


SWEPT

Surveying the Waterway Environment for Pollution Threats Volunteer Project 2018-19

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Final project report. March 2020

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West Wales Rivers Trust
Ymddiriedolaeth Afonydd Gorllewin Cymru
- caring for rivers, lakes and wetlands

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Darwin

Cyfoeth Naturiol Cymru
Natural Resources Wales

Llywodraeth Cymru
Welsh Government

Acknowledgements

This project would not have been possible without the incredible enthusiasm and dedication of the survey volunteers who exceeded all expectations and made the project not only hugely successful but also highly enjoyable.

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And finally, the Freshwater Rivers Trust who generously shared all their 'Clean Water for Wildlife' information and gave permission for re-use.

Many of the SWEPT volunteers at the feedback event in May 2019.

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Executive Summary

SWEPT (Surveying the Waterway Environment for Pollution Threats) saw over 100 volunteers conducting repeat surveys of stretches of the shore within the Milford Haven Waterway, from tidal limits at Haverfordwest and Canaston Bridge all the way down to Dale, and testing water samples for levels of nitrates and phosphates between November 2018 and March 2020.

SWEPT was led by the Pembrokeshire Marine Special Area of Conservation (SAC) Officer and co-delivered with the West Wales Rivers Trust, Pembrokeshire Coastal Forum and the Darwin Centre. Funding for the project came from Natural Resources Wales.

The primary objective of the water quality citizen science project was to gather data and look at the effects of nutrient pollution from land run-off on the marine environment. It proved to be hugely successful, both in terms of the involvement of volunteers and the acquisition of useful data. So much so, that it won a national award. The Park Protector Award, run by Campaign for National Parks, the charity for England and Wales' 13 National Parks, celebrates and supports projects that make a difference to protecting some of the most famous countryside in the world. SWEPT was the only project from Wales to be shortlisted and raised awareness of the important connection between what we do on the land and the state of our coastal waters.

The quality and amount of data generated far exceeded project expectations. During the four months of repeat surveying, 2105 photos and 881 nitrate and phosphate tests were taken by volunteers. Four canoe trips collected data from hard to reach areas. Results saw a myriad of different freshwater inputs from seeps and mini waterfalls to pipes and streams, 320 were described across the waterway during the period of heaviest rainfall in December. Mapped results showed nitrate levels to be very high in many locations. Phosphate was generally low throughout. No significant temporal difference in pollution levels was found although higher rainfall was noted to accompany higher levels of pollution. Three university students aided data handling and analysis and two students utilised SWEPT data for their theses (both receiving a first). In line with previous comparison studies (Biggs *et al*., 2016), SWEPT concluded that PackTest kits are a quick, easy and cost-effective way for citizen scientists to identify nutrient pollution over large areas. The colour-change field kits were less accurate than laboratory test comparisons, but importantly they did identify pollution where it existed and were unlikely to provide false positives.

Marine features of the Pembrokeshire Marine SAC (which extends around the Pembrokeshire coast and includes the Milford Haven waterway to tidal limits) are in unfavourable condition due in part to nutrient pollution from agricultural run-off carrying fertilizers and sewage. The waterway has also failed to meet 'Good' status which is required for Water Framework Directive compliance by 2027. SWEPT data will supplement that already gathered by Natural Resources Wales (NRW) and will help NRW to prioritise land conservation actions and lead to environmental improvements.

In addition to the water quality results, volunteers also collected information on marine litter, non-natives and any other pollution threats such as oil or fly tipping. All immediate pollution concerns logged during the fieldwork were followed up and resolved by NRW. A Big River Clean-up, led by a Pembrokeshire Coast National Park Ranger, removed and recycled a considerable amount of marine litter from 'hot spots' highlighted by survey volunteers.

SWEPT proved popular with participants and undoubtedly raised awareness of the issue of land run-off affecting the marine environment. Including local people in local environmental issues aids awareness and understanding of human impacts and this provides real impetus for environmental protection. Interest in applying "SWEPT methodology" to other areas has already been expressed; it is hoped that this report can aid replication elsewhere.

Crynodeb Gweithredol

Fel rhan o waith SWEPT (*Surveying the Waterway Environment for Pollution Threats*) gwelwyd dros 100 o wirfoddolwyr yn cynnal ail-arolygon ar rannau o'r glannau yn Nyfrffordd Aberdaugleddau, o derfynau'r llanw yn Hwlffordd a Phont Canaston yr holl ffordd i lawr i Dale. Buont yn profi samplau dŵr am lefelau nitradau a ffosffadau rhwng mis Tachwedd 2018 a mis Mawrth 2020.

Arweiniwyd SWEPT gan Swyddog Ardal Cadwraeth Arbennig Sir Benfro Forol ac mae'n cael ei gyflwyno ar y cyd ag Ymddiriedolaeth Afonydd Gorllewin Cymru, Fforwm Arfordir Sir Benfro a Chanolfan Darwin. Daw'r cyllid ar gyfer y prosiect gan Cyfoeth Naturiol Cymru.

Prif amcan y prosiect gwyddoniaeth dinasyddion sy'n ymwneud ag ansawdd dŵr, oedd casglu data ac edrych ar effeithiau llygredd maetholion o ddŵr ffo oddi ar y tir ar yr amgylchedd morol. Profodd yn brosiect hynod o lwyddiannus, a hynny o ran cynnwys gwirfoddolwyr a chaffael ar ddata defnyddiol. Cymaint oedd llwyddiant y prosiect nes iddo ennill gwobr genedlaethol. Mae Gwobr 'Park Protector' sy'n cael ei rhedeg gan Ymgyrch y Parciau Cenedlaethol, sef yr elusen ar gyfer yr 13 Parc Cenedlaethol yng Nghymru a Lloegr, yn dathlu ac yn cefnogi prosiectau sy'n gwneud gwahaniaeth trwy warchod rhai o'r darnau enwocaf o gefn gwlad yn y byd. SWEPT oedd yr unig brosiect o Gymru i gyrraedd y rhestr fer ac roedd yn codi ymwybyddiaeth o'r cysylltiad pwysig rhwng yr hyn yr ydym yn ei wneud ar y tir a chyflwr ein dyfroedd arfordirol.

Mae ansawdd y data a swmp y data a grëwyd wedi rhagori'n sylweddol ar ein disgwyliadau. Yn ystod y pedwar mis o ail-arolygu, llwyddodd y gwirfoddolwyr i dynnu 2105 o luniau a gwneud 881 o brofion nitrad a ffosffad. Yn ogystal, bu pedair taith canŵ yn casglu data o ardaloedd anodd eu cyrraedd. Ymhlith y canlyniadau, gwelwyd myrdd o fewnbynnau dŵr croyw gwahanol, o darddleoedd a rhaeadrau bychain i bibau a nentydd, a disgrifiwyd 320 ledled y ddyfrffordd yn ystod y cyfnod o law trymaf ym mis Rhagfyr. Roedd y canlyniadau a fapiwyd yn dangos bod lefelau nitrad yn uchel iawn mewn nifer o leoliadau. Yn gyffredinol, roedd ffosffad yn isel ar draws yr ardaloedd. Ni chanfuwyd unrhyw wahaniaeth amserol sylweddol yn lefelau'r llygredd, er y nodwyd bod glawiad uwch yn cyd-fynd â lefelau llygredd uwch. Bu tri myfyriwr o'r brifysgol yn cynorthwyo gyda'r gwaith o drafod data a'u dadansoddi, a bu dau o'r myfyrwyr yn defnyddio data SWEPT ar gyfer eu traethodau ymchwil (gan ennill gradd ddosbarth cyntaf, ill dau). Yn unol ag astudiaethau cymharol blaenorol (Biggs *et al*., 2016), daeth SWEPT i'r casgliad fod pecynnau PackTest yn ffordd gyflym, hawdd a chost-effeithiol i alluogi gwyddonwyr o blith dinasyddion i adnabod llygredd maetholion dros ardaloedd helaeth. O'u cymharu, roedd y pecynnau maes sy'n newid lliw yn llai cywir na phrofion mewn labordai, ond, yn hanfodol, roeddent yn adnabod llygredd lle'r oedd yn bodoli ac yn annhebygol o ddarparu canlyniadau positif ffug.

Mae nodweddion morol Ardal Cadwraeth Arbennig Sir Benfro Forol (sy'n ymestyn o amgylch arfordir Penfro ac yn cynnwys dyfrffordd Aberdaugleddau hyd at derfynau'r llanw) mewn cyflwr anffafriol ac mae hynny'n rhannol oherwydd llygredd maetholion o ddŴr ffo amaethyddol sy'n cludo gwrtaith a charthffosiaeth. Nid yw'r ddyfrffordd wedi cyrraedd y statws 'Da' sy'n angenrheidiol er mwyn cydymffurfio â'r Gyfarwyddeb Fframwaith DŴr erbyn 2027.

Bydd data SWEPT yn ategu at yr wybodaeth a gasglwyd yn barod gan Cyfoeth Naturiol Cymru ac yn gymorth i Cyfoeth Naturiol Cymru flaenoriaethu gwaith ar warchod y tir, gan arwain at welliannau amgylcheddol.

Y ogystal â chanlyniadau ansawdd y dŵr, bu gwirfoddolwyr hefyd yn casglu gwybodaeth am sbwriel morol, rhywogaethau anfrodorol ac unrhyw fygythiadau eraill gan lygredd er enghraifft olew neu dipio anghyfreithlon. Aeth Cyfoeth Naturiol Cymru ar drywydd pob pryder dybryd ynghylch llygredd a gofnodwyd yn ystod y gwaith maes ac mae wedi eu datrys. Cafwyd ymgyrch fawr i lanhau'r afon, dan

arweiniad Parcmon Parc Cenedlaethol Arfordir Penfro, gan waredu ac ailgylchu sbwriel morol o'r mannau lle y mae llawer o sbwriel yn dueddol o gronni, a amlygwyd gan y gwirfoddolwyr a oedd yn gwneud y gwaith arolygu.

Roedd SWEPT yn boblogaidd ymhlith cyfranogwyr a, heb os, llwyddwyd i godi ymwybyddiaeth o effaith dŵr ffo oddi ar y tir ar yr amgylchedd morol. Mae cynnwys pobl leol mewn materion amgylcheddol lleol yn gymorth i godi ymwybyddiaeth ac i feithrin dealltwriaeth o effaith pobl, ac mae hyn yn ysgogiad go iawn i warchod yr amgylchedd. Eisoes mynegwyd diddordeb mewn defnyddio "methodoleg SWEPT" mewn ardaloedd eraill; gobeithir y bydd yr adroddiad hwn yn gymorth i efelychu'r gwaith mewn ardaloedd eraill.

1. Introduction

1.1 Background / need for the project

SWEPT (Surveying the Waterway Environment for Pollution Threats) emerged from a need for more localised information on nitrate pollution entering the Milford Haven waterway ("the waterway") and improved awareness of the impacts of land run-off on the marine environment which are obvious and substantial.

Marine features of the Pembrokeshire Marine Special Area of Conservation (SAC) (which extends around the Pembrokeshire coast and includes the Milford Haven waterway to tidal limits) are in unfavourable condition due in part to nutrient pollution from agricultural run-off carrying fertilizers and sewage. The waterway has also failed to meet 'Good' status which is required for Water Framework Directive compliance by 2027. More data was considered helpful to Natural Resources Wales (NRW) to better identify problem areas and help to best target effective management effort in order to make conservation improvements.

This report summarises the key findings from SWEPT and importantly is designed to be useful to others interested in running a similar initiative. For this reason, all project outputs are included in the Appendices which are available as editable word documents from the project lead. There are already plans to extend the SWEPT methodology to other parts of Pembrokeshire in 2020.

1.2 Land run-off as an issue for the marine environment.

Excessive quantities of nitrates (NO_3) and/or phosphates (PO_4) are referred to as nutrient pollution. Nitrates predominantly come from fertilisers/slurry spread onto agricultural land. As nitrates commonly drain off the land via multiple rivers and many streams or via groundwater flows, this is called diffuse pollution. Phosphates can originate from detergents (soap) and sewage as well as from agriculture. They mainly enter watercourses through specific inputs (e.g. an outlet pipe from wastewater treatment); this is referred to as point source pollution.

Point source pollution is easier to manage than diffuse pollution. Both make their way into the marine environment where elevated nutrients (especially too much nitrogen from nitrates) stimulates excessive plant growth. In the Milford Haven waterway this primarily manifests as dense growth of opportunistic macroalgae (seaweed) species, primarily green seaweeds such as *Ulva* spp., in the form of mats that cover the saltmarsh and mudflats, and occasional phytoplankton blooms.

The abnormal mats of green seaweed smother saltmarsh plants and seagrass beds and can impede feeding birds. In addition, the eventual rotting of the mats consumes all the available oxygen, suffocating marine species. Impacts aren't exclusive to the marine wildlife - detached rafts of seaweed cause problems for waterway users by entangling boat propellers and clogging nets, and the smell from decaying mats can impact local communities and tourists.

In addition to nutrient pollution, soil run-off has a negative effect on the marine environment as the increased sedimentation that results can smother and clog seabed species (and fish gills). Sediments can also carry 'hitchhiking' contaminants including pesticides, metals and bacteria.

Land run-off of nutrient pollution is a widespread issue. A European Union (EU) Commission (2018) report recognises that agriculture, occupying nearly half of EU territory, causes detrimental effects to marine ecosystems as a result of a current and historic legacy of nutrient loss. The report highlights that although reductions in manure/fertilisers and better practices have been enforced under the Water Framework Directive (2000/60/EC) (WFD) and its agriculture-focused Nitrates Directive, an increase in the nitrogen and phosphorus balance was observed between 2008 and 2015, leading to higher potential losses to the environment. This is an issue that has yet to be adequately resolved.

The Milford Haven waterway has a huge catchment area that can be seen in Figure 1. It is not surprising, therefore, that with such a large catchment draining into it, particularly of agricultural land, that the waterway should suffer water quality issues.

Figure 1: Map showing the Milford Haven Inner and Outer water bodies and their catchment areas. (NRW 2016)

1.3 Existing legislation and monitoring data.

Natural Resources Wales (NRW) is required by law to monitor water quality. Multiple locations are sampled, including for both nitrogen and phosphorous levels, on a monthly basis. However, most of these are situated far upstream of marine influences, with only five stations within the main body of the waterway itself (see Figure 2).

Figure 2: Location of NRW long-term sampling points (NRW reference numbers) within the marine environment of the Milford Haven waterway (Gil 2020).

SWEPT aimed to increase the number of data points directly adjacent to the waterway in order to provide a more detailed snapshot of the sources of diffuse nutrients entering the marine environment. Quite simply SWEPT intended to 'fill in' gaps in the data in the areas of waterway shoreline coloured grey in Figure 3.

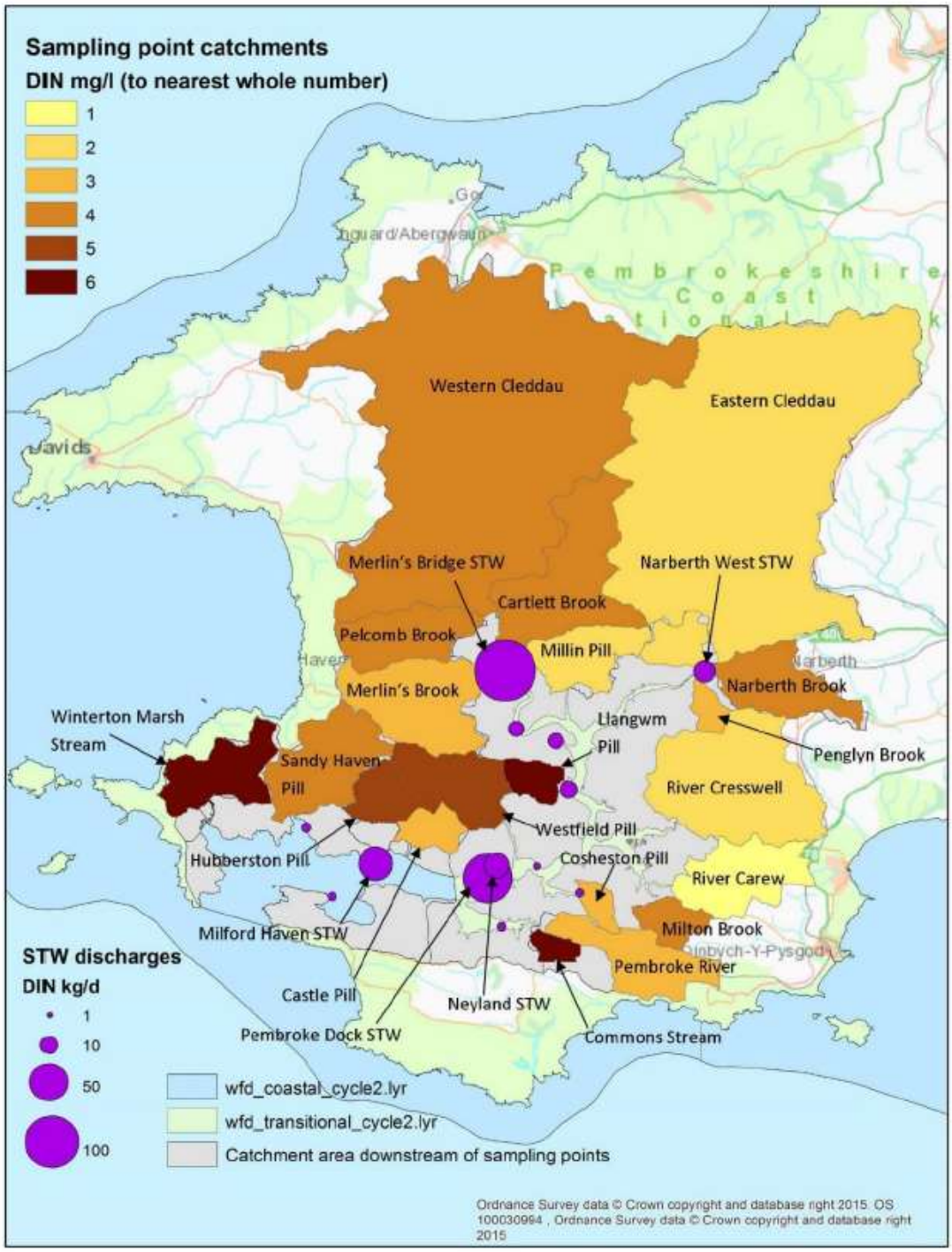

Figure 3: Map of dissolved available inorganic nitrogen (DIN) concentrations in river inputs to the Milford Haven waterway and DIN loads from sewage treatment works (STW) discharges downstream of these river inputs. (NRW, 2016)

Evidence from this monitoring in the Milford Haven waterway shows that dissolved inorganic nitrogen (DIN) levels are too high (see thresholds in Section 3.4). The waterway is "hypernutrified" and has been identified by NRW as being at risk of eutrophication (an excess of nitrogen compounds leading to dense growth of plant life) from diffuse nutrient pollution from agriculture (NRW 2014, 2016) and assigned moderate status for water quality.

Compliance with the current Water Framework Directive (2000/60/EC) regulation demands that the waterway improve from moderate to good status by 2027 (NRW 2016). The Water Framework Directive categorises waterbodies by their water quality status as bad, poor, moderate, good, and high, which encompasses levels of nitrogen and phosphorous in accordance with eutrophication risk. For WFD assessment purposes, Milford Haven has been divided into two: Milford Haven Inner (a transitional water) and Milford Haven Outer (a coastal water). The boundary between the two is just west of the mouth of Pembroke River (refer to Figure 1).

In addition to the Water Framework Directive, the Nitrate Directive (91/676/EEC) also has provisions for eutrophication. This Directive requires that waters which are eutrophic due to nitrates derived from agricultural sources, or at risk of shortly becoming so unless protective action is taken, must be identified as Polluted Waters (Eutrophic) and areas of land draining to those waters, and which contribute to their nitrogen pollution, must be designated as Nitrate Vulnerable Zones (NVZs). Legislation is stronger in NVZs where there are enforceable rules that must be adhered to regarding fertilizer spreading.

NRW made the recommendation in 2016 (NRW, 2016) that a case for designation under the provisions of the Nitrates Directive should be made for the catchment area for the Milford Haven Inner water body. For the Outer water body, despite there being evidence to suggest the waters were hypernutrified (failing for DIN), evidence did not support a case for designation as macroalgal growth was more localised in the Outer water body and it was not failing for opportunistic macroalgae or phytoplankton. NRW recommended that monitoring continue, and the outputs be reviewed in four years (due therefore in 2020).

In a long-awaited announcement that was made in November 2018 as the first SWEPT survey was in preparation, Lesley Griffiths the Rural Affairs Secretary from Welsh Government said tougher regulations would be introduced in 2020. Rules on spreading and storing fertiliser and slurry would be tightened. Ms Griffiths stated "As we move into winter, I am already receiving reports and images of bad practice and the number of incidents this year has already exceeded last year's figure. This is unacceptable. Our rural communities, which depend on tourism, angling and food industries, must be protected."

Concerns about nitrate pollution specifically in the Milford Haven waterway have led to calls to declare the area an NVZ. More widely, environment groups have previously urged Ms Griffiths to designate the whole of Wales as an NVZ, which would impose strict conditions on all farmers. However, there are also some concerns that an NVZ will not actually reduce nitrate pollution and that it will put many farmers out of business (Worrall *et al*. (2009), Macgregor and Warren (2006)). The agriculture industry has called for more advice and funding for farmers to help with fertiliser storage and management.

As well as monitoring water quality, data on phytoplankton and opportunistic macroalgae (as algal (seaweed) mats) is also recorded by NRW. Phytoplankton growth is not considered a eutrophication problem in the waterway, but macroalgal records also report moderate status for the 'inner' waterway (upstream of Pembroke river), although there is localised evidence throughout the whole waterway of impacts from excessive algal mats (NRW 2016). Figure 4 shows areas where excessive growth of macroalgae has been previously recorded as widespread across intertidal areas, leading to a degradation of pioneer saltmarsh species (*Salicornia* spp.) and dwarf eelgrass (*Zostera noltei*). Concern over the existing problems around opportunistic macroalgal growth on the inter-tidal mudflats and sand flats within the sheltered bays and inlets of the waterway was first expressed in a report by the Countryside Council for Wales in 2009 (CCW 2009). Milford Haven Inner at mean low water spring has an available intertidal habitat (the intertidal area considered to be suitable for opportunistic macroalgal growth) of approximately 900 hectares. Milford Haven Outer at mean low water spring has an intertidal habitat of approximately 300 hectares. Figure 4 shows those areas most affected by opportunistic macroalgal growth. Various methods using aerial photography have tried to establish percentage cover. Aberystwyth University have been using drones to study this.

Figure 4: Map providing geographical representation of the extent of opportunistic macroalgae growth as a result of nutrient enrichment of the Milford Haven waterway, 2014. (NRW, 2016)

As part of the Pembrokeshire Marine SAC, the Habitats Directive (92/43/EEC) requires marine wildlife features in the waterway to be in favourable condition. Many features of the SAC, including the 'estuary' feature which encompasses much of the upper waterway, are currently in unfavourable condition and need improvement. In addition, the hyper nutrification of the waterway can present a barrier to economic development in the waterway through combined likely adverse effects on the SAC.

1.4 Agriculture in Pembrokeshire

In agriculture generally, the trend towards greater intensification and higher productivity has been accompanied by a significant increase in the use of both organic (slurry and manure) and inorganic nitrogen and phosphorous fertilizers. The application of these allows farmers to make the most of a short growing season.

Dairy farms predominate over arable in Pembrokeshire and many farms are increasing their dairy herd size, resulting in much greater production of slurry. Unfortunately, in many cases the farms do not increase their slurry storage capacities or acquire more land, due to cost, and therefore must spread slurry more frequently on fields that do not need fertilizers, or in weather conditions not suitable for spreading. Instead of the slurry being valued and used as a natural fertilizer it is often viewed as a waste by-product that needs disposing of.

There is little legislation in place to tackle nutrient overloading unless a direct pollution is caused (i.e. when slurry, silage leachate or any other damaging substance actually enters a watercourse, be it by storage failure or inappropriate land spreading). There are Agricultural Codes of Practice that farms should follow, but these are not legislation, and therefore not enforceable.

1.5 Project design

Applications for NRW funding through a competitive grant process were invited and SWEPT was submitted as an idea that helped to address one of the major issues impacting upon the features of the Pembrokeshire Marine SAC. The use of citizen science volunteers was important, not only to spread awareness of the important connection between land management and marine conservation, but also because the area concerned was so large and contributions from multiple participants would aid in kind support. SWEPT was successful in attracting £13,400 of NRW grant funding, matched by 'in kind' contributions from volunteer participation and some cash match from the Pembrokeshire Marine SAC Relevant Authorities Group and from the West Wales Rivers Trust. Project partners included the West Wales Rivers Trust due to their experience with river pollution and surveys and their network of volunteers, Pembrokeshire Coastal Forum in order to connect with different user groups and facilitate canoe-based surveys, and the Darwin Centre to make use of educational groups.

SWEPT took its methodology from the inspiring Freshwater Habitats Trust *Clean Water for Wildlife* project (2015-2017) and the Earthwatch 'FreshWater Watch' citizen-led water quality monitoring programmes (see Biggs *et al*., 2016 and McGoff *et al*., 2017) using cheap and easy to use Kyoritsu PackTest kits. It was important that the project was designed in order to make best use of citizen scientists, as well as providing a broad and interesting experience for participants. As well as individual surveyors, survey sessions were also conducted with educational groups, and during canoeing trips to hard-to-reach areas. To add value, surveys included recording of all pollution concerns, non-native species, and general things of interest (see survey form in Appendix 7).

Liaison with NRW during project conception concluded that fieldwork in late autumn and winter would be the optimum time for nutrient testing as this tended to be the best season for picking up signs of pollution. Data analysis of NRW monitoring data has shown a significant seasonal pattern in nitrate concentrations at all five of the long-term sampling points within the waterway, with a reduction in concentrations in the summer, probably due to combination of lower freshwater load from precipitation and higher algal uptake (NRW, 2016). It was also important that surveys were timed to avoid sensitive times for breeding birds on the estuary, so for this reason surveying through the Spring was not appropriate.

The project's overall aim was to improve the resilience and quality of the Pembrokeshire Marine SAC and Milford Haven Waterway SSSI through improved management informed by the data and raised awareness generated by the project. The project set out to:

- Generate essential useful data to fill evidence gaps and help inform management of nutrient pollution summarised in a project report;
- Support immediate NRW pollution prevention reporting;
- Raise awareness of nutrient pollution amongst rural and urban communities and its impact on the Pembrokeshire Marine SAC;
- Promote increased community involvement, health and well-being.

SWEPT was designed to complement, and not duplicate, existing initiatives already underway within the project area. These include the First Milk pilot, EcoBank and BRiCs (Building Resilience into Catchments) all of which have been/are exploring adaptive innovative ways of addressing nutrient pollution.

2. Methodology

2.1 Volunteer recruitment

Requests for survey volunteers went out two months before training was due to start, on social media (Facebook and Twitter) and via local email networks; these were shared by project partners and others. Registration forms (see template in Appendix 1) came pouring in. The level of interest took all by surprise.

In the end the project manager had to regrettably turn away any more volunteers. For health and safety reasons, surveys were to be conducted by buddy pairs. Most, but not all, volunteers registering their interest came as a survey pair or group by commandeering family and friends; individual volunteers were matched with buddies.

During registration volunteers were asked their preferred language for communication, Welsh or English. As all respondents requested English, all materials and training were produced in English only.

Recruitment of volunteers to join in with four organised canoe surveys was handled by Pembrokeshire Coastal Forum via Eventbrite with advertising via social media and local networks. The trips were run by Martin Leonard from Sea Kayak Guides.

2.2 Selection of survey stretches

The large number of volunteers meant that more stretches of the waterway could be surveyed. The survey stretches were determined largely by access (publicly accessible) and estimated time to complete. In some cases, stretches would only be accessible from one end requiring walking along the shore or path in both directions. Tidal state was an important consideration and a limiting factor for some stretches. Then the process of assigning stretches to volunteers began according to volunteer location preference. Some participants wanted the convenience of a stretch close to home but generally volunteers were very accommodating. In the end 46 stretches were allocated to volunteers (see Figure 5).

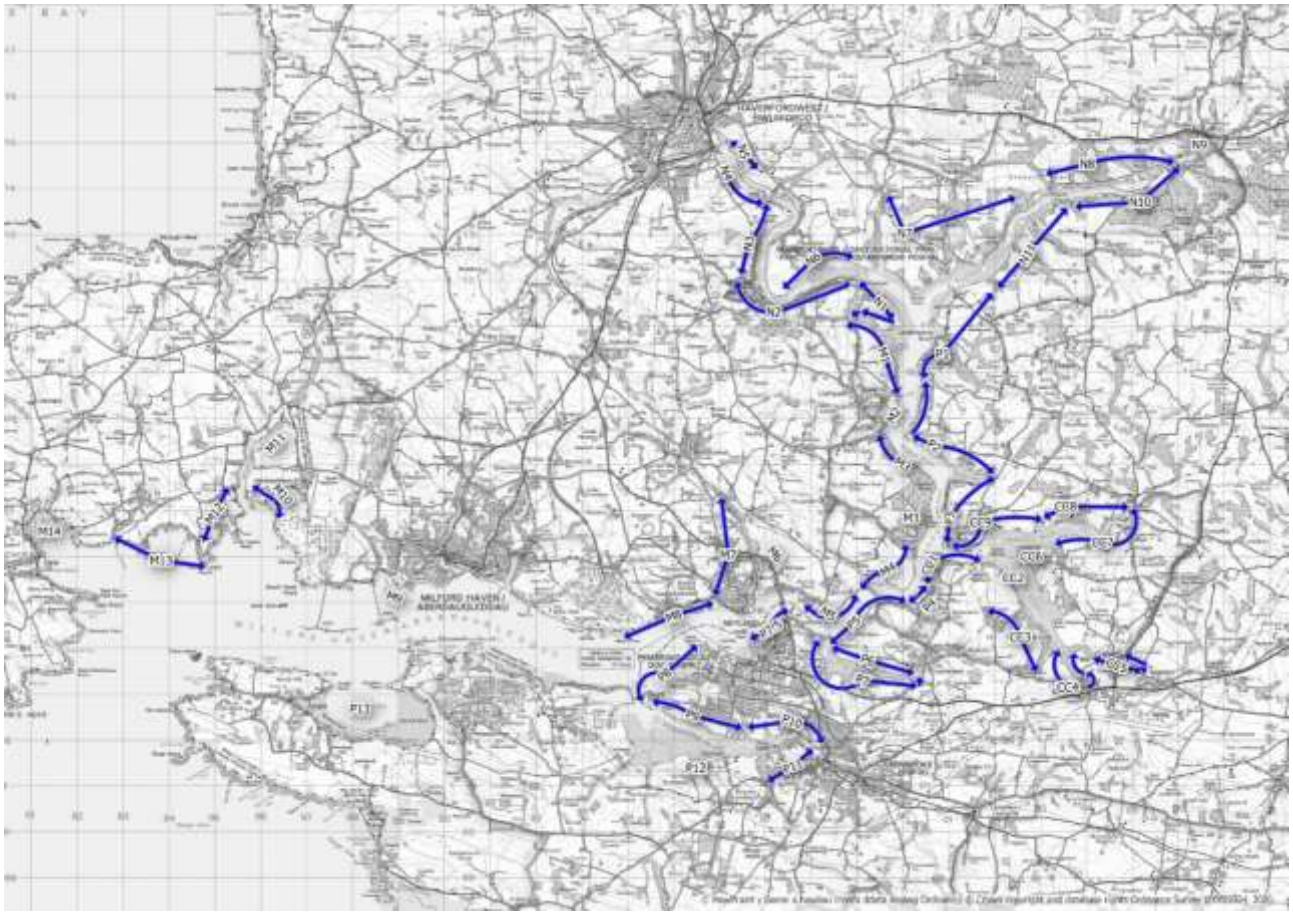

Figure 5: Survey stretches within the Milford Haven Waterway covered by the SWEPT project (see Appendix 10 for a list of site codes and location names).

2.3 Survey training and guidance

Training of volunteers took place via two evening training events in the month prior to the start of surveys, north and south of the waterway, with a small additional mop-up event to capture those that had been unable to attend either.

Following training and provision of a survey pack (see forms in Appendices 2-9), volunteer 'citizen scientists' carried out repeat monthly surveys of their allocated coastal stretches between November 2018 and February 2019. Volunteers were assigned a survey stretch and given a preferred 10-day window encompassing two weekends to complete a survey of their designated location. This gave a level of consistency to the data overall and was mostly adhered to. The survey windows were timed to try to overlap with low spring tides during daylight hours in order to aid access to the shore. They were as follows:

Survey 1: November 23rd – December 2nd (November 2018 survey)
Survey 2: December 21st – December 30th (December 2018 survey)
Survey 3: January 25th –February 3rd (January 2019 survey)
Survey 4: February 22nd –March 3rd (February 2019 survey)

Reminders and tips were sent out by email prior to each survey. Volunteers were asked to log and photograph each freshwater source found draining into the main waterway along their survey stretch. They were encouraged to walk along the foreshore, where it was safe to do so, or along adjacent public rights of way to locate these freshwater inputs. In order to spatially analyse the data collected it was important to get accurate location information. In order to do this, volunteers were asked where possible to make use of smart phone photo 'geo-tagging' capability; this method utilises the global positioning system (GPS) of mobile phones – volunteers can take a photograph of the testing site which in turn gives a GPS coordinate. This data was generally manually transferred to individual spreadsheets following the survey, either by the volunteer or by the project manager/data handler. If smart phones were not available, then participants were asked to provide 6 figure grid references to locate their records.

Whereas all freshwater inputs to the marine environment were logged, photographed, and briefly described, only a subset were tested for nitrate and phosphate levels. This was due to the finite number of tests available, and the need to spread testing across the waterway. Provision was made for volunteers to test five water samples (for nitrates and phosphates) per stretch per month. The number of water quality tests per volunteer pair per survey stretch varied according to need and availability. The Freshwater Habitats Trust kindly gave permission for use of their survey guidance materials which were incorporated into the survey pack (see Appendices 2-9).

In addition to the water sampling and description of water inputs, volunteers also recorded several in-field observations including any evidence of pollution, descriptions of any algal mats present and mention of any non-native species or points of interest.

To complement the individual volunteer surveys, there were also four canoe trips during January - March 2019 to enable testing of water samples in hard to access locations. Participants in these trips were briefed on the SWEPT project and shown how to take and record water samples.

2.4 Water quality testing

Nitrate (NO^3) and Phosphate (PO^4) low range field chemistry kits used by volunteers were Kyoritsu PackTest kits (Kyoritsu 2000), manufactured in Japan. Product information and costs can be found in Appendix 10. These kits had been used by the Freshwater Habitats Trust's Clean Water for Wildlife surveys[1], a large citizen science survey that aimed to raise awareness of the true extent of nutrient pollution and identify clean freshwater habitats in England and Wales. They were chosen for use in SWEPT because of their cost, ease of use and proven reliability for landscape scale projects (whilst recognising their limitations). Biggs *et al.* (2016) provides an in-depth analysis and discussion of the reliability of the testing kits; whilst McGoff *et al.* (2017) lays out a case study for the use of the kits for large scale citizen science projects such as SWEPT, providing evidence for their applicability where costs incurred from laboratory analysis are likely to be prohibitive. Further evaluation of the reliability and applicability of the test kits is provided in section 4.5.

[1] https://freshwaterhabitats.org.uk/projects/clean-water/

Procurement of the Packtest kits was necessary through European distributors Envirocare in Sweden and a lead-in time of 60 days required from ordering to delivery. These were ordered in August to ensure arrival in time for training of volunteers in October. Acquisition of the test kits proved to be the most challenging aspect of the SWEPT project. Manufacturers Kyoritsu had a 'conflict' with their primary distributor in Japan which then meant that the European distributors Envirocare could not get stock. In the end, Envirocare provided some tests free of charge to cover training needs in October, some tests (but not enough to cover the first month's survey) were obtained from the Freshwater Habitats Trust's Clean Water Project, and Envirocare then managed to provide some tests from existing stock that were received in time for the first survey (end of November 2018). The Project Manager was put in touch with Earthwatch[2] to see whether they had any surplus stock that they would be willing to sell and send quickly; 500 tests were procured which ensured enough tests for the second (December) survey. Ultimately, direct repeated contact with Kyoritsu resulted in a shipment being made direct from Japan which arrived just before the December survey and provided enough tests to complete the project.

Kyoritsu low range PackTest kits WAK-N03 and WAK-PO4(D) respectively measure nitrate-nitrogen with a minimum detection limit of 0.5 mg/L and phosphate-phosphorus with a minimum detection limit of 0.02 mg/L. Tests are based on colourimetry and judged by eye against a colour chart following the introduction of the test water sample and reaction with a chemical reagent within the testing tube. Each test takes either 3 minutes (nitrate) or 5 minutes (phosphate). The small testing tubes are easy to transport and use (see Figure 6).

SWEPT methodology noted results within the following seven ranges:

Nitrate ppm	<0.2	0.2-0.5	0.5-1	1-2	2-5	5-10	10+
Phosphate ppm	<0.02	0.02-0.05	0.05-0.1	0.1-0.2	0.2-0.5	0.5-1	1+

Figure 6: PackTest nitrate testing tube being compared against the colour testing chart provided in the SWEPT survey guidance.

2.5 Water quality test comparison with laboratory analysis

In order to provide a measure of the effectiveness of the Kyoritsu PackTest kits within the SWEPT survey, NRW provided for a small number of samples to be sent to the laboratory where water framework directive sample analysis is routinely conducted. Three SWEPT volunteers were provided with bottles to collect some water samples whilst carrying out SWEPT testing during survey 4.

[2] https://earthwatch.org.uk/2-uncategorised/54-freshwater-watch Earthwatch's FreshWater Watch project was originally launched as part of the HSBC Water Programme in 2012 and has gathered more than 20,000 water quality samples from around the world.

In addition, NRW monitoring staff, whilst carrying out statutory testing of some freshwater sites within the Inner Waterway catchment during May, June and July 2019, conducted some simultaneous PackTest testing and noted the results.

2.6 Data submission and collation

Volunteer pairs could submit data electronically via email or send in survey forms as hard copies.

Basic and ancillary survey details from the main survey sheet were encouraged to be submitted via Google docs where a form[3] was created to mirror the details provided on the hard copy form provided to volunteers in their survey pack. Freshwater input details and water testing results were encouraged to be submitted via an Excel spreadsheet template. Survey forms can be found in Appendix 7.

Photos could be emailed, or use could be made of data transfer software such as Dropbox, Google Drive and WeTransfer.

Data collation occurred as data came in following surveys and was carried out by the project manager with assistance from a student on placement with Pembrokeshire Coastal Forum. A checklist of completed surveys was maintained, and volunteers provided with help and reminders for data as required.

2.7 Data analysis

Data analysis was conducted primarily by the project manager with assistance from placement students. Mapping expertise using QGIS was provided by Pembrokeshire Coast National Park Authority. Statistical analysis was carried out with assistance from NRW.

3. Results

3.1 Surveys

For the 46 individual survey stretches, 45 were visited for survey 1, 43 for survey 2, 40 for survey 3 and 39 for survey 4. This gives a 91% completion rate for the 187 survey 'events'.

The online survey form was completed for 44 survey stretches for survey 1, 37 for survey 2, 33 for survey 3 and 34 for survey 4. Some participants posted or returned scans of hard copies and commented that, where details remained unchanged from the previous survey, they had not completed the survey electronically.

Time spent on surveying varied according to length of stretch and ease of access. Although on-line survey forms recorded time spent surveying, to ease administrative burdens a standard 3 hours was used for each volunteer for each of the surveys conducted (to include data entry and submission). In addition, 2 hours for training and 2 hours for the feedback event was also included.

A total of 1927 volunteer hours have been calculated for the project. This includes contributions from volunteers on the four canoe surveys and placement student time input. Additional to this was time given to the project by NRW staff.

Canoe surveys were conducted as follows:

Canoe survey 1 (23rd January 2019), Western Cleddau launching at Haverfordwest, exiting Black Tar.
Canoe survey 2 (10th February 2019), Eastern Western from Landshipping.
Canoe survey 3 (19th March 2019), Carew River from Lawrenny.
Canoe survey 4 (31st March 2019), Pembroke River launching at Llanreath and exiting at Bentlass.

[3] The link to this is https://goo.gl/forms/vLJ63SA9R7Uyv7El1

Figure 7: Canoe surveys were able to reach hard-to-access locations and test freshwater inputs to the Milford Haven waterway.

3.2 Data submission and handling

Data was collated into monthly survey spreadsheets and checked for any missing or obvious erroneous location points and entries standardised. Most volunteers submitted data electronically via the online google docs form and Excel spreadsheet template. Locations were provided either through coordinate recordings from GPS trackers, map references or through geotagged location photos of sample points where smart phones allowed. Location information was either manually extracted and filled in (around a quarter of volunteers usefully supplied forms with these pre-filled) or block extracted using the freeware BR's EXIF Extractor Software 2016 and then added to records. Locations were converted to decimal degrees to ensure easy processing and uniformity via various on-line tools provided by British Geological Survey and Rapid Tables[4]. The UK Grid Reference Finder online tool[5] proved to be useful for checking data points.

The amount of data coming in was time-consuming to process. However, once survey 1 was completed, and methods of data submission sorted (some Mac to PC compatibility issues), subsequent data processing became easier.

QGIS was used for mapping data. The ability to directly map geo-tagged photos was a useful function to quickly check location accuracy.

A list of surveys completed with the number of freshwater sources described and water samples tested can be found in Appendix 11.

[4] https://www.bgs.ac.uk/data/webservices/convertForm.cfm#degMinSecLatLng
https://www.rapidtables.com/convert/number/degrees-minutes-seconds-to-degrees.html
[5] https://gridreferencefinder.com/

3.3 Freshwater sources

SWEPT set out to record all freshwater inputs to the waterway within allocated survey stretches and test a sub-sample of those for levels of nitrate and phosphate pollution using Kyoritsu PackTest kits (see 3.4). Results saw a myriad of different freshwater inputs from seeps and mini waterfalls to pipes and streams (see Figure 8).

The number of inputs can obviously vary according to rainfall; December had the greatest number logged at 320 individual inputs across the 46 survey stretches. Descriptions of freshwater inputs included an estimate of average depth and width, flow, clarity of the water and whether there was any smell or sign of pollution. No detailed analysis has been done regarding these features, but it can be noted that the majority of inputs were clear and visibly unpolluted. Also, most water inputs were deduced to be direct run-off rather than from groundwater.

Figure 8: Some examples from surveys of the variety of freshwater inputs to the Milford Haven waterway.

3.4 Water quality data – temporal and spatial analysis

A total of 851 water samples were tested by individual volunteers walking stretches of the waterway over the course of the four surveys. An additional 30 water sample test results were provided by volunteers during canoe surveys.

Water samples were generally easily obtained due to the very small amount of water needed for the test. Where muddy banks or obstacles impeded access to water, volunteers came up with simple but ingenious ways of acquiring samples to test involving poles and cups.

SWEPT followed the thresholds utilised in the Clean Water for Wildlife survey when observing whether water samples were 'polluted' or not (Biggs *et al*. 2016). Nutrient pollution categories were:

	Phosphate (mg /L)	**Nitrate (mg /L)**
Clean water	**<0.05**	**<0.5**
Some evidence of pollution:	**0.05-0.1**	**0.5-1**
High or very high levels of nutrient pollution	**>0.1**	**>1**

This definition of clean water is equivalent to the EU Water Framework Directive (WFD) 'High' status.

Figure 9 illustrates that in the PackTest kits, the two lowest categories (<0.02 and 0.02-0.05 for phosphate; <0.2 and 0.2-0.5 for nitrate) are broadly equivalent to clean, or minimally impaired, values i.e. values less than 0.05 ppm[6] for phosphate, and less than 0.5 ppm for nitrate. Categories above these values are polluted. Therefore, nitrate samples above 1 mg/l and phosphate samples above 0.1 mg/l are considered polluted. Test results were recorded in range categories, with seven different options available for each (see survey guidance form in Appendix 8). For nitrate, four of those recorded 'polluted' samples; 1-2, 2-5, 5-10 and 10+. For phosphate 'polluted' samples were in the range 0.1-0.2, 0.2-0.5, 0.5-1 and 1+.

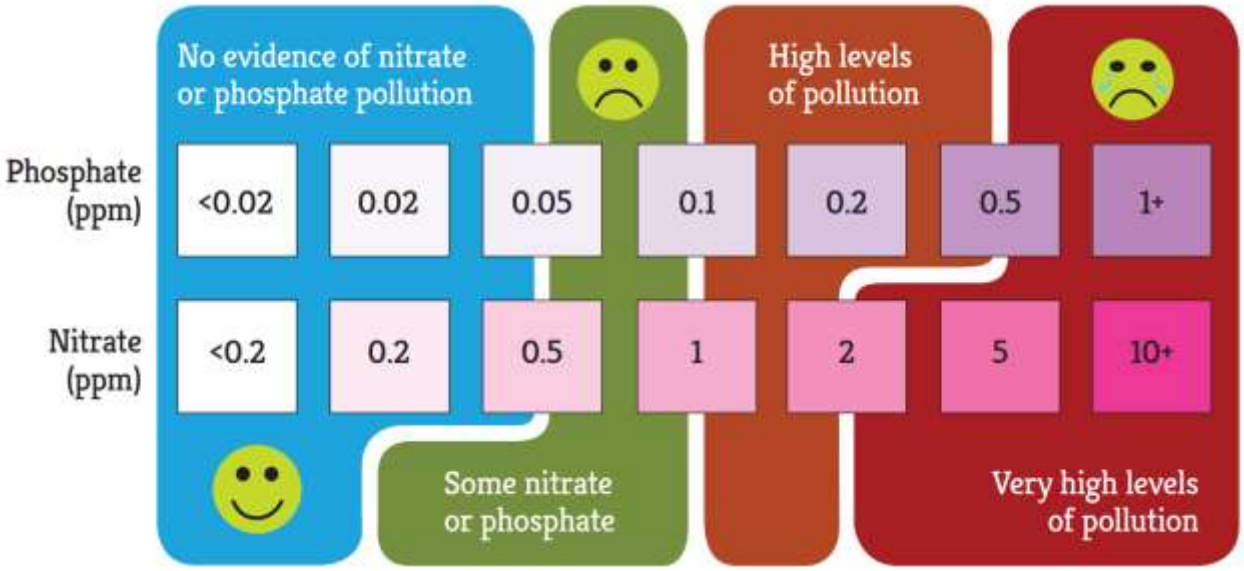

Figure 9. PackTest kit ranges and Clean Water for Wildlife thresholds for nitrate and phosphate, Biggs et al. (2016).

Mapped results for water quality data collected from the individual survey stretches can be seen in Figures 10 (nitrate) and 11 (phosphate). Data collected from the canoe surveys is added to survey 4.

The results show widespread high levels of nitrate across the waterway with many in excess of 1 mg/L. Results for phosphate are lower in terms of pollution with only a few data points above 0.1mg/L and none recorded in the highest two categories above 0.5mg/L. The results are a snapshot of inputs and show that nutrient pollution can be mainly attributed to high nitrate levels in the waterway, with pollution levels of phosphate showing it to be less of a problematic nutrient. The high levels of nitrate were not a surprise as this was expected, but the results clearly illustrate the widespread nature of nitrate pollution and provide local detail 'filling in the gaps' from NRW statutory monitoring points.

Using the Bartlett test of homogeneity of variances, no significant differences in nitrate water quality were found over the four monthly surveys in November 2018, December 2018, January 2019 and February 2019 which suggests that even though water testing results during surveys were merely snapshots, pollution levels were consistent throughout the project survey period and were not simply as a consequence of single events.

Detailed analysis of each specific stretch in terms of results and any local variability has not been possible within the project period, but all data and photos have been archived and can be made available as required.

[6] Note: ppm (parts per million) and mg/ L (milligrams per litre) are equivalent in this context. It is not always exactly true that the measure mg/L is the same as ppm. For many purposes if the fluid is water, its density is close enough to 1 at normal conditions for this to be true. Pure water at standard temperature and pressure has a density of 1 kg/L, therefore: mg/L = mg/kg = ppm. But that is only true when using pure water at standard temperature and pressure. Any other substance will have a different density and will not be a direct conversion between mg/L and ppm.

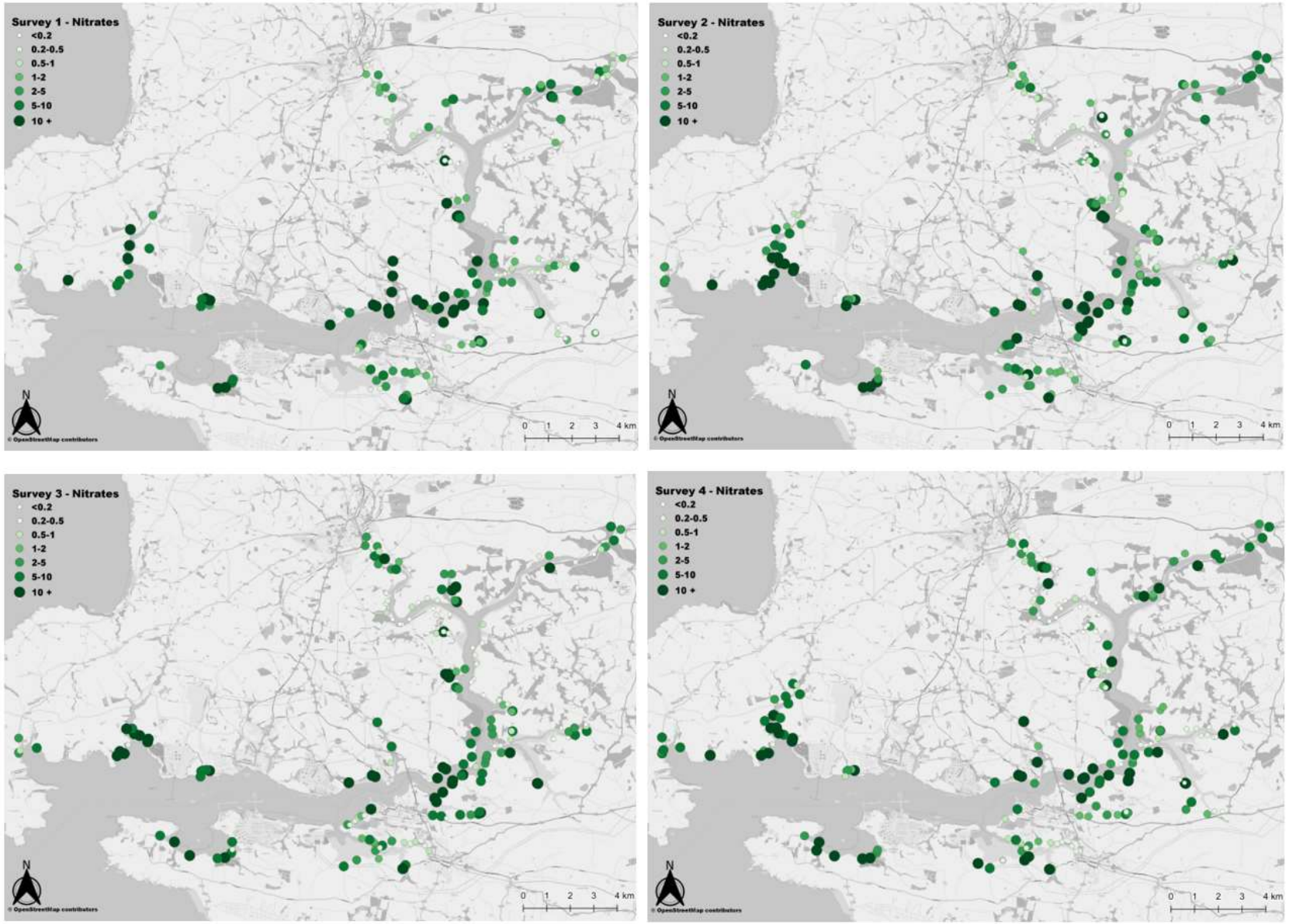

Figure 10: Maps of SWEPT nitrate water sample results in the Milford Haven waterway across the 4 survey months (Survey 1 November 2018, Survey 2 December 2018, Survey 3 January 2019 and Survey 4 (including canoe surveys) February 2019).

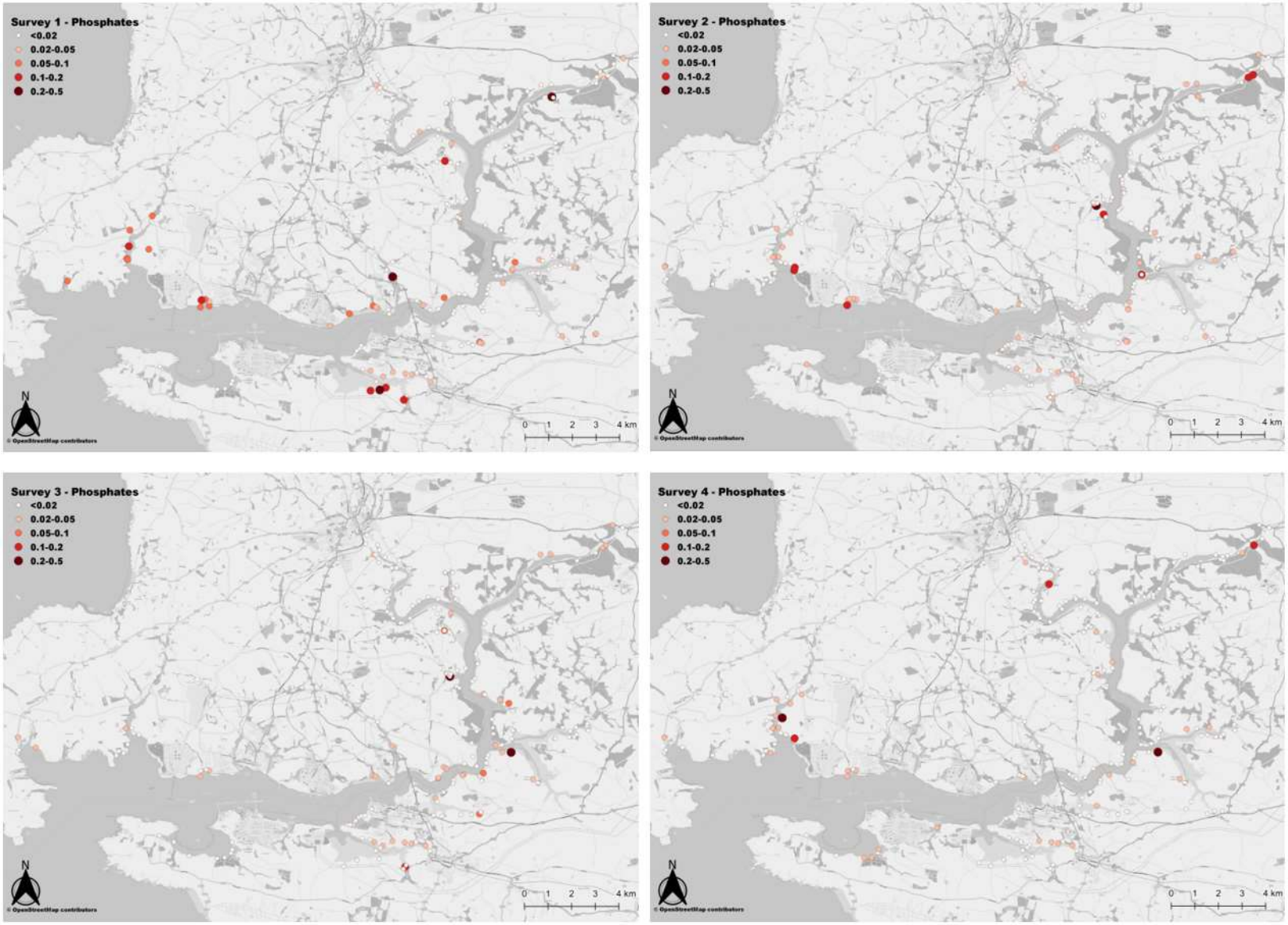

Figure 11: Maps of SWEPT phosphate water sample results in the Milford Haven waterway across the 4 survey months (Survey 1 November 2018, Survey 2 December 2018, Survey 3 January 2019 and Survey 4 (including canoe surveys) February 2019).

3.5 Water quality data – Laboratory versus SWEPT results

Alongside SWEPT sampling for the final survey in February 2019, three volunteer pairs also collected some water samples to be sent in to NRW for laboratory analysis. A total of 12 water samples were analysed and results are given alongside *in situ* SWEPT testing in Appendix 12.

In addition to this small test comparison, NRW arranged for their monitoring team members to use SWEPT methodology and Kyoritsu PackTests alongside water collection during statutory monitoring between May-July 2019. A total of 25 samples were taken, and the results are presented alongside their simultaneous laboratory tests in Appendix 12.

Results showed some differences in the laboratory versus PackTest test results. Laboratory tests are assumed to be more accurate than in field PackTest kit results. For the purposes of SWEPT, the importance in the field is to ascertain whether a freshwater source is 'polluted' or not (nitrate above 1 mg/l and phosphate above 0.1 mg/l).

Some statistical tests were applied to see if differences were significant or if there was a pattern discernible. When analysed within the ranges of clean water, some evidence of pollution, and polluted (see section 3.4) the data is found to be normally distributed. Pearson's test shows a significant positive correlation at 5% between PackTest and laboratory nitrate data. Figure 12 illustrates the results of each sample pair comparison. For those comparisons where there was not a match in result, the PackTest kit is seen to consistently record a lower concentration.

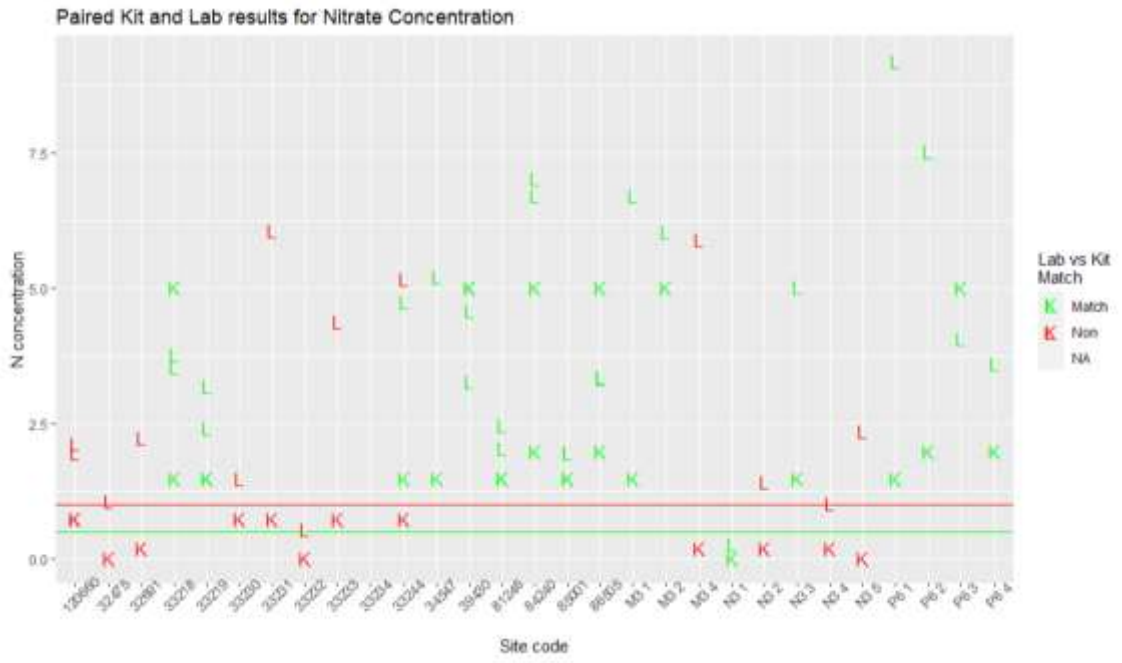

Figure 12: R Statistics analysis directly comparing Kit (PackTest) and Laboratory sample results for nitrate. Each column gives the results comparisons of a sample pair (K and L) or more at a single site. Results are compared according to whether they are in the categories of clean water (<0.5 mg/l), some evidence of pollution (0.5-1mg/l marked by the green line) or polluted (>1mg/l marked by the red line). If green, the pair shows a match. If red the pair is unmatched (e.g. kit is within the unpolluted range, but the lab result is in the range indicating some pollution).

Phosphate samples followed a similar pattern, although due to the very small concentrations of phosphate found, and the subsequent very small range in result, analysis would not have been meaningful.

3.6 Algal mat recording

As an obvious visual sign of elevated nutrient levels, algal mat recording was important and was given a dedicated section within the survey form. Recognising algal mat was initially difficult for volunteers resulting in many queries following the first survey. Surveyors found it easiest to start with the premise that only green algal mat growing on sediment was recorded, not that found on rocky substrate.

Figure 13: Algal mat at Garron Pill – unsightly opportunistic green macroalgae growing over pioneer saltmarsh and brown seaweed.

From the online survey forms completed and submitted for the first survey in November, 21 of the survey stretches reported zero coverage. Others ranged mostly between 10%-50% with four between 60%-80%. In subsequent surveys, online form entries rarely reported higher than 25% coverage and figures seemed to show a decrease in algal mat cover over the winter months. On survey stretch P5 (Cosheston Point to Mill Bay), algal mats were present between 25-40% coverage in November but dropped down to 5% coverage for the rest of the survey time.

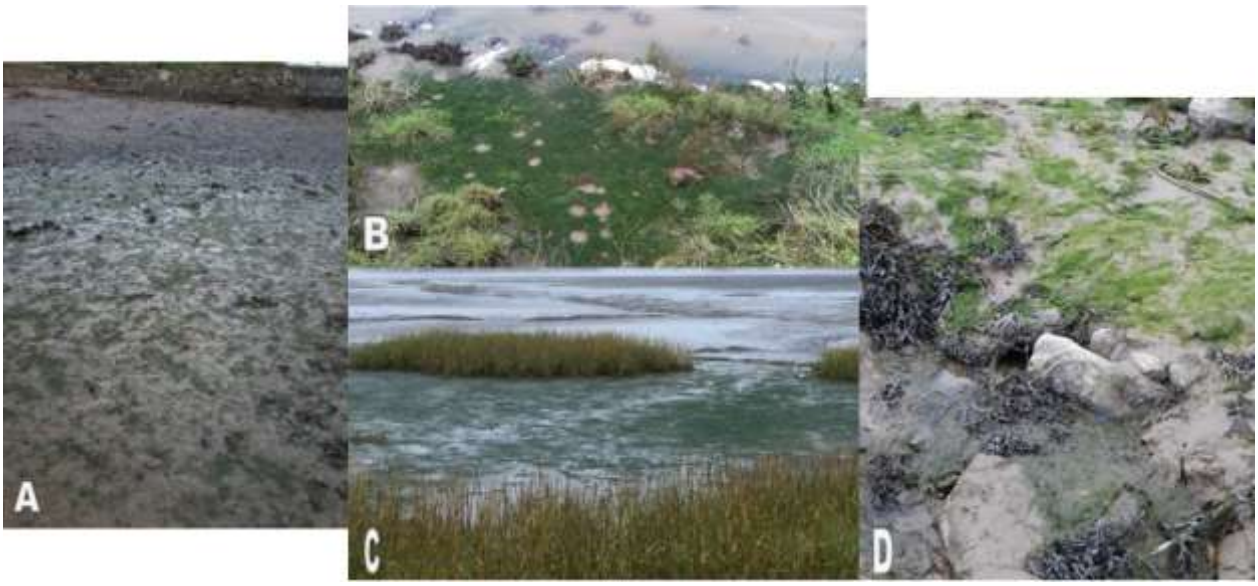

Figure 14: Examples of algal mat photos A: Lawrenny during Survey 1 in November 2018. B: Algal mat between Millin Ford and Slebech (November 2018). C: Algal cover in Cresswell (December 2018). D: Cosheston Pill (January 2019).

3.7 Pollution reporting

Immediate pollution reporting to the NRW hotline was encouraged in order to aid pollution prevention. All reports (5 during actual surveys, with others reported as a consequence of increased awareness) were dealt with and resolved by NRW staff. These included reports of slurry spreading close to water courses and whilst raining, fly-tipping and oil contamination.

In December and January, there were oil pollution incidents from one of the terminals (both incidents connected to the same equipment failure and subsequent leakage) and a large clean-up operation was activated. Volunteers were warned to keep a look out for oil on the shore. Some oil was noted as a result, highlighting the benefit of having trained volunteers on the ground.

Figure 15: Photos taken by SWEPT volunteers. Oil clean-up and contingency operation (December 2019) – boom to protect Sandy Haven inlet and County Council beach notice at Pennar.

A breakdown of some different categories of pollution records noted during the surveys can be seen in Figure 16.

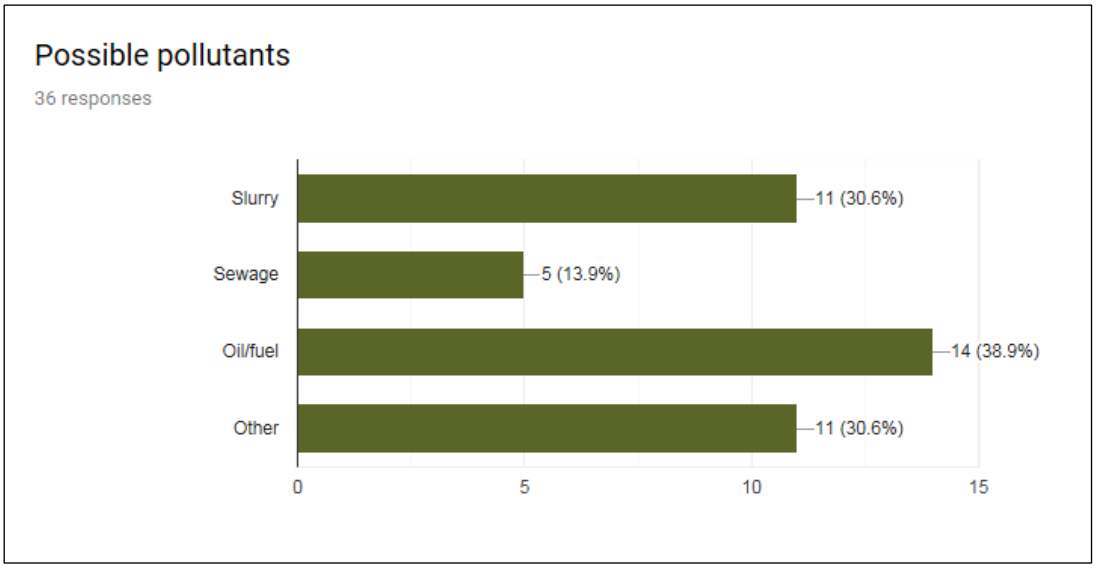

Figure 16: Pollution reporting section summary automatically generated from online forms.

3.8 Pollution recording – fly-tipping

Fly-tipping is illegal dumping of rubbish. This can vary in scale from the occasional bin bag, fridge or mattress to large quantities of waste dumped from trucks. It can be found anywhere - along roadsides, in lay-bys or on private land. Examples of some fly-tipped debris from surveys can be seen in Figure 17.

NRW is responsible for dealing with fly-tipping of commercial waste in excess of 20 tons or 20 cubic meters. Most quantities sighted are well below this and as such need to be reported to the local authority who are responsible for dealing with quantities under this threshold.

Reports in surveys 2, 3, and 4 were often repeated sightings of the same fly-tipped rubbish noted in the survey comments. In terms of new sightings, there were 8 recorded in November, 7 in December, 1 in January and 1 in February.

Figure 17: Example images of fly-tipping recorded during surveys. ***Top:*** *Construction waste/debris in Cosheston Pill.* ***Bottom:*** *Construction waste at Pennar.*

3.9 Pollution recording – marine "litter"

Marine 'litter' debris, whether accidentally or deliberately entered into the marine environment is pollution. A lot of this, due to its longevity, is plastic pollution.

Out of the 146 responses to this section submitted online, only 31 (21.2%) reported no marine litter. Figure 18 shows the breakdown generated by the online information.

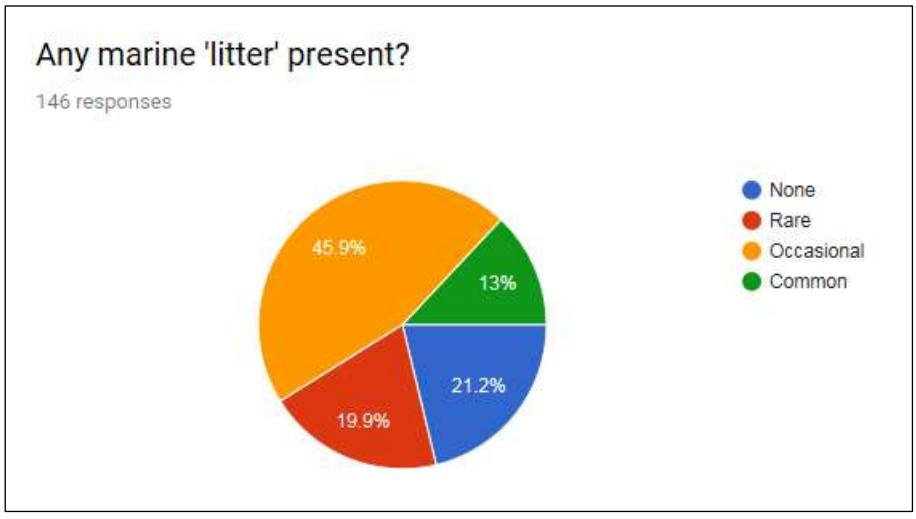

Figure 18: Marine litter summary automatically generated from online form content.

In terms of breakdown according to type, 71% of the litter reported contained plastics. There was also some sanitary litter. Assorted 'other' items included broken ship parts and two lawn mowers. Litter was noted from farming, fishing and the construction industry (building gear and materials) as well as non-sourced (community/visitor?) comprising mainly plastic bottles and food wrappers.

In some areas, considerable amounts of accumulated debris were found. Extreme high tides had clearly deposited floating debris in litter 'sinks' where material had been concentrated by the action of the tidal

currents and topography over a long period of time. Hidden by the low tree canopy in remote stretches, these piles of debris had remained undiscovered for years (decades by the bottle and can styles and labelling observed).

The discovery of a plastic pigeon (one of many colourfully adorning business premises in Haverfordwest) at Little Milford, nicely illustrated the 'city to sea' easy transmission of marine plastic pollution downstream. The pigeon was returned to a grateful Haverfordwest Business Circle who commented that thefts often sadly resulted in river dumping (see Figure 19).

Figure 19: This Haverfordwest Business Circle plastic pigeon, after several miles journey downstream, needed a little help to get home.

3.10 Non-native species recording

Not many non-native species were found along the shore. There were a handful of Pacific oysters noted, some slipper limpets and some *Sargassum muticum* (Japanese wireweed). Most of the species found were Japanese Knotweed and Rhododendrons growing alongside footpaths with others including Laurel.

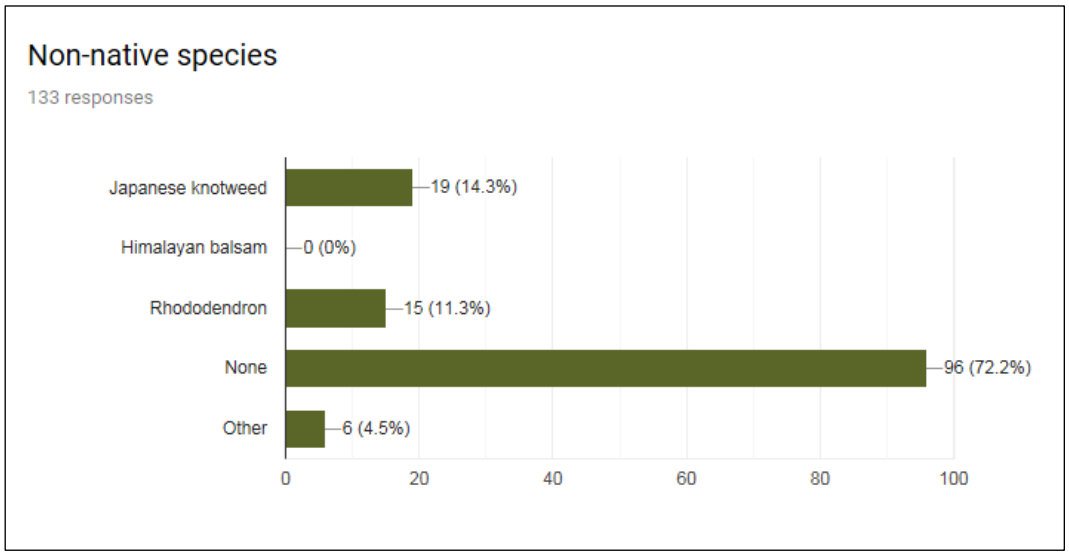

Figure 20: Non-native species reporting section summary automatically generated from online forms.

3.11 Human activity and other survey observations

Human activity noted whilst on survey was dominated by walking and dog-walking (see Figure 21). Other activities that were recorded included wildlife observing, recreational canoeing/yachting, cycling, bird watching, social gathering (evidence of small fires, litter from eating and drinking), and horse riding.

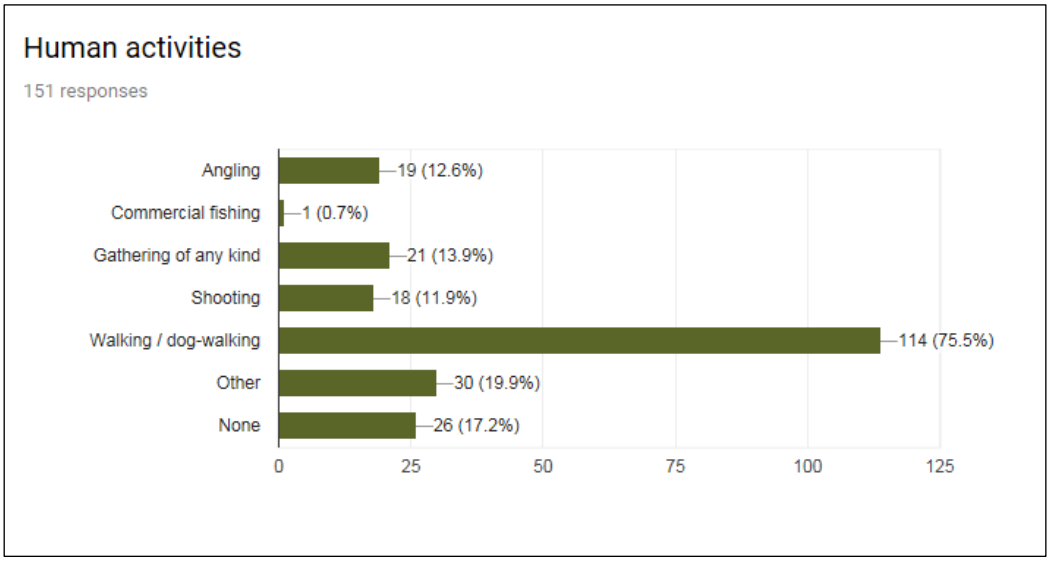

Figure 21: Human activity reporting section summary automatically generated from online forms.

One miscellaneous observation that was raised repeatedly was that of abandoned derelict boats (see Figure 22). As well as being an eye-sore, there were concerns over pollution (fibreglass, corroding batteries, fuel contamination).

Figure 22: One of the many abandoned or derelict boats noted whilst on survey.

4. Discussion

4.1 Use of survey volunteers (citizen scientists)

Although initially inundated by volunteer offers, SWEPT benefitted due to the increased survey coverage made possible. The higher than expected number of participants did increase the time input needed for organisation and data handling, but the resulting large amount of data generated was welcomed. The only negative knock-on effect was that there was less time available within the project for data analysis and reporting.

From a grant funding point of view, the commitment from volunteers in terms of in-kind support far exceeded the budget. In hindsight, the size of the overall project budget could have been much higher had the in-kind proportion been correctly anticipated.

Overall positive responses about participation in SWEPT were gained from volunteers following feedback questionnaires (Francis, 2019) after survey 1. Francis (2019) concluded that the methodology for volunteers was well planned and easy to adopt. The training and equipment were well received, attributed to the vast amount of instructions and background information given to volunteers and the easy to use PackTest kits. The main difficulties faced by participants were in GPS location recording and data submission. These were mainly all ironed out after the first survey; this ability to learn from previous experience is an advantage of repeat surveys.

Over 90% of volunteers stated that SWEPT had improved their scientific knowledge, 76% of volunteers felt that participation had benefitted their wellbeing and 100% would be interested in participating in a similar project in the future. Francis (2019) concluded that participation leads to benefits to volunteers' wellbeing and scientific understanding regardless of demographic in concurrence with literature on the topic.

It is likely that the attraction of SWEPT to volunteers lies not only in eudaimonic wellbeing (meaningfulness) but also in the simplicity of water testing as a 'scientific' activity; there is no 'wrong' result, as opposed to species monitoring where there exists potential concern over making an inaccurate identification.

It is interesting to note that feedback surveys gave the top motivations for volunteer participation in the project as *environmental concern* and *personal interest*. Figure 23 shows a summary of the demographic breakdown of volunteers.

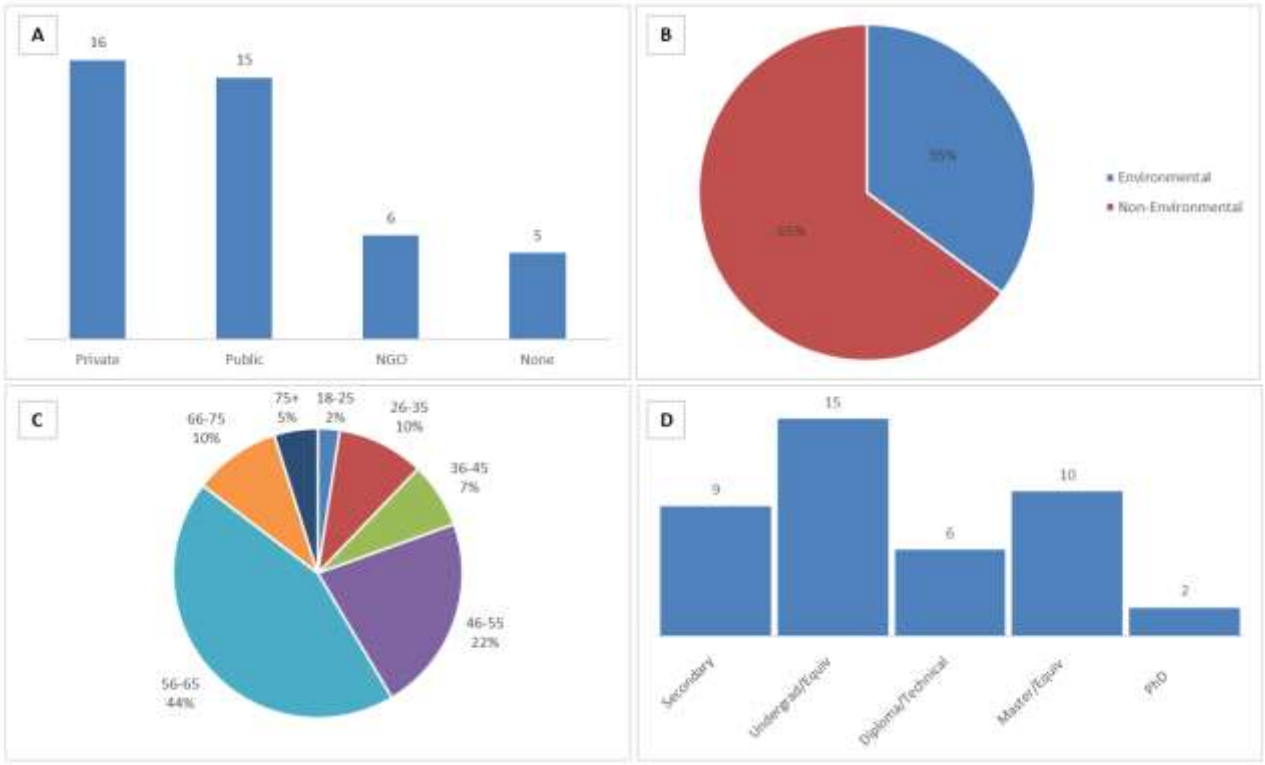

Figure 23: Summary of volunteer demographic from respondents (N = 42) from Francis (2019). ***(A)*** *Employment sector (total count value above bar).* ***(B)*** *Percentage of respondents working within the environmental vs non-environmental sector.* ***(C)*** *Percentage of respondents by age group.* ***(D)*** *Level of education of respondents (total count value above bar).*

4.2 Data handling and analysis

SWEPT collected a lot of detailed information about a wide area, including little-visited remote locations. The full data set remains available for more detailed investigation and analysis; this was not feasible in the lifetime of the project due to time spent on data handling. Use of a mobile survey app such as Open Data

Kit[7] (ODK) could greatly aid data submission and subsequent collation in a similar future project, reducing data processing/checking time. This free app uses custom-made forms to collect data and send the records back to a central point such as project manager or data analyst (it can cache the records to send when an internet connection is available). It can also collect a GPS location. ODK can be used with google drive as the server for records (utilising Google sheets) and photographs. Spreadsheets on Google Drive are limited to 400,000 rows and there is only 15GB of storage with a free account but that should be ample for a SWEPT type project. An alternative app is Survey123. This allows data entry directly into downloaded forms and adds the information straight into a GIS database, but it is specific to mapping software ArcGIS which is not open source like QGIS.

4.3 Freshwater sources

The scale of diffuse pollution is driven by many forces, ranging from soil chemistry to the density of drainage types, but the largest external impact is precipitation, both in its intensity and duration. The leaching and transport of nutrients into waterbodies from the land is a natural process. However, this process is exacerbated through human input, particularly in areas of intense agriculture where land can become increasingly compacted and natural drainage impeded.

According to data from the Meteorological Office (Met Office, 2018a), rainfall in November 2018 was extensive and increased towards the second half of the month coinciding with the survey.

Continuous rainfall was seen during December 2018 in both the lead up to and during the survey period (Met Office, 2018b). Continuous rainfall can saturate the topsoil and underlying geology. Saturated land will see a higher proportion of surface run off taking with it topsoil along with any associated nutrients or fertiliser etc. The prolonged rainfall may account for Survey 2 containing the largest number of polluted samples (where nitrate levels were above 4.99 mg/l) of any survey, an increase of 20% from the previous survey (Gil 2020).

The lowest rainfall volume of the survey period coincided with Survey 3 in January 2019 (Met Office, 2019a). Survey 3 resulted in the lowest percentage of polluted samples with 59% of nitrate samples above the 1 mg/l threshold (Gil 2020). Survey 4 starting at the end of February 2019 saw an increase in polluted samples by 35% from the previous survey in January. February precipitation levels traditionally see a reduction of 31% compared to January (Met Office, 2011). However, unseasonably low precipitation levels in January, coupled with prolonged rainfall throughout February (Met Office, 2019b) over the catchment area may account for this increase in polluted samples.

Whilst high precipitation levels can lead to an increase in surface runoff and as a result, nutrient inputs into a waterbody, so can groundwater, albeit through a longer timeframe. In some catchments with well-drained geology, inputs of nitrogen components occur through groundwater by as much as 97%, and in moderately draining soils such as those found in Pembrokeshire, 50% of nitrates may reach a waterbody through groundwater (Mellander *et al*., 2012). Groundwater is slow moving and can take days to centuries to surface, potentially many miles from where it first entered the ground. As a result, pollutants entering the ground may not be detected until many months later. As the majority of water inputs noted during surveys were deduced to be direct run-off rather than groundwater, this suggests that pollutants recorded over the four months were not down to leaching.

[7] Further information on Open Data kit is available at https://opendatakit.org. Link to the app page on google play: https://play.google.com/store/apps/details?id=org.odk.collect.android. A short video that gives an overview and a demonstration of how it works: https://www.youtube.com/watch?v=GnXwGmhaI9U.

4.4 Water quality data – temporal and spatial analysis.

Each of the SWEPT surveys provided an insight into the nutrient levels at a specific point in time over the four months surveyed as opposed to a continuous temporal analysis. Statistical analysis showed no significant difference in nitrate water quality over the four monthly surveys suggesting consistent pollution levels throughout the project survey period rather than levels as a consequence of single pollution events.

Taking a sub-set of complete repeatable inputs across the four surveys, and therefore those directly comparable (omitting 139 of the 851 sample results), Gil (2020) reports that the percentage of nitrate samples recorded as above 1mg/l varied from 70% in survey 2 to 59% in survey 3. These coincide with the periods of highest and lowest rainfall within the surveys respectively.

Nitrate levels:

The results for nitrate show a wide scale distribution of pollution, with many hotspots consistent throughout the survey period, for example Sandy Haven, Angle Bay and upstream of Milford Haven and Pembroke Dock. Levels above 5mg/l (and even 10+mg/l) were not uncommon.

NRW (2016) analysis of the five statutory waterway sampling stations shows an overall gradient of decreasing mean dissolved inorganic nitrogen (DIN) (and dissolved inorganic phosphorous DIP) concentrations with increasing salinity from the upper estuary to the mouth of the waterway from 2009 to 2012. Levels during this time, and previous historic records, do not reach the high levels of pollution found during SWEPT although the data presented is from the summer when there is lower freshwater load and higher algal uptake. Average winter DIN levels are shown to not exceed 1.2mg/l at the uppermost station in the waterway just downstream of Port Lion. Further detailed data analysis is available from stations above the influence of seawater in the Eastern and Western Cleddaus where DIN levels are generally higher than the waterway stations. For example, NRW (2016) give the average DIN concentration from the Eastern Cleddau over the five years 2010-2015 as 2.16 mg/l.

The measurement of DIN is one that includes nitrates plus nitrites plus ammonium. It is the most bioavailable form of nitrogen used by algae. NRW have calculated from available data that 93% of the DIN load to the waterway comes from the catchment (losses from agricultural land), as opposed to the direct discharges from sewage treatment works (STWs) and Environmental Permitting Regulation installation discharges (e.g. Liquefied Natural Gas (LNG) terminals, Pembroke Power Station and the Valero oil refinery). The direct STWs contribute 5% of the DIN load, while EPR-installation industries contribute 2% as a worst-case scenario, including the contribution from their aerial emissions (NRW, 2016).

Adding to the nutrient load in the waterway will also be ammoniacal nitrogen which oxidises to nitrate. Potential sources of ammoniacal nitrogen are ammonium nitrate fertiliser, wastewater treatment plant effluents, sewer and storm overflows, septic tank effluents and animal slurry. Kyoritsu do an ammonium PackTest which measures both ammonium ion (NH4+) and ammoniacal-nitrogen (NH4+-N) and works in the same way as the nitrate and phosphate tests. Importantly, unlike these two tests, it is not affected by the presence of saline water and so is suitable for seawater samples.

Nutrient pollution can also be a marker for other pollutants which are too difficult/expensive to measure (e.g. pesticides, heavy metals). Waterbodies affected by nitrate pollution caused by farming in their catchments are quite likely to also be exposed to unnaturally high sediment runoff and intermittent pesticide pollution. Likewise, nutrient rich runoff from urban areas will often have high levels of heavy metals, sediment, pesticides and sewage waste Biggs *et al.* (2016).

Gooday *et al*. (2016) provides further explanation of the role agriculture plays in this catchment in increasing the levels of nitrate. Gooday *et al*. (2016) suggest that for the waterway to reach good status a significant reduction in livestock head is necessary, as improvements in practices alone would not allow for enough of a reduction in the nitrate load entering the system.

Phosphate levels:
No levels of phosphate entering the waterway were recorded as highly polluted. Some match can be seen between the highest levels recorded and the location of sewage treatment works (STWs) (see Figure 3).

NRW (2016) indicate that direct STW discharges account for 32% of the DIP load to the waterway, with the remainder (68%) coming from river/catchment inputs. The largest STW contributions come from Merlin's Bridge (13%), Milford Haven (5%) and Pembroke Dock (3%) STWs.

Importantly, manufacturers information that came to light only after sampling suggests that sample temperature for phosphate should be kept in the range 20-40^{o}C. Lower temperature necessitates longer reaction time. For example: at 10°C, the response time for phosphate is 20 minutes rather than the normal 5 minutes. It is highly possible that the low temperatures during the winter sampling may have resulted in underestimates of phosphate levels. A solution to sampling in cold weather, or if the water itself is cold, is to collect the water sample in a small bottle and warm it in hands, or a pocket before testing. This could also have contributed to lower results in comparison to laboratory tests although those taken in May to July would have been closer to the suggested temperature range than those taken in the winter.

The mapped nitrate and phosphate water quality data generated provide a good visual summary of what was gathered through the SWEPT project. This data would not have been gathered otherwise and fulfilled the aim of providing more local detail on nutrient pollution around the Milford Haven waterway (filling in some gaps in data coinciding with the grey areas marked on the NRW map in Figure 3) to supplement Water Framework Directive statutory monitoring. This data can help to inform the case, under the provisions of the Nitrates Directive, for designation of the waterway as a Polluted Water (Eutrophic) and for the catchment draining into the waterway, and which contributes to the nitrogen pollution, to be designated as a Nitrate Vulnerable Zone (NVZ).

These results are already being used by NRW officers to help to target resources to tackle nutrient pollution in the waterway catchment and are helping to join up issues for management of natural resources, informing area statement work. Results and awareness of the SWEPT project have been communicated to the Wales Land Management Forum and the Agricultural Pollution Sub-Group. NFU Cymru expressed an interest in use of the testing kits and were given the surplus tubes at the end of the project to give to individual farmers who were interested in doing their own monitoring. Involvement fosters a sense of stewardship in people, which helps with compliance of regulations and reduces enforcement costs (Giakoumi *et al*., 2018).

Despite awareness within the catchment of the problem of nutrient pollution and the possibility of an NVZ, the problem has yet to be addressed. Pollution incidents continue to be reported against the already high and widespread background level of nutrients in the area.

On 21st January 2020, Rural Affairs Minister Lesley Griffiths said "Farmers are not just food producers. Their role as stewards of the rural environment is vital to the well-being of Wales. Many do superb work managing and improving soils and habitats and I know the sector can rise to the challenge on water pollution - something that is so detrimental to public health, nature and the rural economy."

The possibility of an NVZ, which could even be an all-Wales NVZ, is not welcomed by the agriculture industry because of the impossible financial burden that it could bring to businesses. Information obtained by NFU Cymru from NRW, obtained as part of a freedom of information request, said that NRW did not have enough resources to implement the new rules if they applied to all farm businesses across Wales. The revelation has added to the union's growing concerns that a decision on Welsh Government's All-Wales NVZ proposals is being taken without a comprehensive understanding of costs and impacts (Western Telegraph, February 7th 2020).

The delay in introduction of new regulations, and the uncertainty about what they will entail is damaging not only to the target industry, but also to the wider environment and other important employment sectors in Pembrokeshire.

4.5 Water quality data – statutory monitoring and SWEPT data comparison

The nitrate and phosphate PackTest kits used mostly *underestimated* the level of pollution when compared to NRW laboratory sample results. This means that it is highly unlikely that a PackTest result will give a false positive (i.e. show that a clean freshwater source is polluted when it is not) but it is also very likely to underestimate the extent of any pollution that *is* present. This was also the finding of Biggs *et al.* (2016) on evaluating PackTest nitrate and phosphate kits for the Freshwater Habitats Trust. They found that the kits will slightly over-estimate the amount of clean water present, but they are highly unlikely to over-estimate the level of either phosphate or nitrate pollution in waterbodies.

Manufacturers information that came to light only after sampling suggests that sample temperature should be kept in the range 15-40^{o}C for nitrates and 20-40^{o}C for phosphates; testing at temperatures lower than this necessitates a longer reaction time. This could have contributed to underestimates of levels, more so for phosphate than for nitrate, although the test comparisons in May to July should not have been significantly affected as temperatures would have been closer to the recommended range.

Biggs *et al.* (2016) concluded that although none of the field tests they investigated approached the accuracy of laboratory analysis, and all had their limitations, Kyoritsu PackTest kits compared favourably with professional scientific testing and were a simple, rapid and effective way to identify nutrient pollution, especially in large landscape-wide surveys where the costs of laboratory analysis are likely to be prohibitive. SWEPT results and analysis echo those findings. PackTest kits are seen to be a quick, easy and cost-effective way for citizen scientists to identify nutrient pollution over large areas.

The data collected by SWEPT volunteers is not to the same standard of accuracy as NRW and their Water Framework Directive statutory monitoring, however, this was never the intention. The aim of SWEPT was to provide a detailed local map of hotspots of nutrient pollution entering the waterway, using a low-cost method which would not have been available otherwise. Aside from cost, an advantage of PackTest results is that they are instant (3 minutes for nitrates, 5 minutes for phosphates) and can be determined in the field. This ability to 'see' water pollution is a valuable one. The accuracy of the data is more than adequate to meet the aims of the research and this is further supported by the findings of McGoff *et al.* (2017).

Further evaluation of the reliability and applicability of the testing kit is provided in Muneoka *et al*. 2014.

An alternative to Kyoritsu PackTest kits is a product from Kasahara Chemical Instruments Corporation in Japan (via European distributors Envirocare in Sweden). This product came onto the market after SWEPT surveys had been completed. The product similarly uses colourimetry with the same reagents as PackTest. However, rather than individual plastic tubes for each test carried out, a testing cell is included for use multiple times. Reagent is provided in sealed packets to add to the testing cell as required. The advantages of this product are that use of single-use plastics is reduced and product shelf life is 24 months instead of 12. However, for a project like SWEPT with participation by a large number of volunteers, the PackTest individual single-use testing tubes are preferred from both a logistical and a health and safety perspective.

4.6 Algal mats

Marine macroalgae derive their nutrients from the water column and under the right conditions can colonise, grow and reproduce quickly. As a consequence, they tend to respond rapidly to changes in nutrient concentrations and so presence of algal mat can be a good indicator of elevated nutrients. Algal mat tends to be found in areas of reduced water flow, like small pills, where flushing of nutrients is restricted. Once eutrophication occurs it can be difficult to control as nutrient build up continues to increase as the macroalgae mats grow (Meyer-Reil and Köster, 2000). Algal mat should not be confused

with the thin ribbon or hair-like green *Ulva spp*. algae that colonises areas of freshwater influence on the shore, where it outcompetes other seaweed species.

NRW monitoring staff note percentage cover of algal mats during summer statutory monitoring visits, but little data exists for the winter months. Algal mat is known to proliferate during the warmer summer months in the waterway and so thick amounts were not expected during the SWEPT surveys. However, November still saw some areas of obvious and substantial coverage. Data collected shows how algal mat can persist in some areas even through the winter months. This provides extra useful detail to add to Water Framework Directive monitoring and information to add to evidence of Category II opportunistic macroalgae response parameter impacts.

4.7 Pollution reporting follow-up

Having volunteers repeatedly visiting often remote and large stretches of the waterway was useful in order to improve pollution prevention capability. That pollution concerns were raised and also quickly followed-up and resolved by NRW was testament to the dedication of volunteers and also the processes in place within organisations to respond to reports.

Observations on fly-tipping were often repeated. Those that could not be easily traced to an origin may still need following up and removing. Fly-tipped waste is unsightly and of potential harm to wildlife. It can also encourage further fly-tipping in the same area.

Marine litter hotspots highlighted during surveys became the catalyst for a **Big River Clean-up** organised by the Pembrokeshire Coast National Park Authority. This resulted in 256 bags of litter being cleaned from the waterway and also as much of it recycled as possible (this included 2807 plastic bottles, 461 glass bottles and 1271 cans). It was clear that much of this had been in place for decades. Whilst clearing accumulated debris doesn't solve the problem, it does help to reduce pollution (especially of micro-plastics eventually) further downstream. Clean-ups are also good opportunities to raise awareness of the fact that urban littering particularly of plastic pollution is directly linked to problems in river, then estuary, then marine systems as pollution is carried downstream. This is an example of the importance of joining up actions between the Marine and the South West (terrestrial) Area Statements, addressing issues highlighted in the Statements by NRW and collaborators.

Figure 24: Pembrokeshire Coast National Park's Big River Clean 2019 summary poster and image of debris accumulation at extreme high-water mark hidden beneath the tree canopy in the Western Cleddau.

4.8 Other survey observations

As many survey stretches necessitated walking along public rights of way near to the shoreline, reporting of terrestrial non-native species was encouraged in order to add further value to surveys and to increase interest for participants. Whilst many of these reports will not comprise new data, local land managers including Pembrokeshire Coast National Park Authority may find value in these observations.

The number of derelict boats reported warrants further follow-up. In some cases, local knowledge was able to report suspected owners, but this was often not the case. The reasons why obviously derelict and abandoned vessels are left to rot are varied. Sometimes neglect can simply render vessels useless and finances may prevent restoration and/or removal. In some cases, it is thought that derelict vessels are moored/left simply to hold a space and prevent others from utilising the area perhaps inconveniencing a local resident. Whatever the reason from both a pollution prevention and a landscape point of view, the presence of these vessels within a Special Area of Conservation and often also within a National Park is not appropriate and needs to be addressed. This is something that local organisations including Pembrokeshire Coast National Park Authority and the Port of Milford Haven will need to collaborate on to resolve.

4.9 Student support and theses

SWEPT provided data for and supported two undergraduate theses. Cardiff University Marine Geography student Rhys Francis received a first for his thesis "*Evaluating the use of Citizen Science for Water Quality Monitoring*" submitted in January 2019 (Francis, 2019). Cardiff University Marine Geography student Abigail Gil helped with methodology and data handling during the period from August 2018 to February 2019 whilst on placement with Pembrokeshire Coastal Forum, and went on to submit her thesis "*An Analysis of Nitrate Levels within the Milford Haven Waterway and the Contributions of Management in Reducing these Levels*" in January 2020 for which she also received a first.
Southampton University Marine Biology undergraduate Jannah Kehoe was enormously helpful in data analysis whilst on a 3-week placement with the Port of Milford Haven in June/July 2019.

4.10 Awareness raising

Fundamentally, SWEPT aimed to raise awareness of the issue of nutrient pollution (especially the effects of nitrates from agricultural run-off) and its impacts on the marine environment. Many stakeholders do not understand the impacts or significance of downstream impacts of nutrient pollution. The fact sheet on 'why is nutrient pollution an issue' (see Appendix 3) was provided to volunteers as part of the survey pack and was also promulgated more widely to businesses and agricultural and urban communities via the Building Resilience into Catchments (BRiCs) project. Participation, social media activity, articles in various publications and increased exposure as a result of a national award all contributed towards increasing awareness.

Figure 25: Various media articles helped to raise awareness of the SWEPT project and the negative impacts of land run-off on the marine environment.

SWEPT proved to be very popular with participants and undoubtedly raised individual awareness of the issue of land run-off affecting the marine environment. Volunteers were surprised that the Agricultural Codes of Practice that farms should follow are not legislation, and therefore not enforceable. Some wonderful feedback quotes were collated by Francis (2019) and include:

"I think that projects like this have the potential to dramatically enhance the detail of our scientific understanding of the waterway, and this increase in understanding should lead to improved decision-making and policy-making."
"SWEPT has been intellectually stimulating. It even provoked me to read a short book about farming! With fifty pairs of volunteers talking to friends and family, it spreads awareness of the risks/threats to our waterway."
"It's been an interesting activity and has allowed me to raise the issue of nitrate pollution with my local friends and within the community."

SWEPT won a national award which helped to raise the profile of the project and the issue of land run-off. Project partners and participants were all delighted at the success of the project. **The Park Protector Award**, run by Campaign for National Parks, the charity for England and Wales' 13 National Parks, celebrates and supports projects that make a difference to protecting some of the most famous countryside in the world. Six projects from across the UK were shortlisted for the Park Protector Award in a year that saw the most applicants apply in the competition history. SWEPT was the only project from Wales to be shortlisted. The award included a grant of £2000 sponsored by the Ramblers Holiday's Charitable Trust. News[8] of the award went out in a press release and on social media in July 2019. Anne Bunker Senior Marine Advisor for Natural Resources Wales said "I am delighted that the work with the SWEPT project has been recognised. Solving issues that affect the marine environment can be challenging, and it's been a privilege to work with our partners and fund this project. The Milford Haven waterway is a rich and important habitat and protecting Wales' waterways and the wildlife that relies on them is one of the most important jobs that we do. The high levels of nutrients that can be found in the marine environment have an adverse effect on sensitive habitats like seagrass and maerl that are found in the Milford Haven Waterway."

Figure 26: Sue Burton, Pembrokeshire Marine Special Area of Conservation Officer, and Anne Bunker and Simon Shorten from Natural Resources Wales received the Campaign for National Parks Park Protector Award for SWEPT at a parliamentary reception on July 10th at the House of Commons.

A SWEPT sharing event is planned for later in 2020 in order to more widely promulgate the project's experiences. This is aimed at land managers and the agriculture sector as well as project partners and participants. A feedback event was held in May 2019 that reported back results to volunteers and discussed the project, but external interest in the project has prompted the need for a wider sharing event.

[8] A link to the award: https://www.cnp.org.uk/news/outstanding-achievement-national-park-projects-celebrated-time-crisis-our-countryside And on Twitter: https://twitter.com/PembsMarineLife/status/1148989544164995073 and https://twitter.com/PembsMarineLife/status/1149341763750027265

5. Conclusion and Recommendations

SWEPT set out to better understand levels of nutrient pollution on a local scale within the Milford Haven waterway (and to supplement NRW monitoring). This was achieved through the results of 881 tests for nitrates and phosphates taken throughout the waterway from Dale right upstream to tidal limits at Haverfordwest, Canaston bridge and the Carew/Cresswell and Pembroke River tributaries.

Nitrate levels in excess of 10ppm were widespread. Phosphate was generally low throughout, with only a handful of survey sites with levels recorded higher than 0.2ppm, although it is acknowledged that low temperatures during sampling may have resulted in an underestimate of levels.

Data comparing the accuracy of SWEPT results against NRW laboratory analysed samples generally show SWEPT PackTest tubes under-record pollution. They are seen to be a simple, rapid and cost-effective way to identify nutrient pollution across large landscape-wide surveys in line with previous studies (Biggs *et al.,* 2016). The instant results are valuable and an excellent aid to raising awareness of nutrient pollution.

The ease of attracting volunteers to participate in the project was a surprise; people were keen to take an active role in helping to make environmental improvements. SWEPT methodology was designed to be as easy as possible. This was helped by use of the Kyoritsu PackTest kits and existing guidance from the Freshwater Habitats Trust. Feedback from SWEPT participants was favourable. Volunteers commented that the training and support was good. Participation led to benefits to volunteers' wellbeing and scientific understanding regardless of demographic (Francis, 2019).

SWEPT saw approximately 150 volunteers (over 100 conducting regular individual surveys) spend a total of over 1700 volunteer hours on the project and take 2105 photos to log water sources, algal mats and features of interest. Although the focus was on water quality, surveys included recording of all pollution concerns, non-native species, and general things of interest to provide a broad and interesting experience for participants as well as to make best use of the citizen scientists and add value to the data collated.

Immediate pollution reporting to the NRW hotline was encouraged in order to aid pollution prevention. All reports (5 during actual surveys, with others reported as a consequence of increased awareness) were dealt with and resolved by NRW staff.

SWEPT results can help inform NRW's 4-yearly evidence review of the status of the Milford Haven waterway (due in 2020). The review process is used to recommend whether a case for designation as a Polluted Water (Eutrophic) should be made under the terms of the Nitrates Directive, and whether the catchment should be designated as a Nitrate Vulnerable Zone (NVZ). The Cleddau has recently been identified as an "Opportunity catchment" by NRW, partly because of the data presented in this report. This means that increased resource can be input to the area to help address local issues.

Run-off from agricultural land of slurry and manure undoubtedly result in water quality issues in the waterway. Fundamentally the costs of improving slurry storage on farms is prohibitive to many, so it follows that pursuit of ways to reduce the quantity of slurry produced in the first place is advisable. Good practical recommendations are given in Afonydd Cymru's West Wales Water Quality Improvement Project report 2019 (Speke-Adams *et al.,* 2019). These include the need for increased awareness of what slurry is, how it should be stored and the consequences of allowing it to enter a watercourse. Spreading of slurry and manure should be a well-planned application of nutrients to benefit the crop/land rather than simply a disposal activity. Tools like SCIMAP can provide a guide for runoff risk based on topography. Use of this simple visual tool can identify high risk areas to avoid as a spread zone during periods when runoff is more likely to occur (e.g. during the winter) and aid positioning of useful buffer strips to reduce pollution of watercourses (Speke-Adams *et al.,* 2019).
Ultimately, the introduction of regulations to improve slurry management on farms, their subsequent compliance, and enforcement is seen as needed by many land managers to improve the situation.

New Welsh Government regulations, proposed for introduction from 2020, could resolve these issues if NRW are sufficiently resourced to enforce the requirements. Relying on best practice for environmental protection is not adequate in a commercial world; a tightening of agricultural regulations will be needed in order to make improvements. Better land management not only benefits those in the agriculture and conservation sectors, but also other industry/business, tourism and recreation. This is especially true in an area like Pembrokeshire where industry within the waterway and tourism and recreation are particularly high profile. The delay in the introduction of new regulations is damaging to both the agriculture industry who face great uncertainty, and the wider environment which continues to be degraded. Something needs to happen to break the current impasse between those calling for tighter regulations to help to reduce nutrient pollution and those who say that the regulations will cripple the agriculture industry.

Afonydd Cymru suggest that if regulations are in place to manage slurry spreading, then there is a chance that very significant improvements in water quality could be achieved; at present there is no perceived consequence for bad practice (Speke-Adams *et al.,* 2019).

Recommendations from SWEPT:

- **The widespread nitrate pollution within the Milford Haven waterway highlighted in this report needs to be reduced. Investigation and implementation of methods of reducing nutrient inputs to the waterway is urgently required.**
- **Greater insights could be gained by a more in-depth study of the data should this be warranted by NRW or other land managers. The amount of time spent on analysing and presenting the data (reduced as a result of the volume of data and volunteers involved) does not do the dataset justice.**
- **Use of a mobile survey app such as Open Data Kit (ODK) could greatly aid data submission and subsequent collation, but this does rely on having volunteers with smart phones who are sufficiently confident with technology.**
- **Professional production of the survey guidance form involving colour matching the master copy colour change chart provided by Kyoritsu for test analysis would aid test result accuracy.**
- **Although not as accurate as laboratory testing, the use of Kyoritsu PackTest kits for detecting polluted sites was seen to be of value. Their ease of use, immediate *in situ* results and cost efficiency on a landscape scale make them the test of choice for multiple volunteer use.**
- **Any citizen science project needs a central coordinator who can spend time liaising with individual volunteers. This role can be time consuming, so enough resource should be allocated to it. It is important to provide enough training and support, but also vital to ensure that the feedback process is not forgotten. Citizen scientists invariably volunteer because they are interested in the topic; their efforts need to be repaid with adequate follow-up to ensure satisfaction.**
- **It would be of value to repeat the SWEPT project in the waterway in the future to observe any potential changes in levels of nutrient pollution. If additional regulation is brought to the catchment to control agricultural run-off, it would be interesting to see if any reductions in nutrients are noticeable as a result.**
- **Additional effort into clearing marine litter pollution would build on the success of the Big River Clean-up organised by the Pembrokeshire Coast National Park Authority where 256 bags of litter were cleaned from the waterway. Pockets of debris remain, and the cleared areas could do with repeat visits to determine the level of continual accumulation.**
- **The issue of abandoned/derelict boats is one that needs following up. This will require a coordinated approach involving the Port and the National Park Authority.**
- **Applying SWEPT methodology elsewhere in areas where further insight into nutrient pollution is needed would benefit land environmental management as well as public participation and awareness. Immediate insights into local nutrient levels could be gained by individual land managers and farmers conducting their own monitoring.**

- **The potential for the use of Kyoritsu PackTest testing tubes for alternative environmental sampling (for example for Ammoniacal Nitrogen) should be considered where appropriate.**

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7. Appendices

These are provided in a separate document in order to reduce the file size of this report.

Please contact SWEPT Project Manager Sue Burton directly with any queries or requests for information including all the individual results of water testing.

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