Bait Collection Disturbance Literature Review 2016 -

Exe Estuary EMS Case Study

Exe Estuary Management Partnership

2016

Summary

The Exe Estuary is an important site with local, national and international conservation designations. It is a Special Protection Area (SPA), Ramsar and Site of Special Scientific Interest (SSSI) that provides protection for various interest features including wading birds and the habitats that support them. The collection of bait for fishing is a common use of the Exe Estuary, the two main types being crab-tiling and bait-digging, however the effects that these activities have on the site are not fully understood.

The aims and objectives of this report are to study the present literature and establish the implications of:

1. Prey abundance and quality for wading birds and

2. Disturbance of birds by the physical presence of a person

The evidence presented in the current literature shows that both activities can influence, to varying degrees, the composition of infauna present. These potential changes in infauna can in some cases lead to longer feeding times and/or a reliance on other prey sources by over-wintering bird species. While disturbance associated with these activities can also affect these species, research has shown that habituation to low levels of disturbance can occur in some species.

This review highlights potential further research specifically relating to Exe. Suggested research includes a complete census of both activities in the Exe Estuary, continuation of work carried out by Sheehan (2007), and studies into the biomass of both important prey species on the Exe and the designated over-wintering bird species.

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Introduction

The collection of bait for fishing is a common use of the estuarine system. There are two main types practised within the Exe Estuary. One method is crab-tiling which involves the distribution of artificial refugia for shore crabs, *Carcinus maenas*, to use as shelter for moulting. During low tide, crab-tilers overturn these artificial shelters and collect the moulting crabs for use as bait (Sheehan, 2007). The other method is to dig within the intertidal substrate for lugworms (*Arenicola spp.*) and ragworms (*Nereis* and *Nephtys spp*) (Ukmarinesac.org.uk, 2015). A recent recreational disturbance survey highlighted that within the estuary bait digging is popular around the Exmouth estuary shore and Duckpond, whilst crab tiling more commonly occurs on the western side of estuary around Starcross (Liley et al., 2011).

The Exe Estuary has legislative protection under local, national, European and international legislation. The Exe Estuary is designated as a Special Protection Area (SPA) and Ramsar site designated under the 1979 EC Birds Directive and Convention on Wetlands of International Importance respectively. Alongside these designations the Exe is also a Site of Special Scientific Interest (SSSI) designated under the Wildlife and Countryside Act 1981(with amendments). These designations are principally to protect the internationally important waders and wintering wildfowl which are attracted to the estuary. In addition to these designations, the site also contains Dawlish Warren Special Area of Conservation (SAC), National and Local Nature Reserve status and the Exmouth Local Nature Reserve (Exe Estuary Management Partnership, 2014).

Many of the studies into bait-digging and crab-tiling are based on the impact of disturbance to infaunal species. This is primarily because species in the sediment tend to have reduced mobility and high abundance, allowing them to be easily sampled. Studies previously researching the impacts of these activities have focused on; direct mortality to the benthos via trampling and digging; alteration to the bed topography and hydrodynamics; increased predation and bioturbation; alterations of habitat; and lastly changes to the population and size structure of the exploited and associated species have all been attributed. (Scherer and Reise, 1981, Schratzberger and Warwick, 1999, Sheehan, 2007, Haedrich and Barnes, 1997, Cryer et al., 1987, Shepherd and Boates, 1999, Jackson and James, 1979, van den Heiligenberg, 1987, Zwarts and Wanink, 1993).

Any changes to the supporting habitats of overwintering birds species, protected under international and national legislation, has the potential to affect the behaviour, distribution and diversity of these species (Sheehan, 2007). To understand the potential effects of commercial and recreational bait collection activities such as crab-tiling and bait-digging should be properly assessed and monitored within the context of the protected sites and their features. An-example where this has occurred include the involvement of Natural England in supporting research such as Sheehan (2007) to assess the ecological impact of the crab-tiling fishery.

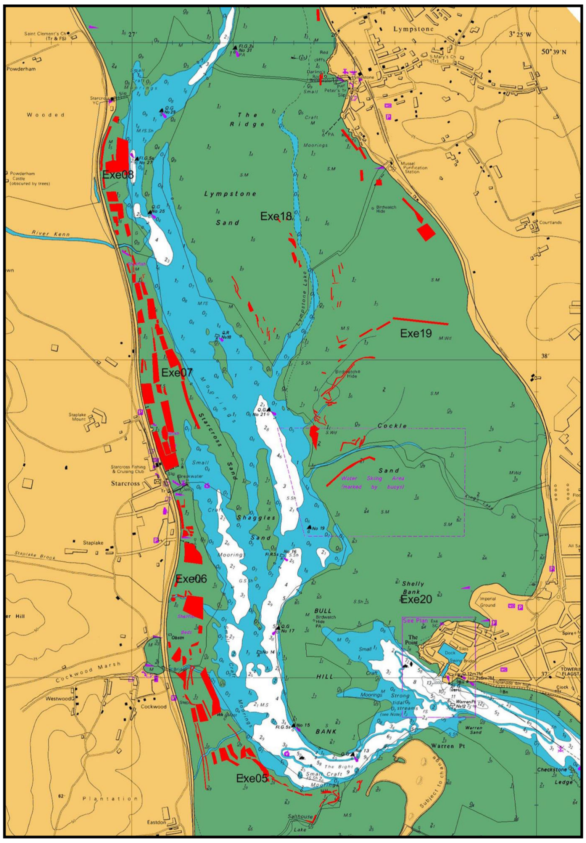

Figure 2: Distribution of Crab Tiling Areas in the Exe Estuary

Aims and objectives

The aim of this literature review is to collate information and evidence relating to bait digging and crab tiling on the Exe Estuary, and how these activities may affect the distribution, behaviour and health of wading bird species. It is specifically focussed on the potential effects that these activities have on bird species via;

1. changes in prey abundance, and;
2. the disturbance of birds by the physical presence of a person.

Crab Tiling

Statutory authorities such as the Devon Sea Fisheries Committee (DSFC) first started to regulate this fishery in 2008. When the Sea Fisheries Committees Inshore Fisheries and Conservation Authorities in 2011, the responsibilities of the DSFC was inherited by Devon & Seven Inshore Fisheries and Conservation Authority (D&SIFCA). Collection of shore crabs on the Exe is managed by both statutory and voluntary means. D&SIFCA Byelaw 24 states that the taking of shore crab must be confined to certain areas of the estuary, whist a voluntary code of conduct, created with crab tilers in 2003, requires that the number of tiles must not exceed baseline levels (26,796 tiles) (Noble, 2013, Exe Estuary Management Partnership, 2014).

To ensure that these management measures are being upheld, a crab tile audit is conducted every four years. In 2012 D&SIFCA compiled a report stating that there has been an overall decrease in the number of tiles since 2008 by 5491 tiles to a figure of just over 20,000 tiles (fig 3).

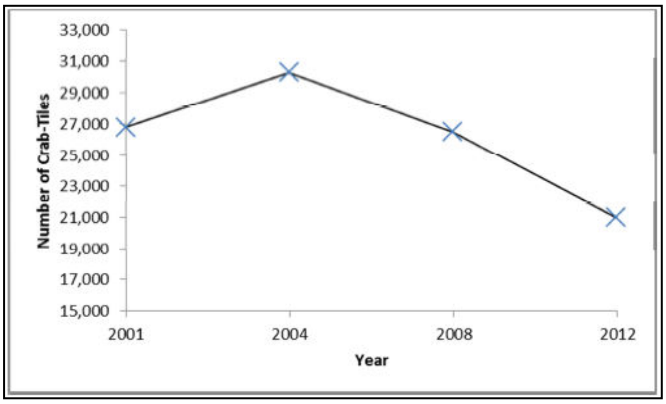

Figure 3: D&S IFCA crab tile audit 2001-2012

Noble (2013) cites anecdotal evidence of tiles becoming buried by sediment through lack of use by the tilers, but whether this is due to a decline in crab population or a decreased demand for bait is not known (Noble, 2013).

Effects on *C. maenas* abundance & community composition

Some studies have attributed an increase in the abundance of *C. maenas* to the presence of crab tiles. Reasons for this increase in abundance include an increase in structural and habitat complexity reducing physiological stresses (Peterson, 1991), a reduction of predation risk at low and high tide (Moksnes et al., 1998, Peterson, 1991, Lohrer et al., 2000) and an increase in suitable substrate for settlement of prey species, and larval *C. maenas* which tend to prefer more complex habitats than mudflats (Cook et al., 2002, Moksnes, 2002). The likely wider impact of changes to the population of *C. maenas* may have on the estuarine ecosystem are difficult to predict and test as many complexities of ecosystem processes, multi-level interactions and variations in spatial and temporal patterns may affect the overall result of how changes in populations occur in a given estuary. Multiple studies have been shown that *C. maenas* has a myriad of direct and indirect effects on estuarine communities mainly due to *C. maenas*'s varied, opportunistic and shifting diet (Crothers, 1967), as shown in Table 1 (Jensen and Jensen, 1985, Scherer and Reise, 1981, Elner, 1981). This leads to varied top down pressures affecting different species, dependant on the availability of said prey items, causing potential adverse or beneficial effects.

Table 1: Typical prey species for juvenile and adult *C. maenas*

Age Form	Primary Food Form
Juvenile	nematodes, flatworms, ostracods, amphipods, young cockles and barnacles
Adult	mussels, clams, gastropods, juvenile *Carcinus maenas* and algae

Sheehan (2007) noted a significant difference in the abundance of crabs between tiled and non-tiled estuaries with four times as many crabs recorded in estuaries where crab tiling took place. Size of crabs also differed between the estuaries with a greater number of smaller crabs within tiled locations and a greater number of larger crabs in the untiled locations. With these differences a change in abundance and the potential size distribution of prey species could well occur. Gee et al. (1985) has confirmed this assumption with a survey into juvenile and adult *C. maenas* in the River Lynher (Cornwall, UK) and found juveniles reduced the abundance of polychaetes, however conversely adults increased the abundance of various species of small polychaetes. This is of interest as polychaete worms are an important food source for wading birds. Baeta et al. (2006) noted no difference between width of the carapace (commonly used to assess age), the stomach content and therefore diet of *C. maenas*, this would imply that within their survey that all polychaetes would be affected equally across age classes. Other studies which examine impacts to estuarine species as a result of *C. maenas* includes (Fernandes et al., 1999) which found *C. maenas* could affect populations of various mudflat species (Table 2).

Table 2: Infauna effected by *C. maenas* Fernandes et al., 1999

Molluscs	Polychaetes
- ***Hydrobia ulvae*** - Laver spire shell or mudsnail - ***C. edule*** - Common Cockle - ***Macoma balthica*** – Baltic Clam - ***Retusa obtusa*** – Arctic barrel-bubble	- ***Pygospio elegans*** - ***Nephtys hombergii*** - Catworm

Schratzberger and Warwick, (1999) found that the activity of *C. maenas* via predation and through modification of the sediment led to a decrease in the total abundance of nematode worms. Interestingly, this study also found that the digging behaviour of *C. maenas* in foraging activity often lead to the aeration of stable and anoxic mud, creating favourable habitats for other infauna. However, not all studies identified in this review reported changes to species composition and abundance. Some studies that manipulated *C. maenas* densities have reported little impact on infauna (Thrush, 1986, Raffaelli et al., 1989).

With many organisms in estuarine environments providing key food sources and biological processes such as bioturbation (reworking of the sediment), any alteration in crab population size, abundancy of certain size classes or physical impacts of the tiles and trampling may lead to associated changes in assemblage structure, alterations in bioturbation and aeration of the sediment, prey abundance of wading shore birds and lastly the ecosystem functioning.

Effect on overwintering birds

The impacts of the use of crab tiles on shorebird behaviour have been studied in south west estuaries by Sheehan et al (2007, 2012). While this type of fishery has the potential to alter prey species and abundances there was no indication that the presence of the tiles changed bird abundance or assemblage composition. Studies showed that changes in feeding behaviour of Redshank and Curlew wading birds occurred where crab tiles are present. Redshank spent more time next to tiles, while Curlew did not. Both spent more time probing than pecking when next to tiles but spent similar times feeding compared with conspecifics in a nearby non- tiled estuary. Other birds including Little Egret (Sheehan pers coms) have utilised the pools of water around the tiles to fish. It is suggested that the smaller waders utilise a 'shelter effect' the tiles provide as they were seen resting next to the tiles.

Bait Digging

Bait-digging generally has a greater level of physical disturbance to the sediment associated with it than crab tiling, therefore there may be greater potential impacts to associated infauna associated with this activity. As well as disturbance via trampling bait digging usually occurs to depths of 30cm, unearthing a deeper sediment that would usually remain undisturbed unless via bioturbation (Jackson and James, 1979).

Effect on community composition

Studies have shown that a reduction in the abundance and biodiversity of infaunal communities has been attributed to bait digging. Jackson and James' (1979) study on the consequences that bait digging has on cockle populations highlighted that increased digging in an area caused higher cockle mortality, especially for smaller individuals. Through laboratory experiments it was deduced that bait-digging causes mortality to cockles due to the increased likelihood that cockles are buried at a depth deeper than 10cm. Few cockles buried this deep under laboratory conditions could survive. As most bait digging occurs to depths of 30cm it is likely that other organisms especially juveniles could become smothered. Other mollusc species that have shown decreased population as a result of smothering effect include *Littorina littorea* (Watson et al., 2007). This study showed some large, long lived species do not recover for a number of years in response to manual bait collection. *Neoamphitrite figulus* and the polynoid scaleworm *Harmothoë glabra* both suffered immediate decline to near-zero levels once digging had occurred and remained low during the five years of the study period. The study also attributed loss of certain organisms as a result of reduced symbiotic organism, reduction in the population of *N. figulus* was closely linked with the loss in *H. glabra*, as both species may live together in one burrow. Failure in a species ability to recolonize a dug area due to its near-sessile nature will result in associated species also suffering.

Other studies have shown that reproduction rates are heavily affected by bait digging. Studies have observed a slow recovery rate in lugworms and other infaunal species concluding that bait digging reduces the abundance of all major species in the survey area (Cryer et al., 1987, Van den Heiligenberg, 1987). The studies also noted a higher juvenile recruitment rates in these areas.

Regarding recruitment it has been said that some macrofauna including *Nereis virens*, *Arenicola marina*, *Macoma balthica* and *Scoloplos armiger* are not affected by extensive digging as the recolonization of the area is rapid due to adult or larval migration (Watson et al., 2007). However in other surveys *N. virens* and *A. marina* (Cryer et al., 1987, van den Heiligenberg, 1987) as well as *M. balthica* (Fernandes et al., 1999) did not show similar rates of recolonization. Watson et al. (2007) noted that *Nephtys hombergii* did experience a decline during the study period.

What is important to note is that the effects of bait digging are not uniform between estuaries with other factors attributing to these declines in population. Carvalho et al. (2013) showed, on the South Iberian coast, that the mud content of sediments has an effect on the recoverability of benthic biota to disturbance caused by bait digging. Sites with proportionally lower mud content showed a faster recovery of benthic assemblages. Areas with high mud content were dominated by species which typically took longer to recover. The Exe Estuary is a relatively sandy estuary similar to that found in Carvalho et al. (2013) study (Sheehan, 2007).

Effects on overwintering birds

In a recent survey focussing of recreational disturbance of the Exe Estuary bait digging was one of a number of activities which accounted for major flight events of overwintering bird species (Liley et al., 2011). In comparison to crab-tiling, there is a larger volume of scientific literature relating to the impact of bait digging on different species of wading bird. Particularly focusing on direct effects such as visual and noise disturbance and the indirect effects of removing prey and the modification of the habitat (Fowler and Nature, 1999). This is most likely a result of peak times of year for collection coinciding with the presence of overwintering birds which arrive for feeding to many south west estuaries (Birchenough, 2013). As mentioned in this review, removal of the target bait species can affect the number and diversity of other organisms within estuarine areas. Changes in the behaviour, population and foraging efficiency have all been studied with a variety of results; pinpointing these key effects in species such as Curlews, Sandpipers, Redshank, Wigeon, Dunlin, Oystercatcher and Bar-tailed Godwit (Townshend and O'Connor, 1993, Shepherd and Boates, 1999, Navedo and Masero, 2007, Sheehan, 2007, Fearnley et al., 2013). Many of these species and the habitats they inhabit are protected under national and international legislation making it important that we understand the impacts.

Discussion

The evidence presented so far has shown that in certain situations both crab tiling and bait digging can impact the infaunal communities present in estuarine environments. These changes in infauna abundance and diversity could potentially affect wading bird species. The following discussion is split into two sections; one which looks at changes in prey supply which might occur as a result of these activities; and secondly looking at how these activities may lead to disturbance of overwintering bird species.

Prey Supply

An important attribute relating to wading bird distribution, behaviour and health is the supply and availability of food for energy. As previously discussed disturbance to intertidal sediments has the potential to lead to changes of infaunal abundance and population. Zwarts and Wanink (1993) demonstrated the link between biomass, and therefore energy content, of estuarine infauna and the behaviour of wading birds. It was shown that wading birds extend their feeding period, increase their attack rate, broaden the prey they will eat or move to different areas to cope with seasonal changes in infaunal population and age structure. Therefore reduced population and/or changes in age structure of certain infauna caused by crab-tiling and bait-digging could lead to changes in behaviour of wading birds as listed in Zwarts and Wanink (1993).

Estuarine intertidal mudflats are relatively homogenous environments. An increase in hard substrata, such a crab tiles, creates a new environment for epibionts, sessile organisms that attach themselves to the substrate or other organisms, whilst also decreasing the availability of soft sediment for other organisms. Sheehan (2007) found that smaller (Redshank & Dunlin) or piscivorous (Little Egret) bird species within the tiled areas of the Exe and Teign estuaries tended to be more abundant than larger bird species. This is thought to be most likely due to usage of cover and for fishing respectively.
Sheehan (2007) also found that while birds were within tiled areas the amount of time spent next to the tile feeding was significantly higher than time spent feeding away from the tiled areas. Further studies have shown that shorebirds tend to forage generally where food is in relatively optimal supply (Ravenscroft and Beardall, 2003) and/or when predation risk is low (Whitfield, 2003). This could explain the higher levels of time spent within the tiled areas feeding. Sheehan (2007) subsequently concluded that crab tiles provide either one of or an amalgamation of the following factors; a boost in local prey supply and a form of protection from predation via obscuration and/or from competition.

Whitfield (2003) observed birds tended to be seen alone or in small flocks while within tiled areas, whereas in non-tiled the birds were seen in larger flocks. This difference wasn't quantified, however suggested reason for this behaviour is down to a lower risk of predation close to crab-tiles. Alternatively it has been suggested that within and in close proximity to these tiled areas there is a lower supply of food stock which may support small numbers of birds (Whitfield, 2003). Sheehan (2007) provides further evidence for this, recording a lower abundance of infauna near the tiles. This decreased abundance of infaunal prey types may cause certain bird species to alter their feeding behaviours. In turn this result in birds feeding on prey that might not provide the optimum source of energy or they may have to feed for prolonged periods of time (Zwarts and Wanink, 1993, Sheehan, 2007).

Decreased foraging efficiency of wading birds may not necessarily be affected by the direct harvesting of their preferred prey. Shepherd and Boates (1999) found that foraging efficiency of sandpipers was significantly lower in areas targeted for bait digging of bloodworms, not a source of food for the sandpiper. Foraging efficiency decreased by 68.5% which was related to a reduction in their food source, the amphipod *Corophium volutator*, as a result of direct mortality and lower juvenile recruitment caused by bait-digging. These changes were seen after just one season of bait-digging, and it was observed that sandpipers on dug regions of the estuary took longer to build up fat deposits needed for migration. This resulted in sandpipers either leaving later or without sufficient fat deposits. It appears that there is a lack of further literature on other bird species and estuaries.

Increased feeding effort has also been attributed to other factors as well, van den Heiligenberg, 1987 noted that a high recovery rate of some juvenile invertebrate species occurred after bait digging. This would cause food supplies to consist of younger and therefore smaller individuals with less biomass. Prey organisms which have less biomass provide a lower level of energy to their predator, requiring predators to consume a greater number of prey species to provide the same amount of energy.

Lastly in regard to prey supply, temporary restrictions to small scale bait harvesting has shown to lead to increases in prey availability. In Lindisfarne National Nature Reserve (NNR), Budle Bay, very rapid recovery of lugworm populations was experienced whenever bait digging ceased. In conjunction with this trend bird numbers using the area rose considerably (UK Marine SACs Project, 2001). Under a Nature Conservation Order and amendments made by Natural England to NNR byelaw 2 (1) (a) bait digging was banned in 1993 as a result of decreased numbers of birds associated with bait digging resurgence (UK Marine SACs Project, 2001). Higerloh et al. (2001) & Townshend and O’conner (1993) similarly found that the removal of bait harvesting activities from estuarine areas resulted in an increase in the availability of optimum food types and could make way for increased populations of or re-emergence of wading bird species.

Disturbance

The presence of people in feeding/breeding areas can lead to changes to the distribution (Peterson, 1991, Goss-Custard and Verboven, 1993, Townshend and O'Connor, 1993) and the behaviour (Urfi et al., 1996, Stolen, 2003) of birds in an estuary . This may cause birds to become displaced moving to alternative areas that have a lower prey density and a higher density of conspecifics (Goss-Custard and Verboven 1993). This disturbance can be dictated by a number of factors including; the noise level of the disturbance, the amount of activity and the number of people in a group. Disturbance from bait collection generally occurs via visual (seeing the collector and responding as if they were a potential predator) and/or noise disturbance (causing distress via deviation from the "natural" ambient noise).

The idea of habituation is an important factor when linking bird disturbance caused by human activities. Studies on multiple sites have suggested that species are able to habituate to the frequent presence of people reducing the distance at which they take flight (Urfi *et al.*,1996) whereas De Boer and Longamane (1996) found a relationship between the size of the bird and the minimum distance human presence initiates disturbance behaviour. In this study larger birds were shown to have greater minimal approach distances and foraging activity also decreased early when approached by humans. Furthermore Goss-Custard and Verboven (1993) found that oystercatcher under minimal disturbance conditions have been known to habituate to people depending on the movement of the individuals. After the initial disturbance oystercatcher will settle down and even feed nearby. However although not directly relevant to habituation Lafferty (2001) noted that even though humans frequently disturbed wading birds in their survey this did not affect the large scale distribution of the survey species. Cutts and Hemingway (2012) provided varying levels of sensitivity/thresholds to noise and visual disturbances of a variety of wading bird species. With an understanding of bait digging hotspots in the Exe, this information could be used to investigate potential habituation of species to disturbance across the Exe Estuary.

Crab tiling is an activity that has been carried out for a number of years on the Exe (Black 2004), therefore habituation of birds to disturbance caused by this activity on the Exe is a possibility. This theory is substantiated in Poole Harbour SPA where a comparison between the frequency of bait collection and the distribution of wading birds has shown wading bird abundance is highest within an intermediate amount of activity (Fearnley et al., 2013). The same study also showed that Redshank and Shelduck counts were at their highest in areas with the highest levels of activity (Fearnley et al., 2013).

Although these activities are associated with varying levels of disturbance, other potential sources of disturbance should also be considered alongside them. Armitage et al. (2002) makes reference to key factors relating to decreases in bird populations, attributing it to over-fishing; aquaculture projects; a change in water quality as a result of a reduction in nutrient availability; and recreational disturbances. These will most likely apply to the Wigeon, Brent Geese, Avocet and Oystercatcher according to Armitage et al. (2002) review of Wetland Bird Survey (WeBS) counts. Sheehan (2007) remarks that the potential impacts of crab tiling on wading birds should be considered in-combination with the other commercial and recreational activities which occur around the Exe. Even though the Exe is considered to have high levels of anthropogenic disturbance, it has been noted that approximately two-thirds of bird feeding effort within the Exe Estuary occurs where anthropogenic disturbance is low or non-existent (Goss-Custard and Verboven 1993).

Conclusion

Having reviewed literature relevant to both crab tiling and bait digging on the Exe, various evidence sources suggest that these activities have the potential to effect estuaries and the overwintering species they support through a variety of direct and indirect mechanisms. Bird species have the potential to be affected either directly via anthropogenic disturbance associated with these activities, or via changes to the infauna which may lead to the reliance on longer feeding times and/or other prey sources. The scale and importance of these effects is dependent on a number of factors including the species of bird present. However, it is important to look at disturbance from bait digging and crab tiling in combination with the wide range of other activities that take place on the Exe Estuary.

With many studies looking at other UK and international estuaries we can build a picture of the subsequent patterns that may emerge from extensive bait collection. However as only Sheehan (2007) bases her wading bird surveys within the Exe Estuary and solely on crab tiling, further work looking at both activities would be beneficial in understanding the effects these activities may be having on the estuary. Further suggested research could include;

- A complete census of both bait digging and crab tiling effort in the Exe, similar to that of Noble (2013). This could be used, particularly for bait digging, to identify hotspots where these activities are taking place.

- Repetition of parts of Sheehan (2007)'s work. Specifically, regarding bird distribution and disturbance as well as the infaunal community assessment; establishing the level of disturbance pressure on wading birds and the infaunal assemblages present between areas.

- Knowledge of prey preference for overwintering species on the Exe could be used to look at biomass of preferred prey species across the estuary or at specific location.

- Biomass of the current wading bird population could be monitored with the results used to formulate an assessment of whether key wading bird species are still meeting their necessary energy demands if known.

Implications for management

Whilst it is not possible from this review to recommend whether any site-specific management measures that need to be undertaken for the Exe it has highlighted areas where further work may be needed to better understand these activities.

If future management of these activities was required, the preferred route could be achieved through continued dialogue between local anglers and management authorities. If it appears within the Exe Estuary there is evidence of a significant detrimental effect upon the SPA features, mitigation measures could then be collectively agreed on.

References

ARMITAGE, M., BURTON, N., ATKINSON, P., AUSTIN, G., CLARK, N., MELLAN, H. & REHFISCH, M. 2002. Reviewing the Impact of Agency Permissions and Activities on Bird Populations in Special Protection Areas: Level 1 Interpretation.

BAETA, A., CABRAL, H. N., MARQUES, J. C. & PARDAL, M. A. 2006. Feeding ecology of the green crab, Carcinus maenas (L., 1758) in a temperate estuary, Portugal. *Crustaceana,* 79**,** 1181-1193.

BIRCHENOUGH, S. 2013. Impact of bait collecting in Poole Harbour and other estuaries within the Southern IFCA District. Southampton: Southern Inshore Fisheries and Conservation Authority.

CARVALHO, S., CONSTANTINO, R., CERQUEIRA, M., PEREIRA, F., SUBIDA, M. D., DRAKE, P. & GASPAR, M. B. 2013. Short-term impact of bait digging on intertidal macrobenthic assemblages of two south Iberian Atlantic systems. *Estuarine, Coastal and Shelf Science,* 132**,** 65-76.

COOK, W., JONES, E. & WYN, G. 2002. *Experimental studies on the effects of shore crab collection using artificial shelters on an intertidal sandflat habitat*.

CROTHERS, J. 1967. The biology of the shore crab Carcinus maenas (L.). *Field Stud,* 2**,** 407-434.

CRYER, M., WHITTLE, G. N. & WILLIAMS, R. 1987. The impact of bait collection by anglers on marine intertidal invertebrates. *Biological Conservation,* 42**,** 83-93.

CUTTS, N. D. & HEMINGWAY, K. L. H. 2012. Bird disturbance from flood and coastal risk management construction activities. Hull: Institute of Estuarine & Coastal Studies, University of Hull.

DE BOER, W. & LONGAMANE, F. 1996. The exploitation of intertidal food resources in Inhaca Bay, Mozambique, by shorebirds and humans. *Biological conservation,* 78**,** 295-303.

ELNER, R. 1981. Diet of green crab Carcinus maenas (L.) from Port Hebert, southwestern Nova Scotia. *Journal of Shellfish Research,* 1**,** 89-94.

EXE ESTUARY MANAGEMENT PARTNERSHIP. 2014. *State of the Exe Estuary - Chapter 3: Natural and Historic Environment - Designations* [Online]. Exe Estuary Management Partnership.

EXE ESTUARY MANAGEMENT PARTNERSHIP. 2014. *Use of the Exe Estuary* [Online]. Available at: http://www.licco.eu/wp-content/uploads/2015/03/7.-Chapter-4_Use-of-the-Exe-Estuary_Fisheries4.pdf. [Accessed 30/11/2015.

FEARNLEY, H., CRUICKSHANKS, K., LAKE, S. & LILEY, D. 2013. The Effects of Bait Harvesting on Bird Distribution and Foraging Behaviour in Poole Harbour SPA. Wareham: Footprint Ecology.

FERNANDES, T., HUXHAM, M. & PIPER, S. 1999. Predator caging experiments: a test of the importance of scale. *Journal of Experimental Marine Biology and Ecology,* 241**,** 137-154.

FOWLER, S. L. & NATURE, E. 1999. *Guidelines for managing the collection of bait and other shoreline animals within UK European marine sites*, Nature Conservation Bureau.

GEE, J., WARWICK, R., DAVEY, J. & GEORGE, C. 1985. Field experiments on the role of epibenthic predators in determining prey densities in an estuarine mudflat. *Estuarine, Coastal and Shelf Science,* 21**,** 429-448.

GOSS-CUSTARD, J. & VERBOVEN, N. 1993. Disturbance and feeding shorebirds on the Exe estuary. *Wader Study Group Bulletin,* 68**,** 59-66.

HAEDRICH, R. & BARNES, S. 1997. Changes over time of the size structure in an exploited shelf fish community. *Fisheries Research,* 31**,** 229-239.

JACKSON, M. & JAMES, R. 1979. The influence of bait digging on cockle, Cerastoderma edule, populations in North Norfolk. *Journal of Applied Ecology*, 671-679.

JENSEN, K. T. & JENSEN, J. N. 1985. The importance of some epibenthic predators on the density of juvenile benthic macrofauna in the Danish Wadden Sea. *Journal of Experimental Marine Biology and Ecology,* 89, 157-174.

LAFFERTY, K. D. 2001. Birds at a Southern California beach: seasonality, habitat use and disturbance by human activity. *Biodiversity & Conservation,* 10, 1949-1962.

LILEY, D., CRUICKSHANKS, K., WALDON, J. & FEARNLEY, H. 2011. Exe Estuary Disturbance Study.: Footprint Ecology.

LOHRER, A. M., FUKUI, Y., WADA, K. & WHITLATCH, R. B. 2000. Structural complexity and vertical zonation of intertidal crabs, with focus on habitat requirements of the invasive Asian shore crab, Hemigrapsus sanguineus (de Haan). *Journal of Experimental Marine Biology and Ecology,* 244, 203-217.

MOKSNES, P.-O. 2002. The relative importance of habitat-specific settlement, predation and juvenile dispersal for distribution and abundance of young juvenile shore crabs Carcinus maenas L. *Journal of Experimental Marine Biology and Ecology,* 271, 41-73.

MOKSNES, P.-O., PIHL, L. & VAN MONTFRANS, J. 1998. Predation on postlarvae and juveniles of the shore crab Carcinus maenas: importance of shelter, size and cannibalism. *Marine Ecology-Progress Series*.

NAVEDO, J. G. & MASERO, J. A. 2007. Measuring potential negative effects of traditional harvesting practices on waterbirds: a case study with migrating curlews. *Animal Conservation,* 10, 88-94.

NOBLE, T. 2013. Exe Estuary Crab Tile Survey 2012. Devon and Severn Inshore Fisheries and Conservation Authority.

PETERSON, M. S. 1991. Differential length-weight relations among centrarchids (Pisces: Centrarchidae) from tidal freshwater and oligohaline wetland habitats. *Wetlands,* 11**,** 325-332.

RAFFAELLI, D., CONACHER, A., MCLACHLAN, H. & EMES, C. 1989. The role of epibenthic crustacean predators in an estuarine food web. *Estuarine, Coastal and Shelf Science,* 28**,** 149-160.

RAVENSCROFT, N. & BEARDALL, C. 2003. The importance of freshwater flows over estuarine mudflats for wintering waders and wildfowl. *Biological Conservation,* 113**,** 89-97.

SCHERER, B. & REISE, K. 1981. Significant predation on micro-and macrobenthos by the crab Carcinus maenas L. in the Wadden Sea. *Kiel Meeresforsch Sonderh,* 5**,** 490-500.

SCHRATZBERGER, M. & WARWICK, R. M. 1999. Impact of predation and sediment disturbance by Carcinus maenas (L.) on free-living nematode community structure. *Journal of Experimental Marine Biology and Ecology,* 235**,** 255-271.

SHEEHAN, E. V. 2007. Ecological impact of the Carcinus maenas (L.) fishery'crab-tiling'on estuarine fauna.

SHEPHERD, P. C. & BOATES, J. S. 1999. Effects of a commercial baitworm harvest on semipalmated sandpipers and their prey in the Bay of Fundy hemispheric shorebird reserve. *Conservation Biology,* 13**,** 347-356.

STOLEN, E. D. 2003. The effects of vehicle passage on foraging behavior of wading birds. *Waterbirds,* 26**,** 429-436.

THRUSH, S. F. 1986. Community structure on the floor of a sea-lough: are large epibenthic predators important? *Journal of experimental marine biology and ecology,* 104**,** 171-183.

TOWNSHEND, D. & O’CONNOR, D. 1993. Some effects of disturbance to waterfowl from bait-digging and wildfowling at Lindisfarne National Nature Reserve, north-east England. *Wader Study Group Bulletin,* 68**,** 52.

UK MARINE SACS PROJECT. 2001. *Berwickshire and North Northumberland Coast candidate SAC, England - Bait Digging in Budle Bay* [Online]. Available: Available at: http://www.ukmarinesac.org.uk/activities/bait-collection/bc11.htm [Accessed 1/12/2015.

UKMARINESAC.ORG.UK. 2015. *Methods of hand digging for bait* [Online]. [online] Available at: http://www.ukmarinesac.org.uk/activities/bait-collection/bc2_3.htm. [Accessed 18/11/2015 2015].

URFI, A. J., GOSS-CUSTARD, J. D., LEV, S. & DURELL, D. 1996. The ability of oystercatchers Haematopus ostralegus to compensate for lost feeding time: field studies on individually marked birds. *Journal of Applied Ecology*, 873-883.

VAN DEN HEILIGENBERG, T. 1987. Effects of mechanical and manual harvesting of lugworms Arenicola marina L. on the benthic fauna of tidal flats in the Dutch Wadden Sea. *Biological Conservation,* 39**,** 165-177.

WATSON, G. J., FARRELL, P., STANTON, S. & SKIDMORE, L. C. 2007. Effects of bait collection on Nereis virens populations and macrofaunal communities in the Solent, UK. *Journal of the Marine Biological Association of the United Kingdom,* 87**,** 703-716.

WHITFIELD, D. P. 2003. Redshank Tringa totanus flocking behaviour, distance from cover and vulnerability to sparrowhawk Accipiter nisus predation. *Journal of Avian Biology,* 34**,** 163-169.

ZWARTS, L. & WANINK, J. H. 1993. How the food supply harvestable by waders in the Wadden Sea depends on the variation in energy density, body weight, biomass, burying depth and behaviour of tidal-flat invertebrates. *Netherlands Journal of Sea Research,* 31**,** 441-476.