AN OVERVIEW OF ENVIRONMENTAL APPRAISALS FOR MARINE AGGREGATE DREDGING

Dr D. R. Hitchcock B.Sc., Ph.D., A.R.I.C.S.

Coastline Surveys Ltd.*, Bridgend Farmhouse, Downton Road, Bridgend, Gloucestershire GL10 2AX United Kingdom*
Tel: +44 (0) 1453 826772 Fax: +44 (0) 1453 826762 email: DrHitchcock@cs.com

INTRODUCTION

In the United Kingdom, marine aggregate dredging has in recent years averaged some 25-28 million tonnes per annum, (Crown Estate, 1998), which equates to 15-20% of the total UK demand. The industry maintains some 2,500 employees, over 40 British registered dredgers, and accounts for a turnover of some £180 million per annum. From the principal aggregate extraction countries of Britain, the Netherlands and Belgium, North Sea and English Channel production amounts to some 100 million tonnes per annum (Oakwood, 1999). Sand and gravel products are widely used for a variety of major construction projects, road building schemes, landfills, beach replenishment schemes for both amenity and coastal protection, and barrage construction, to name but a few. The marine resource of sand and gravel is therefore of national and international importance and is likely to continue for some time to come with government policies to maintain a marine aggregate extraction industry (Minerals Planning Guide 6, Department of the Environment, 1994)

Such an intensive resource-based activity will unavoidably have impacts on the environment. It is important therefore that the industry is appropriately regulated and, better still, *self-regulated* to minimise the impacts of the activity wherever possible. The United Kingdom has in place a competent and workable licensing system to formulate and regulate the exploration and exploitation of the resources and is managed by the Crown Estate Commissioners. Notwithstanding this, the industry itself has responsibly developed effective Codes of Practice to improve integration of their operations with those of other sea users.

Over the past 10-15 years a good deal of concern has been raised regarding the potential impact of marine aggregate extraction on coastal resources. These include impacts on the physical composition and stability of seabed features, on the coastline itself, on fish and fisheries, on wildlife resources and on the marine food webs upon which life in the sea and on the coastal margins depends.

Over the past 5-10 years there has been a corresponding increase in the knowledge of the processes of dredging, on the marine environment and the interaction between (aggregate) dredging and the environment. This has been in response to the development of national and international laws, industry Codes of Practice and an increasing drive towards better efficiency whilst minimising the environmental conflicts. In addition to the survey and research work undertaken by the industry, primary research is funded and undertaken by the Crown Estate Commissioner (CEC), Department of the Environment, Transport and the Regions (DETR) and the Ministry of Agriculture, Fisheries and Food (MAFF).

ENVIRONMENTAL IMPACTS

EC Directive 85/337/EEC “The Assessment of the effects of certain public and private projects on the Environment” was adopted in June 1985 and came into effect in July 1988. This Directive requires that certain development projects may require an Environmental Assessment (EA) to be carried out prior to granting of consent. The extraction of marine aggregates may, under certain circumstances, come under the listing of this Directive.

There are three groups of impacts that must be considered when preparing an Environmental Assessment (from Campbell, 1993). It is important to remember impacts can be positive as well as negative and that impacts will vary in their significance. Importantly, impacts will also vary on a case by case basis.

- **Impact on Physical Resources**
- **Impact on Biological Resources**
- **Impact on Other Legitimate Users of the Sea**

PHYSICAL RESOURCES

By the very nature of the activity, the processes of dredging will impact on the seabed and the surrounding physical environment. The effects and their significance will vary according to the type of dredging but there will be broad similarities between the many mechanisms of dredging.

One can quickly realise that a large body of data is required to competently be aware of the impact of dredging activities. It cannot be understated that the importance of good scientific quality field data will greatly enhance the application for development of any licence to dredge.

Prior to aggregate dredging, it is common practice to employ competent marine survey companies to accurately prospect for the prime resource locations utilising a range of high technology equipment. This will enable not only the surface extent of the resource but also the depth and distribution of the resource to be assessed. Such data will also include the possibilities of any contaminants such as silts and obstructions such as wrecks. Survey companies will use digital echosounders with heave compensators to give a true profile of the seabed prior to dredging. Sidescan sonar will allow the surface topography and micro-topographical structures such as sand waves and ripples to be mapped. Shallow continuous seismic profiling will provide estimates of the depth of the resource below the seabed and thus allow the total potential volume of the resource to be assessed. Physical samples obtained with large grabs and vibrocoring techniques will groundtruth the electronic information and provide tangible evidence of the quality of the resource.

During these surveys or subsequent detailed surveys, if not determined in sufficient detail by the desktop study, data may also be obtained on ;

- local hydrography including tidal and residual water movements – alteration of water depths by removal of the substrate may create new patterns of water flow thus creating erosion or deposition in areas not previously effected
- wind and wave patterns and characteristics, average number of storm days per year – removal of an offshore bank may allow storm waves to reach previously protected beaches
- bedload sediment transport including occurrence of sand waves – high transport rates will infill disturbances caused by dredging and possibly indicate that the indigenous biological communities may be already adapted to a higher level of natural disturbance and be more capable of coping with anthropogenic disturbances
- alterations to natural suspended sediment loads
- relationship and significance to storm or wave-induced bottom activity
- transport and settlement of fine sediment suspended by the dredging activity
- dispersion of an outwash plume resulting from hopper overflow or onboard processing and its impact on normal and maximum suspended sediment load
- implications for prevailing wave/current regime and local water circulation resulting from removal or creation of (at least temporarily) topographical features on the seabed
- implications for the modification of longer term processes and bed-load movement
- nature and type of nearby coastline and implications for coastal erosion

BIOLOGICAL RESOURCES

The principal biological impact of marine aggregate extraction is the disturbance and removal of benthic infauna and epifauna and alteration of the substrate upon which colonisation and growth depends. Where the remnant substrate is identical to the undisturbed surface sediments (and this is normally required by licence condition), disturbance may be temporary and the extraction area will be recolonised. It is interesting to note that, however, recent research (Newell and

Seiderer, 1999) suggests that this view of the relationship between particle size and communities may not be as closely linked as traditionally thought and that other forcing functions may be more important, such as sediment stability and shear strength.

The impact on biological resources will be dependent on the intensity of dredging (both spatial and time), the degree of sediment disturbance (related to dredge techniques) and the intrinsic rate of reproduction, recolonisation and growth of communities normally inhabiting the particular deposits. To assess the biological impact of aggregate extraction, the following information will probably be required:

- assessment of the benthic community structure(s) (species type and abundance) within the proposed extraction area, which may include temporal (e.g. quarterly, seasonal) as well as spatial variations

- information on the fishery and shellfishery resources, including spawning areas, with particular regard to benthic spawning fish (e.g. herring and sand eels), nursery areas, over-wintering grounds for ovigerous crustaceans and known routes of migration

- the predator/prey relationships between the benthos and demersal fish species (e.g. by stomach content investigations)

- the method of dredging, including the effect of different suction equipment upon the seabed and benthic fauna

- the estimated recolonisation time for the denuded sediments

- a list of areas of special scientific or biological interest, such as adjacent Sites of Special Scientific Interest (SSSI), Marine Nature Reserves (MNR) and Marine Consultation Areas (MCA), Marine Special Protection Areas (SPA), sites designated under the 'Ramsar' convention, the World Heritage Convention or the UNEP 'Man and the Biosphere' Programme

- areas of natural beauty or significant cultural or historical importance in or adjacent to the proposed extraction area

Comprehensive *Environmental Impact Assessment* studies of the type which would be required to establish quantitatively the impact of dredging on seabed communities are both time consuming and expensive. In the United Kingdom there has been a significant time span (5-10 years) between the actual identification of a workable resource and the onset of extraction. Conducting full biological analysis at the time of prospecting may lead to unnecessary cost if the resource is not developed due to poor quality or other restrictions. Leaving the biological assessment to just prior to the preparation of the Environmental Assessment may result in a large amount of time and money lost in the development of the application if the resource is inhabited by important biological communities. It is worth remembering that many biological communities exhibit a cyclical 'boom and bust' life history, for example the strategically important tube dwelling worm *Sabellaria spinulosa*, and its position in its cycle when monitored may 'indicate' a detrimental effect due to dredging even before dredging commences.

The methods for analysis of marine community structure are highly sensitive and are dependent on time-consuming and expensive quantitative evaluation of the fauna, which commonly exceeds 300 species in typical gravel deposits of the English Channel and southern North Sea. Two English companies, Coastline Surveys Ltd. & Marine Ecological Surveys Ltd. have pursued the development of a *Rapid Assessment Method* for the preliminary evaluation of seabed biodiversity. This technique was first developed to quickly give an overview of the condition of the benthos within and surrounding working and recently worked dredge licences. The method has been found to give rapid results at costs that are a small fraction of those incurred in performing a fully quantitative survey. The results have been found to conform well with detailed quantitative surveys in impact studies for industrial waste discharges. The method has been used to good effect by management in preparing for application. A similar method has been recently proposed for assessment of the impact of mine wastes tailings in Canada and is increasingly recognised as part of a *Strategic Environmental Assessment* process, carried out at early stage of the environmental assessment procedure (Ellis, 1998).

The ***Strategic Benthic Resource Assessment*** has therefore been developed to indicate to management at an early stage in the prospecting process, (or indeed, *any* marine development), the presence or otherwise of benthic species or communities that may have an important conservation status within the prospecting area. Such community presence, if indicated, would require development of specific mitigation proposals and measures during the development of the Environmental Statement. Inclusion of information on the benthic biological resources at an early stage can therefore be borne in mind when considering the potential implications and costs of developing a new aggregate extraction Licence and assist the management decision to proceed, or otherwise, with an application.

The assessment in no way is intended to replace a fully quantitative baseline study obtained using an approved Hamon Grab with fully quantitative species identification in the laboratory. It is purposefully intended to give an *overview* of the resources at an early, strategic stage.

Notes on the biological resources of the sediments are made by a competent marine biologist during the course of the geological grab survey carried out as part of the above physical resource assessment. Grab samples have been taken with a large hydraulic grab that sampled approximately 0.75 m^2 of the seabed and a smaller 0.2m^2 Hamon grab internationally approved for comparative surveys offshore. Sub-samples are taken for aggregate resource analysis and notes made of the macrofauna observed for each sample obtained.

A *Rapid Assessment Method* for scoring the biodiversity of marine sediments has been developed. Essentially the variety of the main macrofaunal species and their relative abundance is assessed aboard the survey vessel rather than following a lengthy separation and analysis required for a fully quantitative survey. The abundance and variety of macrofauna species is then allocated a 'score' based on the following scale:

++++	=	Fauna abundant in species variety and individuals
+++	=	Fauna rich in species or numbers of individuals
++	=	Fauna representative in species variety but not rich
+	=	Fauna sparse with few species or individuals
Zero	=	Fauna absent

A competent marine biologist can identify most of the larger macrofaunal species that are to be found in the sample, and the identification of key sample species can be subsequently confirmed by a relatively inexpensive examination in the laboratory. Some organisms such as Hydroids, some of the smaller Polychaetes, Crustaceans and Bryozoa do require detailed examination for full analysis. These categories and scores form the basis for development of colour-coded resource maps of the survey area to readily identify zones of potential benthic biological resource sensitivity.

It is clear that the scoring system outlined above could vary according to the competence of the marine biologist. However, we have found that the system is very robust and that similar 'scores' for sediment samples are given by persons of varying experience. Comparability is assisted by provision of a list and schematic diagrams of key organisms by the senior biologist and we recommend that this procedure be adopted when several staff may be involved. The data are summarised in the form of spectral contour plots. These show the boundaries of the area actually surveyed within which there will be clear differences in faunal richness.

It should be emphasised that the results of the Strategic Benthic Resource Assessment are essentially a 'short-cut' method of assessing the presence and condition of the seabed benthic resources. The method does not replace a fully quantitative baseline survey should one be required for the purposes of an Environmental Impact Assessment. The method does however provide a timely, economical overview to assist management with the decision to proceed with an application. Further, recent Licence applications in the United Kingdom have started to include a seasonal element to the assessment, and this technique would provide a very cost-effective method of conducting near-quantitative investigations at a reduced cost. One must also remember that the abundance index used should be regarded as a *relative* scoring system to identify the key community types in the survey area.

INTERFERENCE WITH OTHER LEGITIMATE USES OF THE SEA

The effective management of marine activities is strongly dependent on avoiding confrontation between sea users. Prior to the establishment of marine aggregate dredging at a particular location, there may be established communities of fishermen, or the resource be located in or adjacent to important shipping routes. Careful consideration of the needs of each user should enable all users to be able to co-exist.

- the number of vessels to be used and the duration of dredging campaigns (for example, daily, weekly, occasionally)

- seasonal commercial fishing patterns, including type of gear used, distribution, value and number of fishermen involved

- shipping lanes

- military exclusion zones

- engineering uses of the seabed (e.g. adjacent extraction activities, undersea cables and pipelines)

- adjacent areas of the sea designated as sites for the disposal of dredged material and sewage sludge

- location of wrecks (with an indication of their historic status) and war graves

- recreational uses of the area (e.g.. sport angling, diving)

MITIGATION

In evaluating the overall impact, it will be necessary to identify and quantify the marine and coastal environmental consequences of the proposed activity and the basis of a monitoring plan as well as setting out why the proposal is not thought likely to effect other interests of acknowledged importance to the area.

These consequences can be summarised in an Environmental Impact Assessment (EIA) containing the Impact Hypothesis, which will draw on the results of earlier studies of environmental characteristics and their variability. The EIA will also indicate where measures need to be taken to mitigate the effects of the proposed dredging or associated operations.

It will then be necessary to consider the steps that might be taken to mitigate the effects of extraction activities. This may include:

- the selection of dredging equipment and timing of the dredging operations to limit impact on benthic communities and spawning cycles;

- modification of dredging depth limit changes to hydrodynamics and sediment transport;

- zoning the area to be licensed or scheduling extraction campaigns to protect sensitive fisheries or to respect access to traditional commercial fisheries.

It may also be necessary to demonstrate the need to exploit the resource in question, through careful, comparative consideration of local, regional and national need for the material in relation to the identified impacts of the proposal and the relative environmental costs of provision from other sources, both marine and on land.

MONITORING

A key element to effective management of the dredging process is the development of clear and repeatable monitoring programmes. Monitoring of the marine environment may be generally undertaken for the following reasons;

- to establish whether licence conditions are being observed;

- to establish whether licensing conditions are preventing extraction activities having adverse effects on the marine environment;

- to provide the necessary evidence to demonstrate that the control measures applied are sufficient to ensure that any lasting environmental damage does not result from exploitation of marine resources;

- to improve the basis on which licence applications are assessed by improving knowledge of field effects which are not readily estimated by laboratory or literature assessment.

Monitoring operations are expensive for they require considerable resources both at sea and in subsequent sample and data processing. In order to approach a monitoring programme in a resource-effective manner, it is essential that the programme should have clearly defined objectives, that measurements made can meet those objectives, and that the results be reviewed at regular intervals in relation to those objectives. The monitoring scheme should then be continued, reviewed or even terminated.

ENVIRONMENTAL IMPACT ASSESSMENT

The Impact Hypothesis prepared from the environmental statement summarises the effects of the proposal on the environment, an important element in the establishment of a monitoring programme. Before any monitoring programme is drawn up and any measurements are made, the following questions should be addressed;

- what measurements are necessary to meet specified objectives?
- what is the purpose of monitoring a particular variable or biological effect?
- in what environmental compartment or at what locations can the measurements be made cost effectively?
- how many measurements are necessary to meet specified objectives
- for how long should the measurements continue to be made to meet the objective?
- what should be the temporal and spatial scale of measurements be made to test the hypothesis?

Where it is considered that the effects will be largely physical, monitoring may be based on remote methods such as sidescan sonar to identify changes in the character of the seabed. These measurements will require a certain amount of sediment sampling to establish ground truth.

Biological sampling to assess changes in the benthic community structure may also be appropriate provided there is a scientific basis for the interpretation of the resulting data. In order to assess the impact, it will be necessary to take account of any natural biological variability. This is best achieved by comparing the physical or biological status of the affected areas with reference sites located away from the extraction site. Such reference sites can be identified during the preparation of the EIA. The spatial extent of sampling will need to take into account the area designated for extraction, any possibility of operating outside the licensed area and the mobility of fine material raised into suspension by the dredging activity.

Since the effects of marine aggregate extraction will have some similarities in different sites, it will be appropriate to conduct biological monitoring programmes at a few carefully chosen sites. It is also appropriate to consider 'far afield' effects of extraction such as the relationship between spawning grounds and areas of recruitment. Measurements relating to the timing of extraction should be conducted at each site.

Concise statement of monitoring activities should be prepared. Reports should detail the measurements made, results obtained, their interpretation and how these data relate to the monitoring objectives. The frequency of monitoring will depend on the aims and will be related to the scale of extraction activities and the anticipated period of consequential environmental changes, which may extend beyond the cessation of extraction activities.

IMPORTANCE OF MONITORING AND RESEARCH

In the United Kingdom, following effective monitoring programmes, there has only been one case (known to the author) of a dredging permit being removed for non-compliance with licence conditions. This was related to dredging occurring outside the dredge licence boundaries; but in mitigation, this did occur at a time when new positioning technologies were becoming available creating a change in relative accuracy of the dredging operation between that of the dredger (Decca) and the monitoring survey vessel (dGPS).

Important advances in the management of dredging have been made following effective research and monitoring. Through life monitoring of the conditions at the seabed and within the water column if necessary have generally enabled aggregate dredging operations to begin or to continue following objections. Objections are usually and sensibly based on the precautionary approach utilising the best available information at the time. Recent estimates have placed the cost of contribution by the industry to the marine database in the form of prospecting reports, biological assessments, modeling of coastal erosion, study of sediment transport etc at approximately UK £1.5 million per annum. Without doubt this forms a significant contribution towards the research also undertaken and funded by local and national government.

Beach drawdown and coastal erosion: United Kingdom guidelines currently consider that it is unwise to permit dredging in water depths of less than 18m and/or within 1km of the coastline but applications will generally be considered on their individual merit. Few, if any, applications have shown to have a potential for significant impact on the height of waves reaching the coastline, based upon maximum dredging depths.

An excellent example occurs in the Bristol Channel, on the west coast of Britain, where good quality sand is extracted by a number of small trailing suction dredgers for local building purposes at a rate of approximately 2.5 million tonnes per annum. This activity has for a long time been the subject of strong and emotional objections on the basis of perceived coastal erosion. Monitoring programmes associated with the extraction of sand from a particular offshore sandbank have not only included measurement of water depths across the bank itself to assess changes in wave patterns but also monitors water depths and seabed features between the bank and along the coast as well. Four seasonal topographic surveys of the adjacent beaches and hydrographic surveys of the near shore approaches are carried out to monitor possible beach erosion over time. Two storm topographic surveys are conducted before and after significant summer and winter condition storms. Sidescan sonar and sediment sampling surveys have also been undertaken to identify any potential onshore-offshore exchange.

On renewal of the licence to continue to extract sand, all the available data were analysed to see if there was a deleterious effect on the coastline. The results clearly showed that the beaches were dynamically stable over the period of observations (since 1992) and that changes observed were seasonally driven and were repeated. The application was given a favourable view and dredging has been permitted for a further period of four years before the next review.

Sediment plumes: The dredging process by its very nature disturbs large quantities of sediment. In recent years a growing collection of alleged and largely unsubstantiated concerns of the impact of sediment plumes formed in the water column have developed. Allegations have, for example, suggested dredging turns the seabed into a 'biological desert' around the dredge site by smothering all forms of bottom dwelling life.

Sediment plumes may, in the case of trailing dredgers, be formed by the action of the draghead on the seabed, by the rejection of unwanted material from the dredger during onboard processing ('screening') and from overspilling of surplus sediment laden waters from the dredge hopper. For grab dredging with a conventional clamshell grab, the potential effects may stem from the action of the grab on the seabed, losses from the grab whilst ascending and losses by overspilling from the cargo hopper. Potentially there may be a small loss as the grab descends to the seabed and is 'washed clean'.

Sediment plumes have been a serious object of concern because, amongst other concerns, the potential impact has been perceived to continue well outside the actual area of dredging. In the UK early modeling studies were based purely on standard settling velocities for the various fractions of sediments, estimated to be present in the overspill. Plumes of very fine sand settling in 50m of water may then travel up to 11km from the dredge site, fine sand up to 5km, medium sand up to 1km, and coarse sand up to 50m based on simple Gaussian diffusion simulations. Whilst this is indeed possible, two questions arise: (1) does this phenomenon actually occur? and (2) will it have a significant impact?

We have over the past five years conducted an extensive series of research campaigns, both physical and biological, in order to understand the scope of the potential problem on a most realistic or probable case basis rather than the worst case precautionary approach. This data is then input back to the modeling process in order to calibrate and refine the predictive models. Various projects have been financed by individual dredging companies, associations and national government bodies.

With respect to the question 'does the phenomenon actually occur' we have published clear evidence that although the plumes undoubtedly travel a distance beyond the dredge zone, this distance is generally an order of magnitude less than at first predicted. The work has involved extensive field measurements of the 'source terms' i.e. measuring what quantities of sediments are actually lost to the water column and are therefore used to estimate settling thicknesses etc. Further, the plumes themselves have been mapped in detail to provide snapshots of the size and quantities of sediment in suspension at different distances from the dredger. This has provided, for the first time, real field calibration of what the models were trying to predict. It was observed that the sediments overspilling and rejected by screening do not behave with typical settling velocities and that they act together to form fast moving 'density currents'. These drive themselves towards the seabed far faster than single particles might alone fall, thus limiting the spatial extent of the plume. Sediments are now known to reach the seabed largely within a distance of 300-500m from the dredge site, with the finer sediments reaching distances of only 1-2km in currents of two knots before being indiscernible from background suspended solids concentrations. These discoveries, simultaneously but independently observed elsewhere in the world by other workers (Land *etal,* 1994, Whiteside *etal,* 1995), have resulted in new predictive models being developed, the latest of which will be employed in a study just commencing in the UK. Such field results are important in proving not only how far the sediments have traveled but also whether or not suspended sediment plumes may reach sensitive seabed communities such as coral reefs or protected areas such as sites of special archaeological importance.

In order to assess the question 'is the impact significant?' and therefore attach the correct emphasis to this issue in comparison with other issues (given only a finite financial resource for assessment) we have recently completed a fundamental study of a non-screened dredge area on the South Coast of Britain. This site has been dredged since 1991 by anchored suction dredgers and rarely (since late 1998) by trailing suction dredgers, removing a total of nearly 2 million tonnes over that period. The gravelly resource has been extracted from a very small target area of roughly 400m x 400m, within a larger licence. Detailed sidescan sonar mapping has confirmed the areas that have been dredged by observing the extent of small pits formed on the seabed.

We have closely studied the seabed surrounding the dredge pits and worked area to ascertain the physical and biological impacts that may have been caused by the working of the licence. Over 200km of high-resolution sidescan sonar imagery and 130 seabed samples have been obtained. The study area extended up to 10km either side of the dredge zone (one tidal excursion) in order to identify far afield effects. The results so far clearly show that the physical impact of dredging on the seabed (without screening) is limited to a zone within approximately 300m downtide of the dredge area. There is no evidence of suspended sediments falling to the seabed beyond this zone, which may be manifested as infilling of small pits by fine sediments, siltation within crevices or development of migratory sand ripples.

The biological information shows us that there is a reduction in the species diversity and population density within the actively dredged zone as may be expected. However, the data also shows us that small areas (less than $250m^2$) not dredged very recently (within last few weeks / month) may have already begun to recover exhibiting a slight increase in diversity. Other sites which show older dredge marks (from the sidescan sonar) have increasing population density as well as increasing species diversity. Ongoing investigation will expand on these preliminary observations by correlating the known date of last dredging a site with the community analysis. This will lead us to be able to determine recolonisation rates on a spatial context and with respect to different biological communities.

The data clearly show that, for the no-screening scenario, impacts 'experienced' by biological communities are confined to the immediate dredge area, certainly within 300-500m downtide. Further, preliminary examinations of the data suggest that recolonisation may be much quicker than hitherto considered

SUMMARY

The instinctive emotional impressions of aggregate dredging activities are that, amongst a whole variety of impacts there will be mass disturbance at the seabed, substantial loss of benthic resources through disturbance and smothering and subsequent devastational impacts on fisheries, other marine life and ultimately Man. Coastal erosion is also often quickly linked with dredging activities. However, the majority of the scientific evidence does not support these views where activities are rationale, sensible and planned. Obviously on a worldwide basis there are cases of real conflict but these cases should be rare and largely avoidable.

This paper attempts to show that whilst the potential for impact may be large, through careful objective planning and monitoring the actual impacts can be reduced. Effective mitigation strategies and procedures can be developed and often implemented with minimum cost and real benefits.

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