Marine Pollution Bulletin 94 (2015) 260–277

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

A review of the physical impacts of sediment dispersion from aggregate dredging

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ARTICLE INFO

Article history:
Available online 11 April 2015

Keywords:
Aggregate dredging
Plume
Fine sediment
Sand
Dispersion
Field data

ABSTRACT

The disturbance and subsequent dispersion of sediment arising from aggregate dredging results in increases in suspended sediment concentrations and, potentially, settlement of fine sediment or sand onto the bed, which may both cause adverse effects on local ecology. This subject is one area which has seen much research over many years and this paper sets out to synthesise some basic general conclusions for use when assessing the significance of planned operations. The literature detailing the dispersion of fine sediment plumes, and the longer term dispersion of sand released through the dredging process, is scrutinised, and in some cases re-evaluated, and used to identify an evidence-based footprint of potential impact.

1. Introduction

The marine aggregate industry is one of the UK's key suppliers of sand and gravel. In a typical year, over 20 million tonnes of marine aggregate are dredged from around 0.1% of the UK seabed, providing 19% of sand and gravel sales in England and 46% in Wales (BMAPA, 2012). Removal of aggregate from the seabed inevitably results in a disturbance to the local sediment and biological environments (Boyd and Rees, 2002; Boyd et al., 2003, 2005; Cooper et al., 2005, 2011; Robinson et al., 2005; Desprez et al., 2010) and there is an ongoing debate between industry, scientists, regulators and stakeholders as to the significance of this effect for the health of biota in the vicinity of aggregate dredging operations. To this end there is a need to better understand the potential effects of aggregate operations.

This paper reviews the magnitude and subsequent dispersion of the release of fine sediment and sand from aggregate dredging activities. This release of fine sediment results in increases in suspended sediment concentrations and, potentially, settlement of fine sediment or sand, which may cause adverse effects on local ecology. This subject has seen much research over many years and this paper sets out to synthesise some general conclusions which can be used for assessing the significance of planned aggregate dredging operations. This paper focuses on the physical aspects of plume dispersion from the activity of Trailing Suction Hopper Dredgers (TSHD) used by the aggregate extraction companies and represents a necessary step in understanding impact on ecology, which, though greatly influenced by physical processes, is beyond the scope of this paper.

The paper first briefly describes aggregate dredgers and discusses uncertainty in the understanding of dredging impact. An analysis is made of the evidence from measurements of fine sediment plumes in different aggregate dredging areas, showing how the observed plume dispersion can be explained by dispersion theory. The paper then analyses the evidence for the dispersion of sand released from the dredging process.

2. Release of sediment into the water column during dredging operations

Loading a TSHD entails pumping a mixture of solids and water from the seabed into the hopper of the dredger. The solids content in the pumped mixture is relatively low (approximately 25% by weight) and so the vessel fills quickly with (mainly) water. To allow the vessel to load a full cargo of sand and gravel, the excess water in the hopper is returned overboard through overflow spillways. The returned water also contains a proportion of suspended solids (typically fine sands and silt). Once returned to the sea, this sediment will be dispersed horizontally and vertically in the form of a plume by tidal flows and wave action. The processes of advection and dispersion will continue until the sediment concentrations are reduced to background levels. The increase in suspended sediment concentration (SSC) and resulting deposition from these fine sediment plumes could potentially have an impact on local ecology, the significance of which is a source of current debate.

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http://dx.doi.org/10.1016/j.marpolbul.2015.01.025
0025-326X/

The TSHD used by the UK aggregate industry differ from those used internationally for capital and maintenance dredging: they tend to be smaller as they often discharge their loads at wharfs requiring small drafts; most (but not all) aggregate TSHDs discharge their overflow (and screening discharges) over the sides of the vessel into the surface waters, rather than through the vessel hull; the sediment discharges resulting from UK aggregate dredgers are generally much lower because of the coarse nature of the aggregate and the lower discharges from the hopper; and, most aggregate TSHDs have the capacity to screen.

Screening (passing the water/solids mixture over a metal mesh) is undertaken to increase the proportion of gravel (or sand) in the hopper and results in a further return to the water column of a (coarser) mix of sediment size fractions. The greater momentum and negative buoyancy of the screening discharge, and its coarser sediment, mean that the screening plume will descend rapidly to the bed. In the case of screening for gravel, there is usually a significant proportion of fine sand (and a smaller proportion of silt) additionally released. The screened sediment (usually sand but sometimes gravel) settling onto the bed can potentially be transported away from the dredging area by tidal currents and waves, albeit more slowly than the fine material released into the water column. The dispersion of this sand can locally alter the nature of the bed sediment, making it finer and altering the benthic communities where these changes occur (Boyd et al., 2003, 2004; Robinson et al., 2005).

3. Conservative perceptions of dredging impact

This paper provides strong evidence that the physical impacts resulting from aggregate dredging in open coastal waters are relatively modest (except, of course, within the area of dredging). However, the perception amongst a number of stakeholders has been that the impacts are more significant and occur over a much larger area. In view of the precautionary principle, regulators (and their advisors) have justifiably take heed of this concern, and faced with, what has been up to now, a fair amount of uncertainty in the potential effects of aggregate dredging, have (reasonably) taken a conservative view when considering these projects. More recently the increase in information about the effects of aggregate dredging from studies such as those described in this paper, and application of comprehensive reviews of benthic species sensitivity by (e.g. the Marine Life Information Network (MarLIN), Tyler-Walters and Hiscock, 2005; Hiscock and Tyler-Walters, 2006; Tyler-Walters et al., 2011) has led to a more nuanced perspective of aggregate dredging impacts, but overall the attitude of stakeholders, researchers and regulators to the extent of impacts appears to remain mixed. It is recognised that there are a number of studies in the literature which highlight evidence (or risk) of wider and more significant impacts arising from aggregate dredging and these continue to contribute to the uncertainty regarding the nature of potential impact. This paper will demonstrate that in these cases the claims made by those authors, whilst not unreasonable at the time, do not stand up to scrutiny now better data is available and better modelling tools can be applied.

The desire to reduce the uncertainty about the effects of aggregate dredging through dissemination of the results of field observation/modelling is one of the motivations of this paper. There is now sufficient evidence to establish broad limits on the effects of aggregate dredging and it is hoped that a more refined perspective can be used to improve marine planning and to target monitoring resources more effectively.

An example of how conservative perceptions of impact can propagate into the literature and contribute to the uncertainty regarding the indirect impacts of aggregate dredging is illustrated by the interpretation by several researchers of the paper of Cooper et al. (2007). This paper, like many similar papers, examined the variation in sediment and biotopes in dredged areas directly affected by dredging at a particular dredging area (in this case the UK Anglian dredging region), in reference areas untouched by dredging and in areas potentially indirectly affected by dredging (e.g. through a change in substrate). Where the Cooper et al. (2007) paper differed from other papers of this genre is in the consideration of a larger potential area of impact from dredging and in the method of delineation of the areas which might be indirectly affected by sediment rejected through the screening process. A particle tracking model was used to identify the distances over which sediment particles, (between 20 and 200 μm) might travel over a 48 h period before depositing. The high spring tide currents (up to 1.5 m/s) resulted in an identified area of indirect effect stretching over a whole tidal excursion and up to 20 km from the dredging area (see Fig. 1). The large area identified was a result of the movement of individual sediment grains of the finest fraction and was not based on the magnitude of SSC in the plume (which would reduce greatly with distance as the plume disperses). Neither was the identified area based on dispersion of the sand released from the screening plume which is more likely to affect substrate.

The conclusions of Cooper et al. (2007) were that while areas which were directly affected by dredging showed evidence of different benthic populations compared to control areas, there was no relationship between the biotic and particle size datasets suggesting that the overall composition of sediments was not the over-riding factor responsible for the distribution of communities in this region. There were diminished numbers (not statistically significant) of species and individuals in the area of potential indirect impact compared to the control areas but as the potential area of indirect impact actually contained more gravel and less sand than the reference and direct impact areas there is no evidence of significant transport of sand to this area from the area of dredging.

It is concluded that there was no evidence of any impact of dredging on the area identified as potentially indirectly affected by dredging (the grey area in Fig. 1). This conclusion accords with the advice of the JNCC (2013) regarding designation of the area immediately north of the dredging as a Special Area of Conservation. It should be noted that the methodology used by Cooper et al. (2007) to delineate indirect impact, based on the evidence in this paper, over-estimates the footprint of dredging plumes by up to an order of magnitude.

The unsubstantiated hypothesis investigated by Cooper et al. (2007) to delineate indirect impact has been used by other researchers and regulators in the UK as though it was an established fact. Eastwood et al. (2007) used exactly the same methodology (and plume model) to identify the areas affected by dredging plumes in a comparative study of the different human-induced pressures experienced in English and Welsh offshore waters. The footprints of dredging effect derived by Eastwood et al. have in turn been used by marine planning researchers seeking to evaluate the impact of aggregate extraction on fish and ecosystem services on the UK continental shelf (Austen et al., 2009; Stelzenmüller et al., 2010). These studies illustrate how uncertainty in the understanding of the impacts of aggregate dredging can enter the literature. Reducing this uncertainty requires a rigorous approach to the available field evidence.

4. Summary of the literature relating to the measurement of fine sediment plumes resulting from aggregate dredging

This section summarises the measurements of fine sediment plumes associated with aggregate dredging available from the literature, from studies undertaken as research funded by the