Pollution in Plymouth Sound
and the Tamar Waterway

A Historical Review

Peter Holt

The SHIPS Project CIC 2023

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First published in Great Britain in 2023 by The SHIPS Project CIC, Plymouth, UK

ISBN 978 1 7397053 4 3

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The SHIPS Project

www.shipsproject.org

Front cover: Little Egret (*Egretta garzetta*) and a plastic road cone in Pomphlett Creek (Chris Parkes Photography)

This document can be cited as follows:

Holt, P. 2023. Pollution in Plymouth Sound and the Tamar Waterway – A Historical Review. The SHIPS Project CIC, Plymouth.

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Abbreviations

AONB	Area of Outstanding Natural Beauty
BCE	Before Common Era
BGS	British Geological Survey
d	Penny, pre-decimalisation
DDT	Dichlorodiphenyltrichloroethane
EMS	European Marine Site
GRP	Glass reinforced plastic, fibreglass
PET	Polyethylene terephthalate
SAC	Special Area of Conservation
SPA	Special Protected Area
SSSI	Site of Special Scientific Interest (SSSI)
TBT	Tributyl Tin

Acknowledgements

Our thanks go to all the people who provided information for this publication, in particular to Keith Hiscock and Louise Firth. Thanks to Chris Parkes Photography, Stephen Johnson at Cyberheritage, Neil Hope, Jack Baker, and Wavefront Systems Ltd. for the use of their photographs. Thanks also to all the hardworking SHIPS Project volunteers who help remove pollutants from the Tamar waterway.

Abstract

The focus of this white paper is on the historic pollution that can be found in Plymouth Sound and its estuaries. Very little has been published about the effects of historic pollutants in the waterway so their impact on the ecosystem is largely unknown. This document looks at the sources of pollution in Plymouth Sound and its estuaries from historical records and then attempts to summarise the legacy of each in the ecosystem today. At the end of the document, the detrimental effect of historic pollution on marine life is discussed for fish species, native oysters, and seagrass.

1. Introduction

The 1000 Tyres Project aims to clean up Plymouth Sound and its rivers by removing sources of pollution. The reason for doing this clean-up work is to improve the health of the Tamar ecosystem which in turn brings many benefits to the City of Plymouth and the people who live there. When nature is left alone it is often capable of regeneration, but we are limiting the natural regeneration in Plymouth Sound by leaving legacy pollutants in the ecosystem.

The focus of this white paper is on the historic pollution that can be found in Plymouth Sound and its estuaries. Very little has been published about the effects of historic pollutants in the waterway so their impact on the ecosystem is largely unknown. This document looks at the sources of pollution in Plymouth Sound and its estuaries from historical records and then attempts to summarise the legacy of each in the ecosystem today. At the end of the document, the detrimental effect of historic pollution on marine life is discussed for fish species, native oysters, and seagrass.

Many of the harmful substances to be found on and buried in the seabed in Plymouth Sound and its estuaries were put there several decades or centuries ago so can be defined as 'historic'. Few people ever get to see what is on the seabed in Plymouth Sound, so the volume of rubbish abandoned there is not widely appreciated. Current sources of pollution are not included in this white paper because they are being studied and monitored by many organisations and many reports have been written on their nature and effects.

The definition of 'pollution of the marine environment' in the UN Convention of the Law of the Sea (UNCLOS) is (U.N., 1982):

'*the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities;*'

In this document, we consider 'pollution' to be anything in the rivers and the sea that was put there by the hand of man. Domestic rubbish is an obvious example as is a fuel oil spill, but we also include rocks dumped in the sea to form a breakwater as this will have some effect on the ecosystem. The effect of some types of pollution is considered to be much worse than others so we can estimate which are the substances to be dealt with as a priority. At this point, we also must acknowledge that our understanding of how polluting substances affect an ecosystem is not comprehensive and we have to take great care whenever a man-made or man-added substance is determined to be harmless. History suggests that a harmful effect will be discovered in a man-made substance once thought to be safe in a marine environment.

In their topic paper on water resources, Plymouth City Council note that:

In Plymouth, in common with other urban areas, streams, rivers, and coastlines have been physically modified, for instance to protect land and property from flooding, enable land drainage or to allow for navigation. These physical modifications alter the aquatic ecology and threaten species and habitats. Runoff and flooding, especially from urban areas, can cause pollution of streams, rivers, lakes and coastal waters. As well as needing to limit the impact of new developments, there is a legacy of impacts from earlier eras to reverse (PCC, 2014).

2. Overview of the Tamar Waterway

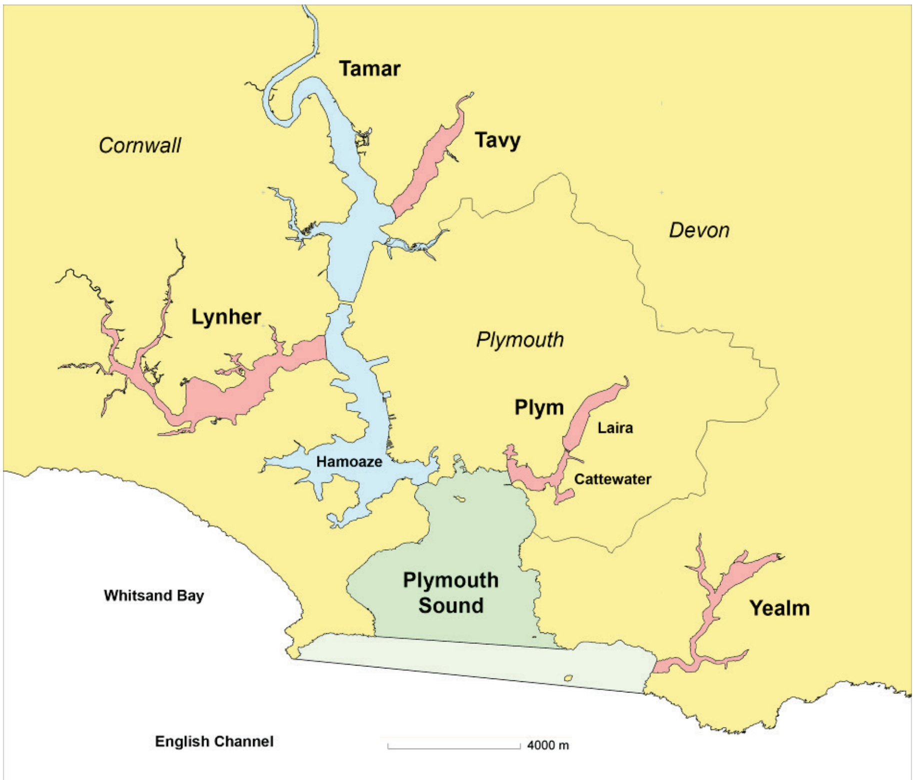

Figure 1: The Tamar waterway showing Plymouth Sound and its rivers [The SHIPS Project]

Plymouth Sound, often referred to locally as 'The Sound', is a wide and shallow tidal bay on the south coast of England that opens to the south into the English Channel. The eastern side is in the county of Devon while the western side and the seabed in the Sound are within the county of Cornwall. The 'Tamar Waterway' is a name given to Plymouth Sound and the many rivers and estuaries that connect to it, see Figure 1. The river Yealm does not flow directly into Plymouth Sound because its southern extent is often considered to be bounded by Penlee Point to the west and Wembury Point to the east. But a case can be made that the ecosystem of Plymouth Sound extends further out in a line between Rame Head to the west and Gara Point on the Devon side so the river Yealm is included in the Tamar waterway definition.

The Sound is protected by hills on both sides and to the north, but it is exposed to severe weather from the south. The prevailing winds are from the southwest and storms from this direction caused many ships at anchor in the Sound to be wrecked on its northern and eastern shores. The shipwreck problem became so bad that in 1841 a huge breakwater was constructed in the centre of the Sound to provide additional shelter for ships at anchor. This time-consuming and expensive civil engineering project drastically reduced the incidence of shipwrecks, and the Plymouth Breakwater still protects ships in the Sound to this day.

Plymouth Sound contains a large volume of seawater mixed with freshwater from its two main rivers Tamar and Plym, and the depth of water in the Sound is subject to variations caused by tides. The surface area of Plymouth Sound is approximately 20km^2 or 2000ha, this includes all sub-tidal areas bounded by Devils Point to the northwest, Mount Batten to the northeast, and south as far as a line joining Penlee Point in the west to the Shagstone in the east (Fig. 2). The average depth inside the Breakwater where the bay is approximately 3000m wide is only about 6m at the lowest state of the tide, south of the Breakwater the average depth is approximately 10m and the width at the entrance is around 4800m. If you stand on Plymouth Hoe at the north end of the Sound and look south toward the English Channel, the water in the bay gives the impression of being deep, but there is only a very thin layer of water covering a predominantly flat seabed, more akin to a puddle than a bowl.

Two rivers flow into the north end of Plymouth Sound, the smaller river Plym to the east joins at Mount Batten while the larger river Tamar joins at The Narrows in the west. The area of land drained by the waterways is 821 km^2, and the rivers contribute a large amount of fresh water to the salty tidal seawater in Plymouth Sound. The Tamar contributes most of the freshwater along with the rivers Tavy, Lynher and Tiddy that drain into the Tamar estuary, providing an average flow of $30m^3s^{-1}$ at the Narrows, fluctuating between 5 and 38 m^3s^{-1}, but instantaneous flows can reach $100m^3s^{-1}$. The average flow contributes $108,000m^3$ of water each hour which equates to approximately 2,600,000 tons of fresh river water added to the salty tidal waters of the Sound; this is a large volume, but it accounts for only a small percentage of the volume of water exchanged in the Sound by the action of the tides (Langston et al., 2003).

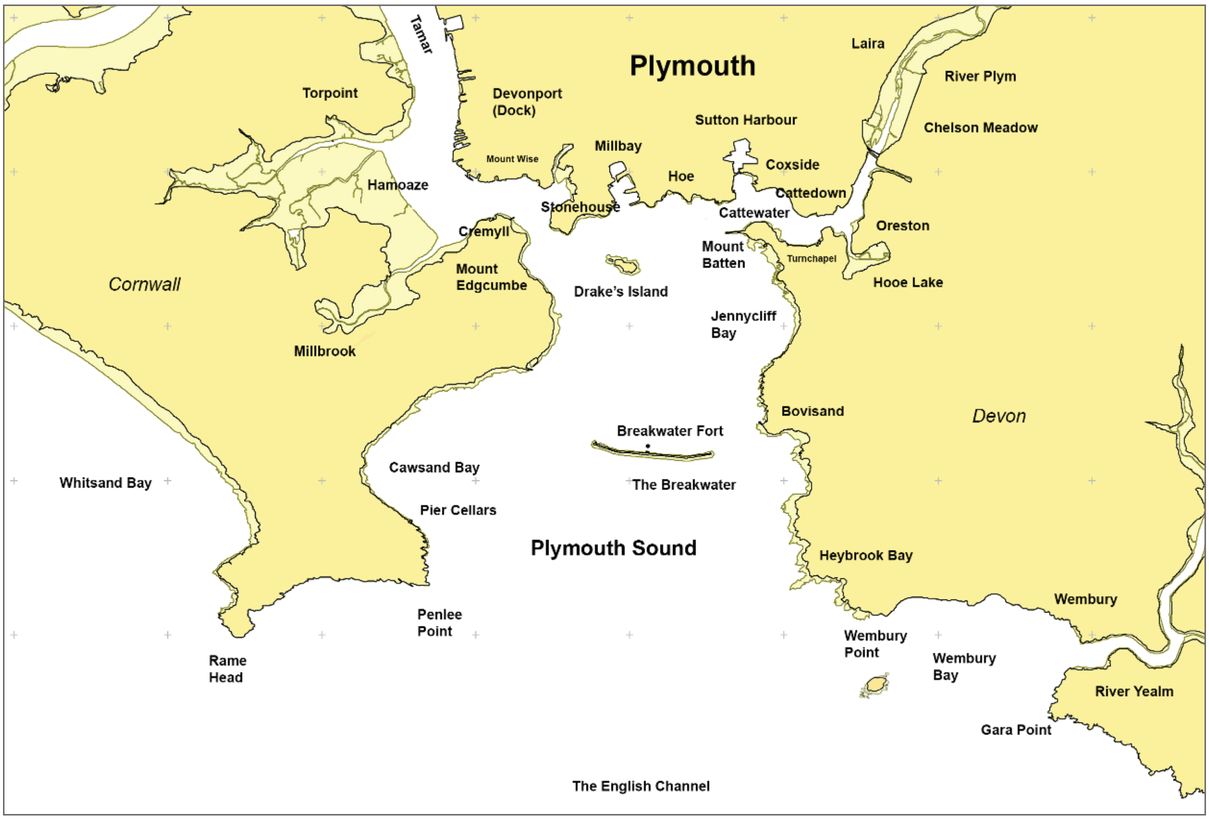

Figure 2: Map of Plymouth Sound showing places mentioned in the text [SHIPS Project]

Plymouth Sound is open to the English Channel so the depth of water in the Sound and estuaries varies with the state of the tide which is itself defined by the relative movement of the Earth, Sun, and Moon. The Sound is subject to an increase in tide height, or water depth, of between 2m on a neap tide and 5.7m on the biggest spring tide. On the biggest tides, the average depth of water inside the Breakwater nearly doubles when the tide comes in, which is a significant amount of water movement in the six hours it takes for the tide to flood. Increasing the depth of water by 5.7m over each square metre requires 5.8 tonnes of water to be moved. Extrapolating this to the whole of Plymouth Sound (not including the tidal estuaries) with an area of approximately $20km^2$ ($20,000,000m^2$) requires approximately 120 million tons of water to flood into Plymouth Sound in six hours on equinoctal spring tides. This same volume of water flows out again in the following six hours. This tidal flow provides regular changes of water in the Sound and provides a mechanism for washing some of the floating and dissolved pollution out to sea. At times of neap tides when the tidal range is lower the amount of water movement is less but the volume of water in the Sound still increases by approximately 25% when the tide comes in.

120 million tons of water flood into Plymouth Sound in six hours.

The underlying geology of the Plymouth area not only defines the landscape but was also a significant factor in the history of the Tamar waterway. Valuable minerals and china clay provided a resource to be exploited, abundant limestone improved the soil for crops to feed the workers, granite and limestone provided building material for houses and the sheltered rivers provided transport for cargoes of all sizes.

The landscape around Plymouth has undergone a complicated series of rises and falls in both the sea level and the landmass over time which has led to the formation of deep, infilled river channels in the Sound formed when sea levels were much lower, and raised beaches formed when it was higher whose remains can still be seen on Plymouth Hoe. This naturally formed backdrop has been significantly modified in recent years by land reclamation, encroachment, coastal erosion and dredging to give us the landscape we can see today. Metal ore deposits at the furthest tidal reach of the Tamar have been exploited for centuries requiring fuel and materials to be transported, needing boats which themselves need infrastructure. Tin working on Dartmoor silted up the lower reaches of the Plym River, forever changed the economic landscape and indirectly gave rise to the City of Plymouth. The long outcrop of limestone that can be found at the northern end of Plymouth Sound gave a home to the earliest settlers, provided building materials for houses, docks, and breakwaters, and made soil improvers that allowed the sheltered Tamar valley to become a huge market garden.

The geology also defines the seabed, riverbeds and estuaries in the area giving us a wide range of habitat types in a very small area which allows a very diverse range of flora and fauna to thrive. The ria or drowned river valley systems entering Plymouth Sound including St John's Lake and parts of the Tavy, Tamar and Lynher, the large bay of the Sound itself, Wembury Bay, and the ria of the River Yealm are of international marine conservation importance because of their wide variety of salinity conditions, sedimentary and reef habitats. Plymouth Sound and its estuaries are protected under several UK and European environmental policies. The coastal cliffs are a Site of Special Scientific Interest (SSSI), it is a European Marine Site (EMS) which includes a Special Area of Conservation (SAC) under the EU Habitats Directive and a Special Protected Area (SPA) under the EU Birds Directive. The Rivers Tamar, Lynher and Tavy are designated Areas of Outstanding Natural Beauty (AONB) (Knights et al, 2016). The area is also designated as Plymouth Sound National Marine Park.

Plymouth owes its existence to the sea and maritime trade. The area has a very long history stretching back millennia that was founded on the exchange of goods with distant shores because the harbour provided a safe environment for foreign trade. Along with the visitors and their trade goods came rubbish in many forms. The sea, Plymouth Sound and its rivers have always been used as a place to dispose of unwanted rubbish and until the late 1800s it was generally thought that the waterway had an infinite capacity for disposal. A small pre-industrial population only created a small amount of waste that was mostly organic in nature, a small enough volume of rubbish that could be washed away out of sight by the sea. Increases in transportation, technology, industrialisation, agriculture, and population increased the amount and range of material that had to be disposed of. Eventually, the volume of rubbish became so great that the waterway could not absorb it all without significant side-effects. Almost everything people have done in the waterway has produced waste or has made a change that left a legacy.

Plymouth Sound and the Tamar waterway are many things to many people all at the same time. It is a large military port, a commercial port, a ferry port, and home to many private boat owners and water users. It is a home for wildlife and an aquarium, a swimming pool, a playground, a museum, and a hidden prehistoric landscape, it is a graveyard and a memorial to the fallen, it is a classroom and a testing ground, as well as being a historic rubbish dump. All these facets are interlinked, so understanding what is in the Tamar waterway and how it got there is the first step in making sense of these connections.

‘Plymouth owes its existence to the sea and maritime trade.’

3. Timeline

12000BCE	People living at Cattedown in Plymouth.
8000BCE	Trees cleared on Dartmoor.
3500BCE	Mount Batten now a Bronze Age trading port.
60AD	Romans construct a fort at Calstock.
1066	Norman Invasion of England.
1100?	Tin streaming waste runoff starts silting up the Plym River.
1211	The name ‘Plym Mouth’ was first mentioned.
1440	The name ‘Plymouth’ officially replaced the original name ‘Sutton’.
1558	Plymouth population estimated to be 3000 to 4000.
1588	The Spanish Armada passes Plymouth.
1665	Construction of the Royal Citadel started.
1690	Construction of the Devonport Royal Dockyard started.
1700?	Mining waste runoff starts in the Tamar.
1712	Newcomen invents the atmospheric engine, the first steam engine to pump water.
1760	Start of the Industrial Revolution.
1801	Plymouth and East Stonehouse population 16,000.
1812	Plymouth Breakwater construction started.
1814	Plymouth Breakwater providing protection, Jennycliff Bay starts to silt up.
1815	First steamship arrives in Plymouth
1823	First railway to Plymouth, from Princetown.
1830	Clay production in Lee Moor begins, clay waste runoff starts in the Tory Brook and Plym.
1840s	Cattewater oyster beds die off.
1841	Plymouth Breakwater completed.
1841	Plymouth and East Stonehouse population 36,000.
1850s	Plymouth sewage drainage system improved; sewage discharged into the Sound.
1846	Great Western Docks construction started at Millbay.
1857	Millbay Great Western Docks construction completed.
1881	Sulphuric acid works constructed at Cattedown, ‘vitriol’ runoff starts.
1889	‘*many animals that were plentiful in the Sound twenty years ago had now deserted it*’.
1891	Complaints about china clay runoff in the Laira.
1891	‘*Fish of all kinds had grown very scarce* [in the Laira] *in recent years*’.
1900	First car in Plymouth, the start of tyre pollution.
1901	Plymouth population 107,000.
1905	Petrol-powered boats were introduced, Admiralty stores petrol for submarines.
1907	Fuel oil starts to be used by the Royal Navy.
1914	The three towns of Plymouth, Devonport, and East Stonehouse merged.
1923	Tetraethyl lead added to petrol, the start of widespread lead pollution.
1932	Seagrass *Zostera marina* nearly wiped out in Plymouth Sound.
1940s	Nylon, acrylic, neoprene, styrene-butadiene rubber (SBR) and polyethylene became widespread.
1945	DDT started to be widely used.
1950s	Nylon fishing nets were introduced.
1960s	Tributyltin (TBT) now used as an antifouling agent on ship hulls.
1978	Two-litre plastic soda bottles were introduced.
1986	DDT banned in the UK.
1987	Tributyltin (TBT) was banned on vessels <25m.
1999	Tetraethyl lead was banned in the UK.
2000	Dry mining for china clay was introduced.
2008	Tributyltin (TBT) was banned on all vessels.
2020	1000 Tyres Project started by The SHIPS Project CIC.
2021	Plymouth population 566,000.

4. Road Transport

Transport in its many forms has been one of the most significant sources of pollution and change in the Tamar waterway. For the very first people who lived in the area the only option for transporting anything overland was by carrying it themselves. The landscape was not conducive to overland travel as the area is hilly and cut by many shallow, marshy creeks and wide rivers. Travellers kept to the high ground wherever possible so tracks were formed on high ridgeways and the routes they followed can still be seen in the landscape today. With the arrival of the domesticated horse, goods could be carried in crooks on the horse's back which increased the amount that could be transported. Few medieval farmers or merchants possessed a cart and even if they did the roads were often not suitable for them. Even by the 1600s a journey from Plymouth to London took 12 days on roads that were narrow, muddy, and not maintained. Celia Fiennes in her journey through England around 1698 describes the road to Plymouth:

Figure 3: The embankment on the west side of the Laira, a man-made landscape [The SHIPS Project]

'The wayes now become so difficult yt one Could scarcely pass by Each other, Even ye single horses, and so Dirty in many places, and just a track for one horses feete, and the Banks on Either side so neer, and were they not well secured' (Feinnes C., 1888).

This account is significant because it highlights the relative unimportance of road transport to Plymouth at that time because Plymouth's transport infrastructure was based on shipping. In 1758 the roads to Plymouth began to be improved, and by 1762 a stagecoach was established to run between Plymouth and Exeter, the next major city to the east, performing the journey in about 12 hours, and by 1796 regular mail coaches had been established. The firm surface of the new 'McAdam' roads allowed coaches to travel faster and heavier goods to be transported (SDMM, 1834), but this important development only happened in the 1820s (Cooke, 1820, p167).

Although seemingly a non-polluting means of transport, the horses needed for coaches and carts created a large quantity of manure that had to be disposed of, often finding a use as a fertiliser for crops. In other ways, this early road transport did leave a permanent mark by changing the landscape itself. The Plympton Creek running east from the Laira at Marsh Mills to the ancient town of Plympton was once deep enough to be navigated by small ships but had silted up over time leaving just a small channel to allow a stream called the Tory Brook to empty into the larger river Plym. Horse transport changed this landscape in 1784 when an embankment was built across the end of Plympton Creek to provide an access road for horses from the main turnpike at Longbridge to Saltram House on the eastern bank of the Laira. The new embankment caused Plympton Creek to dry out still further which allowed the marshland to be reclaimed, later to be used for the main railway line to Plymouth and now as a site for several industrial estates. Further down the Laira on the west side were once two long, marshy inlets that lay in the valleys between a row of low hills. In 1802, the two inlets at Tothill Bay and Lipson Lake were cut off by an embankment which created 181 acres of reclaimed land intended to be used for agriculture. Almost immediately a road was built on top of the new embankment which created a flat and level route from the main road at Marsh Mills into the centre of Plymouth which avoided the existing, hilly route through Lipson. This route along the Embankment still serves as the main access road into Plymouth from the east (Fig. 3).

The invention of the internal combustion engine allowed more reliable and faster road transport to be developed. The first motor bus arrived in Plymouth in 1900 and the first domestic car a year later (Gill, 1997a p139), bringing with them the continuing problem of pollution from fuel and oil spills, dumped tyres, tyre dust and unwanted vehicles dumped on land and in the sea. A significant source of pollution in surface waters is rainwater runoff from roads, this carries a variety of contaminants and debris which enter the drainage system with rainfall. After long dry periods concentrations of pollutants can be very high. Some of the highway drains carrying this pollution will discharge directly to the environment, causing harm to wildlife and presenting potential health hazards for residents (PCC, 2014). Pollution from road construction materials was noted as a hazard as far back as 1924 when the UK Ministry of Agriculture and Fisheries reported that a preparation called 'Tarvia' made from refined coal tar could pollute rivers and should not be used on roads that ran alongside them (NDJ, 1925).

Petrol containing tetraethyl lead went on sale to the public in 1923, the additive was used to stop engine 'knocking' caused by uneven burning of petrol fuel. The safety of leaded fuel was questioned as early as the 1960s, but its use was not phased out in the UK until 1999, after having dumped an estimated 140,000 tonnes of lead into the atmosphere from vehicle exhaust pipes in the UK alone. Marine ecosystems took up some of this lead which is a neurotoxin and not biodegradable, and it remains in the environment creating multiple negative impacts on marine invertebrates and disturbing ecosystems (Botte et al, 2022). Because of this additive, the lead levels in the environment today are much higher than they were in the 19th century, the addition of tetraethyl lead to petrol significantly increased lead levels in the bodies of every animal on the food chain (Epstein, 2016).

Overland transport developed from foot traffic to horse-drawn vehicles, rail transport briefly flourished then withered away leaving the internal combustion engine as the reigning champion, perhaps soon to be unseated by the electric vehicle. But any approach to Plymouth overland is like entering a stately home through the back door, because the impressive front door is Plymouth Sound and to view that properly you need to arrive by sea.

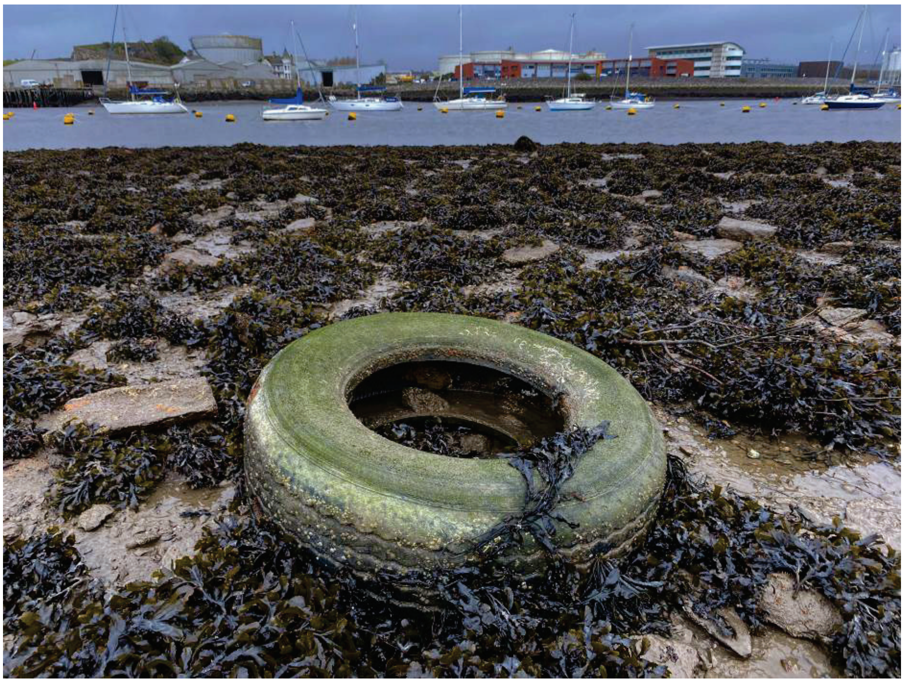

Figure 4: Tyres can be found all along the foreshore and thousands more lie on the seabed in Plymouth Sound [The SHIPS Project]

5. Shipping

Early Ships

Plymouth is a maritime city which owes its origin and existence to sea and river transport. Until the 1800s all bulky material was transported by sea and rivers whenever possible, with only the shortest journeys being made over land. This was particularly true in the hilly land around the Tamar waterway where steep gradients, marshy river valleys and ample rainfall made overland travel extremely difficult.

Stone tools found on the shores of Plymouth Sound show that the earliest visitors to the area had a connection with the sea. Human remains found in caves in Cattedown have been dated to 12,000 BCE and later stone tools have been dated to the Mesolithic and Neolithic suggesting that the area had been occupied continuously for millennia (Firth et al, 1998). The next visitors who left traces were traders in the minerals tin (Sn) and copper (Cu) used to make the alloy bronze, coming to the Mount Batten peninsula by sea in the Bronze Age (Cunliffe, 1988). The lower reaches of the Plym river known as the Cattewater is a natural harbour, well set back in Plymouth Sound and protected from strong winds, it provides a secure anchorage next to a firm shelving foreshore which is ideal for haul boats up on, with dry and level ground behind the beach for a settlement. It is hard to say how early Mount Batten was first used by people, but the first signs of intensive occupation begin in the 8th century BC, with Armorican bronze axe heads found at the site indicating trade with Brittany in northern France. It has been suggested that this trade was with ships coming west along the coast from Portland in Dorset, connecting with larger vessels that would cross the English Channel to France. However, evidence of ships using Mediterranean Bronze Age technology can be found in the many ancient stone anchors found in Plymouth Sound, anchors whose parallels can be found in abundance in the Mediterranean (Fig. 5). Perhaps the technology used by these foreign ships was adopted by local craft or ships coming from the Mediterranean may have visited Plymouth. What we can say is that the presence of so many stone anchors is evidence of a very early connection between the Mediterranean and southwest England.

Figure 5: One of the Mediterranean Bronze Age style stone anchors found in Plymouth Sound [The SHIPS Project]

Only scant evidence has been found so far for shipping and trade in Plymouth until the Norman Conquest. From documentary records, we know that the inland town of Plympton once had a thriving port with a quay and ships would sail up the river Plym at high tide and into a shallow creek that reached Plympton priory (Ray, 1998). The large quantity of sand that washed down the Plym from tin streaming work on Dartmoor filled the upper reaches of the Plym known as the Laira, eventually making the river impassable to the town of Plympton (see Minerals). There is some debate about when this happened, the earliest date suggested being the 11th Century, however Burnard (1887) states that the river was navigable by barges to Plympton in the late 1600s. Acts of Parliament were created to limit the damage done by tinners sending sediment down into the Laira and Cattewater, but the streaming works continued to choke the waterway. The silting up of the Laira forever changed the economic balance of power in the region. While the river was navigable to Plympton the town was the power base in the area, but once the river silted up ships could no longer reach Plympton to trade, and the power that went with it shifted to the newer and much smaller town of Sutton at the entrance to the Cattewater (Firth et al, 1997). Polluting the Laira with so much sediment also affected the river lower down, forming the shallow 'Middle Bank' on the south side of the Cattewater that stretches from the Mount Batten shore northward into the river. The navigable river channel passed close to Queen Anne's Battery on the north side before swinging around the rocky landmass of Cattedown, so the shallow Middle Bank became the place where merchant ships would anchor. Sand washed down from Dartmoor from tin streaming works would accumulate in this area and be joined by ballast dumped overboard from ships loading cargo in the port. Dumping of ballast in the Cattewater was a perennial problem that the harbour authorities found hard to stop.

By 1635 the Cattewater had become so silted up that the Mayor sent a petition to the Privy Council asking for money to repair the harbour. In April 1636, Thomas Crampporne, the Mayor of Plymouth, Sir James Bagg, and Sir Francis Glanville inspected the harbour and found it:

'much decayed, and "quar'd" up, which they attributed to the quantities of sand and earth thrown out of certain tin-works, and ballast cast out at Saltash, and also allowing a ship sunk there eleven years since to lie still, and to the quantities of sand and gravel brought down by the rivers Plym and Mew.' (Glanville-Richards W. 1882)

This hard layer of sand and ballast can still be found in the Cattewater just under a thin layer of modern estuarine silt, identified in records of core samples from the river (Wolfe Barry & Brereton, 1897).

The security of the Cattewater as a harbour was also dependent on the protection of the land mass of Mount Batten. Big waves washing over the isthmus between Mount Batten and the mainland during storms put anchored ships at risk. This low-lying strip of land was reclaimed over the centuries by dumping spoil, ships' ballast, and quarry waste, but it still was subject to the ravages of the sea, and the sea would occasionally break through. In the 1600s a defensive sea wall was built on the south side of the isthmus to protect the reclaimed land; it was built around the same time that the small castle was built on top of Mount Batten. Later it was ordered that each year, every lighter and sand barge operating in the waterway should take a load of rubble from the Cattewater and dump it on the southern side of the isthmus. But by the early 1800s, the rubble and ballast had washed away, and the sea was encroaching again, so more spoil was dumped to raise the level of the land. This problem was not completely solved until the Mount Batten isthmus was sheltered by the huge Plymouth Breakwater constructed in 1841 (Burnard, 1887).

Infrastructure

Trading ships require infrastructure in the form of navigation buoys, moorings, quays, jetties, and docks, proliferating coastal and offshore structures in many forms known as 'ocean sprawl' (Firth, 2016). Some of the earliest ocean sprawl in the area were the first quays constructed in Sutton Harbour in what was once a shallow and muddy tidal bay. Quays and slipways have been built and rebuilt around the edges of Sutton Harbour since it first came into use, narrowing the available water space but making the limited space more useful for shipping but less accommodating for the indigenous wildlife (Fig. 6). The entrance to the harbour was originally narrow with limestone walls on both sides, but this was made narrower by the building of the East and West Pier in 1791 and 1799, reducing the entrance to 30m in width (Cooke, 1820). The access to the harbour was further limited by the addition of a huge concrete lock gate structure across the entrance to the harbour in 1992 (Gill, 1997b). Sutton Harbour has been repeatedly dredged over the years to keep the quays and fairways clear of silt. In what was probably the first major dredging work, in the 1840s the Sutton Harbour Improvement Company deepened the harbour which previously had completely dried out at low water (White, 1850).

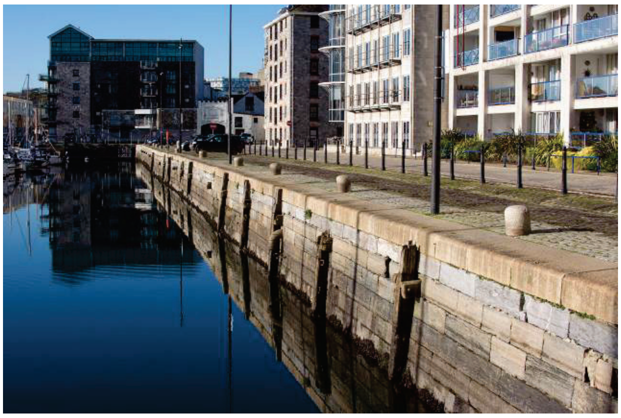

Figure 6: Vertical smooth stone walls where there once was a flat and muddy foreshore in Sutton Pool [The SHIPS Project]

The oldest quay on the Cattewater was constructed for the Plymouth and Dartmoor Railway in 1825. The river channel was narrowed by the building of quays all along the banks on both sides below Laira bridge, on limestone ground where quarry stone was plentiful, and the river was still deep enough to accommodate bigger ships. Major capital dredging was undertaken on the north side of the Cattewater when Cattedown wharves were built in 1887, removing 114,000 tons of silt, rubble, and rock from 2.8ha of seabed to 7.3m below Chart Datum, as well as removing the remains of an armed sailing ship 30m long thought to date from the English Civil War (Burnard, 1887).

Similar development work happened in the small anchorage and marshy ground to the west at Millbay. This area was without any port facilities until 1756 when John Smeaton established a yard for producing the stonework for the third Eddystone lighthouse, building a jetty used for unloading ships bringing in the rough-cut stone. In the 1830s the Union Dock had been constructed in Millbay but in the 1840s the entire bay was redeveloped by the Great Western Dock Company who constructed a huge dock complex that was designed and built by the great engineer Isambard Kingdom Brunel (Langley & Small, 1987). The once marshy bay was completely redeveloped with stone-built quays and docks permanently changing the natural environment. The huge dock complex was built and used at a time when there were few pollution controls, so the sediments within Millbay docks likely contain residue from the historic pollution that had been deposited there.

In the late 1600s, the Admiralty needed a new dockyard in the west and the Surveyor of the Navy was sent on a tour of the Westcountry to find a suitable site. The Cattewater was the second choice, but Point Froward on the east bank of the Hamoaze on the lower reaches of the Tamar was selected as the site for the new Royal Dockyard. The area was all fields at the time it was chosen but soon a series of stone-built docks were constructed on the waterfront. The place came to be known as 'Dock' (Dicker, 1971), one of the three towns that later were amalgamated to form the City of Plymouth. The dockyard was expanded many times over the years, spreading northwards along the east bank of the Tamar. A steam yard was built at Keyham in 1846 that was designed to handle the new steamships of the Royal Navy, this required more land reclamation by filling in Keyham Creek and Lake. The huge quantity of mud dredged from in front of the new steam yard was dumped in the Barn Pool (Burns, 1984). His Majesty's Naval Base Devonport is now the largest naval base in Western Europe with four miles of waterfront and covering an area of 2.6 km^2, and it is now the sole nuclear repair and refuelling facility for the Royal Navy.

Further up the Tamar River, the riverbank was modified by several smaller-scale developments. A great many stone and earth bank quays were constructed to allow cargoes to be unloaded to shore from small boats, often built by private landowners. Some of the salt marshes along the edge of the river were drained and the course of the river straightened to make it easier for larger ships to access the port at Morwellham at the furthest tidal reach of the river. The addition of quays projecting into the river altered the flow of water and changed the pattern of scouring that decided where riverine sediment would accumulate. Mine working and land clearance upstream deposited large quantities of sediment into the river, so the river had to be scoured to shift the sediment downstream. The shallow quays would fill up with silt and had to be periodically dredged. The Tamar riverbed as far up as Gunnislake has been infilled, scoured, dredged, and straightened since the start of the industrial revolution so little of it can still be considered 'natural'.

Piers were built in Plymouth Sound to support the extensive ferry and steamer traffic that plied the Tamar waterway. The largest of these was the Plymouth Pavilion Pier built in 1884 at the west end of the Hoe. The iron pier was 146m long and included a promenade deck where visitors could walk, places where steamships and ferries could come alongside, and a later addition was a pavilion at the far end that was used for events and shows. The pier was no longer in use by the time it was destroyed by German bombs in 1941, the remains were demolished in 1953 but some of the ironwork and tubular piers still on the seabed are now a habitat for marine life.

In more modern times much of the sheltered water close to Plymouth has been occupied by marinas for pleasure craft, such as at Turnchapel, at Queen Anne's Battery, inside Sutton Harbour, inside Millbay Docks, and at Ocean Quay opposite Stonehouse.

> *'Catwater Bay appearing like a lake encompassed with a town (Orson [Oreston] being upon it), is one of the most beautiful landscapes that can be conceived.' (Pococke, 1888)*

Navigation

Figure 7: The Breakwater sheltering the waters of Plymouth Sound in a storm. Huge waves still make their way in through the eastern entrance showing what storm conditions would have been like in Plymouth Sound before the Breakwater was built. [The SHIPS Project]

One of the attractions of the Hamoaze as a site for the new Royal Dockyard whose construction started in 1690 was the winding route that ships must take to access that stretch of sheltered water. Enemy ships intent on attacking the Royal Dockyard would have to run the gauntlet past a series of gun batteries as they turned sharply to port around Drake's Island and then to starboard to enter the Narrows between Devils Point and Cremyll. Several of our own Royal Navy vessels met with accidents when following that route so attempting it whilst under enemy fire was unthinkable. Even sailing into Plymouth Sound to drop anchor was hazardous. The entrance to Plymouth Sound is wide but contains several rock reefs which are dangers to shipping, so buoys have been used for centuries to mark the location of the reefs and shallows. Improvements in hydrography in later years produced better charts with shoals found and mapped by lead line surveys, tidal flows and currents analysed and ship navigation becoming more science than art. Once inside the shelter of the Sound, the ships would anchor where there was room, usually held in place by a pair of large iron anchors attached with stout rope cables. But the ropes would rot from the inside and the anchors were poorly made, and the ability for the anchors to take hold on the seabed depended on where in the Sound they were deployed. Later, permanent moorings for ships were placed in Plymouth Sound, the Hamoaze and the Cattewater once a reliable means had been developed for anchoring the moorings with iron chains. Some of the older, disused concrete mooring blocks and iron mooring anchors can still be found on the seabed along with lost anchor chains and the remains of one or two navigation buoys that were holed and sank.

Losses from shipwrecks became such a problem in the 19th Century that a huge Breakwater 1560m long was constructed across the entrance to Plymouth Sound to protect shipping in the harbour (Fig. 7). The construction of the Breakwater changed the flow of water in Plymouth Sound, with the massive construction forming an obstacle to both tidal flow and to the outfall from the Tamar and Plym rivers. Comparisons between charts dated before and after construction show that the area north of the Breakwater is now shallower, with Jennycliff Bay accreting approximately 5m of sediment since 1798 (Heather, 1798). It is hard to determine what effects the additional deposition of sediment had on wildlife in the bay because the Breakwater was providing effective protection by 1814 and there are no records of the seabed environment from before that date. The marine ecosystem in the Sound has had more than 200 years to stabilise the habitats that were modified by the addition of the Breakwater so those habitats are what can be considered 'natural' today. In 1881, a smaller breakwater was built at Mount Batten to provide further protection for ships at anchor in the Cattewater and this also had the effect of helping trap sediment in its lower reaches. By 1948, the Cattewater had silted up yet again to such an extent that it was affecting shipping trade and dredging was urgently required (WMN, 1848) The shoaling of the Cattewater by tin mining runoff, ballast dumping, and sediment entrapment is a form of pollution with perhaps the largest impact over the longest time in the area. Even now the problem can limit the ability of the port to operate so this material is still occasionally removed from the Cattewater by dredging. Parts of Plymouth Sound are dredged to ensure that it can be accessed safely by larger vessels and Millbay is dredged to allow ships to go alongside the quays, with the inner basin dredged in 2010 as part of a marina development (This Is Plymouth, 2010). The large Devonport Naval Base is in the Tamar Estuary so is affected by the deposition of sediment transported around the estuary by both tidal and alluvial flow. The accreted sediment is removed during essential, regular maintenance dredging work to ensure adequate under-keel clearance to all vessels using the facility (Black & Veach, 2010).

More structural changes to the seabed have also happened in the area. The shallow German's Rock near Vanguard Bank in the Sound was a hazard to ships entering and leaving the Hamoaze so was removed by the Admiralty in 1858 using explosives. A large area of shallow rocks was removed from the Cattewater when the harbour was improved in the 1870s (Burnard, 1887). More recently, the shallow rock outcrop at Asia Knoll was dredged away in 2003 to provide better access to Millbay docks for large cross-channel ferries (ABP, 2003). Spoil recovered by dredging was dumped just outside the Port of Plymouth in the late 1800s but later a dedicated dump site was allocated to the west of Rame Head. The Whitsand Bay site to the west of Plymouth, today known as Rame Head disposal site (PL030), was the intended destination for all of Plymouth's unwanted material, the dredge spoil, Dockyard rubbish and household waste, while sewage sludge was dumped in a separate area south of Plymouth Sound. Spoil dumped at the Rame Head site smothered the rocky and sandy seabed nearby and some of the material washed inshore so a campaign was set up to get the dump site moved (Anbleyth-Evans, 2020). In 2017 a new dump site opened south of Plymouth Sound called Plymouth Deep which allowed the original Rame Head South (PL031) site to be disused after 5 years and then closed after 10 years (MMO, 2017).

A polluting side-effect of shipping in recent years has been the use of car and truck tyres as fenders to protect ship hulls. The tyre fenders are considered sacrificial and many end up on the seabed, particularly at quays and pontoons where the tyres can break away from their attachments when the ships come alongside at speed. Less used on private vessels than they used to be, tyres are still seen hanging over the side or attached to workboats or used as cheap fendering on pontoons and docks. Scrap tyres have the properties required for a workboat fender as they are robust, they provide good shock absorption, they can last for years, and they cost nothing. A suitable non-polluting replacement that also costs nothing is not yet available so we can assume that tyres will be used as fenders for the foreseeable future.

Fuel

The 19th century saw an expansion of the shipping trade and a change in ship propulsion from sail to steam brought with it more sources of pollution. The first steamships used coal for fuel and the port of Plymouth became an important fuelling station. Coal was brought in bulk by sea to be unloaded and stockpiled at Victoria Wharf on the north side of the Cattewater. Smaller steamships would take on coal alongside coal hulks anchored in the Cattewater off Turnchapel, while larger vessels were attended by a coal hulk that would be towed out to the ship at anchor in the Sound, a practice that lasted until the end of WWII. Some of the coal fuel would be lost overboard during loading, particularly if attempting to coal a ship on a rough day, so areas of the seabed in Plymouth Sound are still covered in small, black fragments of coal. Fuel for ships changed later from solid coal to liquid fuel oil and diesel. The new liquid fuels were much easier to manage as they could be pumped on board ship rather than having to be loaded by hand, and soon the coal hulks were taken away and fuel storage tanks were built on the shore.

In 1903 the Admiralty took over Turnchapel Wharf on the south side of the Cattewater, buying the land to the east intending to develop the base to be a huge coaling station for the fleet. Instead, the area was used for storing petrol for submarines and then for storing fuel oil when the Navy switched from coal to oil for propulsion (WMN, 1903). Tanks for aviation fuel for the flying boats at Mount Batten were built alongside the fuel oil tanks, with more tanks built nearby at Radford in the 1930s. Leaks and spills of fuel oil into the Cattewater, Tamar and Dockyard basins then followed, disturbing, damaging or killing marine life by smothering, direct toxic effects and the contamination of sediments. The spilled oil would make its way into Sutton Harbour and stain the hulls of the freshly painted watermen's boats (WMN, 1931). Heavy fuel oil is slightly less dense than seawater so the floating oil slick would be blown onto the rocky shores and beaches that surround Plymouth Sound leaving a sticky residue that trapped and poisoned marine life. A letter to a newspaper in 1923 reported that the Cattewater had been covered in an oily scum and the ferryboats had '*churned up a smelling olive green wave from pier to pier*' which smelled strongly of paraffin, with the source of the oil pollution suspected to be from ships in the Cattewater or the oil tanks at Turnchapel (WMN, 1923).

In 1933, the Devon Sea Fisheries Committee debated the problem of oil pollution that had been ongoing since 1926, after an enquiry had been made to them by the U.K. Ministry of Agriculture and Fisheries. A report on the debate showed that the subject was poorly understood and the opinions of those involved varied greatly, they could not even agree if the problem had got better or worse since 1926. One commentator who was a professional fisherman thought that oil was not a deterrent to fish. A Mr Cload commented that '*the nearer they got to the oily water at Cattewater the more mackerel they caught, they also caught an enormous amount of prawns there, which to him showed that oil did not interfere with fish below the water*'. Calls were also made to fit all ships with oil separators as had already been done with Royal Navy ships, to stop them from discharging oil at sea (Exeter, 1933).

War brought pollution in many forms but one of the most dramatic was an oil spill in Hooe Lake. In the early days of WWII in November 1940, a German aircraft dropped four bombs near Turnchapel, two landed in Hooe Lake, one on the railway bridge and one landed on an Admiralty oil fuel tank. The tank exploded into flames and the fire could not be put out, the other nearby tanks heated up and burst, and the burning oil boiled over the tall bund built to contain it. The burning oil poured into Hooe Lake and set fire to the timber yard on the Oreston shore (Kingdom, 1996). As recently as 1970 an underground tank in Hooe Lake quarry exploded and burned for hours, spilling oil into Hooe Lake (Gill, 1997a).

Non-Native Species

Another form of pollution that can directly affect marine life is the introduction of non-native species. Ports like Plymouth are a focus for their transport as the ships using the port can unwittingly bring non-native species with them (Floerl & Inglis, 2005). Sometimes the non-native marine life takes hold and thrives in the new environment leading to a range of effects, from undetectable to the complete detriment of native communities. A Natura 2000 Site Improvement Plan for Plymouth Sound and Tamar Estuary identifies several invasive species, including the Pacific oyster, *Crassostrea gigas*; Wakame, *Undaria pinnatifida*; and Wire weed, *Sargassum muticum*, which are increasing in density in the area and have the potential to dominate and thus exclude native species (Wood et al., 2017, 2018).

Ship Losses

Figure 8: The cargo ship* **Kodima** *came ashore in Whitsand bay in 2002 dumping timber on the beach, and shortly after there were hundreds of people on the beach taking away the timber [The SHIPS Project].

Where there are ships there are shipwrecks. Plymouth Sound is a safe and secure harbour except in the most severe weather when the wind blows from the south, and on these occasions, there are records of hundreds of sailing ships dragging their anchors and being wrecked on shore (Larn & Larn, 1995). The problem was so great that in 1841 a huge and expensive Breakwater was built across the entrance to the Sound in a bid to make it safer. Navigation errors put many ships on the rocks, such as the huge 68-gun warship *Conqueror* which ended up on shore on Drake's Island in 1760 due to an error by the pilot (SHIPS, 2023). Navigation buoys were installed to mark the shallows and dangerous rocks and later buoys were added to mark the route ships should take when entering and leaving port.

Shipwrecks have always been a significant source of pollution, but when ship hulls were made of timber that pollution was mostly not harmful and, in many cases, readily recyclable. Iron anchors have always been valuable as they were expensive to manufacture so those found on shipwrecks were soon recovered. Anchors lost due to their cables breaking or being abandoned quickly when a ship had to 'cut and run' in a storm soon littered the anchorages. Abandoned anchors became such a problem that one of the first diving bells put into service was employed to recover anchors from Plymouth Sound (Smith, 1820). A timber-built ship that had wrecked on shore would break up quickly and the timbers were taken away to be used for repairing or building other ships, sometimes they were incorporated into buildings and the fragments were used as firewood. Cargoes would be salvaged as they were often valuable; in areas like Plymouth where shipwrecks were common, there was often a race to recover what was available on shore in a public free-for-all. When the Dutch East Indiaman *Aagtekerke* was wrecked on the shore at Bovisand in 1721, a huge crowd gathered to pick up the spoils, the local militia had to be called out to quell the ensuing riot and several people were killed in the fray (Morris, 1722). It seems that this practice is intrinsic to those living on the coast, as recently as 2002 when the 6395-tonne *Kodima* cargo ship went ashore in Whitsand Bay in Cornwall it dumped thousands of tonnes of timber on the beach. In a matter of hours there were hundreds of people on the beach taking the timber away, scenes reminiscent of the crowds that would gather around a shipwreck on shore hundreds of years earlier (Fig. 8) (CornwallLive, 2022a). This enthusiasm for recovering shipwreck material has been a useful means of minimising the polluting effects of these wrecked vessels. Today beachcombers pick up all sorts of material from the foreshore including driftwood that was once part of a ship, with perhaps copper or iron fasteners still attached or the remains of a chiselled joint or wooden trenail to show the timber's origins.

Iron or steel-built ships are more of a pollution hazard as they often contain lubricating or fuel oils which can escape into the environment, and later ships may contain plastics and asbestos. On shore, the ships tend to break up by the action of the sea, so whatever pollution is on board comes out in a short period. Shipwrecks that sink in deeper water tend to fall apart more slowly and release their pollutants over a longer period, such as has happened recently with the WWII Liberty ship SS *James Eagan Layne* beached in Whitsand Bay in 1945, this wreck started to leak oil some 77 years after it sank (CornwallLive, 2022b).

Disposal and Shipbreaking

Figure 9: A hulk called* Destiny*, or perhaps* Mam Goz*, falling apart in Hooe Lake in 2022. Timbers and fibreglass from this ship are scattered across the foreshore [The SHIPS Project]

It made economic sense to reuse as much of a wooden ship as possible when the vessel came to the end of its working life. A large sailing ship may have its life extended by being cut down to be used as a coal hulk or a timber lighter by having its masts, rigging, deck gear, and bulwarks removed. For smaller vessels the options were fewer, break them up or abandon them on the foreshore depending on the remaining worth of the vessel. Shipbreakers operated alongside shipbuilders in Cattedown, Sutton Harbour and Stonehouse Creek from the earliest days, salvaging what useful material they could and often burning the rest. Breaking up timber ships leaves little pollution other than a few lost iron and copper fasteners that can still be found on many sheltered beaches in the area. But later shipbreakers had to deal with more persistent materials and those can still be found on the foreshore too. Eldred Marshall was a shipbreaker at Deadman's Bay in the Cattewater (Gill, 1997a p45), Castle was at Cattedown Wharf, Demelweek in Sutton Harbour and Davies and Cann by the Laira Bridge, and pollution from scrapping can still be found in many of these places. The abandoned ship hulks that can still be seen at Laira Bridge, in Hooe Lake and Stonehouse are leftovers of shipbreaking operations. These hulks now provide us with a dilemma as they are considered by some people to be an unsightly nuisance to be removed while some of these vessels are of historical interest and should be conserved (Fig. 9). Plymouth City Council attempted to flatten three vessels at the east end of Hooe Lake around 1994 in a bid to tidy up the lake, but the vessels are the last remaining of their type and are worthy of protection. The iron-hulled vessel embedded in the foreshore at Freeman's Wharf in Stonehouse is also the remains of a shipbreaking operation and has been subject to attempts to remove parts of it for decades. So far, the unusual iron hull has resisted both dismantling and the elements, and this unknown vessel is also in need of protection (Holt & Cotton, 2022).

The older, timber-built hulked vessels may be less of a pollution hazard as they pre-date most unpleasant contaminants and any that were present on the vessel are likely to have been washed away by the action of the sea and rain. More modern shipbreaking sites and abandoned hulks are a different story. The low-lying 'hump' that can be seen in the mud by the stone jetty in Hooe Lake is the remains of several 1960s-era vessels broken up there. The visible remains include corroded steel, tyres, plastic, oil, and asbestos matting while it is likely that the sediment contains antifouling paint residue and oil-based lubricants. Many abandoned wooden fishing vessels dating from the 1960s lie on the foreshore in the waterway. Tanks inside the hulls may still contain diesel fuel and machinery may still contain lubricants so these ships may become a source of pollution as they collapse. The timber or steel hull may be unsightly but not poisonous, but these ships were once painted with TBT antifoul paint below the waterline which in many cases has now partly washed off. Paint containing tributyltin (TBT) was found to be an effective antifouling coating for ship hulls, becoming popular in the late 1960s but a few years later the undesirable consequences of pollution from the paint became apparent. TBT has toxic effects on a range of marine organisms, it particularly affects gastropod molluscs and was found to destroy oyster beds. Paint containing TBT was prohibited from use in the UK from 1987 on all vessels smaller than 25m but continued to be used on larger vessels until banned on all ships in 2008 (Santillo, 2001). Unfortunately, TBT is readily incorporated in marine sediments which may act as reservoirs for the substance, releasing the compound back into the water for many years (Pope, 1998).

A modern and more widespread problem is the many abandoned GRP/fibreglass boats that can be found in the creeks and rivers of the Tamar waterway. The fibreglass material degrades over time and the hulls shed into the environment a mix of polyester resin (poly diallyl phthalate) and aluminium calcium borosilicate glass fibres. In terms of plastic pollution, effects from the physical breakdown of GRP boats on ecosystems and bioaccumulation through food webs are less well understood but research is ongoing (IMO, 2019) and the detrimental effect on oysters and mussels has been recorded. It is believed that ageing GRP in the marine environment is a source of micro (<5 mm) and macro plastic release, plus fragmented silicate fibres which behave similarly to asbestos (Hopkinson, 2021). Upon entering an organism, the fibres sever flesh and become embedded, the organism develops inflammation, tumours, and cancers (Ciocan, 2020). Abandoned GRP boats are a prime candidate for removal from the environment however disposal of the GRP is a problem and a better alternative to sending them to landfill is needed.

Figure 10: Shipbreaking in Hooe Lake in the late 1980s, the pollution from this activity can still be found in the seabed. [Jack Baker]

6. Railways

Figure 11: The railway bridge across the Tavy [The SHIPS Project]

The coming of the railways in the 19th Century heralded the demise of the river and seaborne traffic which had enabled Plymouth to become prosperous. Sailing ships and boats are forever at the mercy of the wind so were unreliable, slow, and at risk of catastrophic loss by shipwreck. Ships could only transport a comparatively small amount of cargo and they could only access places with port facilities, so the cargo often needed to be transhipped onto another form of transport which added cost and extended delivery times. The limitations of sail power alone were mitigated in part by fitting auxiliary engines to sailing cargo ships as this 'iron topsail' could be used when navigating in confined waters, where the winds were contrary or where there was no wind to fill the sails. The auxiliary engines did allow sailing vessels to extend their useful life but only by a few decades. The railways had the advantage as they were not limited by the weather, steam engines only needed coal and water to operate, they were fast and efficient, they could pull huge wagonloads of freight and they could take it anywhere on the UK mainland. The first railways in Plymouth were used within yards to transport heavy materials for dock construction, building the Eddystone lighthouse and cutting stone for the Plymouth Breakwater. The first tramway that covered any distance went from Princetown on Dartmoor down to the quays at the Cattewater and was built in 1823, followed by the tramway to Lee Moor on Dartmoor in 1854 (Shepherd, 1997). The first mainline railway was the South Devon Railway which connected Plymouth to Exeter with a terminus at the docks in Millbay in 1849, with lines soon laid to Sutton Harbour and Devonport (Chalkley et al, 1991). The railways reduced the cost of transportation which enabled new businesses to flourish. Where transport was a limiting factor, the rail network could reduce costs or reduce time to market sufficiently to allow a business to be economically viable. A catch of fresh fish landed in Sutton Harbour could be transported by rail much quicker than it could by sea which opened a huge new market for fish in London. Flowers grown in the Tamar Valley could be picked one day, transported by rail to London, and sold in prime condition at Covent Garden flower market the following day.

The marine pollution in Plymouth caused by the railways appears to be much less significant than many other forms of transport. Most of the coal used for railway engine fuel was transported by rail so never went near the sea, unlike the coal used by steamships which was loaded from coal barges. Railways did change the landscape with embankments narrowing rivers and the construction of many bridges to cross the waterways, further industrialising the landscape at the expense of the wildlife that used to call it home. Now many of the small branch lines have been closed and the tracks lifted, to become new roads or cycle paths, and in some places nature has moved back in to reclaim the land.

7. Agriculture

The sheltered valley of the Tamar river was found to be an ideal location for growing crops. Produce was initially sold locally but improvements in river transport made it possible to ship fruit and vegetables downriver to be sold at markets in Plymouth. For this to happen, small quays were built all along the banks of the waterway where farmer's wagons could load straight into waiting boats. Many of the small quays can still be seen today in various states of disrepair along the banks of the rivers Tamar, Lynher and Tavy.

One of the oldest Tamar River trades was in soil improvers. Centuries ago, it was found in North Cornwall that spreading beach sand onto nearby fields improved crop yields but without understanding why this happened. This practice was copied in the Tamar Valley using sand and estuary mud from the Plym River, with added manure and scrapings from hedgerows. North Cornwall beach sand contains lots of calcium unlike the sand from the bays around Plymouth which is poor in this mineral, but the significance was not recognised, and they still shipped sand by barge up the Tamar in huge quantities. By the late 18th Century, they understood that to sweeten the acid soil of the Tamar Valley it was lime that was needed rather than just beach sand. There is no limestone in the Tamar Valley but there is a huge amount in Plymouth in an outcrop running east-west across the top of Plymouth Sound. In the years 1817 to 1827 over 70,000 tons of limestone were landed at Morwellham to enrich the fields around Tavistock, having been brought up the Tamar in barges. Quays were constructed all along the Tamar to be able to unload the stone and lime kilns were built alongside to burn the lime with coal or the cheaper coal dust called culm. The lime was usually shipped in its raw rock state and burnt near where it was to be used because the burnt product called quicklime (calcium oxide) became caustic when wet as it converted to slaked lime (calcium hydroxide), which made for an unpleasant cargo. Small boats were still used to distribute the caustic slaked lime to farms bordering the rivers and creeks when there was no other option (Paige, 1982). By the middle of the 19th century, the amount of limestone carried on the river exceeded that of any other single cargo. Soil enrichment was so closely tied to the land that farm leases in the 1820s specified to the tenant what improvers must be applied: '*60 measures of lime, or 200 horse-loads of sea-sand, sea- weed, Plymouth, Exeter, or other rich, rotten dung, shall be applied per acre*'. (Cooke, 1820). A huge amount of money was invested in soil improvement and next to stock and buildings, lime was the next most expensive outlay for a Tamar farmer and being located near a quay on the river was a big selling point when a farm was to be sold (Holt & Cotton, 2022).

Figure 12: Small stone-built quays can be found all along the waterway; this one is at Longbridge on the River Plym [The SHIPS Project]

Fertilisers were also spread on the fields; in the early days raw bone and animal manure was used, then the heady compost known as town soil or Dock dung (see Domestic Waste) or seaweed collected from the foreshore. Town soil as delivered on the dockside often contained a lot of unwanted materials such as ceramics and glass. The unwanted debris in the mix was partly filtered out on the quay when the dung was unloaded onto carts, so the quays and the river nearby became littered with this rubbish. More debris was removed when the compost was spread on the fields with the unwanted material thrown into nearby hedgerows, so fragments of ceramics, clay pipes and glass bottles can still be found along the edges of fields in the Tamar Valley. Seaweed was collected from the foreshore using watermen's boats owned by farmers, they would be towed down to Plymouth Sound in a group, filled with seaweed from the shore at low tide then towed back up the Tamar (Paige, 1982). The seaweed and organic material from the town soil soon broke down and became incorporated into the fields but the ceramics and glass remain by the docks and on the fields to this day. The pottery and glass transported in town soil have now become a favourite with collectors and with artists who reuse the material in their work. The muddy quays became a favourite hunting ground for bottle collectors who have since removed most of the intact containers, but fragments of pottery and glass still litter the rivers in places where the town soil was unloaded.

The largely natural but very smelly town soil and manure were eventually replaced by more efficient chemical fertilisers, some of which were first developed and produced in a factory in Cattedown by Burnard and Alger from 1854 onwards, as described later. Not all the fertiliser that was spread on the fields stayed there, some of the soluble chemicals were washed off the land by rain and ended up in the rivers and streams, eventually making their way to Plymouth Sound. Agriculture now covers almost 70% of the waterway catchment area, of which 80% is grassland, and agricultural runoff can still be found as a pollutant in the waterway. The development of pesticides in the 1930s and 1940s led to widespread use as it was thought that these organic compounds were the cure for the problem of pests without any adverse side effects. But doubts about pesticides had been voiced by entomologists as far back as 1945 (Cottam & Higgins, 1946), decades ahead of the publication of Rachel Carson's book *Silent Spring* in 1962 which highlighted this problem to the world (Carson, 1962). It was found that pesticides are poisonous to more than just their pest and they persist in the environment for a long time, continuing to damage the ecosystem. The most notorious early-use insecticide is DDT (Dichlorodiphenyltrichloroethane), this was in common use from the end of WWII until its ban in the UK in 1986. This substance is toxic to a range of wildlife including birds and marine animals by affecting the nervous system. DDT is an extremely persistent compound with a high tendency to biomagnification. DDT is also readily absorbed into sediments which then act as sinks for the chemical, DDT breaks down very slowly and its breakdown products are also persistent and have similar chemical properties, so contaminated sediments become long-term sources of exposure.

8. Minerals

Figure 13: A disused Okel Tor Mine on the banks of the Tamar at Calstock, showing the devastation to the landscape that can be created by mineral extraction [The SHIPS Project]

Mineral extraction on land within the Tamar waterway catchment has had a significant and long-lasting effect on the waterway. Mining and mineral processing on an industrial scale also changed the shape of the landscape while uncontrolled runoff from the mines and quarries choked rivers and polluted their sediments.

The Tamar Valley is rich in minerals including copper (Cu) and arsenic (As) but also contains tin (Sn), silver (Ag), lead (Pb), wolfram (W), iron (Fe), manganese (Mn), fluorite (CaF_2), zinc (Zn), gold (Au) and barytes ($BaSO_4$) (Booker, 1967, Rawlins 2003). The first record of mining in the area dates from the 13th Century at a silver mine at Bere Alston, but it is possible that mineral extraction happened much earlier but remained undocumented. Copper mining was undertaken in earnest during the Napoleonic wars when demand for copper rose with the development of coppering on ship hulls as a form of antifouling protection. In the 1850s and 60s, the Tamar Valley was an important source of copper and for 30 years it was the centre for arsenic production in the UK, there were lead and silver mines and at the height of the mining boom in the Tamar there were over 100 mines at work in the valley (Booker, 1967). Mining needed a considerable amount of manpower and the large workforce needed housing and feeding, so the development of the mines built up the communities along the river, such as at Calstock where mineral produce was shipped from its quays. The mines used waterwheels to provide motive power until the invention of steam engines that could be used for hauling, rock crushing, and driving water pumps. The landscape was altered to channel water along leats to power waterwheels at remote locations away from the river. The water pumped out to drain the mines was directed in channels into the nearest watercourse, mixed in with the mine water were dissolved and suspended minerals which also ended up in the rivers. Quays were built to allow the extracted minerals to be transported downstream by ship which further changed the character of the rivers, later the same quays were used to unload cargoes of coal used to power the steam engines at work in the mines.

Arsenic is toxic in elemental form as are many of its compounds. Arsenic was processed close to where it was mined in the Tamar Valley, and this released large quantities of poisonous fumes into the atmosphere. Mixed with the vapours of the many other chemical processes and smoke from fires, the natural fog that forms in the

Tamar was exacerbated by this industrial smoke and became a serious health hazard. The smog was also a hazard to shipping as it reduced visibility on the river for any vessels using it. Chimneys of arsenic refineries were eventually built very tall, so they discharged their hot, polluting gases above the fog layer. These industrial airborne pollutants were released next to the market gardens of the Tamar Valley, so the vegetation of the upper slopes was often blighted by the fumes from arsenic refineries. Fortunately, despite the 'gold rush' mentality that was prevalent at the time, the beautiful Tamar valley was saved from excessive development by landowners whose families had owned the land for centuries and had only a passing interest in what they considered to be a 'fad' of mineral extraction.

Heavy metals, sometimes referred to as trace metals or trace elements, are natural constituents of the Earth's crust, they are relatively stable and cannot be degraded readily, so tend to accumulate in sediments (Kennington, 2018). The lighter stream sediments around former mining areas have concentrations of potentially toxic elements including arsenic, copper, lead, and zinc that are well above normal levels found in the Earth's crust and are a by-product of mining in the area. Large quantities of rainwater in the river put the sediments containing these elements into suspension in the streams and rivers, washing them into the estuary (Rawlins, 2003). The downstream effects of the pollution from the mines were noted early on, a newspaper account from 1880 attributes the lack of salmon in the Tamar to pollution from the Devon Great Consols mine, but another noted cause was illegal fishing using small nets (WMN, 1880).

Figure 14: A 1.5m thick layer of estuarine mud in the Laira is cut through by a stream to show the hard sand and gravel underneath [The SHIPS Project].

A report from the Tamar and Plym Fishery Board in 1888 said that pollution in the Tamar was not as bad as in former years except for the Plym River, described as '*one of the best sea trout rivers in Devonshire*', but the previously excellent spawning grounds had been '*much injured by mine pollution, and the state of the river was deplorable*'. The water bailiff for the Plym river stated that there had been a great decrease in the fish taken in the Cattewater which he attributed to blasting operations and the spawning beds destroyed by dredging. The river Lynher had been affected by mine runoff, but nothing could be done unless it could be shown that fish were being killed by the pollution, so convincing landowners to force mine operators to trap the runoff was their only recourse (Field, 1888). In 1895, fisherman Henry Clark reported that there had been a large decrease in sea fish in the estuaries of the Plym and Tamar rivers, attributed to pollution from mines on the Tamar and vitriol (sulphuric acid) discharged into the Cattewater (WMN, 1895). In 1896, a newspaper account reported on pollution of the river Tavy from the Lady Bertha mine, which was strongly denied by the mine captain, the agent for the mine (WEH, 1896). Water samples taken downstream of the mine were so polluted that fish could not live in it. In April and June 1896, large quantities of fish were found dead downstream of the mine while none were found dead above it, and the dead fish appeared to have been poisoned. Other sources of pollution linked to mining and arsenic works affected the local rivers and were brought to the attention of the public through press reports of meetings such as the Tamar and Plym Board of Conservators (WDM, 1889a).

Although mines are no longer in operation in the Tamar waterway, the remains of the mines that were once in operation are still a source of pollution. Piles of mining waste, the mine adits and shafts, and the land contaminated by mineral processing remain sources of contamination to water courses, leaving rivers such as the Tamar at risk of failing pollution targets. This long-term leaching of mining-related contaminants into the Tamar waterway has resulted in concentrations of elements, such as copper, arsenic and zinc that locally exceed environmental quality standards for water and sediments (Mighanetara, 2009; Turner, 2011).

Tin can be found at the headwaters of the rivers Plym and Erme on Dartmoor to the east of Plymouth. Tin extraction is likely to have started on Dartmoor in the Bronze Age; bronze is an alloy of copper and tin, so tin was in great demand as a military resource at that time because weapons were made of bronze. The process of extracting tin deposits from riverbeds uses water for excavating and is known as tin streaming. Tin streaming moves vast quantities of overburden at the streaming site and deposits a huge amount of sand into the waterway which then makes its way downstream. Sand waste from tin streaming washed down the Plym River and filled its lower reaches in the Laira and Cattewater, making the once navigable river impassable to the town of Plympton (see Shipping). The effect on the Laira and Cattewater was considerable, and evidence of it can still be seen today. A borehole drilled under Laira Bridge found the solid rockhead at 32m depth with a covering of 2m of broken slatey limestone, then estuarine deposits of 2m loose coarse sand and gravel and a 15m thick layer of soft dark grey silt and clay. On top of this 'natural' deposit is a 7m thick layer of loose grey sand which is thought to be runoff from tin washing (BGS SX55SW1). The sand that filled the river eventually became a useful resource. Flat-bottomed Tamar barges would come to the Laira to load a cargo of wet sand when the tide went out, when the tide returned the barges would sail away and unload elsewhere at the next low tide. Burnard (1887) estimated that in the late 1800s, the Tamar barges were removing between 50,000 and 100,000 tons of sand each year from the Laira.

Figure 15: White china clay runoff can be seen in the river Plym in this aerial view of Laira Bridge under construction in 1961 [Cyberheritage]

China clay was discovered at Tregonning Hill near Helston in Cornwall by William Cookworthy in 1746, starting a chain of events that led to the production of porcelain in England and the start of the UK china clay industry (Compton, 1895). China clay or kaolin extraction at Lee Moor on the southern side of Dartmoor was a messy business that used huge quantities of water as the clay was washed out of the rock using water jets.

Large volumes of waste are generated by this process, typically 6 tonnes of sand and stent (waste rock), 1 tonne of overburden and 1 tonne of micaceous residue are created for each tonne of marketable clay (Nuttall & Bielby, 1973). A huge amount of water was used to extract, process, and transport the china clay and large volumes were discharged as wastewater containing sand, mica, and clay in suspension. Mica dams and settlement tanks were used to trap the clay but some of the waste would leak and overflow, discharging into nearby streams and rivers. One of the earliest discoveries of china clay on Dartmoor was in 1827 at Whitehill Tor near Lee Moor with production starting there in 1830, and when the extraction first started there was little care taken in trapping the runoff from the clay setts. The Tory Brook has its source at Lee Moor near the china clay works and it empties into the Plym river which would run white with suspended china clay waste, adding to the sediment deposition problem in the Laira and Cattewater. The effect on the ecosystem was catastrophic and long-lasting. In 1876 complaints were made about the enormous quantity of pollution that had gone down the river Plym, reaching down to the Cattewater, and it was reported that there was '*a deposit now upon the bed of the river never known before*' (WMN, 1876). In 1891, Henry Clark held the fishing rights in the upper part of the Cattewater, and he stated that '*fish of all kinds have grown very scarce there in recent years, probably, in his opinion, in consequence of the pollution of the estuary by manure and china clay refuse'*. (WMN, 1891). The problem was still significant in 1950 when the Cattewater Commissioners petitioned the Minister of Health to include runoff in the new Rivers (Prevention of Pollution) Act to stop the silting up of the Cattewater by pollution still coming from the Lee Moor china clay works (WMN, 1950). A study in 1971-72 of invertebrates in southwest rivers found that '*rivers polluted by clay waste supported a sparse population of a few species*.' Streams unaffected by clay waste supported thirty-six times the density of animals found at clay-polluted stations and the composition of species was greater in unpolluted rivers, moorland headstreams and even stations downstream of sewage outfalls compared with clay-polluted reaches (Nuttall & Beilby, 1973).

'Rivers polluted by clay waste supported a sparse population of a few species.'

As well as providing huge quantities of limestone to be used as a soil improver, the limestone outcrop that runs across the top of Plymouth Sound provided high-quality building stone known as 'Plymouth marble', with many different colours available from the quarries in the area (WMN, 1876b). The limestone quarries changed the shape of the landscape leaving permanent scars that can be seen at Hooe Lake, Oreston, Pomphlett and West Hoe, while so much of Cattedown was removed by quarrying that it is hard to determine the original shape of its once high limestone hill. Waste from quarrying was also used to change the topography of the rivers as it was used as an infill for building small quays. Quarry waste was also used to alter parts of the Cattewater to form hard-standing areas for ship repair or shipbreaking, such as at Oreston and Mount Batten where large areas of limestone quarry rubble can still be seen on the foreshore.

Runoff from tin streaming and china clay production and the waste from quarries are examples of pollution that are not intrinsically man-made but were created by man, so still fit within the definition of 'pollution'.

Figure 16: The flat tracts of sand that now fill the Laira dry out at low tide [The SHIPS Project]

9. Domestic Waste

One of the biggest volumes of historic pollution in Plymouth Sound has been domestic waste and sewage. Plymouth experienced massive population growth in the nineteenth century but the space in which the people lived could not grow quickly as the three towns were encircled by rivers and marshland, so overpopulation became a huge problem. Census reports showed a population of just 16,000 in Plymouth and East Stonehouse in 1801, a number so small that the entire population would fit comfortably in Plymouth Argyll's Home Park football stadium. The population had risen to 36,520 people 40 years later (White, 1850) but by 1900 this had grown to 107,000 through the influx of labour from West Devon and Cornwall, lured by the employment opportunities available in the towns. Plymouth town at that time was hemmed in by creeks and marshland and included many areas too steep to build houses. The land surrounding the town that was suitable for housing formed part of large privately-owned estates and the owners were unwilling to sell the land, so Plymouth was unable to spread outwards and create more space for houses. The shortage of housing meant that any incomers had to share the same limited accommodation, water supply, and refuse facilities as those already living in the town. The middle class once owned large houses in the commercial heart of Plymouth, but they moved out and their houses were subdivided so they could crowd more people in. There was severe overcrowding, and the population density was higher than that of mid-Victorian London and Liverpool (Pointon, 1989). An example of just one street, New Street near the Barbican, contained just 23 houses but 598 people lived there, an average of 26 per dwelling. In one court off Lower Street, there were six houses and 171 people living there with no drains and just one standpipe for water (Brayshay & Pointon, 1983).

This high density of people produced a lot of waste in a very small area. Initially, there were no organised means for disposing of household waste, so the townspeople would throw their rubbish into the streets. The frequent rain showers in Plymouth would sluice the collected refuse into the nearest waterway which was usually Sutton Harbour or the marshes at Millbay and Stonehouse. Sutton Harbour became an open-air sewer full of floating sewage, manure, vegetable waste, rags, fish waste and dead animals. Early travel writer Celia Fiennes gave a rose-tinted description of Plymouth:

'… the streetes are good and Clean, there is a great many tho' some are but narrow, they are mostly inhabitted wth seamen and those wch have affaires on ye sea…' (Feinnes, 1888).

The streets of Plymouth probably were good and clean when the lady saw them, but only because all the rubbish from the streets had been washed into the sea by the abundant rain. But Plymouth Sound appears to have had a remarkable capacity for dealing with this waste even in the mid-1800s:

'In this respect few towns possess greater advantages than our own for the speedy removal of the deposit in its sewers; for in consequence of the undulating surface of the ground on which the town is built whenever a smart shower of rain falls every nook and corner is so completely washed, that within half an hour afterwards it may be traced flowing into and through our harbour, on its way to nature's great laboratory for purification – the ocean;' (Truscott, 1847).

Sadly, the reality was that the coastline was strewn with rubbish as Maryatt (1834) describes in a more accurate scene in his novel 'Peter Simple'. In this tale, a ship's boat has come ashore at Mutton Cove in Devonport and one of the boat crew sees his wife with his laundry, so the Midshipman in charge tells the lady to come to the boat:

'*Now,' she would reply, 'aren't you a nice lady's man to go for to axe me to muddle my way through all the dead dogs, cabbage stalks, and stinking fish, with my brand-new shoes and clean stockings?*'

Human waste was also a problem with so many people living in a small area with no sewage system to deal with it. Space in back gardens for cesspits was limited so for many the only option was to transport their sewage in buckets to one of the nearby spoil heaps, but later some people would take the waste away for a fee (Gregory, 2020). The human waste would be mixed with ash, manure, and domestic refuse in a big pile on quaysides such as Dung Quay in Sutton Harbour, which was created as a dump in 1639, or at Pottery Quay in Devonport (WMN, 1885). This stinking compost known as 'town soil', 'night soil' or 'Dock dung' was taken away and thrown in the sea, but later it was found to be excellent fertiliser and was soon powering the market gardens in the Tamar Valley. Living alongside the people in the town were lots of animals used for transport and as a source of food, transport relied on horsepower and the many horses together produced tons of manure each day in the town. Animals kept in the town for food included pigs, chickens, and a few cows. The Health of Towns Association's report of 1847 stated that there were 80 pigsties and 12 slaughterhouses in Plymouth, along with associated animal carcass rendering plants, fullers, and tanners to process some of the animal waste. Animal manure and the waste from animal processing were added to the piles of refuse that built up on quaysides. The smell of the piles of town soil was always a problem, and no one wanted the pile near their land, so the town fathers stepped in to organise its removal and agreements were made to ship local piles away from habitation every 24 hours. The job of removing the soil was eventually contracted out and 'scavengers' were employed to collect refuse from the houses, so the waste became a resource for many. Among the refuse were items that could be reused or sold, particularly things that were lost or thrown away by mistake. Once the town soil had been identified as a fertiliser for crops it became another resource for sale, but the rate at which it was created often outstripped the rate it was taken away to be used, so the piles grew bigger, particularly in the hot summer months when farmers were busy with other tasks (WC, 1848). Rev. W. J. Odgers investigated the public health of Plymouth in 1847 and reported that Plymothians '*were living on vast dung heaps*', and the accumulation of town soil had contaminated the town water supply to a point where dysentery and diarrhoea became endemic (Pointon, 1989).

In 1847, the Plymouth Corporation rented land for a new town rubbish dump on the shore at Deadman's Bay in the Cattewater. This site was downwind of Plymouth and as far from human habitation as they could get while still being within the bounds of the City. Thomas Pitts got the contract to clean the paved streets of the town, so he started to advertise manure for sale from the heap at Deadman's Bay at 20d per ton. Pitts highlighted its benefits over other piles of compost on offer because his compost contained so much fish waste from Plymouth's fish processing industry. Pitts' advert went on to say that he would also avoid any unsuitable additions, presumably the broken bottles, clay pipes and pottery that got thrown in with everything else (WC, 1847). In 1852, the Corporation bought the land at Deadman's Bay as the pile of town soil had grown bigger and the problem was not easily solved (WC, 1852), by this time the huge stinking mess was affectionately known as 'Spice Island' and was a feature noted by the sailors on ships at anchor in the Cattewater (WDM, 1886). Transporting town soil was a nasty job but provided regular work; the Tamar barge *Triumph* was based at Calstock and was employed in the early 1900s on a regular contract in transporting town soil from Plymouth Dockyard to Okel Tor mine quay near Calstock on the Tamar (Holt & Cotton, 2022). Between 1876 and 1878, a total of 549 barge loads of town soil were removed but much more was added in the same interval (WMN 1879). In 1877 complaints were made about the pile stacking up and parts of it being on fire (WMN 1877), by 1884 the pile was much bigger, containing an estimated 10,000 tons of compost, and suggestions were made that it be shipped out by railway (WMN 1884). The town soil was still for sale, but the farmers didn't want it at the price charged as the contractor had set the price of 3d per ton in 1887 which is equivalent to £3 today (WMN, 1887b). To try and reduce the amount being added to the huge heap, the contractors had taken to getting rid of the town soil by dumping it in a field on the outskirts of Saltash, with 1500 tons being added in just 3 months (WMN, 1887a). The next year they started shipping it away from Cattedown in railway trucks so there were soon a series of complaints from the people living in houses near the goods yard at Friary Station where it was temporarily stored before being sent up country (WMN, 1888). This seemed to solve the problem and by 1889 the Corporation were no longer letting the town soil accumulate at the dump in the Cattewater (WMN, 1889). Some of the town soil was dumped directly into Plymouth Sound, which is why so much pottery, bottles and clay pipes that were mixed in with the refuse still litter the seabed. This practice seems to have been taking place in more recent times because in 1932 there were complaints in a newspaper about dumping from lighters near Heybrook Bay because old boots, tins and a large number of pigs' heads had washed up on shore nearby (WMN, 1932).

Figure 17: A horse and cart stands by to load town soil recently deposited on the quay in Tamerton Lake [Cyberheritage]

Although large quantities of domestic waste and sewage had been dumped in the sea there is little to show that this happened because the largest constituent of town soil was organic and thus became food for marine life. The non-organic component of the town soil was predominantly pottery and glass but with coal, ash and some metal, materials that are largely inert and relatively harmless. Although this was a significant source of pollution at the time it was not persistent and has only had a minor lasting effect on the environment.

Figure 18: A scourge of the modern age, single-use plastics washed up on the strandline [The SHIPS Project]

Up until the Second World War, most domestic pollutants were short-lived in the environment, were low in volume or were inert and would have little impact on the ecosystem. By the 1940s this was to change dramatically with synthetic materials like nylon, acrylic, neoprene, SBR and polyethylene (PE) becoming widespread (Recyclenation, 2011). These new materials were the wonders of the age being cheap to produce, hard-wearing, light in weight, strong and food safe, so became used for everything from packaging to clothes to fishing nets. Unfortunately, these same materials do not break down safely in the environment and they shed fragments and microplastics that adversely affect marine life in ways that we are only starting to comprehend. In the 1950s, High Density Polyethylene (HDPE) was developed, and plastic bottles made from this new material quickly became popular, then in 1978 Coca-Cola and Pepsi introduced the first 2-litre polyethylene terephthalate (PET) plastic bottles to the world (Coca-Cola, undated). Plastic replaced the glass bottles that had been used since the Victorian era, bottles that could be returned and reused, and if they ended up being thrown away the glass they were made from was largely inert. But glass is heavy and expensive to transport, and it breaks easily forming dangerous fragments, so there was both commercial and consumer pressure to replace the glass with plastic. So now the sea surface, seabed and seashore are littered with millions of plastic bottles and other single-use plastic items.

10. Sewage

When the population of Plymouth was low the sewage waste from the town known as 'night soil' was treated in the same way as the other domestic refuse and was added to the town soil. This means of disposal was simple and cheap, but it was also a significant risk to public health. A public health campaigner called Odgers noted in 1847 that large areas of Plymouth were marshy, and some streets were below sea level at high tides, particularly Sutton Harbour and Union Street, so the cellars in houses that were built on reclaimed land regularly filled with stagnant and polluted water. In 1633, Sutton harbour flooded so much that there were boats afloat in the streets, it happened again in 1744 when £3000 worth of property was destroyed and again in 1762 and 1824 (White, 1850). Surveyors working for Odgers noted that the foundations beneath the houses had become '*perfectly saturated from nearby cesspools*' and what the town needed was a sewage disposal system (Pointon, 1989). When the first sewage system was constructed in the 1850s, the untreated sewage was pumped straight into the river Tamar at Mount Wise, Millbay and Stonehouse Mill, into the Laira and in the Cattewater at Deadman's Bay and Fisher's Nose, from outlets that were above the high-water mark. The sewage in the bays eventually made its way into Plymouth Sound. The Admiralty were happy to let the sewage run into Deadman's Bay in the Cattewater if catch pits were constructed to trap the solids, but this seems not to have happened and the solids were just broken up before discharge (WT, 1855). In 1850 the Three Towns together formed the eighth-largest urban cluster in England and ranked seventh for national unhealthiness (Gregory, 2020).

All the inshore seawater pools in the Sound became filled with raw sewage as was the Hoe foreshore. But in 1874 it was reported that the disposal system was working well:

Water-carried sewage contains refuse from dye and soap works, is drained direct into the sea, below low-water mark; water-closets in use; middens not allowed, and ashes removed second day by contract. Discharging direct into the sea has been found in the locality to be the best method of disposing of the night soil. (Society of Arts, 1876, p560)

When the population of the town was small, the sewage and waste dumped into Plymouth Sound had no recorded adverse effect on the ecosystem, but by 1889 a survey by Mr Bourne at the Marine Biological Association noted that '*many animals that were plentiful in the Sound twenty years ago had now deserted it*'. Bourne attributes this to the increased outfall of sewage from the Three Towns (WDM, 1889b). Those trying to promote Plymouth as a holiday destination were always confronted by the problem of sewage, particularly in the warm summer months when the smell was greatest, so a trip to the seaside or a walk along the Promenade Pier could be marred by unpleasant sights and odours. A letter to a newspaper in 1923 asked what steps the Port Sanitary Authority was going to take to deal with the problems of oil pollution and sewage discharge from several outfalls in Plymouth Sound as it was affecting visitor numbers (WMN 1923). A similar letter a year later complained of sewage around the Promenade Pier, saying that on one day that week, it was so bad that '*even the dogs objected to entering the water*' (WMN 1924). The Tinside Bathing Houses and Arcaded Sun Terraces on Plymouth Hoe were built in 1913 and the Tinside Lido was constructed in 1935 to attract more tourists and visitors, so the presence of sewage in those bathing waters would have been most unwelcome. The situation had not been improved just before the start of the Second World War, with the greater part of the sewage from Plymouth still being discharged untreated into Plymouth Sound, with large quantities of sewage and refuse from industrial works being discharged into the Cattewater through Corporation sewers. The only treatment of the discharge was to pass it through a disintegrator to break up the solids (Halifax, 1938). Plymouth Port Health Authority banned the sale of oysters from the Tamar in 1937 because the shellfish were polluted, and it was not until 30 years later that the local fishermen attempted to revive the fishery. Before the ban, any oysters caught below the Royal Albert bridge across the Tamar had to be sold for re-laying in cleaner waters, while those caught above the bridge could be sold for human consumption (CG, 1965). Much later the raw sewage began to be treated before being dumped, and for some processing plants, the remaining slurry was loaded onto tanker barges and taken out and dumped in the sea south of Plymouth.

11. Manufacturing

Manufacturing in the Plymouth area has historically been associated with uncontrolled pollution and the rivers were seen by business owners as a convenient way to dispose of the pollution they created. Small-scale manufacturers produced small amounts of waste which often was amalgamated into the town soil or allowed to run into a river. Larger scale industries would often sell on the by-products and waste from their business and so dispose of it profitably. At a time when there were few environmental regulations, the occurrence of spills and leaks of polluting material was probably so common that it went unrecorded. The original centre for industrial-scale manufacturing in Plymouth was at Cattedown because it was away from the town centre and in a location where the smells, noise and smoke would affect fewer people. The workshops and factories were constructed on land recently levelled by quarrying away the limestone hill on the northern shore of the Cattewater between Prince Rock and Cattedown Wharf. The Ordnance Survey map of 1894 shows a range of industrial activities colonising the former quarries, including a large chemical works close to Cattedown wharf, as well as gasworks, potteries, soap works, cement works, lead works, sawmill, tannery and shipbuilding and shipbreaking yards. Other works processing animal products included a fellmonger, a leather dresser, a tanner, a fish liver oil manufacturer, a glue factory, candle makers, incinerators, a pig swill dump, and a knacker's yard. This was a time when someone had a use for every part of an animal or a fish and the waste for one process became the raw material for another. This industrial development soon spread west into Coxside to join the smaller factories around the east side of Sutton Harbour.

Figure 19: An aerial view of Cattedown in the 1980s from the south, showing the tightly packed factories, rail and road links, fuel storage and the power station [Cyberheritage]

One of the largest factories in the area was producing agricultural fertiliser. Farmers had been spreading crushed bone on their fields as fertiliser, it was not very effective in the raw state, but it was later found to become so once treated with sulphuric acid. This discovery led to the development of a range of artificial fertilisers. In 1854, Charles Burnard and John Lack founded a chemical and patent manure manufacturing business called the Phoenix Chemical Works based near Phoenix Wharf, in Sutton Harbour. A year later a patent was given to Charles Frederick Burnard for the manufacture of superphosphate of lime, the world's first artificial fertiliser, a compound produced by treating rock phosphate with sulphuric acid. The company became Burnard and Alger in 1872 and transferred to a new and bigger factory in Cattedown in 1881 which was known as the Plymouth Chemical Works.

For their process of producing artificial fertiliser, Plymouth Chemical Works made its own sulphuric acid, or 'vitriol' as it was known at the time. The company shipped thousands of tons of iron sulphide ore from Rio Tinto, in Spain, to Plymouth to use as the raw material. After the sulphur had been obtained from the ore by burning there remained in the cinders an amount of silver, copper, and iron so the cinders would be sold on to be reprocessed. Burning the sulphur ore produced a large quantity of noxious fumes which added to the exotic mix of smoke and smells emanating from the other nearby factories, thankfully few people lived downwind from Cattedown at the time. One of the '*effluvium nuisances*' reported on by Ballard in his 1882 government report on industrial pollution was the production of artificial fertiliser. Ballard noted that the sulphuric acid made on the Plymouth site tended to be rich in arsenic (0.5%) and some antimony, both of which are poisonous and would be included in the fumes from the factory (Ballard, 1882). Another problem for the environment was the runoff of liquids from the factory, particularly the very reactive sulphuric acid itself, which was absorbed into the ground or spilled into the Plym river. In 1895, the fisherman Henry Clark reported a large decrease in sea fish in the estuaries of the rivers Plym and Tamar, which he attributed to pollution from mines on the Tamar and vitriol (sulphuric acid) discharged into the Cattewater (WMN 1895). Fertiliser manufacture became a hugely important chemical trade at the time which was second only to alkali production used for the manufacture of textiles, soap, and glass. Plymouth Chemical Works grew in scale and soon needed to receive raw materials in bulk delivered on bigger ships, so under the authority of the Cattewater Wharves Act 1887 they constructed deep-water wharves at Cattedown, with spacious warehouses and the most modern equipment available at that time. The original foreshore infrastructure was removed and built over by quays. The adjoining riverbed was dredged to make a deep-water berth, removing a shallow rocky outcrop and a considerable amount of dredge spoil which was then dumped at sea.

Most manufacturers disposed of their waste products by selling them to someone else or dumping them in a river if they were not profitable and there are scant records of this pollution as it was accepted practice. Complaints were heard only when the person complaining was of high standing, such as the man who wrote to the newspaper complaining that a company cleaning rags had polluted a stretch of river and killed all the fish when '*he had been able to catch 21 trout the day before at the same place*' (WMN 1886).

Alongside the chemical works in Cattedown is Deadman's Bay quarry which is an area of flat land used for a range of polluting industries once all the useful limestone had been quarried away. As well as being the location for the huge town soil dump, there had been a tar distillery on the site, a gas works and a cement factory, along with petroleum and benzene stores (Whitfeld, 1900). Mr Harvey's tar distillery processed crude tar, a waste product from gas manufacturing companies, which arrived in bulk in railway tankers or barrels. In a report about the site from 1927, it was disclosed that the site was receiving 2,500,000 gallons of crude tar per year from the various gas companies in Devon and Cornwall. From that crude tar, the distillery produced some 2 million gallons of road tars, 200,000 gallons of creosote, 12,000 gallons of crude carbolic acid, 15,000 gallons of crude cresylic acid, 7,000 gallons of crude pyridine acid and 50,000 gallons of motor benzole and other white spirits. A new processing plant was constructed in 1955 and manufacture continued until 1971 (Old Plymouth, 2019). In 1927 and again in 1929, to the previous complaints by bathers of oil and sewage in Plymouth Sound they could add tar from the Cattewater processing plant. One newspaper reported that the Port Medical Officer of Health went for a swim at Jennycliff Bay and emerged covered in tar, the seagulls in the Sound were dirty, and shrimps offered for sale tasted of tar (WMN, 1927; WMN, 1929).

The nearby Cattedown gas works were built in 1845 and as well as making gas from coal it produced naphtha as a by-product, a mixture of hydrocarbons used for fuel. By 1893, two oil tanks had been constructed behind Cattedown Wharfs so oil could be pumped ashore from tankers and there was also an oil storage tank constructed in Deadman's Bay quarry. By 1912, petroleum imports through the Cattewater were 16,000 tons per year and after WW1 this increased to 23,000 tons (Gill, 1997a). It is to be expected that spillages and leaks from these many plants and processes were common but went unrecorded, so the land at Cattedown may still retain traces of these chemical mixtures and some would also make their way into the river. De-industrialisation in the 1980s led to the closure of the remaining industry at Cattedown leaving a fish processing plant, the fuel depot and Cattedown wharves still operational. Other notable sources of pollution close by were the timber processing plant in Oreston where telegraph poles and railway sleepers were pressure treated with creosote and other preservatives, some of which would have made their way into Hooe Lake and the Plym River.

Millbay was also a centre for manufacturing, but much smaller in scale than Cattedown. Thomas Gill built a soap factory at Millbay in 1818, the Millbay Soap Works was the first in the area and allowed the people of Plymouth to buy their soap locally rather than from Bristol or London (Whitfeld, 1900). The plant grew over time and by 1855 the firm was producing tons of soap and soda crystals, but like the factories at Cattedown, it would create a lot of waste which would make its way into the waters of Millbay and the Great Western Docks.

12. Fishing

The fishing industry has been severely affected by historic pollution which has reduced the number of fish available to catch, but this industry has also been a significant contributor to marine pollution. Waste from fish processing was one of the earliest pollutants from the time when Sutton Harbour became a fishing port, but the amount would have been relatively small, so the local animals and birds would happily dispose of some of the waste and the rest would be thrown in the sea. The volume of waste eventually increased beyond the ability of cats and seagulls to remove it, so the fish waste became a pungent component of the town soil (see Sewage). By 1847, this was being advertised as a bonus to the farmers who bought this rich compost because the Plymouth town soil contained so much waste from fish processing.

One of the earliest man-made structures in the Plymouth area is a fish trap constructed at the entrance to Hooe Lake to ensnare fish on a falling tide, this could be considered pollution because it is an abandoned built structure, but this is secondary to its position as an important historic monument.

Figure 20: Lost fishing gear on the wreck of the WWII armed trawler Kingston Alalite in Plymouth Sound. The nets still trap marine life and are a source of plastic pollution [The SHIPS Project]

The more significant pollution from the fishing industry can often be found on the seabed in Plymouth Sound in the form of lost fishing nets, lost lobster and crab pots and abandoned or lost wrasse pots. Fishing nets were made from natural hemp rope until 1900, and then cotton and hemp were used. In the 1950s the nets that had been made from natural fibres were replaced by nylon nets which were lighter, easier to handle, more robust and hard-wearing. Fishing nets occasionally get trapped on the seabed and must be cut loose from the fishing boat. When these lost nets were made from natural fibres they degraded harmlessly in the sea, but lost nets made from nylon can survive in the sea for a very long time. The lost plastic nets continue to ensnare fish, crustaceans, and occasionally marine mammals in a process known as 'ghost fishing' so there is now a concerted effort by teams of volunteer divers to locate and recover lost fishing gear from the sea. Lost crab and lobster pots are also a hazard to marine life, often rendered safe by divers who cut the pots open so marine life can no longer be trapped inside, or they are recovered from the sea by volunteers. The modern plastic fishing nets, floats and pots also break down in the sea over time and become a source of plastic pollution. Lost scallop dredges lie on the seabed in Plymouth Sound, but these are considered unsightly but relatively harmless because they are made of steel and tend not to trap marine life.

Several fishing boats have sunk in Plymouth Sound and the Tamar waterway, some were salvaged, some broke up and the pieces washed away while one or two can still be seen partially buried in the seabed. More prevalent are the decommissioned fishing boats that were abandoned on the foreshore and not disposed of properly.

A largely unknown form of pollution is the hundreds of used trawl warps to be found on the seabed in Jennycliff Bay on the east side of Plymouth Sound. These steel wire ropes are between 8mm and 18mm in diameter and were used to tow a trawl net behind the fishing boat. According to some local fishermen, unwanted trawl warps would be disposed of by laying them out on the seabed; one end would be tied to a pair of used tyres and thrown over the side then the wire would be paid out as the fishing boat sailed away. Sonar surveys of the seabed in Jennycliff Bay show the mud and reefs crisscrossed with many wires tangled up on top of each other (Fig. 21).

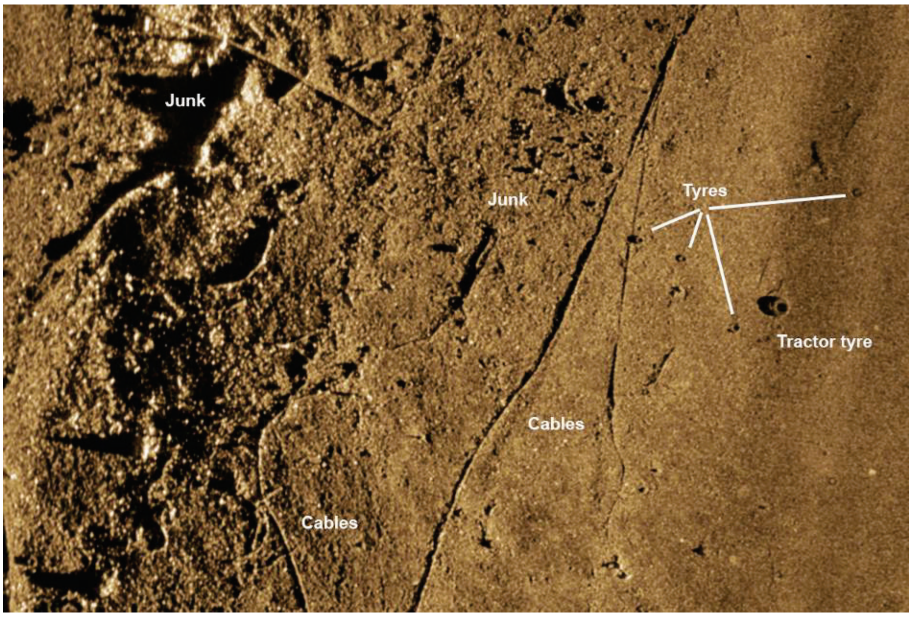

Figure 21: A sonar image of a 100m wide swath of seabed south of Mount Batten Breakwater showing car and truck tyres, a large tractor tyre, many cables and lots of unidentified junk [Wavefront Systems Ltd.].

The same location has also been used for many years as a place to dump any objects that were trawled up by fishermen working outside of Plymouth Sound. It was thought that it was better not to dump the trawled-up scrap where it was found because it would simply get trawled up again, so instead it would be brought inshore and dumped in Jennycliff Bay where no one trawls the seabed.

Another form of pollution which is disproportionately represented in the Tamar waterway is waste from sport fishing or angling. Fishing lines and lures are made from plastic, usually nylon, polyethylene, and polypropylene, which degrade slowly in the sea producing large quantities of plastic fragments and microplastics. Various steel fishhooks, spinners and lead sinkers are attached to the fishing line, and they remain in the environment for years. Discarded fishing lines can be found in the shallows at every location where the foreshore can be accessed by anglers and on sport fishing locations at sea such as reefs and shipwrecks. Plastic fishing line gets snagged on the seabed or on shipwrecks and often cannot be recovered so has to be cut away and discarded. The motion of the sea weaves the discarded line into an amorphous net which traps marine life, the marine life then dies and attracts

Figure 22: Volunteers sorting miles of fishing line recovered from Mutton Cove in one weekend by the 1000 Tyres Project and PPPP in 2022 [The SHIPS Project]

more marine life which also gets trapped. Fishing line recycling schemes for anglers are being rolled out, such as the Anglers National Line Recycling Scheme (ANLRS, 2023), but this only disposes of the line that can be recovered leaving the part trapped underwater out of reach. Recovery by hand using divers is often the only way to remove this pollution. Recovery by hand is time-consuming and carries a degree of risk for the divers from ensnarement in fishing lines that are designed to be invisible underwater, and from being stabbed by rusty fishhooks attached to the fishing line. A solution to the most significant aspect of this problem would be the adoption of biodegradable fishing line that would break down naturally in the sea.

The collection of bait for fishing is a common use of estuaries and mudflats and can be another source of pollution. One of the two main types of bait collection practised in the southwest of England is crab-tiling. This involves installing objects such as plastic guttering, tyres and roof tiles in the intertidal area that shore crabs, *Carcinus maenas*, will use for shelter. During low tide, crab tilers inspect these artificial shelters and collect the moulting crabs for use as bait for fishing. Over 1 million moulting or 'peeler' crabs are removed for bait each year in the southwest UK, making it a major commercial use of estuaries in this area (Sheehan, 2010). This activity not only adversely affects the ecosystem by selective removal of shore crabs but directly adds plastic pollution to an environment where it will break down by the action of both sunlight and the sea.

Figure 23: Crab 'tiles' in the Laira, here plastic guttering has been pushed into the soft foreshore sediment [The SHIPS Project]

13. Military

Plymouth has been used as a military port since at least the 14th Century and some of the pollution to be found here is of a particularly military type (Gill, 1997b). Standing on Plymouth Hoe looking into Plymouth Sound you can see military infrastructure all around the foreshore, and some constructed in the sea such as the Breakwater Fort (Holt & Haas, 2022b).

Figure 24: Unidentified ordnance on the seabed in Plymouth Sound, the scale bar is 500mm long [The SHIPS Project]

Ordnance of all kinds and ages can be found on the seabed and rivers around Plymouth Sound. Many armed wooden sailing vessels were wrecked in Plymouth Sound and round shot from their guns can often be found on the seabed. Along with the many solid iron round shot can be found the occasional, much older round shot made of stone which would have been fired from the earliest type of cannon. Some of the iron cannon that fired round shot can also be found on the seabed, these guns survive well underwater and can often be the last remaining evidence of some maritime catastrophe long ago, when the rest of the shipwreck has washed away. Many of the Palmerston forts built in the 1860s that surround the city face Plymouth Sound, so practice rounds fired from the large guns mounted in the forts ended up in the sea. Large numbers of shells of different types can be found on the seabed in places where the guns were routinely aimed when training their gun crews. The outside casing of the shells is made of cast iron which survives well in seawater, so the shells are often found intact by divers. WWII-era artillery rounds can also be found on the seabed, either lost on a shipwreck or simply dropped overboard. In 1940, the Germans dropped aerial mines at the entrance to Plymouth Sound using aircraft, a pair of mines would often be dropped, perhaps one triggered by acoustic waves and the other by magnetic disturbance, and they succeeded in sinking at least five vessels in this way in just six months. Vessels would be anchored outside of the Breakwater and tasked with watching for the fall of these mines to see where they landed in the sea so divers could be sent out later to dispose of them. Not all the mines were located so some can still be found on the seabed. Not all the bombs dropped on the City and in the Dockyard during the Plymouth Blitz fell onto dry land and some ended up in the sea, in the Cattewater and the Tamar. Not all the bombs that landed in the sea and rivers were recovered so these too can be found on the seabed. Other ordnance found in Plymouth Sound includes several WW1-era torpedoes from practice firing in Cawsand Bay and off Penlee Point, fortunately not dangerous as they were fitted with dummy warheads. There is a report of a sports diver seeing the remains of a wire-guided Brennan torpedo fired from Pier Cellars in Cawsand Bay and lost off the Breakwater, a rare example of the world's first guided weapon (Beanse, 1997). The correct procedure for dealing with unexploded ordnance is to report it to the Coastguard who will pass on the information to the relevant authorities.

More than 25 warships have been lost in Plymouth Sound, with most of them being wrecked on shore in bad weather. The sailing warships were built from timber so little remains that can be considered pollution, other than a few copper fasteners used to hold the ship's timbers together. The steel-built trawler *Kingston Alalite* sunk in the Western entrance to the Sound in 1940 is a pollution hazard as it is draped with plastic fishing nets and does contain some plastic material and asbestos. There is so little left of the iron-built armed trawler *Abelard* and the steel transport ship *Poulmic* that their remains are now merging with the seabed and have become artificial reefs.

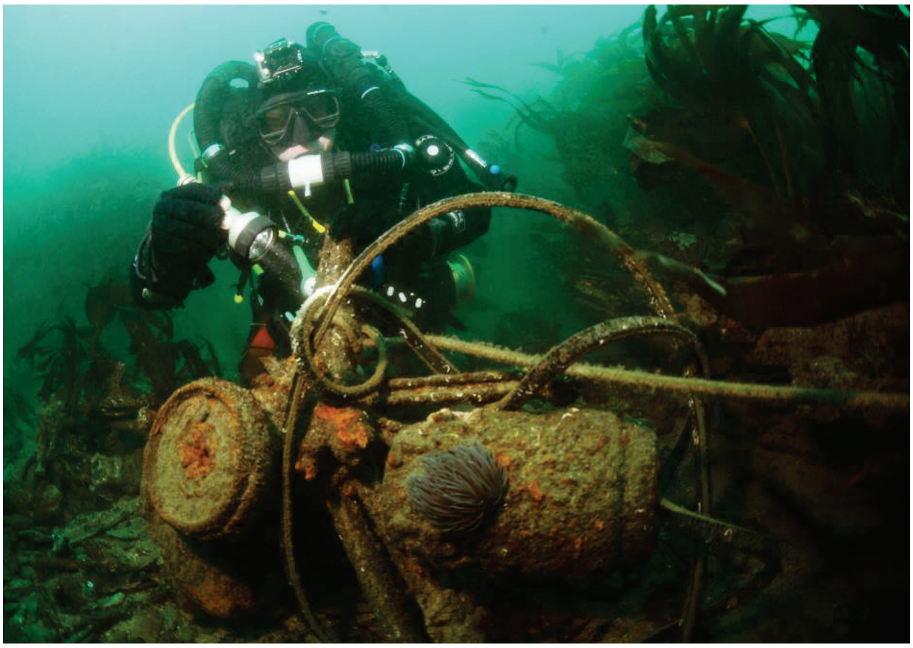

Figure 25: A diver explores the remains of Short Sunderland Mk II flying boat W3998 that crashed south of Plymouth Breakwater on 21st December 1941 with the loss of 11 lives [Neil Hope]

There are records of 18 aircraft that crashed in Plymouth Sound, most were constructed from aluminium but with some steel components. The aluminium airframes break up into small pieces that can be found scattered across the seabed in several locations in the Sound. The steel components such as engines and landing gear remain at a few of the crash sites although most have nothing left to mark their location as many of the engines were recovered in the 1970s and 80s. These crash sites are also memorials because more than 80 Allied and German airmen died in the air crashes and 43 airmen were never recovered from the sea (Holt & Haas, 2022a). All the aircraft crash sites are protected under the Protection of Military Remains Act 1896 making it an offence to interfere, without authority, with the wreckage of crashed, sunken and stranded military aircraft and vessels, and with associated human remains.

There will be an interesting range of historical junk and pollutants dumped into the basins and off the jetties in the Dockyard at Devonport, but few records of what was dumped will have been kept as much of it will not be officially sanctioned. On the seabed in the Hamoaze where there used to be moorings for wooden warships, sports divers have found huge quantities of Royal Navy mess plates, bowls, and other types of crockery. The crockery had been thrown over the side of the ships moored above, a practice that appears to have been repeated over decades suggested by the range of styles of pottery recovered. Many of the places in the Dockyard where historical rubbish had been deposited are regularly dredged to maintain a working depth for ships. So much of what had been thrown in the sea has been dredged up and taken to the official disposal site in Whitsand Bay in Cornwall to be dumped on the seabed there. Locations in the Dockyard that have not been dredged or only the surface skimmed off will most likely still contain historic pollution mixed in with older objects with significant cultural value.

By the 1800s the amount of rubbish created by the Dockyard had increased so disposal became a problem. Waste disposal was contracted out and the waste was collected in horse-drawn tipping carts taken around the yard, when a cart was full the waste would be dumped down a chute into a hopper barge moored alongside a wharf. When the barge was full it was swapped for an empty one and the barge full of rubbish would be towed out to Whitsand Bay and dumped (Carter, 2008). The contents of the barges would include anything that was no longer wanted which in the Dockyard included large quantities of non-ferrous scrap metal. Many years later the dumping ground in Whitsand Bay would become a rich source of metal for sports divers to recover and sell to scrap merchants for a profit.

Another form of pollution left behind by the military are the numerous cables laid across Plymouth Sound. The cables were laid to provide electrical power and communications links to outlying structures in the Sound such as the Breakwater, Breakwater Fort, and Drake's Island, and later to provide continuous power to lights on navigation and mooring buoys. The cables were laid across the seabed over the rocky ground but were either partly or wholly buried on softer ground and in anchorages where the cables may be snagged by a ship's anchor. The cables are made from a conductive core of copper or aluminium insulated by rubber and protected by a thick layer of steel wire armour, usually between 50mm and 75mm in diameter. Other cables have been laid for civilian purposes, such as across the narrow stretch of water between Devil's Point in Devon and Mount Edgcumbe in Cornwall. The theoretical route taken by some of the cables is shown on the navigation charts. However, the cables often appear on geophysical surveys which show that the charted cable routes are only approximate and that not all the cables are included on the chart. The surveys also suggest that multiple cables have been laid between the same endpoints and a previous cable would be left in place when a replacement was laid. The now-disused cables are usually covered in steel armour which slowly corrodes and releases whatever material was used inside the cable as an insulator, with older cables this would be some form of rubber. But the cables also can be a hazard to navigation as they can snag an anchor laid on the seabed, so the cables are another candidate for removal from the seabed.

14. Legacy

Impacts

The focus of this document is on the historic pollution in the Tamar waterway. Current sources of pollution are not included as they are studied and monitored by many organisations and several academic papers have been written on their nature and effects. This white paper concentrates on what remains from previous polluting practices and the effect they may have on the Tamar ecosystem.

The legacy of many centuries of pollution can be found on the foreshore and seabed, banks and riverbeds that form the Tamar waterway. Pollution in its many forms will have varying degrees of harm from being a nuisance or eyesore to being lethal to wildlife. The pollution may change in its ability to harm as time passes, either reducing or magnifying its harmful effects. Our understanding of the harmful effect of a material will also be on a scale where at one end the effects are well known (or thought to be so) and at the other end of the scale the effects are not known at all. Cumulative and interactive effects between pollutants and the environment are particularly difficult to analyse because they are a function of too many variables. The overriding principle should be that no man-made materials are abandoned in a natural ecosystem, but some of these abandoned materials will be worse for the ecosystem than others. If we do not fully understand the polluting capability of some type of material then using the precautionary principle we must assume that it has an adverse impact, and it should be removed.

Figure 26: Not all pollution is worthless. SHIPS Project archaeologists explore the remains of an abandoned hulk in Hooe Lake thought to be the ketch* Alfred Rooker *built at Mount Batten in 1876 [The SHIPS Project]

The notion of what constitutes pollution is also subjective in cases where opinions vary about the worth or value of a polluting feature. It would be hard to argue that an oil spill in the Tamar is not pollution, but an abandoned ship on the foreshore may be both a form of pollution and a historic asset depending on your viewpoint. It can be difficult to explain that an abandoned ship on the foreshore also has value as a historic object without also taking time to explain the context. Difficulties arise when the decision to dispose of an abandoned hulk or foreshore historic feature is made without discussion with subject matter experts. This happened in Hooe Lake in the 1990s in a misguided attempt to tidy up the lake by digging up four wooden hulks with an excavator, when the four were some of the most important historic hulks on the waterway.

The same issue can occur with 'natural' features that are not really natural and are in some way man-made but have been there so long they are considered to be part of the natural landscape. Many areas in the Tamar waterway appear to be natural but are very different to how they were originally before being modified by the hand of man. A case can be made to preserve some features as the current ecosystem includes them but there may also be a case for removing these features to be able to rewild an area. An example on land would be leaving polluting waste untouched in an abandoned quarry because wildlife now lives there that tolerates the waste and that wildlife should not be disturbed. In the marine environment, a similar question is asked about the value of removing polluting tyres as they can be used as a shelter by crabs and lobsters. This raises some important questions about rewilding which are beyond the scope of this white paper.

There may also be hidden impacts of this historic pollution in the scientific experiments that are undertaken within the Tamar waterway or that use water taken from it. Researchers using these waters should consider that the water itself is a chemical soup and any of its components may affect an experiment in unusual ways. Water removed from Plymouth Sound may vary in its composition depending on where it was collected. Salinity and temperature will vary depending on where the water is collected as the outfall from the Plym and Tamar rivers will be less saline than the sea, it will also vary depending on when it was collected as these properties vary with the state of the tide. But the water may also contain traces of historic and current pollutants specific to a particular area. Water quality also varies over time, varying diurnally with the state of the tide, but also after heavy rain when the water in the Tamar and Plym rivers turns brown with suspended sediments and runoff, increasing the turbidity in Plymouth Sound.

Modified Habitats

Millennia of human interaction with the landscape has changed Plymouth Sound and the Tamar waterway. But the underlying landscape is still very recognisable because the most significant change has been limited to a small area. You can stand on Plymouth Hoe today and look southwards to Plymouth Sound and still see it bordered by cliffs and hills rather than houses and roads, a view much like that seen by Sir Francis Drake in the 16th Century, other than the addition of the large Plymouth Breakwater. The hills are now ordered farmland rather than a wild forest, but they are still very much countryside rather than urban. We are fortunate to still be able to see Plymouth Sound and the Tamar Valley as they have been for centuries, whereas in many similar locations, the natural landscape has been buried under a rash of roads and buildings.

Land reclamation has permanently changed the landscape, but this has mostly been limited to the extent of the city of Plymouth, bordered by the river Tamar to the west and the river Plym to the east. Reclamation can be considered pollution in the loosest definition because it is something in the environment that has harmful effects, but these negative effects on wildlife may be counterbalanced by beneficial effects on people. Reclamation along the Laira provided better transport access to Plymouth which allowed the town to connect to the rest of the country by rail and road as an alternative to the limitations of sea transport. The downside was that the reclamation removed the shallow inlets and marshland on the east side of Plymouth which had been home to many species of wildlife. Reclaimed saltmarsh is now being restored along the banks of the Tamar, but it is unlikely that calls would be made to restore the natural habitat along the Laira because that land has long been used for housing and transport infrastructure. The land behind the Embankment on the Laira will soon itself need protecting because of future sea level rise, in some places the land lies only a few metres above the level of the highest spring tides.

Quay walls and piers are a localised form of land reclamation which replace shallow and gently sloping sedimentary foreshore with hard, smooth, vertical walls of steel and concrete. The quays replaced one habitat with a completely different type, displacing the wildlife found on a sub-horizontal muddy foreshore and offering it unsuitable, featureless, high-rise accommodation in its place. The hard structure soon gets colonised by sessile species which attract other species such as fish and crabs, forming a different marine community from the one originally present. Quays built out from the shallow banks into deeper water tend to narrow and straighten the course of a river, this affects water flow and sediment transport which eventually changes the riverbed topography. Accumulation of sediment has reduced water depths alongside many disused quays and allowed nature to revert some of the hard infrastructure back to something like the soft sedimentary foreshore. Pomphlett Creek to the east of Plymouth was initially a soft-sided tidal creek which was modified by the construction of vertical quay walls along its length, but silt accumulation in the creek has now made it shallower and buried some of the quay walls, reverting more of the creek to its original form. The quays built in the Tamar waterway were constructed at a time when nature conservation was not a consideration. Fortunately, there are now moves to better include wildlife in the development of new infrastructure and so lessen the adverse impact on the natural environment (Firth, 2010).

The quays were built for loading cargo but not all the cargo made it safely between ship and shore, so quay waterfronts still contain the remnants of whatever was dropped into the water and remained out of reach. Some of this lost material will be polluting so should be dealt with appropriately. Waterfronts may also contain important heritage buried within the sediments, this particularly applies to the very old quays to be found in places like Sutton Harbour and Calstock, so any decision to modify a waterfront must be done with both nature and heritage in mind. An example of the cultural material to be found during dredging work is the English Civil War period cannon that was pulled up from the riverbed in front of Cattedown Wharf in 2019 by a dredging vessel's grab (SHIPS, 2019). Quays were often periodically dredged to maintain a minimum depth for ships berthing alongside which would remove some of the objects dropped in the water, both historic and polluting. If the quay has not been used for some time then some historic material may remain in situ, protected under a later deposition of sediment.

Figure 27: Plymouth Hoe foreshore with its mix of natural limestone rock outcrops and man-made structures [The SHIPS Project]

The structures built alongside or in the sea and rivers are a mixed bag of subjective pollution. Many of the structures on the foreshore are built from local stone such as limestone and granite and may be seen as a vertical rearrangement of the underlying geology, although smoother in surface than natural. These structures could be considered less of a problem than the flat, brutalist concrete and steel so often found where the sea meets the land. Many of the built structures have a historic value which may not be widely recognised so care is needed when deciding what to tidy up. For example, the remains of the iron-built Plymouth Pavilion Pier can still be found on the seabed at West Hoe, opposite the Belvedere or 'Wedding Cake' and is a form of pollution. But the pier has historic value, and the remaining ironwork is a feature of the seabed providing shelter and a foundation for marine life. Although a candidate for removal and cleaning up as it makes the seabed untidy, the habitat benefit, and the historic significance of the pier site suggest otherwise. Some of the structures in the waterway are now redundant and constructed from modern featureless concrete, some of these structures could be removed to restore the natural underneath. Alternatively, the extant infrastructure can be modified by eco-engineering to enhance biodiversity and improve the ecosystem, such as retrofitting more suitably textured precast concrete panels or adding texture by drilling pits onto smooth seawalls, softening the hard engineering for the benefit of the wildlife, and ultimately, ourselves too (O'Shaughnessy et al., 2020).

Domestic Waste

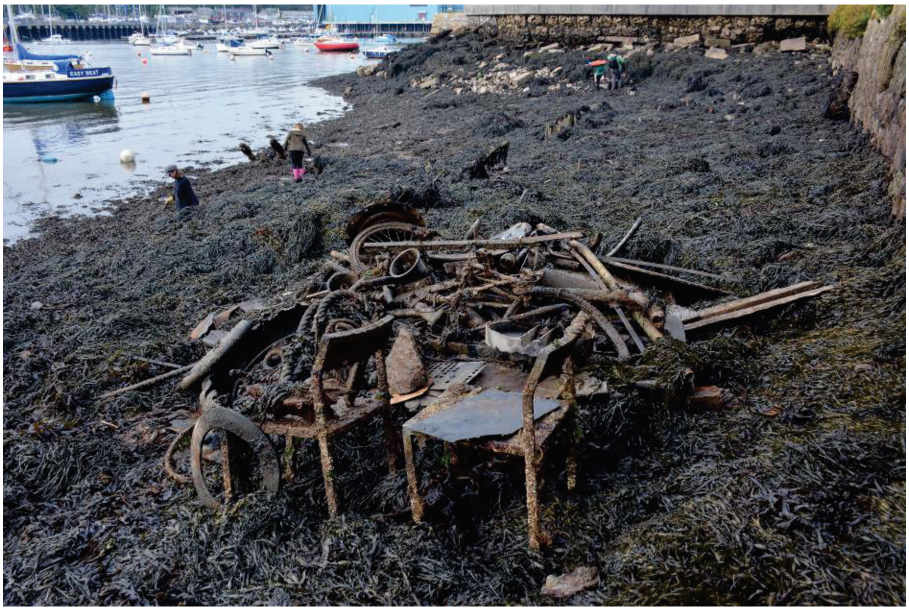

Figure 28: Metal and plastic junk removed from the foreshore at Stonehouse during a 1000 Tyres Project clean-up operation [The SHIPS Project]

Plymouth's domestic waste and sewage are no longer dumped at sea but the remains of some of the historic dumped rubbish can still be found on the seabed and in the rivers. The waste material is significant because the waterway is littered with rubbish of all ages, filtered by the effects of time and all jumbled up together. Some of the litter is made from ceramic and glass, but these materials are an acceptable form of rubbish as they are largely inert so not harmful, they may have historic value and sometimes they provide a home for marine life. The pottery and glass found today in Plymouth Sound are often the insoluble remains of the town soil 'compost' dumped in the sea by the barge load, the organic part of this compost washed away or was consumed by wildlife leaving the glass bottles, pottery, clay pipes, ash, bone, and coal dust behind. Some of the town soil was intended to be dumped at the designated site in Whitsand Bay but not all the rubbish made it that far. There is a trail of debris on the seabed running from Penlee Point to the dump site caused by the bargemen opening the hopper barge doors early to get a quick turnaround. In Cawsand Bay, among the common Victorian pottery and glass from dumped town soil, divers who explore the seabed find 17th-century Delft pottery, medieval pottery from England and Saintonge pottery from France, and occasionally find pottery dated to the Roman period, all from unknown sources. Some of the pottery and glass make their way onto the foreshore and beaches and so gain a different kind of cultural significance. Intact glass and stoneware bottles can still be found on mudflats while polished 'beach glass' is much sought after by collectors and artists, with unusual blue glass and the rarer red often being the most sought-after colours. Some historic rubbish appears on the beaches washed out by erosion of the land by wave action, such as on the southern side of the Mount Batten peninsula. Here the land has been raised using modern fill, but Mount Batten is an ancient port so old pottery and cultural material can also appear, mixed in with the modern bricks, glass, and fragments of asbestos cement from demolished military buildings.

Modern litter in the form of plastic bottles, crisp packets, and plastic packaging are commonplace, found floating on the sea surface and washed up on the foreshore by wind and tide. Marine plastics have recently been identified as one of the most serious forms of pollution in the world's oceans. Plastic debris can be found everywhere from the poles to the equator and from shallow coastal waters to the deepest waters of all oceans. There is a growing body of evidence that plastic debris is having drastic impacts on marine wildlife either through ingestion, entanglement, or smothering. Additionally, they can adsorb toxins in the water, increasing their possible adverse impacts. Plastic debris in the sea can be found in many forms and size scales from items of several metres to micro and nano-plastics which can adversely impact different parts of the ecosystem. It has been estimated that around 70% of all the litter in the ocean is made of some form of plastic polymer (Kennington, 2018).

Modern litter found all along the edges of Plymouth includes plastic road cones, car and truck tyres, shopping trolleys, bicycles, motorbikes, scaffolding poles, and unidentified scrap metal, along with plastic of all types and sizes. One of the more common items to be found on the bottom of Sutton Harbour is the heavy PVC plastic 'feet' from temporary fencing, along with the usual large quantity of tyres and road cones. Many lighter items get blown into the water such as plastic bags and plastic wrapping, and on one clean-up the 100 Tyres team recovered several large plastic roadside banners made by organisations to publicise events. Waterside pubs are rich hunting grounds for waste material such as plastic chairs and sunshades, often laid on top of a thick stratum of bottles and drinking glasses.

Figure 29: A tyre, plastic chair, plastic bags, drinking glasses, and unidentified debris on the bottom in Sutton Harbour [The SHIPS Project]

As well as being a source of plastic fragments and microplastics, the visible marine litter on the foreshore can undermine the psychological benefits that the coast ordinarily provides so it is important to keep beaches clean for more than just the removal of pollutants (Wyles et al, 2016). Fortunately, there has been an increase in the number of groups that organise beach cleans in the Plymouth area, so the easily accessible and thus most popular beaches are now periodically tidied up. The beach cleaning organisations often do not have the means to remove tyres and other large objects, so the 1000 Tyres Project is working alongside these groups to recover the litter that is large or hard-to-reach.

Other Waste

The debris from shipping can be found on the foreshore and on the seabed. The foreshore of Plymouth Sound and its rivers has been a dumping ground for abandoned vessels for centuries and a place where these ships were broken up or repaired. Waste from these industries can be found in many locations but notably Hooe Lake, on the Oreston foreshore and at Stonehouse Beach. There are plenty of abandoned ships still to be seen, and these have recently been catalogued by The SHIPS Project (Holt & Cotton, 2022). Most of the abandoned vessels are constructed from timber which will slowly degrade over time, they break into pieces and their timbers scatter across the foreshore. A few of the hulks are of historic importance and should be preserved so care needs to be taken when deciding what to clean up. Three of the most important hulks were partly demolished by an excavator in the 1990s in an ill-advised attempt at cleaning up Hooe Lake. What can and should be removed are the abandoned boats constructed from GRP or fibreglass, these vessels break down over time releasing plastics and glass fibres into the environment which are harmful to marine life. GRP vessels are more easily and safely removed when they are still intact so they should be removed as soon as possible.

Some of the objects to be found on the seabed today are shipwrecks or crashed aircraft. This historic marine litter has intrinsic cultural significance and heritage value particularly if the ship is an example of a rare type or was associated with a notable historic event. Two shipwreck sites in the Plymouth area are designated under the Protection of Wrecks Act 1973 and can only be dived or disturbed under license. Some sites are also memorials because they are the last resting place of a ship or aircraft's crew. All crashed military or civilian aircraft that were lost during military service in the UK and its territorial waters are automatically designated as 'Protected Places' under the Protection of Military Remains Act 1986. The Act makes it a criminal offence to interfere with the wreckage of any crashed military aircraft without a licence. This is irrespective of loss of life or whether the loss occurred during peacetime or wartime (Holt & Haas, 2022a).

Figure 30: Abandoned plastic boats can be found all over the Tamar waterway, they are difficult to recover and difficult to dispose of [The SHIPS Project]

Any shipwreck remains visible on the seabed are limited to objects made from metals, glass or ceramic because timber is swiftly destroyed by erosion and the effects of marine life, but timber can still be found buried in softer sediments where it is protected. Typical shipwreck remains include iron and steel hull structure, iron anchors and chains, iron cannons, and smaller objects made from copper alloys, lead, glass, and ceramics, all of which are low-hazard pollutants. World War II era shipwrecks may also contain rubber, plastics and asbestos which are candidates for removal from the ecosystem, while one of the local shipwrecks also contained the hazardous materials white phosphorus and radioactive radium-226 (Linsley, 1975). Oil pollution is also a potential threat, the WWII Liberty ship SS *James Eagan Layne* in Whitsand Bay started leaking oil in 2022, but few other shipwrecks in the area remain sufficiently intact to still contain any oil. Crashed aircraft usually break up on impact scattering structural components across the seabed, most of those lost in the area were made from aluminium which soon breaks into small fragments. Often only the steel components of the aircraft engines and landing gear survive with a few recognisable items made from copper alloy, so they can be considered a low-level pollution hazard.

There are many abandoned concrete mooring blocks on the seabed originally deployed by the Navy, many more than 3 tonnes in weight, as well as lost mooring anchors and their chains and the remains of a few navigation buoys. The blocks are made of concrete so are a low-level hazard as are the iron anchors, but both can be an obstruction on the seabed ready to ensnare a ship's anchor chain. As disposal of these blocks may be difficult, it has been suggested that the disused mooring blocks and large anchors are relocated to somewhere more suitable, such as the Breakwater Fort as it already has a collection of structures on the seabed around its base (Holt & Haas, 2022b). The seabed is also crisscrossed with numerous armoured power and communications cables which are no longer in use, along with the many abandoned steel trawl warp wires, some partially buried while others lying on the surface as another snag hazard. These cables are another potential candidate for removal.

Abandoned car and truck tyres are a particular feature of the seabed and rivers around Plymouth, with estimates of more than 1000 in Plymouth Sound alone. Tyres are a significant source of long-term pollution so are being removed from the foreshore and seabed of the Tamar waterway by the 1000 Tyres Project. Cars have occasionally been dumped in the sea with the remains of some still to be found on the beach at Bovisand Bay and Jennycliff Bay, with reports of more having been dumped off the end of Mount Batten Pier. These too are candidates for removal from the sea.

Plymouth started as a fishing port so lost fishing gear has always been a problem on the seabed and foreshore. Before the use of plastics for fishing gear, any lost gear would break down over time and wash away, but modern fishing gear only breaks down slowly and causes harm to the ecosystem for decades. Lost fishing nets continue to trap fish and other wildlife, with the dead marine life attracting the living so they too get trapped, but they also damage the seabed or cultural heritage they get snagged on. Floating fishing gear can foul ships' propellers and steering gear while gear washed in from abroad can transfer invasive species. The plastic slowly breaks down scattering larger fragments across the seabed which degrade down to smaller fragments and then down to microplastics. Some of this plastic debris ends up on beaches and adversely affects recreation and tourism. Locating and removing lost fishing gear should be considered a priority.

Figure 31: Lost fishing gear snagged on the seabed off panther Shoal, south of Plymouth Breakwater. These nets are a hazard to both marine life and sports divers [The SHIPS Project]

Chemical Pollution

Pollution found in the water itself is monitored by several organisations and is considered here to be current rather than historic, such as fuel oil spills, agricultural runoff, china clay runoff, and releases of raw sewage. But some of the pollution in the water is the result of industries that stopped many years ago. The old mine workings along the Tamar are still contaminating the river with water drained from disused mines and surface water from spoil heaps, creating elevated copper and zinc levels in various parts of the catchment. Metals such as arsenic, cadmium, lead and mercury can bioaccumulate in shellfish and pose a risk to human health. Other metals, such as copper, are directly toxic to shellfish and can also impact lower food chain organisms consumed by shellfish. Other sources include copper from antifouling paint remaining in the sediment which can elevate local ambient water concentrations (Webber, 2021).

Sediments and Dredging

Figure 32: Turnchapel beach pre-1995 (left) and in 2022 (right) showing that some of the mud has now gone from the beach, the residents recently removed tons of rubbish so now the foreshore habitat is much improved [The SHIPS Project]

The sediments in the Tamar waterway contain traces of historic pollution going back millennia, to a time when the first people accidentally altered the maritime landscape. Deposits of waterborne material in rivers and streams were a side-effect of early agricultural and industrial activity on Dartmoor which eventually silted up the lower reaches of the Plym River. China clay production at Lee Moor washed thousands of tonnes of china clay fines into the Tory Brook and then into the Plym, so the top layer of sediment in the Laira includes a large proportion of fine white particles, topped off with a modern layer of sedimentary deposits brought in by the river. Now a feature of the landscape, the sediment filling the Laira is a form of pollution as it was caused by industrial activity and is industrial waste.

Further downstream the harbour of the Cattewater is also full of similar industrial waste and its removal by dredging may be required in a future port development. The Cattewater abuts what was once the main industrial area of Plymouth so the river would have been the repository for a vast amount of historic pollution. Raw sewage direct from Sutton Harbour and later from sewage outfalls would have once filled the Cattewater along with town soil compost and the refuse and runoff from industrial works. Even today you can see rainwater from Cattedown running into the river through cracks in the retaining wall at Cattedown and during its industrial heyday that same source of rainwater would be mixed with whatever effluent was present. Fortunately, most of the historic manufacturing industry at Cattedown used natural and organic raw materials which tended to produce benign or short-lived waste. Even the runoff from the sulphuric acid works leaching into the ground would be partly treated before it made its way into the river because it would be neutralised by the underlying limestone rock, but the acid was rich in arsenic and antimony so that too would end up in the soil and in the river. One industry that has left a permanent mark on the land, and perhaps in the river, is the tar distillery in Deadman's Bay quarry as the underlying porous rock still retains traces of substances including road tar, creosote, motor benzene, white spirit, and other related chemicals produced there until 1971. Another is likely to be remnants of fuel oil spillages and petroleum products from both Cattedown and the storage tanks at Turnchapel. More modern pollutants in the sediments may include the TBT used as an antifouling coating on ships from the 1960s to 2008, as this would have been present on the vessels using the Cattewater port. Another legacy pollution that is evident today is the remains of shipbreaking operations particularly at Stonehouse and in Hooe Lake. The remains of several ship hulls are buried in the seabed at Stonehouse and the mud at the east end of Hooe Lake contains many hundreds of cubic metres of ship debris, plastics, and asbestos.

The sediments in the upper reaches of the Tamar contain high levels of metals such as copper, arsenic and zinc that were deposited from mine runoff. Further down, the seabed will contain traces of the unknown historic pollutants from the dockyard from a time when few records were kept, but like the Plym, they are likely to include remnants of fuel oil. Some of the pollutants will make their way into Plymouth Sound where they get redeposited into the sediments. The age of the sediments varies because some of the muddy parts of Plymouth Sound are dredged to maintain a minimum depth for the ships using the port, so some of the deeper mud will contain much older pollutants.

The pollutants that can be found in the sediments in the Tamar waterway vary by location, sediment type and age. The Environment Agency has recognised that the contamination of the sediments of Plymouth Sound and its adjoining estuaries is widespread but variable in degree. Hooe Lake is recognised as an example as the sediments are contaminated with heavy metal and organic pollutants (Environment Agency, 1996), as have Salt Mill at Saltash, Drakewalls Mine, Chelson Meadow and Southdown at Millbrook. So before undertaking any activity likely to disturb and mobilise the sediments the potential for releasing pollutants is determined by sampling. Dredging produces temporary increases in the volume of suspended sediment in the water column which reduces the growth of algae and seagrass by increasing turbidity, it may reduce oxygen levels in the water by releasing organic material, it may release contaminants and it may smother benthic and foreshore communities. But the adverse effects are to some extent dependent on the location and depth of the disturbance to the seabed. Dredging to maintain depth at a berth that only clears recently deposited material from the original dredge pocket will not disturb any historic sediment as the material removed has only accumulated since the last time the berth was dredged. Removing material from a new area or excavating deeper into an existing dredge pocket disturbs historic sediment which may contain historic pollution and historic cultural material. We must also correctly understand the age of any pocket of spoil due to be removed, fortunately, there are a series of historic charts for Plymouth Sound and its estuaries that record in some detail the changes in depth going back to the 17th century. The waters around Plymouth have gradually got shallower over the years so what may look like the original seabed may have only been deposited in the last 50 or 100 years.

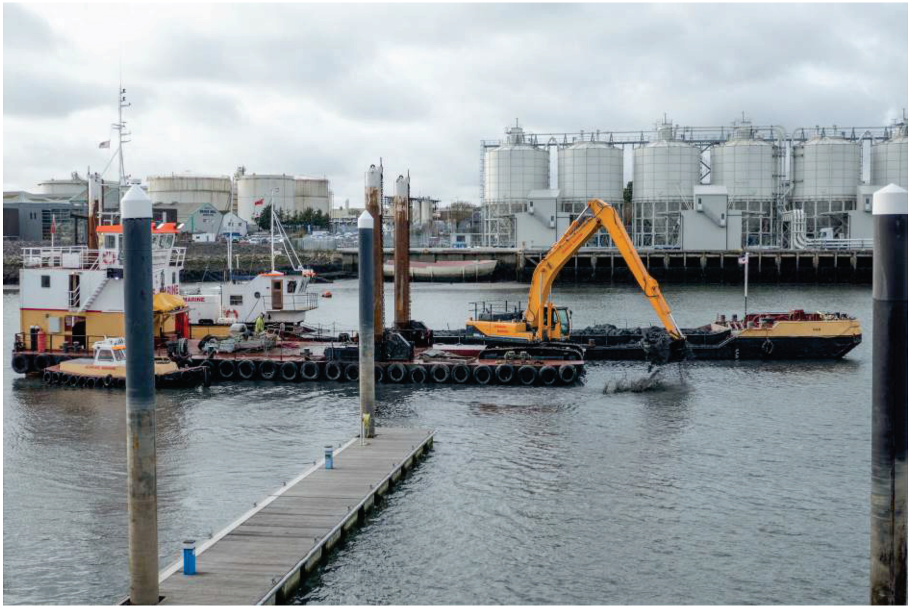

Figure 33: Dredging the east side of the Cattewater north of Oreston [The SHIPS Project]

15. The Effect of Historic Pollution on Marine Life

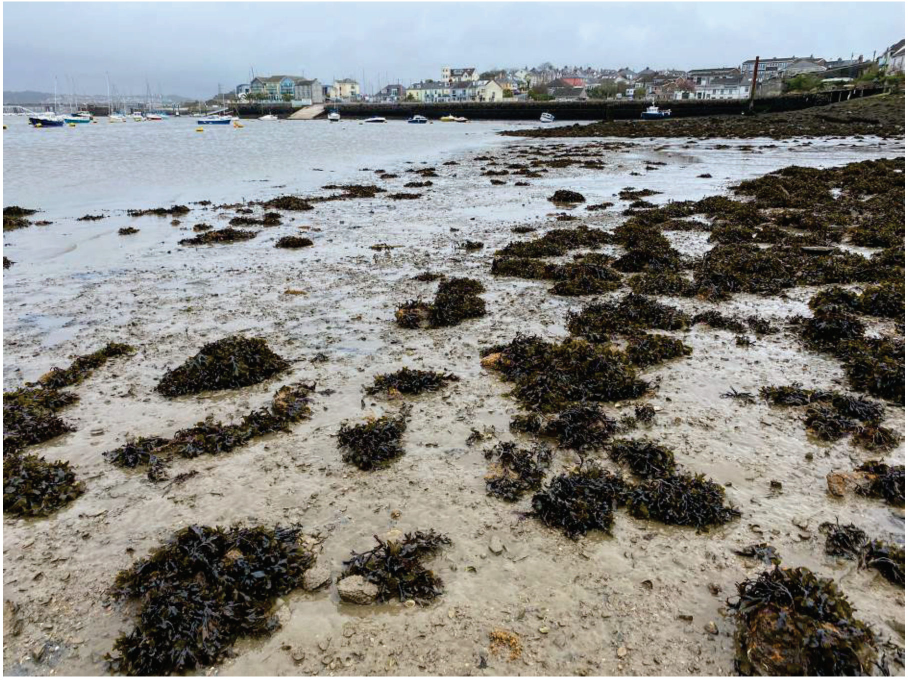

Figure 34: The foreshore at Oreston in the Cattewater, once a thriving oyster bed but now covered in silt, rubbish, and tyres, but a few native and pacific oysters can still be found [The SHIPS Project].

But what effect has this pollution had on marine life? The answer is not straightforward because detailed information is missing about the state of the ecosystem in previous centuries. The state of the ecosystem is also subject to a collective amnesia known as the 'shifting baseline syndrome' where there is a gradual acceptance of degradation to what is considered a natural environment, and each new generation believes that the world they see is in its 'natural' state. There are no scientific records of types and quantities of marine life in the Tamar waterway until 1887, but we can gather some clues from newspaper accounts which mention marine life usually in relation to some other issue. Two species that we do have information about are native oysters and seagrass, possibly because the loss of both species was swift and thus noticeable in one generation, the die-off took 10 years for the oyster beds in the Cattewater and just one or two years for the seagrass.

'You know what's weird? Day by day, nothing seems to change, but pretty soon…everything's different.' (Bill Watterson)

Oysters

There are records of fees paid for the right to drag for native oysters, *Ostrea edulis*, in the Cattewater from 1719 to 1841 (Gill, 1997). This tells us that the environmental conditions in the Cattewater at that time were suitable for enough oysters to grow to support a fishery. But something happened in the 1800s that destroyed the oyster beds as the leases for the seabed stopped in 1841, with one speculative license taken much later in 1887. In that same year, Heape wrote notes on the fishing industry of Plymouth in the Journal of the newly created Marine Biological Association of the United Kingdom, in the notes he said, '*There used to be oyster beds up the Cattewater, near Laira Bridge, and up the Plym, and in Cattewater Harbour, opposite Queen Anne's Battery, they used to be abundant; there are, however, no beds now*' (Heape, 1887). There was also a small trade in cockles from the river, '*Cockle beds exist both up the River Plym, near Laira Bridge (to the north of it), and on a bank bare at low water, which lies in the centre of the Tamar river, some little distance north of Saltash.'* Mussels were also plentiful on the moored ship hulks lying in the Cattewater and the Hamoaze and on the rocks of the Breakwater. The Plym River was known as '*one of the best sea trout rivers in Devonshire*', but the previously excellent spawning grounds had been '*much injured by mine pollution, and the state of the river was deplorable*'.

The Plym, Laira and Cattewater had for centuries been filling up with waste washed down from Dartmoor in the form of fine granite sand. In the 1800s, the Cattewater was still being filled with untreated town sewage from pipes discharging straight into the river and from manufacturing waste from Cattedown. Yet the oysters thrived in that polluted environment. Heape goes on to name the cause of the loss of the oysters, '*This failure of the Cattewater beds is, by some, attributed to over-dredging, but it would appear more probably to be due to the refuse from china clay works pouring down the river and choking the beds.*' (Heape, 1887). China clay production started on Lee Moor in 1830 there was little care taken in trapping the runoff into nearby streams. The Tory Brook has its source at Lee Moor, and it would run white with suspended china clay fines that would flush into the Laira and Cattewater, which killed off the oysters within 10 years. In 1876, complaints were made about the enormous quantity of pollution that was in the Plym and Cattewater, and it was noted that there was '*a deposit now upon the bed of the river never known before*' (WMN, 1876a). The filter-feeding oysters tolerated (or perhaps appreciated) the raw sewage and didn't mind the manufacturing waste and sand but were finally killed off by the china clay waste from Lee Moor.

There were oysters and cockles in the Tamar and the oysters would tolerate being stored on the seabed off West Hoe, suggesting that conditions in both places at that time were good enough for the filter feeders: '*There are oyster beds up the Tamar and they were being laid down for storage opposite West Hoe Terrace. They are also dredged in large quantities in the lower reaches of the Hamoaze and are then bedded on a bank near Saltash Bridge*' (Heape, 1887). The oysters in the Tamar were not affected by china clay production like their counterparts in the Plym river so remained viable, despite destruction by the Admiralty testing sea mines in the Lynher or deepening shipping channels in the Tamar. As recently as 1965 there were calls to restart the oyster fishing industry after a lapse of 40 years. The practice was still subject to a ban by Plymouth City Council because of river pollution taken up by the shellfish, but it was thought that there were 250,000 oysters ready to be harvested by the fishermen of Saltash. The Ministry of Agriculture Fisheries and Food said that the oysters had a small amount of copper pollution which could be solved using a cleansing plant (CG, 1965). The loss of the oysters had a much wider effect than the loss of just one species as they have a huge capacity for cleaning seawater, a single oyster can filter 200 litres of water every day, so the beneficial effect of a large oyster bed on the water in the rivers Plym and Tamar would have been significant. Oysters also create their habitat by attracting other species around them, they serve as an essential habitat in which other marine species can find refuge from predators and for their young. Solent Oyster Restoration Project, led by the Blue Marine Foundation, aims to reintroduce a million oysters to help clean up the Solent and in the first year they identified 130 other species within the oyster nurseries (Blue Marine Foundation, 2021). The loss of the oyster beds in the Plym and Tamar may have had far-reaching negative effects on the ecosystem that are still with us today.

'Many animals that were plentiful in the Sound twenty years ago [1869] had now deserted it.'

Fish

Mentions are also made in newspapers of fish that could once be found in the waterway. In 1888, the water bailiff for the Plym stated that there had been a great decrease in the fish taken in the Cattewater which he attributed to blasting operations and the spawning beds destroyed by dredging (Field, 1888). At this time the Laira and Cattewater were a source of sand to be used for construction with many thousands of tonnes removed each year. In 1891, Henry Clark held the fishing rights in the upper part of the Cattewater and he stated that '*fish of all kinds had grown very scarce there in recent years, probably, in his opinion, in consequence of the pollution of the estuary by manure and china clay refuse.*' (WMN, 1891). The sea and rivers had acted as a sink for sewage since Sutton was a small fishing port and even by 1847 the sea appeared to be coping with waste thrown in it, described by Truscott as '*nature's great laboratory for purification – the ocean;*' (Truscott, 1847). The accelerating population growth in the town created an equivalent growth in sewage and household waste which eventually the sea could not dispose of, so by the 1870s marine life was being adversely affected. In 1895, Henry Clark reported a large decrease in sea fish in the estuaries of the rivers Plym and Tamar, attributed to pollution from mines on the Tamar and vitriol (sulphuric acid) discharged into the Cattewater (WMN, 1895). Heape in 1887 also describes the fishing industry in Plymouth Sound. Notably, he reports that pollack are abundant enough for a fishery '*on the east side all along the shore at a depth of about three fathoms*', '*especially off the Mewstone, Leek Beds* (Ramscliff) *and Batten Bay*', and most everywhere else including the Tamar, apart from Cawsand Bay. Heape also mentions mackerel, bass, pouting, and bream and provided a chart that shows the best place to catch each type of fish. Eel spearing would occur in the Tamar in the early part of the year and mill ponds would be used for trapping and catching mullet. Crab and lobster were caught in Plymouth Sound with shrimps and prawns netted using small trawls, particularly in the area behind the Breakwater. Changes to marine life have been noted in more recent years. Some of the first sports divers to explore the seabed in Plymouth Sound described the type and quantity of fish to be found there in the 1950s. One diver told us about the large number of sizeable pollack that used to be seen inside the Sound while another said that snorkel divers could always catch flatfish in the shallows that were big enough to be cooked on a barbeque when going to the beach for a picnic.

Seagrass

One of the most noticeable changes to the ecology of Plymouth Sound was the loss of the seagrass (*Zostera marina*) beds. Seagrass has been a focus of the rewilding movement as there have been claims of its ability to capture carbon and its beneficial role as a habitat for seahorses, juvenile fish, and invertebrates. Seagrass, or eel grass as it is often known, is mentioned in historic papers and newspaper articles by many names, including 'sea wrack', 'grass wrack', 'eel-wrack', and 'widgeon grass'. However, 'sea wrack' is also used for seaweed so context is important when reading an article. Seagrass is mentioned in 19th-century accounts as a resource for several manufacturing industries. It is also mentioned as supporting scenery in documentary accounts describing some other marine life that lives within the seagrass. Accounts from this time suggest that seagrass was abundant on the UK coastline as '*it abounds all along the sea coast*' (WT, 1862), '*Zostera marina or sea wrack is a very abundant and hence probably a cheap material*' (CT, 1861) and '*It grows in great numbers, or rather in great fields, affording pasture to innumerable living beings*' (ST, 1863). Seagrass was so readily available that it was used as a packing material, for upholstering and sound insulation (Butcher, 1933), it was collected from beaches and used as manure for fields, along with the seaweeds *Laminaria*, *Fucus* and *Ulva* (NDJ, 1920). It was so abundant in Jersey in 1863 that the large quantities that washed up on the strandline were taken away to be used as fuel and manure (DCC, 1863). The American Civil War between 1861 and 1865 created a shortage of cotton for the mills of Lancashire and a serious proposal was made in 1862 to use seagrass as a substitute (WDM, 1862), but it was later proved to be unsuitable. Where seagrass is mentioned in historical accounts about Plymouth it is only ever in its supporting role, and no one felt the need to record where it could be found.

> *'(Seagrass) grows in great numbers, or rather in great fields, affording pasture to innumerable living beings.'*

But we can gain a few clues from scientific reports about where the seagrass grew as the locations are sometimes mentioned, and particularly interesting are the locations mentioned where seagrass now no longer grows (Fig. 35).

- Today there is still a small patch of seagrass in Cawsand Bay on the west side of Plymouth Sound but in 1890 *Zostera* was found '*between North Point and Pier Cove, in the 2-4 fathoms limit*'. Note the 4 fathom (8m) maximum depth range. North Point is shown on the 1939 Imray chart as being off Kingsand Beach and Pier Cove is also known as Pier Cellars (Johnson, 1890).

- Johnson goes on to say, '*in this part and towards Penlee Point Zostera beds are plentiful, affording anchorage for different algae*' (Johnson, 1890). Zostera is now only found in a small area of Cawsand Bay which could not be described as plentiful, and it no longer extends southwards to Penlee Point.

- Wembury Point is described as having excellent Zostera beds on the shore between the Point and the Mewstone (Johnson, 1890) but there is no seagrass to be found there now.

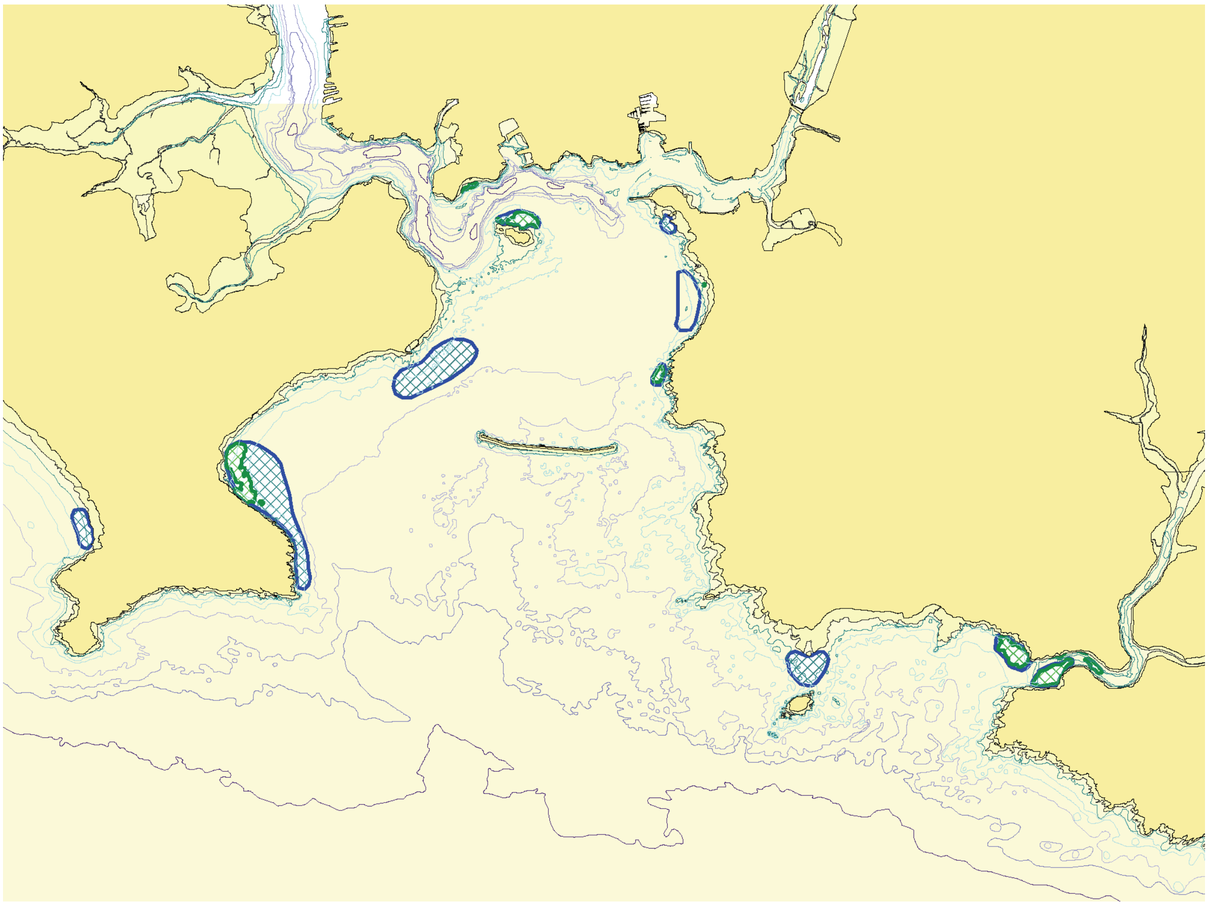

Figure 35: Chart showing existing seagrass beds in green and estimated pre-1930 seagrass beds in blue. The extent of the historic seagrass coverage in Jennycliff Bay is unknown. [The SHIPS Project]

- Holt (1898) refers to Zostera in Plymouth Sound at Jennycliff Bay and northeast of Drake's Island as well as Cawsand Bay. Seagrass can still be found in these places, but it is very sparse and patchy in Jennycliff. Patches of sand covered with seagrass were reported in Marra Pool (Allen, 1904) or '*south of Batten Castle*' (MBA, 1904, p209) at the north end of Jennycliff Bay in 1904. which are now no longer present. Holt also mentions the Cattewater, but this may be when he refers to 'sandy and muddy ground' in the same paragraph.

- The document Plymouth Marine Invertebrate Fauna mentions a seagrass bed to the north of Drake's Island (p162), the mouth of the Yealm (p166), and along the southern shore (p167), the '*eastern shore of Yealm mouth*', Drake's Island, Jennycliff Bay, Cawsand Bay, Whitsand Bay, Yealm Estuary (MBA, 1904, p244 & p270). Unusual here is the mention of seagrass in Whitsand Bay to the west of Plymouth.

- Lebour reported taking samples '*outside the Breakwater*', and '*specimens from both within and without the Breakwater*' (Lebour, 1918 p443, p456, p457). It is not clear where this refers to as there are no known seagrass beds outside of the Breakwater, perhaps it is referring to the area between Pier Cellars and Penlee Point mentioned above. Were this referring to the Yealm beds which are the only known seagrass beds 'outside' of the Breakwater then it is surprising that the author was not more specific about the location.

The document Plymouth Marine Fauna also mentions a seagrass bed at Queen's Ground at the north end of Cawsand Bay (MBA, 1957, p87) which is no longer present and nor can it be found near the New Ground buoy further to the northeast which is also mentioned (p125). The length of the seagrass fronds is mentioned in one report by Wilson (1949) where he says that '*plants from the estuary of the river Yealm near Plymouth certainly reached a length of 5ft or more prior to 1931 and a width of at least 8mm*'.

In 1931 the seagrass in Plymouth Sound suddenly died off leaving only a few small patches surviving. The problem was widespread; in 1933, Cotton reported that the loss of *Zostera* on the Atlantic coast of the US had started in 1930, the seagrass died off in France in 1931, then along the coast to Holland and by 1933 the loss had reached Denmark and Sweden (Cotton, 1933). Several localities in Devon were noted in 1932 to have bare seagrass beds with dead roots, with a few stray plants surviving, and the swans that had lived on the river Yealm for years deserted that estuary for Plymouth in search of food. Over 90% of the *Zostera* populations disappeared (Muehlstein, 1989) and the speed of loss was rapid; the abundant and extensive beds of seagrass at Cape Ann, Massachusetts, started to disappear in 1931-32 and were practically gone by 1933 (Dexter, 1944). The problem may have started earlier and was only noticed in the 1930s. Cottam reported that '*In England, two definite periods of decrease in Zostera can be distinguished; one immediately after the War, that is between 8 and 12 years ago or perhaps even longer, and another at the same time as the epidemic in France and America, namely in 1931 and 1932*' (Cottam, 1935). The die-off was sudden and widespread so many attempts were made to determine the cause which had affected all the *Zostera* on two continents in the space of just a few years. In 1933, some experts thought the cause was oil pollution, but the French thought it was disease (TC, 1933; MS, 1934). Lack of sunshine in 1931-32 was proposed as a reason but this theory was proved incorrect by Atkins (1947). The die-off was not caused by variations in seawater, or salinity and no causal link could be established with climactic factors (Giesen, 1990). By 1949 the situation had not improved, with one newspaper reporting that the '*Eel grass in the River Yealm today is also nothing like the length it used to be. There has been very little in Cawsand Bay for years*' (WMN, 1949).

We still do not know what caused the loss of 90% of the seagrass in America and Europe a but historical review of pollution in Plymouth rules out some possible causes. Changes to the ecosystem brought about by the Plymouth Breakwater were not the cause as this structure had been in existence for more than 100 years, so the seagrass had by then established a new equilibrium with the changes to the marine habitat caused by extra silt deposition in Plymouth Sound. Before the 1930s, Plymouth Sound was still the repository for the town sewage, pumped directly into the sea through several outfalls and into the Tamar and Plym estuaries, yet the seagrass appeared to thrive. Mines were still active in the Tamar Valley so pollution from mine runoff would still be occurring, and agriculture had not changed its practices for decades, so the seagrass was already tolerating any contemporary pollution runoff from the mines and fields. All these pollutants were local in character so unlikely to be the culprit for what became a problem that occurred on both sides of the Atlantic Ocean. Oil pollution in some form is a candidate for the cause of the die-off as it was being used as fuel in both the US and Europe. The use of oil as fuel was relatively new in 1930 but cars had been in Plymouth for 30 years and oil-powered ships for more than 20 years. Another potential candidate is the changes to the environment caused by the addition of Tetraethyl lead to petrol that started in 1923, a change that happened in both the US and Europe and one that could affect the environment in both locations. Modern pollutants such as plastics, DDT and TBT can be ruled out as causes as they had yet to be invented, but they may still be adversely affecting seagrass now in other ways.

> *'Eel grass in the River Yealm today (1949) is also nothing like the length it used to be.'*

The seagrass in Plymouth Sound has not recovered since the die-off in the 1930s and historic accounts tell us that seagrass could be found in areas of Plymouth Sound where it cannot be found today. Johnson's comment about the maximum depth where seagrass can be found in the Sound to be 4 fathoms or 7.3 metres, is a deeper range than today where the seagrass can usually be found in a depth of 5m or less (Johnson, 1890). It is thought that the depth range of seagrass is limited by available light, which is a function of turbidity, hinting that underwater visibility was perhaps better in 1890 than today which allowed more sunlight to reach the seabed. In 1890, the waters of Plymouth Sound were a repository for all of Plymouth's sewage so it is hard to understand how the water could be clearer then than it is now. Perhaps the presence of large oyster beds and their ability to filter seawater had a larger beneficial effect on the ecosystem than is currently appreciated.

It is also important to note potential changes to the seabed sediment caused by the loss of seagrass in the 1930s. In Salcombe, the *Zostera* was holding sandbanks together with its extensive network of roots and when the seagrass died off the sand washed away leaving just stones and seaweed, with no substrate remaining for the seagrass to recolonise (WMN, 1949). This may also have happened in Plymouth and other locations, so some areas where seagrass once grew cannot now be re-established because all the substrate suitable for growing seagrass has washed away. Unfortunately, no detailed records exist of what the seabed in Plymouth Sound was like before 1930 so it is impossible to know.

16. Cleaning Up the Tamar Waterway

Figure 36: Bicycles and shopping trolleys recovered from the seabed off Mutton Cove on one weekend in 2022 during a 1000 Tyres clean up operation [The SHIPS Project]

The 1000 Tyres Project believes that if we are to improve the health of the marine life in the Tamar waterway then we need to start tidying up. The state of the waterway is monitored regularly because the rivers, Sound and foreshore are covered by many environmental designations. But this work concentrates on modern pollution in the water itself, floating plastic pollution, or pollution visible on the foreshore. The pollution hidden beneath the waves also affects the health of the ecosystem, so we are keen to remove as much polluting material as possible from the Tamar waterway.

The definition of what constitutes pollution also varies, where some may consider a car tyre to be a habitat for crabs and lobsters others see a tyre as a source of chemical pollution and microplastics. Having to prove the harm caused by a substance before taking action may be the wrong approach, as it could take years and significant levels of funding to obtain a definitive answer, which is time and money better spent simply removing the pollutant. Time is short, so a more proactive approach is needed to gain a significant benefit to the environment - anything man-made should not be in the ecosystem and pollutants should be removed where it is sensible to do so.

What can still be found on the seabed and riverbeds of the Tamar waterway is the insoluble, inedible, and unreactive remains of all the historic pollution dumped into Plymouth Sound. Fortunately, the largest volume of pollutants was historic sewage and organic material which became food for marine life so little of that now remains. What does remain on and within the seabed is a mix of materials including:

- Car, truck, and tractor tyres.
- Plastic litter in many forms.
- Plastic fishing nets and floats.
- Plastic lobster and crab pots.
- Plastic and metal angling gear.
- Rubber-based materials.
- Steel and rubber cables.
- Asbestos from buildings and shipbreaking.
- Fibreglass boats.
- Scrap steel in many forms.
- Steel and plastic shopping trolleys.
- Steel and plastic bicycles and motorbikes.
- Steel trawl wires.
- Modern glass and ceramics.

Glass and ceramics are inert and a low-level hazard, so we do not intend to remove the historic material. This material will be recovered in a series of campaigns targeting areas of the seabed and foreshore, the material is sorted and taken for recycling by commercial partners of the 1000 Tyres Project. Only material that can be disposed of at that time is recovered and any other material is recorded so that it may be dealt with later. The project records the location, mass, type, and material of everything that is recovered so the true extent of the historic pollution problem in the Tamar waterway is documented.

The seabed is hidden from most people other than divers, and the usually poor underwater visibility in the area hides most of the seabed even to them. Sports divers tend to dive in the same places, usually on shipwreck sites, scenic reefs, or shore dive locations, so large areas of the seabed in Plymouth Sound may never be seen by anyone. Visibility is often too poor for divers to see anything in the Tamar and Plym rivers so very little of the riverbed has ever been seen. However, the Tamar waterway is one of the most mapped areas of seabed in the world as Plymouth has for years been the home of several academic, commercial, and military hydrographic survey organisations. Modern sonars use acoustic signals to 'see' through water to image the seabed in great detail, with some instruments capable of imaging something as small as a beer can or a steel cable only 20mm in diameter. The 1000 Tyres Project team uses donated survey data and undertakes geophysical surveys in the Tamar waterway, the sonar images are interpreted to locate and identify any man-made objects on the seabed which are then added to a digital map. The map is used to plan a targeted recovery of polluting material which is raised from the seabed and then taken away to be recycled.

For more information on the work of the 1000 Tyres Project please visit the website: 1000tyres.org

Figure 37: 1000 Tyres Project divers recovering tyres from the bottom of Plymouth Sound [The SHIPS Project]

17. About The SHIPS Project and 1000 Tyres Project

This white paper is one of a series written by The SHIPS Project to document what can be found in Plymouth Sound and the Tamar waterway, not only the wealth of cultural heritage that lies underwater or on the foreshore but also the pollutants and man-made objects dumped there. The waterway contains over 1000 shipwrecks, more than 35 crashed aircraft, and over 100 vessels abandoned on the foreshore, as well as thousands of dumped tyres and tonnes of plastic rubbish.

The SHIPS Project CIC is a volunteer non-profit organisation that undertakes research and exploration of maritime historical sites and events, both on land and underwater. The SHIPS Project also runs The 1000 Tyres Project as an environmental direct-action campaign to clean up Plymouth Sound. The SHIPS Project is based in Plymouth, England, and the focus of our work is centred on that city. Plymouth has a wonderful maritime heritage that stretches in time from the Bronze Age to the present day that includes maritime and shipping, military and aircraft, fishing, industrial and transport, piers, docks, and harbours as well as Roman and prehistoric sites. The work of The SHIPS Project is undertaken by unpaid volunteers, but the project was kindly sponsored by the US research foundation ProMare from 2010 to 2016. In 2021 The SHIPS Project became a Community Interest Company (CIC), a special type of limited company which exists to benefit the community rather than private shareholders. The SHIPS Project has been kindly assisted by several commercial organisations, institutions, and universities, in particular many departments at Plymouth University and the Plymouth Sound and Totnes branches of the British Sub-Aqua Club (BSAC).

The SHIPS Project can be contacted by:

- Sending an email to pete@shipsproject.org
- Sending a message through the website feedback forms at shipsproject.org
- Contacting us through social media; Twitter, Instagram, and Facebook

Figure 38: The 1000 Tyres crew recovering tonnes of waste from Pomphlett Creek [Chris Parkes Photography]

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A 1000 Tyres Project white paper
The SHIPS Project CIC

ISBN 978 1 7397053 4 3