “recovery” is less likely as the continued disturbance will prevent the ecosystem returning to its previous condition (Wilber *et al.,* 2008).

1.2.2 Bird disturbance and prey availability

There is evidence that wading bird populations can either be disturbed directly by the presence of bait collectors or suffer from secondary effects caused by reductions in key prey species (Watson *et al.,* 2007). Poole Harbour, within which bait dragging occurs, is designated as a Special Protection Area (SPA) for internationally important numbers of shelduck and black-tailed godwit and nationally important numbers of avocet, dunlin, curlew and redshank (Thomas *et al.,* 2004). It is therefore important to consider the impacts that bait dragging as an activity could have on these populations as such impacts require mitigation within the marine protected area.

The impacts of bait digging on resident bird populations has been extensively researched and studies have shown that disturbance to birds both directly through visual and noise disturbance and indirectly through removal of prey and habitat modification are one of the most serious impacts of bait collection activity (Fowler, 1999). Peak times for collection often coincide with the presence of overwintering bird species and collection, both by digging and dragging, has the potential to decrease the population of prey species available to these birds during the time at which they are most reliant on maintaining energy reserves over winter. The combination of bait digging and bait dragging in Poole Harbour means that there are few areas not subject to bait collection potentially compounding the effects of prey removal.

Previous studies (Thomas *et al.,* 2004; Durell *et al.,* 2006) have aimed to assess whether the prey available from different areas of the harbour is meeting the energy requirements of “important” predator species. Thomas *et al.,* 2004 indicated that the levels of invertebrates in the Harbour may cause some degree of stress to bird populations through an assessment of the balance of energy between what is required and what is available. However, assessment of the needs of individual species indicated that this is not likely to be the case for all species. Limitations in data collection and the reliance on existing literature in the absence of new data mean that there are uncertainties in estimating energy requirement. While the indication is that the removal of prey by activities such as bait dragging could have a detrimental effect on bird populations if not regulated carefully, the outcome would need to be assessed on an individual species level and, as with other proposed impacts, assessed in terms of the cumulative effects of similar activities.

1.2.3 Target species

Alitta virens is the most common species collected for fishing bait in the UK. However the species also has an important role within intertidal communities as a prey species for many species of bird, fish and crustacean as well as aerating sediments and acting as a key predator and scavenger in benthic communities (Giangrande *et al.,* 2005; Watson *et al.,* 2007). The impacts to this target species from anthropogenic activity therefore need to be considered along with wider impacts to the biological and physical condition of the environment.

The effect on *A. virens* population abundance from bait dragging is thought to be minimal and stocks are believed to be substantial and sustainable at current levels of bait harvesting activity (Dyrynda and Lewis, 1994; Fowler, 1999). Fishermen are of the belief that a greater population of *A. virens* exist in areas which are routinely dragged (Gerry Gibbs, per comm.), which is supported by the fact that a large degree of intra-specific competition is known to occur within populations of Nerididae, thus the removal of larger adult worms on a regular basis allows for a greater colonisation of these areas by smaller, juvenile individuals (Lewis *et al.,* 2003; Watson *et al.,* 2007). This is further supported by studies which have shown that individuals had a significantly lower mean weight in areas subject to bait digging than those that were not (Watson *et al.,* 2007).

Previous studies have also shown that although the population of *A. virens* is greater in more disturbed areas, the number of reproductively mature individuals is less (Watson *et al.,* 2007) as the removal of larger adults through bait collection removes a larger percentage of the reproductively mature population. However, in many other species that are commercially exploited there is a shift toward individuals achieving sexual maturity at a smaller size when compared to unexploited populations (Jennings *et al.,* 2001). It is speculated that this pattern may be seen in *A. virens* as an adaptation to continual exploitation within an area such as Poole Harbour.

A proportion of *A. virens* will be damaged during the process of bait dragging. It is common practice for these damaged individuals to be immediately returned to the sea as they are of less economic value than whole worms. It is thought that the survival rate of these worms returned to the fishery will be high (Fowler, 1999) provided that they are not predated before being able to re-bury in the sediment. Polychaete annelids are capable of regenerating lost caudal segments increasing survival chances when damaged, however this is dependent on the position of the segment in which the damage occurred (Golding, 1967; Olive, 1974), an uncontrollable factor in bait dragging.

1.2.4 Non-target species

One of the well documented impacts of bait collection is that of impacts on the wider benthic community present in the substrate (Jackson and James, 1979; Cryer *et al.,* 1987; Brown and Wilson Jr., 1997). Whilst most information relates to impacts caused by bait digging, there are some studies which look at mechanical impacts of bait removal e.g. Van De Heiligenberg, 1987. Many studies relate to general disturbance of benthic communities which result from different types of fishing activity (Wynberg and Branch, 1994; Kaiser *et al.,* 2001; Olsgard *et al.,* 2008). The main impacts for non-target species include direct removal of certain species, indirect changes to community structure and changes to sediment structure which can also result in reburial of some species beyond a recoverable depth (McLusky *et al.,* 1983; Dayton *et al.,* 1995). Natural disturbance events will govern typical patterns of community composition for a given area but these can be compounded by anthropogenic disturbance (Thistle, 1981).

"Recovery" rates following disturbance can vary from months to years and are dependent of a wide variety of factors such as the type of disturbance, the initial habitat type, the spatial scale over which the disturbance occurred and the sediment characteristics of the area (Beukema, 1995; Wilber *et al.,* 2008). The life history and characteristics of species affected will also govern the rate of "recovery" (Sousa, 1980) and also, to some extent, the degree to which the disturbance is "perceived" by the wider ecosystem (Levin, 1984). Studies looking at the impacts of disturbance on non-target populations have shown that typically after a disturbance event, short-lived, rapidly growing opportunistic species (r-selected species) are able to colonize quickly (Harvard and Tindal, 1994; De Boer and Prins, 2002). However, long-lived, larger and less abundant species (k-selected species) are much slower to recolonize after removal and a population mortality of 25% can cause serious population change especially where disturbance occurs many times over a single year (Dayton *et al.,* 1995; Watson *et al.,* 2007).

Bait collection activity has been shown to impact a wide variety of species. Disturbance caused by digging for *Arenicola marina* was shown to deplete populations of the cockle *Cerastoderma edule* on the North Norfolk Coast; the bivalve was re-buried too deep within the sediment to survive (Jackson and James, 1979; McLusky *et al.,* 1983; Cryer *et al.,* 1987) and small, surface-dwelling, polychaete species have been shown to be severely compromised by changes to sediment structure (Brown *et al.,* 1997). The removal of large predators can have persistent effects on other trophic levels possibly altering the predator-prey ratio (De Boer and Prins, 2002) and so the processes of intra and inter-specific competition within the ecosystem (Nicholson, 1933). Alterations to these processes can alter the distribution and abundance of species that don't ever come into direct contact with the mechanism causing the disturbance and can be felt by bird and fish stocks, especially where disturbance is persistent and at a high level (Van de Heiligenberg, 1987).

It is important to remember that where fishing activity occurs, and for bait dragging within Poole Harbour in particular, multiple disturbances occur within a given area. In estuaries and intertidal areas, the naturally occurring species have developed strategies with opportunistic characteristics such as increased population size, higher reproductive rates and the ability to increase adult and larval dispersal (Blake, 1979; Gunther, 1992) to survive in such naturally variable environments.

1.2.5 Sedimentology

A common effect of many anthropogenic fishing activities is a change to the sedimentology of a habitat, occurring in two main forms; a change in the layering of the sediment and corresponding grain size fractions and the re-suspension of contaminants contained within the seabed (Contessa and Bird, 2004; Cooper *et al.,* 2011). Research has been carried out into the effects of different types of bottom towed fishing gear on the sediment (Churchill, 1989; Meyer *et al.,* 1981; O'Neill and Summerbell, 2011) but there is a lack of data on bait dragging specifically. As a form of bottom towed fishing gear, there are some similarities that can be drawn between this and commonly researched dredging activities however the effects are likely to be seen over a much smaller scale than for predominant types of commercial bottom towed gear.

1.2.5.1 Sediment structure and organic matter

The structure of the sediment can be a determining factor on the benthic community found within a particular area (Ozolin'sh, 2000). The percentage of different grain sizes and the way in which these are layered will dictate, to a certain extent, whether certain organisms will colonise (Weiser, 1959).

Different anthropogenic activities appear to affect the sediment composition in different ways, for example large scale aggregate dredging around the UK coast was observed to increase the coarse grain fraction as fine sediment was re-suspended (Cooper *et al.,* 2011). However, where bait pumps were used for shrimp harvesting, there was an increase in small size grain fractions after disturbance, where depressions caused by the bait pumps accumulated suspended sediment (Wynberg and Branch, 1994; Contessa *et al.,* 2004). The same effect was found (McClusky *et al.,* 1983), where depressions from holes dug accumulated suspended sediment. These changes in granulometry affect the infaunal benthic community, resulting in a change in assemblage to that originally present (Cooper *et al.,* 2011), which in turn can affect the type and amount of prey available for birds and other species. The impact on the sediment from bait dragging is a combination of an implement being dragged through the seabed and the resulting depressions that are left from the drag digging into the sediment. The result may be a difference in sediment structure between the edges and the middle of the depressions leading to different benthic communities over short spatial scales.

The organic content of the sediment was also seen to change after bait digging activity as organic matter was trapped in the holes dug. Bacteria species have been shown to benefit through the passive settlement of detritus into depressions (Wynberg and Branch, 1994) resulting in a readily available food source. Where organic matter is left in lower concentrations, typically around the top edge of depressions, colonisation and succession by sedentary species may be inhibited (Grant, 1981) therefore a difference in the organic matter content within a disturbed area may result in a difference in benthic community composition. The movement of the bait drags through the layers of sediment may also alter the redox layer bringing anoxic sediments to the surface (Cryer *et al.,* 1987; Parker and Pin, 2005). Some studies have shown that increased levels of anoxic sediment resulted in habitat modification through the direct death of some small polychaete species as well as retarding recolonization processes (Reise, 1984). The degree to which anoxic conditions will affect the habitat however will depend on the size of the area perturbed and the duration at which the anoxic layer persists at the surface, it is likely that the amount of anoxic material brought to the surface would be small and that it would oxidise quickly.

Furthermore, the depressions created by bait dragging can persist for several weeks. The persistence of the effects caused depends on the sediment bed-load transport, the suspended sediment load in the water column and the exposure to wave and tidal action (Parker and Pin, 2005). Poole Harbour has a low tidal range (around 2m) and limited water exchange as a consequence of the narrow entrance, which is no more than 370m wide (Humphreys and May, 2005) combined with low wave activity, particularly within the southern and western bays, the depressions left by fishing activity, primarily bait dragging and pump scoop dredging, can maintain for an extended period of time.

1.2.5.2 Metals contamination

Metals are one of the most common environmental pollutants, particularly in estuaries where they become trapped, and therefore not biologically available, within the sediment and water column (Kennish, 1997) and increased toxicity of metals such as cadmium, chromium and zinc result from reduced salinities (Hübner, 2009). Estuarine sediments act as sinks for metal contaminants due to their low solubility and high adsorption rates, which, if left undisturbed should hold metals indefinitely (Hubner, 2009). Where disturbance occurs however, metals can be re-mobilised into the water column attached to fine sediment particles, which can cause direct ecotoxicological effects on invertebrate populations and further effects through build up in the food chain leading to impacts on fish, birds and even humans (Kalman *et al.,* 2010). There can be wide variations in concentration of different metals within the same estuary due to inputs of freshwater, tidal action and flushing capabilities (Boyden, 1975). In addition the sediment characteristics will also affect distribution as finer grained sediments have a higher adsorptive capacity for contaminants

(Hubner, 2009) and fine grained sediment is believed to constitute the most important source of available metals contained in sediments (Haynes *et al.,* 1995).

Poole Harbour has played host to a considerable amount of industry in the past including a major chemical works where the effluent flowed directly into the Harbour, particularly within the secondary embayment of Holes Bay (Wardlaw, 2005). In the past elevated concentrations of cadmium, cobalt, iron, lead, manganese, nickel and zinc have all been found in the water and sediments around Poole Harbour with concentrations reaching levels considered toxic for humans in Holes Bay in the 1970s-80s (Boyden, 1975). Poole Harbour has a poor flushing rate caused by its narrow opening (less than 370m) and micro-tidal regime (tidal amplitude of 1.8m for Spring and 0.6m for Neap tides) (Humphreys and May, 2005) meaning that pollutants are easily trapped, especially within the inner zones of the Harbour. Metals accumulate in the fine sediment where natural breakdown is slow, however it has been suggested that some metals such as cadmium are more labile and could be re-mobilized by disturbance to sediment layers making them biologically available to benthic organisms which can take up these metals through ingestion of pore water and sediment mobilisation (Howell, 1985; Wardlaw, 2005). This rate of uptake will depend on the nature of the sediment and also the interaction between different metals within the sediment, where the concentration of one metal may inhibit or increase the uptake of another for example uptake of silver was shown to be reduced when copper concentrations were low for the bivalve *Scrobicularia plana* (Luoma and Bryan, 1982).

Tributyltin (TBT) was used for boat/ship antifouling up until sale of TBT products was limited in the 1980s and in 2008 banned for use on ship hulls in EU ports. TBT has been found within Poole Harbour where poor tidal flushing caused levels to build around moorings and marinas. In 1987 TBT concentrations of 0.71 µg g^{-1} were found in Holes Bay with estimates that 99% of the TBT leached into the water was removed into the sediment within 12 hours (Langston *et al.,* 1987). TBT has been shown to cause shell-thickening in the oysters *Crassostrea gigas* and *Ostrea edulis*, reproductive impairment (imposex) in the dogwhelk *Nucella lapillus* and acute mortality of mussel *Mytilus edulis* larvae (Langston *et al.,* 1987; Wardlaw, 2005). The strong affinity of benthic sediments for suspended particulates and sediments has led to the bethic environment becoming a major sink for TBT (Antizar-Ladislao, 2008). While TBT is particularly hazardous to marine life, once bound within the sediment there appears to be very little de-adsorption and therefore the release of TBT from the sediment due to disturbance by fishing activity is thought to be minimal.

Studies have been conducted into the levels of heavy metals within the Harbour but results vary and there is no full database of levels of metals and TBT throughout the Harbour. Hübner (2009) suggested that a significant fraction of metal loading in the sediments within Poole Harbour may not be stable and thus have the potential for being remobilised into the water column; however the sheltered conditions and low-energy tidal regime maintain some of this stability. It is more likely that release of heavy metals and TBT will occur in areas subject to continual disturbance activity, the sites sampled for bait dragging in this study are not within areas known for levels elevated above natural background levels of heavy metals and TBT therefore it is anticipated that any release of heavy metals from the sediment will be negligible. It is important to note that it is often difficult to extrapolate results of laboratory based testing of metal levels within sediments to the wider ecological community (Grant *et al.,* 1989) and that toxicity levels should be interpreted with the notion that not all of

Figure 1.2: overview of Poole Harbour (© Google Earth) showing the five islands and secondary embayments of Lychett Bay and Holes Bay. Bait dragging activity occurs predominantly in the west and the south of the Harbour as well as within Holes Bay when conditions are unsuitable in the wider Harbour area.

the concentration of metal detected will be bioavailable for uptake by the benthic community.

1.3 Poole Harbour

Poole Harbour is an estuary enclosed by a bar at the mouth and was formed by the drowning of a river valley during post-glacial sea level rise (Humphreys and May, 2005). It is a complex system with a prime basin, two smaller embayments, Lychett Bay and Holes Bay, and five islands (Figure 1.2) (Humphreys and May, 2005; Hubner, 2009). Fresh water enters the Harbour through several small rivers and streams, the largest of which is the River Frome (Dyrynda, 2005). The Harbour is designated as a Special Protection Area (SPA), Site of Special Scientific Interest (SSSI) and a Ramsar site, cumulatively known as a European Marine Site (EMS). Within these designations are a number of conservation features, with particular importance given to overwintering seabirds. The Harbour supports internationally important numbers of shelduck and black-tailed godwit and nationally important numbers of avocet, dunlin, curlew and redshank (Thomas *et al.,* 2004). The need to achieve good conservation status within the harbour is constantly being balanced against the large variety of activities that occur.

The total area of water within the Harbour is around 3600 ha at high water spring tide, making it one of Europe’s largest lowland estuaries (Humphreys and May, 2005). The poor flushing capacity of the Harbour combined with the sheltered embayments across the Harbour mean that contamination by pollutants is common, and although levels are reduced today, concentrations of heavy metals and TBT have previously been at hazardous levels particularly in Holes Bay where decades of industrial effluent have been trapped within the sediment (Langston *et al.,* 1987).

Studies have shown that the infaunal biomass of the Harbour is dominated by polychaetes and that over time; changes in macro-invertebrate community composition are more common than population stability (Caldow *et al.,* 2005). The Harbour is characterised by several intertidal species associated with mudflat areas, most commonly the King Ragworm *Alitta virens*, the anemone *Cereus pedunculatus* and the cockle *Cerastoderma edule* (Thomas *et al.,* 2004). The estuary contains a broad range of sediments with the southern and western portions of the harbour being predominantly mud, these areas forming the most common sites for bait dragging activity. The variation in habitat type across the Harbour has led to a wide variety of benthic communities with the mud and fine to medium sands characteristic of intermediate tidal energies proving the most favourable for the development of benthic communities (Dyrynda, 2005). The Harbour is also a highly productive environment with growth of seaweeds and saltmarsh providing a sustainable food supply for suspension feeding, deposit feeding and grazing communities (Dyrynda, 2005).

Poole Harbour is subject to a large degree of anthropogenic activity both from fishing and other harbour processes such as maintenance dredging. Fishing activity occurs throughout the Harbour with a well-developed shellfish fleet managed by the Southern IFCA through the Poole Harbour Order (1985). There is also a well-developed aquaculture industry with approximately 182 ha leased from the Southern IFCA for oyster and mussel farming (Jensen *et al.,* 2005). The combination of activities makes individual sources of disturbance difficult to determine and effects even more difficult to pin point to a single activity. Most of the effects of disturbance seen within the Harbour are likely to be the result of “in combination” effects of multiple activities and this must be taken into account when assessing the suitability of different fishing methods against the conservation features of the Harbour.

2. AIMS AND HYPOTHESES

The main aim of the project was to gain a better understanding of the effort levels of bait dragging within Poole Harbour and to further determine whether the activity is having an impact on target species population and/or the sediment granulometry and what the consequence of these impacts might be. The results of the project will support the development of evidence based and sustainable management by the Southern IFCA for bait harvesting across the District.

2.1 Detailed Aims

- To quantify the amount of bait obtained per drag for bait dragging vessels
- To quantify the effort level of bait dragging vessels in Poole Harbour by determining the number of drags completed over a set time period
- To quantify the size and number of reproductively mature *Alitta virens* and compared this data between dragged and un-dragged sites
- To quantify sediment size fractions and the organic matter content of the sediment and compare these data between dragged and un-dragged sites
- To quantify the levels of heavy metals and organotins in the sediment and compare the data between dragged and un-dragged sites

2.2 Hypotheses

- Populations of *Alitta virens* will differ between areas that are consistently used for bait dragging and those that are not
    - The number of *A. virens* present will be higher in the areas used for dragging than in the control areas
    - The average size of *A. virens* individuals will be higher in the control areas than in the areas used for dragging
    - The number of reproductively mature *A. virens* will be higher in the control areas than in the areas used for dragging

- Sediment composition and chemical content of the sediment will differ between areas that are consistently used for bait dragging and those that are not
    - The percentage of fine grained sediment in the surface layer will be greater in the areas used for dragging than in the control areas
    - The percentage of organic matter present in the surface layer will be greater in the areas used for dragging than in the control areas
    - The concentration of heavy metals will be higher in the surface layer of areas used for dragging than in the control areas
    - The concentration of organotins will be higher in the surface layer of areas used for dragging than in the control areas

- The effort level of bait dragging boats in Poole Harbour will change seasonally and spatially with increased activity during the spring and summer months.

3. MATERIALS AND METHODOLOGY

3.1 Impacts of Bait Dragging Data Collection

Sampling was carried out from five sites within Poole Harbour (Figure 3.1). The two sites used to represent a disturbed, bait dragged area within the Harbour were Arne Bay (Site 3d) and Furzey Island (Site 2d). For each of these sites a corresponding control site was sampled based on areas which have a suitable habitat for *A. virens* but are not used for bait dragging activity. For the Arne Bay site, the corresponding control was located in part of one of the leased beds under the Southern IFCA Poole Regulating Order (Site 3c), where activity other than that carried out by the shellfish farmer is not permitted. In this case, the area of leased bed was lying fallow and had not been used for shellfish farming. For the Furzey Island site, the corresponding control is on the Eastern side of the island where access to the intertidal area is more tide dependent and there are certain obstacles on the seabed which could damage bait drags meaning that the site is not used for this activity (Site 2c).

In addition, a further control site in Newton Bay was sampled (Site 1). The scale and variety of activity occurring in Poole Harbour from both commercial and recreational sources means that no one area of the Harbour can be described as being completely undisturbed. Therefore results from the control sites (3c and 2c) may still indicate a level of disturbance. The site at Newton Bay is enclosed and shallow; it is part of the areas closed to fishing outlined in the Southern IFCA Poole Fishery Order (1985) and as such is subject to a much lower degree of activity than the other control sites.

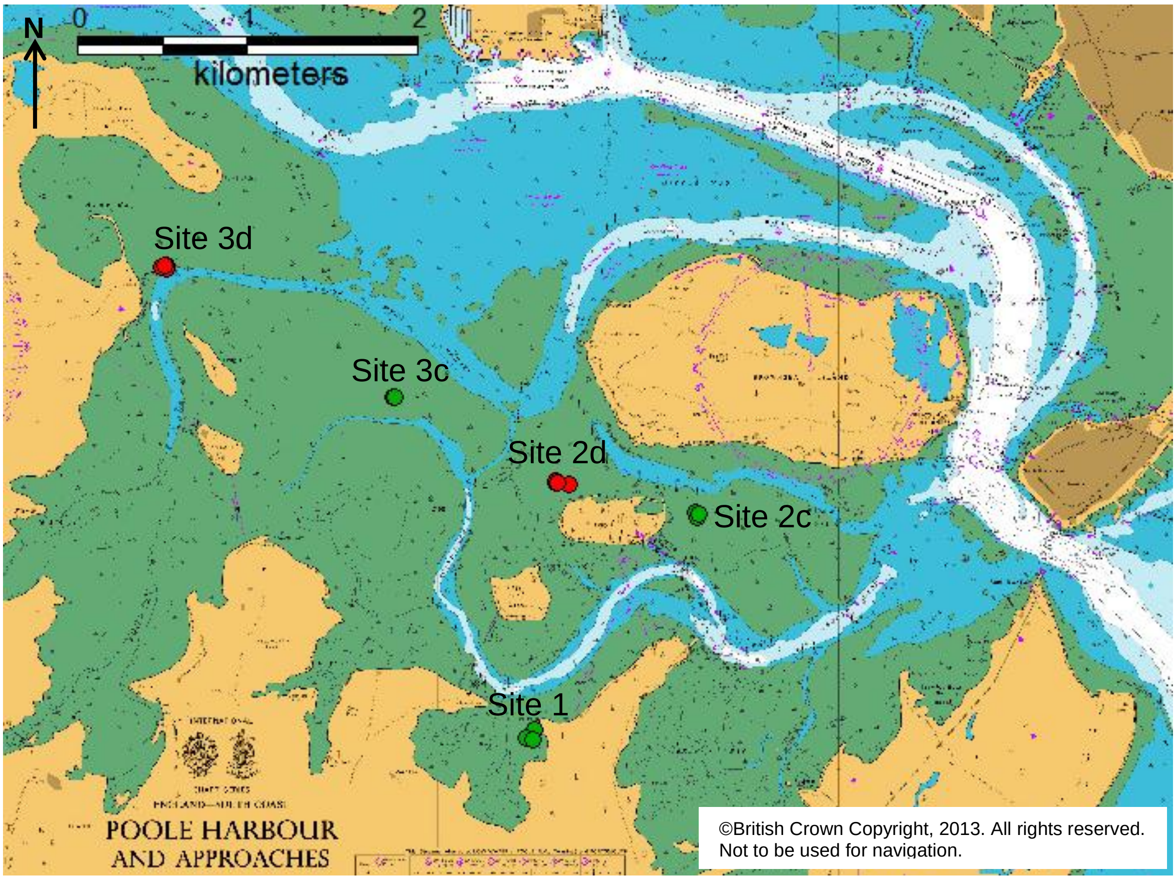


Figure 3.1: sampling sites within Poole Harbour, • bait dragging sites • control sites. Stake positions are plotted for sampling trips in October 2012, February, April and June 2013; all replicate samples were taken from within a 20m radius of the stake position.

	Arne Bay Dragged	Arne Bay Control	Furzey Island Dragged	Furzey Island Control	Newton Bay
	3d	3c	2d	2c	1
01/10/12	50°41.793	50°41.378	50°41.104	50°41.008	50° 40.293
	002°00.227	002°01.366	001°59.414	001°58.701	001° 59.534
14/02/13	50°41.786	50°41.358	50°41.110	50°41.013	50°40.325
	002°01.366	002°00.230	001°59.414	001°58.718	001°59.521
11/04/13	50°41.791	50°41.583	50°41.102	50°40.994	50°40.296
	002°01.386	002°00.224	001°59.351	001°58.712	001°59.562
11/06/13	50°41.792	50°41.377	50°41.106	50°41.008	50°40.290
	002°01.371	002°00.224	001°59.411	001°58.700	001°59.532

Table 3.1: Positions for the five sampling sites within Poole Harbour over four survey periods, October 2012, February, April and June 2013. All replicate samples were taken from within a 20m radius of an initially placed stake, the slight variation in stake placement is due to changes in weather, sea and tidal state between survey dates.

The results from site 1 reflect the most undisturbed conditions possible for the intertidal environment in Poole Harbour. The survey was carried out in October 2012, February, April and June 2013 to cover a seasonal cycle of the target species *Alitta virens*. Surveying was carried out from Fisheries Patrol Vessels Tenacity and Endeavour; a stake was placed into the seabed at each of the sampling areas at the sampling positions with replicate samples taken from within 20m of the initial stake position (Table 3.1).

3.1.1 Target Species (Alitta virens) Samples

Five replicate samples were taken at each site from within a 20m radius of the stake position, recording the time and position of each replicate. For sampling in October 2012, April and June 2013, samples were taken using a long handled "scoop" (Figure 3.2a,b) with a surface area of $0.06m^2$ and a depth of 150mm. The "scoop" had successfully obtained samples of *Alitta virens* in previous surveys of Poole Harbour carried out in 2003/04, 2004/05 and 2005/06 (Table 3.2).

Month	Year	Abundance of *A.virens* (Seagull Island)
October	03 to 04	42
	04 to 05	5
	05 to 06	25
January	03 to 04	19
	04 to 05	0
	05 to 06	26

Table 3.2: Average abundance of five replicates of *Alitta virens* from the area of Seagull Island in Poole Harbour, sampled over three years using the scoop method employed in this study.

Figure 3.2: a) Scoop used to collect the samples, as the vessel moves forward, for target species, b) Scoop being deployed, manually pushing into the sediment, c) Sieving the target species samples on board, d) Van-Veen grab using for collection of sediment samples.

The average abundance for October each year in that area being between 5 and 42 worms and for January between 0 and 26 worms. The scoop was attached to the vessel and manually pushed into the sediment, the vessel then moved forward at a speed of 1.5-2 knots for approximately 30 seconds.

When surveying in February 2013, it was found that the sediment was in a more liquid state than previously encountered and as such was not being retained within the scoop as it was moved from the seabed to the vessel. In order to obtain samples for analysis the Van Veen Grab that was used in all instances to obtain the sediment samples (section 3.1.2), was used giving samples with a surface area of $0.027m^2$ and a depth of approximately 100mm. In order to quantify these samples against those taken using the scoop, an additional set of target species samples were taken, again using the Van Veen Grab, concurrently to the scoop samples in the April 2013 sampling session. All target species samples were treated using the same protocol after sampling.

Samples were sieved through a 500µm wire mesh sieve using the on board water supply (Figure 3.2c). Any material retained on the sieve was placed in a 1 litre airtight container and fixed with a 4% formalin solution and Rose Bengal, a stain which adheres to proteins, thus staining biological material magenta. Once sorted, samples were further preserved in propanol.

Samples were analysed for the presence of individuals belonging to the family Nereidiae, which contains the King Ragworm *Alitta virens*. As the aim of the study was to investigate *Alitta virens* as a target species for bait dragging, individuals were selected from the samples based on the minimum size for retention on a bait drag. This size was determined from measurements of King Ragworm from a series of drags obtained from a bait dragging vessel (see section 3.3.3), the smallest of which was recorded as 2.7cm. Therefore any individual King Ragworm of 2.5cm or larger was taken from the samples for analysis. The aim of the survey was to assess the size of sexually mature Nerididae between sites in the harbour, however the number of Nerididae found within the samples meant that comparisons could only be made for one site between two of the four months sampled. Any individuals found were measured for length using calibrated vernier callipers. Measuring animals that have been preserved in formalin and propanol has inherent difficulties in that the shape of the individual can change during preservation, however the measurements were taken as approximate in order to compare the length of the Neridae obtained using the scoop with those taken from a bait drag as part of the effort survey (see section 3.2.4). The Nerididae found in the scoop samples were not present in sufficient quantities of sizably mature individuals to test for the state of reproductive maturity.

3.1.2 Sediment Samples

Four samples were taken at each site from within a 20m radius of the stake position, recording the time and position of each sample. Samples were collected using a Van Veen Grab with a surface area of 0.027m^2 and a depth of approximately 100mm (Figure 3.2d). Once obtained, the samples were sealed in a 1 litre airtight container. All samples were tested for organic matter content, grain size distribution and presence of a suite of heavy metals and Tributyltin.

3.1.2.1 Organic Matter Analysis

Sediment samples were analysed to determine the percentage of organic matter present using the Loss by Ignition (LOI) method as outlined in Dean (1974) and Heiri (2001). The method is based on differential thermal analysis, where organic matter beings to ignite at approximately 200ºC and is completely depleted at 550ºC.

Each sample was mixed to homogenise layers and a known weight was placed in a crucible. Each sample was then dried for 24 hours at 50ºC to remove all water, after which samples were placed in a desiccator (to prevent moisture increasing the dry weight) and allowed to cool to room temperature. The samples were then weighed to obtain the dry weight in grams, DW_{50}. Samples were then placed in a muffle furnace and heated at 500ºC for 24 hours before being cooled to room temperature in a desiccator before a second weight was taken in grams, DW_{500}. The percentage of organic matter present in the sample (LOI_{500}) was calculated using the following equation as outlined in Heiri (2001):

$$LOI_{500} = ((DW_{50}-DW_{500})/DW_{50})*100$$

3.1.2.2 Grain Size Analysis

Samples were sent to the National Laboratory Service for determination of particle size distribution by laser diffraction. Where samples contained particle sizes greater than 2mm, samples were pre-sieved before laser diffraction.

Analysis by laser diffraction involves placing a sediment sample in a sample cell where it is illuminated by a parallel, monochromatic beam of light from a low power visible laser transmitter. The incident light is diffracted by the particles giving a stationary diffraction pattern regardless of particle movement. These patterns are integrated and a representative bulk sample of the particles contributes to the final measured diffraction pattern (methodology supplied by Environment Agency, National Laboratory Service).

The resulting data from this analysis was grouped according to the grading of different sediment fractions on the Wentworth Scale (Wentworth, 1922) from gravel to clay based on the phi value of the grain (Table 3.3). Phi values for all samples ranged between -6 and 10. The data also showed values for the sorting coefficient, kurtosis, inclusive graphic skewness and mean particle size diameter (mm).

Phi Value	Grain Size (µm)	Wentworth Size Class	
-6 to -1	2000 - 63000	Gravel	
-1 to 0	1000 - 2000	Very coarse	Sand
0 to 1	500 - 1000	Coarse	
1 to 2	250 - 500	Medium	
2 to 3	125 - 250	Fine	
3 to 4	62.5 - 125	Very fine	
4 to 5	31.3 - 62.5	Coarse	Silt
5 to 6	15.6 - 31.3	Medium	
6 to 7	7.81 - 15.6	Fine	
7 to 8	3.91 - 7.81	Very fine	
8 to 10	0.98 - 3.91	Clay	

Table 3.3: Wentworth size class grading for sediment grain size, class is listed against the phi value and grain size in micrometres (Wentworth, 1922).

3.1.2.3 Heavy Metal and Organotin Analysis

Samples were sent to the National Laboratory Service for analysis of the presence of a suite of heavy metals and Tributyltin (TBT).

Samples for heavy metals were freeze dried and sieved to the required size fraction. Samples were then digested with a mixture of nitric, perchloric and hydrofluoric acids. This acid mixture allows for a complete dissolution of metals from most sediment types. The resulting digests were analysed using a combination of inductively coupled plasma mass spectrometry (ICPMS) and inductively coupled plasma atomic emission spectroscopy (ICPOES). The instruments used for the analysis were a Perkin Elmer Elan 9000 ICPMS and a Perkin Elmer Optima 3300RL (methodology supplied by Environment Agency, National Laboratory Service).

Samples for TBT were analysed using aqueous extraction with derivatisation. Samples were extracted with methanolic acetic acid, derivatised and then analysed

Metal/Compound	Concentration Range	Analysing Instrument
Aluminium (Al)	0 – 2.5 mg/L	Optima 3300RL
Arsenic (As)	0 – 200 ug/L	Elan 9000
Cadmium (Cd)	0 – 20 ug/L	Elan 9000
Chromium (Cr)	0 – 200 ug/L	Elan 9000
Copper (Cu)	0 – 200 ug/L	Elan 9000
Iron (Fe)	0 – 2.5 mg/L	Optima 3300RL
Lithium (Li)	0 – 200 ug/L	Elan 9000
Manganese (Mn)	0 – 200 ug/L	Elan 9000
Nickel (Ni)	0 – 200 ug/L	Elan 9000
Lead (Pb)	0 – 200 ug/L	Elan 9000
Vanadium (V)	0 – 200 ug/L	Elan 9000
Zinc (Zn)	0 – 200 ug/L	Elan 9000
Tributyltin (TBT)	0 – 500 mg/Kg	GC-MS

Table 3.4: The suite of heavy metals and TBT for which sediment samples were tested by National Laboratory Service along with the concentration ranges to which metals were detected and the corresponding analysing instrument used.

by GC-MS (methodology supplied by Environment Agency, National Laboratory Service). The metals and organotin tested, with the corresponding concentration ranges used by NLS are shown in table 3.4.

3.2 Effort Survey Data Collection

The following data was obtained as part of the survey into the effort of bait dragging activity within Poole Harbour.

3.2.1 Sightings Data

The number and position of bait dragging vessels within Poole Harbour has been collected between September 2012 and June 2013 as part of routine land and sea patrols by the officers of the Southern IFCA. For each vessel sighted, a co-ordinate position, time and the name of the vessel was recorded. Where the vessel did not display a name, a description of the vessel was recorded. This data is limited to the times during which officers were present in Poole Harbour and is therefore not carried out in a set pattern over the duration of the survey.

3.2.2 Shore Based Data Collection

For two days each month, between September 2012 and June 2013, observations were carried out from a fixed point overlooking Poole Harbour (50º 43.047 N, 002º 02.015 W). This position was chosen as it has a good view over the Harbour including the main areas used for bait dragging.

For each month, one sampling day was chosen to coincide with a neap high tide and one for a spring high tide. On each day, the number of bait dragging vessels that could be seen was recorded and, for up to four boats (a total of four boats were not always present), the number of turns made by the vessel and the number of drags deployed was recorded for a period of 30 minutes. Additional data on when a vessel entered of left the fishing ground was also collected where possible.

3.2.3 iVMS Data Collection

A vessel, which engages solely in bait dragging activity, was fitted with a Succorfish SC2 iVMS unit in September 2012. The SC2 unit is an advanced GPS tracking system which links via GMS technology to locate mobile assets down to a distance of 2m. The unit is fixed on the roof of the wheelhouse and transmits position data to a central database.

Data was collected between September 2012 and June 2013. Between September 2012 and May 2013, data on the position of the vessel was recorded at 10 minute intervals, for May to June 2013; this was increased to 1 minute intervals. The datasets were cleaned to leave only positions that corresponded to fishing activity by initially removing points that registered a speed greater than 2.5 knots (the data collected from on board a bait dragging vessel showing an average speed when engaged in fishing activity of 1.9 knots and no speeds in excess of 2.4 knots. Any speed greater than this was therefore considered to be the vessel transiting to and from the fishing grounds). The cleaned dataset was plotted using MapInfo Professional 7.8 and the dataset was further processed to remove positions corresponding to the vessel being on berth or in large channels within the Harbour where fishing activity could not occur. At various points, the vessel speed when transiting dropped below 2.5 knots and therefore these points were removed by hand once the data had been overlaid on a chart.

The positional data was overlaid onto a 250m^2 grid, the MapInfo Professional 7.8 software used to determine the number of individual positions within each grid square and a thematic map created to show the gradient of effort within the Harbour for each month. This data was further used to determine the time spent within each grid cell for each month both for 10 minute and 1 minute reporting.

Initially two vessels were fitted with the iVMS technology, however the skipper of the second vessel decided after 2 months that he no longer wanted the unit on board and so data for this project has been taken from the first vessel only. There are gaps in the data recorded for this vessel; initially there were issues with the iVMS unit draining the battery of the vessel, leading to the skipper turning the unit off. During three separate periods over which the battery problem had to be rectified there are three months (December 2012, January and April 2013) where data could not be collected. The vessel was also initially fitted with an RFID Gear In/Gear Out sensor which recorded when the drags were deployed and recovered. It was determined that this was causing the majority of the issues with the on board battery and so this equipment was disconnected from the vessel and the data is not included as part of the results of this survey.

3.2.4 Quantifying Catch

In order to quantify the amount of target species taken per drag, a day was spent on board the fishing vessel fitted with the iVMS unit. During this period, data was recorded on the number of drags within the period of 1 hour along with the speed and position of the vessel, the speed information being used to inform the cleaning of the iVMS dataset. *Alitta virens* were also obtained from ten sets of two drags with each sample from two drags weighed and then preserved on board in 70% Propanol in a 1 litre airtight container.

Samples were sorted into incomplete (damaged) and complete (undamaged) individuals and from the complete individuals a random sample of 15 worms was measured for length. The ash free dry weight for each sample was also obtained, with separate weights for the incomplete and complete sub-samples. Each sub-sample was weighed before being baked in a 50ºC oven for 24 hours. Samples were allowed to cool for 12 hours in a desiccator before being weighed and put in a muffle furnace at 500ºC for 24 hours, after which samples were allowed to cool and then weighed again. This method gives the ash free dry weight of the sample which was used to determine the weight of bait in both grams and pounds obtained per drag and in turn the Kcal of bait obtained per drag. It should be noted that the samples of *Alitta virens* were not given the opportunity to void their gut contents before the above analysis was carried out, and therefore the ash free dry weight may not be wholly representative of the worms in the sample. However, the size of the worm relative to the gut content is large and therefore the variation in ash free dry weight caused by the presence of gut contents will be negligible.

3.3 Statistical Analysis

The data collected was analysed using Microsoft Excel and the statistical program SigmaPlot 12.3. Datasets were analysed for normality using the Shapiro-Wilk test. Experimental data was compared between months and sites within each month using a one-way ANOVA when the dataset was normally distributed with the Holm-Sidak test used to determine where in the dataset the significant results occurred. Where the data was determined not to be normally distributed and transforming the data did not lead to a normal distribution, the non-parametric Kruskal-Wallis test was used with a further Tukey test to determine where differences in the dataset occurred.

For the data collected from the iVMS system, time spent per grid square was grouped into five areas within the harbour that are most commonly used for bait dragging activity. The time spent per area was evaluated using the Kruskal-Wallis test with a subsequent Dunn's test as the sample sizes for each month were unequal. Further effort data was compared using a mixture of one-way ANOVA and Kruskal-Wallis tests dependent on whether the data passed the test for normality. For comparison of the length of Neridiidae found in the scoop samples, only two months were able to be compared therefore a T-test was used to test for any significant difference between months.

4. RESULTS

4.1 Effort Survey

4.1.1 Sightings Positional Data

Data was collected by officers of the Southern IFCA as part of land and sea patrols around Poole Harbour. As the data was collected only when officers were present in the area, there was no standardisation to the data collection and as such the number of sightings of bait dragging vessels recorded varies between months based both on the presence of the vessels themselves as well as the availability of officers. Due to this variability in data, it was deemed inappropriate to look for statistically significant differences, as any difference shown could be related to the presence or absence of officers rather than any conditions changing the fishing behaviour of these vessels. The data was plotted on a chart of the Harbour and overlaid with a 250m^2 grid, the grid was then shaded according to the number of vessels recorded within each grid cell for September 2012 to June 2013 (Figure 4.1). The areas of Arne Bay and Patchin's Point showed the highest levels of activity, with sightings of up to 6 bait dragging vessels per grid cell being recorded in this area. Activity within Holes Bay appeared restricted to the Autumn/Winter period between September 2012 and January 2013, consistent with the theory that this area provides a more sheltered environment for bait dragging when weather conditions prevent vessels from operating in the more exposed areas of the Harbour. Data obtained in this way shows the main areas that are used within the Harbour for this activity.

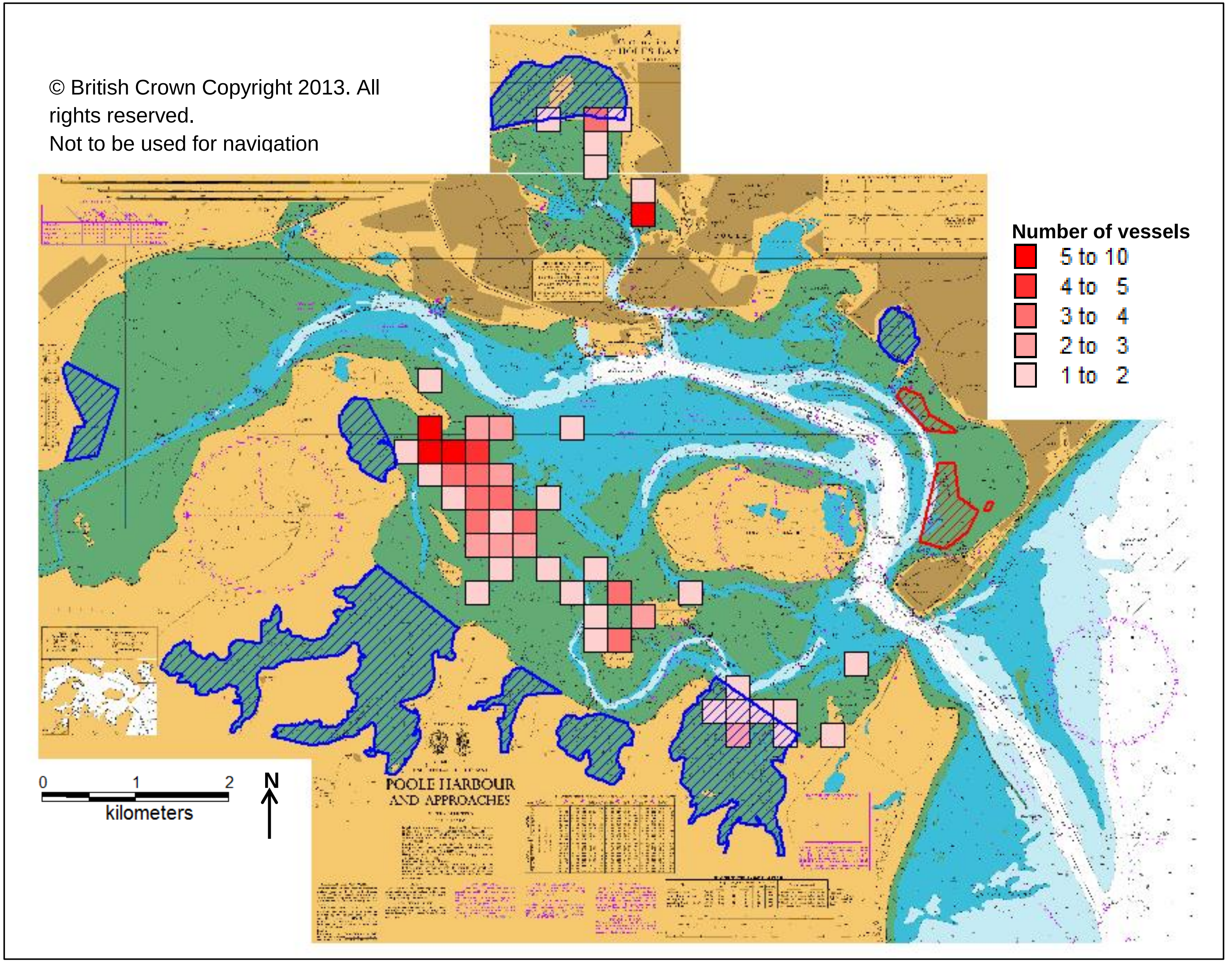


Figure 4.1: Positional data of bait dragging vessels between September 2012 and June 2013 collected as part of Southern IFCA officer patrols. Grid cells are shaded according to the number of vessels recorded per cell over the 10 month period. Bird sensitive areas, seagrass beds.

The results show (Figure 4.1) that over the 10 months of observation there was realtively little overlap between bait dragging activity and the conservation features of Poole Harbour. In Brands Bay, incursions into the bird senstive area were seen during November to April with a maximum of three boats in the area at any one time.

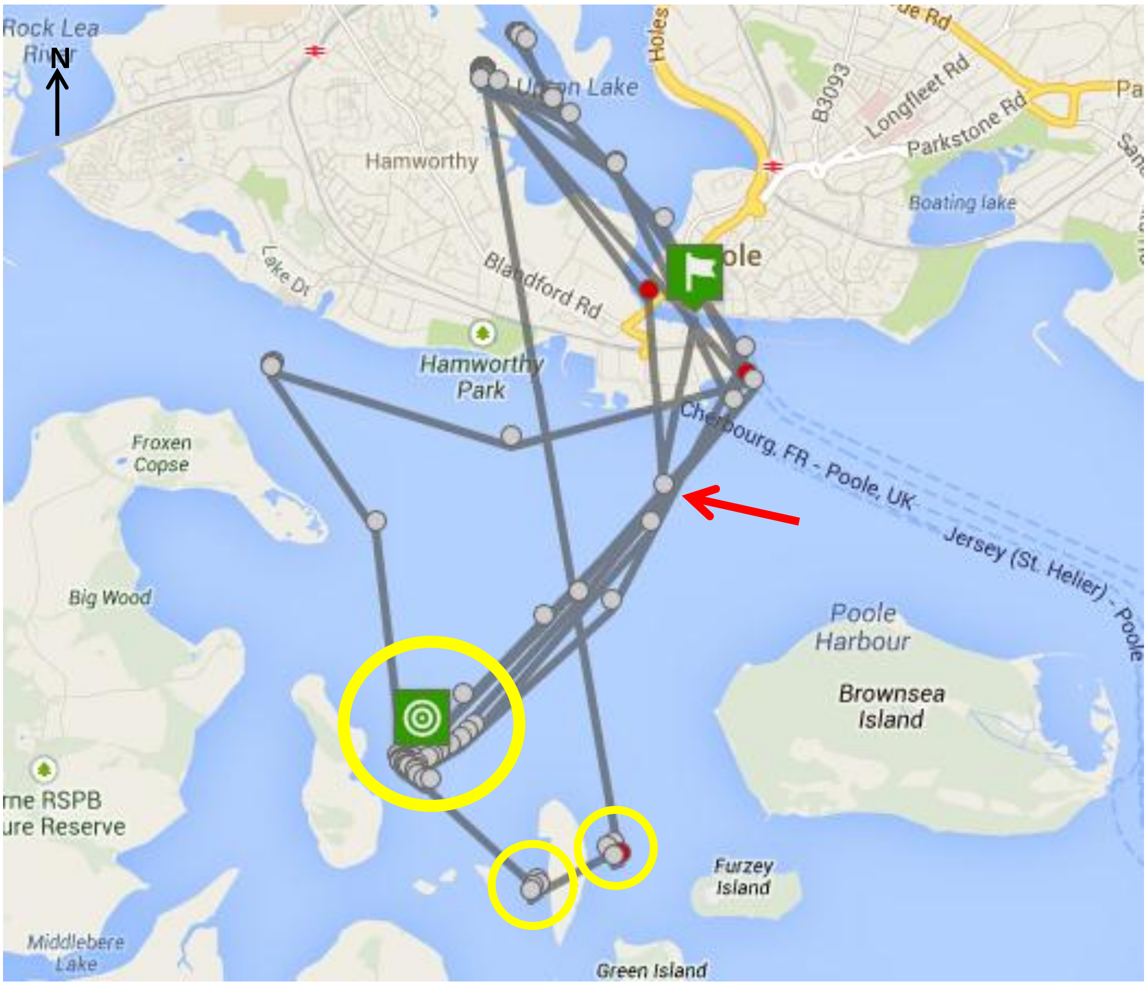


Figure 4.2: screenshot of the graphical user interface of the Succorfish SC2 iVMS system on 10 minute reporting for a two day period. Each grey circle represents a recorded position. The red arrow indicates the routes used by the vessel when transiting and the yellow circles show the concentration of positions indicative of fishing activity.

4.1.2 iVMS Positional Data

Data recorded at 10 minute intervals (Figure 4.2) from September 2012 to May 2013 were plotted over a 250m^2 grid and grid cells shaded according to time spent per cell. The data was grouped into five areas within the Harbour, based on the most common areas used for bait dragging activity (Figure 4.3) and the time spent per area was compared. Data for September, October, November, February, March and May are shown in Figure 4.4a-f, data for December, January and April were not available (see Materials and Methodology, section 3.2.3). For analysis, the number of 0 time results in grid squares necessitated that the data be transformed, an arcsinh transformation was applied to the dataset. Results showed that there was a significantly longer amount of time spent in Area 1 during October than in September, March and May ($H=36.500$, $df=5$, $P<0.001$, Kruskal-Wallis Test) and that this area was used significantly more than Area 4 in October ($H=11.469$, $df=3$, $P<0.05$, Kruskal-Wallis Test) and in November ($H=20.953$, $df=3$, $P<0.001$, Kruskal-Wallis Test).

Area 2 also showed significantly higher usage in November than September, October, March and May and in October than September, March and May ($H=43.297$, $df=5$, $P<0.001$, Kruskal-Wallis Test). Area 4 showed higher usage during the spring, with March showing significantly more fishing activity than September ($H=25.705$, $df=5$, $P<0.001$, Kruskal-Wallis Test) and overall, time spent in this area was significantly higher in March when compared to Areas 2 and 3 ($H=17.595$, $df=3$, $P<0.001$, Kruskal-Wallis Test).

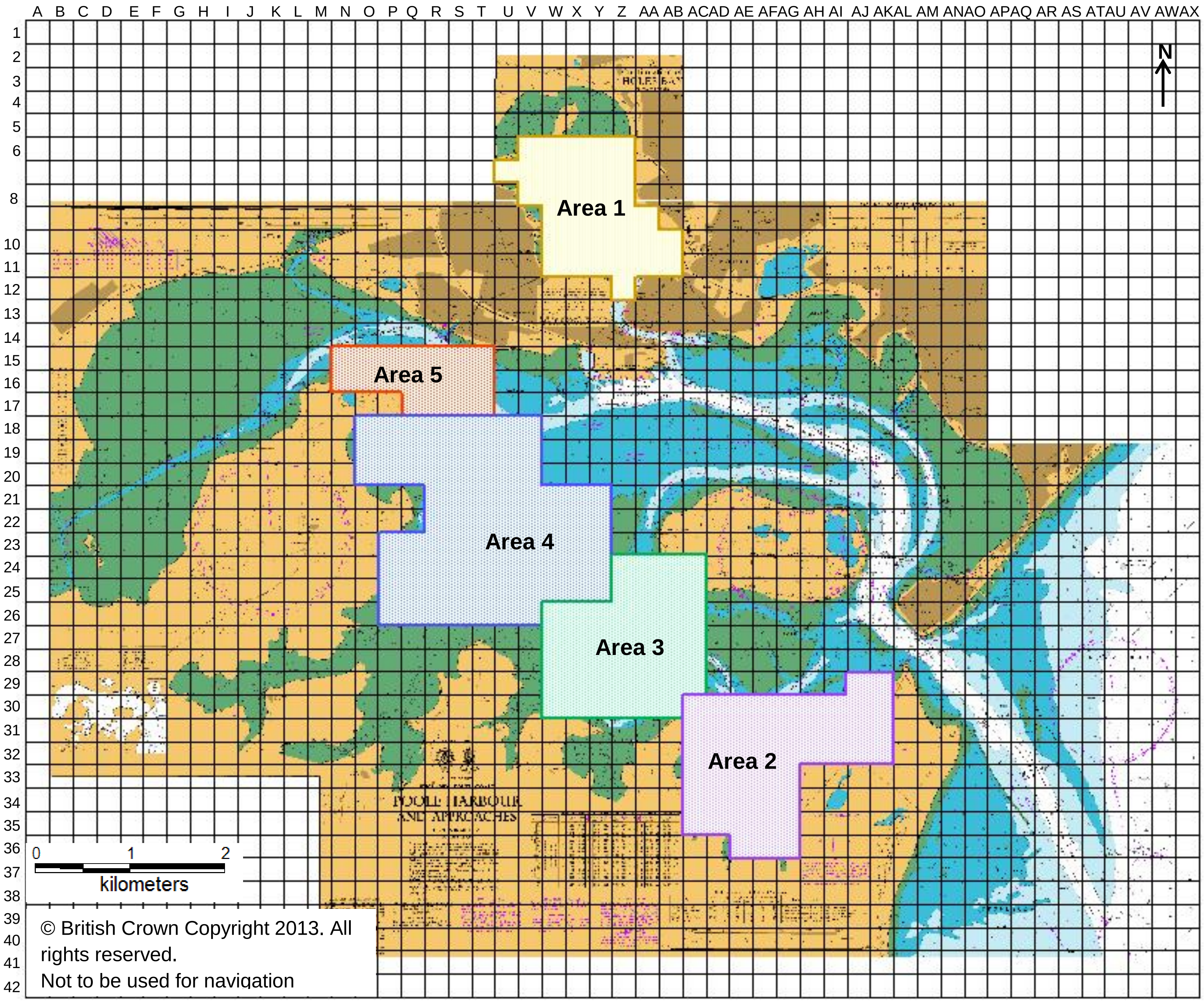


Figure 4.3: Chart of Poole Harbour overlaid with 250m^2 grid. Time spent per grid square was determined and from the general pattern of common usage by bait dragging vessels, five areas were outlined. Time spent per area was calculated and compared between months for which positional data was available. The same grid and areas were used for both the 10 minute and 1 minute reporting datasets.

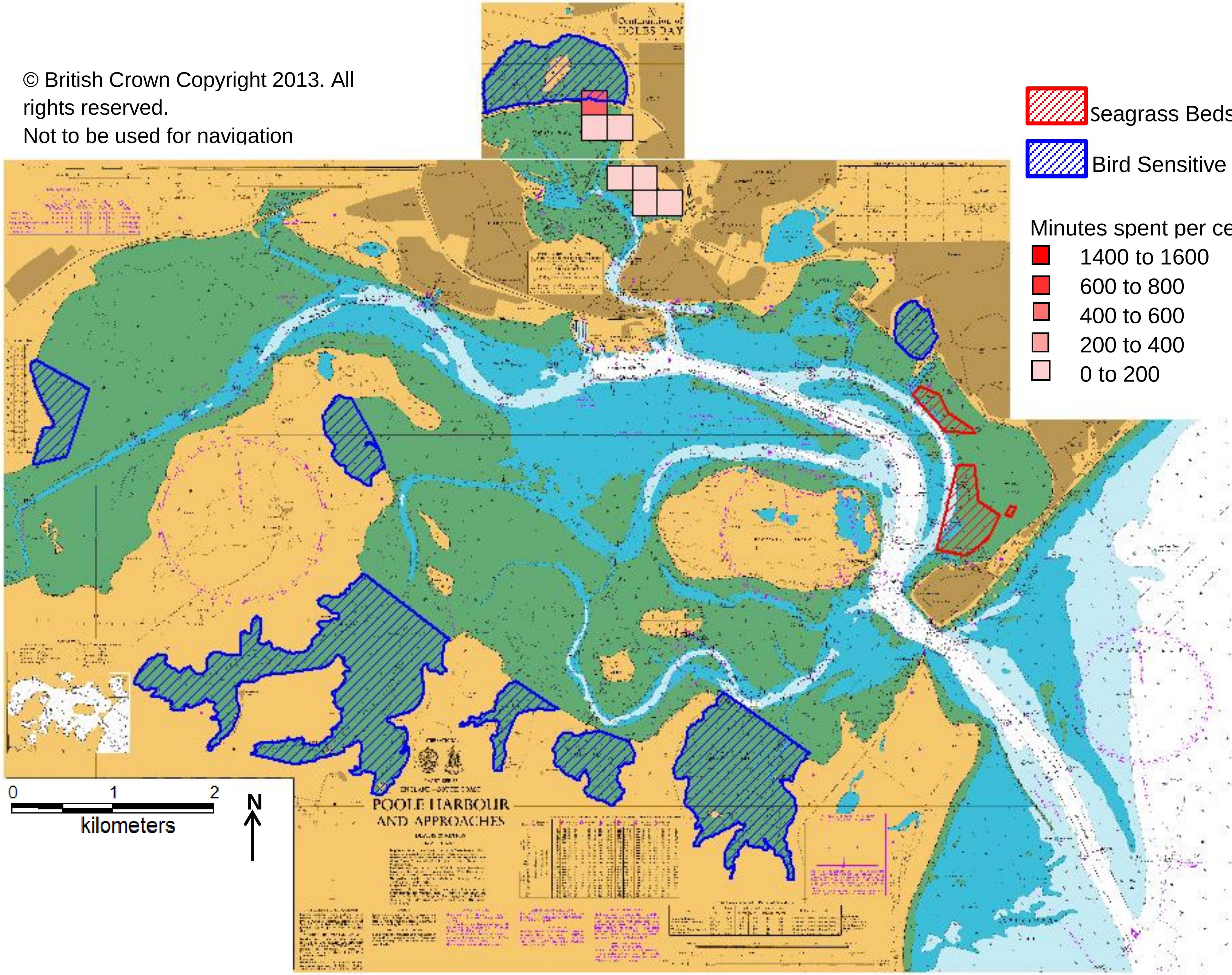


Figure 4.4a: iVMS data for September 2012 based on 10 minute reporting of positional data. Data is shown as time spent per grid cell (250m^2 grid) overlaid with the bird sensitive areas and seagrass beds within Poole Harbour. Incursion north of railway line in Holes Bay is caused by the grid position; there was no activity in this area.

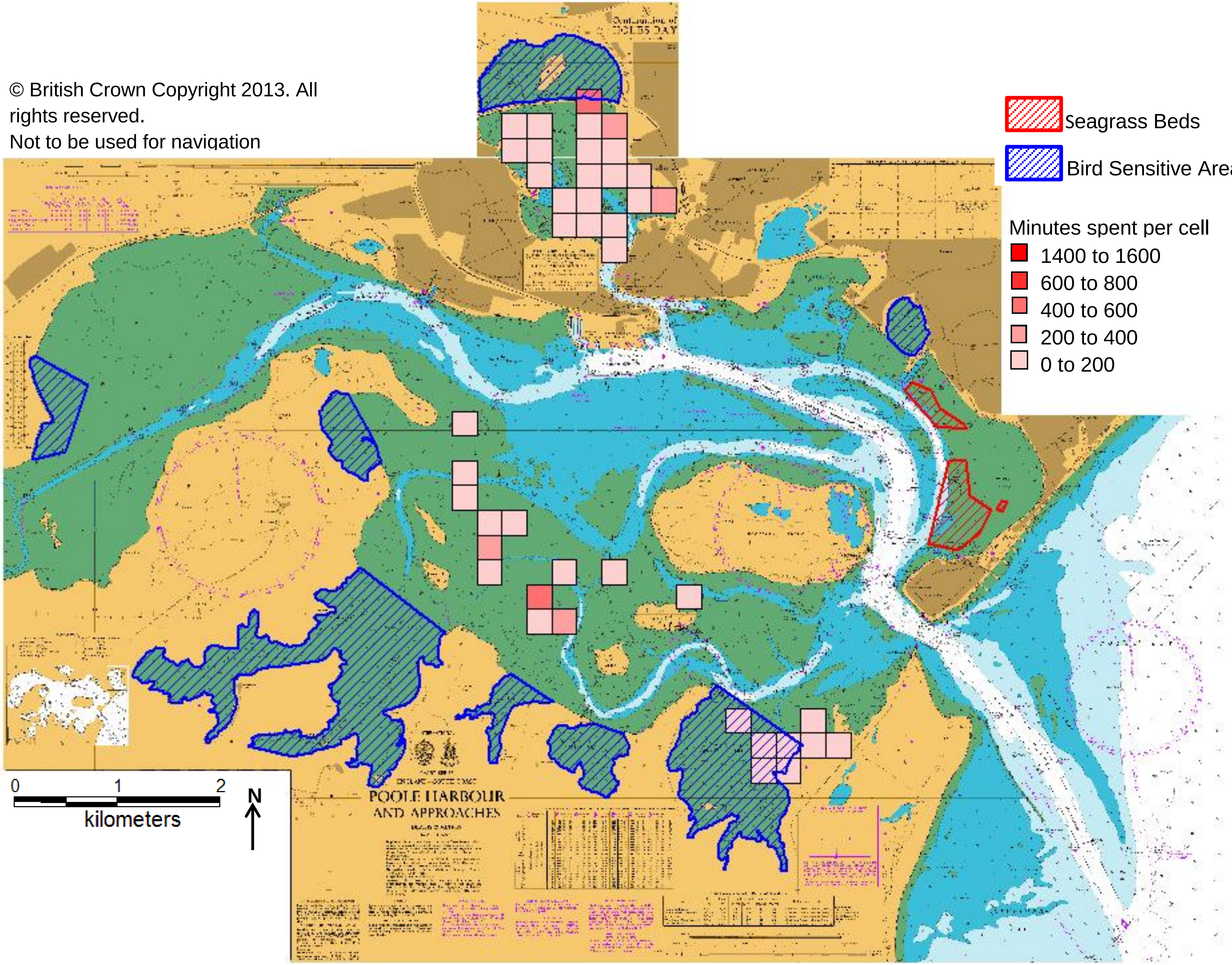


Figure 4.4b: iVMS data for October 2012 based on 10 minute reporting of positional data. Data is shown as time spent per grid cell (250m^2 grid) overlaid with the bird sensitive areas and seagrass beds within Poole Harbour. Incursion north of railway line in Holes Bay is caused by the grid position, there was no activity in this area.

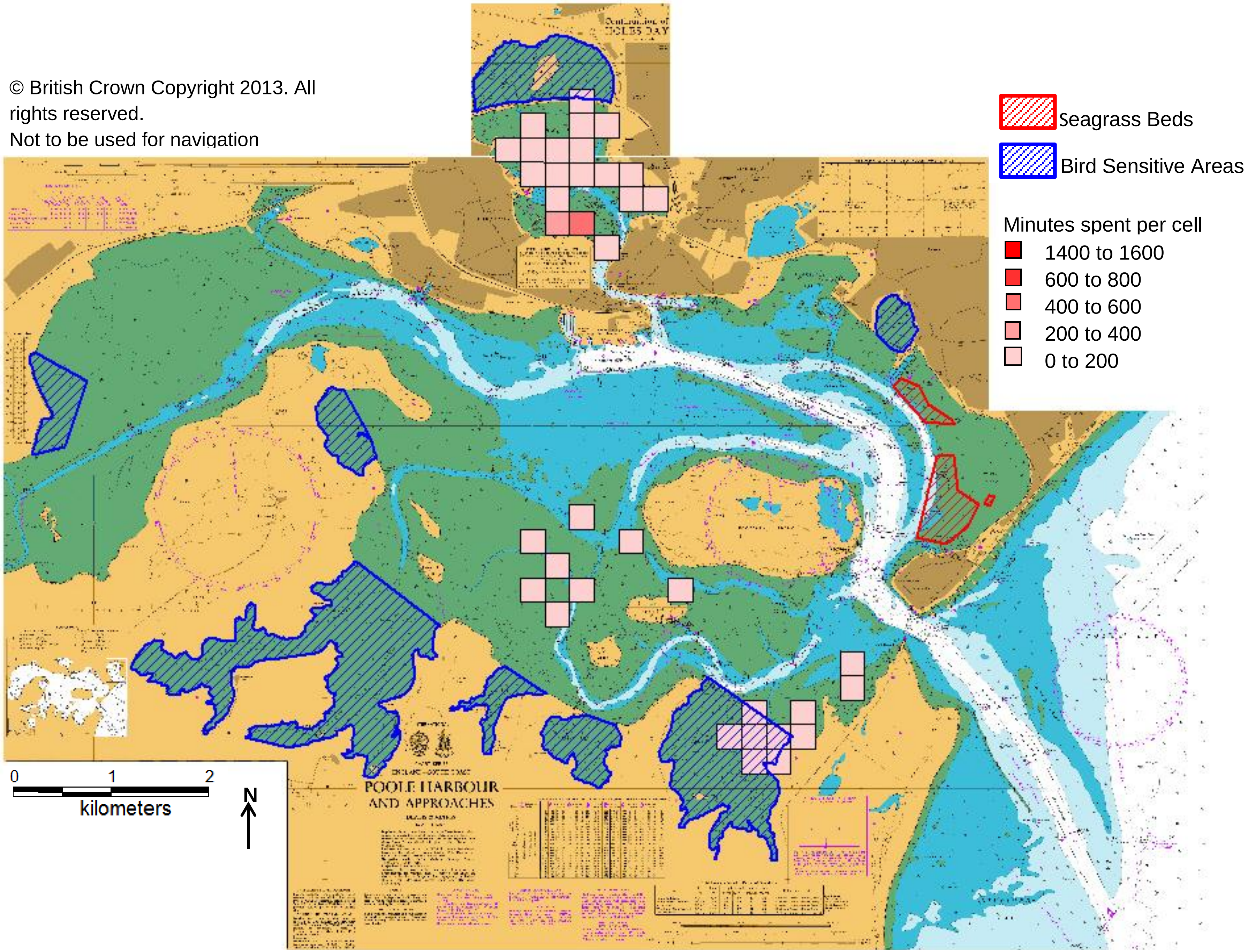


Figure 4.4c: iVMS data for November 2012 based on 10 minute reporting of positional data. Data is shown as time spent per grid cell (250m^2 grid) overlaid with the bird sensitive areas and seagrass beds within Poole Harbour. Incursion north of railway line in Holes Bay is caused by the grid position; there was no activity in this area.

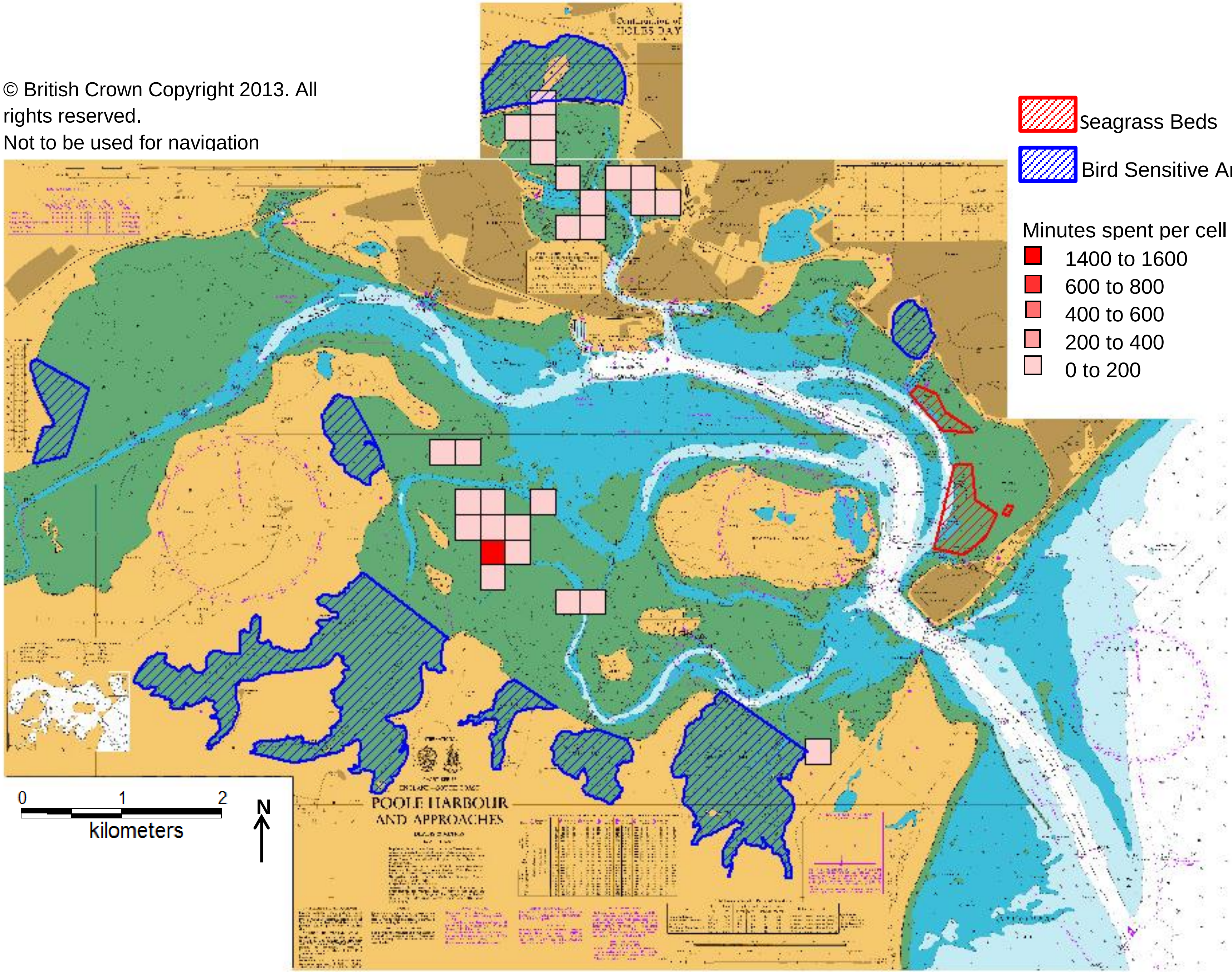


Figure 4.4d: iVMS data for February 2013 based on 10 minute reporting of positional data. Data is shown as time spent per grid cell (250m^2 grid) overlaid with the bird sensitive areas and seagrass beds within Poole Harbour. Incursion north of railway line in Holes Bay is caused by the grid position; there was no activity in this area.

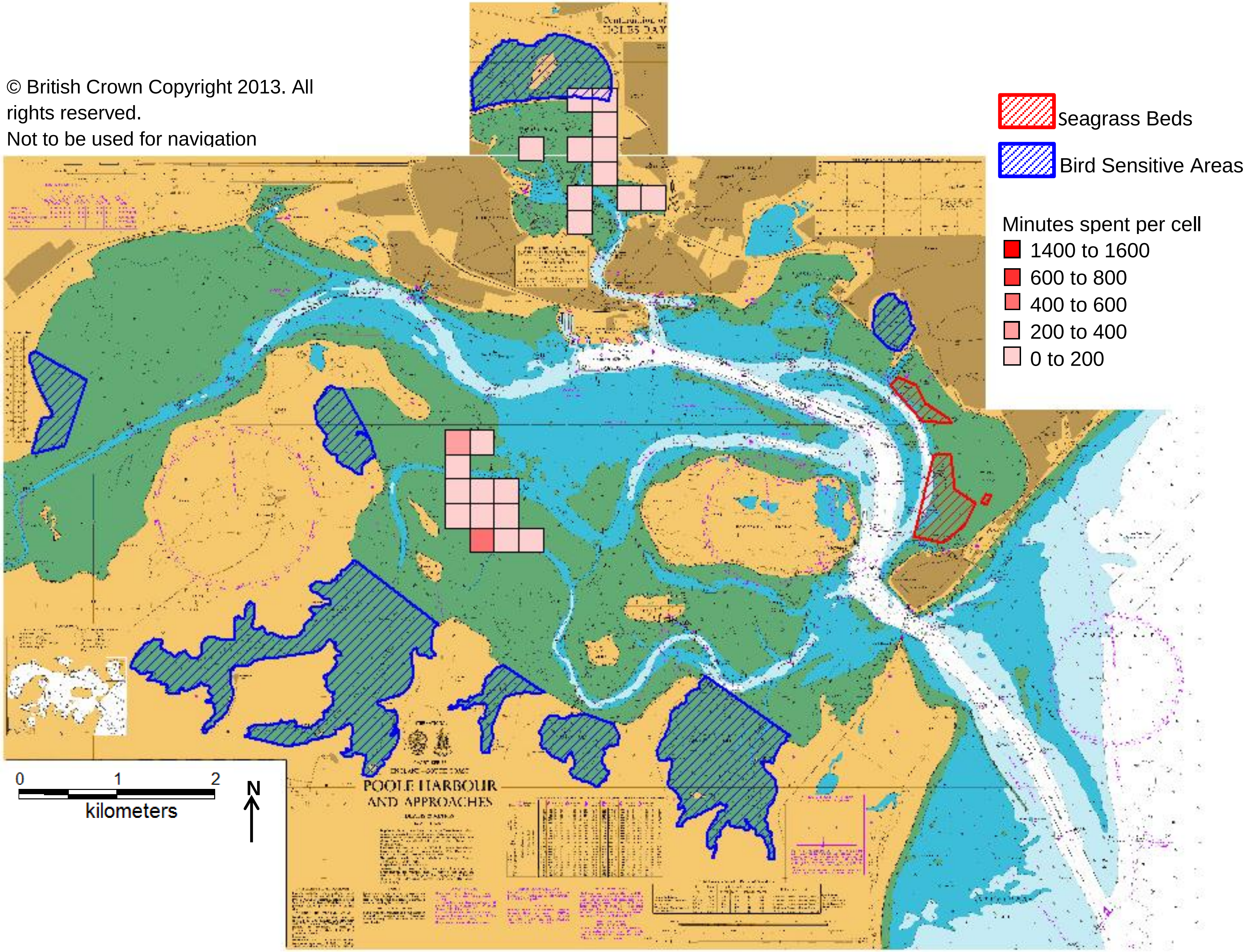


Figure 4.4e: iVMS data for March 2013 based on 10 minute reporting of positional data. Data is shown as time spent per grid cell (250m^2 grid) overlaid with the bird sensitive areas and seagrass beds within Poole Harbour. Incursion north of railway line in Holes Bay is caused by the grid position; there was no activity in this area.

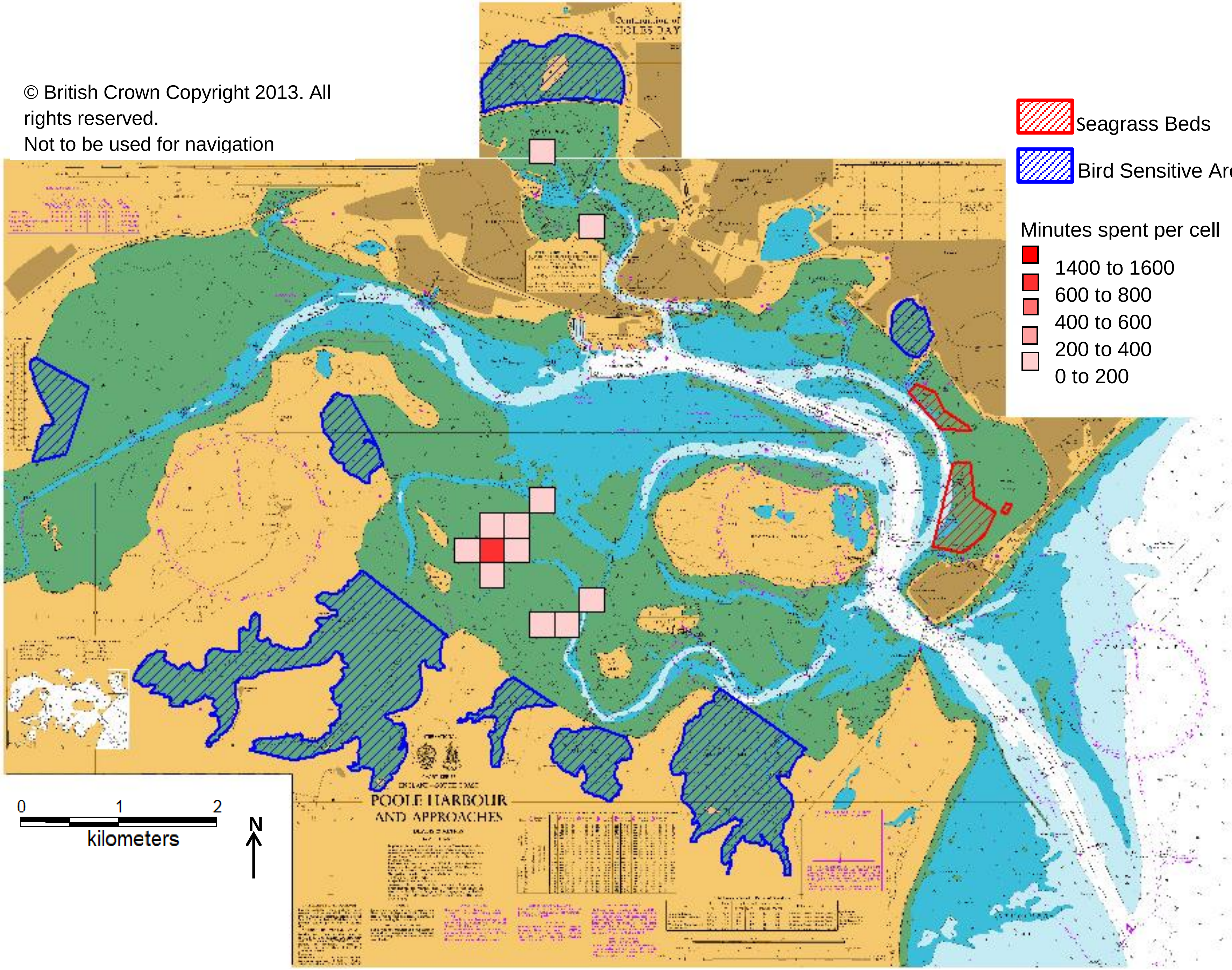


Figure 4.4f: iVMS data for May 2013 based on 10 minute reporting of positional data. Data is shown as time spent per grid cell (250m^2 grid) overlaid with the bird sensitive areas and seagrass beds within Poole Harbour.

For May and June 2013, the iVMS system was switched to 1 minute reporting to see from a visual perspective whether the increase in position recording provided a clearer picture of the areas used for fishing within the harbour (Figure 4.5). The appearance on the graphical user interface shows more detail within areas used for fishing than on 10 minute reporting, showing how the area is used during the process of bait dragging. This data could be particularly useful if comparing positional data to potential scaring caused by fishing activity within the same area. However, for determining the areas used for fishing, both the 10 minute and 1 minute reporting show these areas to be clearly defined.

The 1 minute data set was assigned to the same 250m^2 grid as the 10 minute data (Figure 4.6a-b) and time spent per each of the previously defined areas was calculated. The data had an arcsinh transformation applied due to the presence of 0 time data within grid cells.

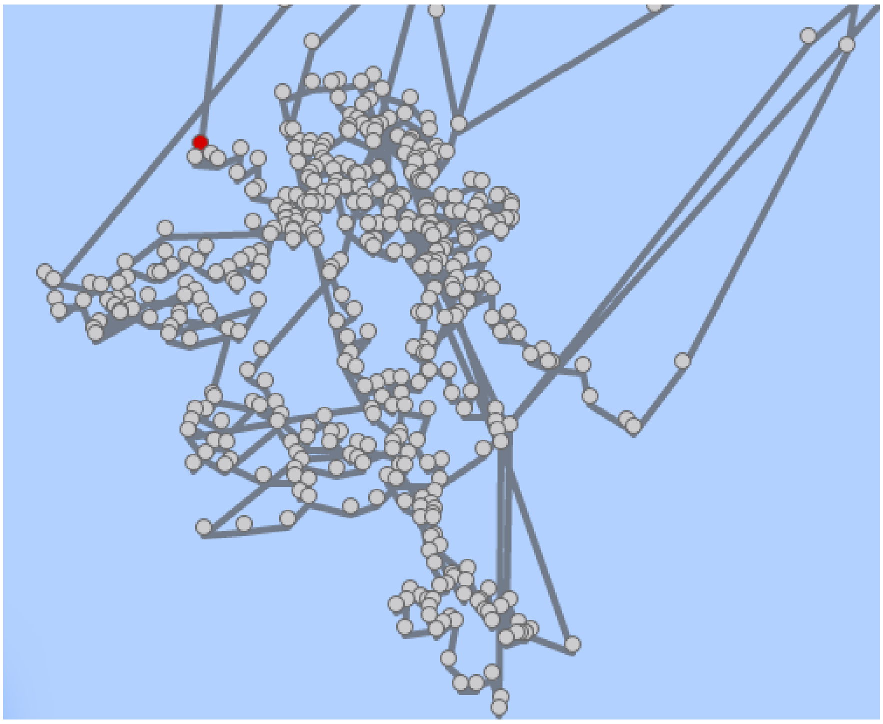


Figure 4.5: screenshot of the graphical user interface of the Succorfish SC2 iVMS system on 1 minute reporting zoomed in on an area used for fishing activity. Each grey circle represents a recorded position.

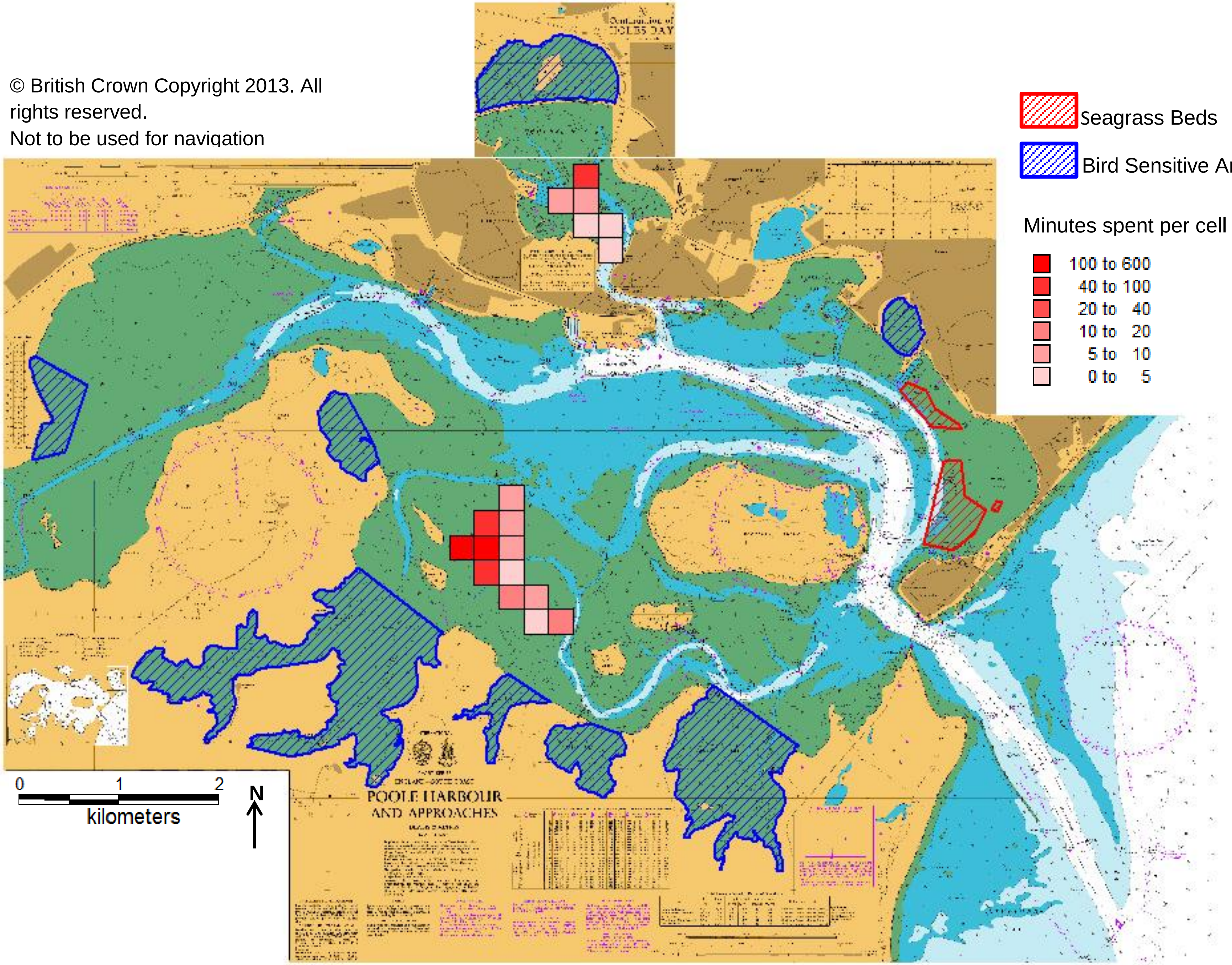


Figure 4.6a: iVMS data for May 2013 based on 1 minute reporting of positional data. Data is shown as time spent per grid cell (250m^2 grid) overlaid with the bird sensitive areas and seagrass beds within Poole Harbour.

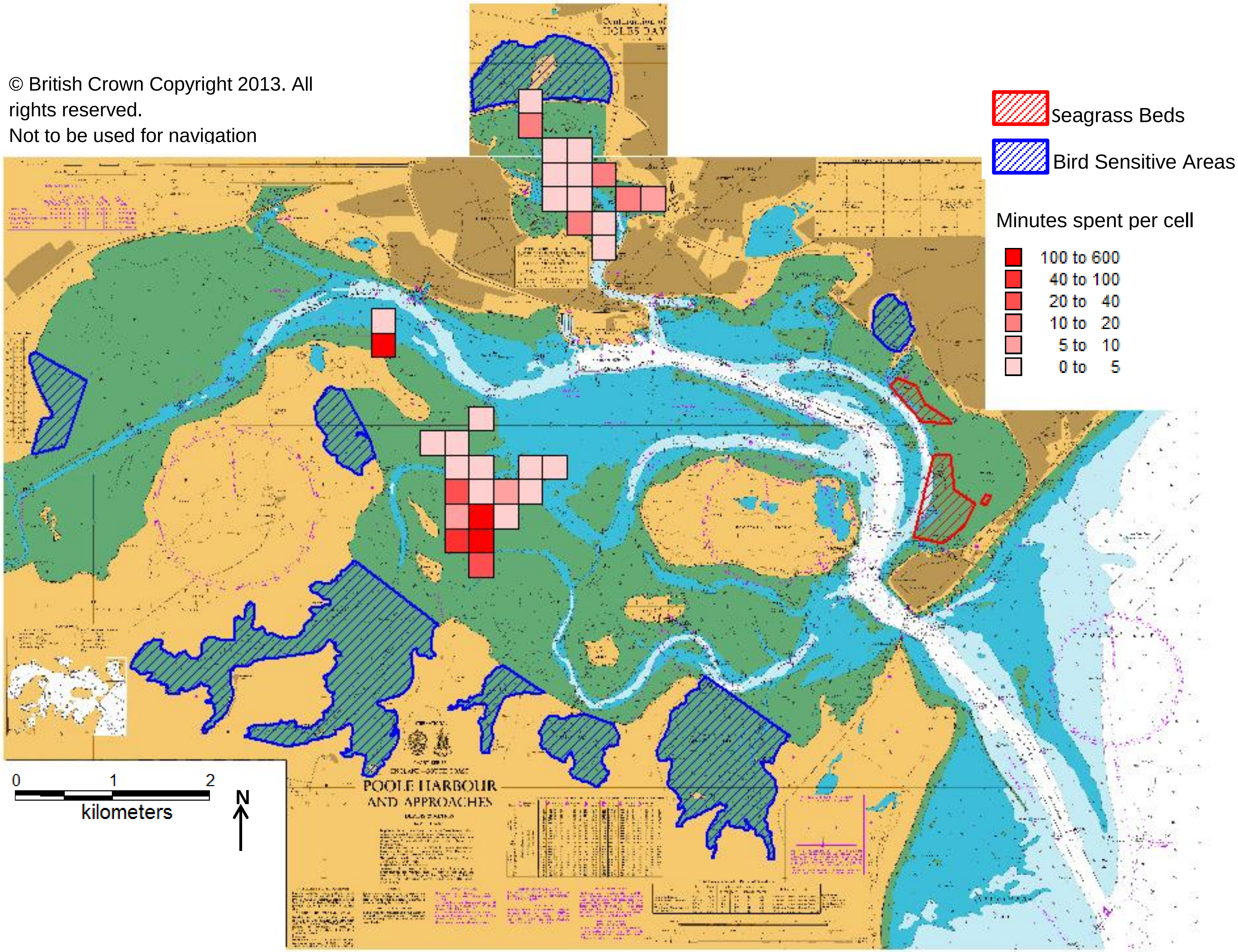


Figure 4.6b: iVMS data for June 2013 based on 1 minute reporting of positional data. Data is shown as time spent per grid cell (250m^2 grid) overlaid with the bird sensitive areas and seagrass beds within Poole Harbour. Incursion north of railway line in Holes Bay is caused by the grid position, there was no activity in this area.

The data showed no significant difference between May and June for any of the areas except Area 1 which showed a higher level of activity in June than May (U=55.00, $P<0.05$, Mann-Whitney U-Test). The average time spent in this area for June was 6 minutes which is comparable with the results shown for the 10 minute data which indicated lower levels of activity in Area 1 for the spring and summer months than in the autumn and winter. For the months where data was available for the same area, comparisons showed no significant difference between the areas used within the same month.

The general pattern shown by the 10 minute reporting data is that Area 1 (Holes Bay) and Area 2 (Brands Bay) are used preferentially during the months of October and November (Figures 4.4b and 4.4c), with Area 1 being preferred to the areas around Arne Bay (Area 4) and the islands on the western side of the Harbour. This western area appears to be used more for bait dragging activity during March. The data matches the general pattern shown by the sightings data (section 4.1.1) indicating that the enclosed bays of the Harbour are preferred fishing areas, probably because they provide more shelter from wind and wave action during months where weather conditions are likely to be less compatible with fishing activity. Conversely, in the spring when weather conditions in the wider harbour are likely to be suitable for bait dragging, the vessel fitted with the iVMS system and those seen through general sightings show more activity in the western Harbour. These patterns are also shown in the “1 minute reporting data” with the majority of fishing activity occurring within the area of Arne Bay and the western islands, although there appears to be activity in Holes Bay. The difference in the reporting interval time (1 minute versus 10 minute) means that the time spent in Holes Bay is low, more consistent with the vessel engaging in minimal fishing activity either immediately on leaving or before returning to its berth, which is located in Holes Bay, in addition to the main fishing activity occurring in the wider harbour during these months.

4.1.3 Dragging Effort and Bait Obtained Per Drag

Between September 2012 and June 2013, each month on a neap and spring high tide the number of drags deployed by up to four bait dragging vessels (four vessels were not always present) were recorded over a half hour period (Figure 4.7). The data was converted to the number of drags per hour for each vessel and results were compared between months and between different tide states. The number of drags per hour varied between 30 and 117 across all months and tide states, results showed that there were no significant differences between the number of drags used per hour between any of the months sampled or between spring and neap tides, indicating that levels of effort by bait dragging vessels on a specific fishing area is independent of season and tidal phase.

The amount of bait obtained per drag was assessed by extrapolating the amount of bait taken per drag for a known vessel to the vessels for which the number of drags per hour was determined. The ash free dry weight of bait obtained per drag in grams was compared between months and tide phases as above (Figure 4.8). The average quantity of bait taken per drag varied between 182.9 g and 277.4 g across all months and tide states. Results showed that there was no significant difference in the amount of bait obtained per drag between months or between different tide phases.

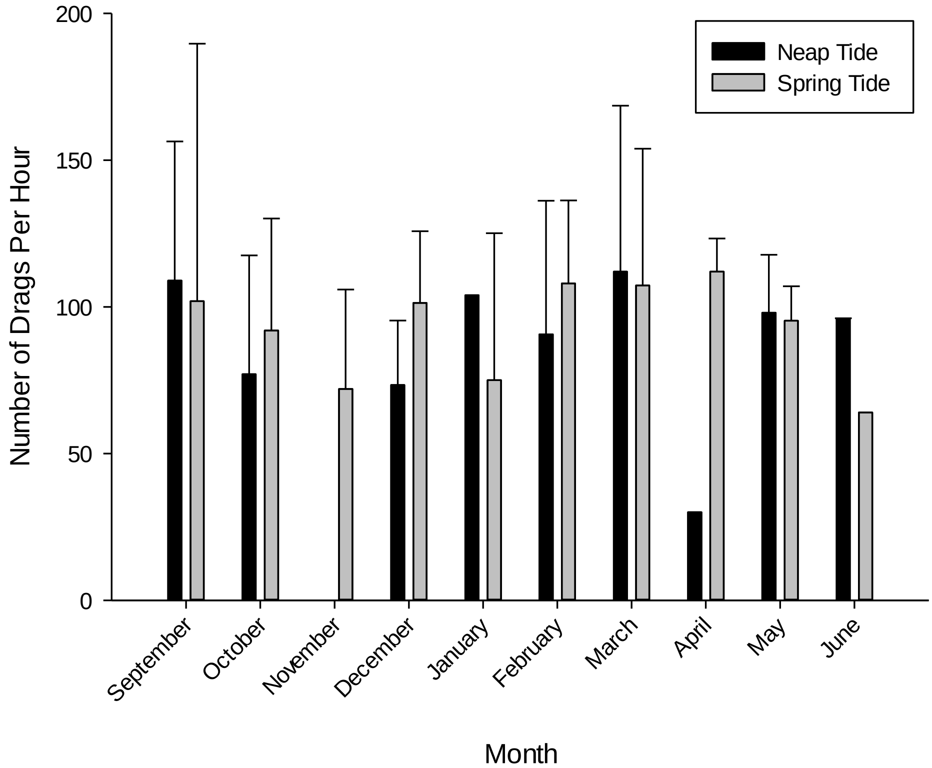


Figure 4.7: average number of drags per hour for up to four bait dragging vessels between September 2012 and June 2013. Results are shown for neap and spring tides each month. Error bars refer to standard deviation.

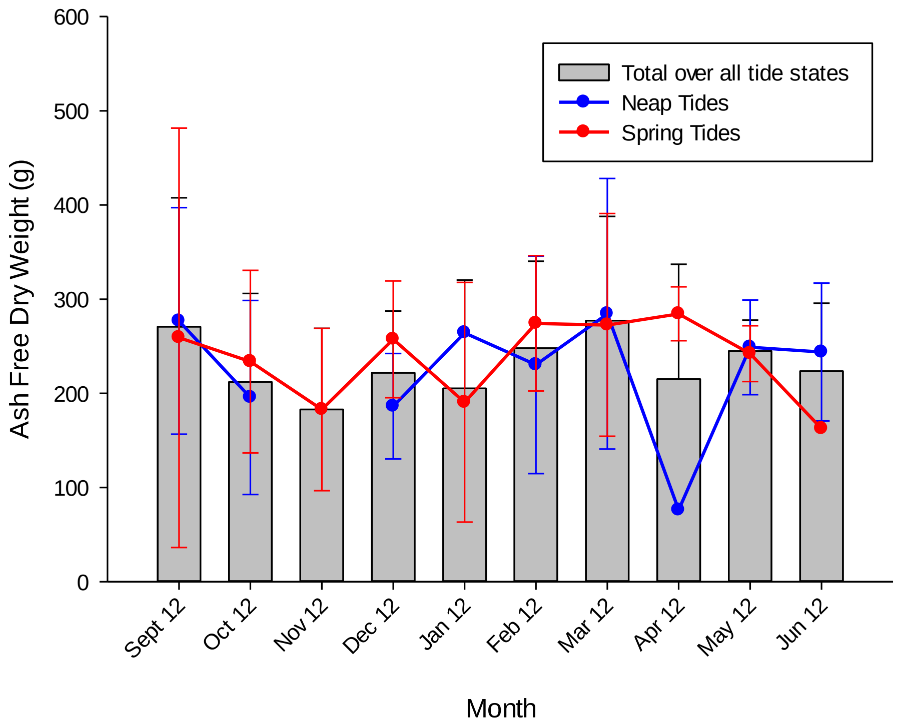


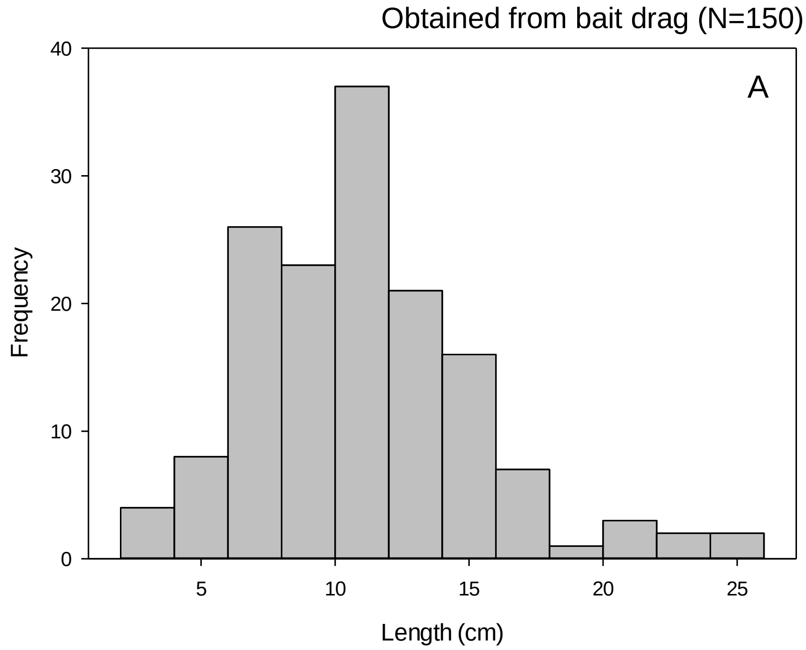
Figure 4.8: average ash free dry weight of bait per drag (g) for up to four bait dragging vessels between September 2012 and June 2013. Results are shown for neap and spring tides each month as well as the total across both tide states. Error bars refer to standard deviation.

Both of these results indicate that the amount of bait removed from the harbour as well as the effort level of dragging is dependent on the number of boats present in the area at any one time rather than the impact that an individual vessel is having as single vessel activity does not appear to vary in intensity over a seasonal cycle.

4.2 Impacts of Bait Dragging on the Marine Environment

4.2.1 Target Species

Samples were taken during October 2012, February, April and June 2013 from five sites in Poole Harbour (see section 3.1). The general pattern of abundance across October, April and June was very low with only 21 out of 75 samples containing worms of the family Nerididae. Within these 21 samples, 12 contained only a single worm. The data showed no significant difference in the abundance of worms between months for each sampling site, and for October and April, no difference in abundance between sites. June however showed a significantly higher abundance of worms at site 1 when compared to sites 2c and 2d ($H=15.051$, $df=4$, $P<0.05$, Kruskal-Wallis). Because of the low number of worms and the general small length of individuals, comparisons were made between the length of the worms obtained experimentally using the scoop method and those obtained from a bait dragging vessel. The length of organisms preserved in formalin and alcohol is inherently variable, however this analysis was undertaken to show the difference in the bait worms obtained from a bait drag and the experimental method within a similar area of the Harbour. The experimental samples should have contained ragworm of marketable size in large quantities as seen from the bait dragging activity; this suggests that the method of obtaining target species samples used in this study needs refining so that full comparisons can be made between areas used for dragging and those that are not. Figure 4.9 shows size frequency histograms for the two sets of Nerididae and there is a clear difference with the dominant size class for the scoop obtained individuals being 2> to ≤4cm and the dominant size class for the dragged individuals being 10> to ≤12cm, the median for the dragged samples being significantly larger than the median of the scoop obtained samples (U=450.00, P<0.001, Mann-Whitney U-Test). The overall range of size classes varied between methods with worms up to 26cm in length in the dragged samples compared with worms up to 20.6cm in length from the scoop samples.



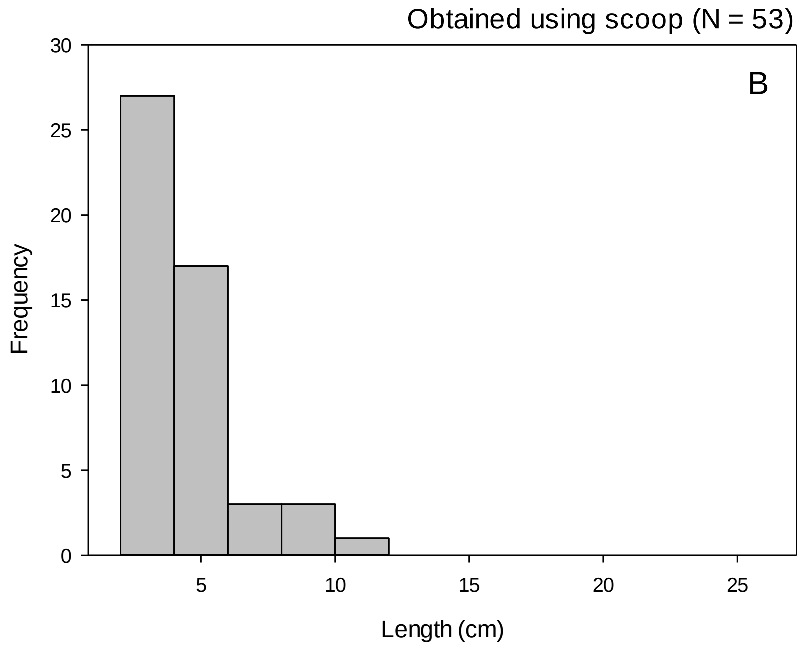


Figure 4.9: size frequency histograms for Nerididae found in A) samples from a bait drag and B) samples obtained using the experimental scoop method. There is a greater range of size classes shown for the individuals obtained through bait dragging ranging up to 26cm in length.

Phi Value	Grain Size (µm)	Wentworth Size Class	
-6 to -1	2000 - 63000	Gravel	
-1 to 0	1000 - 2000	Very coarse	Sand
0 to 1	500 - 1000	Coarse	
1 to 2	250 - 500	Medium	
2 to 3	125 - 250	Fine	
3 to 4	62.5 - 125	Very fine	
4 to 5	31.3 - 62.5	Coarse	Silt
5 to 6	15.6 - 31.3	Medium	
6 to 7	7.81 - 15.6	Fine	
7 to 8	3.91 - 7.81	Very fine	
8 to 10	0.98 - 3.91	Clay	

Table 4.2: Wentworth size class grading for sediment grain size, class is listed against the phi value and grain size in micrometres. Grouping of data resulted in grains across 11 size classes from -1 to -6 phi to 10 to 8 phi covering the spectrum from gravel to clay respectively.

4.2.2 Sediment

4.2.2.1 Sediment Structure

Sediment samples were analysed to determine the percentage of different grain size fractions. The data was grouped according to the Wentworth Scale for size class grading of sediment grains (Table 4.2) based on phi value data, resulting in 11 size classes from -1 to -6 phi to 10 to 8 phi covering the spectrum from gravel to clay respectively. Figure 4.10a-d shows the monthly sediment profiles for each sampling site indicating the percentage of different grain size fractions.

As the data was presented as percentages, it required transforming using an arcsine transformation. The data was then analysed using a mixture of ANOVA and Kruskal-Wallis tests.

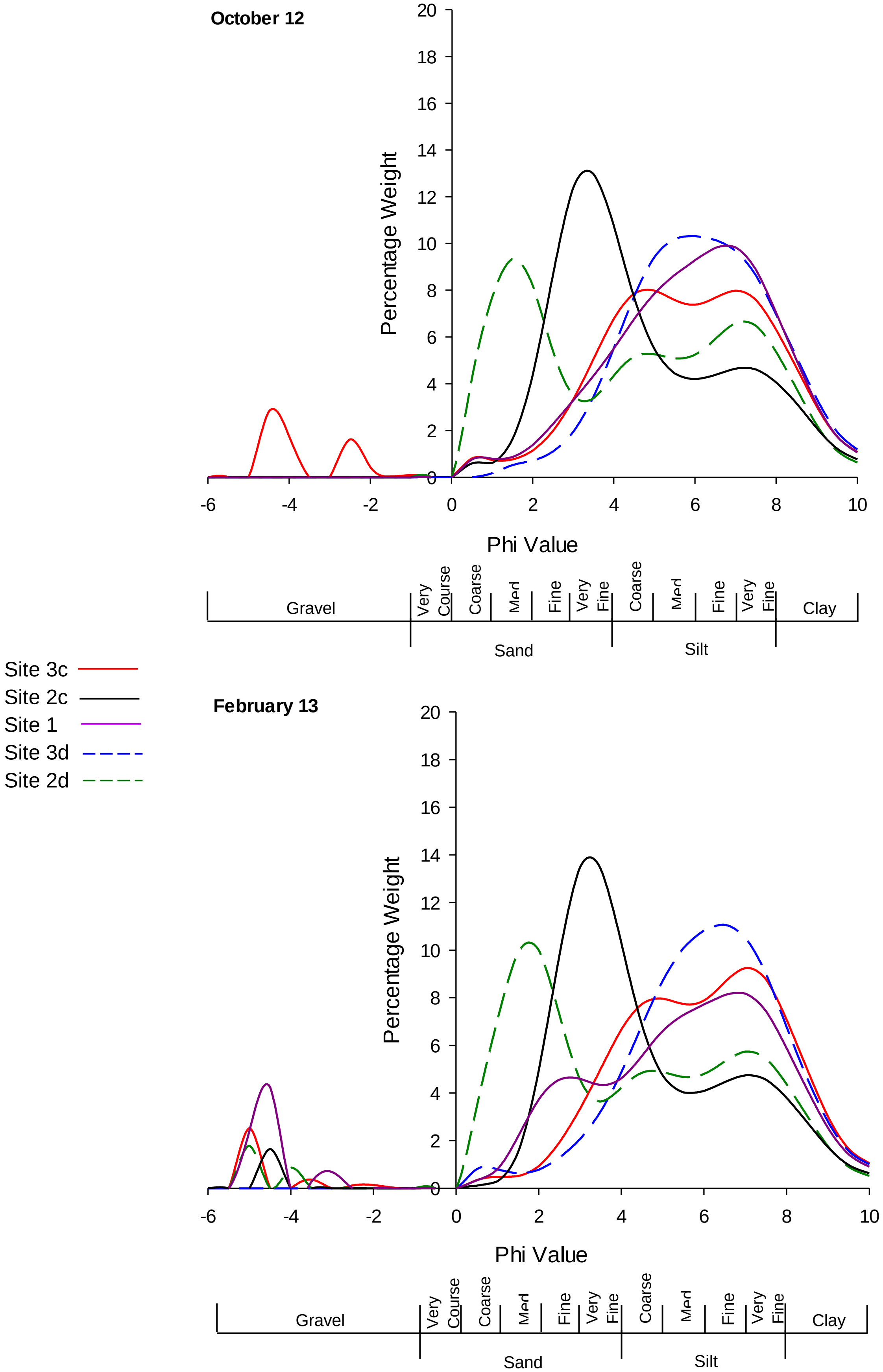


Figure 4.10a-b: sediment grain size profiles according to phi value for sites 3c, 3d, 2d, 2c and 1 for a) October 2012 and b) February 2013. Sites 3d and 2d are represented by a hashed line to indicate that they are used for bait dragging activity. The sediment size class classifications for the Wentworth Scale are shown under each profile.

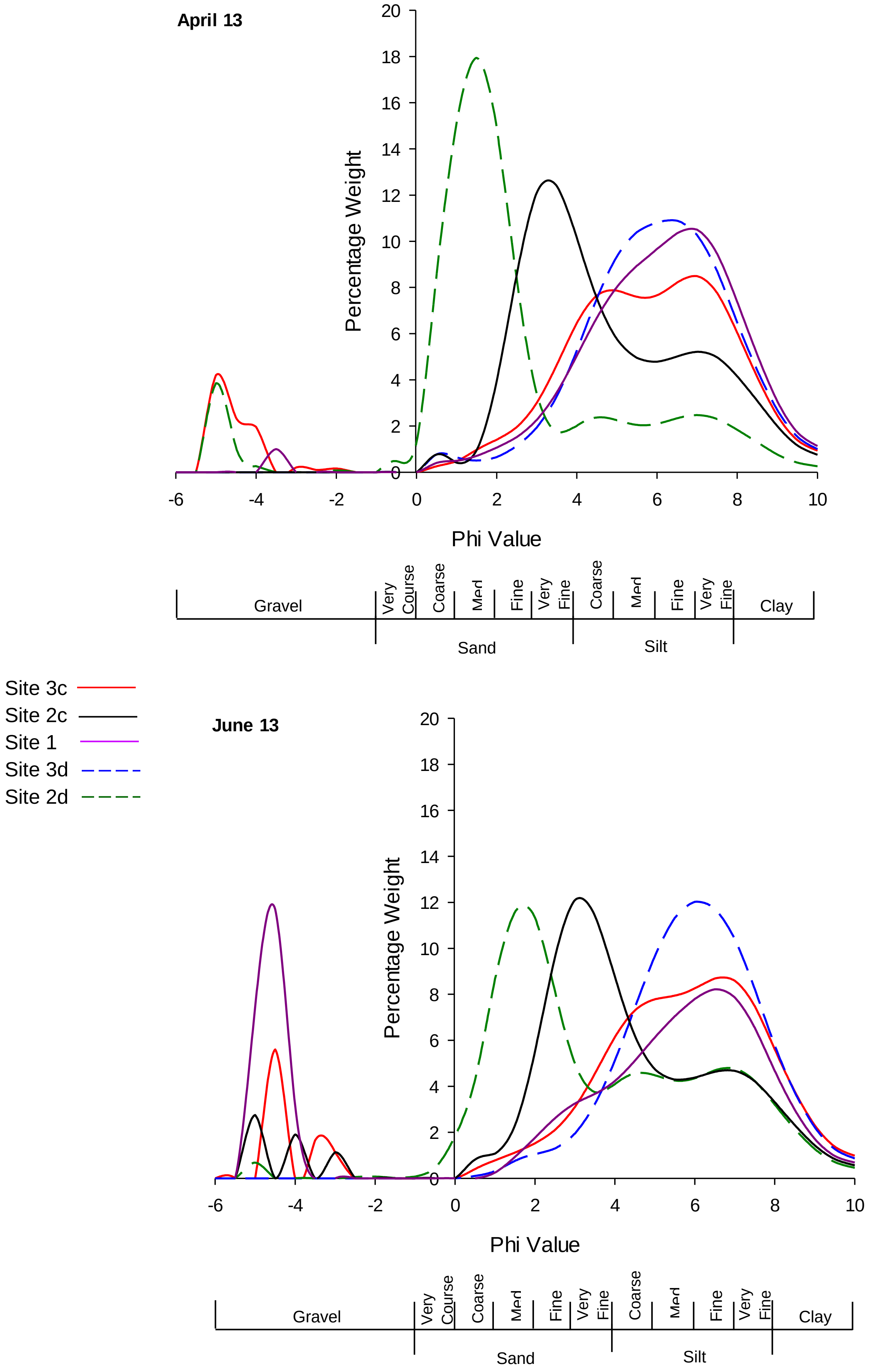


Figure 4.10c-d: sediment grain size profiles according to phi value for sites 3c, 3d, 2d, 2c and 1 for c) April 2013 and d) June 2013. Sites 3d and 2d are represented by a hashed line to indicate that they are used for bait dragging activity. The sediment size class classifications for the Wentworth Scale are shown under each profile.

When comparing data for the same site between the four months sampled, sites 3c and 2d showed no significant difference in the percentage of different grain size classes between all months sampled. The results for sites 3d, 2c and 1 showed a mixed pattern with the class of 10 to 8 phi, clay sediment, showing significantly lower percentages in June than other months at site 3d ($F_{3,12}=15.644$, $P<0.001$, one-way ANOVA), site 2c ($F_{3,12}=5.059$, $P<0.05$, one-way ANOVA) and site 1 ($F_{3,12}=8.895$, $P<0.05$, one-way ANOVA) and a significantly higher percentage in October than all months (d ($F_{3,12}=15.644$, $P<0.001$, one-way ANOVA). In addition for the month of June, the class of 6 to 5 phi showed a significantly higher percentage than for other months at site 3d ($F_{3,12}=9.154$, $P<0.05$) and at the same site a significantly high percentage at class 7 to 6 phi than for October ($H=7.922$, $df=3$, $P<0.05$). In addition June showed a significantly higher percentage of grains in the -1 to -6 phi class than October for site 1 ($F_{3,12}=4.225$, $P<0.05$) but a significantly lower percentage than October and April for class 8 to 7 phi ($F_{3,12}=6.384$, $P<0.05$). Other significant results were a lower percentage of size 5 to 4 phi in February than all months at site 3d ($F_{3,12}=7.328$, $P<0.05$) and at the same site October showed a significantly lower percentage in class 1 to 0 phi than February and April ($F_{3,12}=6.949$, $P<0.05$).

The general pattern appears to show that the percentage of smaller grain sizes representing the clay fraction are higher in the Autumn than in the Summer and that higher percentages of coarse sand and gravel are seen during the summer than the winter. There appears to be no set pattern of difference between sites that are dragged and those that are not temporally.

The data was also analysed between the five sites within each month sampled. The significant results are shown in Table 4.2. The overall pattern of the data shows

	October	February	April	June
10 to 8	H=9.971, df=4 P<0.05 Kruskal-Wallis	H=9.914, df=4 P<0.05 Kruskal-Wallis	H=16.671, df=4 P<0.05 Kruskal-Wallis	F4,15=6.526 P<0.05 One-way ANOVA
8 to 7	H=10.114, df=4 P<0.05 Kruskal-Wallis	H=11.283, df=4 P<0.05 Kruskal-Wallis	H=16.957, df=4 P<0.05 Kruskal-Wallis	F4,15=8.936 P<0.001 One-way ANOVA
7 to 6	H=12.805, df=4 P<0.05 Kruskal-Wallis	H=15.029, df=4 P<0.05 Kruskal-Wallis	H=17.029, df=4 P<0.05 Kruskal-Wallis	F4,15=15.088 P<0.001 One-way ANOVA
6 to 5	H=17.086, df=4 P<0.05 Kruskal-Wallis	H=14.786, df=4 P<0.05 Kruskal-Wallis	H=18.286, df=4 P<0.05 Kruskal-Wallis	F4,15=20.660 P<0.05 One-way ANOVA
5 to 4	H=15.400, df=4 P<0.05 Kruskal-Wallis	Not significant	H=15.011, df=4 P<0.05 Kruskal-Wallis	F4,15=6.450 P<0.05 One-way ANOVA
4 to 3	H=15.214, df=4 P<0.05 Kruskal-Wallis	H=16.241, df=4 P<0.05 Kruskal-Wallis	H=17.066, df=4 P<0.05 Kruskal-Wallis	F4,15=24.046 P<0.001 One-way ANOVA
3 to 2	F4,15=40.125 P<0.001 One-way ANOVA	H=14.771, df=4 P<0.05 Kruskal-Wallis	H=18.286, df=4 P<0.05 Kruskal-Wallis	F4,15=49.864 P<0.001 One-way ANOVA
2 to 1	Not significant	H=11.900, df=4 P<0.05 Kruskal-Wallis	H=17.001, df=4 P<0.05 Kruskal-Wallis	H=16.743, df=4 P<0.05 Kruskal-Wallis
1 to 0	F4,15=40.125 P<0.001 One-way ANOVA	F4,15=7.326 P<0.06 One-way ANOVA	F4,15=33.074 P<0.001 One-way ANOVA	F4,15=22.639 P<0.001 One-way ANOVA
0 to -1	Not significant	Not significant	Not significant	H=13.307, df=4 P<0.05 Kruskal-Wallis
-1 to -6	Not significant	Not significant	Not significant	Not significant

Table 4.2: Results comparing percentage of grains assigned to a particular grain size class between sites 3c, 3d, 2d, 2c and 1 across all four months sampled. A mixture of one-way ANOVA and Kruskal-Wallis tests were used as the data showed both normal and non-normal distributions.

that across all months, sites 3d and 3c showed a significantly higher percentage of grains within the size classes 10 to 8 phi, 8 to 7 phi, 6 to 5 phi and 5 to 4 phi (October, April and June only) than sites 2c and 2d. Similarly site 1 showed significantly higher percentages of grains within size classes 10 to 8 phi (clay) (April) and 8 to 7 phi (silt) (October and April) than sites 2c and 2d. Conversely, sites 2c and 2d showed significantly higher percentages of grains within the size class 3 to 2 phi (fine sand) (October, February, April and June), 2 to 1 phi (medium sand) (February, April and June), and 1 to 0 phi (coarse sand) (October, February, April and June, site 2d only) than sites 3c and 3d. Within the results for these sediment size classes, site 2c showed a significantly higher percentage of grains within class 4 to 3 phi (very fine sand) and 3 to 2 phi (fine sand) for all months than site 2d. Site 2d had significantly higher percentages of grains within class 1 to 0 phi (coarse sand) than site 2c across all months. These results indicate that within the area of site 2 there is a significant difference in the predominant grain size class between the area used for dragging and the control with the area used for dragging showing a higher percentage of coarser grained sand than the control area which is predominantly fine to very fine sand.

Looking at the grain size classifications between sites across all months, the general pattern seems to suggest that those differences seen relate to the area of Poole Harbour from which the samples were taken rather than the difference between sites used for dragging and the control sites. The lack of consistent pattern across different months suggests that these sites were similar in terms of sediment composition over a seasonal cycle and reiterates that the differences seen are more attributable to the location of the sample in the Harbour. The samples taken within

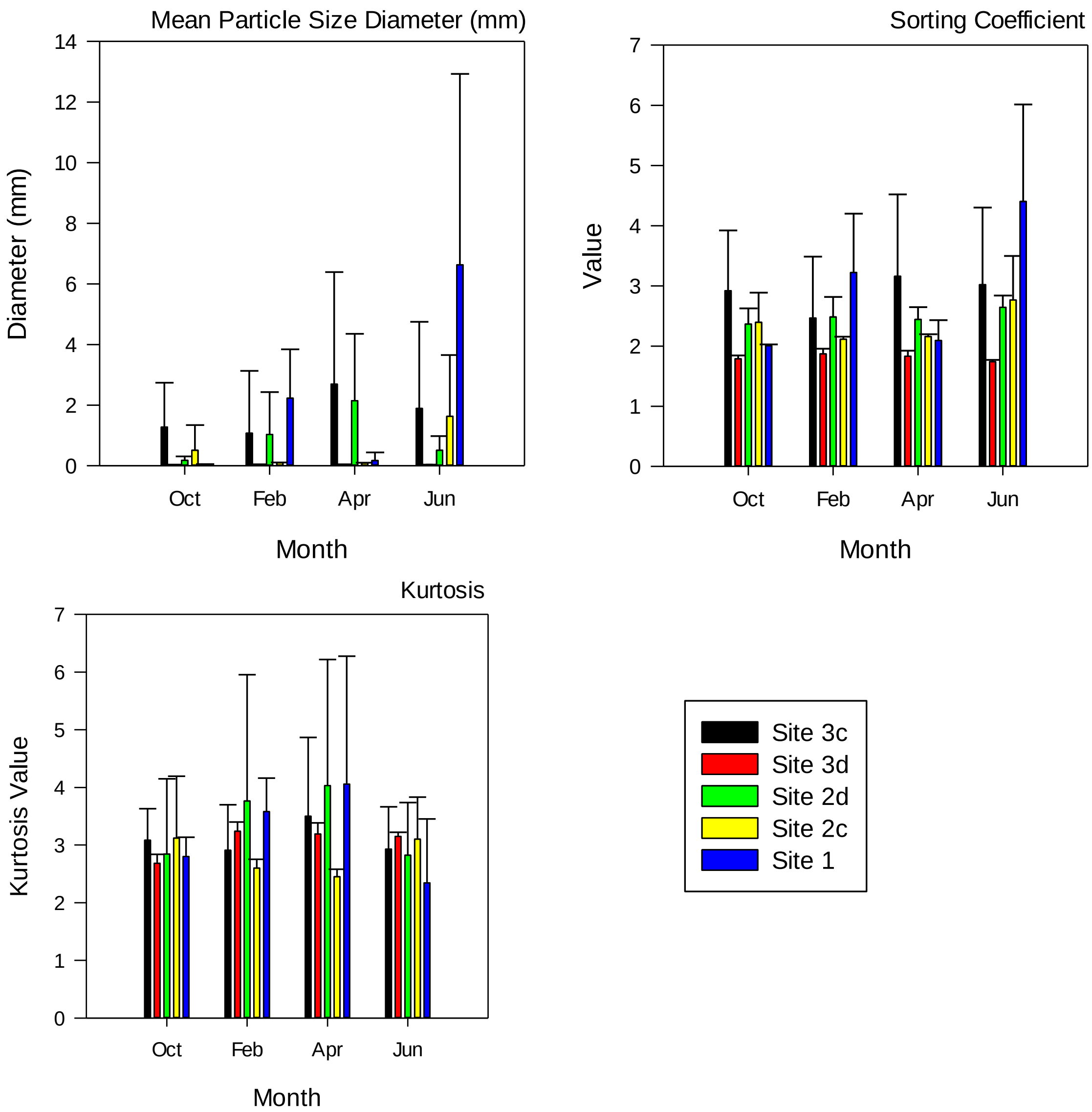


Figure 4.11: average mean particle diameter, sorting coefficient and kurtosis values for October, February, April and June across all sampling sites. Errors shown represent standard deviation.

sheltered bays such as site 1 in Newton Bay show a dominance of fine silt and clay fractions whereas the more exposed sites around Green Island, 2c and 2d showed a dominance of coarser grained sediment. The difference in the dominant fraction shown within these sites however indicates that the levels of bait dragging and other fishing activity within these areas may be having an effect on sediment structure.

In addition to assigning the data collected to grain size classes, values for Kurtosis, Skewness, Sorting-Coefficient and Mean Grain Size (mm) were also determined (Figure 4.11).

Results showed that there was no significant difference in the kurtosis value between the different sites during each of the sampling months. Sites 3c, 2d, 2c and 1 showed no significant difference in kurtosis value between months. Site 3d showed that values for October were significantly lower than all other months ($F_{3,12}$=11.634, $P<0.001$, one-way ANOVA) however all values for kurtosis were above 1 indicating that the sediment profiles of all the sites are leptokurtic to very leptokurtic.

The data for mean particle size diameter (mm) and the sorting coefficient both showed no significant difference between the sampling months for any of the sites sampled. Site 2d showed a significantly larger mean particle size diameter than site 3d for October (H=13.278, df=4, $P<0.05$, Kruskal-Wallis) and February (H=11.112, df=4, $P<0.05$, Kruskal-Wallis) and a more poorly sorted sediment than site 3d for October (H=13.832, df=4, $P<0.05$) and April (H=11.235, df=4, $P<0.05$). Site 1 also showed a significantly larger mean particle size than site 3d in June (H=10.157, df=4, $P<0.05$) and a more poorly sorted sediment than site 3d also in June (H=10.308, df=4, $P<0.05$). The sorting coefficient ranged from 1.72 to 4.87 indicating sediments were moderately sorted through to extremely poorly sorted.

The values for inclusive graphic skewness showed that site 2c had a significantly coarser skewness compared to all other sites in February ($F_{4,15}$=7.544, $P<0.05$) and that site 3d showed an increase in samples being finely skewed in October compared to February and April and in June when compared to February ($F_{3,12}$=

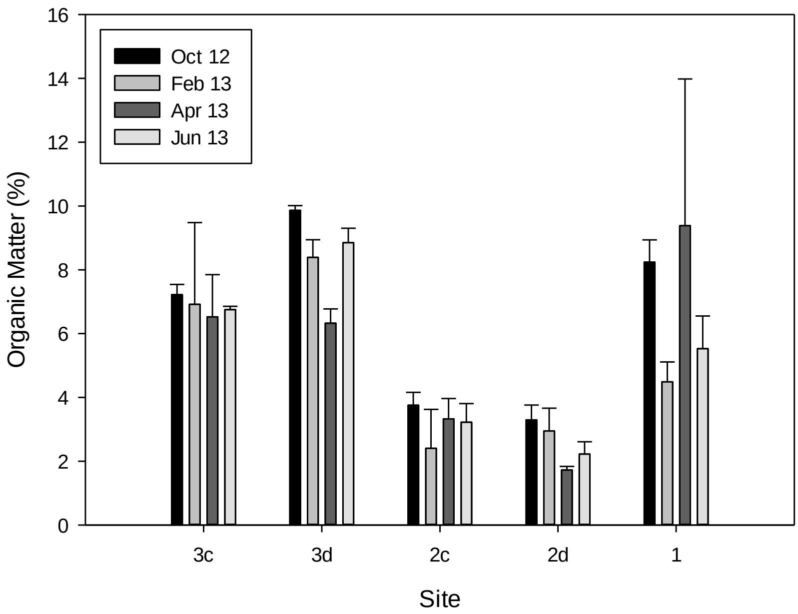


Figure 4.12: average percentage of organic matter present in sediment samples across the five sampling sites for Oct 12, Feb, Apr and Jun 13. Error bars refer to the standard deviation.

9.060, P<0.05). Skewness values ranged from <-1 to 0.841 showing sediments from finely skewed to very coarsely skewed. The results shown indicate that there is no set pattern for these parameters across sites or months and that there appears to be no significant difference between samples from dragged sites and those from control sites. The significant results present do show that site 2c showed increased grain size, poorer sorting and coarser skewness which is consistent with this site being closest to the Harbour mouth therefore sediment grains in this area have not travelled as far within the Harbour being subject to lower pressures of wind and tide which lead to smaller, well sorted sediments.

4.2.2.2 Organic Matter

The percentage organic content of the sediment was calculated. The percentage data was transformed using the arcsine transformation. Data was analysed by looking at the difference between sites over each month sampled and also the difference between months for each individual site (Figure 4.12). The general pattern showed that sites 3d, 3c and 1 had a significantly higher percentage of organic matter than sites 2d and 2c for October ($F_{4,15}=150.098$, $P<0.001$, one-way ANOVA), February ($F_{4,15}=13.688$, $P<0.001$, one-way ANOVA) and June ($F_{4,15}=74.383$, $P<0.001$, one-way ANOVA). Site 1 also showed a significantly higher percentage than site 2d during April ($H=15.586$, $df=4$, $P<0.05$, Kruskal-Wallis). Comparing between months, October showed a significantly higher percentage of organic matter than February, June and April at site 3d ($F_{3,12}=47.569$, $P<0.001$, one-way ANOVA), April and June at site 2d ($F_{3,12}=9.969$, $P<0.001$, one-way ANOVA) and February at site 1 ($H=11.537$, $df=3$, $P<0.05$, Kruskal-Wallis). Additionally at site 3d, percentages were higher in February and June than April ($F_{3,12}=47.569$, $P<0.001$, one-way ANOVA) and at site 2d February showed a higher percentage than April ($F_{3,12}=9.969$, $P<0.001$, one-way ANOVA). Site 2c showed no significant differences between any of the months sampled.

As would be expected, the sites that showed a dominance of clay and fine silt grain size fractions also showed the highest percentages of organic matter. Organic matter levels increased in the Autumn and Winter months compared to values from Spring and Summer samples. As with previous data on sediment characteristics, the differences seen appear to relate to the area of the Harbour where the sampling was carried out rather than to whether the area is used for bait dragging activity.

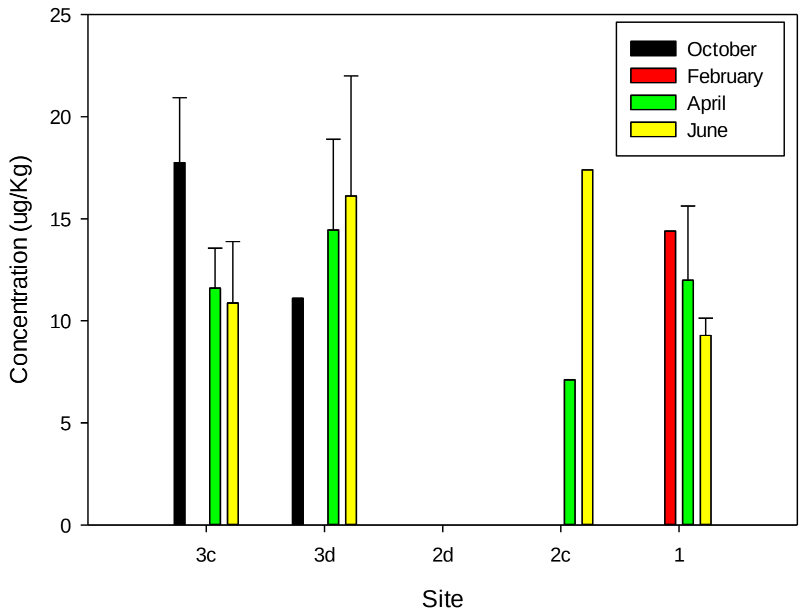


Figure 4.13: average concentration of Tributyltin (TBT) in µg/Kg for all sites for Oct 12, Feb, Apr and Jun 13. Levels at site 2d were below detection limits for all samples. Error bars represent the standard deviation.

4.2.2.3 Organotin

Sediment samples were anlaysed for the presence of the organotin Tributyltin (TBT), a common marine pollutant. For a number of samples across the five sites, throughout all months sampled values were determined to be lower than the detection limit of the equipment used to carry out the analysis (see section 3.1.2.3). Therefore statistical analysis of the results is based on data available where samples showed concentrations that were detectable.

Concentrations ranged from 7.11µg/Kg to 20.00 µg/Kg, the average concentration for each site per sampling month shown in figure 4.13. The data indicated that there was no significant difference in the concentration of TBT either between sites during the same month or between months for the same site for sites where there was sufficient data for analysis to be carried out.

4.2.2.4 Heavy Metals

Sediment samples were analysed for the presence of a suite of heavy metals commonly found within the marine environment. Data was collected for 11 metals; Arsenic, Cadmium, Chromium, Copper, Lead, Lithium, Manganese, Nickel, Tin, Vanadium and Zinc with all concentrations measured in mg/Kg.

Figure 4.14a-k shows the average concentration of each metal for the five sampling sites across all months sampled. Zinc, Manganese and Chromium showed the highest concentrations across the harbour of all the metals tested. Concentrations were compared across the five sampling sites for each of the months sampled as well as between months for each site.

Results showed that concentrations of Chromium and Nickel did not vary significantly between sampling sites for any of the months sampled. Results also showed that the sites around Arne (3c and 3d) and Newton Bay (1) showed generally significant higher concentrations of metals than the sites around Furzey Island (2c and 2d).

For October, concentrations of Arsenic ($F_{4,15}$=13.500, $P<0.001$, one-way ANOVA), Lead ($F_{4,15}$=20.613, $P<0.001$, one-way ANOVA), Manganese ($F_{4,15}$=29.726, $P<0.001$, one-way ANOVA), Vanadium ($F_{4,15}$=21.487, $P<0.001$, one-way ANOVA), Zinc ($F_{4,15}$=97.578, $P<0.001$, one-way ANOVA), Cadmium (H=12.009, df=4, $P<0.05$, Kruskal-Wallis) and Tin (H=15.400, df=4, $P<0.05$, Kruskal-Wallis) showed higher concentrations at sites 1 and 3d than sites 2c and 2d. Similar patterns were seen in February with sites 3c and 1 showing significantly higher concentrations than sites 2c and 2d for Arsenic ($F_{4,15}$=44.485, $P<0.001$, one-way ANOVA),

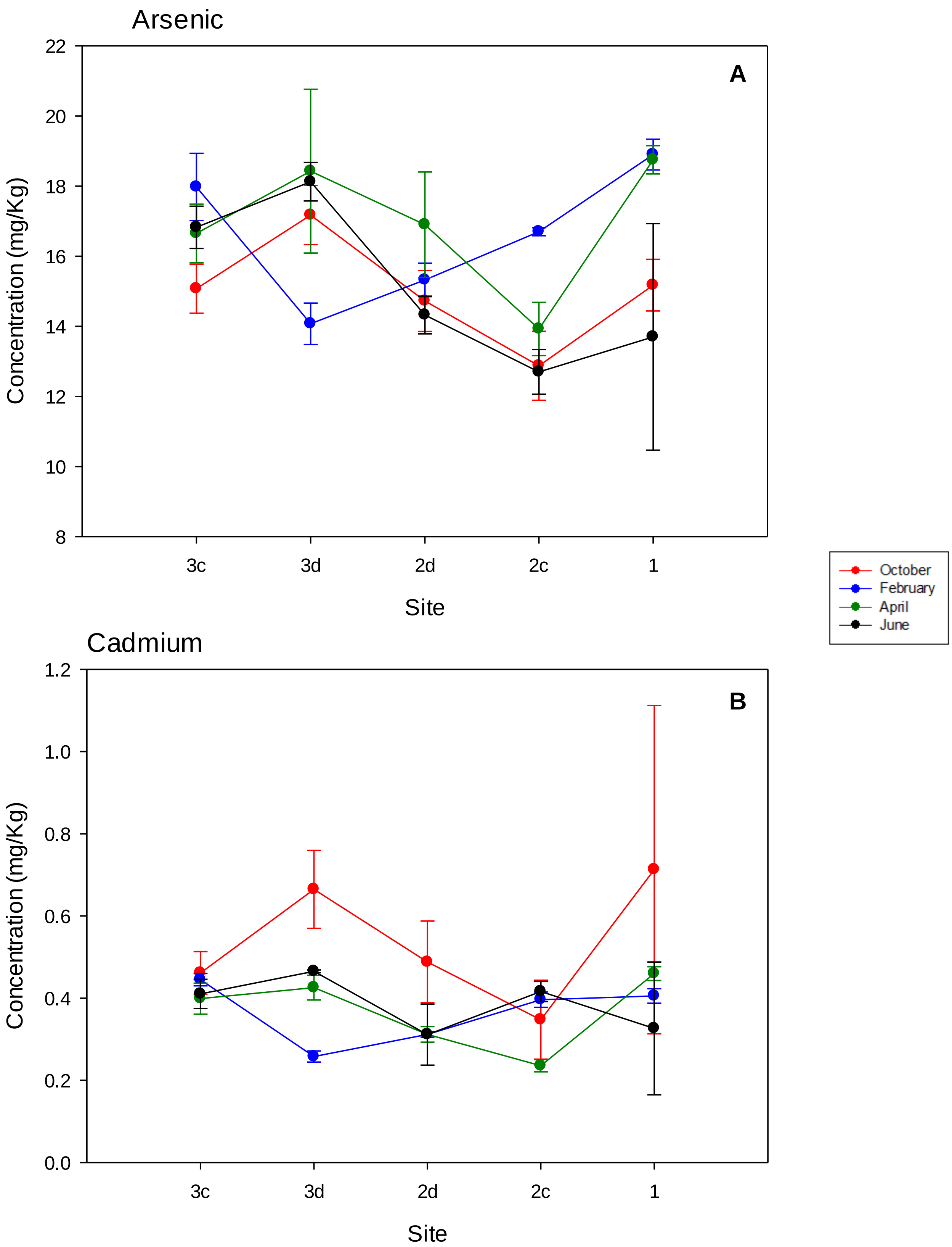


Figure 4.14a-b: average concentration of a) arsenic and b) cadmium (mg/Kg) for five sites in Poole Harbour for Oct 12, Feb, Apr and Jun 13. Errors represent the standard deviation.

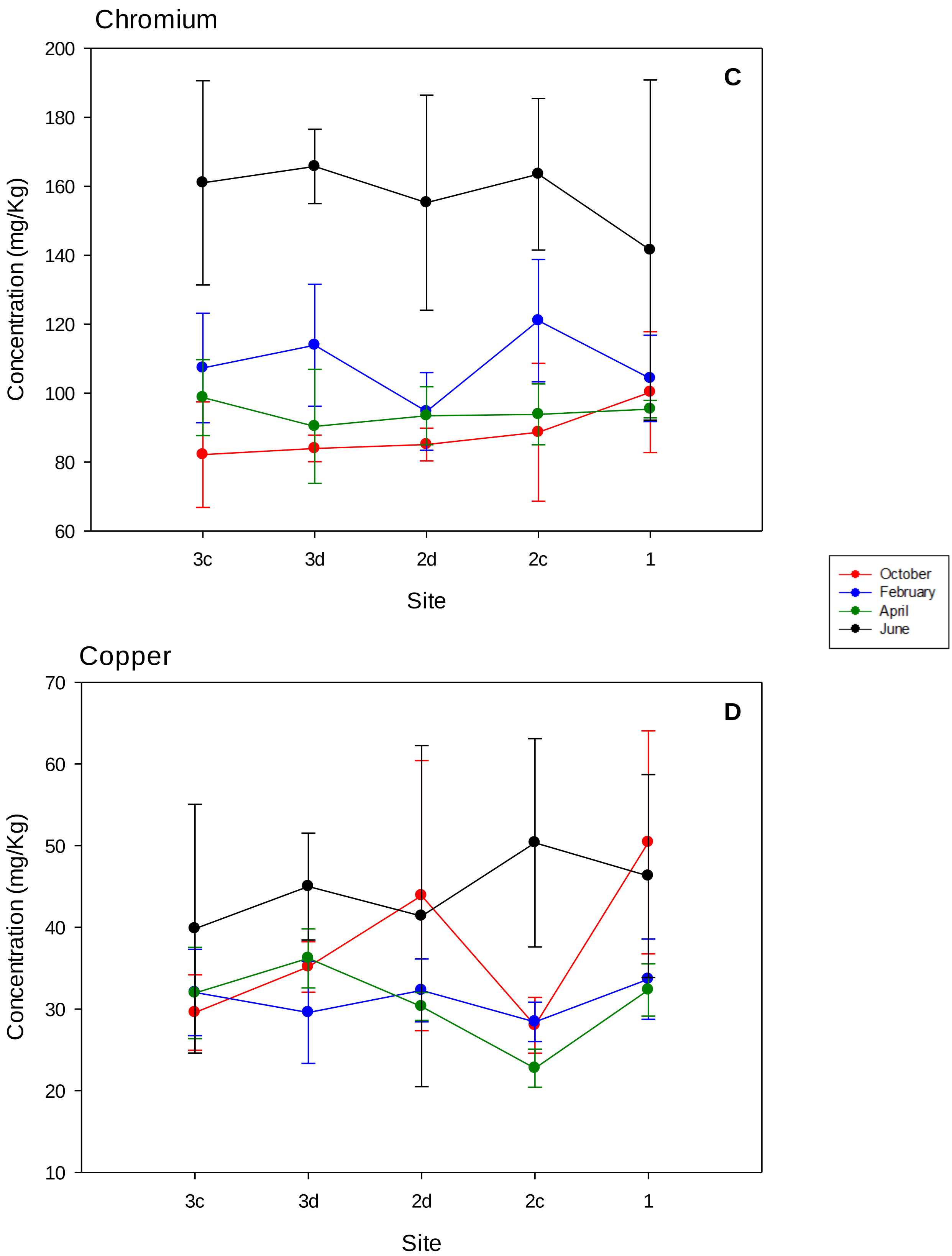


Figure 4.14c-d: average concentration of c) chromium and d) copper (mg/Kg) for five sites in Poole Harbour for Oct 12, Feb, Apr and Jun 13. Errors represent the standard deviation.

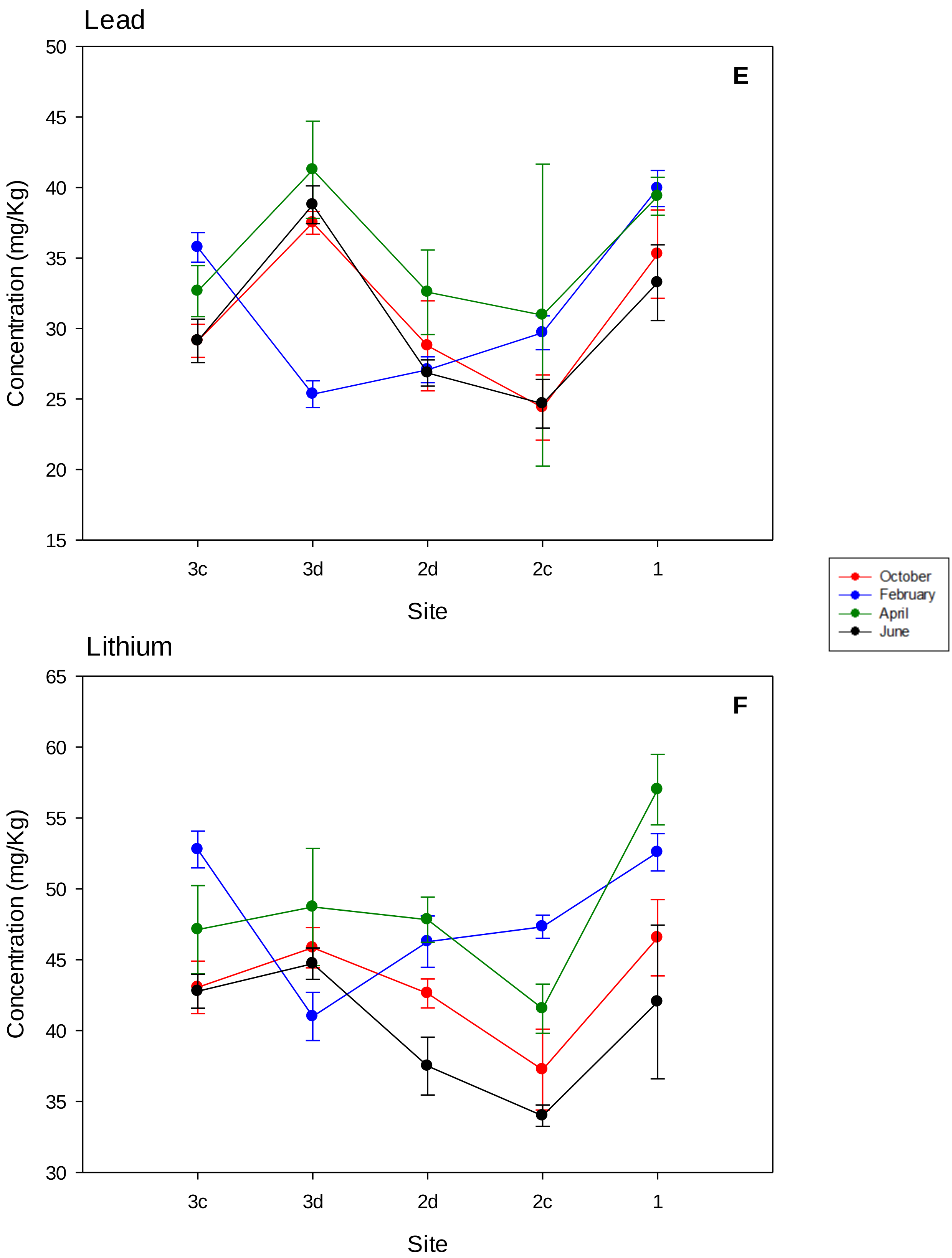


Figure 4.14e-f: average concentration of e) lead and f) lithium (mg/Kg) for five sites in Poole Harbour for Oct 12, Feb, Apr and Jun 13. Errors represent the standard deviation.

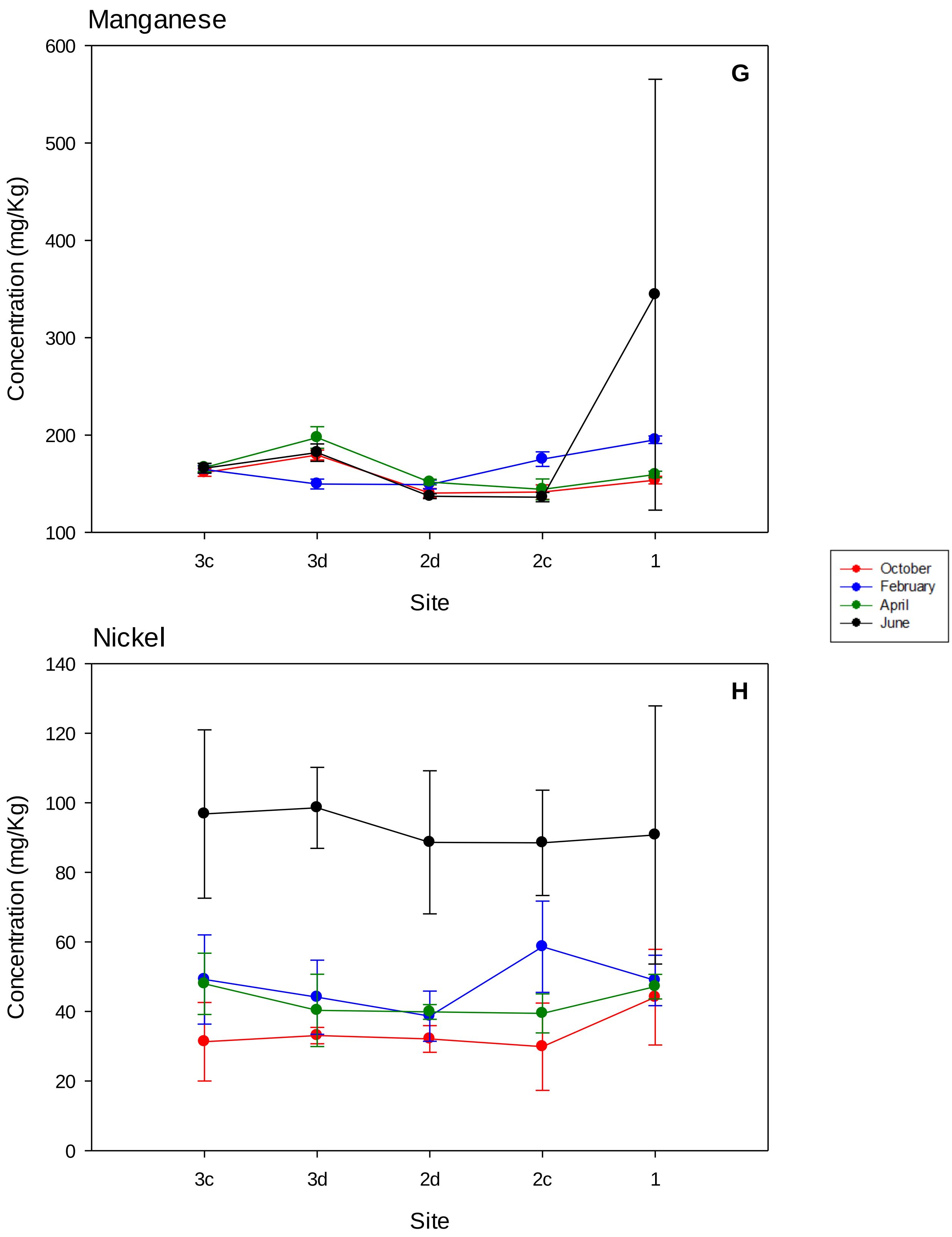


Figure 4.14g-h: average concentration of g) manganese and h) nickel (mg/Kg) for five sites in Poole Harbour for Oct 12, Feb, Apr and Jun 13. Errors represent the standard deviation.

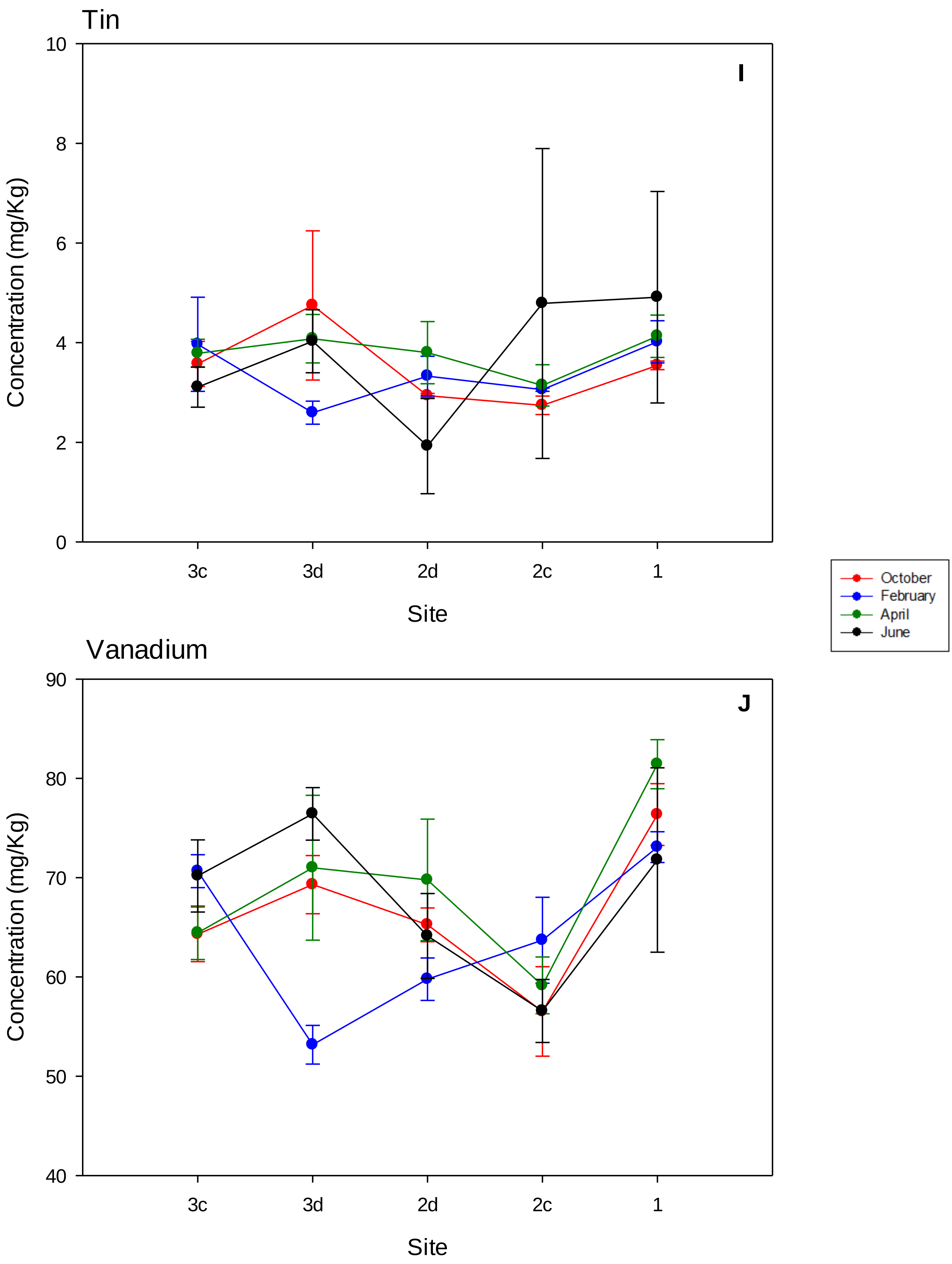


Figure 4.14i-j: average concentration of i) tin and j) vanadium (mg/Kg) for five sites in Poole Harbour for Oct 12, Feb, Apr and Jun 13. Errors represent the standard deviation.

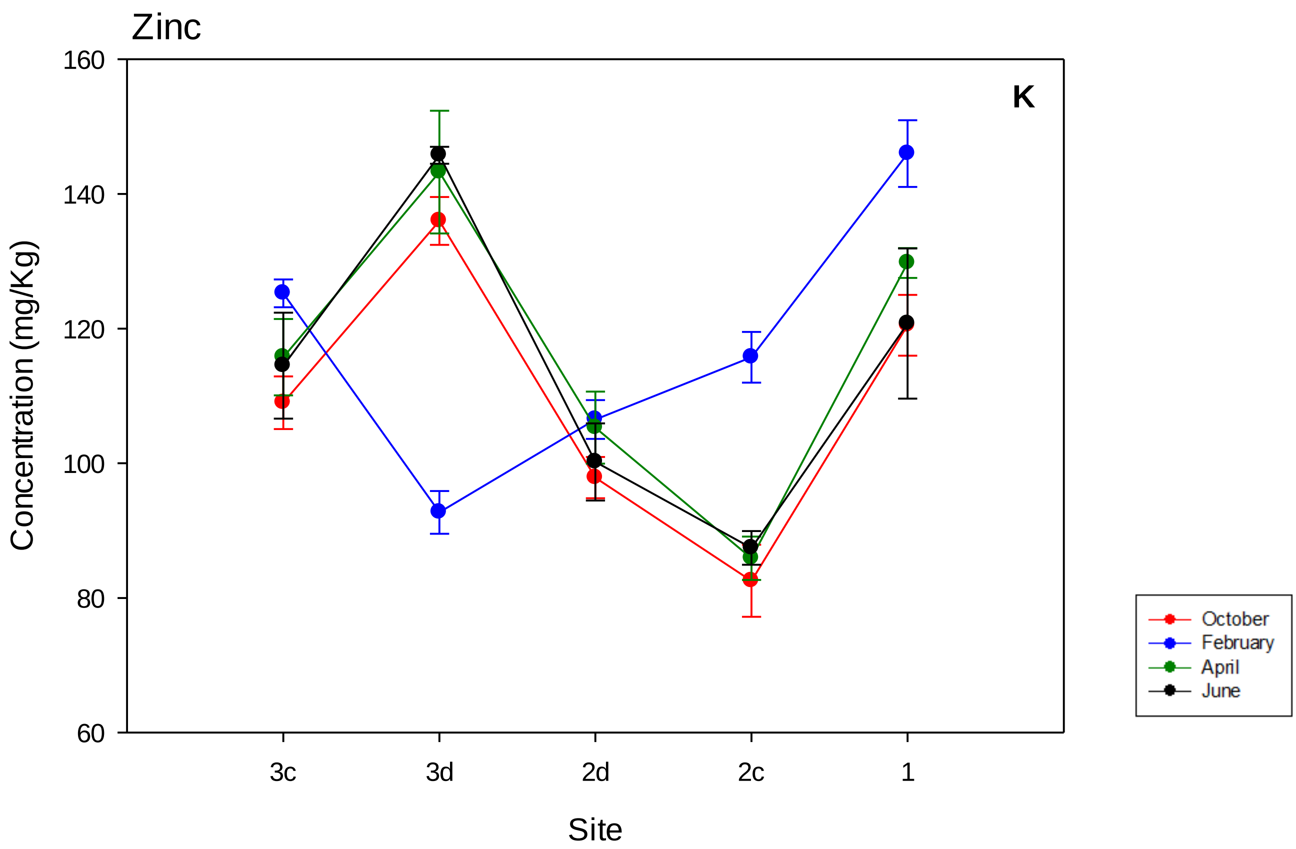


Figure 4.14k: average concentration of k) zinc (mg/Kg) for five sites in Poole Harbour for Oct 12, Feb, Apr and Jun 13. Errors represent the standard deviation.

Cadmium ($F_{4,15}$=104.367, P<0.001, one-way ANOVA), Lead ($F_{4,15}$=126.302, P<0.001, one-way ANOVA), Lithium ($F_{4,15}$=47.000, P<0.001, one-way ANOVA), Vanadium ($F_{4,15}$=40.593, P<0.001, one-way ANOVA) and Zinc ($F_{4,15}$=130.707, P<0.001, one-way ANOVA). For February, site 3d commonly showed lower concentrations than all other sites for the metals outlined above, significantly for levels of chromium ($F_{3,12}$=30.742, P<0.001, one-way ANOVA).

For the month of April, a similar pattern to October was seen with sites 1 and 3d showing significantly higher concentrations of Arsenic ($F_{4,15}$=8.008, P<0.005, one-way ANOVA), Cadmium ($F_{4,15}$=52.387, P<0.001, one-way ANOVA), Lithium

(F4,15=16.005, P<0.001, one-way ANOVA), Zinc (F4,15=61.355, P<0.001, one-way ANOVA) and Manganese (H=17.093, df=4, P<0.05, Kruskal-Wallis).

From figures 4.14c and h, concentrations of Nickel and Chromium were significantly elevated. Results showing a significantly higher concentration of chromium for sites 3c (F3,12=12.536, P<0.001, one-way ANOVA), 3d (F3,12=30,742, P<0.001, one-way ANOVA) and 2c (F3,12=14.696, P<0.001, one-way ANOVA) compared to all other months and significantly higher levels compared to October for site 2d (h=10.301, 3df, P<0.05, Kruskal-Wallis). Concentrations of Nickel were shown to be higher in June compared to all other months for sites 3c (F3,12=13.300, P<0.001, one-way ANOVA) and 2c (F3,12=18.135, P<0.001, one-way ANOVA) and when compared to October for sites 3d (H=11.537, df=3, P<0.05, Kruskal-Wallis) and 2d (H=11.902, df=3, P<0.05, Kruskal-Wallis). Comparisons between sites for this month again showed that site 3d had significantly higher concentrations of Lead (F4,15=41.174, P<0.001, one-way ANOVA) and Zinc (F4,15=43.029, P<0.001, one-way ANOVA) than all other sites and higher concentrations when compared to site 2c for Arsenic (H=14.511, df=4, P<0.05, Kruskal-Wallis), Vanadium (H=13.214, df=4, P<0.05, Kruskal-Wallis), Lithium (H=13.910, df=4, P<0.05, Kruskal-Wallis) and Manganese (H=14.697, df=4, P<0.05, Kruskal-Wallis).

Comparisons for individual sites between months showed that for site 3c higher concentrations of metals appeared to be in the months of June and Feb for Arsenic (F3,12=9.207, P<0.05, one-way ANOVA) and Vanadium (F3,12=6.322, P<0.05, one-way ANOVA) and for February for Lead (F3,12=20.126, P<0.001, one-way ANOVA) and Lithium (H=11.404, df=3. P<0.05, Kruskal-Wallis).

For site 3d, June showed higher concentrations for Copper ($F_{3,12}=6.248$, $P<0.05$, one-way ANOVA), Manganese ($F_{3,12}=24.979$, $P<0.001$, one-way ANOVA), Arsenic ($H=9.345$, df=3, $P<0.05$, Kruskal-Wallis), Vanadium ($H=10.213$, df=3, $P<0.05$, Kruskal-Wallis) and Zinc ($F_{3,12}=91.886$, $P<0.001$, one-way ANOVA) than February.

For site 2d, a different pattern was seen with significantly higher concentrations in April for Arsenic ($F_{3,12}=5.796$, $P<0.05$, one-way ANOVA), Lead ($F_{3,12}=5.372$, $P<0.05$, one-way ANOVA), Lithium ($F_{3,12}=30.509$, $P<0.001$, one-way ANOVA), Manganese ($F_{3,12}=16.494$, $P<0.001$, one-way ANOVA) and Tin ($F_{3,12}=6.960$, $P<0.05$, one-way ANOVA).

Site 2c showed a similar pattern to sites 3c and 3d with the months of June and February showing higher concentrations for Arsenic ($F_{3,12}=27.796$, $P<0.001$, one-way ANOVA), Lithium ($F_{3,12}=43.022$, $P<0.001$, one-way ANOVA), Manganese ($F_{3,12}=20.294$, $P<0.001$, one-way ANOVA) and Zinc ($F_{3,12}=63.494$, $P<0.001$, one-way ANOVA) for February and Cadmium ($H=10.096$, df=3, $P<0.05$, Kruskal-Wallis), Tin ($H=7.875$, df=3, $P<0.05$, Kruskal-Wallis) and Copper ($H=11.968$, df=3, $P<0.05$, Kruskal-Wallis) for June when compared to October.

Site 1 showed that for the majority of metals sampled, there was no significant difference in the concentrations detected between months. Zinc showed higher concentrations in February compared to all other months ($F_{3,12}=13.156$, $P<0.001$, one-way ANOVA) and Lithium ($F_{3,12}=15.611$, $P<0.001$, one-way ANOVA) and Lead ($F_{3,12}=8.152$, $P<0.05$, one-way ANOVA) showing elevated concentrations in February and April compared to June and October. Cadmium was elevated during October compared to February and June ($H=10.553$, df=3, $P<0.05$, Kruskal-Wallis) and Vanadium showed higher concentrations in April compared to February (H=9.566, df=3, $P<0.05$, Kruskal-Wallis).

The overall patterns emerging seem to indicate that the concentrations of metals are related more to the site within the Harbour with differences seen between sites around Arne Bay (3c and 3d) where metals are associating with the finer grained sediment and higher levels of organic matter in the sediment. It is important to note that the concentrations of metals obtained from the surface sediment are not necessarily representative of the concentration that is biologically available. Therefore although the concentrations of some metals appear high, this may not be all available for uptake by organisms reducing the toxic potential of these compounds.

5. COMPLETION OF AIMS AND OBJECTIVES

The main aim of this project was to gain a better understanding of effort levels of bait dragging within Poole Harbour and to determine if the activity is having an impact on target species populations or the sediment within the Harbour.

5.1 Detailed Aims

- To quantify the amount of bait obtained per drag for bait dragging vessels
    - **Completed:** the amount of bait obtained per drag was calculated for up to four bait dragging vessels between September 2012 and June 2013

- To quantify the effort level of bait dragging vessels in Poole Harbour by determining the number of drags completed over a set time period
    - **Completed:** effort levels of bait dragging in Poole Harbour were quantified by determining the number of drags completed over a one hour period for up to four bait dragging vessels between September 2012 and June 2013.

- To quantify the size and number of reproductively mature *Alitta virens* and compared this data between dragged and un-dragged sites
    - **Partially Completed:** the size of individual worms belonging to the family *Nerididae* that were collect from sampling were determined and compared to target species obtained from bait dragging. The sampling method used provided very few individual worms and those that were

collected were predominantly of a size less than that collected when dragging. The lack of data meant that statistical comparison of the number of reproductively mature *Nerididae* from the samples was not possible.

- To quantify the percentage of different sediment size fractions and the organic matter content of the sediment and compare these data between dragged and un-dragged sites
    - **Completed:** data on sediment grain size classes as well as data on the sorting coefficient, kurtosis, mean particle size and skewness were determined for all samples across the duration of the project along with the percentage of organic matter. This data was compared for dragged and un-dragged sites between each of the sampling events and also between the different sites within each month sampled.

- To quantify the levels of heavy metals and organotins in the sediment and compare the data between dragged and un-dragged sites
    - **Completed:** data on the concentration of 11 metals and Tributyltin was determined for all samples across the duration of the project. This data was compared for dragged and un-dragged sites between each of the sampling events and also between the different sites within each month sampled. For the Tributyltin data, concentrations for a number of samples were below the detection limit of the analysis method used and therefore analysis of the data was based on those samples showing detectable concentrations.

6. DISCUSSION

6.1 Effort of bait dragging activity in Poole Harbour

The collection of anecdotal sightings data for the position of bait dragging vessels in Poole Harbour has allowed for the identification of key fishing areas for this activity. At peak times up to 6 bait dragging boats were identified within the area of Arne Bay and Patchin's Point and this appeared to be the maximum level of activity over a single tide. Previously, it was estimated that up to 15 boats were employed in bait dragging (Fowler, 1999) with the same number again of casual fishermen engaging in this amongst other activities. The level of activity appears to have declined since this time although in the past 6 months there appears to have been a small increase again in the number of fishermen engaging in bait dragging in addition to their usual method of fishing. Although the sightings data is limited in that it is based on observations made only when Southern IFCA officers were present in the area, the data shows the areas commonly fished and also indicated that other than Brands Bay, the bird sensitive areas within the Harbour, defined as key areas for overwintering and breeding nationally and internationally important bird species, do not overlap with the areas used for bait dragging.

In order to determine the potential impact of an activity on the conservation feature of a European Marine Site, authorities such as the Southern IFCA must often rely on data collected as part of routine work as resource limitations mean that detailed and structured effort surveys are not always possible. The results here show that such surveys can provide useful data to indicate where management may be necessary within a small area.

The addition of data collected via the Inshore Vessel Monitoring System (iVMS) fitted to a bait dragging vessel meant that the fishing areas defined from sightings data could be quantified. The Harbour was divided into five key fishing areas based on clusters of fishing activity from both iVMS datasets. Analysing the data showed a preference for bait dragging activity within the area of Holes Bay during the autumn and winter months, most likely due to the area being enclosed and sheltered compared to areas such as Arne Bay, providing bait draggers with the opportunity to fish in adverse weather conditions that make other areas of the harbour inaccessible. The proximity of this area to the berth of the fishing vessel in question also provides shorter transiting times during less favourable conditions. The area of Brands Bay also showed an increased usage during the autumn months, but to a lesser scale than Holes Bay. Accessing this area requires transiting across the Harbour but in itself is also more sheltered than other areas, providing a fishing area during unfavourable weather conditions. Usage of Holes Bay during the autumn and winter months coincides with the key time of year for overwintering bird species, and although the whole of Holes Bay is not defined as a bird sensitive area there are still concerns that this area provides shelter and increased feeding grounds for these bird species during poor weather conditions. Overlap between fishing grounds and the conservation feature needs therefore to be considered in terms of effort. The number of bait dragging vessels operating in this area at any one time is limited to an average of three vessels, fishing during high tide when the mud is not accessible to feeding birds. The actual disturbance factor associated with this overlap therefore could be minimal and management in the form of a cap on effort to ensure that this level is maintained could allow bait dragging activity to continue without resulting in adverse impacts on the conservation feature.

This is the first time that iVMS technology has been used on boats of this size within an enclosed harbour area. This project has shown that the use of such technology provides quantifiable evidence of areas used for fishing and in addition a robust assessment of overlap between such activity and key areas of a harbour that are of conservation interest. Although technical issues meant that three months data were “lost”, the data presented covers a seasonal cycle and provides a good assessment of effort for a single vessel. It would have been preferable to use multiple vessels however issues with cost and stakeholder involvement prevented this, the vessel in question is one of the most active bait dragging vessels within the Harbour and therefore the data is considered to be representative of this activity. A combination of both 1 minute and 10 minute reporting intervals were used and compared, both clearly illustrating the areas used for bait dragging. Additional benefits that could be gained from 1 minute reporting are related to the ability to map scarring patterns of bait dragging activity with patterns shown through aerial photography and thus distinguish these scars from similar marks made by pump scoop fishing activity. The use of a set reporting time therefore depends on a compromise between the cost to the fisherman and the data obtained. In previous trials with similar technology, the reporting time increases when a vessel approaches or is within a prohibited area and this could be adopted here with reporting time based on 10 minutes until a vessel approaches a conservation feature for example a bird sensitive area at which point reporting is increased to 1 minute intervals to carefully map the proximity of the vessel to that area.

In order to quantify the effort of the bait dragging vessels within the Harbour, the number of drags per hour and the amount of bait obtained per drag was calculated across a seasonal cycle. The data indicated that there was no difference in the effort of these vessels seasonally or dependent on the tidal state. It is possible therefore that the effort levels of the fishery are dependent more on the number of vessels present in a single area and the duration of the time spent fishing in that area rather than the effort exerted by a single vessel over a fixed time period. For example it would be expected that the number of vessels and therefore the overall effort would increase during the summer months when angling activity along the coast is elevated thus increasing the demand for bait. A fixed survey of the number of vessels present in one area over a series of months, where data is collected in a fixed pattern accounting for tidal state and time of day, would be needed to determine effort in this way.

The hypothesis that activity varies spatially within the harbour over seasonal scales can be accepted but the overall level of effort needs further quantification. This data is a good first step towards management of this fishery and has provided, for the first time, detailed positional data on the main areas used for fishing within the harbour and how these overlap with conservation features. Bait dragging will require management due to its location within a European Marine Site and the data produced here has fulfilled the objective of the project to start filling the gap in understanding of dragging effort across the harbour for the Southern IFCA and other relevant authorities. The aim in the future will be to have more vessels fitted with iVMS technology to facilitate such management and to further test the capabilities of such technology within enclosed harbour areas for small, inshore vessels.

6.2 Impacts on target species

Data collected experimentally to assess the impact of bait dragging on the target species *Alitta virens* was problematic and did not return the expected results. The method used to obtain these samples had been used previously (Dr A. Jensen, per comm.) to obtain polychaete worms belonging to the family Nerididae and thus was deemed suitable for this project. The results showed very few worms within the samples taken and of those obtained; the overall size was small compared to the ragworm obtained from bait dragging. In addition the month of February was unable to be analysed due to the different method needed to collect the samples and a lack of comparable data from April which was to be used to allow the February samples to be compared to other months. The reasons why this method proved unsuccessful in this case are unknown. Some comparisons were possible indicating a higher abundance of ragworm in the area of Newton Bay in June compared to the area of Furzey Island which could be explained by the higher percentage of organic matter found at Newton Bay during this month, however there are conflicting opinions as to the importance of the sediment composition for worm density with studies by Weiser (1959) emphasising the importance of fine grained sediment and high levels of organic matter compared to studies by Kennedy (1984) which found that proportion of sediment size class does not influence polychaete distribution. If we were seeing distribution in relation to grain size and percentage of organic matter it would be expected that a similar increase in abundance would have been seen for sites around Arne Bay which showed a similar sediment composition to Newton Bay. It is more likely therefore that the differences seen here are related to random sampling variability. The data presented here should not be used as an indication of the stock of ragworm in Poole Harbour. Worms obtained from dragging directly showed a markedly larger average size, similar to that expected for adult ragworm of up to 200-300mm, and were more abundant over an area similar to that used for sampling. The hypotheses that the number of *Alitta virens* will be higher in dragged areas, of a smaller size and with a decreased abundance of reproductively mature individuals should not be rejected on the basis of the analysis carried out as part of this project. The lack of data makes comparisons harder to determine and further sampling is needed with a more suitable method to fully determine whether in Poole Harbour bait dragging is impacting the target species population.

6.3 Impacts on the sediment

Analysis of the potential impacts of bait dragging on the sediment of Poole Harbour looked at changes to the sediment structure through the abundance of different grain size classes and the presence of organic matter as well as through changes to the concentrations of heavy metals and Tributyltin (TBT) in the surface layers.

6.3.1 Sediment structure and organic matter

Sites in Arne Bay and Newton Bay showed a dominance of clay and silt size fractions whereas sites at Furzey Island showed a dominance of grain sizes from fine to coarse sand, with samples from this area also showing a poorer sorting coefficient. In addition, for sites where clay and silt fractions were dominant the percentage of grains in the clay fraction increased during the autumn. The same pattern was seen for organic matter with a higher percentage at Arne Bay and Newton Bay and also during the autumn months. When considering the overall pattern, the differences seen between grain size dominance are more related to the area of the harbour in which the sampling was undertaken rather than the difference between areas that are used for bait dragging and those that are not.

Sites around Arne Bay and Newton Bay are further from the mouth of the Harbour than the sites at Furzey Island, the sediment at these sites has therefore travelled further around the Harbour before settling so being subject to a greater degree of wind and tide pressure over time leading to reduced grain size. The sites at Furzey Island are closest to the mouth of the Harbour and the deposition of sediment in this area may be directly from Poole Bay with minimal transport around the harbour. The decline in sorting coefficient is common with coarser grained material with a leptokurtic distribution as seen in these samples. The sediment will have been primarily sorted in Poole Bay, in a higher energy environment and is then deposited amongst finer grained material within areas adjacent to the harbour entrance leading to poorer sorting and a dominance of coarser grains. The dominance of these coarse grains should therefore decline further into the Harbour which would explain the pattern of results seen here.

However, for the sites around Furzey Island, there were differences observed between the area that is used for bait dragging and the control area with a significant percentage of coarser grained sediment in the area used for bait dragging across all months sampled. This is similar to studies investigating the impact of other fishing activities such as dredging on the marine environment (Cooper *et al.,* 2011) indicating that bait dragging activity may be causing the re-suspension of fine grained sediment leading to a dominance of coarser grained material. Changes such as these have been shown to influence the dominant species in the assemblage of benthic organisms which can have further influence up the food chain. Again it is important to remember that the number of vessels operating in this area is small and that with the large amount of activity occurring in Poole Harbour as a whole these changes may not be wholly attributable to bait dragging activity. In addition, to further this work, the data needs to be considered alongside the benthic communities present in both the dragged and control sites to determine if these changes to the sediment structure have in turn altered the community composition.

The fact that such differences between dragged and control areas were not seen at the Arne Bay and Patchins Point sites could be explained by the higher levels of cumulative fishing activity occurring at this site and that the control site, whilst not used for bait dragging has been used in the past for relaying and dredging of mussels. The overlap of different activities in this area over a long time scale may have resulted in an altered sediment regime which is maintained and thus individual impacts from single activities would be harder to pick out. Furzey Island sites however are less used by multiple fishing activities and are separate from the main areas of the Harbour used for recreational and commercial activity. Impacts from bait dragging may be seen here as lower levels of other activity result in lower overall levels of disturbance, short term disturbance from periods of bait dragging activity making changes to the sediment more apparent. Previous studies have shown that where dredging activity occurs and causes marked depressions, as with bait dragging activity, the differences in sediment structure can be seen over very small spatial scales i.e. within and immediately adjacent to the depressions, with the sampling regime carried out as part of this project the depressions left by bait dragging could not be seen and therefore the samples may have been taken too far from drag marks to show the more subtle changes in sediment structure that may occur.

The hypothesis that the amount of organic matter in the sediment will be greater in dragged areas than control areas can be rejected, data showed differences related to the area of the harbour sampled rather than areas used for fishing activity. The hypothesis that the percentage of fine grained sediment in the surface layer will be greater in the area used for dragging than in the control areas can be rejected on the basis of the differences between the dragged site at Furzey Island and the control. However, the lack of similar results at the other paired sites in Arne Bay suggest that further work may be needed to fully determine the impacts on the sediment structure. The results of this study emphasise the difficulty in separating impacts from a single fishing activity from the levels of background disturbance particularly in an area like Poole Harbour which is subject to a wide range of recreational and commercial disturbances. In terms of management of fishing activity in relation to intertidal mud as a conservation feature of Poole Harbour European Marine Site, authorities may have to consider the need to manage activities cumulatively if evidence cannot be robust enough for single activities on their own. The effort levels of bait dragging determined within the harbour are low compared to other fishing activity, it could be that the current levels are sustainable with maintaining the conservation features of the site as differences between dragged and control sites were only seen for one area.

6.3.2 Metals and Tributyltin

The pattern of metal concentrations and Tributyltin (TBT) were inconsistent across the sampling sites and months sampled, with different metals showing different patterns. The concentration of TBT varied from 7.11 to 20.00 µg/Kg which is comparable to previous studies (Langston *et al.,* 1987) which showed that levels of TBT in UK sediments can vary from around 20 µg/Kg up to 520 µg/Kg in the most polluted estuaries. Concentrations in Poole Harbour are therefore relatively low compared to other areas of the UK, further work to look at the area of Holes Bay, which is considered to be the most contaminated area of the Harbour due to past proximity to industry could show more elevated concentrations which could be relevant given the increase in bait dragging effort in this area during the autumn and winter months. The lower concentrations seen in this study, compared to that shown in Langston *et al.* (1987) could also relate to the sample sites not being in close proximity to moorings and marinas, areas known as hotspots for TBT accumulation in sediment (Langston *et al.,* 1987). The results showed no difference between sampling sites or between months sampled indicating that levels remain fairly consistent throughout the Harbour over a seasonal cycle. In the past levels were seen to elevate during the summer when newly painted boats were put in the water (Bryan *et al.,* 1992) however, restrictions on TBT usage have been in place since 1987 so mediation by processes such as microbial degredation to Dibutyltin (DBT) and Monobutyltin (MBT) and general breakdown in the sediment will have occurred reducing overall levels. The level of bait dragging occurring in the areas sampled may not be occurring at significant enough levels to raise the concentration of TBT above that of background levels.

Sediments are known to play a major role in the transport and storage of contaminants in the marine environment (Bryan *et al.,* 1992). Copper, zinc, cadmium, tin, lead, arsenic and chromium all showed concentration ranges similar to those seen for other UK estuaries, and all are within the lower limits of ranges seen suggesting that metal concentrations in Poole Harbour are not elevated beyond normal limits. Sites in Arne Bay and Newton Bay showed elevated concentrations of a number of metals sampled compared to Furzey Island which is most likely related to the dominance of fine grain size particles which have a higher adsorptive capacity for metal contaminants (Fatima *et al.,* 1988; Hübner, 2009). These sites are also further from the Harbour mouth and are more enclosed further reducing the flushing capacity which is generally poor throughout the harbour as a whole leading to a build-up of metals in the sediment (Kennish, 1997). The lower concentrations around Furzey Island could therefore be attributed to their proximity to the Harbour mouth compared to other sites where the increased mixing of the sediment reduces overall concentration (Thorne and Nickless, 1981).

Although there were a number of significant differences between sites and months, there appeared to be no fixed seasonal or spatial pattern for concentrations of individual metals in the harbour. When looking at metal contaminants, variation between samples can result from a large number of factors, biological, chemical and physical as well as anthropogenic influences. Tidal factors can cause differences in sediment concentrations of heavy metals over very small time scales for example Morrisey *et al.,* (1994) showed that variation occurred over spatial scales as small as a 2m patch of sediment. Variation caused by background natural processes has also been shown to be greatest in estuarine environments (Birch *et al.,* 2001) with a relationship between concentration and grain size, with finer grained sediments having a higher sorptive capacity for metal contaminants (Hübner, 2009).

The metals assessed in this study have a mixture of toxicities with some, such as tin and zinc, showing impacts on fertility in high concentrations and others such as chromium showing negligible impacts on benthic species. Most metals appear to be more toxic when present in pore water and the overlying water column, the concentration of which is often three to five orders of magnitude lower than that in the sediment (Bryan *et al.,* 1992). Therefore the concentrations of metals seen here indicate that levels in the water column are small and will most likely have a negligible impact on the benthic community and thus the wider food chain. It is also important to remember that the metals analysed in this study are also present in the sediment in natural levels, many of which are necessary for various functions of flora and fauna, therefore the levels detected are a combination of natural background concentrations as well as those provided by anthropogenic inputs.

It is likely that background levels of disturbance in Poole Harbour caused by commercial and recreational activity as well as other fishing methods are preventing changes caused by individual fishing activities from becoming evident. In terms of fisheries management, cumulative assessments and management of fishing activity may be necessary in order to ensure that current levels of metal contamination resulting from anthropogenic inputs are not increased. As with TBT, determination of metal concentrations in Holes Bay would be beneficial to determine if any changes are seen in this more contaminated area and whether an increase in bait dragging activity in the autumn and winter will have significant effects on these contaminants.

The hypotheses that the concentration of heavy metals and organotins will be higher in the surface layer of areas used for dragging than in the control areas can be rejected based on this study. This does not mean that levels of contaminants are not elevated beyond natural levels but the difficulty in distinguishing between anthropogenic activities and between natural variation mean that the pattern seen cannot be attributed to bait dragging alone.

7. CONCLUSIONS

- Effort of bait dragging in Poole Harbour is limited with the maximum number of vessels seen in a single area at a single time being six boats. Arne Bay is used as a preferential site for this activity with an increase in activity within the enclosed and sheltered area of Holes Bay in autumn and winter. The pattern of activity appears to be related seasonally to weather conditions and accessibility. Limited overlap of bait dragging activity with bird sensitive areas was seen indicating that at current levels this activity may be compatible with the maintenance of this conservation feature within Poole Harbour European Marine Site.
- The effort of bait dragging is related to the number of boats present and the time spent within certain areas of the harbour. The actual level of activity for a single vessel over a fixed time period showed no seasonal variation.
- Granulometry and organic content of the sediment varied spatially with differences being seen between the different areas of the Harbour sampled rather than between dragged and control areas. The sites around Furzey Island indicated a difference in granulometry between the dragged and control site with an increase in coarse sand grain size fractions at the dragged site, a similar pattern to impacts of other dredging activity. This area is used less frequently for multiple activities than the other paired dragged and control site sampled in this project therefore it is though that background levels of disturbance are reduced and as such impacts from a single activity are easier to distinguish.

- Concentrations of Tributyltin (TBT) and other metals sampled were within the range of concentrations documented for other estuaries within the UK. The length of time since restrictions on TBT usage were developed could explain the lower concentrations seen across the Harbour as a mixture of biological and chemical processes will have acted to breakdown the compound within the sediment. The general pattern of concentration of metals was not fixed and, as for TBT, did not indicate a difference between areas that are dragged and those that are not. The presence of metals was related, in part, to the structure of the sediment with areas showing a dominance of fine grained material having a parallel increase in the concentration of metals. The conclusion is that the overall pattern seen is most likely to relate to natural and anthropogenic variation, the effects of which are not able to be separated within the scope of this project. Variation in metal levels has been shown to occur across small spatial scales and to change over short time scales making any impacts of a single activity difficult to determine.
- The overall conclusion is that the design and implementation of this project has successfully provided robust and quantifiable data on the effort levels and spatial variation of an activity for which there was no existing baseline. In addition the impact on the sediment environment of the Harbour has shown that for some areas individual activity levels may be able to be attributed to changes seen but that for the majority of cases the in combination effects of disturbance from a number of sources is most likely the cause of the observed patterns.

8. LIMITATIONS

- The main limitation of this project is the lack of data on the impacts of bait dragging on target species populations. The method employed as part of the survey, whilst previously successful in obtain ragworm, did not yield Nerididiae in sufficient numbers to allow for robust comparisons between dragged and control areas. In addition, the nature of the sediment in February meant that a separate method was required to obtain target species samples and therefore this data was not comparable to other months.
- The vessel monitoring system data was only available for a single bait dragging vessel. The original plan had been to fit out two vessels, however, issues with stakeholder involvement prevented data from two vessels being available. The data from a single vessel covered a seasonal cycle effectively but analysis needs to take account of the fact that this represents the pattern of activity for a single vessel and may therefore not be fully extrapolated to all vessels undertaking bait dragging in the harbour.
- Sightings effort data is limited in that it is based on anecdotal sightings made when officers of the Southern IFCA were present in the area and as such the number of boats seen over a particular time frame is not necessarily a true representation of effort. However, this data has provided information on the main areas of fishing used in the Harbour and as a basis for collecting effort when resources are limited, and therefore a full and detailed effort survey may not be possible, this method of collecting information provides usable data on the effort level of the fishery.

- The outcome of the data collection in this project has highlighted the need to consider the combination effects of multiple activities on the conservation features of European Marine Sites and one of the limitations of this report is that it cannot conclusively relate the results seen to bait dragging activity in isolation. The data has shown that the background level of environmental parameters and disturbance of the habitat that has been in place for an extended time period makes fishing activity disturbance, or lack of, from a single source difficult to distinguish.

9. IMPLICATIONS AND FUTURE WORK

Results from this project will be used to inform the assessment of fishing activity in European Marine Sites by the Southern IFCA and other relevant authorities. Bait dragging is listed as an amber risk in Poole Harbour for a number of conservation features including intertidal mud and therefore it has been determined that further evidence on the impacts of this activity on these features is required before management decisions can be made. Until the implementation of the Marine and Coastal Access Act (2009) where the IFCAs were vested in April 2011, the collection of bait in any form was not subject to fisheries legislation and as such had gone largely unmanaged, particularly for bait dragging. In order to manage this fishery sustainably and proportionately, evidence on levels of activity and potential impacts on conservation features is required. This project has gone a long way to fill the gaps in understanding for this fishery and has provided effort data to suggest that fisheries management measures to maintain the current level of effort and adjust some of the fishery locations should minimise impacts on overwintering birds, a key conservation feature. This project has particularly highlighted the need to consider fishing and other human activities in combination when considering impacts on conservation features, results have shown that whilst differences in sediment parameters may be seen, it is difficult to separate these out from wider disturbance impacts and as such changes in environmental parameters cannot necessarily be attributed to a single fishing activity. Moving forward, management will need to consider the Harbour holistically and identify how interactions between activities contribute to the overall disturbance patterns seen.

Results from the effort survey have also shown the benefits in using vessel monitoring technology for small scale inshore fisheries. This technology has enabled detailed patterns of fishing activity to be determined within a small area and illustrates how these fisheries are operating against the background of the conservation features of the harbour. One of the main implications of this project is that the usage of such technology will facilitate the collection of robust and quantifiable effort data and as such aid the development of management over the appropriate scale for this activity.

The project has highlighted some areas where future work would further inform the evidence base for this fishery:

- To extend the survey of bait dragging effort by comparing positional data to wind and tidal data for Poole Harbour to quantify the factors contributing to the spatial seasonal pattern of areas fished. In addition, a survey based on sightings taken from fixed positions over a fixed seasonal pattern of varying tidal states and times of day would indicate how effort varies annually within defined areas. As the effort data from this project indicated that the level of activity of a single vessel did not vary seasonally, environmental pressure is more likely to result from a change in the number of vessels operating within a particular area.
- To fit additional vessels with iVMS technology to determine patterns of activity and so quantify time spent per area of the Harbour, as done within this project, for a larger number of vessels.

- The method for determining potential impacts of bait dragging activity on target species requires refining. Results from this study did not provide sufficient data to answer the question of whether target species populations are impacted by this activity. In addition to assessing abundance and reproductive state, data needs to be collected on the way in which these species recolonize disturbed areas and the time scales over which this process occurs.
- To extend the survey carried out by analysing the benthic community within the samples taken to determine if any changes are seen between dragged and control areas. In addition this data can be related to the sediment patterns seen, particularly for the sites around Furzey Island to determine if the difference in sediment structure between sites is further impacting the benthic community. In addition a similar survey protocol could be extended to other areas of the Harbour such as Holes Bay which has been shown from this project to be a key area for bait dragging in the autumn and winter months. The likelihood that this area is historically contaminated with metals, its enclosed nature and importance to the fishery as well as being an area of conservation interest suggests that impacts need to be quantified in this area over a seasonal cycle.

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