## Southern Inshore Fisheries and Conservation Authority

# Shore Gathering
# Literature Review

### Supporting Document for the
### Shore Gathering Byelaw

# Contents

# Section A: Introduction to the Literature Review

This Literature Review is a supporting document for the development of management for shore gathering activities in the Southern IFCA district.

This document uses best available evidence, namely peer-reviewed papers and reports, to ensure that sound scientific evidence is used to inform assessments of relevant activities. The Literature Review is provided in two sections, general impacts which relate to multiple activities and potential impacts which relate to a specific shore gathering activity. Under the sections for specific activities, an overview is also provided of how that activity is carried out. The document also highlights where specific studies have been carried out and whether these have been conducted in the UK or outside the UK.

Summary boxes have been provided at the end of each section to give an overview of the section's content and key points.

This Literature Review is to be read in conjunction with the Southern IFCA Shore Gathering Review Conservation Assessment Package and Site Specific Evidence Package.

# Section B: Literature Review

## 1. Potential Impacts from Shore Gathering Activities - General

### 1.1 Overview

- The gathering of fish and shellfish species has been carried out commercially and recreationally along the Dorset, Hampshire and Isle of Wight coasts for centuries.
- Harvesting consists of the removal of target species at low tide, either in selective collection such as hand gathering or collective harvesting using rakes or mechanical power.
- Frequently gathered species within the Southern IFCA District include the Manila Clam (*Ruditapes philippinarum),* the common cockle (*Cerastoderma edule),* Pacific oysters (*Magallana gigas)* and the bait worm species King ragworm (*Alitta virens*) and lugworm (*Arenicola marina*).
- Shore gathering activities which occur or have the potential to occur in the district are; bait digging/gathering, shellfish gathering, crab tiling, push netting, seaweed collection and mechanical harvesting (commonly for bait species but also potentially for shellfish species).

### 1.2 Removal of Target Species

- The removal of target species in shore gathering techniques reduces the target species population in the area. Species recoverability is determined by a number of characteristics including magnitude of pressure, species fecundity, environmental conditions, human interaction and life cycle (Hutchings, 2000; Kaiser *et al.,* 2006; Lotze, 2011).

- Similarly, removal of species can disrupt ecosystem balance and impact community structure. As a result, other species display fluctuations, dominant species may alter and habitat structure may change (Turner *et al.,* 1999; Rice, 2000; Kaiser *et al.,* 2000; Dernie *et al.,* 2003; Rossi *et al.,* 2007).
- Harvesting structurally significant species, such as kelps, causes habitat structural changes which may alter light availability throughout the water column and affect potential nursing and breeding sites. (Connolly, 1994; Auster and Langton, 1999; Turner *et al.,* 1999).
- Removal of target species has the potential to affect prey availability for predatory species, such as birds. This affects higher trophic levels via non-targeted removal (Tasker *et al.,* 2000; Sieben *et al.,* 2011; Montevecchi, 2023) and through the disruption of predator-prey interactions which may impact community compositions. For example, the removal of small bivalves and crustaceans can reduce foraging opportunities for shorebirds and fish (Navedo *et al.,* 2008).
- Changes in prey availability can cause shifts in the location of populations of predator species. For example, bird species may move to areas where harvesting of prey species does not take place which could then lead to increased bird densities in these areas (Sutherland & Goss-Custard 1991; Goss-Custard and Verboven, 1993).
- A meta-analysis of studies on hand gathering techniques (and other fishing methods) found that data from the first 10 days following a disturbance showed a significant reduction in the abundance of annelids, however it was also noted that annelid worms and crustaceans appear to recover more quickly in comparison to molluscs (Clarke *et al.,* 2017). This was postulated to be related to sediment preferences and the relatively sedentary nature of molluscs compared to annelids and crustaceans where there is the potential for recolonisation of an area through adult migration as well as larval dispersal (Clarke *et al.,* 2017). It was noted that the localised nature of hand gathering activities would create an impact over a much smaller scale than other fishing activities but that the initial impact may be observed deeper within the sediment as hand worked equipment will often penetrate deeper than dredges (Clarke *et al.,* 2017).

**Summary**

- Direct removal of target species has the potential to lead to population declines of those species, in which recoverability is based on a number of conditions including magnitude of pressure, species fecundity, life cycle, human interactions and environmental conditions.
- Removal of target species may disrupt ecosystem balance and lead to impacts to other species populations, habitat changes and impact community structure. For example, predatory prey interactions may change, resulting in a change in behaviour of the predator species.
- Removal of structural species as seaweeds can alter habitat structure, which may impact the distribution of light throughout the water column and affect potential nursery and breeding sites.
- Impacts are species specific both in terms of the target species itself and the impact on any predatory species. Recovery is also species specific and is likely related to habitat type and methods of recolonisation by each species.

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## 1.3 Removal of non-target species

- Certain methods of shore-gathering have the potential to remove or disrupt non-target species, which play roles in intertidal food webs and support ecosystem biodiversity (Nunes *et al*., 2011).
- Harvesting can cause sediment disturbance, resulting in the removal, damage, or mortality of epifauna and infauna in the surrounding sediment (Dernie *et al.,* 2003; Rossi *et al.,* 2007). This also applies to the exposure and excavation of individuals that are found below the surface of the substratum (Clarke *et al.,* 2017).
- Some species may not be returned to the sediment following harvesting. For example, small species such as those in the larval phase may be attached to species such as kelps (McAllen, 1999).
- The timescale of recovery for benthic communities is largely dependent on sediment type, associated fauna and the rate of natural disturbance (Roberts *et al.,* 2010).
- In locations where natural disturbance levels are high, the associated fauna is characterised by species adapted to withstand and recover from disturbance (Collie *et al.,* 2000; Roberts *et al.,* 2010).
- Non-target species found in more stable habitats, which are often distinguished by high diversity and epifauna, are likely to take a greater time to recover (Roberts *et al.,* 2010).
- Many studies have found that meiofauna exhibit a different response to disturbance than macrofauna. Some meiofauna show very little, or short-term effects of disturbance, whilst others can utilise increases in resources and benefit from disturbance (Wynberg & Branch 1994; Sherman *et al*., 1980; Wynberg & Branch, 1997; Johnson *et al*., 2007). Turbellarians significantly increased after digging and remained above control levels for 35 days (Wynberg & Branch, 1994). However, copepods and polychaetes were significantly reduced immediately after digging, and whilst numbers did bounce back approximately 10 days after the disturbance, they did not return to control levels for more than 70 days (Wynberg & Branch, 1994).
- Population recovery rates are known to be species-specific (Roberts *et al*., 2010). Long-lived bivalves will undoubtedly take longer to recover from disturbance than other species (Roberts *et al*., 2010). Megafaunal species such as molluscs and shrimp over 10 mm in size, especially sessile species, are more vulnerable to impacts of fishing gear than macrofaunal species as a result of their slower growth and therefore are likely to have long recovery periods (Roberts *et al*., 2010). Short-lived and small benthic organisms on the other hand have rapid generation times, high fecundities and therefore excellent recolonization capacities (Coen, 1995).
- Meiofauna has been found to recover quickly, within just one tidal cycle after mud had been turned over (Sherman *et al*., 1980). Some groups, such as foraminifera, even benefited from the disturbance and increased in number after digging (Sherman *et al*., 1980). Wynberg & Branch (1994) also found that meiofauna react positively to disturbance after initial declines, but they then return to control levels. On the other hand, Johnson *et al*., (2007) found that meiofauna reacted negatively to trampling on an English Mudflat. Similarly, though the recovery period for this group of species was short, between 36 and 144 hours (Johnson *et al*., 2007). Hand raking for clams led to a significantly lower nematode assemblage 12h after disturbance, however the meiofaunal community had once again recovered within 48 hours (Mistri *et al*., 2009).

- For example, the use of mechanical dredging or rakes has the potential to impact non-target with the potential for a significant removal. Despite returning non-target species, the risk of mortality is increased. It is noted that some studies on this have shown high recoverability rates of non-target species (Hall and Harding, 1997).
- Gastropods, such as *Peringia* (formally *Hydrobia*) *ulvae*, have been found to be positively affected by the presence of disturbance including digging (Carvalho *et al*., 2013; Watson *et al*., 2007).
- Effects are difficult to quantify, marine ecosystems are complicated and subject to large natural fluctuations caused by changes in parameters including temperature and tidal/current action (Gislason *et al.*, 2002). This is in addition to other human-caused impacts, for example, changes in nutrient levels. This combination of effects makes the impact of a particular fishing activity on marine species communities hard to isolate (Gislason *et al.*, 2002).

There are specific species which are designated species within the MPAs covered by the Shore Gathering Review which may be impacted as non-target species. Where general evidence on these species is available it is reported in Sections 1.3.1 and 1.3.2 below, specific evidence relating to certain pressures is presented in relevant sections.

### 1.3.1 Seahorse Species

- No direct evidence is available on the impact of shore gathering activities on seahorse populations.
- Seahorses spend the majority of their time attached to the substrata for example, seaweed, rock and artificial surfaces (Lorrie *et al.,* 1999; Curtis and Vincent, 2005). Seahorses are also associated with eelgrass and seagrass beds which may be impacted by shore gathering activities (see Section 1.4.1). The species is therefore most likely to be impacted through impacts to associated habitats.
- Seahorse species can be affected by physical degradation and destruction of their habitats resulting in population decline in the most extreme circumstances (Vincent *et al.,* 2011).
- Abrasion and disturbance to the surface of the substratum could result in the direct removal of seahorses attached to substrata or a decrease in populations as a result of the removal of habitat (Foster and Vincent, 2004).
- Similarly, individuals are sensitive to crushing such as during trampling in access to harvesting sites (Nash *et al.,* 2021).
- Short generation times, rapid growth rate and early maturity suggest recovery may be rapid (Harasti, 2016; Woodall, 2017), however, this is contradicted by their limited mobility, small home range and limited dispersal. It is suggested that complete removal of individuals from a population would result in poor recovery rates, otherwise it is thought that resistance and recovery to disturbance events may be high.

### 1.3.2 Stalked Jellyfish

- No direct evidence is available on the effect of shore gathering activities on stalked jellyfish species.
- The species is found attached to algae in pools/the low water line on rocky shores and therefore, could be exposed to abrasion pressure used in harvesting techniques and during access to sites.

- Removal of target species such as seaweeds could lead to a reduction in the abundance of individual stalked jellyfish and available substrate reducing stalked jellyfish populations (Tyler-Walters and Head, 2017).
- Stauromedusae are soft-bodied and therefore unlikely to be able to withstand direct crushing/ abrasive pressure used in shore gathering activities themselves of trampling via access to sites (Miranda, *et al.,* 2012; 2016).
- Stauromedusae are likely to be lost if their supporting habitat the algae is lost due to abrasion or physical change (Corbin, 1979; Miranda *et al.,* 2010).
- It is difficult to determine recoverability, although the short life span and potential for asexual reproduction suggests rapid recovery. However, if over 75% population is lost, recovery is limited (Tyler-Walters and Head, 2017).

### 1.3.3 Peacocks tail (*Padina pavonica*)

- No direct evidence is available on the effect of shore gathering on *P. pavonica*.
- The species occurs on the rock surface and therefore, would be exposed to any present abrasion pressure.
- Disturbance of the seabed and trampling in accessing sites may deplete populations of peacock's tails and in harvested areas and may lead to the smothering of individuals.
- If abrasion of *P. pavonica* were to occur damage to individuals' fronds is likely, but holdfasts should remain. The species has a high recovery potential from regrowth of fronds from rhizoids/holdfasts and also, through its high reproductive potential with both sexual and asexual reproduction possible, so long as some rhizoids/fronds remain (Schiel and Taylor, 1999). Recolonisation can also occur from propagules (Schiel and Taylor, 1999).
- It is suggested that in areas of unfavourable conditions, asexual reproduction may maintain populations (Price *et al.,* 1979).
- Dislodges and drifting fronds with spores may support dispersal and colonization of shores that are isolated from other populations although recovery through this method could be slow (Herbert *et al.,* 2016).
- The species is therefore considered to have a low sensitivity to the abrasion pressure.

## Summary

- Non-target species have the potential to be disrupted or removed through shore gathering activities, which in turn can impact food webs and ecosystem biodiversity.
- Where levels of natural disturbance are higher, associated fauna is often characterised by species adapted to a certain level of disturbance.
- Timescales for recovery are largely dependent on sediment type, associated fauna and the rate of natural disturbance.
- Recovery rates are also species specific, mollusc species often take longer to recover than annelid worms and crustacean species.
- Effects are difficult to quantify as effects from a specific activity are difficult to isolate from any impacts caused by variation in environmental variables and additional anthropogenic impacts such as water quality.
- Seahorse species do not have any direct evidence of impacts related to shore gathering activity. Impacts are likely to result from impacts to their associated habitats such as seagrass and seaweeds. The species is also vulnerable to crushing from trampling or direct removal from abrasion. It is postulated that direct removal of a significant proportion of the population would be required to cause a large negative effect.
- Stalked jellyfish species do not have any direct evidence of impacts related to shore gathering activity. Impacts are likely to relate to impacts to their associated habitats such as seaweeds. The species' are soft bodied and unlikely to withstand abrasion or trampling.
- Peacocks tail does not have any direct evidence of impacts related to shore gathering activity. The species would be exposed to any potential abrasion pressures in associated rocky habitats. Impacts are likely to be the fronds whilst the holdfast should remain. This increases the potential for recovery.

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## 1.4 Sediment Impacts

This section covers general impacts relating to the pressures:

- Abrasion/disturbance of the substrate on the surface of the seabed
- Penetration and/or disturbance of the substratum below the surface of the seabed including abrasion
- Habitat structure changes – removal of substratum (extraction)

- Abrasion and disturbance are generally related to the direct and physical effects of handwork activity including digging and trampling. Such impacts include the creation of basins and mounds, burial and removal of the substratum, sediment disturbance, changes in vertical distribution of sediment layers and changes in the properties of the sediment (McLusky *et al*., 1983; Watson *et al*., 2017).

- Waves and tides can wash away finer sediment and associated organic content that has been dissociated through turning over of sediment (Watson *et al.,* 2017). The effects of this can lead to increased turbidity, pollutants within the water column and potential eutrophication (Watson *et al.,* 2017).
- The upturning of large sections of substrate to access buried invertebrates below the surface can result in layering disruptions and changes in chemical concentrations in the sediment surface layer (Fowler, 1999).
- The physical marks associated with activity may persist over a number of weeks. Where tide and wave action is low or there is limited water exchange within an estuary, the time taken for depressions to be filled following activity increases, potentially resulting in slower rates of sediment recovery than in higher energy sites (Birchenough, 2013).
- Impacts resulting from anthropogenic activity are most evident where the level of disturbance causes differences in sediment structure that are elevated above natural background changes caused by biotic and abiotic factors including changes caused by the benthic community through burrow formation and deposition of faecal material (Probert, 1984).
- A meta-analysis of global studies on hand gathering (and other gear type) impacts found that the magnitude of the response of fauna to fishing varied with the degree of abrasion to the surface of the substratum and changes to habitat (including sediment type) (Clarke *et al*., 2017).
- Studies on bait pumping for shrimp and bait digging showed an increase in finer sediment accumulation where depressions caused by the activity persist after the activity has taken place (McLusky *et al.,* 1983; Wynberg and Branch, 1994; Contessa and Bird, 2004).

### 1.4.1 Effects on Seagrass Beds

- Shore gathering activities have the potential to remove, uproot and bury seagrass shoots and rhizomes (Barañano *et al.,* 2018).
- Seagrass is highly sensitive to burial at just 2-16cm depth (Cabaço & Santos, 2007). Burial results in the reduction of leaf and rhizome carbon and starch content, the occurrence of dead shoots and reductions in leaf and sheath lengths (Cabaço & Santos, 2007).
- Impacts are noted to be variable with activity. The sedimentary carbon stock of *Zostera marina* beds was noted to be reduced by 50% in areas subject to clam harvesting, reflecting levels found in unvegetated areas (Barañano *et al.,* 2018), however low-intensity digging activity in *Zostera noltii* beds was noted not to cause any changes in sediment variables or photosynthetic efficiency (Branco *et al.,* 2018).
- Seagrass species can respond in several ways to hand work activity. In response to disturbance, seagrass beds often increase their reproductive effort (Cabaço & Santos, 2012).
- Mechanical disturbances such as clam harvesting have resulted in a nine and four-fold increase in plant reproductive effort (Cabaço & Santos, 2012; Alexandre *et al*., 2005; Suonan *et al*., 2017).
- Reproductive effort is a measure of parameters such as; the number of flowering shoots, the number of spathes per flowering shoot, and flowering period (Alexandre *et al*., 2005; Suonan *et al*., 2017; Park *et al*., 2011). However, the response of reproductive effort is species-specific, with a strong positive correlation apparent between rhizome diameter and increased reproductive effort (Cabaço & Santos, 2012). The correlation indicates that species with a higher storage capacity (*Z. marina*) have a higher capacity for investing in

sexual reproduction (Cabaço & Santos, 2012). Those with lower storage capacity such as *Z. noltii* may not be able to recover through reproduction (Cabaço & Santos, 2012).

- On the other hand, research has found that seedlings do not contribute to the recovery of *Z. marina* and therefore increased reproductive effort may not be an effective recovery strategy (Qin *et al*., 2016). When shoots and rhizomes were removed/buried by clam harvesting in China, seedlings were observed almost as soon as the disturbance had ceased. However, seedlings in both disturbed and control areas did not survive the following winter, unlike the perennial beds in the control site (Qin *et al*., 2016).
- Recovery time varies considerably between species and location. Boese *et al*., (2009) stimulated disturbance to a *Z. marina* bed by removing the shoots. Disturbed areas recovered through the growth of rhizomes from perennial seagrass beds. Recovery of an area disturbed within a well-established seagrass bed took 24 months, however in a disturbed area located in the transition zone of seagrass beds (where the bed ends and bare sediment begins) seagrass took 32 months to recover (Boese *et al*., 2009). The estimated rhizome growth rate was 0.5m per year. Meanwhile, *Zoster noltii* has been found to take approximately five years to recover in Wales, although there is strong variability in seagrass beds from year to year (Bertelli *et al*., 2018).
- Zostera japonica in Korea can recover from clam harvesting vehicles within 5 months of the immediate elimination of shoots (Park *et al*., 2011). Post recovery the bed had higher above and below ground biomass and rhizome internode length than the control (Park *et al*., 2011).
- Where seagrass declines the habitat can be recolonised by other species. However, research has shown that *A. marina* may colonize a declining seagrass bed and the presence of the annelid prevented the recovery of the *Z. marina*. Sediment reworking by the worm led to rapid burial of eelgrass seeds below critical depth where they could not develop (Valdemarsen *et al*., 2011).

### 1.4.2 Trampling

- In some harvesting methods, abrasion is not caused by the direct impact of the activity itself, but, by the indirect impact of the access required to access resources. The damage occurs when human footsteps interact with the communities residing in the intertidal area, known as trampling.
- Trampling leads to direct and indirect effects. Direct impacts include the immediate damage, crushing or removal of algae and invertebrates, and indirect impacts include changes in community assemblages, due to loss of habitat and changes to environmental variables.
- While the intensity of the trampling has been found to be the key factor in governing the level of impact caused it is also correlated to the recovery time (Araujo *et al*., 2009; Milazo *et al*., 2002; Povey & Keough, 1991). Typically, the relationship between trampling intensity and recovery is negative, with more intensely trampled areas requiring longer time frames to recover (Povey & Keough 1991; Araujo *et al*., 2009; Rita 2011).
- After one year following impact Araujo *et al*. (2009) found the communities of medium and high intensity trampled areas remained significantly different to controls and low trampled sites. Rita (2011) studied recovery over a longer term of five years and found that 36 months following trampling, *A. nodosum* (algae) had recovered in low intensity areas only. 54 months following disturbance, *A. nodosum* had recovered in medium-intensity sites but had not achieved full recovery in high-intensity sites (Rita, 2011).

#### 1.4.2.1 Reefs

- Trampling abrasion during access to sites may lead to crushing/ dislodging or damage to ecologically significant species within reef habitats (Tyler-Walters and Arnold, 2008; Plicanti *et al.,* 2016).
- The extent of damage is dependent on the species and exposure. For example, species with hard exteriors such as mussels or barnacles, may be less impacted than softer bodies individuals within the reef habitats (Tyler-Walters and Arnold, 2008; Plicanti *et al.,* 2016).
- Studies suggest disrupted areas do not recover in highly exposed areas, due to wave action. This therefore suggests that the ability for reefs to recover following trampling is dependent on exposure to wave action and tides (Tyler-Walters and Arnold, 2008; Plicanti *et al.,* 2016).
- Differences in impact vary, studies have found large declines in *Mytilus californianus* after trampling in mussel beds, with up to 54% loss in experimental plots after 1 day of trampling (Brosnan and Crumrine, 1994). However, Smith and Murray (2005) found only 15% of loss as a direct result of trampling, during experimental exposure to mussel bed reefs.

#### 1.4.2.2 Mud and Sand Flats

- Trampling intensity has been shown to be a crucial factor in the level of impact caused to sandy beach macrofauna on the Eastern Cape coast (Moffett *et al*., 1998).
- In soft intertidal mud, clear footprints have been found to remain four days after trampling and disturbance is still visible 21 days later (Rossi *et al*., 2007), however, it was concluded this does not affect abiotic characteristics of the sediments.
- Johnson *et al.,* (2007) found no significant differences between the grain size, total organic content and penetrability following six trampling events on an intertidal mudflat habitat in Southwest England.
- Rossi *et al*. (2007) also found no difference in inorganic nitrogen content in the top centimetre of surface water, however higher trampling intensities have been found to impact chlorophyll levels (Wynberg and Branch 1997).
- Research on the effects of trampling on sediment habitats has mostly focused on the impacts on the communities living below the surface of the sediment, with general decreases in tube-dwelling, sub-surface deposit feeders and deep burrowing species (Wynberg and Branch, 1994).
- In one specific study from SW England, twelve hours following trampling, nematode abundance and species number significantly declined but were seen to recover within 36 hours (Johnson *et al*., 2007).
- It is understood that meiofauna bury themselves deeper into the sediment in response to trampling and therefore the community can recover quickly once the impact has ceased (Johnson *et al*., 2007).
- Mobile species, such as annelids have shown no changes from trampling, although adult bivalve species, *Cerastoderma edule* and *Macoma balthica*, significantly declined in abundance at trampled sites (Rossi *et al*., 2007).
- In contradiction, trampling enhanced the recruitment rate of juvenile *M. balthica* and did not impact juvenile *C. edule* (Rossi *et al*., 2007).
- On sandy beaches, often visited by tourists rather than shellfish collectors, trampling in the supralittoral zone has been shown to lead to mortality and declines in sand hopper (*Talitrus saltator*) density (Ugolini *et al.,* 2007).
- Between the high tide and swash zone clear negative impacts of trampling on sand communities have been demonstrated during the summer season in southern Spain (Reyes-Martinez *et al.,* 2015). Over time, trampling changes the density and taxonomic

structure of the macrofauna compared to a protected site. The sand shrimp *Bathyporeia pelagica* was severely affected in the most trampled area reducing to zero individuals per $m^2$ (Reyes-Martinez *et al*., 2015). Crustaceans can decrease by more than 60% in trampled areas, meanwhile polychaetes increase by more than 60%. In a protected area, microbenthic density increased compared to a significant decrease in disturbed areas (Reyes-Martinez *et al*., 2015).

- A study of a number of animals in enclosures found that at low trampling intensities few of the macrofauna were damaged, but the level of damage was substantial (mean 70% and 63%) for *Gastrosaccus psammodytes and D. serra respectively,* under intense trampling (Moffett *et al*., 1998).

### 1.4.2.3 Saltmarsh

- Low-level trampling was not found to affect the redox discontinuity layer, organic matter content, silt-clay content and soil pH of saltmarsh in the UK in winter or summer (Chandrasekara and Frid, 1996). Trampled areas versus untrampled areas showed no difference in winter and summer.
- Chandrasekara and Frid (1996) concluded that the saltmarsh vegetation cushions the impact of trampling and therefore prevents impacts to the sediment infauna.
- In Wales, a study of long-term (48 years) trampling on saltmarsh found that it did not affect the physical characteristics of the sediments, water content or bulk density (Headley and Sale, 1999).
- However, the penetration resistance (sediment compaction) increased significantly in trampled areas. As with short-term disturbance, long-term trampling reduced the abundance and vegetation height by 14cm on average, of *Halimione portulacoides* and four other species, resulting in higher bare ground cover (Headley and Sale, 1999). This led to increased abundances of typically lower-growing halophyte species in the midmarsh zone, which were significantly more present in trampled areas including; *Armeria maritima, Aster tripolium, Glaux maritima, Salicornia europeaea, Spergularia marginata* and *Suaeda maritima*. Overall, trampling anthropogenically increased the species diversity of the saltmarsh communities and led to new plant communities (Headley and Sale, 1999).
- Natural saltmarshes in Denmark were found to be relatively resistant to trampling, showing limited changes in species abundance and diversity (Andersen, 1995).
- However, other habitat types, such as uncut grassland, artificial dunes and dunes, had clear negative impacts of trampling. Andersen (1995) concluded that saltmarsh is resistant to a low trampling level of approximately five visitors per day.
- Intensity of trampling studies on Californian saltmarsh (*Salicornia virginica)* found all trampling led to a decrease in intensity and frequency of saltmarsh height and flower production over a six-month period. However, heavy trampling led to 90% cover of bare ground (Woolfolk, 1999).
- In one area lightly trampled plots did not initially show signs of damage, but six months later *S. virginica* canopy declined by around ten percent whilst controls did not, showing a delayed response to trampling. Overall, trampling can decrease saltmarsh abundance, change community structure and promote invasion of introduced species all contributing to the loss of marsh habitat (Woolfolk, 1999).
- Trampling and other disturbances have also been found to affect the reproductive potential of saltmarsh *(Plantago maritima)* in Poland (Lazarus *et al., 2020*). Although intensive grazing had the largest impact on saltmarsh, intensive human trampling had a similar effect, decreasing fruit seed abundance and size.

- Recovery studies in California reported that heights did not reach the height of controls within two and a half years after trampling (Woolfolk, 1999). Significant differences between insects and arachnid communities were still present between trampled and controls (Woolfolk, 1999).
- Martone, & Wasson (2008) found that after nine months of recovery trampled plots still had significantly lower percent cover of native plants. For tidally flushed sites, by 12 months native plants had recovered, however, for tidally restricted sites, recovery of native plants took between 12 and 22 months and was still lower (not significantly) at the end of the 22-month study period (Martone, & Wasson, 2008).

#### 1.4.2.4 Seagrass Beds

- Access to seagrass beds for shore gathering activities results in trampling of the substratum. The higher the activity level the worse the effects of the trampling might be (Eckrich & Holmquist, 2000).
- Intensive trampling from tourist visitors over *Zostera marina* beds, resulted in a significant reduction of seagrass cover (Travaille *et al*., 2015).
- Seagrass (*Thalassia testudinum*) biomass was noted to directly relate to trampling intensity and duration (Eckrich & Holmquist, 2000; Major *et al*., 2004). As well as trampling intensity, the substrate type plays an important role in the severity of trampling impacts on seagrass beds; with softer substrates more vulnerable to significant biomass reductions (Eckrich & Holmquist, 2000).
- Different types of footwear can also lead to significant effect levels (Major *et al*., 2004).

## Summary

- Abrasion impacts may include the creation of basins and mounds, burial and removal of the substratum, sediment disturbance, changes in vertical distribution of sediment layers and changes in the properties of the sediment.
- Impacts resulting from anthropogenic activity are most evident where the level of disturbance causes differences to sediment structure that are elevated above natural background changes caused by biotic and abiotic factors including changes caused by the benthic community through burrow formation and deposition of faecal material.
- A meta-analysis of global studies on hand gathering (and other gear type) impacts found that the magnitude of the response of fauna to fishing varied with the degree of abrasion to the surface of the substratum and changes to habitat (including sediment type).
- Shore gathering activities have the potential to remove, uproot and bury seagrass shoots and rhizomes.
- Impacts to seagrass are noted to be variable with activity and different species can respond in different ways. This includes increasing reproductive effort, potential related to the storage capacity of the particular species. However, seedlings have been noted not to survive to produce a full adult plant in some cases, offsetting the increased reproductive effort.
- In some harvesting methods, abrasion is not caused by the direct impact of the activity itself, but, by the indirect impact of the access required to access resources.
- Trampling leads to direct and indirect effects. Direct impacts include the immediate damage, crushing or removal of algae and invertebrates, and indirect impacts include changes in community assemblages, due to loss of habitat and changes to environmental variables.
- Typically, the relationship between trampling intensity and recovery is negative, with more intensely trampled areas requiring longer time frames to recover.
- Reefs, mud & sand flats, saltmarsh and seagrass beds may all be subject to impacts from trampling. Different habitats will be subject to different levels of impact and recovery times.

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## 1.5 Protected bird species: visual disturbance

- Anthropogenic disturbance can affect an animal's behaviour and rate of survival (Liley, *et al*, 2012a; 2012b).
- In this context, disturbance is defined as any human activity that has the potential to affect the behaviour of an animal. The disturbance may be audible or visual and where possible, these disturbances are distinguished.

### 1.5.1 Levels of Disturbance and Immediate Response

- Immediate results of disturbance range from birds becoming alert to taking major flights (>50m) to alternative suitable habitats (Liley *et al.,* 2010; Liley *et al.,* 2012a).
- Water-based and mechanically fuelled human activity are likely to cause higher levels of disturbance in bird populations whereas slower moving activities such as bird watching and hand picking of clams do not usually cause birds to flush or take flight (Burger, 1981).
- Furthermore, activities in the intertidal area are more likely to cause a disturbance event than activities occurring further up the shore due to the closer proximity to feeding intertidal birds (Riddington *et al.,* 1996; Liley *et al.,* 2010; Liley and Fearnley, 2012).
- The local level of disturbance intensity varies with ease of access to the location, habitat, and activity type (Goss-Custard and Verboven, 1993; Liley and Fearnley, 2012).
- The level of response to a disturbance is species-specific for shorebirds with individuals spending up to a third of their time displaying disturbance-related behaviours (Blumstein *et al.,* 2003; Schlacher *et al.,* 2013).
- Studies suggest the likelihood of a bird to respond to an anthropogenic disturbance can be indicated by the body size and quantity of food consumed by a species, with larger species becoming alert at extended distances (Blumstein *et al.,* 2005; Palacios *et al., 2*022).
- An earlier response time is necessary for larger species due to a lack of agility, in comparison to smaller species, making predator avoidance more difficult (Witter *et al.,* 1994).
- Other factors influencing the level of disturbance include flock size, distance to the disturbance and noise levels (Rees *et al.,* 2005; Wright *et al.,* 2010).
- Scan rates increase with the speed at which a visual disturbance is occurring, and the likelihood of an energetically expensive behavioural response increases with noise level (Fitzpatrick and Bouchez, 1998; Wright, *et al.,* 2010).

- Birds are reported to display both decreased nest attentiveness and increased vigilance when exposed to higher levels of disturbance (Riddington, *et al.,* 1996; Baudains and Lloyd, 2007).
- Research within Poole Harbour suggests that sites with higher levels of access lead to a lower level of bird response due to the type of activity. Sites in Baiter Park and Holes Bay showed the highest levels of access however, the activities were mostly limited to slower and quieter activities, such as walking and cycling. Areas with more frequent disturbance events were concentrated on the Studland side of Poole Harbour (Arne, Pilots Point, Bramble Bush Bay) and were predominantly the result of unpredictable and loud activities, such as unleashed dogs and water sports (Liley and Fearnley, 2012).
- Other models suggest the complete removal of human disturbance could increase bird (in this case, Ringed Plovers) populations by up to 85% (Liley and Sutherland, 2007) and to 100% survival in the Solent (Stillman *et al.,* 2012).
- In a study in South Africa, birds displayed a greater tolerance to the distance humans could approach the nest before taking flight and returned faster after frequent disturbance (Baudains and Lloyd, 2007).

- Literature on the effects of disturbance on feeding behaviours found contrasting positive, negative and no affect results with increased disturbance (Riddington, *et al.,* 1996; Fitzpatrick and Bouchez, 1998; Navedo and Masero, 2008; Verhulst, *et al.,* 2001).
- Although, Fitzpatrick and Bouchez (1998) describe a decrease in the amount of food redistributed to chicks as disturbance increased.
- Other changes in feeding behaviour include an increased concentration of wading shore birds feeding around crab tiles and geese altering feeding patterns to feed for an extra hour at night to balance their daily energy expenditure (Rees, *et al.,* 2005; Sheehan, 2007).

### 1.5.2 Longer Term Response

- The majority of the literature reviewed described habituation and redistribution/loss of habitat as a long-term impact of anthropogenic disturbance of bird populations. Habituation is defined as the alteration of an instinctual behaviour of birds as a result of frequent anthropogenic disturbance.
- Redistribution and a temporary loss of habitat as a result of disturbance occurs at a range of temporal and spatial scales and varies with species depending on the level of disturbance (Burger, 1981).
- There is evidence to suggest birds opt not to use areas of suitable habitat that experience disturbance; this evidence discusses roads, shipping, offshore wind farms and organized scaring (Gill, 1996; Klassen *et al.,* 2005).
- Oystercatchers have been reported to alter their feeding schedule within a tidal cycle to avoid coinciding with humans in the mussel beds of the Exe Estuary (Goss-Custard and Verboven, 1993).
- Similar results have been displayed with Redshank, Curlew and Oystercatchers, altering their arrival and departure from sites in Belfast Lough, depending on the levels of recreational activity (Fitzpatrick and Bouchez, 1998).
- Studies in Glasgow found whooper swans displayed a short-term decrease in sensitivity to disturbance when daily disturbance levels were high (Rees *et al.,* 2005). There was no evidence to suggest these short-term habituations remain on a longer time scale.

- Literature suggests an increase in anthropogenic disturbance causes a reduction in egg incubation time and parental care, leading to a decrease in reproductive success (Verhulst *et al.,* 2001; Baudains and Lloyd, 2007).
- However, it has been stated that there is no guarantee behavioural responses (as a result of disturbance) are related to changes in reproduction or mortality and, species should be assessed on an individual basis (Stillman, *et al* 2007).

### 1.5.3 Shore gathering and disturbance

- There is little research focused on areas within the Southern IFC District (five out of 62 papers reviewed). A significant amount of the research relies on models and is species-specific.
- Of the 22 pieces of literature reviewed that discussed an interaction between birds and intertidal fisheries only six discussed disturbances by shore gatherers, the remainder discussed the implications of removing a food source.
- Two out of the six discussed the disturbance or change of behaviour caused by the structures used in the fishery (crab tiles and oyster culture trestle tables) (Higherloh *et al.,* 2001; Sheehan, 2007).
- Of the remaining four articles, only one discussed hand gathering of clams as a potential disturbance causing activity and the remaining three referred to bait digging.
- No information was found regarding birds being disturbed by seaweed gathering or shrimp push netting.
- As these activities also occur in the intertidal zone and are carried out at a relatively slow pace when compared to jogging or water sports, we can assume the potential for bird disturbance is likely similar to bait digging and hand gathering of clams.
- Shellfish hand gatherers are reported unlikely to cause a disturbance to birds as a result of the slow-moving behaviour of the activity (Burger, 1981).

*Studies from the Southern IFCA District*

- A report focusing on Poole Harbour described an observed 1558 potential disturbance events by bait diggers over an 11-day period. Only seven percent of these observations resulted in a disturbance. The disturbances ranged from birds walking or swimming away to taking a major flight (Liley *et al.,* 2012).
- In the Solent, during more than 70% of bait digging, crab tilling and shellfish gathering events, no bird disturbance was caused, although most events where disturbance did occur led to major flights by birds (Liley *et al.,* 2010*).* Data collected did not suggest that sites with higher access levels (e.g. more people) do not experience significantly higher disturbance events which could indicate that some level of habituation occurs within bird populations (Liley *et al.,* 2010).
- Bird disturbance in general declined with distance, where events occur 100m or more away from birds rarely led to disturbance (Liley *et al.,* 2010).
- Developing on this work, Stillman *et al.* (2012b) used a model to understand the likely impact of disturbance to bird survivability in the Solent. Due to the assumed relative infrequence of bait digging activity (1.2% of visits), removal of the activity from the model did not lead to higher survivability of birds, although the model did not factor in the effect on bird prey availability.

*Studies from the wider UK*

- In contrast, other evidence discusses a negative correlation between the number of bait diggers and wader and gull abundance, and the reduction in the extent of uses of a refuge area by waterfowl species in the Northeast of England. These results are suggested to be due to the larger body mass of waders and an increased vulnerability to predators. The decreased abundance of gulls was not expected as they are thought to be a more tolerant species, however, this is likely due to a lower level of access and hence decrease habituations of the gulls in the study area (Townshend and O'Connor, 1993; Watson *et al.,* 2017).

**Summary**

- Anthropogenic disturbance causes a range of species-specific responses to bird species, which scale from increased vigilance and scan rates to longer term redistribution of a species.
- Disturbance can result in changes to the fitness of bird species and has the potential to cause changes in population size through increased mortality.
- The information relating directly to intertidal fisheries and shore gathering activities is minimal; however, due to the slow moving and quiet nature of shore gathering, the majority of interactions are not likely to result in disturbance, unless the activity begins to occur in areas with previously very low levels of access and decreased levels of habituation as a result.

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## 1.6 Protected bird species: food availability

### 1.6.1 Removal of target species

- Shellfisheries can provide a potential source of conflict by competing with the same food resources as certain bird species (Atkinson *et al*., 2003).
- The removal of food resources by shellfish fishing therefore has the potential to have detrimental effects on the amount of food available per bird and subsequently increases the chance of a threshold being reached where mortality from starvation begins to increase (West *et al*., 2005; Navedo *et al*., 2008).
- The removal of shellfish from productive beds, along with associated disturbance, can drive birds from preferred feeding grounds to areas of poorer quality. This can lead to an increase in bird densities and a subsequent intensification of interference and exploitation competition for food, which can reduce intake rate and probability of starvation, particularly in winter (Goss-Custard & Verboven, 1993; Clark, 1993; Goss-Custard *et al*., 1996).

- It is important to understand to what degree bird species can switch to other food resources, if their target species (that may also be the target species of the fishery) is reduced (Schmechel, 2001).
- It was reported by Zwarts *et al*. (1996a) that along the north-west European coast there are limited possibilities of alternative prey items for certain bird species, especially in winter due to changes in availability.
- Using individual behaviour-based models, it has been shown that shellfish stocks should not fall below 2.5 to 8 times the biomass that shorebird populations require to survive (Stillman *et al*. 2003; Goss-Custard *et al*. 2004; Stillman *et al*. 2010).
- Stillman *et al*. (2001) used a behaviour-based model to investigate the effects of present-day management regimes of the Exe estuary mussel fishery and Burry Inlet cockle fishery on the survival and numbers of overwintering oystercatchers. Results of the study concluded that at present intensities (for cockle hand raking: 50 persons, max 100kg per day) the fisheries do not cause oystercatcher mortality to be higher than it would be in absence of the activity (Stillman *et al*., 2001).
- Hand raking cockles had negligible effect on how much time oyster catchers spent feeding because it only removed cockles >22mm (Stillman *et al*., 2001). Increased fishing effort up to 500 persons hand raking cockles did not affect the mortality rate, mean mass of birds, or bird time spent in fields, whereas increased dredging did. The difference was caused by the significantly higher rate of depletion of the stocks seen in dredge fisheries (Stillman *et al*., 2001).
- However, for mussel hand raking, the effects on oystercatchers were greater than dredging because the activity removed mussel beds and caused disturbance and so these impacts combined (Stillman *et al*., 2001).
- In a study by Ferns *et al*. (2000), bird feed activity increased shortly after cockle harvesting (mechanical), particularly in areas of muddy sand rather than in areas of clean sand. However, following the increase in feeding activity, the level of bird activity declined for more than 80 days (curlew and gulls) and for more than 50 days (oystercatcher) following harvesting when compared to control areas. It was noted that the initial net benefit of harvesting was matched by decreased feeding opportunities in the winter (Ferns *et al.,* 2000).

### 1.6.2 Size of prey species

- The exact role of the fishery and its effect on bird population, because of direct competition, will largely depend on the distinct size fractions of the stock that may be exploited by fishers and birds (Schmechel, 2001).
- Whilst there may be an overlap in the size of cockles taken by both fishers and birds, most bird predation is of a smaller size class than fishers take (Norris *et al*., 1998).
- If sizes overlap, there can be a genuine conflict of interest between the birds and the fishery, therefore larger minimum sizes are more favourable to birds (Lambeck *et al*., 1996).
- Bowgen *et al*., (2015) used an individual-based model to investigate how invertebrate species regime shifts would affect wading bird populations across Poole Harbour. Shifts were considered in terms of size class changes and complete removal, which represent similar effects of intertidal fishing activity. Curlew, black-tailed godwit and redshank numbers were most reduced when the abundance of the largest marine worms was removed (Bowgen *et al*., 2015). The strongest effect was on curlew, with modelled numbers reduced to zero percent if worm sizes above 75mm were removed, whilst for godwits, removal of worms above 60mm had the same effect. Curlew and black-tailed

godwits were not able to compensate with other marine invertebrates and could switch only to earthworms (Bowgen *et al*., 2015). Contrastingly, for a reduction in bivalve size classes an effect was seen when only the very smallest bivalve size classes remained at <19mm and <15mm respectively for oystercatchers and curlew and black-tailed godwits (Bowgen *et al*., 2015).

- Overall, the curlew was found to be most sensitive to regime shifts due to its large size, and specific feeding strategy, whilst generalists such as oyster catchers are likely to survive during invertebrate species shifts. However, because birds adapt to changes by switching to alternative prey species, size classes and feeding areas, it was concluded that changes in invertebrate size and species distribution do not affect the number of birds the Harbour can support (Bowgen *et al*., 2015).
- Caldow *et al*. (in Jensen *et al.* 2005) demonstrated that the non-native Manila clam, forms a prey item of the oystercatcher population in Poole Harbour. The size of individuals targeted by oystercatcher's range in length from 16 to 50mm. Between late summer and the following spring, a significant increase in the proportion of the population (up to 40 to 50%) consumes this target species. Using an individual's-based simulation model, the study predicts the presence of Manila clams, at low densities of 5 clams per m$^2$ (mean density when the study was undertaken), has reduced over-winter mortality rates of oystercatchers by 3.5% in Poole Harbour (Caldow *et al.,* 2005). The impacts in this study were related to the dredge fishery rather than shore gathering activity.
- Oystercatchers have shown a preference for older cockles, 20 to 40 mm, and will not take cockles less than 10 mm when these larger size classes are available (Hulscher, 1982; Zwarts *et al*., 1996a). However, oystercatchers do not necessarily choose the largest cockles as they are difficult to handle, with studies reporting that larger cockles were refused more often than small ones (Zwarts *et al*. 1996a). Oystercatchers are known to refuse small prey due to low profitability and the size of cockles left after fishing may therefore have an impact on feeding rate of the oystercatcher (Zwarts *et al*. 1996b; Wheeler *et al*., 2014).

**Summary**

- The removal of food resources during shore gathering such as shellfish collection has the potential to impact the amount of food available per bird inhabiting a particular area.
- The removal of target species may lead to changes in feeding behaviours, modification in feeding grounds to areas of poorer quality, increased density of feeding birds in areas with resources and increased competition for food.
- Increased impacts increase the chances of a threshold being reached where mortality from starvation begins to increase. Although this is dependent on the extent of removal, alongside the likelihood of species switching to other food sources in the even that their target food species is removed.
- Studies have shown that certain levels of activity, for example 50 cockle gatherers at a maximum of 100kg cockle harvested per day did not cause mortality of specific species to be higher than it would be in the absence of that activity.
- The extent of impact from fishing is also related to the size of prey species taken by fishers in comparison to the size taken by bird species. If there is an overlap between the required size ranges the impact is likely to be greater.

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## 2. Potential Impacts from Shore Gathering – Activity Specific

This section covers evidence relating to specific shore gathering activities, the evidence in this regard is less comprehensive than general impacts. The majority of the potential impacts from shore gathering activity apply generally and are not specific to a particular gear type, these more widely applicable impacts are covered through the review of evidence in Section 1.

## 2.1 Bait digging

- Bait digging plays a significant role in the cultural and economic sectors of coastal communities. The blow worm (*Arenicola defodiens*) is one of the five most expensive marine species on the global fisheries market (retail price per kg), according to a recent assessment of the polychaete bait industry, which revealed that 121,000 t are collected annually, valued at £5.9 billion (Watson *et al.,* 2017a).

### 2.1.1 Ecological impacts

2.1.1.1 Removal of target species

- *A. virens* (King ragworm) is often one of the most dominant macroinvertebrates within estuarine sediment communities providing an important prey species for many species of bird, fish and crustacean as well as being a key predator and scavenger Removal may therefore impact benthic communities (Giangrande *et al*., 2005; Watson *et al*., 2007).
- Individuals of *A. virens* subject to bait digging activity showed a significantly lower average mean weight than those in areas not subject to activity (Watson *et al.,* 2007).
- There is the potential for continued disturbance to alter the proportion of sexually mature individuals within a population with bait dragging selectively removing those individuals of a marketable size which are commonly those that are also sexually mature. Previous studies support this, with areas routinely used for bait digging showing that while the overall population numbers are greater, the number of reproductively mature individuals is lower than in areas where the activity does not occur (Watson *et al*., 2007). However, this may result in a shift in population dynamics rather than an overall detrimental impact.
- Studies have shown that other commercially exploited species exhibit a shift toward earlier onset of sexual maturity at a smaller size (Jennings *et al*., 2001). A. virens is known to be able to become sexually mature between 1 and 8 years old (Last and Olive, 1999) with the exact age (and therefore size) affected by environmental conditions (Breton *et al*., 2003), it could be therefore that A. virens are also able to shift toward achieving sexual maturity at a smaller size to compensate for the removal of larger individuals, thus reducing the impact on the overall population.
- Another potential impact is the loss of segments from damage caused during the bait dragging process. Damaged individuals are often immediately returned to the fishery as they have low market value; however the survival rate of these individuals is thought to be high provided that they are able to re-burrow quickly to avoid predation (Fowler, 1999). The ability of an individual to regenerate lost caudal segments is dependent on a number of factors including the position in the body at which the damage occurred (Golding, 1967; Olive, 1974), however the proportion of individuals returned damaged is thought to be low and the associated levels of predation not above what is seen naturally.
- Preferential removal of larger lugworms has resulted in changes in lugworm population structure, such as smaller individual sizes (Shahid, 1982) and increased mortality in the Solent (Beukema, 1995; Volkenborn and Reise, 2007).
- Decreases in lugworm can have significant impacts on the environment as they play a vital role in sediment stability and bioturbation (the reworking of soils and sediments by animals or plants through burrowing, ingesting and defecation). Bioturbation is believed to be a main driver of biodiversity (Tinlin-Mackenzie *et al.,* 2022).

2.1.1.2 Removal of non-target species

- Where impacts of bait digging have been observed, the recovery rates of infauna communities can range from several months up to five years for most vulnerable species (van den Heiligenberg, 1987; Beukema, 1995; Blake, 1979; Cryer *et al*., 1987; Fowler, 1999; Klunder *et al*., 2021, Cravalho *et al.,* 2013).

- Digging for the lugworm *Arenicola marina* has been shown to deplete the population of the cockle *Cerastoderma edule* on the North Norfolk Coast as the turning over of the sediment resulted in the cockles being re-buried too deep to survive (Jackson and James, 1979; McLusky *et al*., 1983).
- A study on bait digging in Fareham Creek, UK found that changes in sediment from the activity did not result in significant changes to the macrofaunal community although there was a significant increase in the variability of dispersion of species (Watson *et al.,* 2017). However, significant changes were seen in a neighbouring estuary site (Dell Quay) where it was noted that digging occurred for the majority of the time in areas which had already been dug (Watson *et al.,* 2017). It was postulated that the cumulative impacts of repeated digging prevent the recovery of small macrofauna species (Watson *et al.,* 2017). The overall conclusion of the study was that digging alters the macrofaunal community and associated sediment characteristics across large spatial scales but that the strength and type of response is site specific (Watson *et al.,* 2017).
- A study in an MPA in Northumberland, UK found that there was a significant negative impact on wider sediment communities from lugworm digging in the short-term with reductions in total infaunal abundance, taxonomic richness and alterations in community structure (Tinlin-Mackenzie *et al.,* 2022). Recovery was noted to occur within a few months suggesting that sites have the potential for substantial recovery if disturbance is ceased (Tinlin-Mackenzie *et al.,* 2022).
- Effects on macrofauna are also species specific. 11 days after digging in Norfolk, mortality had occurred in 85% of cockles (*Cerastoderma edule*) (Jackson & James 1979). The effect was observed to be greater on juvenile cockles, and laboratory experiments suggested that burial of cockles beneath the depth at which they can regain their near surface positions, leads to mortality (Jackson & James, 1979).
- Macrofaunal biomass has been noted to be significantly reduced after digging (Wynberg & Branch, 1994) although it is not always the case in all studies (Wynberg & Branch, 1997).
- Digging to 10 and 20 cm depth, where sediment was removed from an area, led to immediate declines in total abundance and species richness (Dernie *et al*., 2003).
- A study from two south Iberian Atlantic coastal systems found that the effects of bait digging were site specific and related to biological and sediment composition of the area prior to digging taking place (Carvalho *et al.,* 2013). Macrobenthic assemblages in areas with less mud, initially presenting the greatest infaunal diversity and eveness values, showed minor effects from digging with recovery within 7 days (Carvalho *et al.,* 2013). Areas with the greatest mud content and assemblages dominated by only a few species were the most affected and recovery occurred over a longer timescale (Carvalho *et al.,* 2013). The abundance of sedentary polychaetes was noted to decline whilst gastropod species increased. Differences in response to the disturbance by benthic assemblages were notes to vary when subjected to the same intensity, frequency and nature of disturbance both between and within different coastal ecosystems (Carvalho *et al.,* 2013). On this basis it was concluded that generalisations of activity impacts on non-target species are not possible (Carvalho *et al.,* 2013).

#### 2.1.1.3 Sediment Impacts

- Studies on bait digging indicate that the organic content of the sediment changed following digging as organic matter was trapped in the holes dug and that the resulting lower concentration of organic matter in the immediate area surrounding the hole resulted in the inhibition of colonisation by sedentary species (Grant, 1981).

- A study in Portsmouth Harbour and Chichester Harbour in the UK found that significant differences between dug and undug sediment were limited to changes in organic content (Watson *et al.,* 2017). It was stated that, as organic matter, binds many contaminants, and sediment disturbance leads to desorption of pollutants that an increase in bioavailability of certain contaminants is a likely impact from bait collection (Watson *et al.,* 2017).
- At a low energy site in the Solent, experimental 1m$^2$ digging scares were observed on foot for 83 ± 30 days after the activity had taken place (Watson *et al.,* 2017).
- A number of studies have identified significant changes of sediment as a result of digging with the activity causing an increased coarsening of grains (McLusky *et al.,* 1983; Edwards *et al.,* 1992; Watson *et al.,* 2017). However, there are also studies where no significant changes in relation to grain size have been seen (Sherman and Coull, 1980; Dernie *et al.,* 2003).

#### 2.1.1.4 Impacts to bird species

- A study on bird disturbance from digging activity in the Solent, UK, found a significant negative correlation in Chichester Harbour between the number of waders and the number of bait collectors (Watson *et al.,* 2017). A significant negative correlation with gulls was also noted (Watson *et al.,* 2017). Both species were noted to move away from areas when bait diggers were presented. There was however, no significant relationship at the site in Portsmouth Harbour, postulated to be due to the area being a highly disturbed site where birds may be habituated to the presence of collectors (Watson *et al.,* 2017).
- There are contrasting results in specific studies of bait digging on bird species foraging behaviours. It has been found that curlew demonstrated no impacts to foraging in areas which had been bait dug (Liley *et al.,* 2012) but semilpated sandpipers showed a reduction of 68.5% in foraging efficiency from bait harvesting, postulated to be related to reduced prey availability and interference with prey cues due to disturbed sediments (Shepherd and Boates, 1999).
- A study in Spain found that digging by hand impacted the bird prey species *Hydrobia ulvae* in terms of density and biomass when the top 5cm of the sediment were compared between dug and undug areas (Masero *et al.,* 2008). It was determined that this part of the sediment was most likely to be used by shorebirds, therefore the documented decrease could have potential impacts to the bird species utilising it as a prey source (Masero *et al.,* 2008).

**Summary**

- Removal of target species for bait digging may impact benthic communities as target species are often dominant within the sediment community and provide prey species for many species of birds, fish and crustacean.
- Potential impacts to target species include individuals' weight and the proportion of sexually mature individuals in a population.
- Impacts to non-target species are noted to be varied, along with recovery rates. Differences in impact have been seen over relatively small spatial scales, with the suggestion that cumulative impacts of regular activity may exacerbate effects.
- Impacts from abrasion directly attributed to bait digging activity are primarily related to organic content of the sediment which may lead to other effects such as increased bioavailability of pollutants. There is also a suggestion that sediment becomes more dominated by coarser grains as a result of digging but this is not seen in all studies.
- Bait digging has the potential to cause disturbance to bird species and impacts to foraging. However, these impacts are seen to be site specific and potentially related to species being more habituated to disturbance.

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## 2.2 Shrimp Push Netting

### 2.2.1 Overview

- Push net gear is usually operated on intertidal mud and muddy sand substrates during low tide. Due to the tidal conditions in the UK, fishers can usually operate for one to two hours (Temple, 2015).

### 2.2.2 Ecological impact

- The ecological impact of shrimp push netting is thought to be relatively small, where impacts do occur, these are related to trampling and removal of target species. Push netting in the UK is generally operated at low frequencies within temporal and spatial limitations (weather conditions, sea state, tide, substrate type and topography).
- Some push nets in the North of the UK have a wooden bar along the bottom that enables the net to bounce along the substrate without digging into it (Haines, 2016).
- Other forms of push net have skis fitted on the end of the frame in contact with the seabed to prevent it from getting stuck on finer substrates (Fisheries and Aquaculture Department (FAO), 2023).

#### 2.2.2.1 Removal of target species

- Nurul Amin *et al*. (2008) describes in a Malaysian estuarine study that the average push net fisher catches 3.54 kg/hour of *Acetes* shrimp. However, the total catch will vary depending on the strength of the operator, their experience, and season.
- Regardless of whether this gear is operated commercially or recreationally, the operation of this gear is known to cause little stress to caught prawn individuals when hand operated (Broadhurst *et al*., 2004).
- In a study in Australia, it was found that the low concentration of Lactate released from stress during and after catch had a minimal effect on the condition and survival rate of the target species. The relatively small size of the gear and the area it can cover in one operation has a limited impact on the population of shrimp in terms of removal of caught individuals (Temple, 2015).

#### 2.2.2.2 Removal of non-target species

- Push nets have a fine mesh for catching prawns and shrimp, because of this fine mesh there is also the potential for catches of juvenile prawns and other small species (Hinz, 1989).
- The ratio of bycatch to targeted species caught depends on the catch capability of the fisher operating the push net (Nurual Amin *et al*, 2008). This includes the strength of the operator, their experience operating this gear for the species they're targeting, and the season this gear is being operated in (Nurul Amin *et al*., 2008).
- Even though push netting is a small-scale fishing operation compared to other gears, continued catch of juvenile fish species could result in stock declines and trophic shifts (Jones *et al*., 2009).
- Various studies conflict over the selectivity of push nets, with some quoting at least 90 % selectivity for shrimp and prawns (Jeyabaskaran, *et al*., 2018; Suebpala *et al*., 2017) and others a minimum of 70 % non-selectivity (Davies *et al*., 2009; Macer, 1967).

- In a study in Wales, it was found that 70 % of the total catch from push net activity consisted of juvenile fish, including Plaice and Dab, and some decapod species (Macer, 1967). Dependent on the frequency the gear is operated, continued catch of juvenile fish could have an impact on their recruitment to adult stocks (Macer, 1967).

#### 2.2.2.3 Sediment Impacts

- Contact with the substrate from this gear is low compared to some other gear due to its small footprint, however due to this type of gear requiring manpower, there is a risk of trampling from the fisher during operation (Rossi *et al*., 2007).
- The impact of this gear both directly and indirectly from trampling from fishers when in operation or to gain access to the operation site can disrupt sediment on the surface of the seabed, damage fragile features, and bury or crush epibenthic species (Rossi, *et al*., 2007).
- Hand operated push nets are designed to be light weight so that they can glide across substrate without penetrating the seabed or damaging fragile features including seagrass and Mearl beds.
- A study in India found there was evidence of burrowing fauna being caught as well as fragments of seagrass and other seaweed (Rajan *et al*., 2017).
- A study in Thailand also found that the activity had the potential to dislodge or remove sessile species (Janekarn & Chullasorn, 1997). Extending this impact, it is postulated that the gear could cause damage to habitats such as seagrass by cutting or uprooting plants.

#### 2.2.2.4 Impacts to bird species

- North Western IFCA assessments of push netting activities (Haines, 2016; Temple, 2015) determined that the operation of this gear within SPAs has no significant impact on nesting or feeding birds. The small scale and non-motorised operation of this activity is unlikely to exceed ambient noise levels and is limited spatially and temporally in terms of operation (tide restriction).
- A study in Thailand (Galbraith *et al*., 1999) found that fishers operating hand-held push nets were generally ignored by resident bird populations. However, when there was a large group of push net fishers, or if fishers were present at the site for an extended period of time, then there was a temporary decline in bird foraging activity (Galbraith *et al*., 1999). There was also an impact on breeding birds when there was a large gathering of people, excessive noise being produced, or fishers getting too close to the nesting sites (Galbraith *et al*., 1999).

## Summary

- Push netting usually occurs on intertidal mud and muddy sand substrates during low tide for 1-2 hours at a time.
- The ecological impact is thought to be small, related primarily to trampling and removal of the target species.
- Mitigative measures are often already applied to push nets to reduce impact on the seabed.
- Impacts to target species have been found to be minimal with stress responses observed during and following catch to have a minimal affect on condition and survival rate.
- There is the potential for bycatch of juvenile prawns or other small species, the degree to which bycatch is observed is primarily based on fisher behaviour when operating the gear. Gear selectivity is documented at between 30%-90%.
- Two studies have shown that sessile species can be impacted by push netting, with one study documenting seagrass being removed by the activity.
- Bird disturbance from push netting is documented to be not significant, the number of operators and fishers getting too close to nesting sites were exacerbating factors where any impact was noted to occur.

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## 2.3 Crab tilling and collection

- Crab tiling is the collection of shore crab (*Carcinarus maenas*) for the purpose of being used as angling bait. The crab tiling fishery operates within estuarine mudflats at a commercial scale and the process involves laying crab tiles, also referred to as crab shelters (hard man-made structures such as roof tiles, half round guttering and vehicle tyres) on the shore. Shore crabs are harvested from underneath the tiles periodically at low tide (Sheehan *et al*, 2010).
- There are areas where crab tilers only remove crabs over 40mm carapace width, avoid berried females and only harvest crabs which are in the stage of pre-ecdysis (moulting) (Sheehan *et al*., 2008).
- Over 1 million shore crabs are removed from south-west UK shores annually to be sold as bait (Sheehan *et al*., 2008). The mild climate in the south of the UK allows crabs to moult all year round, providing a year-round fishery. In other parts of the UK, crabs may only moult in summer months, leading to a seasonal fishery (Russel *et al.* 1999).
- The location at which crab tilers can place crab shelters is limited due to the requirements of landowner’s permission. This is because, crab-tiling does not follow the standard right to lay fishing gear as it does not “entrap” species.

### 2.3.1 Ecological Impact

#### 2.3.1.1 Removal of target species

- *C. maenas* reach maturity within two years at a size of 25-30mm (Neal & Pizzolla 2008). Therefore, crab tilling does not target juvenile individuals and all crabs removed are likely to have had the opportunity to reproduce.
- Sheehan *et al.* (2008) found that when compared to non-tilled estuaries, tilled estuaries support a significantly greater abundance of crabs (63% more), particularly juvenile individuals 20 to 39mm. This was believed to be due to the provision of additional habitat.

- However, the same study found more reproductively active crabs and crabs greater than 60cm in non-tiled estuaries (Sheehan *et al.,* 2008). Similarly, removal of species may lead to reduction of local populations.
- The impact of greater crab abundance in tiled estuaries is unknown. Devon and Severn IFCA (2019) highlighted that estuaries are important nursery areas for many fishes, such as plaice (*Pleuronectes platessa),* bass (*Dicentrarchus labrax)* and turbot (*Scophthalmus maximus). C. maenas* is an important food source for several predatory fish, and therefore an increase in crab abundance may lead to increased abundance of adult predatory fish species (Devon and Severn IFCA, 2019). However, *C. maenas* is also a predator in intertidal systems and predates upon juvenile fishes, and therefore greater abundance of the species may have negative consequences on fish populations (Devon & Severn IFCA, 2019).

#### 2.3.1.2 Impacts to non-target species

- Abundance of aquatic fauna has been noted to be lower around crab tiles compared to non-tiled areas. It is postulated that the congregation of *C. maenas* around crab tiles increases the level of predation on non-target species as tiled areas showed an abundance of the target species over other aquatic fauna (Sheehan, 2007).
- A study in the UK found that the abundance of mobile fauna including benthic gobies, mysids, crabs and pelagic fishes was greater in control sites that in tiled sites during the month of July (Sheehan *et al*., 2010a). This was also observed in March but results were not significant, equally there was a greater diversity of taxa in control sites observed but this was also not significant (Sheehan *et al*., 2010a). Crabs were observed to occupy the tiles during submersion and had a tendency to be aggressive to other species in defending the tile (Sheehan *et al*., 2010a).
- A similar study in the same area of the UK found that mean infaunal abundance declined with increasing mean penetrability of the sediment (Sheehan *et al*., 2008). Control and ‘tile only’ sites showed similar abundance scores to each other whilst ‘trampling only’ sites were least stable and showed the lowest infaunal abundance (Sheehan *et al*., 2008).

#### 2.3.1.3 Sediment Impacts

- Sheehan *et al*. (2010b) studied several sediment parameters in relation to the effects of crab tiling and associated trampling. Impacts to the sediment were though to be mostly related to trampling with the extent of changes to the sediment related to relatively small changes in sediment composition (Sheehan *et al*., 2010b).
- The same study observed no effect of crab-tiling on organic content or grain size, it was determined that existing differences from among-estuary variation masked any impacts from the activity in isolation (Sheehan *et al*, 2010b).
- The effects of year and difference between sites were stronger than effects of disturbances from treatments. Sheehan *et al*. (2010b) concluded that crab tiling modifies sediment stability and measures of infaunal diversity, with muddy habitats more susceptible to disturbance than those which are sandy.

#### 2.3.1.4 Disturbance to bird species

- The estuaries in which the shore crab is harvested act as key feeding habitats for wading birds, some of which prey on *C. maenas.*

- The presence of crab tiles were found to have no impact on bird abundances in Devon estuaries, however curlew and redshank were seen using the crab tiles as a resources for food and spending a significant amount of time around crab tiles (Sheehan, 2007).
- Observations of foraging birds in tiled and non-tiled sites were used to test a model that the fishery modified diversity, distribution and behaviour of shorebirds (Sheehan *et al*., 2012). No evidence was found for a relationship between shorebird species richness, abundance or assemblage composition and the presence of tiles (Sheehan *et al*., 2012).
- It is suggested that crab-tiles could influence the distribution of potential prey species and as such aggregate shorebirds, relieving predation pressure in other areas (Sheehan *et al*., 2012). Bird species such as curlew and redshank were also observed next to crab-tiles without engaging in feeding behaviour suggesting that the tiles may also provide a shelter for shorebirds against negative effects of wind on thermoregulation (Sheehan *et al*., 2012).

**Summary**

- Some mitigation measures are already employed by crab-tilers including targeting crabs over 40mm carapace width, avoiding berried females and only harvesting crabs which are in the stage of pre-ecdysis.
- Estuaries subject to crab-tiling are found to support a significantly greater abundance of crabs, particularly juveniles, believed to be due to additional habitat provision. However, more reproductively active crabs were found in non-tiled estuaries.
- The impact of greater crab numbers in estuaries is mixed, providing both a food source to predatory adult fish but also a predator species for juvenile fish.
- Abundance of other aquatic fauna has been noted to be lower around crab tiles, potentially due to aggressive defending of the tiles by the crabs. In other studies changes in abundance of non-target species has been found to be seasonal.
- The effects of trampling are noted to be the most prevalent abrasion impact, compounding effects of faunal change. Muddy habitats were more susceptible to disturbance than sandy habitats.
- No impacts to organic content or grain size of sediments in crab-tiled areas have been noted.
- The presence of crab-tiles is noted not to have an impact on bird species, certain species have even been noted to use crab tiles for feeding and shelter.

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## 2.4 Shellfish collection

- Shellfish gathering involves the removal of bivalve species such as cockles, native oysters and periwinkles from the surface of the substrate using methods such as digging, raking or hand picking (McLusky *et al*., 1983; Travaille *et al.,* 2015; Watson *et al.,* 2017).

### 2.4.1 Ecological Impacts

#### 2.4.1.1 Removal of target species

- A study in the Western English Channel considered the impact of clam raking in different habitat types and concluded that high energy environments transfer clams and macrofauna, minimising the effect of rake harvesting (Beck *et al.,* 2015). Results showed that experimental clam raking of *R. philippinarum and R. decussatus* significantly decreased the number of clams on gravelly compared to sandy habitats (Beck *et al.,* 2015).
- Research conducted in the Strangford Lough SAC (Northern Ireland) found that previous disturbance to sediment where cockles were returned (i.e. collection via hand rake) had no influence on burial rate of cockles, however larger cockles had a slower burial speed (McLaughlin *et al.,*2007).
- Research by Leitao and Gaspar (2011) in the south of Portugal concluded that neither hand knife nor dredge methods used to collect cockles affected the subsequent burrowing rate of the target species. Regarding the burrowing rate of two groups of cockles, 83% burrowed within 15 minutes and only 10% remained on the surface after an hour (Leitao and Gaspar, 2011).
- However, Crespo *et al.* (2010) found large-scale collection of the common cockle (*Cerastoderma edule*) in Portugal may cause considerable changes in population structure over an 18-month period (Crespo *et al.,* 2010). Population abundance and biomass reduced by 80% and 94%, respectively, with implications for population dynamics and secondary production. The abundance of cockles above 15.25mm decreased significantly, whereas the density of cockles over 20.25mm did not recover within a year (Crespo *et al.,* 2010).
- The same study found that large-scale harvesting caused seasonal variations in recruitment dates, from May to year-round, however production values remained low during the 12-month research. Overall, overharvesting resulted in the disappearance of adult cockles and subsequent lower production values (Crespo *et al*., 2010).
- Investigations into management of cockle harvesting outside of Europe concluded that management of highly variable and unknown species in not possible due to the unpredictable nature of recreational harvest and shellfish population dynamics (Beck *et al.,* 2015).
- Precautionary minimum size limits were deemed the best management solutions, with bag limits and closed areas playing a less vital role where there is an absence of intensive monitoring and management (Hartill *et al.,* 2005).
- Crawford *et al*., (2010) demonstrated that small scale no take zones led to significant increased densities of cockles (*Anadara spp.*), both inside and out of the protected areas.
- In Washington USA, Griffiths *et al.* (2006) studied the effects of clam (*Venerupis philippinarum* and *Protothaca staminea*) digging on several open beaches compared to marine reserve beaches. Clam abundance was greater on reserve beaches compared to non-reserve beaches (Griffiths *et al.,* 2006).
- Similarly, Gray (2016) compared the impact of clam harvesting on two commercially hand-fished beaches compared to two un-fished beaches in Australia, before and during harvesting of 4,300 and 17,800kg of clams. No effect of clam harvesting was found

however, populations of clams were highly variable across the four sites. Under local management measures, fishers were limited to a 40kg catch per day, so it was considered that this level of harvesting may not be impacting the populations of clams in the area, or that the natural spatial variation observed between beaches and sites is greater than that which is caused by fishing at its current level (Gray, 2016).

#### 2.4.1.2 Removal of non-target species

- The method by which this is achieved e.g., digging, raking or hand picking can also lead to the removal of non-target species through indirect mortality, damage and disturbance (Dernie *et al.,* 2003; Rossi *et al.,* 2007).
- Kaiser *et al.* (2001) examined the effects of hand raking of a small and large area without removing the target species on non-target species and undersized cockles (*Cerastoderma edule*). Initially, raking led to three times more damaged undersized cockles in the experimental plot. Unexpectedly, there was significantly lower mean abundance of individual organisms in the control plot, which demonstrated there were differences in community structure between the experimental and control plots irrespective of treatment. Fourteen days following raking there was a decrease in abundance relative to immediately after raking. After 56 days the small-raked areas had recovered, however for the large-raked areas, whilst the abundance of individuals had increased, it had not fully recovered 447 days following analysis (Kaiser *et al.,* 2001).
- Leitao and Gaspar (2007) compared the impact of *C. edule* collection using a knife versus a hand dredge. Macrofaunal mortality was low in both methods (mean: harvesting knife 1.64% and dredge 0.98%), but unexpectedly harvesting using the hand knife led to a higher (although not significant) mortality of macrofauna. As predicted, the harvesting dredge led to a five-fold increase in both the area fished and catch collected. When the target species were removed from the analysis, no significant difference between the communities exposed to the different fishing methods was observed, indicating both methods had remarkably similar overall impacts to the community, other than the target species (Leitao and Gaspar, 2007).
- Experimental clam raking (*R. philippinarum and R.* decussatus) in the Western English Channel uncovered no significant change in sediment characteristics or macrofauna on sandy, gravelly or mixed gravelly rocky habitats studied (Beck *et al.,* 2015).
- A study on the removal of razor clams by salting in southern Portugal found that there were no effects on the associated benthic community and that similar patterns of fluctuations in abundance were observed in control and experimental areas, attributed to natural variability (Constantino *et al*., 2009).
- Investigation into Manila clam (*Ruditpaes philippinarum)* collection in Italy found hand raking led to significantly lower meiofaunal abundance, particularly Harpacticoids (Mistri *et al.,* 2004).
- Other research has considered the differences between beaches which are fished and those which are protected in some way from the activities. In Washington USA, Griffiths *et al.* (2006) studied the effects of clam (*Venerupis philippinarum* and *Protothaca staminea*) digging on several open beaches compared to marine reserve beaches. Species richness and total polychaete family richness were greater on reserve beaches compared to non-reserve beaches. Non-reserve sites had greater abundances of the un-harvested clam species, limpets and *Nereis* polychaetes.
- Experimental digging led to significantly reduced species richness within the ‘holes’, compared with the dug-out ‘fill’ and controls. There was no significant effect of placing cages over experimentally dug plots showing that on this beach predation was not a key factor affecting the community following digging (Griffiths *et al*., 2006).

### 2.4.1.3 Sediment Impacts

- A study on razor clam harvesting using salt in southern Portugal found that there was no significant impact on the sediment (Constantino *et al*., 2009). The main observed effect was an increase in salinity, however this decreased rapidly with the flood tide and returned to pre-activity levels within a few hours (Constantino *et al*., 2009).
- A study on recreational clam harvesting by raking and digging in the USA found that raking did not impact any of the measured parameters, however clam digging resulted in reduced seagrass coverage and reductions in above-ground and below-ground biomass associated with the seagrass bed 1 month after the last of three-monthly treatments (Boese, 2002). Differences were noted to persist up to 10 months after treatment although were not significant. It was noted that full impacts could only be explore through multi-year studies and that differences in sediment characteristics and clam abundance would affect the level of impact (Boese, 2002).
- A study in Washington in the USA found that digging for clams altered the dug area, affecting grain size, organic matter and oxygen content (Griffiths *et al.,* 2006).

**Summary**

- Impacts to target species from shellfish gathering have been noted to be dependent on sediment type, season and the method of harvesting use.
- For some species, like common cockle, impacts relating to population abundance and biomass have been observed with implications for population dynamics and secondary production.
- Management measures including MCRS and small closed areas have been shown to minimize target species impacts. Low levels of harvesting have also been demonstrated to have a low level of impact.
- Decreased in abundance of non-target species have been noted following shellfish harvesting although this is also dependent on sediment characteristics and method of harvesting with mixed results from studies.
- Changes to species richness have been observed where holes remain from activity compared to holes filled in and control areas.
- Impacts to sediment are not widely studied specifically for shellfish harvesting where sediment effects are separated out from infaunal community effects. Studies which have looked specifically at sediment have found mixed results, some no effect and another showing affects to grain size, organic matter and organic content.
- Impacts to seagrass beds have been noted from clam digging with impacts (not significant) persisting up to 10 months post-treatment.

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## 2.5 Seaweed collection

- Seaweed harvesting targets a variety of brown, red and green seaweeds in the intertidal zone, by hand collection.

- Biological characteristics of key targeted species are summarised in Table 1.
- The process involves selective cutting from monospecific strands of seaweed such as rockweed and kelps or alternatively collection of the storm-cast fronds, which result in mixed species harvest (Mac Monagail *et al*., 2017).
- Seaweed harvesting has a large economic value and is harvested for commercial and recreational uses such as food, cosmetics, pharmaceuticals, or creation of materials.
- Key seaweed species targeted within the commercial industry include Sea spaghetti (*Himanthalia elongate),* dulse (*Palmaria palmata)*, carrageen (*Chondrus crispus),* sea lettuce (*Ulva spp.),* red algae (*Porphyra spp.),* serrated wrack (*Fucus serratus) and* bladder wrack *(Fucus vesiculosus).* Other kelps include oarweed (*Laminaria digitata)* and sugar kelp (*Saccharina latissimi)* (Wilding *et al.,* 2021).

## 2.5.1 Ecological Impacts

### 2.5.1.1 Removal of Target Species

- Seaweeds are a key source of primary production and dissolved inorganic matter, therefore playing a key role as a food source both when dead and alive (Kelly, 2005).
- For each species, the holdfast, stipe and fronds provide substratum for other flora and fauna to attach (Kelly, 2005).
- Studies have shown that seaweeds mediate environmental conditions of the substrate, therefore, if harvested, have the capability to cause cascade affects to the surrounding ecology (Pocklington, 2017). These effects on the community have been seen to last for decades (Ingolfsson and Hawkings, 2008).
- The three-dimensional structure created by seaweed functions as habitats to mobile invertebrates such as fish, birds and seals, and also act as important nesting and breeding grounds (Mineur *et al.,* 2015). Harvesting eliminates the structure to attach eggs to or build nests within and is certain to impact communities living within the surrounding area harvested (Kelly, 2005).
- Removal of *Ascophyllum* led to significantly more *Fucus and Ulva spp.* and an increase in *Cirratulus* biomass (Boaden and Dring, 1980; Jenkins *et al.,* 2004).
- Removal of 100% and 75% of seaweed fronds led to understorey substratum temperatures three degrees Celsius higher than if only 0-50% of fronds were removed, due to a double in light intensity reaching these levels (Pocklington, 2017).
- Jenkins *et al*., (1999) found that removal of *Ascophyllum* in the Isle of Man directly resulted in the bleaching and death of turf species. This led to an increase in the area grazed by limpets, a subsequent increase in limpet recruitment and increased bare substratum (Jenkins *et al*., 1999). Eighteen months following removal, *Fucus* species had become dominant, partly restoring the understorey algal turf and interactions between limpets (Jenkins *et al*., 1999). Five years later, the algal turf had not fully recovered, showing long-term effects on the communities (Jenkins *et al*., 1999).
- In Nova Scotia, no effect of *Ascophyllum* removal was found on the use of the intertidal by small fishes (Black and Miller, 1991), although Rangeley (1994) critiqued this research, due to sampling biases and experimental design.
- In contradiction, in the sublittoral, removal of *Laminaria hyperborea* led to decrease in abundance of gadid fish by 92%. Furthermore, cormorants were reported completing significantly more dives in harvested areas, thereby expending more energy to find the same number of resources (Loentsen *et al*., 2010).
- The increase in light penetrating the substratum following canopy forming algae removal in Australia, led to the bleaching of encrusting coralline algae, with their photosynthetic activity reducing to half that observed under canopies (Irving *et al*., 2004).

- Expansion in space as a result of the removal of *Laminairia* led to the increase in blade and stripe length of annual species such as *Saccorhiza polyschides* in Britanny (Engelen *et al.,* 2011).

### 2.5.1.2 Removal of non-target species

- Bycatch is seen primarily for trawling or dredging of seaweed, however hand-raking can remove a certain amount of epiphytes and slow-moving animals if they are attached to fronds or if a holdfast has its own species community (Lotze *et al*., 2019).
- Examples of species particularly at risk are Peacocks tail, bearded red seaweed and stalked jellyfish species due to their small size thus being overlooked by harvesters (Wilding *et al*., 2021).
- Species which are attached securely to seaweeds may have to be removed by hand, there is the potential that, if done in situ, these species may relocate and survive but few epifauna and epiphytes will be able to reattach (Wilding *et al*., 2021). Processing away from the shore will remove the bycatch from the ecosystem (Wilding *et al*., 2021).
- In Atlantic Canada harbour, monospecific strands of Irish moss have been noted to host up to 36 animal and 19 major algal species which are vulnerable to removal as bycatch (Lotze *et al*, 2019).
- A study in South Africa noted that harvesting should be restricted to the distal portion of fronds as this would result in only a 50% reduction of epiphytes (Anderson *et al*., 2006).

### 2.5.1.3 Sediment Impacts

- Removal of seaweeds may affect fluid dynamics of the water column and lead to changes in sediment. Coarser sediment prevalence has been reported for harvested areas of the UK, following *Ascophyllum* collection (Boaden and Dring, 1980).
- Similarly, mortality of turf species as a result of *Ascophyllum* removal in the Isle of Man led loss of entrapped silt (Jenkins *et al.,* 1999).
- In contrast, a study conducted in the Unites States of America found removal of *Ascophyllum* in both experimentally and harvested sites had no impact to sediment type (Phillippi *et al.,* 2014).

- Brown seaweed species are noted to be particularly intolerant and sensitive to trampling impacts (Wilding *et al*., 2021). Understorey algae may suffer indirectly due to increased desiccation, however robust algal turf species, opportunists and gastropod grazers may increase in abundance as an indirect effect of trampling (Wilding *et al*., 2021).

**Summary**

- Studies have shown that seaweeds mediate environmental conditions of the substrate, therefore, if harvested, have the capability to cause cascade affects to the surrounding ecology. The three-dimensional structure created by seaweed functions as habitats to mobile invertebrates such as fish, birds and seals, and also act as important nesting and breeding grounds.
- Impacts from seaweed removal range from changes in light intensity, composition of understorey communities, interactions between species and changes in species composition.
- Peacocks tail, bearded red seaweed and stalked jellyfish species are noted to be vulnerable as bycatch from seaweed harvesting.
- If bycatch species are removed in situ they may be able to reattach and survive but this will be species specific.
- Mixed impacts to sediments have been reported with a prevalence of coarser grains post-harvesting noted in one study and no effect on sediment type in another.
- Brown seaweed species are noted to be particularly vulnerable to trampling. Impacts of trampling to associated species is noted to be species specific.

Table 1. The life history characteristics of common edible seaweeds found on United Kingdom rocky shores.

| **Common name** | **Species** | **Zone** | **Lifespan (Years)** | **Maximum length (cm)** | **Max. Growth Rate cm/day *** | **Size at maturity (cm)** | **Age at maturity (years)** | **Reproduction** | **References** |
|---|---|---|---|---|---|---|---|---|---|
| Gut weed | *Ulva intestinalis* | All | <1 | 30 | 0.25 | Unk | Unk | Spores (sexual/ asexual) >10m dispersal (BIOTIC) | Budd & Pizzola (2008) |
| Sea lettuce | *Ulva lactuca* | All & free growing | Unk | 30 | Unk | Unk | Unk | | Pizzolla (2008) |
| Channelled wrack | *Pelvetia caniculata* | High intertidal | 4 | 15 | 0.01 | 4 | 1-2 | Gametes (sexual) | White (2008a) |
| Spiral wrack | *Fucus spiralis* | High intertidal | 4 | 40 | 0.04 | 3 | 2 | Hermaphrodite (Gametes) | White (2008b) |
| Bladder wrack | *Fucus vesiculosus* | Mid intertidal | 5 | 150 | 0.07 | 15-20 | Unk | Gonochoristic (Gametes) | White (2008c) |
| Knotted wrack | *Ascophyllum nodosum* | Mid intertidal | 10-20 | 200 | 0.04 | Unk | 5 | Gonochoristic (Gametes) | Hill & White (2008) |
| Carrageen | *Chondrus crispus* | Mid intertidal to 24m | 2-3 | 22 | 0.03 | 12 | 2 | Spores (sexual/ asexual) | Rayment & Pizzola (2008) |
| Toothed wrack | *Fucus serratus* | Low intertidal | 5 | 60 | 0.2 | Unk | Unk | Gonochoristic (Gametes) (>10km) | Jackson (2008) |
| Thongweed | *Himenthalia elongata* | Low intertidal | 2-3 | 200 | 0.16 | 0.15 | 2 | Gonochoristic | White (2008d) |
| Oarweed | *Laminaria digitata* | Low intertidal to 20m | 6-10 | 200 | 1.3 | Unk | ~1.5 | Gonochoristic (Gametes) | Hill (2008) |
| Tangle weed | *Laminaria hyperborea* | Low intertidal to 30m | 11-20 | 100 | 0.94 | Unk | 2-6 | Spores (sexual/ asexual) | Tyler-Walters, 2007 |
| Sugar Kelp | *Saccharina latissima* | Sublittoral fringe to 30m | 2-4 | 400 | 1.1 | 100-200 | ~1.5 | Spores (sexual/ asexual) (>100m) | White (2007) |

* Max. growth rate has been converted to cm per day.

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## 2.6 Mechanical collection

- Mechanical collection refers to the use of machines or basic mechanics to gather or extract shore-based resources, such as animals or plants, from their natural environment.
- This method is often used to increase efficiency and productivity compared to manual collection which typically use simple tools (e.g., a rake, spade, etc.).
- This review primarily focuses on the utilisation of ‘bait pumps’ and tractor dredges; the only mechanical devices where evidence was available.

### 2.6.1.1 Bait Pumping

- A specialised pump that collects sand or mud from the exposed shoreline at low tide and filters it to collect target species such as lugworm (*Arenicola defodiens*). Cubbera *et al.* (2018) highlighted that prior bait digging studies had failed to catch lugworm (*A. Defodiens*) because the species burrows deep beneath the surface dirt. As a result, using mechanical bait pumps allows for more effective and efficient collecting below the surface of the seabed at a reduced effort for gatherers.
- Bait pumping originated in the 1800s with British fishermen using a hand-operated mechanism to extract bait from the sand. This evolved into the first mechanical pump in the early 1900s.

#### 2.6.1.2 Mechanical dredging

- Mechanical dredging involves the use of a tractor to pull trailer mounted dredges across low tide sandy bottom shores, in order to harvest target species. Various designs of dredge are used and blades varying between 70 and 100cm wide, which penetrate between 20 to 40cm into the sediment (Hall and harding., 1997; Cotter *et.a.,* 2000; Klunder *et.al.,* 2021).
- Dredged sediment is mixed with water and sieved to harvest the larger/targeted organisms; the smaller organisms are discarded in and around the gullies (van den Heiligen-berg 1987, Beukema 1995, Leopold & Bos 2009).

### 2.6.2 Ecological Impacts

#### 2.6.2.1 Removal of target species

- Bait pumps are more effective than bait digging for removal target species of lugworm with little effort.
- Fowler (199) reported that there was no evidential support to suggest the use of bait pumps depletes populations.
- Fowler (1999) also demonstrated the limited impact the act of bait pumping had on the sediment, highlighting that bait pumping causes far less disruption than traditional bait digging. However, this has been contradicted by more recent studies (Contessa and Bird, 2004).
- A study of Bury Inlet, South Wales, found that the removal of cockles using tractor dredges resulted in significant decline in spawning populations and juvenile cockles, 30-33% and 9-19% reduction in abundance respectively (Cotter *et al.,* 1997).
- A 3-month study by Contessa and Bird (2004) highlighted the negative influence on shrimp abundance while bait pumping for ghost shrimp. These results displayed a decline in abundance, porosity of sediment, organic carbon content and redox potential of intertidal sediment. Ghost shrimp feeding and burrowing activity influence sediment properties that the species inhabit, meaning its biochemical nature can only be restored when shrimp are repopulated. Deeper investigation found that the act of intense bait pumping prevented favourable conditions for shrimp to reinhabit, such as sediment porosity and redox, which in turn created a negative feedback loop (Contessa and Bird, 2004).
- In contradiction, Wynberg and Branch (2002) found full recovery in sand prawn (*Cakkuabass kruassi)* populations 32 weeks after bait pumping. This was following a decline in populations 6 weeks after collection, which mirrored the results of Contessa and Bird (2004).
- A study by Hall and Harding (1997) concluded that the effects of tractor dredges have no significant effect on target species structure, after showing recovery to the same faunal structure of an undisturbed community within 56 days. Hall and Harding (1997) determined the immigration of adults into disturbed areas resulted in the recovery of the target species.
- Studies have shown that the presence target species such as lugworm and ghost shrimp, are essential for long term sustainability of communities (Contessa and Bird, 2006; Volkenborn & Reise 2006, Volkenborn *et al.* 2007).

#### 2.6.2.2 Removal of non-target species

- Although, mechanical dredging can lead to high mortality of discarded organisms, the decaying organisms are considered to increase sediment oxidation and nutrient availability in these fished areas, which in turn, increased abundance of opportunistic species, such as those targeted in shore gathering (Klunder *et.al.,* 2021).

- Species with a longer life cycle recover at slower rates following dredging, while the abundance of opportunistic feeders, such as polychaete worms, increase in quick succession following collection (Klunder *et.al.* 2021).
- Arntz & Rumohr (1982) showed this pattern of community succession within the first 2 years after recolonisation, which is then normalised by the third year.
- Reports have shown ‘rapid’ recovery rates and low overall effects to non-target benthic fauna (Hall and Harding, 1997).
- However, this was contradicted a later study in 2000 by Ferns *et.al.* which highlighted that the effect of tractor dredging on non-target species was widely detrimental, resulting in 31% to 83% loss of the population of polychaetes (Ferns *et.al.* 2000). The populations of non-targeted invertebrates took several months to recover, which consequently has the ability to reduce bird feeding activity (Ferns *et.al.* 2000).
- Wynberg and Branch (2002) highlighted that indirect impacts associated with the physical disturbance in bait pumping were more harmful that the removal of target species itself. As a result of the activity, macrofaunal numbers declined in most gathered areas and showed clear distinct community compositions to other areas.
- When dredging for lugworms in the Dutch Wadden Sea, Volken-born & Reise (2006) demonstrated a positive effect on the biomass of several benthic species shortly after their removal.
- A study in the Netherlands reported no differences in benthic organisms between dredged areas and reference areas (Drenthe, 2013), however this was contradicted by Beukema (1995), stating biomass in dredged areas only recovered after several years.

### 2.6.2.3 Sediment Impacts

- A study in southern Australia found that bait pumping for shrimp showed initial destruction of target species burrows and compaction of sediment from both the pumping and trampling of the mudflat (Contessa and Bird, 2004). This reduced porosity and created reducing conditions to depths of 20cm (Contessa and Bird, 2004). The proportion of smaller grain sizes also increased in surface sediments and organic carbon content decreased (Contessa and Bird, 2004).
- A study in South Africa of the removal of sand and mud prawns including using a pump found that areas where sandprawns were harvested showed finer grained sediments (Wynberg and Branch, 1994). There were no obvious differences in sorting coefficient but the organic fraction was lower in experimental areas 18 days post-activity, a trend which had reversed by the end of the first month where the organic content was then higher than in control areas up to 4 months (Wynberg and Branch, 1994).
- The same study noted that in experimental areas for sandprawns the sediment surface was depressed about 10cm below the surrounding area and penetrability declined following activity as well as the accumulation of a black layer approximately 4cm from the surface (Wynberg and Branch, 1994).
- The same effects were not fully observed for mudprawn harvesting suggesting sediment characteristics influence the degree of impact (Wynberg and Branch, 1994).

**Summary**

- Evidence on mechanical harvesting is limited, primarily relating to two activities; bait pumping and tractor dredging
- Impacts to target species are mixed; for tractor dredging a significant decline in common cockle as a target species was noted in South Wales, however impacts from bait pumping are more variable with some studies suggesting impacts are much lower than traditional digging while others show significant effects resulting from the creation of unfavourable conditions for recolonisation.
- Impacts to non-target species are similarly mixed with some studies suggesting rapid recovery following activity whilst others found significant declines in polychaete species following tractor dredging.
- Sediment impacts are noted to include compaction from both the activity and associated trampling, reduced porosity, increases in fine grain sediments and changes to organic content.
- The nature of the sediment prior to activity was noted to potentially influence the degree of impact.

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