Item 12 Section 2.7

Hydrographic Surveys Ltd.
The Cobbles, Crosshaven, Co. Cork.
Tel: +353 21 4831184 • Fax: +353 21 4831193
E-mail: info@hydrosurvey.com
www.hydrosurvey.com

Malahide Marina

Foreshore License Application Form

Item 2.7

Dredge Material Analysis Report

Report No. PH17027_RpB2_Rev.01

Client:

Malahide Marina Village Ltd.

REPORT CONTROL SHEET

Client	Malahide Marina Village Ltd.					
Project Name	Malahide Marina Foreshore License Application					
Report Name	Dredge Material Analysis Report					
Project Number	PH17027					
Report Number	PH17027_RpB2					
This Report Comprises of	TOC	Text	No. of Volume	No. of Appendices	Drawings	Electronic data
	1	12	1	4	1	*.pdf

Revision	Status	Author(s)	Approved By:	Issue Date
Rev.00	Draft	HP	JBJ	21.06.2017
Rev.01	Final	HP	JBJ	02.03.2018

TABLE OF CONTENTS

1. INTRODUCTION 1

1.1 SURVEY OBJECTIVES 1

1.2 PRESENCE OF INVASIVE SPECIES 1

2. GRAB SAMPLING SURVEY METHODOLOGY 2

2.1 GRAB SAMPLING SURVEY 2

2.1.1 Horizontal Control 2

2.1.2 Sample Acquisition 2

2.1.3 Geotechnical Analysis 2

3. SURVEY RESULTS 4

3.1 AMOUNT AND COMPOSITION OF MATERIAL 4

3.2 MATERIAL FORM 4

3.3 PHYSICAL PROPERTIES 5

3.4 TOXICOLOGY 5

3.4.1 Metals 5

3.4.2 Organochlorine Pesticides & Polychlorinated Biphenyls (ICES 7) 5

3.5 RADIOACTIVITY 6

3.6 PERSISTENCE IN THE ENVIRONMENT 6

3.7 ACCUMULATION AND BIOTRANSFORMATION IN BIOLOGICAL MATERIALS AND SEDIMENTS 6

3.8 PROBABILITY OF PRODUCTION OF TAINTS OR OTHER CHANGES REDUCING MARKETABILITY OF RESOURCES (E.G., FISH, SHELLFISH). 6

4. APPENDIX A: DRAWINGS 7

5. APPENDIX B: SEDIMENT TRANSPORTATION – PREDICTION IMPACT STUDY 8

6. APPENDIX C: MARINE INSTITUTE SAMPLING ACTION PLAN 9

7. APPENDIX D: TESTING LIKELIHOOD OF THE INVASIVE TUNICATE DIDEMNUM VIXILLUM DISPERSAL VIA PROPOSED WATER-INJECTION DREDGING AT MALAHIDE MARINA 10

8. APPENDIX E: GEOCHEMICAL TEST RESULTS 11

9. APPENDIX F: GEOCHEMICAL RESULTS WITH RELATION TO IRISH UPPER AND LOWER LIMITS 12

1. Introduction

Sediment sampling was required at Malahide Marina in order to provide a detailed characterisation of the dredge material in accordance to Technical Annex 1 of the OSPAR Guidelines. This sampling gave details of the physical and chemical characteristics of the sediment. Further work on the biological characterisation of the dredge material is presented in is presented in **APPENDIX D: TESTING LIKELIHOOD OF THE INVASIVE TUNICATE DIDEMNUM VIXILLUM DISPERSAL VIA PROPOSED WATER-INJECTION DREDGING AT MALAHIDE MARINA.**

Hydrographic Surveys Ltd. was requested by Malahide Marina Village Ltd. to undertake a sediment sampling survey at Malahide Marina, Co. Dublin and report the findings in line with a proposed Dumping at Sea license application. Malahide Marina is located in the Malahide Inlet and has water depths ranging from approximately +3.7mOD Malin to -1.0mOD Malin (+1 to -3.7m Chart Datum) with depths shallowing to the west. The proposed dredge area covers an area of 4.3 ha.

All sample collection fieldwork was undertaken on the 26th April 2017.

1.1 Survey Objectives

The objectives of the survey were as follows;

- Collect 5 no. samples at designated location at Malahide Marina and analyse for pre-designated criteria as set out in **APPENDIX C SAMPLING ANALYSIS PLAN.**
- Report the results of the sampling in line with the criteria outlined in Section B.2 of the EPA Foreshore License Application Form V4.

Please see **APPENDIX A: DRAWINGS** for a location map showing location of the 5 no. samples.

Please see **APPENDIX E: GEOCHEMICAL RESULTS** for a full quantitative breakdown of the survey sampling results.

1.2 Presence of invasive species

It is known that the invasive species *Didemnum vexillum* is present at Malahide Marina. *D. vexillum* is a species of colonial truncate in the family Didemnidae.

A detailed scientific study of Malahide Marina has been conducted by UCD and is presented in **APPENDIX D: TESTING LIKELIHOOD OF THE INVASIVE TUNICATE DIDEMNUM VIXILLUM DISPERSAL VIA PROPOSED WATER-INJECTION DREDGING AT MALAHIDE MARINA.**

2. Grab Sampling Survey Methodology

2.1 Grab Sampling Survey

The locations for sampling were designated by a Sampling Action Plan provided to Malahide Marina by the Marine Institute on 2nd February 2017 (see **APPENDIX C SAMPLING ANALYSIS PLAN**). Please see **APPENDIX A: DRAWINGS** for a location map showing location of the 5 no. samples. The 5 sampling locations were sampled at the following coordinates;

Sample No.	Latitude	Longitude
MH1	53.45412	-6.15214
MH2	53.45327	-6.15233
MH3	53.45567	-6.15321
MH4	53.45516	-6.15368
MH5	53.45549	-6.15370

Table 2.1: Sampling locations [WGS84]

2.1.1 Horizontal Control

Horizontal control for the survey was provided by a Trimble differential GPS receiver. The differential signal was received from the OmniSTAR satellite. Accuracy for this GPS is <0.5m.

2.1.2 Sample Acquisition

The surface sediment samples were taken via a stainless steel Van Veen grab sampler. Sample material was handled via latex gloves and placed directly into the appropriate sample containers (plastic and aluminium). These samples were fast track couriered in a cool box directly to the certified laboratory RPS Laboratories Letchworth for geochemical analysis. The samples were dispatched to RPS Laboratories on 26th April 2017.

2.1.3 Geotechnical Analysis

The Sampling Action Plan was provided to the analysing laboratory prior to the commencement of this project to ensure the quality requirements and detection limits could be met.

Sample numbers MH2, MH3 and MH4 were analysed for the following parameter;

1. Visual inspection, to include colour, texture, odour, presence of animals etc.
2. Water content, density (considering sample collection and handling).
3. Granulometry including % gravel (> 2mm fraction), % sand (< 2mm fraction) and % mud (< 63µm fraction).
4. The following determinants in the sand-mud (< 2mm) fraction:

a) Total organic carbon.

b) Carbonate.

c) Zinc, Nickel. Copper, Lead, Arsenic, Cadmium, Lithium, Aluminium, Chromium, Mercury.

Samples MH1 and MH5 had the above as well as the following additional analysis.

d) Organochlorines including - HCH (Lindane) and PCBs (to be reported as the 7 individual CB congeners: 28, 52, 101, 118, 138, 153, and 180).
e) Total extractable hydrocarbons.
f) Tributyltin (TBT) and dibutyltin (DBT).
g) Polycyclic aromatic hydrocarbons (PAH) - Acenaphthene, Acenaphthylene, Anthracene, Benzo (a) anthracene, Benzo (a) pyrene, Benzo (b) fluoranthene, Benzo (ghi) perylene, Benzo (k) fluoranthene, Chrysene, Dibenz (a,h) anthracene, Flourene, Fluoranthene, Indeno 1,2,3 – cd pyrene, Naphthalene, Phenanthrene, Pyrene.

Values were also measured with reference to Certified Reference Materials (CRM) and the results for these are included along with the results of the geochemical properties analysed.

3. Survey Results

Geochemical survey results are given seperate to this report in **APPENDIX E** and **APPENDIX F** and is summarised below.

3.1 Amount and composition of material

From recent bathymetric surveying a quantity of 17,000m³ is envisaged to be removed to ascertain a level of 1.7mOD Malin (-1m CD) in the marina. A further two dredging campaigns are also proposed as part of this Foreshore License application.

For the initial dredging campaign, a breakdown of the total volume of 17,000 m^3 into its constituents results in 13,506 m^3 of silt, 2108 m^3 of clay and 1336 m^3 of sand. These values are on the assumption that the samples taken accurately represent the material being dredged. See below for a description of the material grain size.

3.2 Material form

The material form is a solid material. According to the results of the sampling survey the dredge material is mainly a silt type material with grain size < 63 µm and > 1.95 µm. On average 79% of the dredge material is composed of silt (min 73%, max 83%). A further 12% on average (min 8%, max 16%) of the dredge material is composed of clay with gran size < 1.95 µm. The rest of the dredge material is composed of sand material which makes up the rest of the composition on average 8% (min 6%, max 9%),

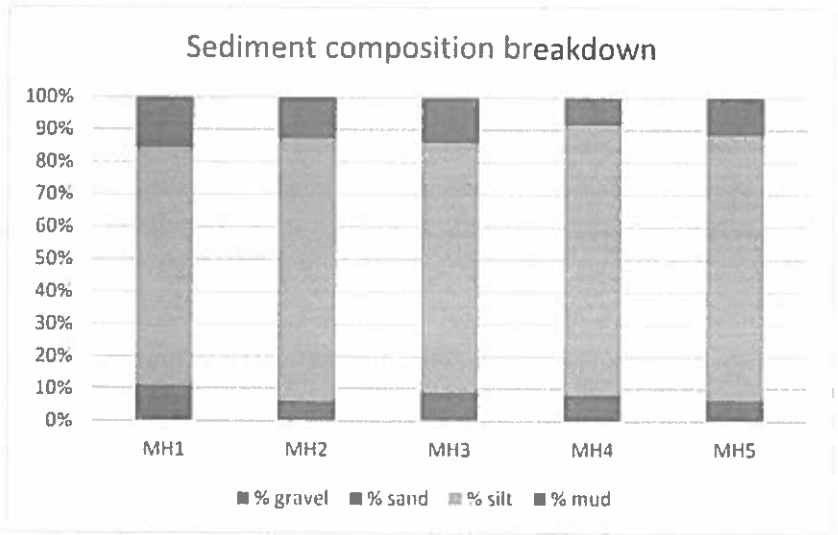


Chart 3.2: Malahide Marina sediment grain size composition.

3.3 Physical properties

The analysed material had an average moisture content of 58% (min 54%, max 60%). The density of the remaining material was on average 1860 kg/m^3 (min 1700 kg/m^3, max 2200 kg/m^3). Taking the density of moisture within pore spaces of the material as 1030 kg/m^3 this results in a bulk density of 1360 kg/m^3 (1.36 tonne/m^3) for the material as a whole. Using this value dredging a quantity of 17,334 m^3 on three occasions would results in a total tonnage of 70,830 t being removed.

1m cubed	Density	Weighted average
60% water	1.03	0.62
40% silt	1.86	0.74
Average density:		1.36

Table 3.3: Calculation of bulk density

3.4 Toxicology

3.4.1 Metals

It can be seen that the concentration of metals within the analysed samples make the dredge material a Class 1 material. A Class 1 material has contaminant concentrations less than Level 1 of the Irish Lower Limit as proposed in *Cronin et al. 2006. Guidelines for the Assessment of Dredge Material for Disposal in Irish Waters. Marine Environment & Health Series, No. 24. Marine Institute.* Arsenic and Nickel show consistent low concentrations, however are over the Irish Lower Level value. Arsenic is seen to be present in the marina at a concentration of 15 mg/kg compared to the proposed Irish Lower Level of 9 mg/kg. It is noted in Cronin et al. that background natural levels of arsenic may exceed the Irish Lower Level in particular. Nickel is present in the marina at a concentration of 36 mg/kg compared to the proposed Irish Lower Limit of 21 mg/kg. It is noted in Cronin et al. that more information about natural levels of arsenic and nickel is needed to set limits more accurately as there is insufficient background data.

3.4.2 Organochlorine Pesticides & Polychlorinated Biphenyls (ICES 7)

Levels of gamma-HCH also known as Lindane, returned values < 2.18 µg/kg for both samples analysed. Levels of HCB were < 2.18 µg/kg for sample MH1 and 3.12 µg/kg for sample MH5. The Irish Upper Limit for both gamma-HCH and HCB is 1 µg/kg.

Polychlorinated Biphenyls concentrations were less than Irish Lower Limit of 1 µg/kg for both samples apart from 2,4,4'-trichlorobiphenyl (PCB congener 28) in MH1 where a concentration of 1.7 µg/kg was reported.

For all other parameters analysed values were less than the Irish Lower Limit.

3.5 Radioactivity

In consultation with the RPII, it is understood that a number of nearby sites along the east coast have had radioactivity testing conducted and none of this testing has identified a radiological hazard to dumping of the material.

The material being dredged has accumulated at Malahide Marina since the last dredged in 2006 and as such it is highly unlikely that material has become radioactive in the previous 12 years as no source of radiation is present nearby.

3.6 Persistence in the Environment

As the material from the dredge site has been shown to have low levels of contamination it is considered that the presence of the dredge material in the environment is not considered a risk.

The presence of the invasive species *D. vexillum* present at Malahide Marina is addressed in **APPENDIX D: TESTING LIKELIHOOD OF THE INVASIVE TUNICATE DIDEMNUM VIXILLUM DISPERSAL VIA PROPOSED WATER-INJECTION DREDGING AT MALAHIDE MARINA.** To mitigate against persistence in the environment dredging activity is to take place in the months of January and December only when the *D. vexillum* are reduced in cover and potential for fragmentation, this is reasoned further in **APPENDIX D.**

3.7 Accumulation and biotransformation in biological materials and sediments

The accumulation of material after dredging is addressed in **APPENDIX B: SEDIMENT TRANSPORTATION – PREDICTION IMPACT STUDY** conducted by Moylan Consulting Engineers on behalf of Malahide Marina Village Ltd. This report concludes;

"It is anticipated therefore that the Water Injection Dredging will contribute only minimal additional silts and muds and that these materials will be dispersed into background siltation by natural scouring from the "short deeps" area.

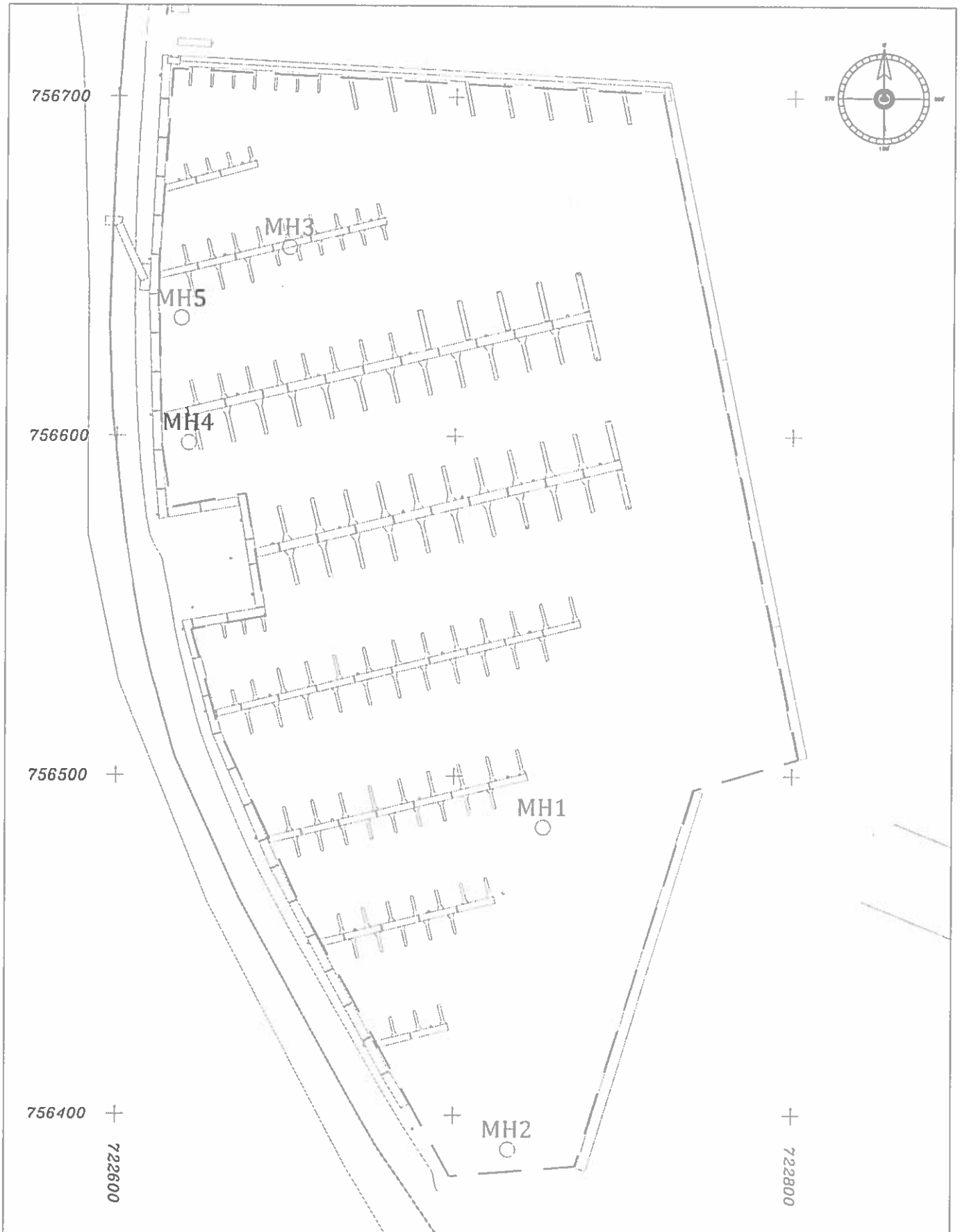
Silts form the Water Injection Dredging process will be well dispersed and are not to be detectable within the background silts outside the broad meadow estuary."

3.8 Probability of production of taints or other changes reducing marketability of resources (e.g., fish, shellfish).

No effect will occur due to the minimal disturbance anticipated.

4. APPENDIX A: DRAWINGS

Drawing Number	Description	Scale
PH17014A_D01	Location map of samples	1:1000 on A3



SITE: MALAHIDE MARINA	CLIENT: Malahide Marina Ltd.	JOB NUMBER: PH17014	DRAWING NUMBER: PH17014_D01	LEGEND	SURVEY PARTY BY: Hydrographic Surveys Ltd. The Cobbles, Crosshaven. Co. Cork. P43 C966 e: info@hydrosurvey.com t: +353 21 483 1184 w: www.hydrosurvey.com
SHEET TITLE: FEB 2017 SAMPLING LOCATIONS MALAHIDE MARINA, CO. DUBLIN	SURVEYED BY: Hydrographic Surveys Ltd. The Cobbles, Crosshaven. Co. Cork. P43 C966 e: info@hydrosurvey.com t: +353 21 483 1184	REVISION: Rev.00	SCALE: 1:1000 @ A1	Proposed dredge limits	Hydrographic Surveys Ltd.
		DRAWN BY: Hugh Power	APPROVED BY: J.B.L.		
		COORDINATE SYSTEM: Irish Transverse Mercator	SURVEY DATE(S): 26th April 2017		
			DATUM: Chart Datum		

5. APPENDIX B: SEDIMENT TRANSPORTATION – PREDICTION IMPACT STUDY

The report below was conducted by Moylan Consulting Engineers on behalf of Malahide Marina Ltd. and details the impact of Water Injection dredging for a campaign in 2006 where approximately 11,000m³ of material was dredged.

Client: Malahide Marina

Project: Malahide Marina Maintenance Dredging

Report Title: Sediment Transportation – Prediction Impact Study

Volume No: 1 of 1

Approval Status	Author (Name)	Date	Approved by: (Signature)	Date
Issue No. 1	Lars Schneider	07.03.06		7/3/06
Issue No. 2				
Issue No. 3				

Moylan
Consulting Engineers & Project Managers

Wilson House Fenian Street Dublin 2
t 01 664 8900 f 01 661 3618 e info@moylan.ie
www.waterman-group.co.uk

Project No: E-264

Table of Contents

		PAGE NO.
1.0.	Introduction	1
2.0.	Water Injection Dredging	1
3.0.	Analysis Carried Out	1
4.0.	Conclusions	2

Appendix 1 - Drawings

Appendix 2 – Water Injection Dredging

Appendix 3 – Material - Particle Size Analysis

Appendix 4 – Estuary Flow Characteristics

Appendix 5 – Particle Flow Calculations

1.0. INTRODUCTION

1.1. It is proposed to use a Water Injection Dredging process to carry out maintenance within the Malahide Marina. This dredging is required to remove settled sediments that have been deposited along the sea wall within the marina.

1.2. The total quantity of material to be removed is estimated to be approximately 11,000m^3.

1.3. The material to be removed consists of silts that have settled at the marina location since the marina was last dredged in 1996.

1.4. On instructions of Malahide Marina, Moylan Consulting Engineers carried out an assessment of the possible movements of sediments within the estuary and the foreshore that are to be dredged from the marina area.

2.0. WATER INJECTION DREDGING

2.1. Traditionally marinas have been dredged with material taken from the marina site to remote disposal areas. However, in recent years greater emphasis has been placed on retaining the sediment within the local system as opposed to removing it to a location remote from the dredge area. This approach has led to the development of suspension dredging methods where the material is moved locally making use of local siltation cycles.

2.2. Water Injection Dredging is a dredging process that utilises water injection techniques to put the sediment materials back into suspension, creating a fluidised layer that initially behaves as a density current. Details of the Water Injection Process are contained in Appendix 2 of this report.

2.3. This fluid layer, flowing primarily under the influence of gravity, will tend to travel to the deepest point within the estuary system. In the case of Malahide Marina this would be the area known as the "short deeps" as indicated on the drawing attached in Appendix 1 of this report.

2.4. The advantage of the Water Injection Dredging process is that the material being dredged is effectively returned to suspension and moved downstream within the water body from which it originated.

3.0. STUDY METHODOLOGY

3.1. Moylan has carried out an analysis on the possible movement of the silts as they are deposited by the Water Injection Dredging process in the "short deep" area. Methodology for this study is as follows:-

1. A particle size analysis was carried out by the Geotechnical Laboratories, Trinity College Dublin, on samples from the sediment material within the Marina. A copy of the analysis is attached in Appendix 3 of this report.

   The analysis confirmed that the material to be removed consists of a clayey silt with very low sand content.

2. On instruction of Malahide Marina, the direction and speed of the currents at the marina basin and estuary were measured by Mr. Tom Ochman, Oceanographer Bsc. The results of these measurements are contained in Appendix 4 of this report.

   An assessment of the direction and speed of the tidal currents off the mouth of the estuary was carried out based on Hydrographic Office map 1468, Tidal Streams at Geographical Position F, which is located at the mouth of the Broadmeadow Estuary. A copy of the graphic analysis of the tidal currents is contained in Appendix 4 of this report.

3. Moylan Consulting Engineers have carried out an analysis of fall velocity of particles and an estimation of the Critical Flow for Sediments. A copy of these calculations is contained in Appendix 5 of this report.

4.0. CONCLUSIONS

4.1. It is understood that the Density Current generated by the Water Injection Dredging process will tend to move material down stream towards the deepest section of the navigation channel approximately 1,100 m downstream of the marina area. At this location the gravity effect of the Density Current will reduce and material will tend to be deposited.

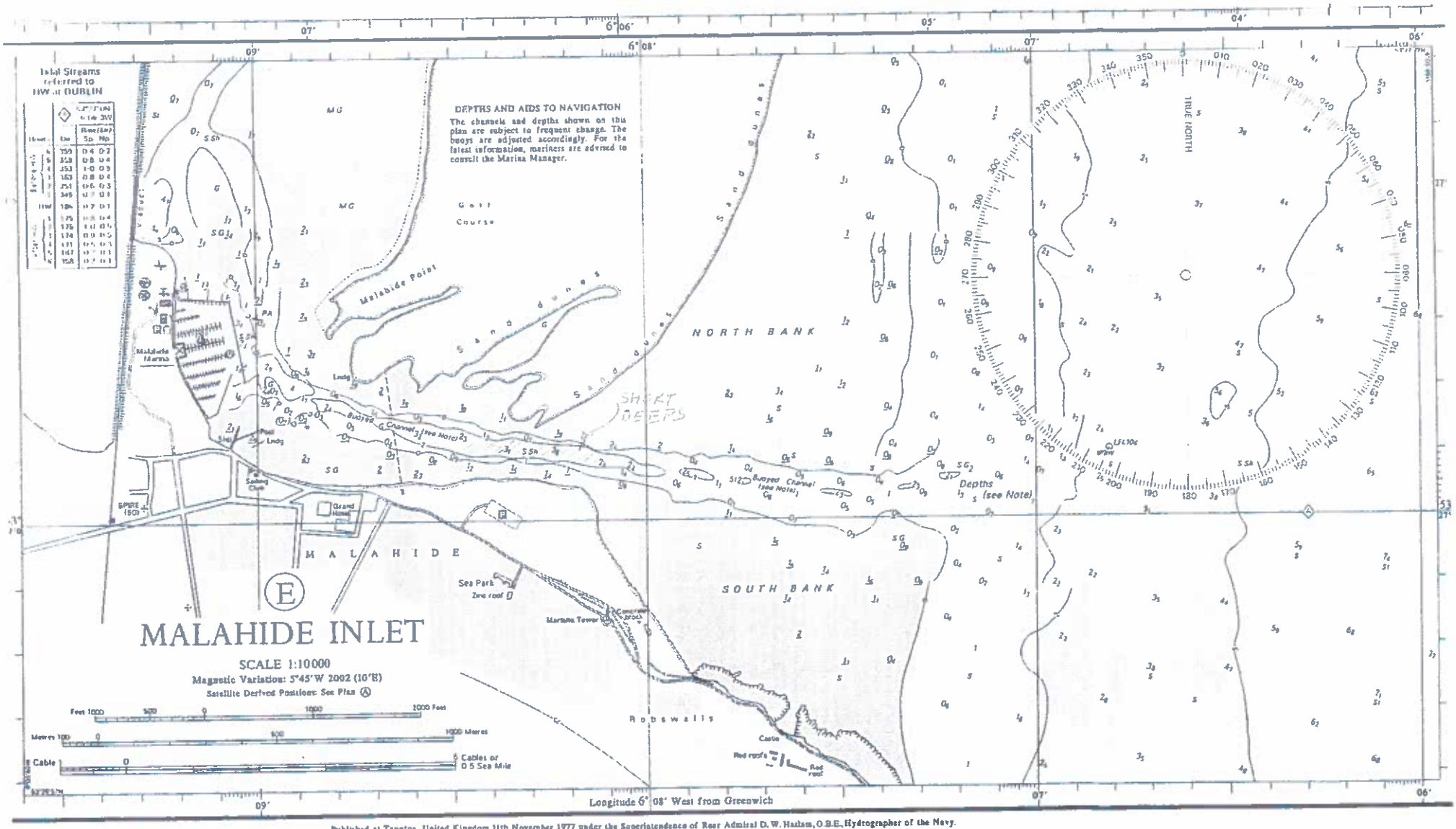
4.2. Estimates of the critical flows for the sediments at the "short deeps" indicate that the sediments will tend to settle in this area and that the velocities of the flows are not adequate to move the sediments in bulk. Sediments deposited at this location will be dispersed through the natural scouring action, which has generated the "short deeps".

4.3. It is anticipated therefore that the Water Injection Dredging will contribute only minimal additional silts and muds and that these materials will be dispersed into background siltation by natural scouring from the "short deeps" area.

Silts from the Water Injection Dredging process will be well dispersed and are not to be detectable within the background silts outside the broad meadow estuary.

APPENDIX 1

Drawings



Published at Taunton, United Kingdom 11th November 1977 under the Superintendence of Rear Admiral D. W. Haslam, O.B.E., Hydrographer of the Navy.
This chart includes copyright material published with the permission of the Ordnance Survey of Ireland.
www.ukho.gov.uk ☎ +44 (0)1823 337900

APPENDIX 2

Water Injection Dredging

Malahide Marina

Application for a Dumping at Sea Permit

Dredging Impact Hypothesis

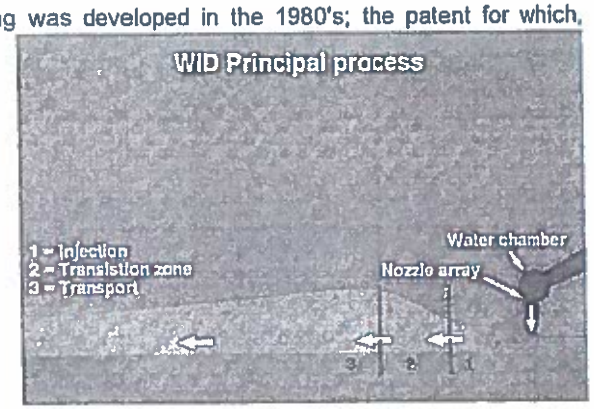
Introduction

Malahide Marina Village Ltd propose to undertake a maintenance dredge of their facilities in order to restore the water depths to those originally prevailing. The current levels of siltation within the marina are such that they affect the operation, safety and commercial viability of the facility . After having considered many different options for these dredging works, Malahide Marina propose to undertake these works using the process of Water Injection.

As detailed below, the process of Water Injection Dredging differs from more conventional systems in that, rather than transporting and depositing material at a remote dumpsite, the settled sediment is re-suspended and allowed to flow under natural forces within the river or estuary system.

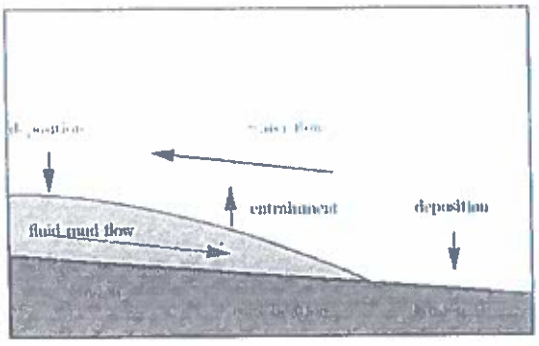
The Water Injection Dredging Process[1]

The process of Water Injection Dredging was developed in the 1980's; the patent for which, through a series of mergers and acquisitions, is now operated by Van Oord NV. Van Oord owns several Water Injection Dredgers which operate throughout the world, but particularly in Western Europe, India and South America.



The Water Injection Dredging process is generally applied on soft seabed deposits, for instance silts and fine sands, where they will be re-suspended and subsequently re-absorbed within the existing sediment transport system.

Water Injection Dredging puts the seabed layer into suspension by injecting water into the subsoil, thus fluidising it. This fluidised top layer, the thickness of which (typically between 1m and 3m) is highly sensitive to both the soil parameters and the distance between the injector pipe and the seabed ("stand-off distance"), then behaves as a density current. The low injector pressure (approx. 1 bar) and keeping a small stand-off distance are key factors in minimising turbidity. The optimum stand-off distance, which depends upon the settled sediments' particle size distribution and permeability, is often determined through practical experience.



[1] Extracted from "Hydrodynamic and Non-Dredging Solutions", a paper presented to the 2nd International Conference on Maintenance Dredging, Bristol (May 2004)

The properties of the induced fluid mud layer depend on a large number of factors, but of prime importance are the particle size and viscosity of the sediment.
The density current thus formed flows under the combined effects of gravitational, hydrostatic, current and friction forces.

The fluid mud layer flows under the influence of gravity caused by the gradient in either the rigid bed or the fluidised layer / water interface. The fluid mud layer may gain material from the rigid bed through erosion or, conversely, material may be transferred to the rigid bed through consolidation.

Similarly, the fluid mud layer may also gain or lose material by deposition from or entrainment to the overlying suspension layer respectively. In general, for a fluid mud layer generated by Water Injection Dredging, the processes of entrainment (loss of material to the water column above) and consolidation (loss of material to the rigid bed below) are the most important.

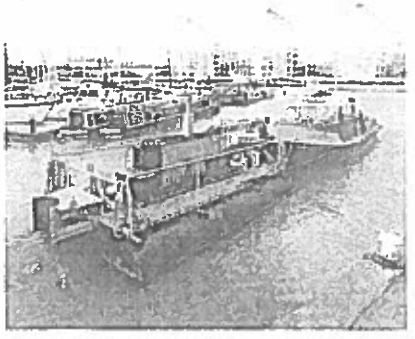
In addition to the gravitationally derived forces detailed above, the flow of water also imposes forces on the fluid mud flow. The force generated by the flow of water, albeit offset slightly by bed friction, is generally the main one acting on the fluid mud.

Van Oord, in co-operation with various Clients and Research Institutions (including Delft Hydraulics and HR Wallingford), have undertaken a number of research projects throughout the world to demonstrate the impacts of Water Injection Dredging on the Environment. During these Projects extensive on site monitoring systems were installed to measure numerous properties, such as soil characteristics, turbidity, dispersion and current velocities, before, during and after dredging operations. In all of these research projects the water injection dredging process resulted in well-defined density currents and interfaces with the surrounding water.

As more experience has been gained in the use of Water Injection Dredging, it has become possible to regulate its use to such an extent that layers of sediments can be removed without unacceptable, adverse environmental impacts. For instance, the majority of water injection dredging within the Thames Estuary takes place only on Ebb tides to prevent the possibilities of deposition of material within environmentally sensitive areas.

The environmental advantages of Water Injection Dredging, assuming the sediment has the required characteristics, can be summarised thus:

- The dredged material is retained within the river system. During transportation the density layer is generally moving towards deeper waters at nature's own pace and therefore has little effect on the surrounding water.
- Only the bottom of the water column (typically between 1m and 3m as described above) is affected during dredging.
- The deposition of the dredged material takes place gradually, preventing any shock effect on the sea or river bed.
- Lower energy consumption per m^3 of material dredged.



Dredging Proposal for Malahide Marina

As detailed above, Malahide Marina proposes to use the process of Water Injection Dredging to remove the settled sediments within their facility. In particular, it is proposed to undertake the works using the road transportable Water Injection Dredger (WID) "Baldur".

FALL VELOCITY FOR SPHERES

$$Re_p = \frac{\sqrt{RgD}\,D}{\nu} \qquad R_f = \frac{v_s}{\sqrt{RgD}}$$

Uses formulation of Dietrich (1982)

g	9.81	gravitational acceleration, m/s^2
ν	1.36E-06	kinematic viscosity of water, m^2/s
R	1.41	submerged specific gravity of sediment, = (ρ_s/ρ) - 1
D	0.05	grain size, mm
Re_p	0.966852352	explicit particle Reynolds no.
R_f	0.053740803	dimensionless fall velocity
v_s	0.141329627	fall velocity, cm/s

Limiting value of R_{ep} is 2.5e6: the formulation does not work for larger values.

b_1	2.891394
b_2	0.95296
b_3	0.056835
b_4	0.002892
b_5	0.000245

Dietrich, E. W., 1982, Settling velocity of natural particles,
Water Resources Research, 18 (6), 1626-1982.

$$R_f = \exp\{-b_1 + b_2 \ell n(Re_p) - b_3[\ell n(Re_p)]^2 - b_4[\ell n(Re_p)]^3 + b_5[\ell n(Re_p)]^4\}$$

Estimation of the critical flow for sediments

Project Mallahide Marina
Location Bottleneck estuary, deepest point

calculated by Lars Schneider

SRT	Particel Size d50 m	d50 m	Depth z m	Water viscosity v m2/s	ps kg/m3	pw kg/m3	s -	D* -	f(D*)	Critical Flow Velocity Van Rijn ucr m/s	Soulsby ucr m/s	Neap Tide Umain m/s	u* m/s	sedi-mentation 1=yes	Mean Tide Umain m/s	u* m/s	sedi-mentation 1=yes
-1	0.0005	0.0001	5.32	1.36E-06	2470	1035	2.39	1.94	0.09	0.35	0.37						
0	0.0005	0.0001	5.32	1.36E-06	2470	1035	2.39	1.94	0.09	0.35	0.37						
1	0.0005	0.0001	5.2	1.36E-06	2470	1035	2.39	1.94	0.09	0.35	0.37						
2	0.0005	0.0001	4.9	1.36E-06	2470	1035	2.39	1.94	0.09	0.35	0.37	0.397	0.10	0	0.84	0.21	0
3	0.0005	0.0001	4.4	1.36E-06	2470	1035	2.39	1.94	0.09	0.34	0.36	0.248	0.07	1	1.16	0.31	0
4	0.0005	0.0001	3.6	1.36E-06	2470	1035	2.39	1.94	0.09	0.34	0.35	0.302	0.09	1	0.70	0.22	0
5	0.0005	0.0001	3.55	1.36E-06	2470	1035	2.39	1.94	0.09	0.34	0.35	0.134	0.04	1	0.44	0.14	0

d50	median grain diameter	sediments starts to settle
d90	90th percentile grain diameter	
ps	sediment density	=>With the incoming tide sediments might be aggitated and taken back into the marina or estuary
pw	water density	
s	ratio of densities of grain and water	
v	kinematic viscosity of water	
D*	dimensionless grain size (Shields)	
u*	shear velocity 0.5m above the river bed	u*=0.4*(1/ln(z/z0)

Critical Flow Velocity

Van Rijn (1984)

ucr=0.19*d50^0.1*log(4h/d9 for 100um<+d50<+500um

Soulsby (1936)

ucr=7(4/d50)^(1/7)(g*(s-1)*d50*f(D*))^(1/2)

D*+(g*(s-1)/v^2)^(1/3)*d50

f(D*)=0.3/(1+1.2*D*)+0.055(1-exp(-0.020*D*))

6. APPENDIX C: MARINE INSTITUTE SAMPLING ACTION PLAN

Marine Institute
Foras na Mara

Rinville
Oranmore
Co Galway
Tel: 091 387200

Mr. Damien Offer
Malahide Marina
Malahide
Co Dublin

2 February 2017

Re: Sampling and Analysis Plan – Malahide Marina WID

Dear Damien,

A sampling and analysis plan is detailed below to cover dredging at Malahide Marina. This plan is designed to cover the water injection dredging of 38 000 m^3 of sediment.

Your selected analysing laboratory must be able to meet the quality requirements for this project. You should give your contractor a copy of this plan. You will need to draw their attention especially to Section 3 and Section 4 to confirm that they are capable of meeting the quality assurance standards.

If you need clarification on anything, please don't hesitate to contact me.

Best regards,

MCronin

Margot Cronin
Marine Environment Chemist

1.0 Sample location and analyses required:

The following surface samples, as listed in Table 1 (below) should be taken[1]. Sample locations are shown in Figure 1 at the end of this document.

Table 1. Locations and details of proposed samples

Sample No.	Longitude (° W) *	Latitude (° N) *	Parameters for analysis
1	-6.15214	53.45412	1, 2, 3, 4a, 4b, 4c, 4d, 4e, 4f, 4g
2	-6.15233	53.45327	1, 2, 3, 4a, 4b, 4c
3	-6.15321	53.45467	1, 2, 3, 4a, 4b, 4c
4	-6.15368	53.45516	1, 2, 3, 4a, 4b, 4c
5	-6.15370	53.45549	1, 2, 3, 4a, 4b, 4c, 4d, 4e, 4f, 4g

* Positions given in decimal degrees, WGS84S

2.0 Parameter Code:

1. Visual inspection, to include colour, texture, odour, presence of animals etc
2. Water content, density (taking into account sample collection and handling)
3. Granulometry including % gravel (> 2mm fraction), % sand (< 2mm fraction) and % mud (< 63µm fraction).
4. The following determinants in the sand-mud (< 2mm) fraction * :
   a) total organic carbon
   b) carbonate
   c) mercury, arsenic, cadmium, copper, lead, zinc, chromium, nickel, lithium, aluminium.
   d) organochlorines HCH and γ-HCH (Lindane), and PCBs (to be reported as the 7 individual CB congeners: 28, 52, 101, 118, 138, 153, 180).
   e) total extractable hydrocarbons.
   f) tributyltin (TBT) and dibutyltin (DBT)
   g) Polycyclic aromatic hydrocarbons (PAH) - Acenaphthene, Acenaphthylene, Anthracene, Benzo (a) anthracene, Benzo (a) pyrene, Benzo (b) fluoranthene, Benzo (ghi) perylene, Benzo (k) fluoranthene, Chrysene, Dibenz (a,h) anthracene, Flourene, Fluoranthene, Indeno 1,2,3 – cd pyrene, Naphthalene, Phenanthrene, Pyrene.
   h) Toxicity tests (Microtox or whole sediment bioassay) using appropriate representative aquatic species. (This requirement will depend on the results of the chemical analyses.)

[1] Further sampling and analysis, at depth if necessary, may be required in the event that problem areas of heavy contamination are identified as a result of the initial testing.

**where the gravel fraction (> 2mm) constitutes a significant part of the total sediment, this should be taken into account in the calculation of the concentrations.*

3.0 Important notes:

3.1 Details of the methodologies used must be furnished with the results. This should include sampling, sub sampling and analytical methods used for each determinant

3.2 Appropriate marine CRM are to be analysed during each batch of analyses and the results to be reported along with sample results.

3.3 The required detection limits for the various determinants are given in Table 2. below.

Table 2. Maximum limits of detection required

Contaminant	Concentration	Units (dry wt)
Mercury	0.05	mg kg^{-1}
Arsenic	1.0	mg kg^{-1}
Cadmium	0.1	mg kg^{-1}
Copper	5.0	mg kg^{-1}
Lead	5.0	mg kg^{-1}
Zinc	10	mg kg^{-1}
Chromium	5.0	mg kg^{-1}
Nickel	15	mg kg^{-1}
Total extractable hydrocarbons	10.0	mg kg^{-1}
TBT and DBT (not organotin)	0.01	mg kg^{-1}
PCB – individual congener	0.1	µg kg^{-1}
OCP – individual compound	1.0	µg kg^{-1}
PAH – individual compound	20	µg kg^{-1}

4.0 Reporting requirements

Reports should include the following information

4.1 Date of sampling

4.2 Location of samples eg ING or lat/long.

4.3 Treatment of samples and indication of sub sampling, compositing etc.

4.4 Tabulated geophysical and chemical test results

4.5 Completed excel spreadsheet for results

4.6 Summary method details

4.7 Method performance specifications: Limit of detection, Precision, Bias

4.8 Clear expression of units and indication of wet weight or dry weight basis

4.9 Blanks & in-house references to be run with each sample batch, and reported with sample results.

4.10 Appropriate Certified Reference Materials (CRM) to be run with each sample batch, and reported in full with sample results.

4.11 If determinant is not detected, report less than values, and indicate LoD/ LoQ used. Other quality assurance information (e.g. accreditation status)

Figure 1: Sampling stations, Malahide Marina.
(Positions given in Table 1.)

7. APPENDIX D: TESTING LIKELIHOOD OF THE INVASIVE TUNICATE DIDEMNUM VIXILLUM DISPERSAL VIA PROPOSED WATER-INJECTION DREDGING AT MALAHIDE MARINA.

Testing the likelihood of the invasive tunicate *Didemnum vexillum* dispersal via proposed water-injection dredging at Malahide Marina

Paul Brooks, Jennifer Coughlan & Tasman Crowe

School of Biology and Environmental Science, UCD

Final report - March 2018

Didemnum vexillum (Kott 2002) is an invasive colonial tunicate or Ascidian, its origin is unknown but it is believed to have originated from somewhere in the Pacific Northwest (Kott 2002; Lambert 2009). Concern over the potential for *D. vexillum* to become invasive stems from ecological traits that it shares with other invasive species, including the ability to overgrow benthic organisms, high reproductive and population growth rates, ability to spread by colony fragmentation, tolerance to a wide range of environmental conditions and the apparent scarcity of predators (Daley & Scavia 2008). Like many invasive ascidians this species has experienced recent range expansions due to human-mediated transportation, such as the unintentional transport on the hulls of recreational and commercial ships (Wasson et al. 2001; Lambert 2009). *D. vexillum* is a strong spatial competitor and once established it may persist and become the most dominant member of the new community (Lambert 2009). In some cases, it is known to reduce the abundance of previously established benthic species and cause significant changes in benthic community structure (Castilla et al. 2004; Lambert 2009). It was found in Ireland for the first time on pontoons and leisure craft at Malahide marina (Minchin and Sides 2006; Minchin 2007) and since been reported at a number of sites around the country (Minchin 2007; Griffith et al. 2009)

Like all colonial ascidians, *D. vexillum* reproduces sexually and broods its larvae, however it is purported that larval dispersal capacity is limited as competency is only minutes to a few hours max (Mather 2002). However, this species can also form new colonies asexually

through fragmentation (Bullard et al 2007). This is particularly true when in its rope-like or tendril growth form; long flaccid lobes containing larvae brooded within the colony tissue extend from the central portion of attached colonies that easily break off (Bullard et al 2007). Coutts (2002) noted that colonies that had fallen off of contaminated barges in Marlborough Sounds in New Zealand eventually died off if they landed on muddy or sandy bottoms. Furthermore, deposition of sediment particles can interfere with the feeding and respiration functions of invertebrate communities, and can lead to smothering if sufficient water currents do not re-suspend and export sediments, in particular fine material such as mud or silt (Lohrer et al. 2006; Maldonado et al. 2008). This die-off observed on soft sub-strata may also be linked to the fact that there is generally a lack of hard substrata (living or otherwise) found in sedimentary habitats (e.g. rocks, mussels, barnacles, encrusting polychaetes, etc). More recent experimental work conducted in both lab and field trials found that tendril reattachment was successful in lab trials only but only one of 80 tendrils at two sites in the field reattached to substrate. In addition tendrils deployed at both sites were degraded within 24 – 50 h after deployment and in general disappeared completely 6 days after deployment, which the authors attributed to the presence of a gastropod predator observed at field sites (Stefaniak & Whitlatch 2014). Equally, it has been suggested that colonies growing on live marine animals seem to be more resistant to the cold, than those growing on rocks, stones and plants (Gittenberger 2007). Hence, depauperate sedimentary habitats would have a reduced chance of facilitating dispersal. One study (Hopkins et al. 2011) reports that the low energy currents at three sites in New Zealand (Nelson, Picton and Waikawa), had associated high rates of mortality on plates transplanted with invasive biofouling species (including *D.vexillum*). In particular plates orientated upwards were covered by a 2 to 3mm layer of sediment at the completion of a 1-month experiment had contributed greatly to the observed mortality rates. In addition, sediment-related mortality was also observed on caged plates

deployed upwards at two other sites, suggesting that even relatively low levels of sedimentation can have a significant effect on survival (Hopkins et al. 2011). Other research has shown that covering of *D. vexillum* in dredge material (70% silt/clay, 20% sand, 10% small cobble) was found to be completely successful in eliminating colonies (Coutts 2006; Coutts & Forrest 2007). As with many invasive species dispersal vectors play a major role in there spread, Herborg et al. (2009) evaluated a range of dispersal vectors for *D.vexillum* across a large spatial scale in Canada. Of the potential dispersal vectors included in the study, the authors found that natural larval dispersal and drift of adult colonies were predicted to have a moderate risk when compared to other vectors such as transportation on vessel hulls, aquaculture transfers and commercial fishing. However, the authors report that this may vary depending on local environmental conditions and/or seasonality.

It is widely reported that there are direct links between expansive growth of this species and temperature/seasonality (Bullard et al 2007; Daley & Scavia 2008; Fletcher et al. 2013). In summer months, in other temperate areas, fragmentation when colonies of *D. vexillum* are at their highest growth rates (rope-like growth forms) resulted in rapid recolonisation through asexual reproduction of fragments but this only occurred on hard substrata (Bullard et al 2007). In winter months, expanded colonies die back and are reduced to basal overwintering patches with little reproductive capabilities (Satoh 1994; Daley & Scavia 2008). Furthermore, it has been suggested that colony growth and reproduction occurs at water temperatures between 10 – 25 °C with optimisation of both occurring between 15 and 20 °C (McCarthy et al 2007; Daley & Scavia 2008). In Europe, its optimal growing temperatures appears to be between 14 and 18 degrees C, with decreases at warmer and colder temperatures and massive die-off at temperatures below 5 degrees (Gittenberger 2007). In terms of seasonal variation in growth rates of *D. vexillum*, observations over a 28 month period in the United States show that colonies began growing by asexual budding when water temperature reached 8 to 12 °C

in the spring, and continued accumulating biomass through the summer, however colonies began to degenerate again when water temperatures declined relatively rapidly to 15 °C in late autumn or early winter (Valentine et al 2007). In other places, the length of the reproductive season has been shown to vary, from 3.5 to 5 months in the Northern hemisphere (Valentine et al 2009; Sorte & Stachowicz 2011) and up to 9 months in the Southern hemisphere (Fletcher et al. 2013). However, this is known to be very much dependent on local conditions such as size of existing population, temperature variation over seasons and preceding years, and other environmental factors such as depth, salinity, etc (Valentine et al 2009; Sorte & Stachowicz 2011; Fletcher et al. 2013)

Experimental work which tested survivability of fragments at varying depths (0.5 – 4m) and salinity (High; 26 -30, Medium; 15-28 and Low; 10 - 26) at three sites, showed that fragment biomass was greatly reduced at depths of 4m in comparison to shallower depths at all three sites. Additionally, fragments placed in medium and low salinity sites had reduced survivability and dramatically reduced growth rates in comparison to fragments in high salinity sites, with fragments in medium/low salinity sites appearing pale, bulbous and decaying (Bullard & Whitlatch 2009). In contrast, more recent work comparing stress resistance of *D. vexillum* with another invasive tunicate sourced in the Irish Sea suggests that *D. vexillum* was more tolerant of low salinity than previously envisaged (Gröner et al. 2011). Although, this was a short term lab experiment, such ambiguity would warrant further study in more natural conditions. Indeed, it has been suggested that lack of success in eradication programs of *D. vexillum* was most likely due to failure to observe such seasonal patterns and local conditions (Fletcher et al 2013).

As such the overall aim of this study is to a) understand the growth and asexual reproduction (through fragmentation) of *D. vexillum* varies seasonally at Malahide marina and b) test the viability and attachment potential of fragments of *D. vexillum* on a range of different substrates in both lab and field conditions.

Methodology:

Study was conducted at Malahide marina, located in the Broadmeadow estuary in North County Dublin, from late April 2017 until mid-January 2018

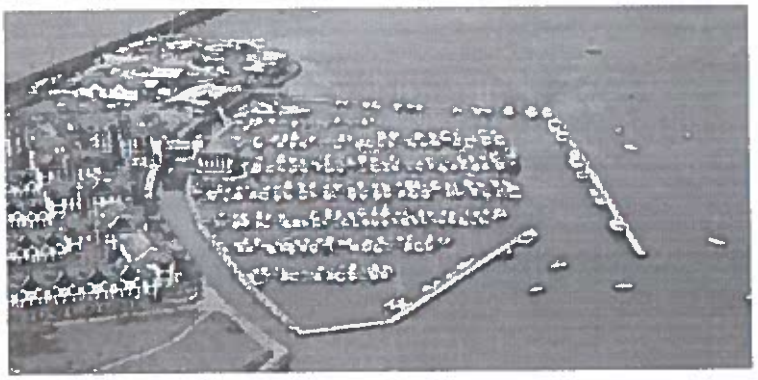


Figure 1 Malahide marina

Monitoring

Malahide marina in North County Dublin (Figure 1) has proposed to use water injection dredging to remove sediment which has accumulated in low flow areas of the marina. As part of the licensing application and to ensure minimum environmental impact and decreased risk of the spread of this invasive, we monitored and experimentally tested the likelihood of *D. vexillum* spreading during the water injection dredging process.

Firstly, we monitored the seasonal growth patterns of *D. vexillum* at the marina by using a survey at the marina, at six locations around the marina on the breakwaters/pontoons (Figure 2), 4 quadrats (0.5 X 0.5 m) were used to record the extent (percentage cover) of this species at three timepoints (April, June & November). These sampling dates were chosen to match closely with the expected growth and dieback patterns previously recorded for *D. vexillum* at Malahide marina (O'Brien & Crowe, unpublished data). Due to a reduction in complete die-back during the study, monitoring was extended with the addition of a further time-point in January 2018.

In addition, at each location the amount of *D.vexillum* fragments on the subtidal sediment was evaluated in three random areas at each time point by scraping the top 30mm of sediment in a 0.4 X 1m strip using a surber net. Collected sediment was then sieved on site and the number of fragments recorded.

Experimental work plan

The aim of these experiments is test the viability of fragments of *D. vexillum* on different substrates. Understanding the viability of fragments over a given time period should guide when the appropriate time to implement the water injection dredging method to minimise the potential transport of viable fragments of *D. vexillum* to new locations in the marina or the wider environment. This was tested using a combination of both field and laboratory experiments ran simultaneously during peak growth periods at Malahide marina. The field experiment consisted of subtidal plots where fragments were placed on trays with different substrates (sediment, natural rock, mussel shells & concrete) in three replicated locations of both high energy (in the tidal race) and low energy (outside the tidal race) water flow areas around the marina (Figure 2). Viability and attachment potential of fragments to the different substrates was evaluated at different sampling points- 2 days, 1 week, 2 weeks and 1 month after initiation, to establish if an appropriate time frame for dredging after die-back of *D. vexillum* growth patterns (reduction of asexual fragmentation in colonies). Communication with leading experts on *D. vexillum*, suggests that fragments on sediment are most likely to be only viable for a number of days/weeks at most (John Bishop; Ashley Coutts, personal communications – see Appendix). In addition, a more controlled experiment tested the same factor (Substrate - sediment, natural rock, mussel shells & concrete) in the laboratory. Previous work on *D. vexillum*'s ability to attach to substrates has only been tested in the lab and may not be truly indicative of how this occurs in the field. In the field, other parameters such as flow rates, natural sedimentation, changes in salinity, fluctuation in water temperature, predation rates could all influence survivability and attachment rates. So a combinational approach of both lab and field experiments was deemed to be a more suitable approach to addressing our overarching questions.

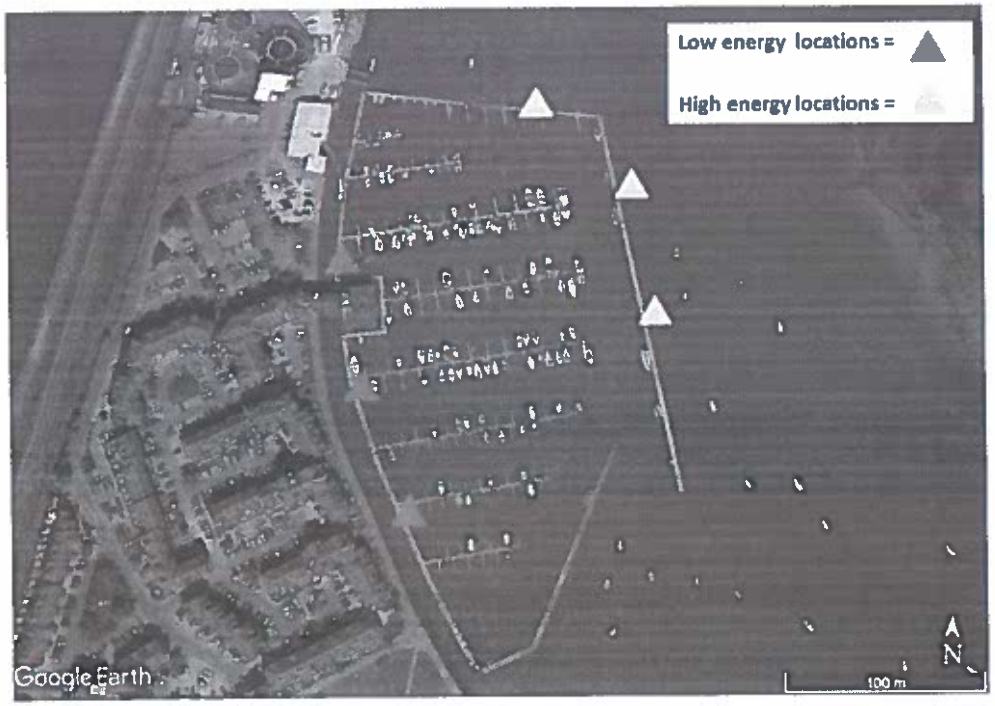


Figure 2 Map of Malahide marina showing six locations used to monitor *D. vexillum* at the marina. The six locations were also used during the field experiment to place experimental substrate treatments. Green triangles denote low current flow areas (Low energy) and yellow triangles denote high current flow areas (High energy).

Data analysis

Monitoring

Data collected during the monitoring study were analysed using ANOVA (Analysis of Variance) in WinGMAV5 (Underwood *et al.*, 1998).The factors and levels used were Current flow (Low energy & High energy), which was a fixed factor, in addition the factor Location (6 levels: 1, 2, 3, 4, 5 & 6), which was random and nested. Cochran's test was then used to test for homogeneity of variance, when Cochran's test was significant data were transformed. When terms in ANOVAs were significant Student Newman Keuls (SNK) tests were used to determine post-hoc comparisons between levels of significant terms.

Lab & Field experiments

For both the laboratory and field experiments Chi-squared tests of association using 2 x 4 contingency tables were used to analyse both viability and mortality data. Viability data had the following factors; Viability with 2 levels/categories - Viable/Unviable and the factor Substrate with 4 levels/categories – Concrete/Mussel shells/Stone/Sediment (n = 12 for both the lab & field experiments). Mortality data from the final sampling dates of both lab (Day 7) and field experiments (Day 30) had the following factors; Mortality with 2 levels/categories - Live/Dead and the factor Substrate with 4 levels/categories – Concrete/Mussel shells/Stone/Sediment (n = 12 for treatments in the lab experiment & n = 9 for treatments in the field experiment). For the field experiment, individual Chi-squared tests of association using 2 x 4 contingency tables were used to analyse mortality data from across both current flow areas – Low & High energy. Data from three locations was pooled for each substrate in both current flow areas (n = 27 for each substrate).

Results

Monitoring

Number of fragments found on the benthos varied both spatially and temporally. On the first sampling date (April 2017), at two of the six locations there was an average of 0.33 fragments per location found but there was no significant differences amongst locations or between current flow areas (n=3). On the second sampling date (June 2017) again fragments were only found at two locations but with an average of one fragment per location (n= 3). On both dates fragments were significantly higher in number in high energy flow areas in comparison to low energy areas where no fragments occurred (Figure 3a & b, Table 1, SNK: High > Low, $p < 0.01$). On subsequent sampling dates (November 2017 & January 2018), however, no fragments were found on the benthos at any of the six locations around the marina and subsequently no analyses could be conducted (Figure 3c & d, Table 1c & d).

Table 1 Analyses of the number of *D. vexillum* fragments data recorded on the benthos at each of six locations beneath pontoons in Malahide marina for both low & high energy current flow areas sampled at four time-points between April 2017 and January 2018 (n = 3).

a) April

Source of variation	df	MS	F	*p*	
Current flow = Cu	1	0.222222	4	0.116117	
Location(Cu)	4	0.055556	0.5	0.736486	
RES	18	0.111111			

b) June

	df	MS	F	p	
Current flow = Cu	1	2	4	0.116117	
Location(Cu)	4	0.5	4.89098E+15	**0**	***
RES	18	0			

c) November

	df	MS	F	p
Current flow = Cu	1			
Location(Cu)	4		**No Test**	
RES	18			

d) January

	df	MS	F	*p*
Current flow = Cu	1			
Location(Cu)	4		**No Test**	
RES	18			

*** denotes significance $p < 0.001$

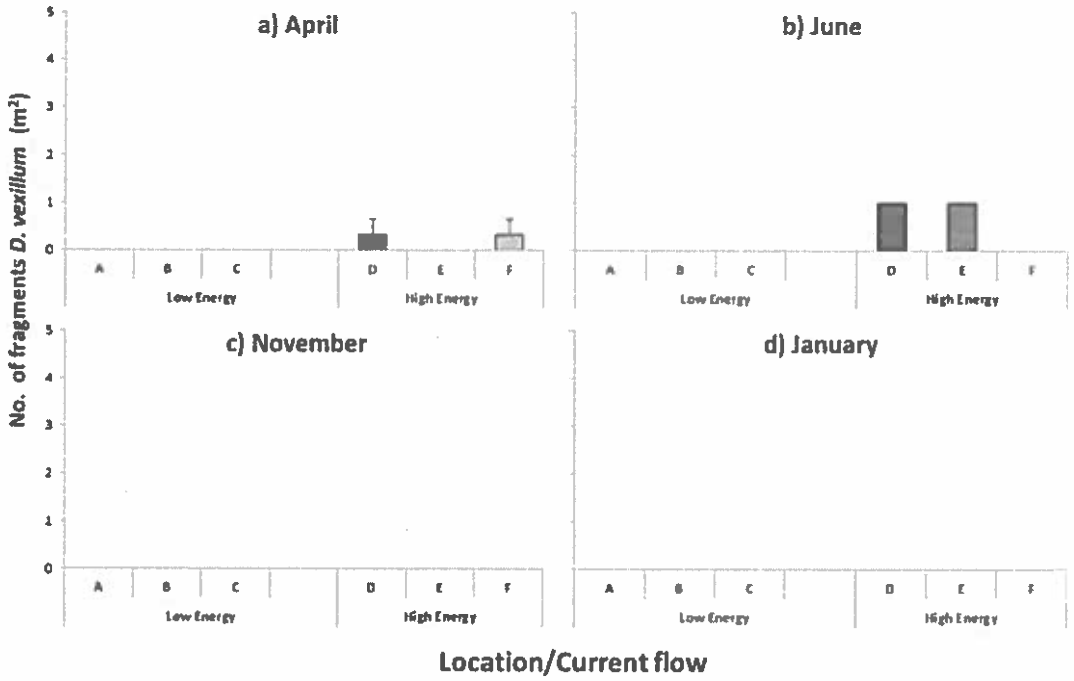


Figure 3 Number of *D. vexillum* fragments recorded on the benthos at each of six locations beneath pontoons in Malahide marina for both low & high energy current flow areas sampled at four timepoints between April 2017 and January 2018 ($n = 3$).

Percentage cover of *D. vexillum* in high energy current flows at all time points were significantly greater than low energy current flows (Figure 4a, b, c & d, Table 1 a, b, c & d, SNK; High > Low, $p < 0.01$). However, there was no significant variation amongst locations in each current flow (Figure 4 & Table 2). In general, the percentage cover was highest on the summer sampling date in June but reduced dramatically during the autumn and winter sampling dates (Figure 4). Colonies of *D. vexillum* remaining at these time-points appeared pale at all locations in the marina when compared visually to colonies sampled at peak growth periods (June 2017).

Table 2 Analyses of percentage cover data of *D. vexillum* recorded in quadrats at each of six locations on pontoons/breakwaters for both low & high energy current flow areas at Malahide marina, sampled at four time-points a) April 2017, b) June 2017, c) November 2017 and d) January 2018 ($n = 4$).

a) April

Source of variation	df	MS	F	*p*	
Current flow = Cu	1	2604.167	100	0.0006	***
Location(Cu)	4	26.0417	1.44	0.2608	
RES	18	18.0556			

b) June

	df	MS	F	*p*	
Current flow = Cu	1	7632.667	313.67	0.0001	***
Location(Cu)	4	24.3333	0.65	0.6321	
RES	18	37.25			

c) November

	df	MS	F	*p*	
Current flow = Cu	1	937.5	45	0.0026	**
Location(Cu)	4	20.8333	0.88	0.4941	
RES	18	23.6111			

d) January

	df	MS	F	*p*	
Current flow = Cu	1	1354.341	87.83	0.0007	***
Location(Cu)	4	15.4204	0.64	0.6417	
RES	18	24.1474			

** denotes significance $p < 0.01$ *** denotes significance $p < 0.001$

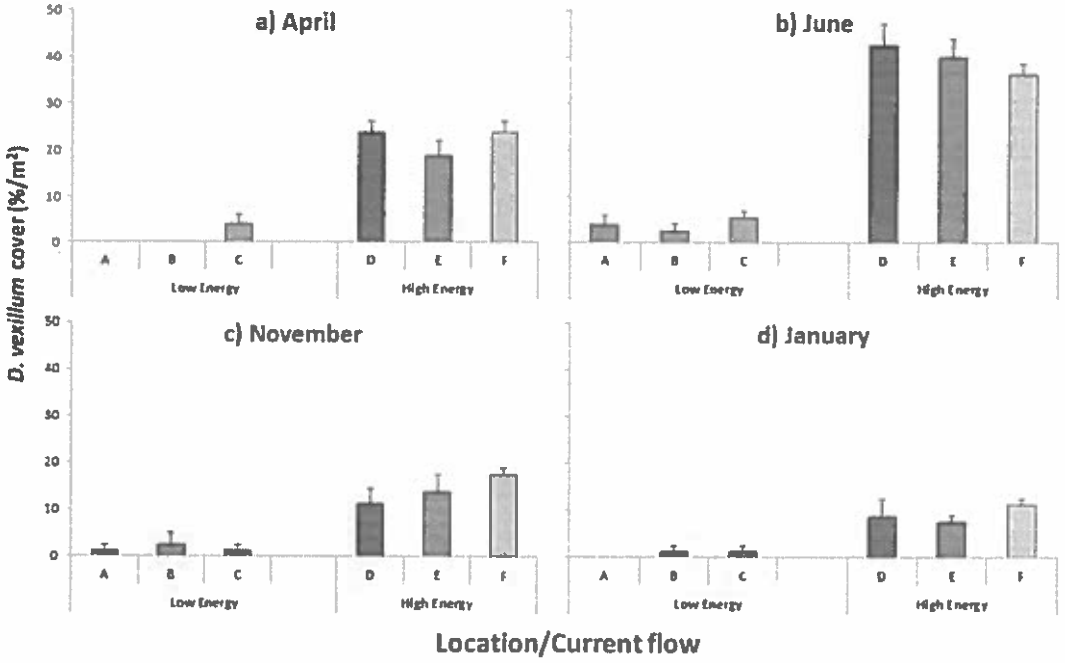


Figure 4 Percentage cover of D. vexillum recorded in quadrats at each of six locations on pontoons/breakwaters for both low & high energy current flow areas at Malahide marina, sampled at four time-points between April 2017 and January 2018 ($n = 4$).

Lab experiment

After four days in the lab experiment viability of all fragments was reduced across all substrates. In particular, 92 % of fragments ($n = 12$) on the substrates; concrete, mussel shells and sediment, showed reduced viability – appearing bleached and pale in coloration. On the stone substrate this was somewhat reduced at 83 %. There was no significant difference between substrate treatments ($X^2 = 0.67$, df = 2, $p = 0.8802$) but the number of unviable fragments was significantly higher than viable fragments (Figure 5a). By day seven, all fragments remaining, across all substrates showed reduced viability, appearing very pale and bleached (Figure 5b, X^2 = No test as number of viable fragments was zero).

Fragment mortality (fragments appeared totally decomposed) on day seven of the lab experiment was 42 % on the substrates concrete and stone. On mussel shells this was higher with 67% mortality recorded. On the final substrate – sediment, fragment mortalities were 92 % ($n = 12$). In particular, there was a significant association between fragment mortality and substrate type ($X^2 = 8.62$, df = 2, $p < 0.05$) with significantly higher mortality of fragments on the substrates mussel shells and sediment in comparison to the other two substrate treatments (Figure 6).

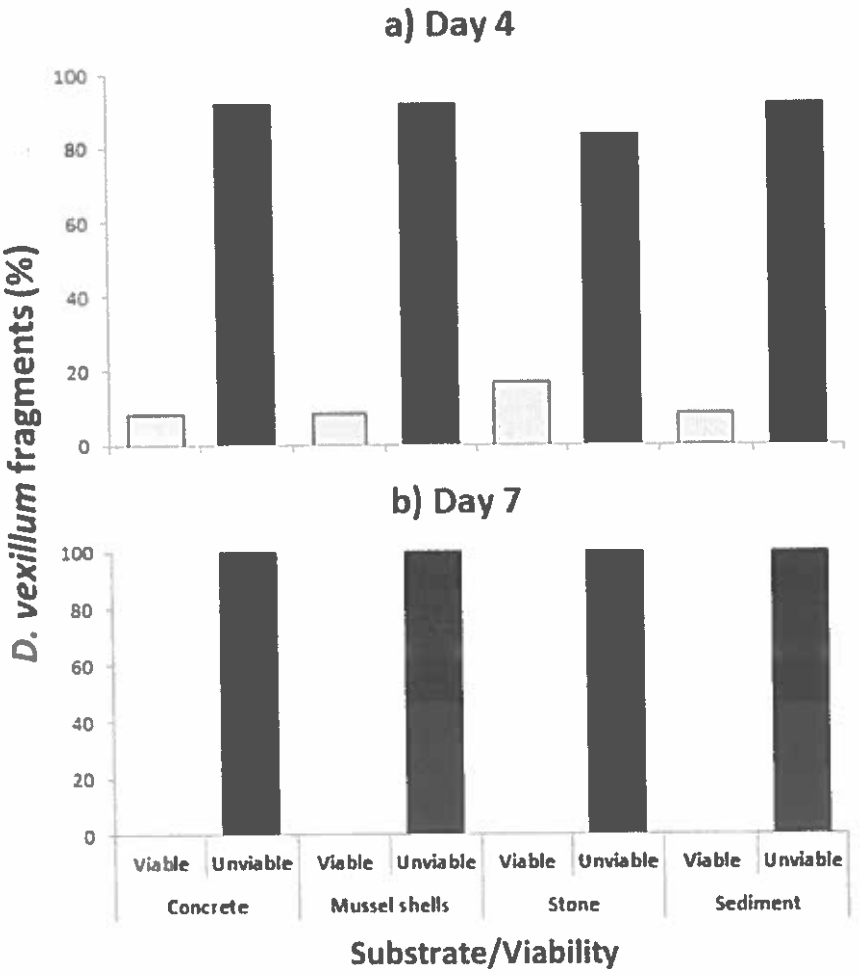


Figure 5 Viability of *D. vexillum* fragments placed on four experimental substrate treatments during the laboratory experiment, viability of fragments was sampled twice on a) four days and b) seven days after initiation. All treatments were replicated ($n = 12$).

Figure 6 Mortality rates of *D. vexillum* fragments placed on four experimental substrate treatments during the laboratory experiment, mortality of fragments was sampled seven days after initiation. All treatments were replicated (n = 12).

Field experiment

Viability of fragments on the first three sampling dates (2 days, one week & two weeks) could not be fully established due to poor visibility for divers, but fragments that were observed at various locations across both current flow sites across all substrates types appeared pale and bleached on all sampling dates (data not shown).

After one month, on the final sampling date mortality rates across all four substrates tested was 100% (Figure 7a & b, X^2 = No test as number of live fragments was zero). In particular, there was no remaining evidence of fragments at all locations, across all substrates in both high and low energy sites with the exception of two pale white unviable fragments at one location in the high energy area (Figure 7c & d) recorded on two different substrates (stone & sediment).

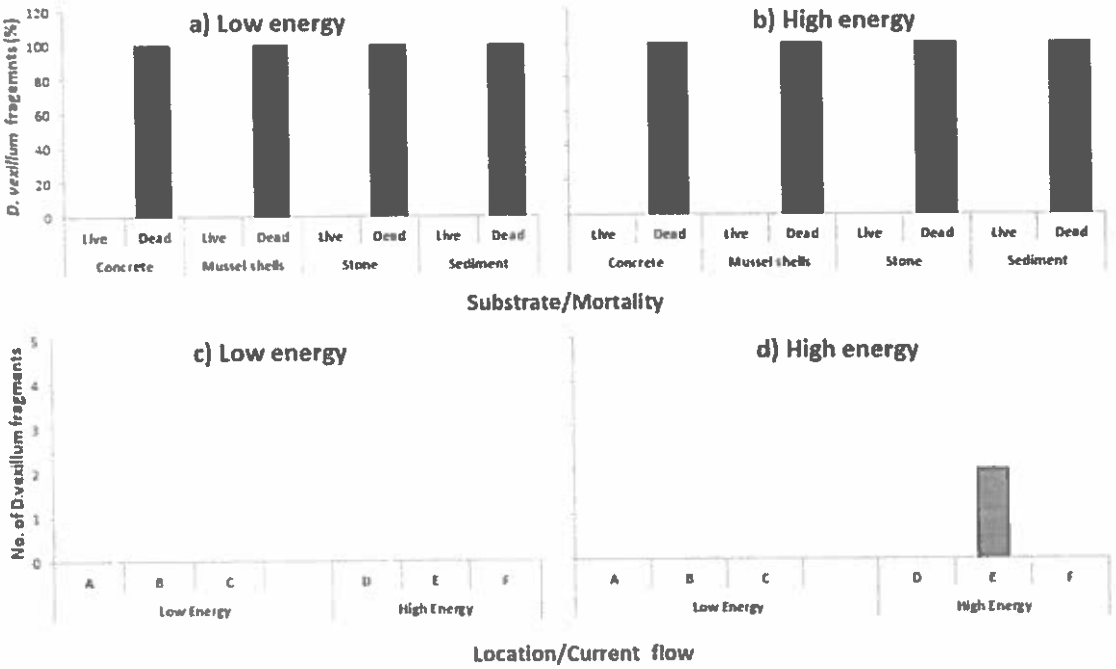


Figure 7 Mortality data of *D. vexillum* fragments on four experimental substrate treatments in both a) Low energy and b) High energy current flow areas sampled on day 30 of the field experiment ($n = 27$ for each substrate). Also shown are the number of fragments found in locations in both c) Low energy and d) High energy current flow areas ($n = 9$ for each location).

Discussion/Conclusions

The overall aim of this study was to a) understand the growth and asexual reproduction (through fragmentation) of *D. vexillum* varies seasonally at Malahide marina and b) test the viability and attachment potential of fragments of *D. vexillum* on a range of different substrates in both lab and field conditions.

Our findings for growth rates of *D. vexillum* show that the peak period for growth at Malahide marina is during the summer, when percentage cover in quadrats peaked (with an mean of ~ 37 +/- 3.5 %) in high energy current flow locations. In contrast, the lowest growth rates occurred in January for both high energy (~ 9.2 +/- 1.35 %) and low energy (~ 0.8 +/- 0.5 %) areas (Figure 4). Equally, those findings for growth of *D. vexillum* were reflected in the findings for the number of fragments found on the benthos throughout the study period (Figure 3). In fact, fragments were only found below pontoons/breakwaters in high energy current flow areas on the spring and summer sampling dates (April & June, Figure 3a & b).

Our expectation based on field observations over the past few years and evidence from the literature on *D. vexillum* growth patterns in other locations was that total die-back would have occurred during late autumn/winter; due to the link with water temperature and growth for this species (Valentine et al 2007; McCarthy et al 2007; Daley & Scavia 2008), however, this was not the case. In fact, monthly sea surface temperatures (sst) for Malahide for 2017 appear to fall within the historical sst range (see Appendix: Figures A1 & A2). As such, there may have been other factors that may have influenced the patterns found in the current study and require further testing. Nonetheless our findings clearly show a trend towards a reduction in growth patterns throughout the year consistent with expectations.

In terms of our findings for the lab and field experiments, we clearly show that fragment mortality and reduced viability of fragments occurs rapidly over a relatively short time-frame. In particular, the findings from the lab experiment show that high levels of fragment mortality and reduced viability within seven days of initiation of the experiment (Figure 5 & Figure 6). In the field experiment, due to adverse conditions, fragment mortality and viabilty rates over shorter periods could not be established. That said, final sampling by one month after initiation, reveals that nearly all fragments across all substrate types had total mortality, with the remaining two fragments clearly unviable (Figure 7). Taken together these findings are consistent with evidence from the literature and expert opinion on the potential for fragment survival particularly on sediment which is the predominant substrate in the

Malahide marina (see Coutts 2006; Coutts & Forrest 2007; John Bishop; Ashley Coutts, personal communications – see Appendix). In the field fragment mortality/viability may also have been influenced by high levels of sediment deposition. During all sampling dates there was distinct sediment loading in the water column at the marina which hampered diving and data acquisition. In addition, observations on the final sampling date found sediment accumulation on trays used for experimental treatments was very evident. In fact, sediment covering of *D. vexillum* colonies has been shown to dramatically increase mortality rates (Hopkins et al 2011). In terms of attachment potential for lab and field experiments, no fragments at any period appeared to adhere to any of the substrates treatments over the observed time (personal observation).

In conclusion, based on our findings, water injection dredging at Malahide marina should ideally take place during the winter months December/January when colonies are reduced in cover and potential for fragmentation. This time period would also fall outside the one month period examined in the field experiment portion of our study to ensure the mortality of any potential fragments on the benthos from the peak period of growth (and reproduction). Thus greatly reducing any potential for resuspension during the water injection dredging procedure. In fact, given that the procedure occurs in low energy areas resuspension of fragments in these areas will not occur based on our finding that no fragments occurred on the benthos in those locations during the November and January sampling dates. Equally, fragments that may have survived in high energy areas will be covered by sediment during the procedure and therefore this will potentially further reduce survival and transport of *D. vexillum* away from the marina. That said based on our findings there was no evidence of fragment accumulation in those areas during that time period.

To strengthen our findings from the monitoring study and ensure that fragment accumulation (and potential transport of fragments) is reduced, we will continue our monitoring study of *D.vexillum* during the licence application and the water injection dredging period if required.

References

Bullard, S. G., et al. 2007. The colonial ascidian Didemnum sp. A: current distribution, basic biology and potential threat to marine communities of the northeast and west coasts of North America. - Journal of Experimental Marine Biology and Ecology 342: 99-108.

Castilla, J. C., et al. 2004. Invasion of a rocky intertidal shore by the tunicate Pyura praeputialis in the Bay of Antofagasta, Chile. - Proceedings of the National Academy of Sciences of the United States of America 101: 8517-8524.

Coutts, A. 2006. An evaluation of incursion response tools for invasive species: a case study of Didemnum vexillum in the Marlborough Sounds. - Cawthron Report 1093.

Coutts, A. D. 2002. A biosecurity investigation of a barge in the Marlborough Sounds. - Cawthron Report 744: 86.

Coutts, A. D. 2003. Slow-moving barge introduces biosecurity risk to the Marlborough Sounds, New Zealand. Hull fouling as a mechanism for marine invasive species introductions. Proceedings of a workshop on current issues and potential management strategies. LS Godwin (ed.) Honolulu, HI, pp. 29-35.

Coutts, A. D. M. and Forrest, B. M. 2007. Development and application of tools for incursion response: Lessons learned from the management of the fouling pest Didemnum vexillum. - Journal of Experimental Marine Biology and Ecology 342: 154-162.

Daley, B. A. and Scavia, D. 2008. An integrated assessment of the continued spread and potential impacts of the colonial ascidian, Didemnum sp. A, in US waters. -.

Fletcher, L. M., et al. 2013. Natural dispersal mechanisms and dispersal potential of the invasive ascidian Didemnum vexillum. - Biological invasions 15: 627-643.

Gittenberger, A. 2007. Recent population expansions of non-native ascidians in The Netherlands. - Journal of Experimental Marine Biology and Ecology 342: 122-126.

Griffith, K., et al. 2009. First records in Great Britain of the invasive colonial ascidian Didemnum vexillum Kott, 2002. - Aquatic Invasions 4: 581-590.

Gröner, F., et al. 2011. Stress resistance in two colonial ascidians from the Irish Sea: The recent invader Didemnum vexillum is more tolerant to low salinity than the cosmopolitan Diplosoma listerianum. - Journal of Experimental Marine Biology and Ecology 409: 48-52.

Herborg, L. M., et al. 2009. Forecasting the potential distribution of the invasive tunicate Didemnum vexillum. - Journal of Applied Ecology 46: 64-72.

Hopkins, G. A., et al. 2011. Factors affecting survivorship of defouled communities and the effect of fragmentation on establishment success. - Journal of Experimental Marine Biology and Ecology 396: 233-243.

Kott, P. 2002. A complex didemnid ascidian from Whangamata, New Zealand. - Journal of the Marine Biological Association of the United Kingdom 82: 625-628.

Locke, A. and Carman, M. 2009. Adventures of a sea squirt sleuth: unraveling the identity of Didemnum vexillum, a global ascidian invader. - Aquatic Invasions 4: 5-28.

Locke, A. and Carman, M. 2009. In situ growth of the colonial ascidian Didemnum vexillum under different environmental conditions. - Aquatic Invasions 4: 275-278.

Lohrer, A. M., et al. 2006. Assessing far-field effects of terrigenous sediment loading in the coastal marine environment. - Marine Ecology Progress Series 315: 13-18.

Maldonado, M., et al. 2008. Effects of sediment on the survival of asexually produced sponge recruits. - Marine Biology 154: 631-641.

McCarthy, A., et al. 2007. Effects of temperature on growth rates of colonial ascidians: a comparison of Didemnum sp. to Botryllus schlosseri and Botrylloides violaceus. - Journal of Experimental Marine Biology and Ecology 342: 172-174.

Minchin, D. 2007. A checklist of alien and cryptogenic aquatic species in Ireland. - Aquatic Invasions 2: 341-366.

Minchin, D. and Sides, E. 2006. Appearance of a cryptogenic tunicate, a Didemnum sp. fouling marina pontoons and leisure craft in Ireland. - Aquatic Invasions 1: 143-147.

Satoh, N. 1994. Developmental biology of ascidians. - Cambridge University Press.

Sorte, C. J. and Stachowicz, J. J. 2011. Patterns and processes of compositional change in a California epibenthic community. - Marine Ecology Progress Series 435: 63-74.

Stefaniak, L.M. and Whitlatch, R.B. 2014. Life history attributes of a global invader: factors contributing to the invasion potential of Didemnum vexillum - Aquatic Biology, 21(3): 221-229.

Valentine, P. C., et al. 2009. Larval recruitment of the invasive colonial ascidian Didemnum vexillum, seasonal water temperatures in New England coastal and offshore waters, and implications for spread of the species. - Aquatic Invasions 4: 153-168.

Valentine, P. C., et al. 2007. The occurrence of the colonial ascidian Didemnum sp. on Georges Bank gravel habitat—ecological observations and potential effects on groundfish and scallop fisheries. - Journal of Experimental Marine Biology and Ecology 342: 179-181.

Wasson, K., et al. 2001. Biological invasions of estuaries without international shipping: the importance of intraregional transport. - Biological Conservation 102: 143-153.

Appendices

Expert opinions:

Response from John Bishop

A resting overwintering phase has been described in Didemnum spp., but I'm not sure it's very relevant to survival after falling onto a silty bottom ……

Jessica Marks described the regression of the zooidal thoraces in colonies from northern Norway (Artic/ sub-Arctic), and the formation of a glossy pellicle over the upper surface of the colonies, which were growing on rock. Brooded larvae were still present in this stage (didemnid larvae are commonly brooded in the colony tunic) and resulting larvae would possibly be released upon the sloughing of the pellicle and return to the active phase after the winter. These observations have only been published in brief in a taxonomic paper, with reference to a second paper 'in press' discussing the resting stage and zooid replacement /regeneration in more detail, but as far as I can tell this was never published. I do have the MS somewhere. Jessica mentions also seeing the same thing in Maine in one of the species she studied.

The taxonomic paper is :

Marks, J.A., 1996. Three sibling species of didemnid ascidians from northern Norway: Didemnum albidum (Verril, 1871), Didemnum polare (Hartmeyer, 1903), and Didemnum romssae sp.nov. Canadian Journal of Zoology 74, 357-379.

No such observations have been published for D. vexillum as far as I know, but we have seen a very similar phenomenon in Dvex that we were trying to culture. (We must have made it very unhappy!)

Since this trick only involves the sealing off of the upper surface, how much it would help a free piece rather than an attached colony is debatable. Conceivably pieces might round off to become 'all upper surface' and develop a continuous pellicle, but this has not been described.

As far as I'm aware, no resistant dispersive propagule (analogous to, say, a statocyst) is known in didemnids nor, I think in any ascidians.

Response from Ashley Coutts

I'm afraid I did not monitor the rate of tendril decay underneath the Steel Mariner barge. However, I did note that it appeared a bacteria developed in the tendrils on the muddy substrate. It was grey white in colour. I suspect this decayed started within a couple of weeks.

Sea surface temperatures for Malahide marina

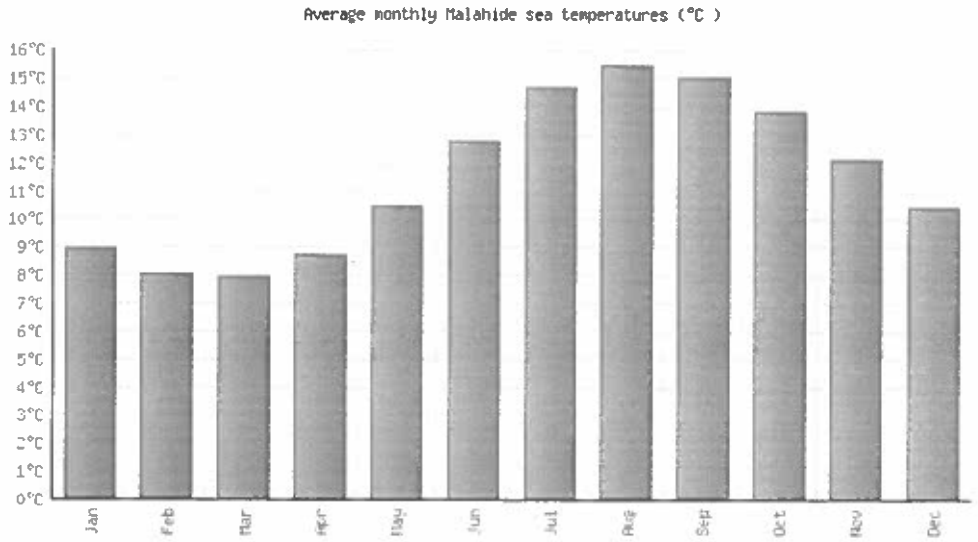


Figure A1 Sea surface temperatures (sst) for Malahide marina for Jan – Dec 2017 (Data source: https://www.seatemperature.org/europe/ireland/malahide.htm - data is derived based on NOAA global sst satellite data).

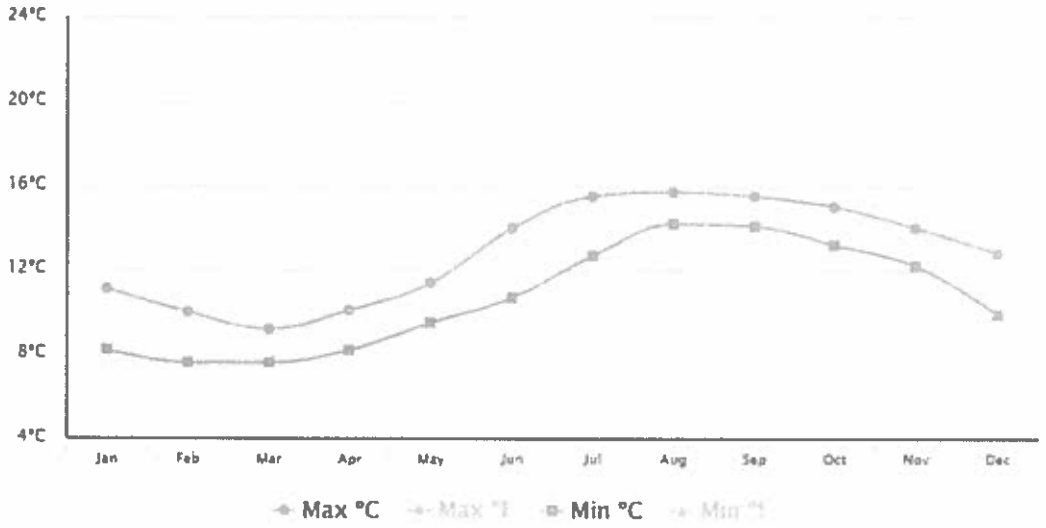


Figure A2 Calculated Mean Max and Mean Min Sea surface temperatures (sst) for Malahide marina. Data is calculated from multiple years of historical data (Data source: https://www.seatemperature.org/europe/ireland/malahide.htm - data is derived based on NOAA global sst satellite data).

8. APPENDIX E: GEOCHEMICAL TEST RESULTS

2 Shaftesbury Industrial Centre, Icknield Way, Letchworth Garden City, Hertfordshire, SG6 1HE
T +44 (0)1462 480 400, F +44 (0)1462 480 403, E rpsmh@rpsgroup.com, W rpsgroup.com

Certificate of Analysis

Report No.: 17-61494-1

Issue No.: 1
Date of Issue 19/05/2017

Customer Details:	Malahide Marina, Malahide, , Co Dublin
Customer Contact:	Damien Offer
Customer Order No.:	JBJ04/05
Customer Reference:	Not Supplied
Quotation Reference:	170421/07
Description:	3 sediment samples
Date Received:	28/04/2017
Date Started:	03/05/2017
Date Completed:	19/05/2017
Test Methods:	Details available on request (refer to SOP code against relevant result/s)
Notes:	None

Approved By: **Matthew Hickson, Laboratory Manager**

This certificate is issued in accordance with the accreditation requirements of the United Kingdom Accreditation Service.
This certificate shall not be reproduced except in full without the prior written approval of the laboratory.
Observations and interpretations are outside of the scope of UKAS accreditation.
Results reported herein relate only to the items supplied to the laboratory for testing.

UKAS TESTING
1663

RPS Mountainheath Limited, Registered in England No. 2772276, a wholly-owned subsidiary of RPS Consulting Services Ltd.
A member of the RPS Group plc. Terms and conditions apply - copy on request

2 Shaftesbury Industrial Centre, Icknield Way, Letchworth Garden City, Hertfordshire, SG6 1HE
T +44 (0)1462 480 400, F +44 (0)1462 480 403, E rpsmh@rpsgroup.com, W rpsgroup.com

Results Summary - Dry Weights, Moisture, Total Organic Carbon, TPH, Organotins & Densit

Report No.: **17-61494**
Customer Reference: Not given
Order No: JBJ04/05

					Customer Sample No	**Certified Reference Material**	**MH2**	**MH3**	**MH4**
					Customer Sample ID				
					RPS Sample No		327962	327963	327964
					Sample Type	**SEDIMENT**	**SEDIMENT**	**SEDIMENT**	**SEDIMENT**
					Sample Location				
					Sample Depth (m)				
					Sampling Date	**CRM-646**	/ /	/ /	/ /
					Sampling Time				
Determinand	**CAS No**	**Codes**	**SOP**	**Units**	**Result**	**Recovery %**			
dry solids (at 105°C)		N	397	%	n/a	n/a	39.6	40.2	41.4
dry solids (assisted air-drying at <30°C)		N	208	% w/w	n/a	n/a	Completed	Completed	Completed
carbonate % dry matter		N	In house	%	n/a	n/a	23.6	22.1	20.5
total organic carbon*		N	In house	%	n/a	n/a	5.71	5.09	5.08
density (on dry solid)		N	In house	g/cm3	n/a	n/a	1.8	1.7	2.2

Dibutyltin and tributyltin results have been dry weight corrected

2 Shaftesbury Industrial Centre, Icknield Way, Letchworth Garden City, Hertfordshire, SG6 1HE
T +44 (0)1462 480 400, F +44 (0)1462 480 403, E rpsmh@rpsgroup.com, W rpsgroup.com

Results Summary - Metals

Report No.: **17-61494**
Customer Reference: Not given
Order No: JBJ04/05

	Customer Sample No	**Standard Reference Material**						**MH2**	**MH3**	**MH4**
	Customer Sample ID									
	RPS Sample No							327962	327963	327964
	Sample Type	**SEDIMENT**						**SEDIMENT**	**SEDIMENT**	**SEDIMENT**
	Sample Location									
	Sample Depth (m)									
	Sampling Date	**SRM-2702**						/ /	/ /	/ /
	Sampling Time									
Determinand		**CAS No**	**Codes**	**SOP**	**Units**	**Assigned Value**	**Measured Value**	**Recovery %**			
aluminium*		7429-90-5	USI	M-129	mg/kg DW	84100	83000	98.69%	49600	51400	54200
arsenic*		7440-38-2	USI	M-129	mg/kg DW	45.3	49	108.17%	15.8	16.2	16.0
cadmium*		7440-43-9	USI	M-129	mg/kg DW	0.82	0.96	117.50%	0.38	0.30	0.34
chromium*		7440-47-3	USI	M-129	mg/kg DW	352	341	96.88%	102	74.3	59.1
copper*		7440-50-8	USI	M-129	mg/kg DW	Not certified	n/a	n/a	28.8	22.1	26.0
lead*		7439-92-1	USI	M-129	mg/kg DW	132.8	141	106.17%	48.1	45.7	45.8
lithium*		7439-93-2	USI	M-129	mg/kg DW	Not certified	n/a	n/a	67.3	64.8	74.1
mercury*		7439-97-6	USI	M-129	mg/kg DW	0.45	0.43	96.11%	0.43	< 0.20	< 0.20
nickel*		7440-02-0	USI	M-129	mg/kg DW	75.4	73	96.82%	44.9	32.3	37.3
zinc*		7440-66-6	USI	M-129	mg/kg DW	485.3	469	96.64%	141	119	139

RPS

2 Shaftesbury Industrial Centre, Icknield Way, Letchworth Garden City, Hertfordshire, SG6 1HE
T +44 (0)1462 480 400, F +44 (0)1462 480 401, E rpsmh@rpsgroup.com, W rpsgroup.com

Results Summary - PSA Results

Report No.: **17-61494**
Customer Reference: Not given
Order No: JBJ04/05

Customer Sample No	**MH2**	**MH3**	**MH4**
Customer Sample ID			
RPS Sample No	327962	327963	327964
Sample Type	**SEDIMENT**	**SEDIMENT**	**SEDIMENT**
Sample Location			
Sample Depth (m)			
Sampling Date	/ /	/ /	/ /
Sampling Time			

Determinand	CAS No	Codes	SOP	Units			
sample type*		S	In house		Bimodal, Very Poorly Sorted	Trimodal, Very Poorly Sorted	Bimodal, Poorly Sorted
textural group (GRADISTAT)*		S	In house		Mud	Mud	Mud
sediment name*		S	In house		Fine Silt	Fine Silt	Fine Silt
arithmetic mean (method of moments)*		S	In house	um	18.5	19.0	26.8
arithmetic sorting (method of moments)*		S	In house	um	26.4	1.10	74.2
arithmetic skewness (method of moments)*		S	In house	um	3.13	6.71	9.08
arithmetic kurtosis (method of moments)*		S	In house	um	15.5	35.7	97.2
geometric mean (method of moments)*		S	In house	um	8.7	8.6	10.1
geometric sorting (method of moments)*		S	In house	um	4.02	5.06	3.79
geometric skewness (method of moments)*		S	In house	um	-0.449	0.077	0.001
geometric kurtosis (method of moments)*		S	In house	um	3.15	3.56	3.54
logarithmic mean (method of moments)*		S	In house	phi	6.94	6.86	6.64
logarithmic sorting (method of moments)*		S	In house	phi	2.01	2.34	1.92
logarithmic skewness (method of moments)*		S	In house	phi	0.449	-0.077	-0.001
logarithmic kurtosis (method of moments)*		S	In house	phi	3.15	3.56	3.54
mean (Folk and Ward method - um)*		S	In house	um	8.9	8.9	10.4
sorting (Folk and Ward method - um)*		S	In house	um	4.01	4.66	3.77
skewness (Folk and Ward method - um)*		S	In house	um	-0.067	-0.019	0.021
kurtosis (Folk and Ward method - um)*		S	In house	um	1.21	1.23	1.16
mean (Folk and Ward method - phi)*		S	In house	phi	6.82	6.81	6.59
sorting (Folk and Ward method - phi)*		S	In house	phi	2.01	2.22	1.91
skewness (Folk and Ward method - phi)*		S	In house	phi	0.067	0.019	-0.021
kurtosis (Folk and Ward method - phi)*		S	In house	phi	1.21	1.23	1.16
mean description (Folk and Ward method)*		S	In house		Medium Silt	Medium Silt	Medium Silt
sorting description (Folk and Ward method)*		S	In house		Very Poorly Sorted	Very Poorly Sorted	Poorly Sorted
skewness description (Folk and Ward method)*		S	In house		Symmetrical	Symmetrical	Symmetrical
kurtosis description (Folk and Ward method)*		S	In house		Leptokurtic	Leptokurtic	Leptokurtic
MODE 1 - um*		S	In house	um	6.7	6.7	6.7
MODE 2 - um*		S	In house	um	0.590	0.417	0.590
MODE 3 - um*		S	In house	um		854	
MODE 1 - phi*		S	In house	phi	7.25	7.25	7.25
MODE 2 - phi*		S	In house	phi	10.8	11.3	10.8
MODE 3 - phi*		S	In house	phi		0.250	
D10 - um*		S	In house	um	1.3	0.9	2.2
D50 - um*		S	In house	um	8.7	8.5	9.6
D90 - um*		S	In house	um	45.9	57.9	55.2
(D90/D10) - um*		S	In house	um	36.3	64.6	25.0
(D90 - D10) - um*		S	In house	um	44.6	57.0	53.0
(D75/D25) - um*		S	In house	um	5.46	6.29	5.74
(D75 - D25) - um*		S	In house	um	17.2	19.1	19.1
D10 - phi*		S	In house	phi	4.45	4.11	4.18
D50 - phi*		S	In house	phi	6.85	6.88	6.70
D90 - phi*		S	In house	phi	9.63	10.1	8.82
(D90/D10) - phi*		S	In house	phi	2.17	2.46	2.11
(D90 - D10) - phi*		S	In house	phi	5.18	6.01	4.64
(D75/D25) - phi*		S	In house	phi	1.44	1.49	1.44
(D75 - D25) - phi*		S	In house	phi	2.45	2.65	2.39
% gravel*		S	In house	%	0.00	0.00	0.00
% sand*		S	In house	%	6.16	9.05	8.33
% mud*		S	In house	%	93.8	91.0	91.7
% very coarse gravel (>32<64mm or <-5>-6phi)*		S	In house	%	0.00	0.00	0.00
% coarse gravel (>16<32mm or <-4>-5phi)*		S	In house	%	0.00	0.00	0.00
% medium gravel (>8<16mm or <-3>-4phi)*		S	In house	%	0.00	0.00	0.00
% fine gravel (>4<8mm or <-2>-3phi)*		S	In house	%	0.00	0.00	0.00
% very fine gravel (>2<4mm or <-1>-2phi)*		S	In house	%	0.00	0.00	0.00
% very coarse sand (>1<2mm or <0>-1phi)*		S	In house	%	0.00	0.00	0.00
% coarse sand (>0.5<1mm or <1>0phi)*		S	In house	%	0.00	2.57	0.74
% medium sand (>0.25<0.5mm or <2>1phi)*		S	In house	%	0.00	0.00	0.05
% fine sand (>0.125<0.25mm or <3>2phi)*		S	In house	%	1.19	1.31	1.89
% very fine sand (>0.0625<0.125mm or <4>3phi)*		S	In house	%	4.97	5.17	5.66
% very coarse silt (>0.03125<0.0625mm or <5>4phi)*		S	In house	%	10.2	9.80	10.7
% coarse silt (>0.015625<0.03125mm or <6>5phi)*		S	In house	%	16.2	14.4	16.1
% medium silt (>0.007813<0.015625mm or <7>6phi)*		S	In house	%	20.8	19.1	21.9
% fine silt (>0.003906<0.007813mm or <8>7phi)*		S	In house	%	21.4	20.8	22.3
% very fine silt (>0.001953<0.003906mm or <9>8phi)*		S	In house	%	12.8	12.8	12.4
% clay (<0.001953mm or >9phi)*		S	In house	%	13.5	14.0	8.40

2 Shaftesbury Industrial Centre, Icknield Way, Letchworth Garden City, Hertfordshire, SG6 1HE
T +44 (0)1462 480 400, F +44 (0)1462 480 403, E rpsmh@rpsgroup.com, W rpsgroup.com

Results Summary - PSA Size Class & Statistics

Report No.: **17-61494**
Customer Reference: Not given
Order No: JBJ04/05

	Customer Sample No	MH2	MH3	MH4
	Customer Sample ID			
	RPS Sample No	327962	327963	327964
	Sample Type	**SEDIMENT**	**SEDIMENT**	**SEDIMENT**
	Sample Location			
	Sample Depth (m)			
	Sampling Date	/ /	/ /	/ /
	Sampling Time			

Sediment	mm	phi ϕ	Units			
Very coarse gravel	>32<64	<-5>-6	%	0.00	0.00	0.00
Coarse gravel	>16<32	<-4>-5	%	0.00	0.00	0.00
Medium gravel	>8<16	<-3>-4	%	0.00	0.00	0.00
Fine gravel	>4<8	<-2>-3	%	0.00	0.00	0.00
Very fine gravel	>2<4	<-1>-2	%	0.00	0.00	0.00
Very coarse sand	>1<2	<0>-1	%	0.00	0.00	0.00
Coarse sand	>0.5<1	<1>0	%	0.00	2.57	0.74
Medium sand	>0.25<0.5	<2>1	%	0.00	0.00	0.05
Fine sand	>0.125<0.25	<3>2	%	1.19	1.31	1.89
Very fine sand	>0.0625<0.125	<4>3	%	4.97	5.17	5.66
Very coarse silt	>0.03125<0.0625	<5>4	%	10.20	9.80	10.70
Coarse silt	>0.015625<0.03125	<6>5	%	16.20	14.40	16.10
Medium silt	>0.007813<0.015625	<7>6	%	20.80	19.10	21.90
Fine silt	>0.003906<0.007813	<8>7	%	21.40	20.80	22.30
Very fine silt	>0.001953<0.003906	<9>8	%	12.80	12.80	12.40
Clay	<0.001953	>9	%	12.50	14.00	8.40

Statistics*					
	Mean (phi)		6.82	6.81	6.59
	Sorting		2.01	2.22	1.91
	Skewness		0.067	0.019	-0.021
	Kurtosis		1.21	1.23	1.16
	% Silt/Clay	%	93.90	90.90	91.80
	Textural Group**		Mud	Mud	Mud

* Folk & Ward

** GRADISTAT classification system (Blott, S. J. & Pye, K., 2001)

2 Shaftesbury Industrial Centre, Icknield Way, Letchworth Garden City, Hertfordshire, SG6 1HE
T +44 (0)1462 480 400, F +44 (0)1462 480 403, E rpsmh@rpsgroup.com, W rpsgroup.com

Results Summary - PSA Wentworth Scale

Report No.: **17-61494**
Customer Reference: Not given
Order No: JBJ04/05

Customer Sample No		**MH2**	**MH3**	**MH4**
Customer Sample ID				
RPS Sample No		327962	327963	327964
Sample Type		**SEDIMENT**	**SEDIMENT**	**SEDIMENT**
Sample Location				
Sample Depth (m)				
Sampling Date		/ /	/ /	/ /
Sampling Time				
Parameter	**Units**			
Pebble	%	0.00	0.00	0.00
Granule	%	0.00	0.00	0.00
Very coarse sand	%	0.00	0.00	0.00
Coarse sand	%	0.00	2.57	0.74
Medium sand	%	0.00	0.00	0.05
Fine sand	%	1.19	1.31	1.89
Very fine sand	%	4.97	5.17	5.66
Silt Clay	%	93.90	90.90	91.80
Total	%	100.1	100.0	100.1

RPS

2 Shaftesbury Industrial Centre, Icknield Way, Letchworth Garden City, Hertfordshire, SG6 1HE
T +44 (0)1462 480 400, **F** +44 (0)1462 480 403, **E** rpsmh@rpsgroup.com, **W** rpsgroup.com

Report No.: **17-61494**
Customer Reference: Not given
Order No: JBJ04/05

Comments

RPS Sample Number	Customer Number	Sample Comments
327962	MH2	Colour - Grey/black Texture - smooth, clay-like Odour - Sulfurish Presence of Animals - No
327963	MH3	Colour - Grey/black Texture - smooth, clay-like Odour - Sulfurish Presence of Animals - No
327964	MH4	Colour - Grey/black Texture - smooth, clay-like Odour - Sulfurish Presence of Animals - No

2 Shaftesbury Industrial Centre, Icknield Way, Letchworth Garden City, Hertfordshire, SG6 1HE
T +44 (0)1462 480 400, F +44 (0)1462 480 403, E rpsmh@rpsgroup.com, W rpsgroup.com

Report Information

Key to Report Codes

U	UKAS Accredited
M	MCERTS Accredited
S	Subcontracted to approved laboratory
US	Subcontracted to approved laboratory UKAS Accredited for the test
MS	Subcontracted to approved laboratory MCERTS/UKAS Accredited for the test
SI	Subcontracted to internal RPS Group Laboratory
USI	Subcontracted to internal RPS Group Laboratory UKAS Accredited for the test
MSI	Subcontracted to internal RPS Group Laboratory MCERTS/UKAS Accredited for the test
I/S (in results)	Insufficient Sample
U/S (in results)	Unsuitable sample
S/C (in results)	See Comments
ND (in results)	Not Detected
DW (in units)	Results are expressed on a dry weight basis

Sample Retention and Disposal

Samples will generally* be retained for the following times prior to disposal:

Perishables, e.g. foodstuffs	1 month (if frozen) from the issue date of this report
Waters	2 weeks from the issue date of this report
Other Liquids	1 months from the issue date of this report
Solids (including Soils)	1 months from the issue date of this report

*Sample retention may be subject to agreement with the customer for particular projects

Analytical Methods

PAH's and PCB's	GCMS analysis following extraction of the wet sediment with hexane:acetone by ultrasonic and equlibrium extraction. Extract cleaned-up with alumina and activated copper.
Metals	ICP-MS analysis following microwave assisted digestion in hydrofluoric acid of the dried (<30°C) and ground sediment.
TOC	Combustion and infrared analysis following carbonate removal with hydrochloric acid.
PSA	Wet and dry sieving followed by laser diffraction analysis.
Density	Determination of density from the dry sediment by gravimetric analysis of a known volume of sediment.
Dry solids at 105°C	A portion of the wet sediment is dried at 105°C to constant weight.
TBT and DBT	GCMS analysis following the extraction of the wet sediment and subsequent derivatisation.
Please note:	**All testing carried out using the <2mm fraction**

Laboratories

RPS Letchworth	UKAS Test House 1663
RPS Manchester (Metals only)	UKAS Test House 0605
ESG Scientifics (TOC only)	UKAS Test House 0001
Thompson PSA only	

Profiency Testing (PT)

RPS Letchworth and Manchester Laboratories participate in the QUASIMEME Proficiency Testing Scheme

9. APPENDIX F: GEOCHEMICAL RESULTS WITH RELATION TO IRISH UPPER AND LOWER LIMITS

Parameter	Units (dry wt) Note 2	Irish Lower Limit	Irish Upper Limit	Sampling points				
				MH1	MH2	MH3	MH4	MH5
Arsenic	mg kg^{-1}	9	70	14	16	16	16	15
Cadmium	mg kg^{-1}	0.7	4.2	0.3	0.4	0.3	0.3	0.3
Chromium	mg kg^{-1}	120	370	71	102	74	59	78
Copper	mg kg^{-1}	40	110	23	29	22	26	23
Lead	mg kg^{-1}	60	218	38	48	46	46	41
Mercury	mg kg^{-1}	0.2	0.7	< 0.2	0.4	< 0.2	< 0.2	< 0.2
Nickel	mg kg^{-1}	21	40	31	45	32	37	35
Zinc	mg kg^{-1}	160	410	116	141	119	139	121
S TBT & DBT Note 3	mg kg^{-1}	0.1	0.5	both samples returned values < 0.005	not analysed	not analysed	not analysed	both samples returned values < 0.005
g-HCH (Lindane) Note 4	µg kg^{-1}	0.3	1	<2.18	not analysed	not analysed	not analysed	<2.36
HCB Note 5	µg kg^{-1}	0.3	1	<2.18	not analysed	not analysed	not analysed	3.12
2,4,4'-trichlorobiphenyl (PCB congener 28)	µg kg^{-1}	1	180	1.7	not analysed	not analysed	not analysed	0.43
2,2',5,5'-tetrachlorobiphenyl (PCB congener 52)	µg kg^{-1}	1	180	< 0.22	not analysed	not analysed	not analysed	< 0.24
2,2',4,5,5'-pentachlorobiphenyl (PCB congener 101)	µg kg^{-1}	1	180	0.76	not analysed	not analysed	not analysed	< 0.24
2,3',4,4',5-pentachlorobiphenyl (PCB congener 118)	µg kg^{-1}	1	180	0.78	not analysed	not analysed	not analysed	0.26
2,2',3,4,4',5-hexachlorobiphenyl (PCB 138)	µg kg^{-1}	1	180	0.63	not analysed	not analysed	not analysed	0.33
2,2',4,4',5,5'-hexachlorobiphenyl (PCB 153)	µg kg^{-1}	1	180	0.7	not analysed	not analysed	not analysed	0.26
2,2',3,4,4',5,5'-heptachlorobiphenyl (PCB 180)	µg kg^{-1}	1	180	0.46	not analysed	not analysed	not analysed	< 0.24
PCB (S ICES 7) Note 6	µg kg^{-1}	7	1260	5.03	not analysed	not analysed	not analysed	1.28
PAH (S 16) Note 7	µg kg^{-1}	4000		1250	not analysed	not analysed	not analysed	1046
Total Extractable Hydrocarbons	g kg^{-1}	1		< 0.01	not analysed	not analysed	not analysed	< 0.01

Legend	
Cell color	Lower than Irish Lower Limit
Cell color	Higher than Irish Lower Limit, lower than Irish Upper Limit
Cell color	Higher than Irish Upper Limit

Note 1:	Applicants should highlight in Table B.1 any results which exceed either the upper or lower Irish action levels. Action levels are published in: *Cronin et al. 2006. Guidelines for the Assessment of Dredge Material for Disposal in Irish Waters. Marine Environment & Health Series, No. 24. Marine Institute.*
Note 2:	Total sediment <2 mm
Note 3:	Sum of tributyl tin and dibutyl tin
Note 4:	1α,2α,3β,4α,5α,6β-hexachlorocyclohexane
Note 5:	Hexachlorobenzene
Note 6:	ICES 7 polychlorinated biphenyls: PCB 28, 52, 101, 118, 138, 153, 180.
Note 7:	Polyaromatic hydrocarbons (measured as individual compounds): Naphthalene, Acenaphthylene, Acenaphthene, Fluorene,Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Dibenzo(ah)anthracene, Benzo(ghi)perylene, Indeno(123-cd)pyrene.